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ATMOSPHERIC TRANSPORT MODELLING

ATM-01/E: Development of the Radionuclide Transfer Model by Atmospheric Flows

V.V. Adushkin, *Institute of Geospheres Dynamics of RAS, Moscow*
Contact: adushkin@idg.chph.ras.ru

Abstract: This article presents the physical-mathematical model of radioactive explosion products transfer by atmospheric flows. The model structure comprises three main stages of radionuclide transfer at explosion. At the first stage the process of gas-duct cloud formation is calculated and the development of explosion thermic within the first few seconds before rising to the maximum height is studied.

The dust mass and the maximum height of thermic rise depend on the explosion power and height as well as on the atmosphere condition. The grain size of the dust captured by thermics depend on the mechanics of dust formation and ground structure. Dust formation mechanics are related to substance evaporation by the explosion thermal influence, fallout from crater, dust blowing from ground surface by gas flow in the shock wave and wind.

At the second stage the gas-dust cloud transfer equation is included. Also gradual particle drop under wind flow conditions, gravitation field and turbulent diffusion are considered. At the third stage the distribution of dropped particle over the fallout is determined and the density of radioactive sediments is calculated.

The processes of dust particle activation are also considered at the model development. These processes are accompanied by radionuclide fractionation that causes the change of isotope composition of radioactive sediment with time. The wind stratification of atmosphere and cloud movement within the cyclone under real atmospheric conditions in the period of explosion are also considered during the model calibration. The calculated and experimental characteristics of radioactive sediments for a series of explosions are compared.

ATM-02/E: High resolution atmospheric transport modelling to support source location estimates

D. Arnold, A.Vargas and P. Seibert, *Institute of Energy Technologies, Technical University of Catalonia, Barcelona, Spain. Institute of Meteorology, University of Natural resources and Applied Life Sciences Vienna, Austria.*
Contact: delia.arnold@upc.edu

Abstract: Within the ISS project, particularly in the ATM section, some questions arose regarding the representativeness of the IMS stations and the quality of the ATM calculations. Stations location differ significantly. Whereas dispersion conditions may be very simple in some of the stations, with a proper representation of them with the current ATM tools and procedures, in others, transport patterns may become very complex and strongly influenced by mesocale circulations. For those specific cases, the standard ATM calculations may not be appropriate and become a misleading factor in the source determination procedure. Therefore, some evaluation of possible improvements and their influence on the final results, should be performed.

As a preliminary step in a study to assess the quality of the ATM calculations and to evaluate how significant are the differences appearing when using different meteorological input data and model versions, Rn-222 simulations with ECMWF fields and with MM5 output have been carried out for some representative stations, including the stations of the radiological surveillance network of Spain. Stations placed in very flat locations, such as Cabauw station (Netherlands) present no difficulties in the modelling and standard set-up and coarse meteorological fields suffice. Stations located in very complex topographical areas, such as Schauninsland (Germany) and Penhas Douradas (Portugal), are more challenging for the dispersion models and their performance is generally poor. Moreover, stations located in places which in principle should not present difficulties in the dispersion calculations, have also shown some problems in reproducing the measured values under some specific meteorological conditions.

A first proposal of an analysis study has been posed in order to asses this issue. High resolution modelling calculations with FLEXPARTv6.2 using different resolutions of the ECMWF fields and also with the new MM5V3.7-FLEXPARTv6.2, able to properly represent mesoscale circulations, will be performed for target IMS stations, susceptible of presenting significant differences in the SRS fields obtained using the standard ATM set-up or a modified one, specific for each of them.

ATM-03/E: On the PTS in-house capacity building in atmospheric transport modelling during the past decade with an outlook on scheduled improvements in support of the noble gas verification regime.

Andreas Becker and Gerhard Wotawa, *CTBTO Preparatory Commission, Vienna International Centre, P.O. Box 1200, 1400 Vienna, Austria,*
Contact: andreas.becker@ctbto.org

Abstract: In contrast to the wave-form technologies, the readings taken in the radionuclide International Monitoring System (IMS) do not contain the information of their possible source regions. This is due to the fact, that the nuclear signal (debris) emanating from a nuclear test is not propagating by itself (alike a wave-form) but needs to be carried by atmospheric winds from the source location to one of the IMS stations. Therefore atmospheric transport modeling methods are required to allow for the proper interpretation of the radionuclide readings in terms of source region estimation and subsequent data fusion with potentially relevant wave-form events.

Therefore, since October 2000 PTS has build up in-house capabilities in the field of receptor oriented atmospheric dispersion modeling supporting the radionuclide (RN) technology branch of the CTBT verification regime. Following the recommendation of an external Ad Hoc Expert Group and based on in-house development a new ATM modeling system was designed, coded, installed and put into full 7/24 operations. In order to facilitate maintainability and inter-operability the system was implemented along four processing layers (pre-processing, dispersion modeling, post-processing, and visualization).

For example cases (e.g. Chernobyl disaster, backtracking of Cesium) the capabilities of the current system are demonstrated. The current operational system supports the particulate IMS network serving mainly an event location function. For the noble gas network, however, xenon background concentrations and potential bogus events related to known xenon sources, put an additional demand on the ATM methods, namely to support in addition to the event location also event characterization (a noble gas categorization scheme). The resulting enhancements scheduled for the ATM system will be described and different avenues to tackle the higher demand on the geo-temporal resolution of the ATM system are discussed.

Finally a description of the ATM software systems packaged into the NDC-in-a-Box (ATM components) shall demonstrate how the PTS is striving for capacity building on side of its member states.

Key words: source-receptor relationship, atmospheric backtracking, CTBT verification, capacity building, NDC-in-a-Box software

ATM-04/E: Application of BMA approach to multi-model atmospheric dispersion ensemble system for emergency response systems

S. Galmarini[1], S. Potempski[1,2;]
[1]European Commission – DG Joint Research Centre, Institute for Environment and Sustainability, Ispra, Italy; [2]Institute of Atomic Energy, 05-400 Otwock-Swierk, Poland
Contact: Stefano.galmarini(at)jrc.it

Abstract: The Bayesian Model Averaging (BMA) approach can be used to the evaluation of model predictions and for building combination of model results using BMA weighing factors. This methodology can be also applied to atmospheric dispersion multi-model ensemble system in the context of emergency response. In particular it can be used in the ENSEMBLE system established as a consortium of 25 national weather and environmental centres which can provide long range atmospheric dispersion simulations in case of accidental releases of harmful materials. The dispersion models are operational systems routinely used in case of emergency. They differ in terms of concept, numerical code, and make use of weather forecasts produced by different either global or limited area models. The ENSEMBLE system has been recently coupled with the European Radiological Data Exchange Platform – EURDEP, which allows for a rapid exchange of radiological information throughout the Europe in order to support nuclear emergency response. Currently the system exchanges measurement data originating from more than 4500 gamma dose rate monitors in 33 countries. Thus these two coexisting systems have created a unique platform that can be jointly applied in emergency response applications: ENSEMBLE provides tools for comparison and evaluation of atmospheric dispersion models as well as for finding optimal combination of model results, while EURDEP delivers information from measurement network. In this respect the BMA approach can be applied as a basis for the application linking these two systems. An investigation of such a possibility has been made using the European Tracer Experiment (ETEX-1) dataset. In particular we consider the following aspects:
(1) How many measurement data are needed in order to obtain stable solutions of BMA weights? This can be done by investigating the time evolution of BMA weights i.e. how they are changing when new measurements are becoming available.

(2) To which extent BMA weights calculated in one case can be ported to another one?(3) What can we gain by applying BMA weights for building combined set of model results? Does such combination provide essentially better results than normal average or median?

ATM-05/E: Comparison of EPS-based ensemble of atmospheric dispersion predictions and multi model performance

S. Galmarini[1], S. Potempski[1], F. Bonnardot[2], A. Jones[3], L. Robertson[4]
[1]European Commission – DG Joint Research Centre, Institute for Environment and Sustainability, Ispra, Italy;
[2]METEOFRANCE, Dir. Prod., Serv./Environ., 42 av. Coriolis, 31057 Toulouse, France; [3]Met Office, FitzRoy Road, Exeter EX1 3PB, United Kingdom; [4]Swedish Meteorological and Hydrological Institute (SMHI), SE-601 76 NORRKO¨PING, Sweden
Contact: Stefano.galmarini(at)jrc.it

Abstract Several techniques have been developed over the last decade for the ensemble treatment of atmospheric model predictions. Among them two have received most of the attention, the multi-model approach and the EPS-based ensemble dispersion which differ for the way in which ensemble members are created. The multi-model approach relies on model simulations produced different atmospheric dispersion models that use weather data produced by potentially different numerical prediction systems. The EPS-based ensemble is generated by running a single atmospheric dispersion model with the ensemble weather prediction members. The difference between the two methods is motivated by the different emphasis that each of them puts on different aspects of model uncertainty and how probabilistic forecast should be used. While the EPS-based method concentrates on the influence of various equally probable weather scenarios on the dispersion produced by one dispersion model, the multi-model considers different answers from multiple sources that include both the uncertainty in the weather predictions and the one that originates from the use of different modeling approached to atmospheric dispersion modeling. The dispersion models considered in this work are long range atmospheric dispersion models normally used for prediction of the dispersion from point releases. All the consideration drawn here can however be extended to any other kind of model or application, e.g. air quality. The multi-model ensemble considered here is made of 25 individual model simulations while the EPS-based relies on four atmospheric dispersion models that have independently used the 51-member ECMWF weather data. The case analyzed in the is the ETEX-1 release chosen for the abundance of measurements collected and the wide range of studies performed on it in the past. For the specific case the ECMWF EPS system was re-run. The two ensembles have been treated statistically and compared. The results clearly show the capabilities of the two methods in separating components of the uncertainty and emphases an overall equivalence in the prediction capacity of the two techniques.

ATM-06/E: Review of the Methodology Used for Global Backtracking of Anthropogenic Radionuclides

***Arnico K Panday**, Atmospheric and Oceanic Sciences Program, Princeton University, Princeton, NJ 08540, USA*
Contact: arnico@princeton.edu

Abstract: The Comprehensive Nuclear-Test-Ban Treaty is only effective if non-compliance is detected, and offending parties are identified. The Preparatory Commission for the Comprehensive Nuclear Test-Ban-Treaty Organization (CTBTO) has thus established a network of measurement stations around the world to detect the presence in the atmosphere of radionuclides released by upwind nuclear tests. Attributing the observed increases in radionuclides at one or more stations to nuclear tests at a specific time and place requires atmospheric models that do back-ward calculations of the atmospheric transport of radionuclides to the measurement site.

In a 2007 paper published in *Atmospheric Environment* titled "Global backtracking of anthropogenic radionuclides by means of a receptor oriented ensemble dispersion modeling system in support of Nuclear-Test Ban Treaty verification", A. Becker et al. tested a methodology using an ensemble of several different lagrangian particle dispersion models to efficiently calculate source-receptor relationships between sites around the globe.

In this paper, we analyze the strengths and weaknesses of Becker et al.'s approach to computing source-receptor sensitivities using an ensemble of Lagrangian particle dispersion models. We discuss the choice and appropriateness of using Lagrangian particle dispersion modeling, as opposed to other modeling frameworks, and we examine the particular model simulations that went into the ensemble. We also discuss potential errors introduced by a backtracking approach that relies on direct use of coarse-resolution global meteorological fields, rather than using more sophisticated model interpolations that take into account higher resolution surface properties. We discuss the compromises due to the required 24 hour response time, and whether higher accuracy modeling would be possible given the existing network, but without the time constraint.

ATM-07/E: The WMO/CTBTO "atmospheric backtracking response system" implementation at ZAMG

P. Skomorowski and U. Pechinger, *Central Institute of Meteorology and Geodynamics (ZAMG), Vienna, Austria*
Contact: ulrike.pechinger@zamg.ac.at

Abstract: In September 2008 the Provisional Technical Secretariat (PTS) of the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO) has put the joint response system with the World Meteorological Organization (WMO) and its regional centres for atmospheric transport modelling into operations.

As one of these regional centres, ZAMG participates in this joint-response system. The ZAMG implementation of the WMO/CTBTO "atmospheric backtracking response system" comprises a fully automated retrieval of the needed meteorological input fields - obtained from the ECMWF - for the dispersion model FLEXPART 6.2, the dispersion calculation itself and a fully automated post-processing and uploading of the "source receptor relationship" files to a CTBTO server via a secured internet connection.

The workflow of the implementation as well as technical and scientific expertises achieved during the development of further increments of the system by e.g. using higher resolved meteorological input fields will be shown at the conference.

ATM-08/E: Current issues in atmospheric transport modelling and source location for the CTBT verification

Petra Seibert, *Institute of Meteorology, University of Natural Resources and Applied Life Sciences, Vienna, Austria*
Contact: petra.seibert@boku.ac.at

Abstract: This presentation will give an overview of potentially relevant extensions of the present atmospheric transport modelling (ATM) system and its applications at the IDC. It will specifically touch upon

- more advanced inverse modelling methods for sources with time-dependent emission profiles and incorporating uncertainty measures, including their possible role in noble gas event characterisation
- possibilities and limitations of quality assessment for ATM
- resolution issues in the input and output data of ATM and other options for improving the quality of the transport simulations
- meteorological issues and OSI .

Inverse modelling is a label for mathematical methods which can extract information on parameters which are initial or boundary conditions etc. of a natural process with a given direction (here, the transport and diffusion of radionuclides in the atmosphere from one or more point sources) from data which represent the result this process (here: ambient concentrations of these radionuclides). A cost function is minimised which includes the misfit between observations and modelled values, and if available also the deviation of the inversion result from some a priori information. In both contributions, it is beneficial, if not critical, to consider uncertainties. The potential of this approach is not yet exhausted in the current IDC operations.

Quality assessment of ATM products is a difficult issue because in general, the truth is not known. Ensembles and associated metrics are a common workaround, but it is important to understand their limitations and risks. On the other hand, past tracer experiments give at least some handle to model quality. The output data quality is, however, not only influenced by the model quality but also by the input data quality, i.e. the meteorological fields delivered from operational meteorological services.

A specific issue in data quality and uncertainty quantification is related to the resolution of the input meteorological fields, especially for stations on mountains or islands. Further options for improving the quality of ATM are related for example to the treatment of convection.

Finally, meteorological issues in OSI appear to have received little attention so far. This refers to issues such as the siting and timing of measurements of airborne radioactive in the inspection area, or small-scale modelling, as well as general meteorological support to OSI operations.

This work has been supported by funding of FWF grant P17924.

ATM-09/E: The operational CTBTO-WMO Atmospheric Backtracking Response system for CTBT Verification-Status and plans

G. Wotawa and A. Becker, *CTBTO PTS, Vienna*
Contact: andreas.becker@ctbto.org

Abstract: After the detection of treaty-relevant radionuclides in multiple air samples collected by the radionuclide (RN) International Monitoring System (IMS) of CTBTO, an inversion technique is employed by the Provisional Technical Secretariat (PTS) to estimate the possible source regions of the measured substances. The source location is based on so called source-receptor sensitivity (SRS) fields computed for every IMS measurement by means of backward Atmospheric Transport Modelling (ATM). In the case of a not fully contained underground nuclear test, the RN source will be co-located with the epicenter of the seismic event belonging to the explosion.

Predictions or analyses of atmospheric transport, forward as well as backward, can be significantly improved and enhanced by employing ensemble techniques. Such techniques can also account for modeling uncertainties. The first atmospheric backtracking experiments with the World Meteorological Organization (WMO) have been conducted in 2003 and 2005, the first data fusion exercises in 2007 and 2008. The assumption for the latter exercise was that a seismic event selected by an automated routine of a National Data Centre was nuclear and has subsequently caused a series of (virtual) detections at IMS sites. The virtual detections were calculated with an forward ATM model and subsequently reported to the IDC. The IDC then made its source location estimates based on its own and the WMO ATM results, and tried to identify seismic events that are consistent with the radionuclide measurement scenario. This process is called data fusion in CTBTO context.

Based on the experience gathered over the years, the PTS has put into its provisional operations a joint response system with the World Meteorological Organization and its Regional Specialized Meteorological Centers for Atmospheric Transport Modelling in September 2008. From this moment on, the system was triggered every time treaty-relevant radionuclides were measured at IMS particulate samplers, which happened in five instances between October 2008 and April 2009.

The results from all experiments and exercises will be presented and discussed together with the first experiences with the operational response system. Furthermore, an outlook for future developments and activities is provided.

ATM-10/E: A refined backtracking and source reconstruction for the noble gas measurements taken in the aftermath of the announced October 2006 event in North Korea

Andreas Becker[1], Gerhard Wotawa[1], Anders Ringbom[2] and Paul R.J. Saey[1]
[1]CTBTO Preparatory Commission, Vienna International Centre, P.O. Box 1200, 1400 Vienna, Austria; [2]Swedish Defence Research Agency (FOI), Defence and Security, System and Technology Division, SE-172 90, Stockholm, Sweden
Contact: andreas.becker@ctbto.org

Abstract: The announced October 2006 event in the Democratic People's Republic of Korea (DPRK) has been the first real test regarding the technical capabilities of the verification system built up by the Vienna based Provisional Technical Secretariat (PTS) of the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO) to detect and locate a nuclear test event. Within a refined backtracking effort the radionuclide release scenario of the DPRK event is reconstructed by analysis of the radioxenon measurements taken at the remote radionuclide station in Yellowknife, Canada, which is part of the PTS International Monitoring System (IMS), and additional measurements taken by a mobile noble gas system deployed quite close to the event location in the Republic of Korea (ROK) by the Swedish Defence Research Agency. Source location methods based on forward and backward atmospheric transport modelling played a crucial role for the source scenario reconstruction. It is shown that the Xenon-133 measurements in Yellowknife were continuously sensitive to releases from the nuclear explosion during the first three days after the event, while the mobile measurements where rather sensitive to releases during the days 2 to 4 after the explosion. According to the analysis, the most likely source scenario would consist of an initial (possibly up to 21 hours delayed) venting of 1×10^{-15} Bq Xe-133 during the first 24 hours, followed by a 2 orders of magnitude weaker seepage during the following three days. Finally, we compare the contribution made by the Swedish mobile measurements regarding the reconstruction of the source scenario with the potential contribution of the IMS radioxenon network once in full operations, and not 25% complete as at the date of the DPRK event. According to the calculations a full scale operating IMS network would have detected the Xe-133 plume at the station in Ussuriysk, Russia, within one day and with an at least 500 times stronger signal compared to the detection at Yellowknife. In the final network, there would have been no such monitoring gap that was now compensated by the mobile measurement. Nevertheless, mobile measurements can play an important role in the verification regime, in particular as part of On-Site inspections once the treaty enters into force, or to supplement IMS monitoring capabilities under certain conditions, mainly announced or expected nuclear explosions where the lead time to deploy such systems at a good location is

sufficiently long. For the DPRK event case discussed here this lead time was longer than to be expected for a fully evasive test scenario.

Key words: October 2006 nuclear test of North Korea, case study, atmospheric backtracking, radioxenon monitoring (network based and mobile), CTBT verification

ATM-11/E: Atmospheric transport of natural radionuclides simulated in tropical regions by a General Circulation Model

Heinrich P. [1]***, Vignon L.***[1]***, Jamelot A.***[2]***, Grillon Y.*** [1]
[1]*CEA DAM Ile de France, Bruyères-le-Châtel, 91297 ARPAJON, France;* [2]*Laboratoire de Métorologie Dynamique, Paris VI, Jussieu, France*
Contact: philippe.heinrich@cea.fr

Abstract: Tahiti, Guadeloupe and Reunion stations (FRP27, FRP28 and FRP29) belong to the Comprehensive Test Ban Treaty network and measure very low level radioactivity on daily routine. In order to define the capacity of these stations to detect a pollutant circulating through oceans, atmospheric transport of the natural radionuclides ^{210}Pb and ^{7}Be is simulated by a General Circulation Model, LMDZ, developed at the Laboratoire de Météorologie Dynamique in Paris. Daily-averaged concentrations of ^{210}Pb and ^{7}Be collected at those stations are compared with numerical results for a 2-years global simulation. Numerical results for the 2006 and 2007 years show the underestimation of concentrations for most recorded peaks when using a traditional convection scheme in this GCM. Sensitivity studies are conducted concerning particles scavenging and the convection scheme. In particular, it is tested Kerry Emanuel's scheme, which is better adapted for tropical deep convection and improves significantly the large-scale distribution of tropical precipitation. In the case of Tahiti station, local circulation over Tahiti is also simulated by a mesoscale meteorological model at a 1-km resolution. The station is located on the northwest coast of Tahiti which is exposed both to topography-induced vortices and thermally-driven local breezes. However, transport simulations using a Lagrangian particle dispersion model show that site-specific effects are limited, when daily-averaged concentrations are considered.

ATM-12/E: Radioxenon in a hypothetical world in which underground nuclear explosions are frequent

Kurt Ungar, Marc Bean, Jing Yi, Ian Hoffman and Trevor Stocki, *Health Canada's Radiation Protection Bureau*
Lars-Eric De Geer and Anders Ringbom, *FOI*
Contact: kurt_ungar@hc-sc.gc.ca

Abstract: Under the CTBTO sponsored International Noble Gas Experiment (INGE), continuous records of noble gas concentrations have been recorded at least daily at a number of locations worldwide beginning in 2001, for example in Ottawa, Canada, Papeete, Tahiti, Freiburg, Germany, and Spitzbergan, Norway. At various points during this experimental operation, there have been gaps in the concentration time series and periods where results were less reliable than others, characteristic of the experimental nature of these radioxenon installations. Nevertheless, it is possible to construct reasonable long term time series of radioxenon concentrations, representative of typical seasonal variations, for a number of locations. Using such validated data combined with state-of the-art meteorological models (e.g. Canadian Meteorological Centre's Global Environmental Multiscale model or the EU's European Centre for Medium-range Weather Forecasting model), it is possible to consider the impact of a nearly infinite range of noble gas releases from hypothetical nuclear explosions across the face of the planet on these actual radioxenon background measurements. The process of validation of the accuracy and representativeness of the background data, the estimation of reasonable distributions of explosion emission scenarios, and improvements to the meteorological models are considerable endeavours in themselves and beyond the scope of this present work. However, this work provides a first estimate of what real world radioxenon observations would be appear to be if also routinely impacted by releases from nuclear explosion sites. For this effort, apparently high quality noble gas background data was selected, state of the art meteorological models were used, and plausible explosion site release scenarios based upon accurate calculation of evolving xenon levels within the explosion cavity were considered. The resulting distributions of these simulated explosion data sets makes a useful contrast to the true background data sets and provide a means of ranking methods to decide the origin of measurements from each group, explosion or background

ATM-13/E: Analysis the spreading of forest fire smoke El Nino/La Nina period by using Regional Model (REMO)

***Kadarsah Binsukandar Riadi**, BMG, Indonesia*
Contact: kadarsah@yahoo.com

Abstract: This research is aimed to analyze the influence of meteorological conditions on the distribution of the smoke haze from the forest fire in Indonesia with a regional climate model (REMO) that has been modified into REMO with Tracer Extension (REMOTE). Forest fire emission inventory of July to December 1997 has been used as main data to simulations that used meteorological condition of 1997 or the El Nino period, condition on the Normal period (July to December 1996) and the La Nina period (July to December 1998). The result of simulations over those three periods will be compared among each other to analyze the influence of the respective meteorological condition toward regional smoke haze distribution vertically and horizontally. The major parameter measured is PM_{10} (particulate with a diameter below 10 μm). The emission data inventory emission and the simulation result shows that Kalimantan, Sumatra, and Papua are major source of smoke haze of forest fire in Indonesia. The research shows that the distribution of the smoke haze will be larger during the La Niña, Normal, and El Niño period, consecutively. The extent of the smoke distribution reaches the maximum on September 1997 in Kalimantan of about 2.904.000 km^2. Meanwhile the concentration becomes larger from the El Niño, La Niña, and normal periods, consecutively. The concentration of PM_{10} reaches maximum on October 1996 and 1998 as much as 35000 $\mu g/m^3$ or during La Niña and Normal periods. The PM_{10} concentration is reduced exponentially in vertical direction, which sharply reduced below 850 mb (2 km). Differences on smoke haze distribution among those three periods are mainly influenced by the sea surface temperature conditions that supply water vapor to the atmosphere that consequently determine the liquid water content (LWC). The water content level will bring implication on the precipitation processes and the wet deposition that is larger and the accumulated PM_{10} will reach the maximum during the La Nina period. Furthermore, the smoke haze distribution is influenced by the wind that reached maximum during the El Niño period, especially on September 1997.

Keywords: Regional Model, PM10, El Niño, La Niña,REMO

ATM-14/E: A long distance measurement of radioxenon in Yellowknife, Canada, in late October 2006

P. R. J. Saey, M. Bean, A. Becker, J. Coyne, R. d'Amours, L.-E. De Geer, R. Hogue, T. J. Stocki, R. K. Ungar, and G. Wotawa
Contact: andreas.becker@ctbto.org

Abstract: Between 21–25 October 2006, elevated levels of atmospheric xenon-133 were observed in Yellowknife (Canada). This station is located in an area where the background level of radioxenon is very low. The few measurements of xenon-133 above background in the last three years have been traced back to known nuclear facilities. The measurements in late October could not be linked to them. According to backward atmospheric transport models (ATM), the air that contained the measured radioxenon could have originated from the Korean Peninsula. On 9 October 2006, seismic networks world-wide recorded an event with characteristics of an underground explosion in the Democratic Peoples Republic of Korea. Forward ATM was performed using these coordinates. The results were consistent with the measurements in Yellowknife, more than 7000 km away. The order of magnitude of the amount measured is consistent with simple leak scenarios assumed for a low yield underground nuclear explosion on the Korean peninsula.

Citation: Saey, P. R. J., M. Bean, A. Becker, J. Coyne, R. d'Amours, L.-E. De Geer, R. Hogue, T. J. Stocki, R. K. Ungar, and G. Wotawa (2007), A long distance measurement of radioxenon in Yellowknife, Canada, in late October 2006, Geophys. Res. Lett., 34, L20802, doi:10.1029/2007GL030611.

ATM-15/E: Changes in radioxenon observations in Canada and Europe during medical isotope production facility shut downs in 2008

***R. Kurt Ungar,** Health Canada's Radiation Protection Bureau*
Contact: kurt_ungar@hc-sc.gc.ca

Abstract: Data collected on radioxenon concentrations at International Noble Gas Experiment (INGE) monitoring sites in North America and Europe are demonstrably impacted by emissions from medical isotope (MI) production facilities at Chalk River (CRL), Ontario and Fleurus, Belgium. Temporary cessation of production at these (MI) facilities in the latter half of 2008 afforded a special opportunity to assess the relative impact of these production facilities in Canada and Europe in terms of distributions of concentrations at the measurement sites and calculated sensitivities to the putative emission locations through meteorological Source Receptor Sensitivity (SRS) computations. In particular, the shutdown of hot cell production in Fleurus, Belgium (August 28 to November 4, 2008) and Petten, Netherlands (August 21, 2008 to February 18, 2009) allowed the

estimate of the predominant impact of the MI facility of Atomic Energy of Canada limited at Chalk River Ontario on a CTBTO operated INGE site at St John's, NL in Canada and the significant impact of this MI facility on CTBTO operated INGE sites in Stockholm, Sweden; Freiburg, Germany and a CEA operated INGE contributing site just outside Paris, France at Bruyères la Châtel.

ATM-16/E: Global distribution of the Radioxenon Background caused by known civilian emissions and its consequences for CTBT verification

G. Wotawa, A. Becker, M. Kalinowski, Paul Saey, Matthias Tuma and Matthias Zaehringer
Contact: andreas.becker@ctbto.org

Abstract: Monitoring of radioactive noble gases, in particular xenon radioisotopes, is crucial for the verification of the Comprehensive Nuclear-Test-Ban Treaty, as has been clearly demonstrated after the announced nuclear explosion in DPRK. Taking into account available emission estimates, it was found that the distribution and magnitude of the global background of the isotope Xenon-133 measured at stations of the International Monitoring System (IMS) is to a large extent consistent with the hypothesis that it results from the currently known civilian sources, namely radioisotope production facilities and nuclear power plants. Monthly average ^{133}Xe values from measurement locations distributed across the globe are well correlated with the respective values predicted by our model. The measured background is dominated by emissions from the facilities Chalk River in Canada and Fleurus in Belgium. Particularly data from the year 2008 provided a unique opportunity to allocate fractions of station-specific background to individual sources as there have been extended downtime periods of major xenon sources. Based on the overall good correlation of the model, a bias-correction of the emission estimates utilized by the model could be performed by means of a multiple linear regression analysis. This confirmed the annual emission totals from the Power Plants as well as from Fleurus, but indicated that the emission totals from Chalk River are significantly underestimated. It was also found that emissions from nuclear power plants can be difficult to treat in hourly or daily samples, due to the unknown timing of the batch releases. Individual batch releases are not dominant on a monthly or yearly scale, but can significantly influence a 24-hours sample in areas away from the major emitters.

DATA MINING

DM-01/A: Strategic Initiative in Support of CTBT Data Processing: vDEC (virtual Data Exploitation Centre)

***Sheila Vaidya** (LLNL), **E. Robert Engdahl** (Colorado Univ), **Ronan Le Bras, Karl Koch and Ola Dahlman** (CTBTO)*
Contact: vaidya1@llnl.gov

Abstract: Over the past 10 years, the IMS sensor network deployed by the CTBTO has successfully detected several low magnitude explosions, and its capabilities continue to expand. However, there have been many significant data processing advancements over the past two decades, in both extracting extremely weak signatures from noisy data sets as well as automatically mining large historical databases, which could be further leveraged in the IDC analysis pipeline. Data mining approaches have blossomed from the purely empirical to learning‐driven probabilistic algorithms, adapted to the physics of the problem. Moreover, an improved methodology for accurate anomaly characterization will greatly enhance the capabilities of the network to detect, locate and characterize events.

To facilitate a focused effort in data exploitation, we propose a Virtual Data Exploitation Center (vDEC) with the goal of defining a development environment for connecting computer scientists and statisticians from across the globe to evolve robust automation techniques for waveform processing and analysis relevant to the IDC. It will provide a forum to cross fertilize methods development with domain expertise for rapid implementation. vDEC will exploit the full spectrum of IMS sensor data sets, as well as aid in evolving system concepts for data mining and data fusion from on‐site inspections.

The Center would be funded initially through seed contributions from CTBTO PTS. In parallel, it will seek additional contributions from participating Member States, including partnerships with national agencies which support synergistic agendas. In turn, vDEC will champion research initiatives across universities and institutions, which address topics of interest to the international monitoring community, and which can bear fruit within a 5‐10 year time horizon.

Member States supporting PTS techniques innovation have already shown interest in such a construct. In addition, seismological institutions external to the PTS, such as the ISC, NEIC, JMA, CEA, NORSAR have begun engaging with the machine learning/artificial intelligence community (re: Data Mining and Seismology Workshop, Vienna 23‐26 Mar’ 09). Participation from developing countries will also be encouraged as vDEC gathers momentum. Such a pooling of resources and ideas from complementary research interests worldwide has the potential of creating a unique open forum conducive to excellence in data processing, with a conduit to an important international security endeavor.

This poster will describe the vDEC charter, proposed organizational construct, its operational model, stakeholders and beneficiaries, and potential risks to success

DM-02/A: Machine Learning for Improved Automated Seismic Event Extraction

Ariel Kleiner, Lester Mackey, Michael I. Jordan. University of California, Berkeley
Contact: akleiner@eecs.berkeley.edu

Abstract: The inaccuracy of present automated systems for seismic event extraction generally necessitates substantial analyst review effort. A significant opportunity for improvement lies in the fact that these systems currently fail to fully utilize the valuable repository of historical data provided by prior analyst reviews. In this work, we present the results of the application of machine learning approaches to several fundamental sub-tasks in seismic event extraction. These methods share as a common theme the use of historical analyst-reviewed bulletins as ground truth from which they extract relevant patterns to accomplish the desired goals. For instance, for the task of seismic phase identification, we demonstrate the use of classification techniques to assign seismic phase labels to station detections. We also investigate the application of classification and ranking methods to the identification of false events in automated bulletins and the ranking of events for subsequent analyst review. Furthermore, we examine the potential of historical association data to inform the direct association of new signal detections with their corresponding seismic events. Empirical results are based upon historical seismic detection and event data received from the Preparatory Commission for the CTBTO.

DM-03/A: Support Vector Regression for phase arrival prediction and SEL3 event evaluation
Heidi Anderson Kuzma, E. Robert Engdahl, James W. Rector, University of California, Berkeley
Contact: hkuzma@berkeley.edu

Abstract: Automatically generated events in the SEL3 are often thrown out or rebuilt by an analyst because the sequence of phase arrivals that have been automatically identified are non-physical; that is, they do not match the pattern of arrivals which should be expected at certain stations from an event in a given location. In this project, we aim to classify events in the SEL3 as true, false or split (partially generated using phases from another event which have been mis-associated with the current event), by correlating the waveforms measured at various stations with a synthetic set of arrivals estimated using a Support Vector Regression (SVR) algorithm. A similar process could be done, and is done by the interactive package used by human analysts, using a 1-d earth model. But arrival times are strongly affected by the regional geology of stations and the location of the event. This means that 1-d earth models are insufficient for making accurate predictions since they do not take lateral or regional variations of the earth's velocity structure into account. However, it would be impractical to use a full 3-d earth model to test every set of arrivals, because such models can take a long time to run. It would also perhaps be misleading, because our knowledge of the earth's structure is too incomplete to produce a perfect model. Instead, the SVR algorithm mimics what human analysts are trained to do: it can produce a set of synthetic arrivals based on experience and substitute predictions from the best model available when such experience is missing. SVR is a computer learning algorithm which computes an output based on comparing an input to a list of example inputs. In this case, the inputs would be event locations and the output would be a sequence of delta functions representing arrivals. SVR is closely related to the family of interpolation algorithms known as kriging. Unlike kriging, however, SVR can be tuned so it does not have to compare a new input to every example. Instead, it only keeps a subset of "type examples," known as s*upport vectors*. This means that trained SVR algorithms are fast and do not require much memory to run. Furthermore, they can be trained using relatively small sets of examples. The key to building an accurate SVR for phase arrival prediction will be using the best available training data. In this project, we use data from a carefully compiled Ground Truth Database. We use SVR to predict arrivals at several IMS stations from events around the world and then compare those predictions to waveforms from events listed in the LEB. We also compare SVR predictions to those of a 1-d model.

DM-04/A: Generative Graphical Models for Classification of Seismic Signals
Ohrnberger, Riggelsen, Scherbaum, University Potsdam
Contact: riggelsen@geo.uni-potsdam.de

Abstract: Seismic networks produce an abundance of time-series data, and issues such as uncertainty, noise, sensor interdependence, etc. pose great challenges for on-line processing and unbiased near realtime analysis. Automatic techniques are needed to aid the human analyst and decision makers in the tedious task of waveform characterization and signal classification of data arriving from seismic broadband stations and arrays as continuous 3 component streams. To this end, methods borrowed from the field of machine learning and data mining provide elegant solutions. By adhering to the multivariate statistical framework of Graphical Models (GMs) combined with insights from the field of automatic speech recognition, real-time signal classification becomes viable.

We depart from a parametrization of the data in the time-frequency domain, and via supervised learning, a GM-classifier is trained to recognize (a series of) waveforms by taking into account the statistical (in)dependencies that hold amongst the parameters in the time-frequency representation. For the supervised learning of class memberships (e.g., phase arrivals) previously hand-picked examples of seismic patterns are presented to the classifier. Using the Expectation-Maximization paradigm, the GM-classifier is trained to capture the intrinsic statistical characteristics of the particular waveform class(es) in question. Subsequently the generative classifier can be submitted to previously unseen short time segments from the data streams and class-membership can be determined in real-time. This generic modeling approach can be implemented in various ways depending on the GM specification partly dictated by the seismological constraints and requirements. We have investigated different alternatives to assess the applicability of this ML technique for real-time seismic event detection and classification. These include the implementation of the "grammar" of seismic phase arrivals into the GM frameworks as well as non-deterministic time dependence modeling the duration of various seismic phases, coda and noise between the phases.

DM-05/A: Supervised Classification for Improving Automatic Labeling of Phase and Identifying False Associations

Jeff Schneider, *Carnegie Mellon University*
Contact: schneide@cs.cmu.edu

Abstract: We propose the use of supervised classification methods to improve two aspects of the CTBTO IMS data processing pipeline. In the first example, we consider the automatic labeling of the phase of a seismic detection. For training and validation data we use the labels ultimately appearing in the REB (i.e. those corrected by human analysts). We compare our results to the accuracy of phase labels generated earlier through automated processing.

In the second example, we consider identification of false detections from the automated processing pipeline. For training data we compare the set of events listed in SEL3 with those ultimately appearing in LEB (i.e. after correction and removal of false associations and detections by human analysts). We propose a two stage method where a supervised classifier first attempts to identify false individual detects and then uses those predicted false detects to aid its decision about which events are due to the false associations of detects. In both examples, we present empirical results on data from the IMS.

DM-06/A: Kernel-based machine learning techniques for hydroacoustic signal classification

Matthias Tuma, Christian Igel. *Adaptive Systems Group, Institute for Neuroinformatics, Ruhr-University Bochum, 44780 Bochum, Germany*
Contact: Matthias.Tuma@rub.de

Abstract: For verification of the Comprehensive Nuclear-Test-Ban Treaty, hydroacoustic signals are continuously recorded across the oceans. They are processed in real-time at the International Data Centre (IDC). This includes automatic classification into three main categories, which is currently achieved through a rule-based expert system. The primary objective is reliable identification of signals with explosive signature, but hydroacoustic class labels may also be used when processing data from other monitoring technologies.

The present study investigates benefits of kernel-based machine learning techniques, in particular Support Vector Machines (SVMs), for hydroacoustic signal classification. Linear analysis of the data serves as a baseline. Standard SVMs are applied to features used by the IDC. Then gradient-based and evolutionary methods are employed to mutually optimize SVM kernel functions as well as the underlying feature set. Current IDC features are complemented by additional measures, with a focus on the exploration of wavelet transforms. Fast second-order learning algorithms and efficient approximation of the kernel classifiers account for real-time constraints. This study constitutes the initial step of a longer-term project, and a short overview over the planned activities is presented.

DM-07/A: Applying machine learning methods to improve efficiency and effectiveness of the idc automatic event detection system

Michael J. Procopio, Christopher J. Young, and John H. Gauthier, *Sandia National Laboratories*
Contact: cjyoung@sandia.gov

Abstract: An analysis is performed on the seismic-event data processed from 1999 through 2009 by the International Data Centre (IDC) of the Comprehensive Nuclear-Test-Ban Treaty Organization. One purpose of the analysis is to determine if there are characteristics of the data that could be utilized to understand and improve automatic seismic-event processing. Another purpose is to determine whether improved station calibration could improve the automatic processing.

The overall quality of the IDC bulletin is excellent, but achieving this quality requires a significant amount of analyst effort. Initial examination of the data shows that automatic processing produces 421,244 origin hypotheses, or about 118 per day over the nearly 11 year period of operation. Of these, 224,643 (53%) do not survive analyst review (i.e. false positives), while the remaining 196,601 (47%) are approved. In addition, analysts build another 30,606 origins (13% of analyst approved total) that the automatic processing missed (i.e. false negatives). Thus analyst-approved origins occur at a rate of about 64 per day. From these figures it is evident that significant improvement of the automatic system, and hence decrease in the analyst workload, is possible both by decreasing the number of false events as well as by decreasing the number of missed real events

Previous work analyzing a much smaller portion of the IDC data from 2002 found that some attributes, or *features*, appear well-suited to *discriminating* among the different families, or *classes*, of events. This evaluation used principled but ad-hoc methods to show a basic ability of certain features, such as signal-to-noise ratio, to identify the true class of a particular detected origin, which may or may not be valid. Building off the premise that there are powerful features in the origin and arrival data, this new study uses modern machine learning and

pattern recognition methods to *train models* on previously labeled data in existing archives, and then use those models to make predictions on future data whose classes are not known. Such methods are able to consider multiple features simultaneously, to achieve better prediction performance. This new work focuses very heavily on identifying these features (typically from the arrival table). Principled *feature selection* methods exist which will identify the most useful features for classification, while also identifying features which have no discriminatory power at all (and hence should not be considered in pattern recognition approaches).

The machine learning approach, which will consider both the Support Vector Machine classification algorithm as well as alternative approaches such as ensembles of decision trees including Random Forests, should result in a marked decrease in the *false positive rate*, that is, the number of incorrect detections with regard to the total number of detections. In parallel, this approach will enable a greater *true positive*, or correct detection rate. Together, such an improved system will reduce both the analyst burden in sifting through false detections, while also reducing the risk that a true event goes undetected by both the automatic system and the analyst.

The techniques presented are rigorously and quantitatively evaluated via *cross-validation*, using known, robust performance metrics in the machine learning and informational retrieval communities such as Precision-Recall curves and Receiver Operator Characteristics curves, and their respective AUC (Area Under Curve) and F-score summary statistics. Colloquially, these metrics are used to evaluate the *efficiency* and the *effectiveness* of the system. Such characteristics do represent a tradeoff, but the application of data-intensive machine learning methods, trained on large archives of data previously examined and labeled by an analyst, offers the possibility of a breakthrough performance gain yielding a state-of-the-art detection system with *both* improved efficiency *and* effectiveness.

Reference: Gauthier, J. H. (2009). Preliminary analysis of the International Data Centre pipeline, *Sandia National Laboratories Report*, in preparation.

DM-08/A: Joint probabilistic detection, association, & localization I: Hierarchical modeling

Nimar S. Arora, Michael I. Jordan, Stuart Russell, and Erik B. Sudderth, *Computer Science Division, University of California, Berkeley*
Contact: sudderth@eecs.berkeley.edu

Abstract: As part of its Comprehensive Test Ban Treaty (CTBT) verification efforts, the International Data Centre (IDC) analyzes seismic and other signals collected from hundreds of stations around the world. Current processing at the IDC proceeds, like many other large-scale monitoring and surveillance systems, in a series of pipelined stages. From station processing to network processing, each decision is made on the basis of local information. This has the advantage of efficiency, and simplifies the structure of software implementations. However, this approach may reduce accuracy in the detection and phase classification of arrivals, association of detections to hypothesized events, and localization of small-magnitude events. In our work, we approach such detection and association problems as ones of probabilistic inference—that is, finding the most likely explanation given evidence from observed waveforms. Inference is applied to a generative probability model that describes events, signal propagation, and signal detection by sensors. In simple terms, let X be a random variable ranging over all possible collections of events, with each event defined by time, location, magnitude, and type (natural or man-made). Let Y range over all possible waveform signal recordings at all detection stations. Then P_(X) describes a parameterized generative prior over events, and P_(Y | X) describes how the signal is propagated and measured (including travel time, selective absorption and scattering, noise, artifacts, sensor bias, sensor failures, etc.). Given observed recordings Y = y, we are interested in the posterior P(X | Y = y), and perhaps in the value of X that maximizes it—i.e., the most likely explanation for all the sensor readings. As detailed below, an additional focus of our work is to robustly learn appropriate model parameters _ and _ from historical data. Calculating and maximizing the likelihood of events is a difficult inference problem; our approach, which is based on Markov chain Monte Carlo (MCMC), is described in a companion abstract. The primary advantage we expect is that decisions about arrivals, phase classifications, and associations are made with the benefit of all available evidence, not just the local signal or the detections associated with a single hypothesized event. Important phenomena—such as the successful detection of sub-threshold signals, correction of phase classifications using arrival information at other stations, and removal of false events based on the absence of signals—should all fall out of our probabilistic framework without the need for special processing rules. In our baseline model, natural events occur according to a spatially inhomogeneous Poisson process, with intensities modelled by a mixture of Gaussians estimated from historical data. Complex events (swarms and aftershocks) may then be captured via temporally inhomogeneous extensions. Man-made events have a uniform probability of occurring anywhere on the earth, with a tendency to occur closer to the surface. Phases are modelled via their amplitude, frequency distribution, and origin. In the simplest case, transmission times are characterized via the one-dimensional IASPEI-91 model, accounting for model errors with Gaussian uncertainty. Such homogeneous, approximate physical models can be further refined via historical data and previously

developed corrections. Signal measurements are captured by station-specific models, based on sensor types and geometries, local frequency absorption characteristics, and time-varying noise models. We have previously developed a formal modelling language with the necessary expressive power to describe probabilistic models of this kind, along with general inference algorithms for all expressible models (Milch et al., 2005). When learning model parameters, we leverage the rich statistical literature on hierarchical, probabilistic graphical models (Jordan, 2004). This approach allows locally estimated historical statistics to be globally calibrated, and can flexibly incorporate complex features or nonparametric representations to better capture large historical datasets. At the conference, we expect to be able to quantitatively demonstrate the advantages of our approach, at least for simulated data. When reporting their findings, such systems can easily flag low-confidence events, unexplained arrivals, and ambiguous classifications to focus the efforts of expert analysts.

References: Jordan, M. I. (2004). Graphical models. Statistical Science, 19(1), 140–155.

Milch, B., Marthi, B., Sontag, D., Russell, S., Ong, D., and Kolobov, A. (2005). BLOG: Probabilistic models with unknown objects. In Proceedings of the Nineteenth International Joint Conference on Artificial Intelligence (IJCAI), Edinburgh

DM-09/A: Joint probabilistic detection, association, & localization II: MCMC Inference

Nimar S. Arora, Stuart Russell, and Erik B. Sudderth *Computer Science Division, University of California, Berkeley*
Contact: sudderth@eecs.berkeley.edu

Methods for automatically associating detected waveform features with hypothesized seismic events, and localizing those events, are a critical component of efforts to verify the Comprehensive Test Ban Treaty (CTBT). As outlined in our companion abstract, we have developed a hierarchical model which views detection, association, and localization as an integrated probabilistic inference problem. In this abstract, we provide more details on the *Markov chain Monte Carlo* (MCMC) methods used to solve this inference task.

MCMC (Gilks *et al.*, 1996) generates samples from a posterior distribution $\pi(x)$ over possible worlds x by defining a Markov chain whose states are the worlds x, and whose *stationary distribution* is $\pi(x)$. In the *Metropolis–Hastings* (M-H) method, transitions in the Markov chain are constructed in two steps. First, given the current state x, a candidate next state x' is generated from a *proposal distribution* $q(x' \mid x)$, which may be (more or less) arbitrary. Second, the transition to x' is not automatic, but occurs with an *acceptance probability* defined as follows:

$$\alpha(x' \mid x) = \min\left(1, \frac{\pi(x')q(x \mid x')}{\pi(x)q(x' \mid x)}\right)$$

It is not necessary that all the variables composing state x be updated simultaneously, in a single transition function. For example, *single-component* M-H algorithms, such as the *Gibbs sampler*, alter individual variables in turn. More broadly, domain knowledge can be used to factor $q(\cdot \mid \cdot)$ into separate transition functions for various strongly coupled subsets of variables. Under easily verifiable conditions guaranteeing the Markov chain's ergodicity (Gilks *et al.*, 1996), the M-H acceptance probability defined above ensures convergence of the Markov chain to $\pi(x)$, the target distribution of interest.

The seismic event model outlined in our companion abstract is quite similar to those used in multitarget tracking, for which MCMC has proved very effective—see, for example, (Pasula *et al.*, 1999; Oh *et al.*, 2009). In this model, each world x is defined by a collection of events, a list of properties characterizing those events (times, locations, magnitudes, and types), and the association of each event to a set of observed detections. The target distribution $\pi(x) = P(x \mid y)$, the posterior distribution over worlds x given the observed waveform data y at all stations. Proposal distributions then implement several types of *moves* between worlds. For example, *birth* moves create new events; *death* moves delete existing events; *split* moves partition the detections for an event into two new events; *merge* moves combine event pairs; *swap* moves modify the properties and assocations for pairs of events. Importantly, the rules for accepting such complex moves need not be hand-designed. Instead, they are automatically determined by the underlying probabilistic model, which is in turn calibrated via historical data and scientific knowledge.

Consider a small seismic event which generates weak signals at several different stations, which might independently be mistaken for noise. A birth move may nevertheless hypothesize an event jointly explaining these detections. If the corresponding waveform data then aligns with the seismological knowledge encoded in the probabilistic model, the event may be detected even though no single station observes it unambiguously. Alternatively, if a large outlier reading is produced at a single station, moves which instantiate a corresponding (false) event would be rejected because of the absence of plausible detections at other sensors.

More broadly, one of the main advantages of our MCMC approach is its consistent handling of the relative uncertainties in different information sources. By avoiding low-level thresholds, we expect to improve accuracy and robustness. At the conference, we will present results quantitatively validating our approach, using ground-truth associations and locations provided either by simulation or human analysts.

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DM-10/A: Can the use of prior information improve signal detection?

Neil Selby and David Bowers, *AWE Blacknest, UK*
Contact: bowers@blacknest.gov.uk

Abstract: The seismic component of the International Monitoring System (IMS) will comprise 50 primary stations, supported by 120 auxiliary stations. One of the main purposes of the IMS seismic network is to detect and identify underground explosions that are potentially violations of the CTBT. To achieve this, seismic signals from underground explosions need to be detected, associated, and their source located. Unfortunately, the IMS seismic network also detects signals from many naturally occurring seismic sources, the vast majority of which are earthquakes. Since 2000 the International Data Centre (IDC), operating in provisional mode, has processed signals from IMS seismic stations to produce daily bulletins of seismic events. When aggregated over a year these bulletins contain tens of thousands of seismic events. Under the CTBT such bulletins should help States Parties verify compliance with the treaty. Future improvements in signal detection, association, and source location should increase the efficiency and effectiveness of IDC bulletin production.

The disciplines of machine learning and data mining are concerned with extracting information from data. IMS seismic data are time series of ground motion recorded either by a three-component seismometer, or by a spatially distributed array of seismometers. Detection is the process of recognising transient signals in the presence of noise, and can be thought of as a classification process. Here, we ask whether seismic signal detection can be improved by using prior information about signal and noise characteristics, seismometer station configuration, and earth structure. Seismic signals have many observable characteristics (or features) such as duration, amplitude spectrum, polarisation, and spatial correlation. Noise amplitude spectra and spatial correlation structure may vary from site to site. In addition, there are other variations, such as in the configuration of IMS stations, e.g., the aperture of arrays, in seismometer response, and earth propagation effects. It seems clear then that a future detection strategy for the IDC could vary from station to station, and potentially from source region to source region, and that such a strategy could exploit prior information using Bayesian inference.

As an example of the utility of prior information, we demonstrate a detector that we find to be effective for P waves recorded at long range (3000 - 10000 km) by small-aperture (< 5 km) IMS arrays, where the noise often has a high level of spatial correlation at the frequencies of interest (0.5-5.0 Hz). Our detector uses prior models for the signal, the noise, and for propagation effects in the earth. The output of the detector can be expressed as the probability of a signal with the assumed characteristics being present in the data, which may be useful input to future association algorithms, perhaps developed through the application of generative machine learning methods.

DM-11/A: Physics-based data mining for seismic bulletins

Stephen C. Myers and Gardar Johannesson*, Lawrence Livermore National Laboratory*
Contact: smyers@llnl.gov

Abstract: Production of high quality data sets that are used in seismic studies remains a painstaking and costly endeavor. The value of meticulous data analysis is inscrutable, but the number and geographic coverage of carefully measured arrival times is not sufficient for either development of high-fidelity (3-dimensional) models or comprehensive empirical calibration of travel times. Although regional and global bulletins of seismic data provide excellent data coverage, these databases are contaminated by noisy and spurious data. In this study, Bayesloc – a stochastic multiple-event seismic location algorithm – is used to mine a database of arrival time measurements (picks) that are predominantly collected from bulletins. A small subset of trusted picks made at Lawrence Livermore National Laboratory is also included. Bayesloc applies data-mining methodologies and constraints afforded by the physics of seismic travel times to sample from the posteriori, joint probability density function across event locations, event-station travel times, pick precision, and phase labels (including identification of erroneous data). Using the posteriori samples, data may be culled based on prescribed precisions for each of the parameters comprising the aforementioned probability density function (e.g. probability that the phase label is correct). Bayesloc is applied to a collection of approximately 2500 events spanning the Middle East. Even after cursory outlier removal, we find that out of ~387,000 P and Pn picks, ~30,000 (~8%) are not members of the P or Pn population, but are erroneous data. Most importantly for seismic studies, Bayesloc analysis reduces residual standard deviation from 1.6 seconds to 0.8 seconds for P arrivals and from 2.3 seconds to 1.8 seconds for Pn arrivals. Posteriori residuals are largely attributable to travel time prediction errors, making the data set ideal for use in 3-dimensional tomographic studies. Data culling on this massive scale with the precision and consistency accomplished here was previous impractical if not impossible.

References:

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DM-12/A: Exploiting the skills of waveform data analysts in the quest for improved automatic processing

Robert G Pearce *and staff, Monitoring and Data Analysis Section, IDC*
Contact: Robert.Pearce@ctbto.org

Abstract: Over the past ten years analysts at the IDC have reviewed all signals detected automatically on IMS seismic, hydroacoustic and infrasound data which were associated to events in the final automatic event list (SEL3). They have retimed and/or changed the phase identification of many such detections, and almost 30% of events which appear in SEL3 have been discarded by analysts as invalid. Analysts have substantially modified a further 50% of SEL3 events. In addition, automatic processing misses potentially valid detections and events. Analysts must therefore build missed events from those automatically detected signals which have either not been associated to any event, or which have been wrongly associated, or which have been missed. Such events added by analysts constitute on average about 20% of events in the reviewed event list (LEB).

The large number of examples accumulated in the (automatic) SEL3 and in the (analyst-reviewed) LEB (more than 250,000 events and more than a million associated detections) invites data-driven searches for patterns in analyst actions that can drive improvements to automatic processing. However, such an approach would benefit from a formal understanding of what the analyst does correctly that the automatic processing does not.

When an analyst looks at a seismic signal, a wealth of experience, including that of previous examples, is instantly recalled and implicitly utilised. Some formal elements of this analyst experience which are not currently used effectively in automatic processing are the following:

1 Knowledge of signal characteristics specific to various commonly observed source-station paths
2 Knowledge of station combinations expected to detect signals from events in a given location or region
3 Expectation of similarities in signal characteristics observed at a range of stations for a given event
4 Ability to estimate signal onset time, azimuth and slowness more accurately than automatic processing
5 Ability to identify signal detections missed by automatic processing, and associate them to valid events
6 Rapid recognition of events which have an unrealistic combination of seismic, hydroacoustic or infrasound signals
7 Ability to identify and associate later-arriving seismic phases from large events
8 Ability to identify data artefacts and anomalies caused by station malfunction or noise sources which automatic processing has mistaken for real signals
9 Ability to correctly interpret complex combinations of signals.

For most of the above elements, negative evidence (i.e. the absence of a signal, for example at particular distances or at particular types of station) plays an important role.

Examples of invalid events from SEL3 will be shown together with co-located past examples which provide evidence that the invalidity could have been predicted automatically. Analyst thought processes used in discarding such events will be described. Examples of signal detections, either missed, mis-associated or detected but not associated in the (automatic) SEL3 will also be given, together with the evidence which has led to the analyst decision.

DM-13/A: Data mining from Antelope at OGS-CRS (Udine, Italy)

D. Pesaresi (1), P.L. Bragato (2), P. Di Bartolomeo (2), A. Saraò (2), P. Bernardi (2), A. Govoni (1)
(1) OGS and INGV, Italy, (2) OGS, Italy
Contact: dpesaresi@inogs.it

Abstract: Since 2002 the Seismological Research Centre (Centro di Ricerche Sismologiche, CRS, http://www.crs.inogs.it) of the National Institute for Oceanography and Experimental Geophysics (OGS) in Trieste (Italy) is involved in the EU INTERREG IIIA project "Trans-national seismological networks in the South-Eastern Alps" together with other four Institutions: Zentralanstalt für Meteorologie und Geodynamik (ZAMG) in Vienna (Austria), the Earth Science Department of the Trieste University in Trieste (Italy) and the Agencija Republike Slovenije Za Okolje (ARSO) in Ljubljana (Slovenia). The commercial Antelope software suite from BRTT has been chosen as the common basis for real time data exchange, rapid location of earthquakes and alerting.

Antelope is a powerful software suite that easily allows sharing data in real time among neighbouring institutions. However it must be tuned to each seismological data centre needs in order to extract the specific information required. At OGS-CRS we adapted existing programs and created new ones like: a customized interface to manually relocate earthquakes, a script for automatic moment tensor determination, scripts for web publishing of earthquake locations, waveforms, state of health parameters and shaking maps, plus scripts for email/SMS/fax alerting.

DM-14/A: How to help seismic analysts to verify the French seismic bulletin?

Pierre Gaillard(1), David Mercier(2), Michaël Aupetit(2), Carole Maillard(1), Robert Quach(1), Jean-Denis Muller(2)
(1) CEA, DAM, DIF, F-91297 Arpajon, France
(2) CEA LIST, Sensors and Signal Technologies Department, 91191 Gif-sur-Yvette, France.
Contact: Pierre.GAILLARD@CEA.FR

Abstract: One of the DASE department's missions (Analysis, Surveillance and Environment Department) is the monitoring of the seismic activity observed on the French seismometer network. Thanks to this surveillance, the French authorities can be rapidly notified when a potentially felt seism happens in the metropolitan France or in a frontier district. The DASE also publishes a weekly seismic bulletin describing the characteristics and nature of the detected events. An event can be an earthquake, a quarry blast, a marine explosion or even a rock burst. This bulletin is the basic information for many researches, especially about seismic hazards whose estimations, for example, are taken into account to define local earthquakeresistant specifications.

The accuracy of the bulletin is therefore essential and several human revisions are carried out to correct any error in the bulletin. These revisions used to be performed according to the observation of a map where all the events were marked with different colors according to their class in order to detect the outliers, or as consequences of *a posteriori* information found in newspapers or official reports (about the opening of a new quarry for example).

This work shows how an automatic system, called RAMSES, can help the analysts to revise the bulletin, using classifiers based on Multi-Layer Perceptrons (MLP) and Support Vector Machines (SVM). Neural networks have already been tested to help seismic analysts for the direct monitoring of seismic events but in the field of revision and verification of seismic bulletins, it is a unique approach we know of. This approach consists in reducing the number of events the analysts have to verify, by selecting the events that are difficult to process or atypical. This is the case for some detection in areas where several kinds of events can occur (seism and quarry blast) or are very rare (a seism in an almost aseismical area). This selection is made by an automatic classifier. If the automatic classifier cannot reach a clear decision or if it disagrees with the choice of the analyst, the event must be revised. Otherwise, the class is certainly right and the event is removed from the revision process.

With 96.5% of good classification, and less than 7% of the events emphasized for verification, RAMSES strikingly improves the speed of the revision. Now the analysts need to verify about only two events per week for the regular revision and these events are automatically emphasized. In the same time, after a complete simulation over 2004 and the exploitation of RAMSES software during 2005, every misclassified event was emphasized. If the revision of a whole year is considered, they can do in 1 month distributed all over the year what they used to do in 2 months distributed over 3 months before

DM-15/A: Swedish-Finnish Infrasound Network – The Research Program

***Ludwik Liszka**, Swedish Institute of Space Physics Umeå, Sweden*
Contact: ludwik@irf.se

Abstract: Continuous observations of infrasound started in Sweden 1972. Three arrays in Northern Sweden were later completed with an array in Uppsala. The Uppsala-array was moved in 2006 to Sodankylä, Finland starting the Swedish-Finnish Infrasound Network (SFIN), a co-operative project between the Swedish Institute of Space Physics and the Sodankylä Geophysical Observatory. The data collected by the SFIN are displayed on the Internet, accessible for the scientific community. The infrasound project at the Swedish Institute of Space Physics covers three main topics.

1. Detection of natural and man-made infrasonic sources. During more than three decades infrasound from numerous natural and man-made sources, like meteoroid entries, supersonic aircraft and explosions were recorded, and in many cases localized. A major achievement was the identification of infrasonic chirps, generated by sprites, high altitude electric discharges occurring at heights up to 90 km.
2. Since 1994 the Swedish Institute of Space Physics maintains a data-base containing digitised time series from all infrasonic arrays operated by the Network. The immense amount of infrasonic data requires efficient methods for data search and event identification. During the recent decade numerous data mining methods were adapted for studies of infrasonic data and tested. One of major projects was the search for unknown meteoroid entries in the surroundings of Northern Europe, occurring during the past 10 years. Also the continuous, automatized search for infrasonic chirps from sprites is carried on.
3. The proximity to the site of regularly occurring explosions in Northern Finland facilitates the access to high-accuracy propagation data. The influence of factors like the occurrence of atmospheric irregularities, non-linear effects around the explosion site, the contribution of tropospheric propagation, etc., is studied.

The aim of this research project is to develop a probabilistic propagation model, which would improve the interpretation of infrasonic observations the determination of the true source location.

DM-16/A: Seismic search engine

Yang Liu *Lawrence Livermore National Laboratory LLNL-ABS-411943*
Contact: liu24@llnl.gov

Abstract: The seismic network of the International Monitoring System (IMS) comprise 50 primary and 120 auxiliary stations, with plans to build and include more stations. Each station collects seismic measurements and transmits the data back to the International Data Center (IDC). The IDC identifies phase picks from the seismic waveforms, associates the picks into events, and publishes the results in an event bulletin. The IDC then archives the seismic data into a database for later review. This seismic database presently stores several terabytes of data and grows at a rate of roughly 3 gigabytes per day. This data set provides a wealth of information for data mining. Unfortunately, the size of the database presents a practical challenge for data exploitation.

IDC currently keeps the seismic data in a relational database (*e.g.* Oracle, SQL); data records are indexed by a predetermined set of attributes (schema) such as the station name, number of channels, and time. Users can access data records efficiently by submitting queries composed from these basic indices. However, users cannot easily access records by means of any other attributes. For example, an analyst wanting to find seismic waveforms with a signal-to-noise ratio above a certain threshold must retrieve **a copy of all records** from the database, compute the signal-to-noise of each seismic data sample, and then apply the threshold to determine the resulting set. This computation is easy to express, but is intractable to compute over a multi-terabyte size database and certainly does not scale with multiple users. Hence, very relational databases are impractical for data mining algorithms where functions are typically evaluated over all data records.

One way to make the seismic database more friendly for data mining is to design infrastructure for distributed processing over the entire data set rather than the efficient retrieval of individual records. Software frameworks such as MapReduce [1] provide support for distributed computing on very large data sets using clusters of many computers. The MapReduce framework factors and expresses data processing in two steps: "map" and "reduce". The map step distributes the data set across a set of worker nodes, which each uniformly evaluates a function over its portion of data records. The reduce step then collects the output from the map step of each worker node and combines them together to produce the final output. To implement the previous example of thresholding seismic waveforms above a certain signal-to-noise using MapReduce, the user explains how to compute the signal-to-noise ratio (map step) and how to perform the thresholding (reduce step). This "query" is broadcasted to each node in the cluster and the details of assigning and balancing computation over the compute cluster are left to the software framework.

The principal difference between the relational database model and the distributed computing model is scalability. For example, the MySQL relational database supports a maximum of 63 nodes. In contrast, Google maintains MapReduce clusters each containing tens of thousands of nodes. Scaling to many nodes also offers considerable advantages beyond faster data processing. By directly hosting portions of the database across multiple nodes (with redundant data assignments), nodes will have local access to data and the database becomes more resilient to disk and hardware component faults whereas centralized databases may suffer from single points of failure.

Drawing upon these advantages, we propose constructing a search engine over a distributed database for seismic data. The search engine will provide a front-end for expressing user queries into the data set and an efficient back-end for implementing data mining and classification algorithms. This capability will allow users to efficiently estimate global statistics over the entire data set and retrieve records using any computable attribute. Furthermore, the search engine will enable a variety of alternative search interfaces for non-experts to explore the data set. One possible example-based search interface is where the user provides a set of inputs for the system to discover other "similar" records in the database [2] to, for example, improve seismic event association or correlate signals on much larger time scales.

References:

[1] J. Dean and S. Ghemawat, "MapReduce: Simplified Data Processing on Large Clusters" *Sixth Symposium on Operating System Design and Implementation*, 2004.

[2] Google Sets http://labs.google.com/sets

DM-17/A: Ranking Methods of Classifying Radioxenon observations using Machine learning

R. Kurt Ungar[1],Ian Hoffman[1], Jing, Yi[1], Marc Bean[1] , Trevor J. Stocki[1],Guichong Li[2], and Nathalie Japkowicz[2]

[1]Radiation Protection Bureau, Health Canada, Ottawa, ON, Canada

[2]School of Information Technology and Engineering

University of Ottawa

Contact: kurt_ungar@hc-sc.gc.ca

Abstract: Realistic distributions of radioxenon observations were simulated using actual time series of noble gas concentrations at 5 locations in the world. State of the art meteorological models and reasonable explosion site release scenarios were employed to generate sets of noble gas observations by summing true background xenon and reasonable additional xenon arising from a nuclear explosion. The actual background data and the simulated explosion measurements were used in a competition to test machine learning methods at the 2008 IEEE International Conference on Data Mining, held in Pisa Italy, to properly categorise observations as being background or impacted by explosion emissions. These results, significant in there own right, are supplemented by a proposed general method for evaluating the effectiveness of different methods of categorization based on a Figure of Merit (FOM) called the Area Under Curve (AUC) of the Receiver Operator Characteristic (ROC) curve. The importance of other, sometimes qualitative, criteria is also discussed.

HYDROACOUSTICS

HYDRO-01/H: Ambient noise

David L. Bradley, *Penn State University, Applied Research Lab, P. O. Box 30, State College, PA 16804-0030*
Contact: dlb25@psu.edu

Abstract: The background noise levels encountered by the CTBTO Hydroacoustic System are described in terms of sources, signal characteristics, and their time and space behavior. The extant data base for ambient noise is extensive, but not continuous; The potential of the CTBTO stored data files to provide a comprehensive "look" at the changes in ambient noise over a decade, over global scales is excellent and will provide an opportunity to study noise characteristics from the perspective of looking for markers of climate change, and its impact on the undersea environment. Historical data will be presented, together with its limits and the understanding gained from early studies.

HYDRO-02/H: Use of CTBTO hydroacoustic resources to investigate global scale ambient noise behavior

David L. Bradley, *Penn State University, Applied Research Lab, P. O. Box 30, State College, PA 16804-0030*
Contact: dlb25@psu.edu

Abstract: The locations of CTBTO Hydroacoustic Sensors present an opportunity to examine oceanic ambient noise behavior for large spatial scales--up to complete ocean basins. There is also the potential to isolate and compare the variation due to sub spaces of ocean basins. In addition, at these scales, the contributions and variability due to, for example, distant shipping, seismic activity, or hydrocarbon resource exploration can be investigated. The focus of this paper is a series of data mining proposals, that exploit both the archived CTBTO data and (near) real time data collection files. Either real time data records, or possibly planned collection times, based on documented events or expected circumstances allow the collection of ancillary data, critical to interpretation of the noise records.

HYDRO-03/H: Concept for hydroacoustic buoy system for CTBTO

Lothar Ginzkey, Christian Kubaczyk, Jan Ehrlich
Bundeswehr Test Center for Ships, Naval Weapons, Maritime Technology and Research, Berliner Str. 115, 24340 Eckernförde, Germany
Contact: janehrlich@bwb.org

Abstract: The hydroacoustic network of CTBTO has relatively few stations compared to the other networks. Therefore the failure of a small number of sensors has a noticeable effect on the overall performance and the detection capability of the network. This can be overcome with a mobile sensor system as a temporary replacement. A buoy system for this purpose is proposed. The buoy has a hydrophone that is placed in the deep SOFAR channel as the sensors of the permanent stations are. This ensures a comparable sensitivity to signals of possible nuclear explosions. In 2002 a prototype buoy was built and successfully tested by FWG in the Skagerak (Baltic Sea) over a period of four months. The system and the results of the tests are presented. Due to the limitations in signal processing and communications at that time a data preprocessing had to be applied. A new, updated concept is presented that uses state of the art components and benefits from the technological improvements made since 2002. The intelligent signal processing ensures a high probability that interesting signals are detected and transmitted. Although not all time series data can be transmitted continuously all time data are recorded and can be retrieved and transmitted later on demand. The whole process of data management and signal processing can be remote controlled by radio link over the Iridium satellite service. Apart from the hydrophone data a network of sensors providing non acoustic data like temperature, salinity can be supported. The buoy uses a field programmable analog array (FPGA) for signal processing, a microcontroller for the system control and digital IP-based network technology throughout the entire system. The data storage capacity and energy supply allows continuous operation of the buoy for 6 – 12 months depending on battery capacity. A buoy system built according to this concept can be a valuable asset for CTBTO as a temporary replacement of broken hydroacoustic sensor at acceptable costs.

HYDRO-04/H: Results from a 14 Month Hydroacoustic Experiment in the Southern Indian Ocean

J.-Y. Royer [1] R. P. Dziak [2], M. Delatre [1], R. Chateau [1], C. Brachet [1], J. H. Haxel [2], H. Matsumoto [2], J. Goslin [1], V. Brandon [1], Y. Cansi [3], F. Samaran [4] & C. Guinet [4].

[1]Lab. Domaines Océaniques, CNRS/Univ. Brest & UEB, 29280, Plouzané, France ; [2]Pacific Marine Environment Lab, NOAA/OSU, Newport, OR, 97365 ; [3]CEA DASE/LDG, 91680, Bruyères le Châtel, France ; [4]Centre d'Etudes Biologiques de Chizé, CNRS, 79260, Beauvoir-sur-Niort, France

Contact: jyroyer@univ-brest.fr

Abstract: From October 2006 to January 2008, an hydroacoustic experiment in the Indian Ocean was carried out by the CNRS/University of Brest and NOAA/Oregon State University to monitor the low-level seismic activity associated with the three contrasting spreading ridges and deforming zones in the Indian Ocean. Using R/V *Marion Dufresne,* three autonomous hydrophones were moored in the SOFAR channel in the Madagascar Basin, and northeast and southwest of Amsterdam Island.

The three instruments successfully collected 14 months of continuous acoustic records. The array detected 1857 acoustic events consisting mostly of earthquake generated T-waves, but also of iceberg tremors from Wilkes Land, Antarctica. Within the triangle defined by the temporary array, the three ridges exhibit contrasting seismic patterns. Along the Southeast Indian ridge (SEIR), the 272 acoustic events (vs 24 events in the NEIC catalog) occur predominantly along the transform faults; only one ridge segment (76˚E) displays a continuous activity for 10 months. Along the Central Indian Ridge (CIR), seismicity is distributed along fracture zones and ridge segments (269 events vs 45 NEIC events), with two clusters of events near the triple junction (24-25S) and south of Marie-Celeste FZ (18.5S). Along the Southwest Indian Ridge (SWIR), the 222 events (vs 31 NEIC events) are distributed along the ridge segments with a larger number of events west of Melville FZ and a cluster at 58E. The immediate vicinity of the Rodrigues triple junction shows periods of quiescence and of intense activity. Some large earthquakes events (Mb>5) near the triple junction (SEIR and CIR) seem to be preceded by several acoustic events that may be precursors. Finally, off-ridge seismicity is mostly detected in the southern part of the Central Indian Basin as a result of the intraplate deformation between the Capricorn and Australian plates.

Other signals of interest are identified such as a 6-week long series of broadband (1-125 Hz) explosive signals detected only by the instrument located between Kerguelen and Amsterdam islands, many cryogenic tremors easily recognizable from their varying tones and harmonics, some of which can be precisely located off the Antarctic shelf, and finally whale calls attributed to four different whale species. This vocal activity is found to be highly seasonal, occurring mainly from April to October with subspecies variations. Detailed analyses of this unique data set are still underway.

The two permanent hydroacoustic stations of the Comprehensive nuclear-Test-Ban Treaty Organization (CTBTO) located near Diego Garcia Island (HO8) and off Cape Leeuwin (HO1) would usefully complement the geographic coverage of our temporary array and would help improving the location of the hydroacoustic events and reduce their uncertainties. Conversely, data from the temporary array may be of interest for further assessing the capabilities of the IMS permanent hydroacoustic stations. We are planning to renew this experiment, with additional autonomous hydrophones and for a period of 2 to 3 years, starting early 2010, for acquiring longer time series regarding the "acoustic" activity of the ocean floor and the presence and migration pattern of some species of large marine mammals in these remote southern latitudes.

HYDRO-05/H: IMS hydroacoustic phase identification

***Paul Dysart**, Technology and Advanced Systems, Science Applications International Corporation, Arlington, Va 22203 USA*

Contact: dysartp@saic.com

Abstract: Release 3 of the International Monitoring System included fully functional hydroacoustic versions of DFX (detection processor), StaPro (station processor) and GA (association, location, magnitude estimation). DFX-H and StaPro-H functionality includes detection, windowing, and feature extraction, and the use of site-specific Neural Network (NNET) weights files for automatic phase identification at IMS hydroacoustic stations. Currently there are there three definitive hydroacoustic phases - N (noise), T (solid earth and water-borne path), H (predominantly water-borne path), and a fourth class U that can be applied to unknown or uncertain results. The desire in assigning the uncertain phase ID is to capture impulsive arrivals similar to H-phases whose paths are not exclusively water-borne such as island nuclear test. These phase types were originally based on observations at prototype stations at PSUR and Wake Island, and assumptions regarding T-phase source coupling and propagation.

The process of generating the ground-truth data used for NNET training begins with the assemblage of the highest quality reviewed arrival data and the characterization of hydroacoustic signals. The original development of DFX-H included the definition of a comprehensive set of signal parameters in a fixed number of octave bands covering the operational bandwidth. In addition to the raw features in the hydro feature table, a number of

parameters invariant to event magnitude and absolute time are derived from the hydro feature set and used to train a multistage MLP (Multilayer Perceptron) classifier. Artificial neural networks are generally analogous to other techniques making their design and usage subject to many of the constraints of conventional error minimization schemes.

The characterization of in-water explosions relies almost exclusively on time-series simulations. Currently, the impulsive data used to simulate H-phase arrivals in a ground-truth data set are generated using a broad-band version of the KRAKEN normal-mode model. To further simulate the characteristics of an actual in-water explosion, explosion source functions are convolved with the modeled impulse response and embedded in samples of real station noise. To obtain features from these synthetic data, the noise-corrupted broad-band simulations are formatted and processed by DFX-H as arrival data.

The summary performance of the prototype system applied to the Psur and Wake Island data demonstrated probabilities of detection (Pd) and false-alarm (Pfa) well within performance requirements. Implementations based on more recent machine learning technologies are currently being developed to enable automatic phase identification at all IMS hydroacoustic sites.

HYDRO-06/H: The role of the IMS hydroacoustic network for characterising events in the REB

Jepsen D. C.[1] & M. D. Fisk[2]
[1]Geoscience Australia; [2] ATK, USA
Contact: david.jepsen@ga.gov.au

Abstract: There are on average around 100 events per day in the International Data Centre's (IDC) Reviewed Event Bulletin (REB). Since its inception, there have been only a handful of "hydro-only" events, with it being dominated by events formed by the seismic network. For many of the seismically formed events in oceanic regions,T-phases detected on hydroacoustic stations have been associated to them. Event screening, the process which screens out events in the REB that are considered to be consistent with natural phenomena or non-nuclear, man-made phenomena, makes use of these T-phase associations to screen out the majority of these events as being of natural origin. Simply, events whose 90% error ellipse is over water depths where it is infeasible to install and test an explosion in oceanic crust, are natural, if no high-frequency hydroacoustic energy is observed for unblocked paths.

In this study, events in the REBs during the period: 2009076 – 2009121 were examined. Over 80% of the events that had an unblocked path to a hydrophone station, were screened out as being consistent with natural sources, namely earthquakes. Since the domination of the REB by signals detected on the seismic network is not expected to change significantly, the screening of seismically formed events over oceanic regions is seen as one of the major verification roles of the hydroacoustic network.

HYDRO-07/H: Detection of an in-water event on seismic and hydroacoustic sensors.

Mark Prior, Paulina Bittner, David Jepsen, Yan Jia, Oscar Meless
Contact: Mark.Prior@ctbto.org; david.jepsen@ga.gov.au

Abstract: Data recorded on seismic and hydroacoustic stations are presented and associated with an event that took place off the coast of Western Australia in November 2008. Arrival times and azimuths at the measuring stations are used to determine event time and location while signal properties are used to characterise the nature of the event. It is hypothesised that the event was an underwater chemical explosion and the energy yield of the event is estimated using signal cepstral and received-energy characteristics. Results obtained from stations in the International Monitoring System of CTBTO are compared with results from a local seismic network operated by GeoScience Australia. It is shown that a combination of land-based and underwater sensors is capable of detecting the event and locating it to within less than 20km.

HYDRO-08/H: Detection, location, and characterization of hydroacoustic signals using seafloor cable networks offshore Japan

Hiroko Sugioka[1], Kiyoshi Suyehiro[2], Masanao Shinohara[3]
[1]Japan Agency for Marine-Earth Science and Technology[2]; [2]Integrated Ocean Drilling Program; [3]University of Tokyo
Contact: hikari@jamstec.go.jp

Abstract: The hydroacoustic monitoring by the International Monitoring System (IMS) for Comprehensive Nuclear-Test-Treaty (CTBT) verification system utilize hydrophone stations and seismic stations called T-phase stations for worldwide detection. Some signals of natural origin include those from earthquakes, submarine volcanic eruptions, or whale calls. Among artificial sources there are non-nuclear explosions and air-gun shots. It is important for IMS system to detect and locate hydroacoustic events with sufficient accuracy and correctly characterize the signals and identify the source. As there are a number of seafloor cable networks operated offshore Japanese islands basically facing the Pacific Ocean for monitoring regional seismicity, the data from these stations (pressures, hydrophones and seismic sensors) may be utilized to verify and increase the capability of the IMS. We use these data to compare some selected event parameters with those by Pacific in the time period of 2004-present. These anomalous examples and also dynamite shots used for seismic crustal structure studies and other natural sources will be presented in order to help improve the IMS verification capabilities for detection, location and characterization of anomalous signals.

The seafloor cable networks composed of three hydrophones and six seismometers and a temporal dense seismic array detected and located hydroacoustic events offshore Japanese island on 12th of March in 2008, which had been reported by the IMS. We detected not only the reverberated hydroacoustic waves between the sea surface and the sea bottom but also the seismic waves going through the crust associated with the events. The determined source of the seismic waves is almost coincident with the one of hydroacoustic waves, suggesting that the seismic waves are converted very close to the origin of the hydroacoustic source. We also detected very similar signals on 16th of March in 2009 to the ones associated with the event of 12th of March in 2008.

HYDRO-09/H: Ocean-acoustic evidence for large conversion of external to internal tide

Hiroko Sugioka[1], Yoshio Fukao[1], Toshiyuki Hibiya[2]
[1]Japan Agency for Marine-Earth Science and Techonlogy, [2]University of Tokyo
Contact: hikari@jamstec.go.jp

Abstract Submarine volcanic event often generates acoustic waves (T-waves) traveling over long distances through the low velocity channel (SOFAR) of the ocean. By a method of coherent stacking of T-waves from a submarine volcanic activity in northern Mariana, we found a significant semidiurnal variation of T-wave travel times. The amplitude of variation is an order of larger than those reported in the previous ocean sound transmission experiments. Ray-theoretical consideration for the numerically simulated ocean tides indicates that such large T-phase travel time variation is a consequence of large up-and-down movement of seawater around the axis of the SOFAR channel due to the M2 internal tide effectively converted from external tidal forcing. T-phases, a ubiquitous feature of the ocean acoustic noise field, can be used to infer internal tidal motion and the associated ocean mixing.

The Japanese submarine cabled OBS (Ocean Bottom Seismometer) arrays include the off-Boso array of four OBSs by the Japan Meteorological Agency, the off-Sanriku array of three OBSs by the University of Tokyo and Tohoku University and the off-Kushiro array of three OBSs by the JAMSTEC. A swarm of T-wave events from a submarine volcanic activity in northern Mariana were detected by these three permanent array as well as some of the temporal broadband OBS array of the Ocean Hemisphere network Project (OHP) located near the swarm region. The swarm lasted about three months from September to December 1999, showing the semidiurnal variation of T-waves travel time. The variation of the order of 0.1-0.2 s represents in situ evidence of such large internal tidal motion along the Izu-Bonin-Mariana Ridge, according to which the converted energy from external to internal mode is about 21GW (equivalent to energy flux of about 7 kW/m) along the ridge with a length of 3000 km. T-phases are naturally, continually and ubiquitously manner described here to retreat information about internal tides and ocean mixing.

HYDRO-10/H: Comparison of CEA hydroacoustic bulletin and IDC hydroacoustic monitoring in the Pacific.

Olivier HYVERNAUD, *Laboratoire de Géophysique de Pamatai, Tahiti, Département Analyse et Surveillance de L'Environnement, Commissariat à L'Energie Atomique, France.*
Contact : hyvernaud@labogeo.pf

Abstract: The Laboratoire de géophysique, french Commissariat à l'Energie Atomique, in French Polynesia, uses to edit an annual hydroacoustic bulletin of seismic activity in the Pacific. From this bulletin, we present the locations of hydroacoustic sources detected in 2008 in the Pacific by the french 'T phase' stations network. Locations are obtained from the synergy of hydroacoustic and seismic Rayleigh phases pickings which enable a highly constrained localization. This set of data is compared with the distribution of seismic sources published in the IDC REB seismic bulletin containing T phase pickings.

We particularly study the localization of a submarine explosion off the east coast of Japan. We compare the location parameters and errors obtained with IMS waveforms data, with both IMS and french CEA waveforms data and the best location obtained with japanese, french CEA and CTBT data.

HYDRO-11/H: Monitoring submarine eruptions and drifting icebergs in the South Pacific Ocean.

Olivier HYVERNAUD, Laboratoire de Géophysique de Pamatai, Tahiti,
Département Analyse et Surveillance de l'Environnement, Commissariat à l'Energie Atomique, France.
Contact: hyvernaud@labogeo.pf

Abstract: The french Commissariat à l'Energie Atomique has settled in French Polynesia a 'T-Wave' seismic stations network since 1960.These 10 high sensitivity broad band stations transmitted in real time enable to monitor natural submarine processes such as volcanic eruptions, colliding icebergs and seismic activity in the Pacific.

In recent years, we have particularly monitored the Monowai volcano, Kermadec islands, which is in constant activity since 2002. This back arc submarine volcano is potentially dangerous for New Zealand, Tonga and French Polynesia and could trigger a tsunami in case of violent explosion. The screening of hydroacoustic phases shows multiple waveform patterns, probably associated with submarine explosions, volcanic tremors and lava emissions on the flanks of the volcano. The combined use of CEA and hydrophone IMS data enables us to improve greatly the monitoring and location of the eruptive activity.

During the 2008-2009 summer season in Antarctic, we have also tracked the giant drifting iceberg B15a in the roaring fifties. During 4 months, we have recorded and located the cracks which accompany the progressive breaking-up of B15a into small bergs and growlers. The use of arrival times and azimuth of H03N triplet reduced significantly the error ellipse of locations. This tracking could supplement the visible and radar satellite image-based tracking which is sometimes difficult because of rough meteorological conditions.

HYDRO-12/H: Estimating the abundance of blue whales (Balaenoptera musculus) in the northern Indian Ocean using vocalisations recorded by sea-bed mounted hydrophones.

Danielle Harris[1], Len Thomas [1], John Hildebrand[2], Sean Wiggins[2], John Harwood[1]
[1]Centre for Research into Ecological and Environmental Modelling (CREEM), The Observatory, Buchanan Gardens, University of St. Andrews, St. Andrews, Fife, KY16 9LZ; [2]Marine Physical Laboratory, Scripps Institution of Oceanography, La Jolla, CA 92093-0205, USA
Contact: dh17@st-andrews.ac.uk

Abstract: There are several benefits of using passive acoustic monitoring (PAM) to assess marine mammal populations, in comparison with visual surveys. The overall goal of this PhD project, funded by the UK Defence Science and Technology Laboratory, is to develop statistically robust methods to estimate absolute whale abundance using whale vocalisations recorded by seabed-mounted hydrophone systems, illustrated by several case studies. The main methodology used will be based on point transect sampling, a form of distance sampling, which is commonly used to estimate bird abundance.

One case study uses a 2-year dataset (2002-2003) from International Monitoring System (IMS) hydrophone stations at Diego Garcia, part of the Chagos Archipelago in the northern Indian Ocean. Three previously described blue whale call types have been identified in the data. The "Southern Ocean" and "Madagascan" call types have been attributed to two different subspecies – the Antarctic blue whale (*B. m. intermedia*) and the pygmy blue whale (*B. m. brevicauda*) respectively (Ljungblad *et al.*, 1998). Much less is known about the third call type – the only documented description is based on recordings of 2 animals made near Sri Lanka in 1984 and 1985 (Alling & Payne, unpublished). The "Sri Lankan" call is the focus of this study.

As a first step to estimating abundance, an automatic detector is being developed to identify Sri Lankan calls. The detector uses a synthetic time-frequency contour, which is constructed using frequency and duration measurements taken from a sample of the recorded calls. Spectrogram correlation is then used to automatically detect other Sri Lankan calls in the dataset. The final results of this analysis will provide the first description of the seasonal occurrence of the Sri Lankan call type in the northern Indian Ocean.

Propagation modelling and estimated source level of the calls will then be incorporated to calculate absolute call abundance in the area. Lastly, an average call rate per individual whale would be required to estimate absolute whale abundance.

HYDRO-13/H: Submarine volcanic activity in French Polynesia detected by broadband ocean bottom seismic array

Aki Ito[1], Hiroko Sugioka[1], Daisuke Suetsugu[1], Yoshio Fukao[1], Hajime Shiobara[2], Toshihiko Kanazawa[2]
[1]Japan Agency for Marine-Earth Science and Techonlogy, [2]University of Tokyo
Contact: hikari@jamstec.go.jp

Abstract Ocean acoustic waves (T-waves) associated with volcanic activity is often observed as a swarm of wave-packets. There are many reports for the detection and locating using by the hydrophone array. Here we show the T-waves associated with submarine volcanic activities using by the broadband ocean bottom seismographs (BBOBSs) in the French Polynesia region. Along with the Japan-France cooperative project we deployed 10 BBOBSs in the French Polynesia area in a period from 2003 to 2005. All the BBOBSs were installed on the seafloor at depths of 4000-5000 m with an average spacing of 500km. Each BBOBS was equipped with the Guralp CMG-3T broadband sensor that could record ground motions at periods from 0.02 to 360 s.

Swarms of T-wave events from submarine volcanic activities, as well as T-waves associated with local and global seismic activities, were recorded. In the northern part of our study area, typical T-waves were recorded at a BBOBS station near the Marquesas hot spot. They are accompanied by no obvious P or S waves. They have shorter durations and higher prominent frequencies than those of tectonic earthquakes. All of these characteristics are similar to those of volcanic T-waves reported by previous studies. Each of the repeated T-wave events has duration of 20-30 s with an intermission of also 20-30 s. Another type of T-wave events was also observed at several BBOBS stations in the southern part of the studied area. Each of the repeated T-wave events has duration of 60 s or longer with an irregular intermission. Using onset times observed by BBOBS network in the southern part, the source locations of the T-waves were determined to be around the Macdonald hot spot, which is located in

Austral islands. We also examined the direction of the particle motions of T-waves to be related to the paths from the source.

In this presentation, we will focus on the T-wave events associated with the submarine volcanic activity around the Macdonald hot spot.

HYDRO-14/H: The significance of horizontal refraction effect for back-azimuth estimation from the CTBT hydroacoustic stations

Binghui Li, Alexander Gavrilov, *Center for Marine Science and Technology, Curtin University of Technology*
Contact: b.li@cmst.curtin.edu.au

Abstract: In this study, an error analysis is carried out for back-azimuth estimation of low-frequency hydroacoustic events observed from the Cape Leeuwin and Diego Garcia CTBT hydroacoustic stations in the Indian Ocean. Errors due to the horizontal motion of hydrophones and the effect of horizontal refraction are considered. The random error of back-azimuth estimation induced by the horizontal motion of hydrophones was estimated using various long-lasting low-frequency hydroacoustic events observed at both stations, such as seismic events, Antarctic ice-related events and signals from offshore seismic surveys. The error due to the effect of horizontal refraction was numerical predicted and its dependence on mode number and frequency was investigated. It was found that the standard deviation of back-azimuth estimates for selected hydroacoustic events was around 0.2 degrees for both stations, which corresponds to standard deviation of the hydrophones' horizontal position of few metres. The effect of horizontal refraction contributes errors to bearing estimates of nearly the same order for the source locations in most areas of the Indian Ocean observed from the CTBT stations. However, the effect of horizontal refraction strongly depends on azimuth and range to the noise source. For certain areas, such as the westernmost and easternmost parts of the Southern Ocean, the bearing error can be as large as nearly 1 degree, which should be taken into account in the event location process.

HYDRO-15/H: Acoustic waves related to tsunami generation

Hiroyuki Matsumoto, Hiroko Sugioka, *Japan Agency for Marine-Earth Science and Technology*
Contact: hmatsumoto@jamstec.go.jp

Abstract: At both the 2003 mega-thrust (Mw8.3) and the 2008 moderate-to-large (Mw7.1) Tokachi-oki, Japan earthquakes, we have obtained the datasets of phenomena such as sea-floor uplift and responding sea-water mass movement by two pressure gauges (PG1 and PG2) of the cabled observatory installed in the tsunami source area. The acquired pressure waveforms at PG1 and PG2 sites show significant fluctuations with respect to both the amplitudes and the periods during the earthquake. PGs have recorded pressure fluctuations with peak-to-peak amplitude of approximately 1000 to 4000 hPa and 500 to 1000 hPa for the 2003 and the 2008 Tokachi-oki earthquakes, respectively, and the predominant periods of 6 s have been recorded at the both PGs. After the 2003 Tokachi-oki earthquake, the pressure waveforms have left significant static changes in the sea-floor, having 40 hPa and 10 hPa, i.e., 40 cm and 10 cm uplift at PG1 and PG2, respectively. On the other hand, the 2008 Tokachi-oki earthquake reproduces uplift of a few centimeters and none of coseismic deformation at PG1 and PG2, respectively calculated from the seismic fault model. Thus, the amplitude of dynamic pressure during the tsunamigenic earthquake is approximately 100 times as large as that of static pressure change. By using this unique instrument, we have found that the sea-floor uplift could reproduce the high amplitude acoustic wave in addition to the tsunami at the time of the earthquake. We introduce that tsunami and acoustic waves can be controlled by static displacement and velocity of the sea-floor under the assumption of constant velocity uplift. The acoustic wave bounces up and down between the sea-floor and the sea-surface, and it forms a standing wave. Since both tsunami and acoustic waves are caused by the same phenomena, one constrains the other to obtain real sea-floor uplift in a time series. The order estimate of the acoustic wave's amplitude led us that the abrupt change in water depth has taken place in a time duration of several seconds. Also, our study reinforces that acoustic waves might have a potential use for the early tsunami warning.

HYDRO-16/H: IMS Hydroacoustic contributions to Tsunami Warning Research

David Salzberg, *Science Applications International Corporation, Arlington, VA 22203 USA*
Contact: David.h.salzberg@saic.com

Abstract: With the installation of the IMS Hydroacoustic stations, persistent (long term) , broad-band, high dynamic range, acoustic data was available to the scientific community for general research. For the past several years, we have been investigating the use of hydroacoustic data for tsunami warning, using the IMS stations as the data source. Through this research, we have demonstrated that the spectral characteristics of hydroacoustic signals from earthquakes (T-phases) primarily results from anaelastic attenuation within the solid earth portion of the propagation. As the attenuation is a fractional energy loss per wavelength, that means that means that, with a few assumptions on the material properties of the solid earth portion of the propagation, the depth of energy release can be determined very precisely. Using that determined depth coupled with the water depth, we are then able to predict the spectral content of the excited tsunami. Because of the way the tsunami propagates in the ocean, the short wavelength (high frequency) component of the tsunami is particularly dangerous in the near field (local), whereas the longer wavelength tsunami is primarily responsible for the far field tsunami. Analysis of IMS hydroacoustic data from the Northern Sumatra (Dec 26, 2004), Nias Island (March 28, 2005), Java (July 17, 2006), Southern Sumatra (Sep 12, 2007), Peru (Aug 12, 2007) and the most recent Tonga (March 19, 2009) earthquakes demonstrates the relationship between T-wave (hydroacoustic) spectral content and the amplitudes of the near and far field tsunamis: Events with shallow spectral slopes have more significant near field tsunamis than would be predicted based on the event size and mechanism. However, factoring in shallow rupture (indicated by the T-phase spectrum), the observed near-field tsunami amplitude can be attributed to a short wavelength tsunami that is non-dispersive in shallow (near-field) waters; the shorter wavelength tsunami, when propagating to the far-field, disperses as the long-wave approximation is not valid in the deeper ocean. We are also have compared the tsunami spectrum predicted by the spectral slope to that observed by the tsunami buoys (DART), and find that in the cases exampled, the predicted spectrum is close to the observed spectrum.

HYDRO-17/H: Using IMS hydroacoustic data to monitor whales in the South-western Indian Ocean.

Samaran Flore[1], Adam Olivier[2], Ruzié Gérard[3], Kate Stafford[4] and Guinet Christophe[1]

[1]Centre d'Études Biologiques de Chizé - CNRS, Villiers-en-Bois, France; [2]LiSSi-iSnS, University of Paris Est, France; [3]Commissariat à l'Énergie Atomique, centre DAM-Ile de France, Bruyères-Le-Châtel France; [4]Applied Physics Laboratory, Ocean Acoustics Department, University of Washington, USA

Contact: samaran@cebc.cnrs.fr

Abstract: In the Southern Hemisphere, the intensive commercial whaling conducted during the 20th century reduced dramatically baleen whale populations to near extinction. The lack of information about the current occurrence and the distribution of baleen whales highlight the difficulty to study these species with traditional visual survey. It's specifically the case for the blue whale, the largest known animal to ever live on Earth. Currently, data to improve knowledge about blue whale ecology to asses the status, the abundance and the trends of many stocks are sparse and difficult to obtain due to their wide–ranging distribution, extensive migration, difficult sighting identification and inaccessibility of the most populations. However, blue whale produce specific low frequency and high intensity sounds year-long which propagate over long distances. Geographic variations in blue whale songs could be used to identify subspecies and to distinguish subpopulations. Blue whales are also good subjects for acoustic monitoring in remote area as Southern Ocean. Here, an analysis of one year of acoustic signal recordings from the permanent autonomous hydrophones of the International Monitoring System in the South-western Indian Ocean (Crozet Islands) has revealed low frequency with high intensity calls produced by 5 species, subspecies or subpopulations of endangered baleen whales: the fin whale, the Antarctic blue whale and the pygmy blue whale Madagascar type, Australia type, and Sri Lanka type. Simple spectrogram observations or automatic call detection method are used to estimate seasonal occurrence and migration patterns of these whales. Vocal activity is found to be highly seasonal with species variations. Results reveal seasonal occurrence and migration pattern of whales which offer the possibility to improve knowledge about ecology and habitat in this past commercial whaling area. In addition, the triangular configuration of the hydrophone arrays has permitted to apply hydroacoustic localization methods to estimate movement and range between the recording system and the calling animals. The potential movements are investigated by using the time difference of arrival (TDOA) of calls to assess the bearing of the sound source. Tracking whales were possible when whales are concentrated of the hydrophone array. The fully range dependent parabolic equation code (RAM – Range-dependent Acoustic Model) was applied to estimate the maximum detection range of calling whales in taking into account characteristics of blue whales calls, hydroacoustic stations location, bathymetry and seasonal ambient noise variation at the study area. The potential call detection area was estimated within a radio of 250km. Hydroacoustic data such IMS data provide unique data set to obtain crucial information on baleen whales that are currently lacking despite their critically endangered status. The next step of this work is to analyse others long term acoustic monitoring from the IMS stations located to the Indian Ocean to compare results in order to obtain a more complete picture of the distribution, the seasonal occurrence and the critical habitat of baleen whales all over the Indian Ocean.

HYDRO-18/H: Deep seafloor arrivals - An unexplained set of arrivals in long-range ocean acoustic propagation

***Ralph A. Stephen, S. Thompson Bolmer**, Woods Hole Oceanographic Institution, Woods Hole, MA 02543-1542; **Matthew A. Dzieciuch, Peter F. Worcester,** Scripps Institution of Oceanography, UCSD, La Jolla, CA 92093-0225; **Rex K. Andrew, Linda J. Buck, James A. Mercer,** Univ. of Washington, Seattle, WA 98105-6698; **John A. Colosi**, Naval Postgraduate School, Monterey, CA 93943; and **Bruce M. Howe**, University of Hawaii at Manoa, Honolulu, HI 96822*

Contact: rstephen@whoi.edu

Abstract: A thorough understanding of long-range sound propagation in the ocean is necessary both to optimally locate man-made and natural sources in the ocean as well as to infer ocean properties from acoustic measurements. In this poster we report the observation of unexplained arrivals observed on ocean bottom seismometers in a carefully executed controlled-source experiment in the North Pacific Ocean. We describe receptions, from a ship-suspended source (in the band 50-100Hz) to an ocean bottom seismometer (about 5000m depth) and the deepest element on a vertical hydrophone array (about 750m above the seafloor) that were acquired on the 2004 Long-range Ocean Acoustic Propagation Experiment in the North Pacific Ocean. The ranges varied from 50 to 3200 km. In addition to predicted ocean acoustic arrivals and deep shadow zone arrivals (leaking below turning points), "deep seafloor arrivals", that are dominant on the seafloor geophone but are absent or very weak on the hydrophone array, are observed. These "deep seafloor arrivals" are an unexplained set of arrivals in ocean acoustics possibly associated with seafloor interface waves.

INFRASOUND

INFRA-01/F: The IMS Infrasound Network

Paola Campus, *CTBTO, IMS Division, Engineering and Development Section, Acoustic Monitoring Project, P.O. Box 1250, A-1400 Vienna, Austria*
Contact: Paola.Campus@ctbto.org

The development of the IMS Infrasound Network has steadily progressed in the last 10 years: by now 70% of the IMS infrasound stations have been installed in very different environments around the world.
A description of the typical features of IMS infrasound stations is presented.

INFRA-02/F: Infrasound data processing for CTBT verification – station processing

N. Brachet, D. Brown, P. Mialle, R. Lebras. *CTBTO PrepCom, Provisional Technical Secretariat, Vienna International Centre, P.O. Box 1200, A-1400 Vienna, Austria*
Contact: Nicolas.Brachet@ctbto.org

Abstract: In its final configuration, the International Monitoring System (IMS) of the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO) Preparatory Commission will operate 60 infrasound stations distributed uniformly over the globe. The International Data Centre (IDC) in Vienna, Austria currently receives and processes in near real-time data from 39 of the 60 planned infrasound stations. Specialized software has been developed to detect coherent infrasound signals, highlight the most significant detections as phases (as opposed to Noise), and subsequently group these phases to form events.

The IDC produces timely, high quality Reviewed Event Bulletins (REBs) using the three waveform technologies: seismic, hydroacoustic and infrasound. At the present time, the contribution of infrasound data to the REB has been intentionally limited as new software was developed, tested and adapted to the IDC operational environment. Non-operational use of infrasound data has made significant progress in the identifying and characterizing infrasound sources and indicates potential for strong synergy with other technologies.

To achieve this goal, the first stage of the automatic processing is the "station processing", where the system attempts to detect signals and extracts their characteristics at the individual stations. The infrasound data is processed using the Progressive Multi-Channel Correlation (PMCC) algorithm to create detections. Groups of detections are then categorized based on the signal characteristics, and detections are assigned the phase name I (infrasound), IPx (seismic P), ISx (seismic S), or N (noise) during the phase identification step.

INFRA-03/G: Infrasound data processing for CTBT verification – sources

N. Brachet, D. Brown, P. Mialle, R. Le Bras.
CTBTO PrepCom, Provisional Technical Secretariat, Vienna International Centre, P.O. Box 1200, A-1400 Vienna, Austria
Contact: Nicolas.Brachet@ctbto.org

Abstract: In its final configuration, the International Monitoring System (IMS) of the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO) Preparatory Commission will operate 60 infrasound stations distributed uniformly over the globe. The International Data Centre (IDC) in Vienna, Austria currently receives and processes in near real-time data from 39 of the 60 planned infrasound stations. Specialized software has been developed to detect coherent infrasound signals, highlight the most significant detections as phases (as opposed to Noise), and subsequently group these phases to form events.

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A large collection of infrasound reference events has been built by the IDC during the last five years, but only a small fraction of them meet REB event definition criteria considering the Treaty verification mission of the Organization. Candidate events types for the REB include atmospheric or surface explosions, explosive meteors, rocket launches, large earthquakes and explosive volcanoes.

INFRA-04/F: A Robust technique for the automatic detection and location of infrasound events

Stephen J. Arrowsmith and Rodney W. Whitaker, *Los Alamos National Laboratory*
Contact: arrows@lanl.gov

Abstract: This paper presents a suite of algorithms for the automatic detection, association, and location of low-frequency acoustic events using regional networks of infrasound arrays. Here, low-frequency acoustic events are characterized by transient signals, which may arise from a range of natural and anthropogenic sources, examples of which include (but are not limited to) earthquakes, bolides, volcanic eruptions, explosions, and rockets. First, a new technique for detecting infrasound signals that works successfully in the presence of correlated noise is outlined. An *F*-statistic, sequentially adapted to ambient noise conditions, is used in order to obtain detections at a given statistical significance while accounting for real background noise. First arrivals at spatially separated arrays are then associated using a grid-search method to form events. A forward algorithm places bounding constraints on event locations, allowing us to compute location polygons that do not require atmospheric models and accurately reflect the uncertainties inherent to the problem of infrasound location. The technique is applied to regional infrasound networks in Utah and Washington State. In Utah, over a period of approximately 1 month, we obtained a total of 276 events recorded at three arrays in a geographic region of 6°–4°. For four ground-truth explosions in Utah, the automatic algorithm detects, associates, and locates the events within an average offset of 5.4 km to the actual explosion locations. In Washington State, the algorithm locates numerous events that are associated with a large coal mine in Centralia, Washington. The methodology and results presented here provide a framework for assessing the capability of infrasound networks for regional infrasound monitoring, in particular by quantifying detection thresholds and localization errors.

Reference: Arrowsmith, S.J., Whitaker, R., Burlacu, R., Stump, B., Hedlin, M., Randall, G., Hayward, C., and ReVelle, D., Regional Monitoring of Infrasound Events using Multiple Arrays: Application to Utah and Washington State, *Geophys. J. Int*., 175, 291–300, 2008.

INFRA-05/F: Towards an automatic and continuous monitoring of the infrasound activity across Europe

Lars Ceranna[1], Alexis Le Pichon[2] & Julien Vergoz[2]
[1] BGR, Hannover, Germany; [2] CEA/DASE, Bruyères-le-Châtel, France
Contact: Lars.ceranna@bgr.de

and location procedures. In central Europe, several years of continuous infrasound waveform data are available for eight stations in Sweden, France, and Germany, whereas only one of them is part of the IMS. This exquisite setting with an average inter-station distance below 500 km allows the analysis of natural and artificial infrasonic a

Abstract: The infrasound network of the International Monitoring Network (IMS) for the compliance with the Comprehensive Nuclear-Test-Ban Treaty (CTBT) is currently not fully established. However, it has demonstrated its capability for detecting and locating infrasonic sources like meteorites, as well as volcanic eruptions on a global scale. Such ground-truth events are rare; therefore regions providing a dense network of infrasound stations have to be considered to test and to calibrate detection ctivity in Europe.

The results of the association of multiple arrays demonstrate the need of continuous infrasound monitoring on a regional scale to advance the development of automatic location procedures. Beside the seasonal variation of the network's detection capability, which is dominated by the prevailing stratospheric winds, prominent source regions are identified showing repeating events. Such clusters are essential because they are enabling a detailed comparison of various atmospheric specifications. An automatic procedure for re-location will also be presented, which is based on a robust grid-search algorithm and which makes use of ECMWF profiles for estimating appropriate celerity values and back-azimuth corrections.

INFRA-06/F: The Gerdec explosion: A benchmark for the infrasound CTBT verification system

Julien Vergoz[1], Alexis Le Pichon[1], David Green[2], Lars Ceranna[3], Elisabeth Blanc[1]

[1]CEA/DIF/DASE, F 91297 Arpajon Cedex, France; [2]AWE Blacknest, Brimpton, Reading, RG7 4RS, United Kingdom; [3]BGR, Section B3.11, Stilleweg 2, 30655 Hannover, Germany

Contact: Julien.vergoz@cea.fr

Abstract: A series of large explosions occurred at a munitions decommissioning facility on Saturday 15 March 2008 in the village of Gerdec, Albania. The factory was in charge of destroying excess ammunition and obsolete weaponry that Albania had stored since the 1960s, when it was under Communist rule. Large amplitude infrasonic signals were generated by the explosions, and were detected by 3 IMS stations (I26DE-Germany, I48TN-Tunisia, and I46RU-Russia) at ranges of up to 5000 km. We present an analysis of the data characteristics and estimate the yield using the stratospheric arrival amplitudes and atmospheric specifications from the European Centre for Medium-Range Weather Forecasts (ECMWF). The calculated yields exhibit one order of magnitude variability between these stations, with a mean estimate of 1 kt. The predicted signal amplitudes and background noise levels are compared at each station located within 5000 km of Gerdec, in order to explain the geographical distribution of detections. Such an event is especially important because it is to our knowledge the first explosion which reaches the 1 kt design goal of the IMS network.

Moreover, we focus on the I48TN station, 1100 km from the explosion. The propagation path is purely upwind when considering the stratospheric wind (steady wind of 45 m/s at 45 km height), a scenario which would favour very weak thermospheric returns due to the large source to receiver distance and the strong acoustic absorption in the lower thermosphere. However, the frequency content (up to 1 Hz), the apparent velocity (280 m/s) and the large amplitude (0.4 Pa peak-to-peak) of the observed signals are much more consistent with stratospheric propagation. In order to understand these arrivals, parabolic and Chebyshev pseudospectral calculations are performed and the simulation results are discussed.

This exceptionally strong explosion is a unique Ground-Truth event, which helps us to assess the ability of the infrasound monitoring component of the Comprehensive Nuclear Test Ban Treaty verification system to successfully monitor atmospheric or surface events.

INFRA-07/F: Studies of infrasound event location involving atmospheric events accurately located using dense seismic network data

Michael Hedlin[1], Doug Drob[2], Catherine de Groot-Hedlin[1], Alexis Le Pichon[3], Julien Vergoz[3] and Kris Walker[1]

[1]Laboratory for Atmospheric Acoustics, University of California, San Diego; [2] Naval Research Laboratory

[3]Commissariat à l'Energie Atomique/DIF/DASE

Contact: hedlin@epicenter.ucsd.edu

Abstract: Dense seismic networks can provide accurate infrasound source locations that can be used to evaluate methods for locating these events using infrasound arrays.

We present a recent study of a large bolide that burst above five hundred seismic stations in the US Pacific Northwest on Feb 19, 2008. The network yielded several hundred recordings of the event that not only provided an accurate source location but also shed light on different propagation paths. The event was recorded and subsequently located by three IMS infrasound arrays (I10CA, I56US and I57US) and NVIAR. The seismic and infrasound locations agree to within error.

Stacking methods developed in this study are currently being modified to handle large volumes of seismic network data to search for impulsive infrasound events that can be used to evaluate our location methods under different atmospheric conditions in different geographic areas with different configurations of infrasound recording arrays. This method is now being applied to data collected by the extensive USArray network, which is being deployed in stages across the continental US.

INFRA-08/F: Characteristics of Seasonally Dependent Propagation of Infrasound Wave around the Korean Peninsula

Hee il Lee, Il Young Che, Tae sung Kim, Jin Soo Shin
Earthquake Research Center, Korea Institute of Geoscience & Mineral Resources
Contact: leel@kigam.re.kr

Abstract: After the installation of the first seismo-acoustic array in 1999, we are now operating an infrasound array network in Korea, which is named KIN (Korean Infrasound Network). This network consists of seven seismo-acoustic arrays (BRDAR, KMPAR, CHNAR, YAGAR, KSGAR, ULDAR and TJIAR). It detects frequently many interesting infrasound signals produced by different type of infrasound sources such as large earthquakes, quarry blast, explosion of the chemical factory, meteorite, missile or rocket launching etc. In locating these infrasound events, information of atmosphere is essential, especially for the event recorded at only one array.

To better understand the characteristics of seasonally dependent propagation of the infrasound wave, we have installed two temporal seismo-acoustic stations at a limestone quarry mine. We measured the seismic and acoustic source signature of the blasting over the past two years. The charge size is about 2 to 10 tons of ANFO and the detonation is carried out every day.

The result of the analysis of the infrasound signals recorded at the KIN shows that the celerity of the stratospheric phase(*Is*) changes sinusoidally according to the season. It changes from 0.26km/s in January to 0.29km/sec in August . Detection rate at each array also varies significantly by season. Detection rate is lowest in winter and highest in summer. This kind of long-term measurement covering all season could be helpful in understanding seasonal variation of celerity as well as in studying atmospheric effects on infrasound propagation around the Korean Peninula, and will increase the accuracy in locating the infrasound events.

INFRA-09/F: Infrasound Calibration Experiment at Sayarim, Israel

Yefim Gitterman[1], Milton Garces[2], Roger Bowman[3], David Fee[2], Hans Israelson[3], Rami Hofstetter[1]
[1]The Geophysical Institute of Israel, P.O. Box 182, 71100, Lod, Israel; [2]Infrasound Laboratory, University of Hawaii, USA; [3]Science Applications International Corporation, USA
Contact: yefim@seis.mni.gov.il

Abstract: Presented research is devoted to establishing a Ground Truth (GT0) infrasound dataset for Eastern Mediterranean/Middle East region, through conducting a large-scale surface calibration explosion at Sayarim Military Range (SMR), Israel. The dataset is intended to characterize the infrasonic propagation in the region: travel times, spectra, amplitudes, depending on source features and atmosphere conditions, and thus to improve monitoring capabilities of infrasound stations of the International Monitoring System (IMS).

Preliminary test explosions of broad yield range and various designs were conducted on the first project stage, in different days and seasons, thus providing a wide range of atmospheric conditions. The explosions were intended to: 1) test charge design and logistics procedures for preparation and conducting of the main explosion; 2) analyze atmosphere effects on infrasound propagation in different azimuths based on collected meteo-data (wind direction and velocity).

In June-July 2008, we conducted a series of 13 outdated ammunition detonations (in the range 0.2-10 ton) and 2 experimental project explosions of 1 ton of pure different explosives (TNT and Composition B). The two explosions, conducted close to an ammunition shot and 10 min afterwards, were intended to estimate ammunition actual yield (TNT), and also to check feasibility of using as a charge element for the large calibration explosion. Some of these explosions were observed at IMS infrasound station I48TN (Tunisia) at ~2500 km, using array processing and analysis.

Two test explosions of 1 ton and 5 tons (mix of TNT and Composition B) in December 2008 were conducted at the new SMR site, intended for the main calibration explosion (planned for August 2009). Many procedures of preparation, coordination, logistics, charge design and assembling for the main explosion were tested and trained. High-pressures in air-shock waves at close distances were measured and speed video recording was done for validation of feasibility of these explosives for the big explosion, and estimation of TNT equivalent.

Analysis of signals recorded at seismic and acoustic channels of portable and permanent stations is presented, including charge scaling estimations, comparison of energy generation for different explosives, and examination of wind direction influence on parameters of infrasound arrivals. Modeling of long range atmospheric propagation of infrasound was conducted using global G2S atmospheric profiles and collected local atmospheric data.

Data obtained from the test series were used for elaboration of design and logistics of the main calibration explosion. Optimal date and time window of the experiment and locations of portable infrasound systems in Mediterranean region were selected based on logistical and infrasound modeling results.

INFRA-10/F: Full-Wave Modeling of Infrasound from Explosions Using the Parabolic Equation Method and Realistic Atmospheric Specifications

Robert G. Gibson, BBN Technologies, Arlington VA, USA
Co-author: Douglas P. Drob, Naval Research Laboratory, Washington DC, USA
Contact: rgibson@bbn.com

Abstract: The Parabolic Equation (PE) method is used to model atmospheric infrasound from explosions at ranges of 100s to 1000s of km. Modeling is conducted using range-dependent specifications of the atmosphere that incorporate synoptic output from global numerical weather prediction models. Full-wave infrasound predictions are derived from PE model results using a Fourier-synthesis technique, in an approach known as the Time-Domain Parabolic Equation (TDPE). Synthesized infrasound waveforms, obtained using the TDPE method, are compared with observed infrasound signals from ground-truth events in order to evaluate the modeling capabilities. The PE method is demonstrated to predict certain observed arrival features that are not predicted using ray-tracing techniques that rely on high-frequency approximations of infrasound propagation paths. Three-dimensional ray tracing has utility for predicting infrasound travel times and azimuthal deviations; however, it predicts strong shadow zones that are contrary to many observations. Model predictions using the PE method are further enhanced by the addition of perturbation terms to the atmospheric profiles in order to characterize fine-scale atmospheric structure that is not resolved by synoptic specifications. The perturbation terms used in the study are obtained from a simple spectral model of wind inhomogeneities induced by naturally occurring gravity waves in the atmosphere. Events analyzed include several recent industrial explosions in and around Europe that have been observed at ground-based infrasound arrays. Results presented in the study are selected from analyses of explosive events at: Billy-Berclau, France (2003); Neyshabur, Iran (2004); Ghislinghien, Belgium (2004); Buncefield, United Kingdom (2005); Novaky, Slovakia (2007); Gerdec, Albania (2008); and Chelopechene, Bulgaria (2008). The availability of full-wave modeling capabilities for infrasound, coupled with realistic atmospheric specifications, contribute to improved understanding of infrasonic wave propagation and enable more accurate event location at regional distances.

INFRA-11/F: Effects of atmospheric fine-structure on characteristics of infrasonic signals and that's azimuths and grazing angles estimation at the long distances from explosions

Sergey Kulichkov[1], Elena Golikova[1]
[1]Oboukhov Institute of Atmospheric Physics RAS, Pyshevsky 3, Moscow, 119017, Russia,
Contact: snk@ifaran.ru

Abstract: A short historical review and an analysis of the current status of both theoretical and experimental studies of long-range sound propagation in the atmosphere are given. Basic results are provided that show how the atmospheric fine-layered structure significantly affects infrasonic pulse propagation and scattering in the lower and middle atmosphere. The effect of time variations (seasonal changes, tides, and both planetary and internal gravity waves) in the effective acoustic speed profile on the characteristics of infrasonic signals from different pulsed sources is discussed. The effect of the atmospheric fine structure on the azimuth and grazing angle of infrasonic signals recorded at long distances from surface explosions is studied both theoretically and experimentally. The data on infrasonic signals recorded at a distance of about 300 km from surface explosions. There were explosions with equivalent to 20—70 t of TNT to destruction of soviet medium range missiles and 31 Finnish explosions to destruction of old weapon and armament. The experiments were carried out during different seasons. Variations in the azimuths and grazing angles of infrasonic signals are observed in all experiments.

The results of the studies of partial reflection (scattering) of low-frequency acoustic pulses from the fine-layered inhomogeneities of the middle atmosphere are presented. The results of the corresponding theoretical studies are also given. The potential of the method for long-range acoustic sounding of large-scale anisotropic turbulence (fine structure) is discussed.

A theoretical interpretation of the experimental results is proposed on the basis of the theory of anisotropic turbulence in the atmosphere. The theoretical and experimental results are compared, and a satisfactory agreement between these results is noted.

INFRA-12/F: Assessing the detection capability of the global IMS infrasound network

A. Le Pichon[a], J. Vergoz[a], L. Ceranna[c] and N. Brachet[b],
[a] CEA/DASE BP12, Bruyères-le-Châtel, France; [b] Federal Institute of Geosciences and Natural Resources, Stilleweg 2, 30655 Hannover, Germany; [c] CTBTO PTS/IDC Vienna International Centre, P.O. Box 1200, Vienna A-1400, Austria
Contact: alepichon.le-pichon@cea.fr

Abstract: A global scale analysis based on available detection lists for all operating IMS infrasound stations confirms that the primary factor controlling signal detectability is the seasonal variability of the stratospheric wind circulation. At most arrays, ~80% of the detections in the 0.2 to 2 Hz bandpass are associated with propagation downwind of the dominant wind direction. The seasonal transition in the bearings and number of detections between easterly and westerly directions is presented. The observed detection capability of the IMS network is compared to the predicted one using near-real time atmospheric updates and station-dependent wind noise models. The influence of individual model parameters on the network performance is systematically assessed. At frequencies of interest for detecting atmospheric explosions (0.2 to 2 Hz), the simulations predict that one kiloton explosion would be detected by at least two stations at any time of the year and any place of the globe. Comprehensive ground-truth databases provide a statistical approach for evaluating the potential of infrasound monitoring. Accidental explosions are analysed and used here as benchmark for validating the calculated threshold maps. Such studies would help to optimize the siting of infrasound arrays with respect to both the number and configuration in order to monitor infrasonic sources of interest. They are an important step to enable a successful monitoring regime for atmospheric or surface events to act as an effective verification tool in any future enforcement of the CTBT.

INFRA-13/F: Estimating the detection capability of the International Monitoring System infrasound network

David Green and David Bowers, *AWE Blacknest*
Contact: dgreen@blacknest.gov.uk

Abstract: As part of the verification measures required by the Comprehensive Nuclear-Test-Ban Treaty a 59 station infrasound network is being deployed for the detection of low- frequency (<10 Hz) atmospheric pressure waves. Studies of detections made at the 39 presently operational stations indicate that the propagation of global infrasound is strongly influenced by stratospheric winds. We update previous models of the infrasound network capability to include the effect of stratospheric wind on signal amplitudes. The model is based on a probabilistic approach, so that estimates of infrasonic noise and propagation uncertainties can be incorporated. The results of our simulations show the expected increase in detection capability downwind of a source, and decrease in capability upwind. Globally, the inclusion of stratospheric wind tends to reduce the detection threshold (defined as the explosive yield at which there is 90% probability that two stations will detect signals). The detection threshold at which there is 95% global coverage, for the full 59 station network and noise values chosen at 0.1 Hz, is _0.6 kt at times of high stratospheric wind and _0.9 kt at times of low stratospheric wind. The completeness of the microbarograph network is shown to be vital for ensuring global coverage; the removal of one key sta tion can increase the detection threshold by at least a factor of two at particular locations, and at some locations the detection threshold may exceed 1kt for over half the year. Although the addition of stratospheric wind acts to decrease the detection threshold, the preferential downwind detection makes location of events more difficult due to the restricted azimuthal coverage. Also, the choice of noise model has a large influence on the absolute detection threshold values. Using an empirical relationship linking source yield and signal period, simulations suggest that detection of signals from explosive yields between 0.35 and 0.7 kt may be hindered by microbarom noise

INFRA-14/G: The Potential of the International Monitoring System Infrasound Network for the Detection of Rocket Launches

Bharath Gopalaswamy & Alexandr Smirnov

[1]Bharath Gopalaswamy is a postdoctoral associate at Cornell University's peace studies program.; [2]Alexandr Smirnov is a leading geophysicist at the Kazakhstan National Data Centre.

Contact: bg265@Einaudi.Cornell.edu, Smirnoff@kndc.kz

Abstract: In this current work, the potential of the international monitoring system's (IMS) infrasound network to detect rocket launches is investigated. The IMS is a network of monitoring sensors which search for, detect and provide evidence of nuclear explosions to State Parties for the verification of the nuclear Comprehensive Test Ban Treaty (CTBT). As a typical rocket infrasound signal is in the 0.1-1 Hz frequency range and as the mean spacing between the IMS stations is 2500 km on land and 4500 km in the oceans, almost all the cases to be studied will be in the acoustic far field. The detection of infrasound from rockets primarily depends on three different factors:

1. The local noise conditions at the site of the receiver
2. The propagation conditions between the source and the receiver
3. Source Characterization

Investigations are being carried out based on open source reports of rocket launch times and the classes of rockets launched. These will help in the search for signals at various IMS infrasound stations and in assessing the capability of the current IMS.

On the confirmation of the event, further technical analysis is carried out by modeling the trajectory of the rocket. The trajectory of the rocket can be modeled by a freely available open source program. Apart from the rocket launch detection signals various infrasound signals obtained at IS31 KZ are also presented, which also show the effects of atmospheric conditions for infrasonic propagation.

INFRA-15/G: Infrasound Signals from the Test of North Korea's Long-Range Missile

Tae Sung Kim, Jin-Soo Shin, Il Young Che and Hee-Il Lee

Earthquake Research Center, Korea Institute of Geoscience and Mineral Resources

Contact: tskim@white.eq.kigam.re.kr

Abstract: On April 5, 2009 a long-range missile, Taepodong-2, was launched by North Korea. Infrasound signals from the missile were detected at regional distances by four acoustic arrays (KSGAR, YAGAR, CHNAR, ULDAR) in South Korea. The acoustic arrays are composed of seven to eighteen acoustic gauges. The aperture of each array is approximately one km. Array process using Progressive Multi-Channel Correlation (PMCC) was performed to identify coherent signals and estimate their array parameters, and to constrain the characteristics of infrasound propagation. The results show that the infrasound signals recorded at each array have relatively high frequency content (3-16 Hz), long time duration (~150 seconds), and systematic variations of back-azimuth (~10^{o}). The time-varying back-azimuth estimates at different acoustic arrays are utilized for signal association to trace the trajectory of the moving source.

INFRA-16/G: Villarrica and Llaima Volcanoes in Southern Chile: An Infrasound Factory

S. Barrientos[(1)], F. Riquelme[(1)], N. Brachet[(2)] , A. Kramer[(2)] and P. Campus[(2)]

[(1)] Departamento de Geofísica, Universidad de Chile [(2)] CTBTO

Contact: sbarrien@dgf.uchile.cl

Abstract: On March 19-21, 2009, a PTS portable infrasound array was installed near the town of Los Laureles in south central Chile, approximately 55 km away from Villarrica and Llaima volcanoes. This collaborative effort between PTS and Universidad de Chile is a pioneering project for both institutions from an engineering and data processing perspectives.

The array is scheduled to operate at the same site until July 2009. The preliminary observations during the first few weeks are encouraging as described below.

The array is composed of four elements arranged in a triangular geometry with a central element; the sides of this equilateral triangle are 450-500 m apart. Each element had a sensor MB-2005 with a Reftek 130, 24-bit DAS acquiring data from a multiple that concentrated pressure changes through six pipes, 15-m long each. The array was deployed in a forest of eucalyptus trees 8-10 m tall which provide excellent shelter against the wind.

During the first days of operation, the array detected episodic signals originated at the same azimuth of Villarrica volcano. This volcano has an almost perfect conic shape lying on top of a previous caldera, located along the Liquiñe-Ofqui Fault Zone. The volcanic edifice covers an area of approximately 250 km^3, with a diameter at its base of about 28 km. It rests on Miocene plutonic and stratified volcanic layers. The crater, located at 2800 m

above sea level, is about 200 m in diameter and exhibits intense fumarolic activity. The bottom of the crater, about 50 -100 m deep, is covered by a lava lake which exhibits frequent, but weak, eruptive activity (Sernageomin).

Llaima volcano began an eruptive cycle from 3 April at 21:00 to 6 April at around midnight (both local times). The infrasound array detected significant activity during this period, consistent with a source at the same azimuth. Llaima volcano is one of the largest of the Southern Volcanic Zone with an elevation of 3125 m above sea level. Its crater is about 350 m wide with significant fumarolic activity. To the south another crater, 2920 m above sea level, also exhibits weak fumarolic activity. The base of the volcanic edifice, located above Tertiary granitic structures, is about 30 km in a north-south direction and about 25 km in an east-west orientation (Sernageomin).

Additionally, on March 22, at 03:29:22.4 a 3.9 magnitude (Ml) earthquake took place about 70 km away from the infrasound array, at a depth of 47 km. Both P and S waves clearly stand out in the infrasound records.

INFRA-17/G: Infrasonic Detection of Bolides

W.N. Edwards1, D.O. ReVelle2, and P. Brown3

1 Natural Resources Canada, Atlantic and Western Canada Branch, Canadian Hazards Information Service, Earth Sciences Sector, 7 Observatory Crescent, Ottawa, Ontario, K1A 0Y3, Canada; 2EES-17, Geophysics Group. Earth and Environmental Sciences Division, Los Alamos National Laboratory, Los Alamos, New Mexico, 87545 USA; 3Department of Physics and Astronomy, University of Western Ontario, London, Ontario, N6A 3K7 Canada.

Contact: Wayne.Edwards@NRCan-RNCan.gc.ca

Abstract: Bolides, or large, bright fireballs, are energetic meteoroids that penetrate deeply into the Earth's atmosphere. These objects, 1 to 10 metres in size and travelling at hypersonic speeds, deposit most of their kinetic energy explosively between altitudes of 20 - 50 km producing significant low frequency infrasound. As these events are a random process, bolides provide an ideal natural and evenly distributed source of global infrasound. From flux estimates (Brown et al., 2002), we expect at least one bolide annually to exceed 4 kilotons (kT) of TNT equivalent energy, while on decadal scales at least one 50 kT event is expected. In recent years there have been a number of very energetic bolides recorded infrasonically, including a 14-20 kT event in the Indian ocean in October, 2004 (Arrowsmith et al., 2007), a 13 kT event in September, 2004 off the Antarctic coast (Kleckociuk et al., 2005) and a newly recognized event over Africa on Dec 9, 2006 with an estimated energy near 10 kT. In this work we present some typical waveforms detected by the IMS network from these bolides and review the techniques used for energy determination. To date, our ongoing program to identify and characterize bolide infrasound consists of a database of over 90 bolides recorded at one or more IMS station since 2000. In addition, the database contains more than 50 additional smaller fireball events (< 10 cm) that produce regional infrasound at ranges less than 250 km, recorded at a research array in Southern Ontario, Canada.

INFRA-18/G: Meteorite detected by Infrasound (IS08) and Seismic (PS06 and Bolivian Network) Stations.

E. Minaya, and B. Burgoa, A. Le Pichon, K. Antier, Y. Cansi, B. Hernandez D. Drob, L. G. Evers and J. Vaubaillo

Contact: eminaya@entelnet.bo

Abstract: The Comprehensive Test Ban Treaty Organization (CTBTO) within the International Monitoring System (IMS) has implemented a worldwide network for infrasound detection with the cooperation of many countries that must participate in the monitoring of nuclear activity. In Bolivia there are an infrasound array IS08, a seismic primary station PS06 and a secondary seismic station SS08 as part of the IMS. The deployment of these array and seismic station was possible due to the cooperation between San Calixto Observatory (OSC), Département Analyse Surveillance Environnement, DASE and CTBTO, being the OSC the operator of the seismic stations.

Bolivia has a small seismic network to monitoring of the seismic activity; this network has been installed with the cooperation CEA, DASE from French.

Up to now, the IS08 has contributed not only with the vigilance of the possible nuclear activity, but has monitored the atmospheric activity with important results. Important atmospheric events like entry of meteoroid and some earthquakes have been recorded by IS08. Those events have been possible to study by group of researches from several countries. On September 15th, 2007 16:45 (GMT) an impact of meteorite opened a big crater in the community of Carangas, region of Puno, Peru; near to Bolivian border and south of Titicaca Lake. The evidences were the records in both array, seismic and infrasound. The analysis of those records allowed us to get more information, with those methodologies of the CTBTO, as the location of impact and origin time, calculation of kinetic energy, mass and explosive energy and other physical parameters. This first evidence of

the impact of a meteor shows the importance of the deployment of infrasound sensor and seismic network and the importance of the cooperation as this case; CTBTO, CEA-DASE and OSC- Bolivia.

INFRA-19/G: Seismic and acoustic wave excitations in a single system of the solid Earth and the atmosphere: In the case of the 2008 Iwate-Miyagi Nairiku Earthquake

Hiromichi Nagao[1], Naoki Kobayashi[2], Yoshio Fukao[1], Yasushi Ishihara[1], and Seiji Tsuboi[1]
[1]Institute for Research on Earth Evolution, Japan Agency for Marine-Earth Science and Technology, Japan; [2]Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency, Japan
Contact: nagao@jamstec.go.jp

Abstract: An infrasound monitoring station IS30 operated by the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO) recorded clearly air pressure variations excited by the 2008 Iwate Miyagi Nairiku Earthquake (Mw ~7.1), which occurred in the northeast Japan at 23:43:45 on June 13, 2008 UTC. The epicenter (39.0283ON, 140.8800OE, and 6km in depth) locates at a distance of 417km in the direction of N7OE from IS30. This seismoacoustic signal has two large wave packets; the earlier arriving wave packet appearing ~1 minute after the main shock corresponds to the Rayleigh wave ground motion, while the later arriving wave packet appearing ~25 minutes after the main shock corresponds to acoustic waves propagated through the atmosphere directly from the rupture zone. We attempt to simulate numerically both seismic and infrasound records by means of a technique to calculate normal modes assuming a realistic fault mechanism and a one-dimensional joint model of the solid Earth and the atmosphere from the center of the Earth to the altitude of 1000km. The resulting synthetic time series succeeds to explain simultaneously, for the first time in the relevant discipline, the Rayleigh waves recorded by broadband seismometers and the seismoacoustic signals recorded at IS30 in a period range >30 seconds. This fact indicates that the different observation quantity, i.e., ground motions and air pressure variations, can be treated in the same manner using a single internal source of an earthquake rather than separating the solution into two parts of the solid Earth and the atmosphere for which crustal surface displacements are used as a boundary condition. This approach leads us to a comprehension on the elasto-dynamic coupling among the solid Earth, the ocean, and the atmosphere up to the ionosphere, and eventually clarifies the whole Earth interaction as a multi-layered system.

INFRA-20/G: Analysis of regional infrasound signals at IS34 and characterisation of local and regional seismic wave propagation: PS25 array

M.Ulziibat, Ch. Bayarsaikhan and Ts.Baasanbat
RCAG/MAS P.O.B-152, Ulaanbaatar-51 Mongolia
Contact: bsb@rcag.ac.mn

Abstract: Seismic and acoustic recordings are particularly important to help identifying and locating industrial blasting sources. We have analyzed seismo-acoustic signals from mine blast for 2000 and 2005 in order to determine detection seismo-acoustic signals of explosion by seismic and infrasound stations. Several large mines in the region routinely generate explosions that are detected seismically and with infrasound. The mine range distance is 40-500 km from the seismic, infrasound array. In last few years mining activity in Mongolia significantly increased. We present the seismic and infrasound IMS stations and some results of analysis.

Also we have been studying for local and regional wave propagation and crustal structure using by PS25 and other local seismic stations data. PS25 plays main role in detection local and regional events. In this study, we focused on azimuth deviation analysis of seismic events using PMCC software and other array seismology method.

INFRA-21/G: Infrasound monitoring in Kazakhstan: source localization and characterization

Alexander Smirnov[1], Valery Kunakov[1], Alexis Le Pichon[2], Jocelyn Guilbert[2], Damien Ponceau[2]
[1]Institute of geophysical researches NNC RK; [2]Commissariat à l'Energie Atomique CEA/DIF/DASE
Contact: smirnoff@kndc.kz

Abstract: The IMS infrasound station (IS31, Aktyubinsk) was installed in 2001 in the northwest of the Republic of Kazakhstan. An automatic detection procedure has been implemented for the last three years. PMCC is the basis of the detection algorithm used which is able to routinely extract infrasound signals across the array within non-coherent noise. Sources of signals have been identified but can not be located using one single station. To do so, seismo-acoustic studies were carried out using the Akbulak seismic array. They allow a firm identification of some regional sources being detected on both arrays. The analyses of satellite views surrounding the station and the characteristics of the detected signals suggest that one prominent source is the Zhanazhol oil and gas field. With the support of PTS/CTBTO and CEA/DASE, a temporary experimental infrasound array, collocated with the Akbulak seismic array, has been installed in 2007. This experiment confirmed the location of this source. Moreover, the analysis of the automatic processing results shows clear seasonal trends in the detected backazimuth and slowness. Sine variations of the azimuth deviation are recorded within a range of 15°. Such variations are explained using a ray tracing method combined with a climatological atmospheric model. Other regional sources are also localized using both IS31 and the Akbulak infrasound arrays, such as oil and gas fields, open mines, industrial explosions or earthquakes. Such studies would help to build up experience and discriminate between environmental noise and events of interest.

INFRA-22/G: The Development of the Romanian Infrasound Array

A.S. Moldovan (1), C. Ionescu (2), I.A. Moldovan (2)
(1) AZEL-Designing Group Ltd., Bucharest-Magurele, Romania (2) NIEP, Seismic Network, Magurele, Romania
Contact: viorel@infp.ro, adrian@azel.ro

The infrasound technology in Romania was developed in the framework of three national projects in the field of monitoring of anomalous phenomena associated with earthquakes, explosions and storms with the very start in 2005.

In the last years, AZEL - Designing Group Ltd. and National Institute for Earth Physics have developed two triangle-shaped infrasound arrays in the epicentral zone, the first one having 400 m aperture and the second one 2.5 km aperture. First array (***IOANE***), surrounding a central point (Plostina-Vrancea), has been completed with another array (***IPLOR***), with a larger aperture, needed for a better event azimuth identification.
In one site there are installed two types of sensors (MBAZEL2007 and Chaparral) for reliability studies.
At present, the infrasound array from Plostina consists in 6 elements: three elements built in *Basic Design Requirements for Pipe Arrays* with **Chaparral** sensors (Model25, 0.1Hz to 200 Hz) and Quanterra Q330 digitizers (two of them with porous hoses and one with a daisy-shaped wind-noise reduction system) installed on external ring and the other three with MBAZEL2007 (+/-50Pa) microbarometer with porous hoses and Hi6 - AZEL digitizers.

First part of the paper depicts the ***IOANE*** infrasound array that is deployed at Plostina site, has an aperture of 400m and it is equipped with three **MBAZEL2007** microbarometers.

IOANE is in operation since June 2008 and is recording on regular basis. For this array, in-situ noise PSD measurements were conducted, showing that **MBAZEL2007** microbarometers, equipped with simple (porous hose) wind-noise filters, have a good dynamic and a low noise., offering a good detection capability.

INFRA-23/G: Observation and events identification from I33S station

RAMBOLAMANANA Gérard, Ramanantsoa Andry, ANDRIANAIVOARISOA Bernardo and RANDRIANARINOSY Fanomezana
IOGA – LABORATORY OF SEISMOLOGY AND INFRASOUND, BP 3843 101–ANTANANARIVO, MADAGASCAR
Contact: rambolamanana_gerard@yahoo.fr

Abstract: I33S infrasonic station located at Imerintsiatosika-Madagascar has collected data since September 2001. This station is among the 60 infrasonic stations operated by CTBT/IMS in the world. PMCC method is used to process the data. Two classes of signals are observed such as High Frequency (up to 0.5Hz) and Low Frequency (less than 0.5Hz) and recognise natural and man-made events. Generally, natural events produce low frequency infrasound signal such as ocean tides, cyclones and volcano eruptions occurred far away the station. Ocean tides monitoring allows to detect and to recognize signals from Atlantic, Pacific Oceans and Antarctic Circumpolar Current (ACC). Seasonal variation is shown on the ACC detection. Cyclones occurred in the Indian Ocean produce infrasound signal generated only on deep sea. Atmospheric characteristic can be determined by using ray tracing method. In high-frequencies domain, lightning monitoring shows events recorded around North, West and South-Western of Madagascar during summer season. Man-made events produce high frequency infrasound such as explosions and quarry blasts surrounding Antananarivo. Calculation of signal characteristics from those sources allows establishing amplitude's law. Roaming of aircraft with helices generates infrasound signal in the range of 1.5 Hz to 3.5 Hz, and can be propagated at distance of 278 km.

INFRA-24/G: New Tool – Small-aperture seismic and infrasound complex "Mikhnevo" for natural and technogenic sources monitoring

Sanina I.A., Rybnov Yu.A., Kharlamov V.A., Nesterkina M.A., Konstantinovskaya N.L.
Institute of Geospheres Dynamics of RAS, Moscow
Contact: irina@idg.chph.ras.ru

Abstract: In 1954 according to the Resolution of the Council of Ministers of the USSR on development of seismic control over nuclear experiments the "Mikhnevo" seismic station was established at 80 km to the South from Moscow. The seismic station was equipped with specially designed high-sensitive SK-M and USF seismic recorders and microbarographs. In 2004 small-aperture seismic array (SSA) was built at this station. The infrasound station was launched in 2006. The seismic array occupies 1 sq. km area and consists of central vertical seismic receiver installed in the well at the depth of 20 m and peripheral sensors – 9 vertical and 2 three-component ones installed in sealed containers at the depth of 0.5 m along three concentric circles. The array seismic channels are made using SM3-KV short-period seismometers that are widely used in practice by Russian seismologists. The sensor frequency-amplitude characteristics is uniform within f=0.5–40.0 Hz frequency band.

Seismic data are registered in GMT system, time registration using GPS. “Mikhnevo” SSA is located on the sedimentary base and this is its difference from other arrays that are installed on rock base. Foundation rocks occur at 1.1 km depth. Microseism power spectrum level for displacement at 1 Hz for “Mikhnevo” array is 2 nm^2/Hz in average.

Infrasound station is equipped with microbarometers having dynamic range of 0.03-200 Pa and pass band of 0.001-10 Hz. Three microbarometers form triangle with 500-600 m sides and are installed in wells at 2 m depth. Additionally the station is equipped with sensors for atmospheric pressure, wind speed and direction, temperature, humidity, solar radiation level and precipitations. The new algorithm is developed for infrasound signal detection. This algorithm is based of main components analysis of multidimensional series arranged of signals from all sensors. At that spectral matrices of multidimensional series are formed that are calculated in the given frequency range in sliding time window.

Since commencement the “Mikhnevo” SSA has recorded over 3000 events of different nature: local and teleseismic earthquakes as well as quarry shots. SASA records practically every earthquake on the Earth witn M>5.5, and for the East-European platform – all events including industrial shots with M>1.5 till the distance about 400 km. Among the recorded events there are in Kaliningrad, Iran , Pakistan , Spitsbergen , Poland , Ukraine and many others. One of the main results of “Mikhnevo” seismic array operation is decrease of magnitude level for weak seismic events recording in the central part of East-European platform .

For the operation period the infrasound station has recorded over 60 signals from passing thunderheads, several dozens of quarry shots at Kursk magnetic anomaly etc.

Seismic and infrasound complex has shown high efficiency of signal detection of different physical nature both lithospheric and atmospheric.

INFRA-25/G: Inversion of infrasound signals for passive atmospheric remote sensing

Douglas P. Drob[1], Robert R. Meier[2], J. Michael Picone[2], Milton A. Garcés[3]

[1]Space Sciences Division, U.S. Naval Research Laboratory, 4555 Overlook Avenue, Washington, DC 20375; [2] Department of Physics and Astronomy, George Mason University, MS 3F3, Fairfax VA 22030; [3]Infrasound Laboratory, HIGP, SOEST, University of Hawaii, Manoa, 73-4460 Queen Kaahumanu Hwy., #119, Kailua-Kona, HI 96740-2638.

Contact : douglas.drob@nrl.navy.mil

Abstract : During the past few years, significant progress has been made in our understanding of atmospheric propagation of infrasound signals from both natural and man-made impulsive events. In this paper, we review this progress within the framework of the early history of infrasound remote sensing, including basic geophysical remote sensing theory and linear acoustic wave propagation. We also review the capabilities and limitations of current global atmospheric specification models available for use in CTBTO detection, location, and characterization activities.

We believe that the state-of-the-art in infrasound propagation research has advanced sufficiently that the opportunity is now at hand to turn the problem around and use detections of infrasound to improve our knowledge of upper atmospheric winds and temperatures. Accordingly, we employ discrete inverse theory, a concept developed by the seismographic and oceanographic communities, to infer winds and temperatures from infrasound observations. We demonstrate the methodology through application to an extensive time series of synthetic data generated using an atmospheric model as the “truth”.

The results of several illustrative numerical experiments carried out with an existing infrasound network show that with selected assumptions, infrasound signals from a single impulsive event can be inverted to provide quantitative information on the state of the middle- and upper atmosphere. We conclude that this approach to infrasound signal inversion is an important step forward in atmospheric remote sensing and we propose several ideas for future directions.

INFRA-26/G: Large scale atmospheric waves observed by an experimental infrasound network

Julien Marty[1], Elisabeth Blanc[1], Damien Ponceau[1], Ulziibat Munkhuu[2], F. Dalaudier[3]
[1]CEA,DAM,DIF,,F- 91297 Arpajon, France ; [2]Research Center of Astronomy and Geophysics, Mongolia; [3]LATMOS, CNRS, Verrières le Buisson, France
Contact : Julien.marty@cea.fr

Abstract : Gravity waves are an important component of the atmospheric motion field because of their ability to transport momentum and energy over considerable distances and their interactions with the mean circulation and other atmospheric processes. Several experiments have described in the past the detection of gravity wave pressure fluctuations using microbarographs networks. Gravity waves were also observed by the infrasound network dedicated to the verification of the CTBT. However, questions about the lower frequency which can be measured by this network and about the significance of the parameters measured by the usual processing methods are still open. To evaluate gravity wave detection from ground pressure signals recorded by the MB2005 microbarographs, CEA has developed a temporary experimental network in Mongolia. Three microbarograph stations separated from 80km have been installed for 20 days in July 2008. Each station was composed of four sensors measuring relative pressure and one meteorological station. The experience is described and examples of gravity waves are shown. Results will precise the possibilities of using the CTBTO network for gravity wave observations.

INFRA-27/G: Study of the dynamics of the upper atmosphere by using infrasound measurements

E. Blanc[1], A. Le Pichon[1], L. Ceranna[2], T. Farges[1]
[1]CEA,DAM,DIF,,F- 91297 Arpajon, France ; [2]BGR, Stilleweg 2, Hannover, 30655, Germany
Contact: elisabeth.blanc@cea.fr

Abstract: The development of the Infrasound International Monitoring System (IMS), used for the verification of the Comprehensive nuclear Test Ban Treaty, represents a powerful tool to measure permanently, on a global scale and over large periods of time, the characteristics of the waves and dynamics of the atmosphere in relation with the climate. The purpose of this poster is to illustrate through different examples the potential of the network for the study of the atmospheric dynamics. The first way is to monitor quasi continuous infrasound sources such as ocean swells or volcanic eruptions to determine the fluctuations of the stratosphere and mesosphere in relation with the activity of planetary waves and large scale polar disturbances such as Vortex Intensification or Sudden Stratospheric Warming. The second way is to monitor gravity waves which are observed in the lower frequency range of the infrasound data. Large scale waves, mainly produced in tropical regions, influence the mean circulation of the middle atmosphere by transporting moment and energy from tropical to Polar Regions with a possible role on tropospheric climate.

INFRA-28/G: The Acoustic Fingerprint of Volcanic Ash Emission: Results from the International ASHE Project

David Fee and Milton Garces
Infrasound Laboratory, University of Hawaii, Manoa
A. Steffke, University of Hawaii, Manoa, USA; D. McCormack, Geological Survey of Canada; R. Servranckx, Canadian Meteorological Centre, Canada; C. Hetzer, University of Mississippi, USA; M. Hedlin and R. Matoza, University of California, San Diego, USA; H. Yepes, and P. Ramon, Escuela Politecnica Nacional, Ecuador
Contact: dfee@isla.hawaii.edu

Abstract: Volcanic ash poses a serious threat to aviation. The primary objective of the Acoustic Surveillance for Hazardous Eruptions (ASHE) project was to demonstrate the possibility of using low frequency acoustic (infrasound) observations over broad regions for automatic, low-latency notification of hazardous volcanic eruptions. Results from this pilot project based in Ecuador and Mount. St. Helens, USA demonstrate that this objective can be reliably achieved for eruptions with a Volcanic Explosivity Index (VEI) of 2 or greater at distances of 40-250 km. For a station distance of 40 km, it appears possible to identify the acoustic signature of stratospheric ash injection (>10 km) and notify the responsible Volcanic Ash Advisory Center (VAAC) within 5 minutes. At 250 km, VEI 2 notification latency increases to ~20 minutes. The large eruptions recorded during the pilot ASHE project in Ecuador show a positive correlation between acoustic energy and ash height. Further, there appears to be a potential to use coherent acoustic energy in the 0.05-0.25 Hz band as a discriminant for stratospheric ash injection. Short duration explosions were found to produce discrete ash emissions of a much smaller magnitude than the longer-duration destructive eruptions. The identification of the acoustic fingerprint from ash producing eruptions associated with high-altitude ash injection implies that acoustic remote sensing can improve the reliability and reduce the latency of volcanic ash notifications. The Washington DC VAAC is

routinely using our automatic ASHE notifications to alert pilots of potential ash hazards at commercial aircraft cruise altitudes (~12 km).

The results of the ASHE project can be extended to the 2000+ km range provided by the IMS network. The powerful, ash-rich 2008-09 eruptions of Okmok, Kasatochi, and Redoubt Volcanoes in Alaska also produced significant infrasound and were recorded by numerous IMS infrasound arrays, including IS59US, Hawaii (~4000 km range). Further examination of these telesonic volcano signals will be part of a new NOAA-supported project for Remote Infrasonic Monitoring of Natural Hazards.

INFRA-29/G: On the monitoring of hurricanes using the international infrasound network.

Roger Waxler, Claus Hetzer, Jelle Assink, Carrick Talmadge and Kenneth Gilbert
NCPA at the University of Mississippi and Milton Garces and Justin Stopa at the ISLA at the University of Hawaii
Contact: rwax@olemiss.edu

Abstract: It is known that cyclonic activity over the ocean generates infrasound due to the interaction of the cyclonic winds with the sea surface. The sound generated by this interaction is in a narrow frequency band centered at about 0.2 Hz, the so-called microbarom band. Through a combination of theoretical developments concerning the radiation of sound by interacting ocean surface waves, analysis of data from infrasound stations near hurricanes, and ocean wave modelling it has been determined that the microbarom radiation from isolated hurricanes over the deep ocean arises from the collision of hurricane generated ocean waves with the background ocean swell. Current research is aimed at improving the models for ocean surface wave generation under hurricanes, at determining the influence of shorelines on microbarom generation and at determining the extent to which the microbarom signal can be used to monitor hurricane intensity.

ON-SITE INSPECTION

OSI-01/B: Geophysical Techniques for On-Site Inspections – Experience & Overview

Rainier Arndt, Luis R. Gaya-Pique*. On-Site Inspection Division, CTBTO PrepCom, Vienna International Centre, P.O. Box 1200, A1400, Vienna, Austria.*
Contact: rainier.arndt@ctbto.org

Abstract: On-site inspections (OSIs) constitute the final verification measure under the Comprehensive Nuclear-Test-Ban Treaty (CTBT). OSIs are launched to establish whether or not a nuclear explosion has been carried out, thus they are conducted to verify States' compliance with the Treaty. During such an inspection, facts are gathered within a limited investigation area of 1000 Km2. Time is one of the challenges that an inspection team has to face when conducting an OSI. Other challenges are the size of the team – which is limited to 40 inspectors - and political limitations imposed by the Treaty in the use of allowed techniques.

Among the techniques that can be used during an OSI, geophysical surveys play a crucial role in order to identify geophysical signatures related to an UNE in terms of changes in the geological strata, to the hydrogeological regime, and in terms of the shallow remains of the infrastructure deployed during the preparation and monitoring of the test. These techniques are grouped under the common name of Continuation Period Technologies (CPT), since they can only be applied during the continuation period of an OSI, and they cover the areas of active and resonance seismics; magnetic, gravity, and electrical conductivity field mapping from ground and from the air; ground penetrating radar; and drilling.

The Integrated Field Exercise 2008 (IFE08) recently conducted in Kazakhstan was the first large-scale on-site inspection exercise ever conducted by the Preparatory Commission of the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO). The exercise took place in a deserted area south east of Kurchatov, within the former Soviet Union's Semipalatinsk nuclear test site. In this work we provide an overview of the geophysical surveys conducted by a subteam of ten geophysicists members of the inspection team during IFE08 in order to collect evidence for a hypothetical nuclear explosion test. The data collected during IFE08, especially ground and aerial magnetic data as well as shallow resistivity data, together with other datasets from previous exercises, set the fundaments of a database of invaluable value to be used by CTBTO in the future for a better understanding of the phenomenology related to a nuclear explosion.

OSI-02/B: OSI: A Challenging Inspection – Logistics for the IFE

John Anderson, Luis R. Gaya-Pique. *On-Site Inspection Division, CTBTO PrepCom, Vienna International Centre, P.O. Box 1200, A1400, Vienna, Austria;*
Contact: john.anderson@ctbto.org

The principles behind CTBT on-site inspection are often similar to other treaty based challenge inspection processes, but involve more people and equipment and last longer than other such processes. For IFE08 in Kazakhstan, logistical support was a major undertaking to ensure the success of the exercise, particularly since the support was needed for Base of Operation infrastructure not just the IT but also ISP, Observers, Control Teams, evaluators and others. Inspection equipment was also brought in from various locations as well as Vienna. The IFE highlighted the critical importance of logistical support for an OSI under the CTBT and provided the PTS with valuable data for future planning of logistical readiness.

OSI-03:/B The use of aeromagnetic surveys in the framework of CTBTO On-Site inspections – Experience from IFE08

Luis R. Gaya-Piqué[1], Ashley Grant[2], Matthew Purss[3], George Tuckwell[4]
[1]On-Site Inspection Division, CTBTO PrepCom, Vienna International Centre, P.O. Box 1200, A1400, Vienna, Austria; [2] ARKeX Limited, Newton House, Cambridge Business Park, Cambridge, CB4 0WZ; [3]Geoscience Australia, GPO Box 378, Canberra, ACT, 2601, Australia; [4]STATS Ltd, Porterswood House, Porters Wood, St Albans, AL3 9PQ, UK
Contact: luis.gaya@ctbto.org

Abstract: Aeromagnetic surveys constitute a quick and straightforward method to obtain a geological picture of the area under study, and at the same time it can be applied to identify the possible presence of anthropogenic magnetic signatures. By this reason, this method is regularly applied in the minerals and oil and gas exploration industries, geological studies, and detection of Unexploded Ordinance (UXO) among many other fields. The use of magnetic field mapping is allowed during the continuation period of an on-site inspection (OSI) in the framework of the Comprehensive Nuclear-Test-Ban Treaty (CTBT). When properly applied, it contributes to the search logic of the inspection team by offering a comprehensive coverage of the inspection area in a short period of time, providing basic information about the geology as well as identifying potential targets that can be inspected later from the ground.

This paper provides an overview of the aeromagnetic surveys conducted during the Integrated Field Exercise IFE08, held in September 2008 in the former Soviet nuclear test site at Semipalatinsk, Kazakhstan. Aeromagnetic data were collected during a 5-hour long overflight at a constant altitude of 100 meters above ground level and 100 meters flight line spacing. Most of the magnetic signatures identified after processing of the data can be attributed to geological units. However, other magnetic anomalies would require further investigation from the ground in order for their origin to be clarified, demonstrating the utility of this technique in the framework of an OSI.

OSI-04/B: IFE08: Integration of On-Site Inspection Elements

Elizabeta JEVTIC, Hermann Lampalzer. *On-Site Inspection Division, CTBTO PrepCom, Vienna International Centre, P.O. Box 1200, A-1400, Vienna, Austria*
Contact: elizabeta.jevtic@ctbto.org

Abstract: On-site inspections (OSI) are designed as the ultimate verification tool in order to address Comprehensive Nuclear-Test-Ban Treaty (CTBT) compliance concerns. The conduct of an OSI requires the integration of several different inspection activities and techniques. Considerate planning, close coordination among the Inspection Team (IT) sub-teams and strong leadership are considered crucial for the efficient conduct of an inspection.

Besides operational aspects, equipment and logistical issues play a major role in the conduct of an OSI. All equipment to be used by the IT needs to be on the list of approved equipment. As part of the activities to be carried out upon receipt of a request for an OSI, an Operations Support Centre (OSC) at the CTBTO headquarters in Vienna to provide the required support to the IT.

The CTBT contains the main provisions regarding the IT's interaction with the Inspected State Party. Specific aspects on IT operational procedures were tested during IFE08 and will eventually be covered in the OSI Operational Manual. Only trained and qualified experts designated by States Parties and by the Director-General from the Technical Secretariat can become members of the inspection team. The conduct of a comprehensive training program for future inspectors and fully developed administrative, legal and logistical procedures pertaining to the inspector status are crucial elements for reaching OSI readiness.

The poster provides a brief overview of different thematic clusters relevant for the conduct of an OSI. A number of these elements were exercised during the Integrated Field Exercise in September 2008.

OSI-05/B: Seismic aftershock monitoring during an OSI - experience and results from Field Exercise in Kazakhstan

Labak, P[1]., Villagran, M[2]., Haege, M.[3]
[1]On-Site Inspection Division, CTBTO PrepCom, Vienna International Centre, P.O. Box 1200, A1400, Vienna, Austria; [2]Golden Jewel Energy, C.R. Construcciones, 1 Calle D 1-06 Zona 1, Guatemala City, Guatemala; [3]University of Stuttgart, Institute of Geophysics, Azenbergstr. 16, 70174 Stuttgart, Germany
Contact: peter.labak@ctbto.org

Abstract: One of the techniques used during the Integrated Field Experiment in 2008 (IFE08) in Kazakhstan was the Seismic aftershock monitoring system (SAMS). The task of the SAMS is to collect the facts, which should help to clarify nature of the triggering event. Therefore the SAMS has to be capable to detect and identify events as small as magnitude -2 in the inspection area size up to 1000 km2.

Equipment for 30 mini-arrays and 10 3-component stations represented the field equipment of the SAMS. Each mini-array consisted of a central 3-component seismometer and 3 vertical seismometers at the distance about 100 m from the central elements. The mini-arrays covered approximately 80% of surrogate inspection area (IA) on the territory of former Semipalatinsk test site. Most of the stations were installed during the first four days of field operations by the seismic sub-team, which consisted of 10 seismologists.

SAMS data center comprised 2 IBM Blade centers and 8 working places for data archiving, detection list production and event analysis. A prototype of SAMS software was tested. Average daily amount of collected raw data was 15-30 GB and increased according to the amount of stations entering operation. Routine manual data screening and data analyses were performed by 2-6 subteam members. Automatic screening was used for selected time intervals. Screening was performed using the Sonoview program in frequency domain and using the Geotool and Hypolines programs for screening in time domain. The screening results were merged into the master event list. The master event list served as a basis of detailed analysis of unclear events and events identified to be potentially in the IA. Detailed analysis of events to be potentially in the IA was performed by the Hypoline and Geotool programs. In addition, the Hyposimplex and Hypocenter programs were also used for localization of events. The results of analysis were integrated in the visual form using the Seistrain/geosearch program. Data were fully screened for the period 5.-13.9.2008. 360 teleseismic, regional and local events were

identified. Results of the detection and analysis will be presented and consequences for further SAMS development will be discussed.

OSI-06/B: OSI: Measurement of levels of radioactivity

Matjaz PRAH, Junichi TANAKA. *On-Site Inspection Division, CTBTO PrepCom, Vienna International Centre, P.O. Box 1200, A1400, Vienna, Austria;*
Contact: matjaz.prah@ctbto.org

Abstract: Radioactivity measurement is one of the main inspection techniques during OSI. This include the gamma radiation level measurement above, at and below the surface, and high energy resolution gamma analysis of samples from the air, and at or under the surface, to search for and identify radiation anomalies. The secondary, but also very important objective is to support the Inspection Team radiation safety principles in potentially hazardous (radioactive contaminated) area. Systematic approach in gamma radiation survey using the aircraft-mounted equipment during the addition overflight or vehicle-mounted equipment for ground missions can highly contribute in search logic and in identification of possible radiation anomalies.

This poster provides an overview of the gamma surveys conducted during the Integrated Field Exercise IFE08, hold in September 2008 in the former Russian nuclear test site of Semipalatinsk.

OSI-07/B: Evaluation of on-site inspection activities for planning and implementation

Ward L. Hawkins[1], Kenneth H. Wohletz[1], Jerry J. Sweeney[2], Brian D. Milbrath[3], Theodore W. Bowyer[3], and Michael G. Vannoni[4]
Los Alamos National Laboratory[1], Lawrence Livermore National Laboratory[2], Pacific Northwest National Laboratory[3], and Sandia National Laboratories[4]
Contact: whawkins@lanl.gov

Abstract: A matrix approach provides a robust method to evaluate On-Site Inspection (OSI) technologies and activities with respect to a number of site-specific variables. Such an evaluation will support rapid and informed decisions regarding planning and implementation of inspection activities. In the limited timeframe for preparation and conduct of the inspection, it will be necessary to prioritize and schedule the inspection activities to emphasize techniques with the highest probability for accomplishing the inspection's purpose and narrowing the inspection area to define locations for further analysis and possible drilling. Once an inspection is approved or even requested, the approach described here can be quickly engaged to determine the potential effectiveness of the OSI techniques and sequence of conduct. Based on knowledge of the inspection area and inspection request information, including geology, topography, technology performance, access, and logistical challenges, detailed plans can be developed. The approach described here provides full flexibility to address any scenario and set of activities. This input, as captured in a matrix format, will enhance the operational and data acquisition planning. Given the site conditions, the strengths and weaknesses of specific monitoring technologies can be estimated by a group of subject matter experts. Special needs can be identified, e.g., logistical support, transportation, and manpower. Many details of OSI activities will have to be agreed upon between the Inspection Team Leader (ITL) and the Inspected State Party. Documentation of the information captured in the evaluation will greatly assist the ITL in addressing the numerous issues that arise during complex field operations. This report presents a matrix approach that demonstrates how a set of criteria can be used to quickly and effectively evaluate the utilization of monitoring technologies for a particular scenario and to provide documentation of the results and assumptions. This approach would also be very useful for OSI inspector training and exercises.

OSI-08/B: Enhancing realism of OSI field exercises: some ideas

Jerry J. Sweeney, Charles R. Carrigan, William H. Dunlop, Stanley J. Luke, Arden A. Dougan, *Lawrence Livermore National Laboratory*
Contact: sweeney3@LLNL.gov

Abstract: Effective field exercises are critical for the training of inspectors for CTBT on-site inspections (OSI) and for the testing and development of operational methods. In order to be effective and to fully engage the participants, exercises must be as realistic as possible. This is a particular challenge for several essential OSI methods: the seismic aftershock measurement system (SAMS); high purity germanium (HPGe) gamma measurements; and gas sampling for noble gases. For all of these applications, it is difficult to create conditions in the field that realistically re-create conditions expected to be encountered in a real OSI: rapidly decaying aftershocks of the specific character and magnitude of those following a large underground explosion (UNE); gamma sources with the energy spectrum of a UNE; and presence of short-lived xenon and argon gas sources with isotopes characteristic of an UNE. This paper proposes specific approaches for all of these to improve

realism during an OSI exercise as well as two proposals for specific activities that can exercise SAMS and noble gas field deployments.

For the SAMS, it should be possible to develop a set of seismic waveform data, or algorithms to generate such data, such that data could be inserted into the seismic analysis system to re-create situations for the inspection team members to analyze and react to. The data would be based on well-known relationships for the number per day and magnitudes of typical aftershock systems from earthquakes and explosions (which are different). Data would be injected into the analysis system in such a way that locations of events could be calculated for an arbitrary distribution of seismic stations that would be consistent with a given scenario. For the HPGe gamma measurements, algorithms could be developed to simulate detections by a HPGe instrument with information barriers. This system would rely on analysis of the full spectrum of energy available (thus allowing full calibration), but the spectrum would be analyzed in such a way that information about certain isotopes is not visible and only a determination of whether or not the spectrum is consistent with a UNE is available. Specific types of simulated spectra could be injected into the instrument at specific times during an exercise in order to simulate specific events during an OSI. A similar approach could be used to simulate gas sampling; an overall algorithm for the transport and availability of gas at particular locations in the inspection area could be developed so that data could be injected into the exercise showing "hits" of gas detection provided the sampling was done at specific places and times.

Finally, natural earthquake aftershocks or earthquake swarms could be considered as a means to exercise rapid deployment of SAMS and its ability to detect and locate aftershocks. Following a moderate (Mb 4.5-5.5) earthquake or inception of an earthquake swarm (most likely in a volcanic region) in an accessible region, a small team could be deployed with SAMS to test and exercise the process. For gas sampling, an existing large underground cavity could be "seeded" with an inert but easily detected and identified gas and a small team would be deployed to sample the surface at a variety of places to test and exercise the effectiveness of noble gas sampling procedures.

OSI-09/B: A systems approach to establishing an effective CTBT on-site inspection (OSI) regime

Jay Zucca[1], Padmini Sokkappa[1], Jerry Sweeney[1], Charles Carrigan[1], Ted Bowyer[2], Harry Miley[2], Brian Milbrath[2], Ward Hawkins[3], Ken Wohletz[3], Mike Vannoni[4], and Jim Arzigian[4]

[1] Lawrence Livermore National Laboratory; [2] Pacific Northwest National Laboratory; [3]Los Alamos National Laboratory; [4]Sandia National Laboratories

Contact: sweeney3@LLNL.gov

Abstract: The Comprehensive Nuclear Test-Ban Treaty (CTBT) allows for the use of several different technologies for performing inspections of regions suspected of being the location of a recent nuclear explosion. The technologies currently under consideration for use in a CTBT on-site inspection (OSI) vary both in their level of complexity and in their effectiveness. Preliminary studies indicate that it may be possible to expedite preparations for an effective OSI by using a systems engineering approach where technologies are reviewed and ranked according to their effectiveness, taking into account the current maturity of the various technologies, the difficulties associated with reaching consensus allowing the use of the different technologies during an OSI, the amount of manpower needed to deploy them, their cost, the time required to establish a significant result, and other factors.

Such a systems engineering approach could lead to both a roadmap for investment in OSI technologies and to the use of a phased approach in which selected technologies are deployed early in an individual OSI or early in the history of the CTBT OSI regime. A phased approach may allow implementation on a timescale that is more rapid than is possible for the full suite of technologies that might ultimately be exercised in the course of a complete OSI.

For example, this approach could identify which small set of technologies are most appropriate to ensure that the OSI component of the CTBT verification regime is ready for effective deployment at entry-into-force (EIF) as required by the Treaty, or in the early stages of a more complete OSI occurring at a later time following EIF, when the suite of technologies available for effective use in an OSI may be more complete.

In this approach, those technologies selected for early deployment in the OSI regime, or early in the course of an individual OSI, would be those that draw a balance between being ready for timely deployment and effectiveness at achieving the objectives of a successful OSI. Technologies that are more difficult to field, those that are less effective in producing early indications of the presence or absence of a recent nuclear explosion, or those that need more research and development before deployment may be chosen to be phased in at a later date. Some examples of technologies that may be technically suitable for early deployment in an effective CTBT OSI regime will be presented.

OSI-10/B: Application of a Bayesian Approach to Search-Area Reduction During a CTBT On-Site Inspection

Charles R. Carrigan and Gardar Johannesson*, Lawrence Livermore National Laboratory*
Contact: carrigan1@LLNL.gov

Abstract: The ability of inspectors to locate the site of a suspected underground nuclear explosion (UNE) depends significantly on their success in reducing the initial size of the search area that may be identified by a combination of different sources of data such as the International Monitoring System (IMS), satellite imagery, human intelligence, etc. The goal of the IMS, in particular, is to define an initial search area of less than one-thousand square kilometers, which is comparable in size to some of the world's larger cities. However, locating the surface ground zero (SGZ) of a suspect UNE using, for example, a combination of visual inspections, seismic aftershock monitoring and subsurface radionuclide gas sampling is labor intensive and is likely to require that the search area be reduced to only several square kilometers. Performing a detailed ground search on even this smaller scale will still be demanding, given constraints on the number of inspectors and the duration of the on-site inspection (OSI), and further search-area reduction resulting in additional focusing of the effort will significantly enhance the potential for success.

Search methodologies based on Bayesian inference have been notably successful in reducing large search areas to a more manageable size and ultimately pinpointing the location of the search target. Examples include the search for the sunken US submarine, Scorpion, which was found using different categories of input data including expert judgement, at a location in the Atlantic Ocean that was very different from its originally anticipated position. An attractive feature of the Bayesian inferential approach is the provision of a rigorous framework for updating an initial or prior probability density function by fusing different types of search data (e.g., seismic, topographic, geologic, atmospheric radionuclide, and the interpretation of visual observations) along with estimates of uncertainty to produce an updated or posterior probability density function. For an OSI, this posterior function then represents a new estimate of the likelihood of finding the SGZ within any given cell of the gridded search area as a result of adding new information. The probability density function will evolve over the gridded search area as repeated additions of new data produce new posterior estimates until ideally converging with a maximum indicating the cells having the highest likelihood of containing the SGZ.

In this paper, we will present one possible approach to applying OSI data to a Bayesian inference framework in which one challenge is the integration of data from sensors (e.g., seismic) with data corresponding to expert evaluation of visual observations. To do this, we formulate an example using information from the 1993 Non-Proliferation Experiment (NPE) which provided an early opportunity to simulate an OSI in the case of subsurface sampling for radionuclides. For the sake of this discussion, we will consider that the existence of an SGZ in any given cell of a search grid can result from one of two hypotheses; (1) a device for subsurface detonation was emplaced by vertical drilling or (2) a device was emplaced horizontally using a tunnel or drift. We present how Bayes' theory can be used to fuse together the different types of data-layers in calculating a probability density distribution for detecting the existence of SGZ in each grid square. Finally, we use this discussion of a Bayesian search scheme to better understand how the different layers of data ultimately contribute to the evolution of the posterior SGZ-location probability density function.

OSI-11/B: The availability and limitation of techniques for on-site inspection

Xiaoyuan Han, Mingyan Jia, Bing Gong, Mei Tian, Hui Xu
Northwest Institute of Nuclear Technology, P. O. Box 69-1, 710024, Xi'an P. R. China
Contact: gbgbgbcycycy@163.com

Abstract: The techniques employed by on-site inspections (OSI) include visual observation, radioactive measurement, environmental sampling and analysis, passive seismological monitoring for aftershocks, resonance seismometry and active seismic survey, magnetic and gravitational field mapping and drilling, etc. In order to know the availability of these techniques, a lot of work had been done in the world in the past decade, and some useful knowledge was obtained. Comparing with the availability, limitation of the techniques was usually neglected. In this paper, the availability were summarized according to the literatures published and the limitation of some techniques was also analyzed simply.
Keywords: OSI, techniques, availability, review

OSI-12/B: Search for a nuclear explosion - deployment of techniques at the IFE
Jean-Michel Millon, Paul Stokes, Alwyn Davies
Contact: Malcolm.coxhead@dfat.gov.au

The purpose of an on-site inspection is to clarify whether a nuclear explosion has occurred, and to gather related facts. The inspection team at IFE08 in Kazakhstan conducted its search over an area of 1000 square kilometres. At the same time that the team obtained its first overview of the inspection area from an overflight, it moved to establish monitoring for short-lived phenomena such as seismic aftershocks. Extensive ground based visual observation and survey for radiation anomalies were next steps to identify artefacts or anomalies requiring closer investigation with techniques such as sampling and analysis and geophysical imaging.

OSI-13/B: Using differential SAR-Interferometry for locating ground zero
Riechmann, Britta, *Carl Friedrich von Weizaecker Centre for Science and Peace Research*
Contact: Briechma@physnet.uni-hamburg.de

Abstract: For On-Site inspections it is important to locate ground zero exactly. Besides seismic data analysis radar satellit imagery could be an aditional tool. The method is called synthetic aperture radar (SAR)-interferometry and uses the intensity and phase informations of radar images from satellits . You are able to create differential SAR-Interferogramms with the help of two images of different times and an external digital elevation model, which shows the ground motion between the different times of the images. Studies of differential SAR-Interferogramms of the Nevada Test Site had confirmed that nuclear underground explosions causes subsidences in the dimensions of the so called spall-effect. The subsidences have a radius between 500m and 1500m, a maximum depth between -2cm and -8cm and a gaussian-like shape. The advantage of differential SAR-Interferometry is that you can use post-seismic images. The timescale of the subsidence rate is so slow, that you are able to see the subsidences still after month and years. This study tries to figure out a filtering method used on the interferogramms of the Nevada Test Site to locate the ground zero automatically, using the second standard derivation method of Mariscotti on two dimensions. Besides co-seismic interferogramms of the Nevada Tests Site and the Chinese testsite Lop Nor shows that drastic changes of the coherency causes noise in the differential SAR-Interferogramms which additionally could help to find ground zero. Both approches will be presented in this poster.

OSI-14/B: OSI - a role for satellite imagery
Malcolm Coxhead, Paul Stokes
Australian Safeguards and Non-Proliferation Office, Geoscience Australia, New Zealand Radiation Laboratory
Contact: Malcolm.coxhead@dfat.gov.au

Abstract: Satellite imagery has revolutionised our ability to effectively map even the most remote terrestrial locations, a capability that would facilitate inspection in remote locations. It also brings the possibility of new forms of analysis to support on-site inspection. Imagery from national technical means could be useful here, but so also could that from open sources. The analysis of images from before and after an event offer particular potential for identifying recent ground disturbance, including disturbance that may not be obvious from ground-based observations.

OSI-15/B: InSAR signatures surface expression of natural disasters and human activities
Salvatore Stramondo, *Istituto Nazionale di Geofisica e Vulcanologia, Rome, Italy*
Contact: salvatore.stramondo@ingv.it

Abstract: The use of Synthetic Aperture Radar Interferometry (InSAR) technique to the detection and measurement of surface effects causd by natural disasters and human activities has become a common issue. It is not far from truth the statement that InSAR is considered an effective tool in most of Earth Sciences. SAR is an active sensor positioned on a moving platform exploiting the flight path to generate a synthetic antenna and to significatively increase the spatial resolution. InSAR is a signal processing technique based on the combination of the phase components from two SAR images relative to the scene and acquired at different time from the same geometry. The result is the interferogram, a per pixel difference of the two SAR images that provide an accurate measurement of surface displacements.

Since 1991 when the European Space Agency (ESA) launched the first SAR satellite, ERS-1, scientists developed ad hoc algorithms leading to InSAR processing. In 1995 ESA launched the twin, ERS-2, thus improving its capabilities to investigate the whole Earth surface.

In the following years, another C-Band (5.6 cm wavelength) SAR sensor was available, Radarsat-1. Today a number of C-, X-, and L-Band satellites daily provide an overall "microwave" picture of the Earth and allow an effective monitoring of those phenomena, natural or man-made, resulting in surface effects.

In particular InSAR is applied to the detection of earthquake induced surface movements, to the monitoring of active volcanoes and to investigate landslides.

Concerning those deformations due to human activities, well known results concern the subsidence from fluid extraction, oil and hydrocarbon extraction, surface deformation from mining and slow long term subsidence related to abandoned coal mines.

A key issue is the characterization of each deformation pattern and the correlation with the possible causes. The InSAR signatures may differ one each other, as for earthquakes and volcanoes, or maybe similar. In this latter case, for instance oil extraction and mining, the use of external ancillary data (in-situ data from ground survey, geological maps, seismological data) provide narrow constraints to detect the source. This approach is more effective when the possible deformation source is a subsurface nuclear test. To this aim InSAR has been used in the Nevada Test Site to investigate the short and long term surface effects induced by tests before and after 1989, using SAR images collected from 1992 to 1996.

The variety of patterns reflect the different subsidence rates, which are affected by the subsurface geologic conditions for each test region. The monitoring shows fault-controlled deformation from the dissipation of residual ground-water pore-fluid pressure changes in response to past underground nuclear weapons testing

OSI-16/B: Geomagnetic Observations in Indonesia Carried Out By BMG (Meteorology and Geophysical Agency)

M.Husni, Dipl. Seis and Mahmud Yusuf, Meteorology and Geophysical Agency
Contact: Mahmud@bmg.go.id

Abstract: Geomagnetic observations in Indonesia were started officially in 1866 together with meteorological observations, called Koninklijk Magnetisch en Meteorologisch Observatorium at Jakarta. In 1901 the magnetic observation was moved to Bogor, Kuyper island (1928) and Tangerang (1964) respectively. At present there are five geomagnetic observatories of BMG, i.e Tangerang (TNG), Tuntungan (TUN), Tondano (MND),Pelabuhan Ratu(PEL) and Kupang (KUP). We are planning to build magnetic observatori in Papua.

Magnetic data are used for the purposes of:

- Aviation and Shipping Navigation. Direction navigation needs magnetic declination data at a site to be corrected to compass needle pointing the true north.
- Topographic Map. Large scale topographic map must include the notation of magnetic declination on each piece of map.
- Geological and Geophysical Survey. Every geological and geophysical survey using magnetic method need daily geomagnetic variation data recorded at geomagnetic observatory. The data are used to correct field data during survey.
- Radio Communication. Geomagnetic storms can influence HF radio propagation in many areas.
- Seismo-electromagnetic Research. To support International Geomagnetic Reference Field (IGRF) in the frame of international data exchange with International Association of Geomagnetism and Aeronomy (IAGA) and World Data Center (WDC) and Geosciences Australian (GA), and British Geological Survey (BGS).

OSI-17/B: Estimation of ground-level Radioisotope Distributions for Underground Nuclear Test leakage

James H. Ely, James E. Fast, Carolyn E. Seifert, Glen A. Warren
Pacific Northwest National Laboratory
Contact: carolyn.seifert@pnl.gov

Abstract: It is critical to have fast, effective verification methods for the Comprehensive Nuclear-Test-Ban Treaty (CTBT). After an event of interest occurs, an On Site Inspection (OSI) may be initiated to increase the confidence of the detection of a nuclear explosion or to show that no test occurred. For this, an Inspection Team will be dispatched to the suspect location and will utilize a number of methods, including geological and radiological, to narrow the search region and to bring the potent tool of sub surface noble gas investigation to bear. An understanding of the type, amount, and dispersion of the possible radiological signatures on the surface of the site is important to guide development of and use of radiological search tools such as airborne, jeep-borne, and hand-held detection devices.

This paper will provide results on the modeling of various possible releases from underground nuclear tests and simulations of the decay and ground deposition of various isotopes. The releases will include what might be

expected from a mostly contained nuclear test with variations on the number of released isotopes and the amount of activity. The simulation will provide estimations of ground deposition in terms of isotopes, activity, and range from the release point for a set of time periods after the suspected nuclear explosion under representative meteorological conditions. These results will be useful in understanding the feasibility of radiological search and verification in terms of the most useful isotopes and the viable time periods for each.

OSI-18/B: Chemical Consideration of Radionuclide Leakage from Underground Nnuclear Tests

Judah I. Friese, Rosara F. Payne, Richard J. Arthur, *Pacific Northwest National Laboratory*
Contact: judah.friese@pnl.gov

Abstract: On-Site Inspection (OSI) is a key component of the verification regime for the Comprehensive Nuclear- Test-Ban Treaty (CTBT). Measurements of relevant radionuclide isotopes created by an underground test (UGT) are the most valuable sign of a Treaty violation. To prepare for future OSI activity, one must understand which radionuclides are likely to be available for sampling and measurement. Selection of isotopes can be made based on typical nuclear physics parameters: half-life, fission yield, activation cross sections, gamma-ray emission probabilities, and other factors. However, chemical behavior of the radionuclides created in the UGT may have a strong influence in determining what will be available for an OSI measurement. This is scenario dependant: if a gross vent of radionuclides occurs, some elements that are not very volatile will be transported to the accessible environment. However, the case of slow post-test seepage will be heavily dependant on chemical considerations. For instance, decay chains with noble gas precursors are more likely to transport to the surface. In addition, reactivity of the elements will play a part. Based on an evaluation of chemical behavior, a list of ranked isotopes will be produced.

OSI-19/B: New radionuclide measurement systems improving search and detection capabilities for OSI deployment

Köble, T. et al., *Fraunhofer-INT, Euskirchen, Germany*
Contact: theo.koeble@int.fraunhofer.de

Abstract: The CTBTO verification system comprises an On-Site Inspection (OSI) to verify the suspicion of a forbidden nuclear test. An OSI comprises different methods of verification, one of them being the radiological survey of the inspection area.

Specific equipment with high sensitivity is needed for the gamma radiation survey. Airborne and carborne survey should clearly be carried out by gross gamma counting with devices of high efficiency, whereas the definition of a sampling spot with hand-held measuring devices should focus on the relevant isotopes. In fact the treaty only allows measuring some specific nuclides, which limits the inspector's ability to analyze the results and to verify the correct functioning of his measuring equipment. For example, variations in natural background may be misinterpreted easily. Until now most of the equipment used in exercises for OSI was not "blinded". The presentation will address some issues specific to this type of instrument. In recent years high resolution gamma systems with electric cooling have become really portable and reliable. Now these systems are also suitable for search tasks in the field. We carried out measurements comparing the performance of low resolution gamma measuring devices (e.g. identifinder) and high resolution gamma devices (e.g. microDetective) for searching and identifying radioactive isotopes. In an OSI the next step after finding an anomaly in the radioactive survey is to take samples and analyze these samples in the field laboratory which is located close to the base of operations. Sample preparation and sample measurement turned out to be a bottle-neck in OSI performance in the last OSI exercises. Therefore, it would be of great value to the OSI if sampling could be focused to relevant spots only thus avoiding unnecessary sample analysis of non-relevant samples. Portable high resolution gamma measuring equipment may help in that.

OSI-20/B: Investigations into Radiological Over-flight Searches for On-Site Inspections

Carolyn E. Seifert, James H. Ely, James E. Fast, Glen A. Warren
Pacific Northwest National Laboratory
Contact: carolyn.seifert@pnl.gov

Abstract: On-Site Inspections (OSI) will be an important verification component to deter violations and help verify compliance with the Comprehensive Nuclear-Test-Ban Treaty (CTBT). An important tool in narrowing the possible locations to collect evidence of a nuclear test during an on-site inspection may be over-flights of the general area using aerial gamma spectroscopy which can measure the energy and intensity of gamma radiation and help identify areas that may warrant further investigation of areas of high concentrations of radioactivity. This paper will investigate the capabilities of gamma ray detectors that are typically used in aerial searches. Modeling and simulation results of the detector response for radionuclide species for an OSI will be presented for a variety of assumed releases, depositions on the ground, and times after a suspected nuclear explosion for typical over flight altitudes and speeds. This data will provide information on the possible applicability for airborne spectroscopy and the challenges and limitations of this tool for OSI. Of particular interest will be analysis of the data for gross count, regions of interest, and isotope identification types of algorithms and the characteristics of each.

OSI-21/B: Detection of Anomalous Gamma-Ray Spectra for On Site Inspection

Carolyn E. Seifert, Mitchell J. Myjak, and David M. Pfund
Pacific Northwest National Laboratory, 902 Battelle Boulevard, PO Box 999, Richland, WA 99352 USA
Contact: mitchell.myjak@pnl.gov

Abstract: On Site Inspection (OSI) teams will face many logistical challenges. The teams must be prepared to search areas as large as 1000 km^2 and complete their inspections in a timely and minimally intrusive manner. The data collected must be strictly relevant to the purpose of the inspection, and not disclose confidential information unrelated to the purpose of the inspection— particularly regarding past activities at the site. Detection of anomalous gamma-ray spectra by mobile search teams, in the air or on the ground, can help select smaller target areas for more detailed inspection or sampling.

Mobile searches present a number of technical challenges as well. For instance, background levels will vary as the relative altitude of a search plane changes or as ground search teams traverse different types of terrain. Additionally, with possible restrictions placed on overflights and limited access by road, gamma sources that are characteristic of nuclear explosions will likely be encountered at large standoff distances. The resulting low net count rates will be difficult to detect against the variable background. Finally, the environment may be contaminated with legacy radionuclides that can produce a large number of false positive alarms.

In this presentation, we discuss a detection algorithm that provides a two-way characterization of gamma-ray spectra as either anomalous or not, and also operates well in the presence of high background variability. The technique relies on a predefined set of non-anomalous sources, which includes natural background as well as manmade isotopes such as ^{137}Cs that are not relevant to the treaty. First, the medium-resolution energy spectra are binned into a few broad regions of interest—only such regions as are sufficient to determine whether the spectra are inconsistent with the set of non-anomalous sources. The algorithm then transforms the count rates in each region into a vector of Spectral Comparison Ratios (SCRs). Each SCR represents the difference in observed count rates between two regions, scaled by the mean background count rates. An orthogonal subspace projection is applied to the vector of SCRs to subtract off any linear combination of the non-anomalous sources. Finally, the algorithm computes a standardized distance metric on the vector of SCRs, weighted by their respective variabilities. A low value indicates that the spectrum is consistent with the set of non-anomalous sources, without disclosing irrelevant information such as the presence of legacy radionuclides.

Our technique has been applied to a variety of low count rate detection applications in prior and ongoing research. We discuss past applications of our anomaly detection algorithm and relate these to the OSI task. Algorithm functions and parameters that are important to this task will be noted, such as the means of tracking background and the integration times of the spectrometer. We also discuss a means to further reduce false positive alarms.

OSI-22/B: OSI Useable Radionuclide Detection Methods and Technologies

A.A. Ustselemov, *RFNC-VNIITF, Russia*
Contact: a.a.ustselemov@vniitf.ru ustselemov@mail.ru

Abstract: The paper discusses radionuclide detection methods and technologies used in On Site Inspections (OSI), capabilities for modeling the evolution of radionuclide anomalies and the necessity of developing equipment to train inspectors.

An underground Nuclear Explosion (NE) produces a cavity containing radioactive nuclides with widely varying atomic numbers Z, half-lives $T_{1/2}$ and yields Y. Some of them migrate to the surface. The OSI goal is to determine whether the suspected event is really a nuclear explosion and to collect all facts which can help identify the candidate violator. To achieve the goal, the inspection can compare activities of two or more radionuclies in a sample. There exists an accepted list of radionuclides whose detection is indicative of violation. The problem is that only a few of them remain highly active and identifiable by γ-peaks during the entire OSI period, which would allow minimization of the measurement error. We compare detectability of radioactive nuclides on the list and some ones beyond it during the entire inspection period and discuss appropriateness of including some of them in the list.

Another problem arises from the complexity of mechanisms governing radionuclide migration from the cavity to the surface. Three basic scenarios of radionuclide migration to the surface and the atmosphere are considered:

1) During a long time radioactive noble gases migrate from the cavity to the surface and reach it after the inspection group arrives at the inspection site; the other radioactive products remain in the cavity and do not reach the surface.
2) The most part of volatile radioactive nuclides and noble gases soon (some hours after the explosion) reach the surface and then slowly flow out from the surface near ground zero.
3) The most part of radioactive products rapidly reach the surface and spread in the environment, forming a plume.

Fission fragments move and decompose into other isotopes which can also migrate. The pattern of their spatial distribution depends on the rock structure, chemical interactions between radionuclides and between radionuclides and soil, the accumulation of fission fragments in the decay chains and other conditions of the explosion site. The experimental data published on the subject are poor and cannot be practically confirmed with full simulation. The paper gives an overview of available data on the subject.

Besides the above problems there is a problem of training the members of the inspection teams to take measurements within the site where a radiation anomaly corresponding to an underground nuclear explosion is detected. It seems impossible to produce such an anomaly, the more so to use it for training. Instead it is possible to use a simulator which would be similar in appearance to the handheld spectrometer approved by the PTS for use in OSI activities. The simulator will generate a virtual (non-existing) radiation anomaly that could be used for training.

OSI-23/B: Study on Technology of Gamma-Spectrometry Measurement While Drilling for On-Site Inspection

Huang Xiong-liang, Jia Li-quan, Lei Wei-Guo and Yin Xiao-li
Northwest Institute of Nuclear Technology, P.O.Box 69-1,710024,Xi'an P.R.China
Contact: gbgbgbcycycy@163.com

Abstract: The technology of Gamma-Spectrometry Measurement While Drilling (GMWD) for On-Site Inspection (OSI) is an important method to clarify whether a nuclear weapon test explosion or any other nuclear explosion has been carried out. In order to collect the facts that might assist to identify any possible violator as soon as possible, this technology has been studied and an instrument of gamma-spectrometry measurement has been developed base on the study. All of the important measurement parameters of the instrument have been specified by Monte Carlo Method. For the purpose of miniaturization, automatization, sensitivity, and reliability, the design of the instrument has been optimized. Several spectra-stable technologies have been used to make it more stable. Also the depth data is collected so it can offer the evidences of abnormal gamma radiation and indicate the depth of radiation source undersurface. The data acquire and analyze system has been programmed. The laboratorial testing results show that the energy resolution of the instrument with 662keV ^{137}Cs is better than 11%, and the peak shift of 662keV ^{137}Cs is less than 0.5% in 17 hours. It is demonstrated that this technology and instrument is very helpful for On-Site Inspection.

Keywords: on-site inspection (OSI); gamma-spectrometry measurement while drilling (GMWD); NaI(Tl) scintillation crystalloid

OSI-24/B: Argon-37 background measurements supporting on-site inspection

Craig E. Aalseth, Martin E. Keillor, James C. Hayes, Justin I. McIntyre, John L. Orrell
Pacific Northwest National Laboratory
Contact: Craig.Aalseth@pnl.gov

Abstract: On-Site Inspection (OSI) is a key component of the verification regime for the Comprehensive Nuclear-Test-Ban Treaty (CTBT). Measurements of relevant radionuclide isotopes created by an underground test (UGT) found in sub-surface soil gas are the most valuable indicator of a recent local nuclear explosion. Argon-37 is a desirable isotope for OSI in many ways: its near-optimum half-life of 35 days provides high specific activity and enough time for successful inspection to be done before decay limits sensitivity. Its production mechanism is via neutrons incident on ubiquitous soil calcium, $^{40}Ca(n,\square)^{37}Ar$, during an UGT. As a noble gas, ^{37}Ar also transports well from an underground test to surface sampling locations. Since it is not produced in quantity in reactor or medical isotope processes, its background in surface air is expected to be low and thus not potentially confuse sub-surface gas collection results. To provide optimum sensitivity from a ^{37}Ar OSI inspection, knowledge of worldwide backgrounds and their variation would be a key to confidence in the detection of an explosion, and conversely, key to confidence that no explosion had taken place. The ^{37}Ar background is expected primarily from ($\square$,n) neutrons and spontaneous fission neutrons produced in the soil and from cosmic-ray spallation neutrons. A prototypical laboratory measurement for background characterization is outlined, along with a discussion of fixed-location laboratory analysis sensitivity and its impact on the robustness of a ^{37}Ar OSI inspection measurement.

OSI-25/B: The barometric driven xenon-tracer transport of the Non-Proliferation Experiment simulated by finite volume – finite element higher-order accurate modeling

Robert Annewandter (1), Karen Schmid (1), Sebastian Geiger (1), Martin B. Kalinowski (2)
(1) Institute for Petroleum Engineering, Heriot-Watt University, Edinburgh, United Kingdom; (2) Carl Friedrich von Weizsaecker-Centre for Science and Peace Research, University of Hamburg, Germany
Contact: robert.annewandter@pet.hw.ac.uk

Abstract: In the Nineties an Experiment was conducted on verifying compliance with respect to the Comprehensive Nuclear Test Ban Treaty (CTBT). This Non-Proliferation Experiment was located at the Nevada Test Site and demonstrated the detectability of an underground nuclear explosion with a clandestine setup. A chemical explosive of approximately 1 kt TNT- equivalent was detonated in a cavity located 390 m deep in the Rainier Mesa (Nevada Test Site) in which two tracer gases were emplaced. No surface fracturing was visible. In this experiment SF6 was first detected in soil gas samples taken near fault zones after 50 days and 3He after 325 days, which indicates advective dominant transport. After the detonation, the nuclear explosion injects radionuclides into the surrounding host rock, creating an initial radionuclid distribution. In the case of fractured permeable media, cyclical changes in atmospheric pressure can draw gaseous species upwards to the surface. This is known as barometric pumping. Due to their diffusive nature, tracers enter the matrix which buffers the transport. The combined process of advection along the fracture and diffusion into the matrix establishes a ratcheting pump effect. The resulting transport is orders of magnitude more effective than transport by molecular diffusion. The experiment was modeled by Carrigan and Nitao using a simulation software for flow and transport in porous media called NUFT (Non-Isothermal Unsaturated Flow and Transport) developed at the Lawrence Livermore National Laboratory by Nitao. The numerical test-site model was realized through a uniform porous medium traversed by a narrow, millimeter-width fracture. Calculations were done for the noble-SF6 and 3He as well as for the noble gases gases xenon-133 and argon-37. We revisit the experiment by simulating the experimental data using a higher-order accurate finite volume - finite element method, which is implemented into the Complex System Modelling Platform CSMP++. This has two advantages. First, we reduce the numerical error by employing higher-order accurate transport schemes, which allows us to predict the arrival times and concentrations with greater accuracy. Secondly, the combination of finite volumes and finite elements allows for better geometric flexibility. We can hence study tracer transport in more complex but geologically more realistic fracture models and evaluate how the predictions change compared to the highly idealized case of a single fracture transversing a uniform porous media. Calculations on arrival times of the four CTBT-relevant radioxenon isotopes and their surface concentration levels depending on weather patterns are critical in narrowing down the on-site inspection activities like soil gas sampling according to the CTBT provisions. A better understanding of the distribution of surface concentration levels can support optimized soil gas sampling schemes This study presents results on time of arrival of the four CTBT-relevant xenon isotopes as well as their surface concentration levels and isotopic activity ratios. The slight mass difference causes a separation of arrival times and changes the isotopic ratios. This has consequences for the multiple isotope concentration ratios that are used for source discrimination.

OSI-26/B: Detection of Trace Noble Gas Emissions From Underground Nuclear Explosions

Charles R. Carrigan, Jerry J. Sweeney and John J. Zucca, *Lawrence Livermore National Laboratory*
Contact: carrigan1@LLNL.gov

Abstract: An underground nuclear explosion (UNE) produces trace amounts of the short-lived radioisotopic gases ^{133}Xe and ^{37}Ar at the subsurface detonation point. Several different gas transport mechanisms are then potentially available to move these gases to the surface where their detection can serve as a highly distinctive indicator or signal of the occurrence of a very recent UNE. How large a signal might be produced by a particular UNE depends most importantly on the ability of the subsurface regime to contain the event. In the case of a poorly contained UNE, the excess cavity pressure will transport gases to the surface resulting in the venting of a significant fraction of the gaseous inventory produced during the detonation. At the surface, the noble gas and particulate signals become available to be transported by the wind to IMS radionuclide sampling stations where detection becomes possible. Evidence for venting at the surface, in this poor-containment scenario, may be dramatic and readily detectable during an on-site inspection (OSI).

Better containment may result in much weaker pressure-driven venting or seepage of gases driven to the surface by over-pressurization of the detonation cavity. As a result, the radionuclide signal that promptly reaches the surface may be very much smaller but still may be detectable, especially during an OSI that includes particulate and subsurface gas sampling. In addition, gamma (γ) spectrometry of surface fissures and cracks may be useful in both this and the poorly contained case to detect radioisotopes and determine the isotopic composition of radioactive particulates that are present at the site.

The most challenging scenario for the IMS and OSI regimes involves a UNE that is very well contained. In this case, no cavity-pressure-driven venting or seepage of gases occurs. That is, all the gases are initially contained within the porosity of the rock and soil as well as within a subsurface fracture network that results from the explosion and naturally occurring faults and fractures. However, even this most difficult of cases can produce a detectable flux of radionuclide gases at the surface long after the excess pressure in the cavity has vanished. This was demonstrated in the Non-Proliferation Experiment (NPE), which involved a one-kiloton chemical explosion detonated 400m below the surface of Rainier Mesa at the Nevada Test Site. Tracer gases were released in the detonation cavity by the explosion and were transported along faults and fractures to the surface over a period of weeks to a year where they were detected at several sampling stations. The transport mechanism was barometric or atmospheric pumping, which is thousands of times more effective than gaseous diffusion. Using the results of the NPE to calibrate computer models, it was shown that had the tracer gases been ^{133}Xe or ^{37}Ar from a UNE, detection would have been possible by sampling of subsurface gas during an OSI. Subsequent modeling has demonstrated that subsurface geologic conditions and the weather play an important role in the predicted arrival times of gases from a UNE and knowing as much as possible about the geology, weather and containment conditions at a particular site is necessary to make informed estimates of the probability that radionuclide gases can be detected during an OSI.

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OSI-27/B: Concept of Operations for NobleGgas On-Site Inspections

Justin I. McIntyre, Craig E. Aalseth, Theodore W. Bowyer, James C. Hayes, Marty E Keillor, Harry S. Miley. *Pacific Northwest National Laboratory*
Contact: justin.mcintyre@pnl.gov

Abstract: The On Site Inspection (OSI) component of the CTBT Verification Regime has come into sharp focus as the next major research and development effort needed by the larger nuclear monitoring community. There has been significant progress over the past decade to address field noble gas analysis equipment for Ar-37. This paper aims to lay out a workable scientific plan needed to maximize samples acquired/measured and confidence of explosion detection, while minimizing staff time and amount of equipment required.

As an example, the required minimum detectable concentration for radioxenon in the International Monitoring System is 1 mBq/m3, as derived from a notional network design criteria of 90% probability of detection within two weeks of a 10% vent from a 1 kt explosion anywhere on Earth. There is no such science-engineering based requirement for radioxenon or radioargon isotopes for an OSI. However, gas leakage from a chemical kiloton has been detected using SF6 and 3He (ref), bracketing the isotopes of interest. In addition, some prototype equipment does exist (ref). However, the experimental detection of SF6 and 3He required many samples from many locations to obtain detection. This implies tens of samples per day must be acquired, though existing prototype equipment can analyze 1-2 samples per day. Further, existing approaches for drilling a shallow sampling hole and daily sample acquisition may be too staff intensive to allow tens of samples per day for the duration of an OSI.

Topics discussed in this paper are as follows: individual sample sizes needed from shallow bore-holes to achieve an Ar background plus any host duplicate requirements, total number of samples from each selected

square kilometer site to satisfy OSI measurement needs, sample counts times, collection efficiencies, and error budget requirements. Importantly, sample mixing can provide rapid radioxenon/argon screening and then narrowing down to the samples of highest interest. The paper will conclude with a best methods approach that is derived from the aforementioned topics and suggest a well reasoned concept of operations for noble gas sampling that will satisfy detection needs and may satisfy OSI operational limitations.

OSI-28/B: High-throughput mobile xenon measurement system for OSI purposes

Popov Yu. S., Popov V. S., PrelovskijV. V. , *Khlopin Radium Institute*
Contact: popov@khlopin.ru

Abstract: For OSI purposes one needs to determine the radioactive xenon concentrations in the ambient air as well as in the subsurface samples. Currently two systems are available which are capable of producing and measuring 2-3 samples per day. Their sampling units are not so easy to transport especially in rough terrain. We have developed a prototype of a highly mobile sampling and drilling system which can be carried on foot by two persons to even the most remote and hard to access points. Sampling unit can also be used on board of a small plane or a helicopter. This system is complemented by a high throughput high sensitivity processing and measurement system capable of processing up to 7-8 samples per day. This can sufficiently increase the efficiency and sensitivity of the OSI.

OSI-29/B: Analysis of Noble Gas Measurement Technique in OSI

Chongyang Zhou, Shujuan Feng, Guoqing Zhou, Mei Tian and Yuren Jin
Northwest Institute of Nuclear Technology, P. O. Box 69-1, 710024, Xi'an P. R. China
Contact: gbgbgbcycycy@163.com

Abstract: Radioactive noble gases (^{131m}Xe, ^{133}Xe, ^{133m}Xe, ^{135}Xe, ^{37}Ar and ^{85}Kr) sampling, separation and measurement is one of the most direct and effect technical way in OSI. In order provide evidence to show whether there have been conducted a clandestine nuclear test, it is necessary to sample, separate and measure the noble gas radioisotopes produced and induced by nuclear test on suspicious area.

Combining the noble gases system with the OSI scenario and the problem faced, the characteristics of noble gases sampling, separation and measurement equipment developed in the world were analyzed and their field adaptability were evaluated based on the analysis of the nuclear test phenomenon. The key techniques in developing noble gas system was introduced, the data result assessment had been initially discussed to determine whether there had been conducted a nuclear test and the trend and direction of development noble gases system had been considered as well.

Keywords: OSI; Noble gas; Sampling, separation and measurement

OSI-30/B: Dig-into-Dust: Resolving ML –2.0 Microearthquakes in OSI Passive Seismics, Landslide Creep, and Sinkhole Collapse by Nanoseismic Monitoring

M. Joswig, Institute for Geophysics, *Universität Stuttgart, Germany*
Contact: joswig@geophys.uni-stuttgart.de

Abstract: The political constraint for OSI Passive Seismics to resolve aftershocks from underground nuclear explosions down to a threshold of ML –2.0 challenges the abilities of classical local seismic networks. To overcome the limits of sufficient signal-to-noise ration (SNR) for reliable phase picking and source location the concept of Nanoseismic Monitoring (Joswig, First Break 2008) was developed acting as a seismic microscope for ten times lower SNR conditions. Nanoseismic Monitoring utilizes seismic small arrays, sonograms as noiseadaptive 2D power-spectral-density representations of detectable signal energy, graphical location constraints, interactive layer modeling, and outlyer-resistant statistics by jackknifing. Instead of black-box hypocenter solutions by classical Geiger inversion Nanoseismic Monitoring guides the analyst to support the most plausible location hypothesis for weak events recorded at the threshold of ambient seismic noise. Having successfully lowered the processing threshold down to ambient noise, any field campaign in a virgin environment starts with 'forensic' seismology, i.e., the characterization of noise bursts from traffic, industry, sonic booms, pipeline pumps, construction works, and quarry blasts. Often the source identification depends on additional observations of time-of occurrence, repetition rate, and amplitude sequence; thus one must overlook larger portions of data at first glance. Also the discovery of exceptional signals, like an OSI aftershock, cannot be performed by routine, automated detection algorithms. To guide this first step of data screening, super-sonograms have been developed that comprise the information of many small arrays, and time periods up to

several hours, at conventional computer screens. IFE08 proved the concept of Nanoseismic Monitoring for up to 30 small arrays. Other reported applications are the mapping of sinkhole collapse at Dead Sea, and the resolution of landslide creep in Austrian and French Alps into sequences of fracture processes.

OSI-31/B: Seismic field exercise at ACIFE08 in Hungary

Endre Zoltán Hegedűs, Attila Csaba Kovács, *Eötvös Loránd Geophysical Institute of Hungary*
Contact: hegedus@elgi.hu

Abstract: A Seismic Aftershock Monitoring System (SAMS) test was carried out in Táborfalva (Hungary) in order to analyse of detection thresholds, noise levels and geological constrains – with simulated seismic events. About two dozen of small underground explosions (50-100-200-400-800 g TNT) to mock week aftershocks in 8 locations were initiated aiming at detecting events below magnitude zero. Field set-up of two mini-arrays and seven three-component single stations – followed by on-site data analysis for event identification – were included in the training program.

The detailed imaging of the upper 1000 m sedimentary strata was carried out along a 600 m long profile using 30 small explosions with 300 g explosives in 3 m deep boreholes. A line of single, one-component geophones were laid out at 10 m spacing each. Autonomous (cable-free) seismic recorders were deployed at each geophone location – with continuous detection of seismic signals with high sampling rate.

The active source seismic reflection method is one of the approved CTBT Continuous Phase Technologies. Due to its quality and capabilities this method should not be rejected. No other method possesses a resolution power comparable to the seismic reflection. For objectives at depths down to 1000 m – like a rubble zone of UNE – the investment necessary for drilling justifies the use of this method.

OSI-32/B: Event Location through the analysis of seismic waves recorded by mini-arrays

Alessandra Giuntini, Alessandro Pignatelli, Rodolfo Console, Stefano Chiappini and Massimo Chiappini, *Istituto Nazionale di Geofisica e Vulcanologia, Rome, Italy*
Contact: giuntini@ingv.it

Abstract: Underground nuclear explosions are thought to generate very weak aftershocks that could be recorded and located by a seismological network deployed during an on-site inspection days or weeks after the suspected explosion. Portable mini-arrays are proposed as flexible and convenient tools for this purpose. In this work we describe and apply an algorithm for analysing mini-array data. The algorithm, implemented on a Matlab platform, estimates back azimuth and apparent velocity of waveforms from seismic records under low signal-to-noise conditions. The differences between the arrival times at pairs of array elements are determined starting with a cubic spline interpolation of the waveforms and using cross-correlation functions between these waveforms.

The main advantages of this technique are: (a) the manual picking of the waveforms is not necessary at each elements of the array; (b) the estimation of time differences has a higher resolution than the sampling rate with the use of interpolation; (c) the analysis can be extended to later phases of the seismograms, as the larger amplitude S or surface waves, more easily detectable than the P first onsets; (d) the value of the apparent velocity indicates the nature of the recorded wavelet and provides a mean for physically checking the results; and (e) the design of the Matlab routines allows fast and userfriendly interactive procedures. In case a four-element array, rather than a simple tri-partite array is used, the consistency among four independent determinations provides a reliability check. As a sort of validation test on a real situation, we have applied this algorithm to the data collected by the temporary local seismological network operated during the IFE08 (Integrated Field Exercise) conducted in Kazakhstan in 2008 by the CTBTO.

OSI-33/B: Passive Seismic Monitoring of Aftershocks during an On-Site Inspection

Albert T. Smith *(USA),* ***Alexander Spivak*** *(RAS, Russia),* ***Zhenfu Li*** *(Northwest Institute, China)* ***Svetlana Kishkina*** *(RAS, Russia)*
Contact: DrAlSmith@aol.com

Abstract: An On-Site Inspection (OSI) must refine the reported location of an ambiguous event to a sufficiently small area to allow agreed technologies to resolve the nature of the event. Passive seismic monitoring is one method for refining this location: The stress relaxation within the rock mass surrounding an underground detonation and collapse process associated with the cavity created by an explosion are sources of small aftershocks. This presentation reviews and discusses observations of aftershocks following detonations of both nuclear and chemical explosions prior to 1992. If aftershocks are diagnostic of the explosion collapse process,

then their detection, identification and location during an inspection could not only narrow the inspection region, but also provide a diagnostic capability between an explosion and natural earthquake as the cause.

To understand aftershocks triggered by underground explosions, the combined observations from fifteen underground nuclear explosions from Semipalatinsk, Novaya Zemlya, and Nevada test sites, two peaceful underground nuclear explosions, and three high-yield chemical explosions are summarized and used to deduce the properties of these aftershocks. These results are then compared to aftershocks of natural earthquakes.

Two processes are associated with aftershocks of underground explosions: First, the explosion triggers relaxation in the surrounding rock mass and produces aftershocks along planes of weakness. These aftershocks are both along pre-existing fractures and along fractures created by the explosion's shock wave passing through the rock mass. These aftershocks have predominately impulse and higher frequency waveforms, similar to earthquake aftershocks. The second source of aftershocks is associated with the collapse of the cavity, a feature formed by the intense energy released by the detonation. The waveforms of these aftershocks are often low frequency and emergent. The plane along which movement occurs varies between aftershocks. In each case aftershocks tend to cluster around the detonation point.

The number of aftershocks and how they decay with time depend upon the characteristics of the rock mass at the point of detonation. For example, there is a marked difference between the alluvium of the Nevada Test Site versus the rock mass of Semipalatinsk. The rate of aftershocks can also distinguish an explosion from a natural earthquake as the cause of the aftershocks.

In conclusion, locating small aftershocks during an OSI can both refine the inspection area for application of other technologies, and help distinguish an underground explosion from a natural earthquake as the source of these aftershocks.

OSI-34/B: Integrated Geophysical Investigations under the On-Site Inspection Regime: Detection of Cavities in a Karst Area

Matthew B.J. Purss[1a], Ruth Murdie[2], Ray Tracey[1b], Ashley Grant[3], Gong Bing[4], Andrew Katumwehe[5], Sam Toon[6], Christoffel J.S. Fourie[7]

[1] Geoscience Australia, GPO Box 378, Canberra, ACT, 2601, Australia; [2] Gold Fields Australia, St Ives Gold Mine, P.O. Box 359, Kambalda, WA, 6442, Australia; [3] ARKeX Limited, Newton House, Cambridge Business Park, Cambridge, CB4 0WZ, United Kingdom; [4] Northwest Institute of Nuclear Technology, P.O. Box 69 – 11, Xian - Shaanxi Province, China; [5] Geological Survey and Mines Department, P.O. Box 9, Entebbe – Kampala, Uganda; [6] School of Physical and Geographical Sciences, William Smith Building, Keele University, Keele, Staffordshire, United Kingdom; Laboratory for Mining Innovation (LMI), Council for Scientific and Industrial Research (CSIR), P.O. Box 395, Pretoria, South Africa

Contact: Matthew.Purss@ga.gov.au

Abstract: During the period 2 to 7 October 2005, the Provisional Technical Secretariat (PTS) of the Preparatory Commission for the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO) conducted a field testing exercise hosted by Geoscience Australia in a karst area in the Bungonia State Recreation Area, New South Wales, Australia. The purpose of the exercise was to assess and compare a number of geophysical techniques and equipment permissible under the Treaty for use in the continuation phase of an on-site inspection (OSI). These techniques included gravitational field mapping and a range of shallow to deep electrical conductivity methods. The knowledge of the size and location of the limestone cavities at the survey site allowed for a controlled assessment of the ability of these techniques to exploit variations in the density and conductive properties of the local geology to detect the cavities.

This exercise provided an opportunity to demonstrate the value of an integrated approach using a number of continuation phase techniques in the search for underground cavities of interest to OSI. The outcomes of this exercise were of great benefit to the preparation of the PTS for the Integrated Field Exercise (IFE08) held in the former Soviet nuclear test site at Semipalatinsk, Kazakhstan during September 2008.

OSI-35/B: Software implementations for quality control on seismic surveys: application to short scale networks.

Josep Vila, *Institut d'Estudis Catalans. Carme, 47, 08001 Barcelona, Spain.*
Contact: jvila@iec.cat

Abstract: In this work an exhaustive analysis of the seismic dataset gathered in the Integrated Field Exercise IFE08 is presented, in order to evaluate its quality and consistency. By means of an application of a set of quality-control procedures, potential low quality data, changes in the behavior of seismic signals or unexpected malfunctioning are detected. The method is based on the analysis of the background seismic noise to detect patterns over which unforeseen contributions or abnormal operation may be observed, thus detecting any anomaly and reducing potentially nonsense data. The analysis consists on quality-control software implementations that may be run off line simultaneously with any acquisition task, thus offering also the possibility to become a real-time monitor of the system status. The method operates the continuous waveform data and the procedure applies to segments of a definite fixed length. The data analysis is done both in time and frequency domain, computing outputs related to averaged amplitudes, averaged squared amplitudes and evolution of predominant frequencies of ground motion waveforms for any desired frequency band. Through all this analysis, new time series are generated, that allow the quantification of the characteristics of the seismic signals and its evolution. As a complement, an evaluation of minimum level of noise for all spectral components is carried out by means of a continuous comparison of the output spectra of every new segment of data with respect to the stored results, keeping the minimum values of each component. The methodology is based on the stability of the very base levels of noise for a given site. This characteristic allows the use of different parts of the spectrum to get a good indication of changes of the seismograph system (quality control), variations of the status of a given site (information of the local structure) and the absolute determination of the response of a station (calibration). This let to obtain a pseudo-spectrum that can be considered as the minimum noise in absence of any type of transitory signal, for a given site. Once a reference level is reached, systematic signals above or below the noise pattern levels indicate bad quality of the data. This avoids late identification of malfunctioning and a clear estimation of the operation of a full set of data is obtained. Stable transitory signals, systematic biases or resonances induced by diverse type phenomena are some of the indicators, that reflects permanent site effects and identify potential low quality data or malfunctioning. This prevents the loss of effective data and increases the efficiency of any technique of seismic monitoring.

The software-based system can be rapidly implemented as a stand alone complement, may run in parallel to any other applications and the output data is provided instantaneously. A first estimation of the main background characteristics may be obtained after the analysis of few days of data. Malfunctioning or permanent resonances are detected almost at once. After an initial adjust to make data from OSI (SAMS) data structure ready to be entered and the most appropriate frequency bands are chosen, the off line analysis of a time span of data requires few minutes per station and day of stored data. The methodology has provided very good results and it is nowadays implemented in several networks in Europe as a quality control monitoring system.

OSI-36/B: Planning an On-site inspection from a potential fields anomaly perspective

Pignatelli A., Nicolosi I., Carluccio R., D'Ajello Caracciolo F., Chiappini M.
Istituto Nazionale di Geofisica e Vulcanologia, Vigna Murata 605, 00143, Roma, Italy
Contact: alessandro.pignatelli@ingv.it

Abstract: Understanding the subsurface is critical to characterize potential underground manmade structures associated to an underground nuclear test. In most cases, developing a high-resolution 3D imaging of the investigated area can delineate the lateral and vertical extent of buried targets. During an On site inspection (OSI), several geophysical activities can be conducted. They include potential fields anomaly data collection as well as electrical and electromagnetic field mappings.

To plan and conduct these surveys it is crucial to know the phenomenology on an underground test, the potential sources of geophysical anomalies and their signatures detectable in the field.
Each OSI scenario is unique, and the anomaly pattern produced by the presence of buried targets is depending upon many variables, e.g. local geology, nature and location of the sources, distribution of contrast in physical properties between sources and surrounding rocks. The ability to compute the anomaly produced by any kind of the sources expected to be found in the inspection area allows the Inspection Team to develop adequate measurement survey plans. Modelling near surface anomaly fields is also relevant to OSI purposes. This implies a strong optimization in terms of time and resources, and can improve the subsequent analytical interpretation of the data collected in the field. In addition, this approach is fundamental for training activities.

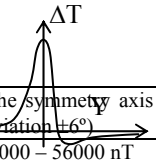
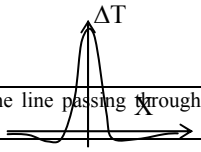
The theory behind the modelling, the software application as well as practical examples relevant to an OSI are shown

OSI-37/B: Features of Geomagnetic Anomalies of Well-type Nuclear Testing

Dmitry A. Sagaradze, *Federal State Unitary Enterprise Russian Federal Nuclear Center – Academician Zababakhin All-Russia Research Institute of Technical Physics (FSUE RFNC-VNIITF), Snezhinsk, Russia*
Contact: sagaradze@mail.ru

Abstract: These studies have experimentally demonstrated that there is an anomaly of the Earth geomagnetic field in the ground zero zone both prior to and after the underground nuclear explosion (UNE). The problem of search of the possible UNE conduct location is solved with the help of geomagnetic measurements technique for magnetic field survey under CTBT verification procedures. The found generalized features of anomaly of the modulus of magnetic induction full vector □T (see Table) may be used for the interpretation purposes at detection of geomagnetic anomalies. These features refer to the anomalies with the ferromagnetic casing columns as the source.

Table – Generalized features of ΔT anomaly generated by UNE in a ground zero zone

Name of ΔT anomaly feature		Description and values.		
1	Shape of anomaly in the ground zero zone	The anomaly is bipolar with areas of positive and negative values. The distance between poles (minimum and maximum of anomaly) is from 10 up to 25 m.	Longitudinal profile. 	Latitudinal profile. 
2	Symmetry, orientation	Shape of anomaly is closed to axis-symmetric. The symmetry axis is the line passing through south - north oriented extremes (with maximum deviation ±6º)		
3	Extremes	Maximum corresponds to the wellhead center, = 15000 – 56000 nT Minimum = –2530– 87 nT		
4	Horizontal gradient	Within the wellhead between the ΔT anomaly poles = 2500 - 44000 nT/m		
5	The domain of positive values of anomaly at the level of ΔT $\geq$0 nT above the wellhead	~ from 20 x 30 m to 350 x 350 m (longitudinal and latitudinal direction accordingly)		
6	The domain of positive values of anomaly at the level of ΔT $\leq$50 nT near the wellhead	$\geq$ 55 x 50 m (longitudinal and latitudinal direction accordingly)		
7	Maximum of anomaly's lifetime	tens of years		

These features will not be the same for the whole world, for the different latitudes. Besides, the features similar to those in the table are the evidences only of artifacts (casing column of the well) typical for UNE but not exactly for UNE itself. That is why there is a problem to find and study other features, which will enhance the probability of UNE detection. The presentation includes the following features indirectly pointing at UNE:

1. change of the direction of ground zero anomaly ΔT axis after UNE effect;
2. change of the amplitude of ΔT anomaly after UNE in time (anomaly dynamic).

Feature 1. The anomaly axis ΔT (line passing through extremes) did not coincide with magnetic meridian of the Earth (deviation up to 17^0) before UNE. The anomaly axis coincided with the magnetic meridian of the Earth (with deviation no more than $\pm 2^0$).

Feature 2. The dynamics of anomaly was recorded. For example:

$\Delta T(dif) = \Delta T(10d) - \Delta T(30d) \neq 0$ where:

ΔT(10d) is the anomaly of modulus of the full vector of the Earth magnetic induction in 10 days after UNE;

ΔT(30d) is the anomaly of modulus of the full vector of the Earth magnetic induction in 30 days after UNE.

The anomaly amplitude changed from ≈1000 nT in the wellhead zone up to tens of nT at a distance of 100 m from the wellhead zone. The coincidence of ΔT anomaly axis with magnetic meridian of the Earth (feature 1) and also dynamics of ΔT anomaly (feature 2) indirectly points to UNE. These features and characteristics from the table are found features (signatures) of the geomagnetic anomaly of wellhead UNE. Whereas these data are obtained on limited experimental data, so additional researches should be performed for detection and studying of the new and mentioned above features with less uncertainties.

OSI-38/B: The Limitations of the Gravity Technique when Investigating a possible Ground Zero under the On-Site Inspection Regime: Modelling of possible Testing Cavity configurations

Christoffel J. S. Fourie[1], Ruth Murdie[2], Luis Gaya-Pique[3]
[1] Laboratory for Mining Innovation, Council for Scientific and Industrial Research, P.O. Box 395, Pretoria, South Africa; [2] Gold Fields Australia, St Ives Gold Mine, P.O. Box 359, Kambalda, WA, 6442, Australia; [3] On-Site Inspection Division, CTBTO PrepCom, Vienna International Centre, P.O. Box 1200, A1400, Vienna, Austria.
Contact : sfourie@csir.co.za

Abstract: The micro gravity technique would form an integral part of the techniques available to an Onsite Inspection Team during an Onsite Inspection (OSI). The success of the gravity technique during an OSI would depend on:

- The configuration of cavity used by the country that performed the nuclear test.
- The geology environment in which the test was performed (Host rock regime).
- The experience of the OSI team with the micro gravity technique.

In order to test these possibilities, two possible geological environments where nuclear tests can be performed in, were investigated, namely Sandstone and Granite.

Two different cavity configurations were also investigated, the borehole scenario and a mining tunnel scenario. Dimensions of these structures were realistic and obtained from real nuclear tests. Gravity responses were modelled for each of these scenarios, to show the ease or difficulty to detect them.

It was assumed that there will be cracking around the cavities after the detonation, improving the density contrast, thus making the cavities a better target.

Modelling results are shown for each of these situations and it also shows the degree of success an experienced team and a very experienced team can expect.

OSI-39/B: Short-range and Long-range Signals of Local Geomagnetic Field Variations

Karimov F.H., *Institute of Earthquake Engineering and Seismology, Academy of Sciences of the Republic of Tajikistan, 734024, Tajikistan, Ajni str., 121, phone: (992-37) 225-57-45, fax: (992-37) 225 44 78,*
Contact: fhkarim@mail.tj

Abstract: Complexion of different type of geophysical observations provides firmer capacity for detection sudden intensive mechanical stresses shock in the earth crust caused by underground technical testaments similar to tectonics earthquake strikes. The success for such identification depends on how comprehensively the properties of concrete type of observations have been taken into account. The present work is devoted to description of high accurate magnetic prospecting method in application to detection of local geomagnetic field generated by sudden mechanical impulse in the earth crust. The method is similar to the well known tectonomagnetic one.

The informative parameters used include the value, space and time features of the magnetic signals, registering at any distance from the epicenter zone. There are two principal ways of the signal spreading. The first is straight pass of geomagnetic field from focal zone into atmosphere and ionosphere up to the registration site. The second one is spreading through the earth crust up to the registration site. The signal via the first way can be in principle be detected evidently at the real time scale. For the second way the mode of signal revealing is different in different zones disposed relatively to the epicenter. Because of limited deformation waves' speed, equal to 10 kilometers per day by order of magnitude, the time shifting of signal with distance turns over. The experience of tectonomagnetic researches in Tajikistan shows, that there are four kinds of such specific zones. The larger is magnitude of the event the more is signal value, squares of the zones and its time duration. The method has been proved effective for as large event as magnitude 5 and larger, but it's assumed that the lowest detection limit in principle can be further reduced by using more sensitive sets registering local geomagnetic filed providing 0,001-0,01 nT accuracy. The nearest to the epicenter is the focal one. The shapes of signals over there look like oscillations or are bay like up to 10 nT in value, originated at the main shock moment and lasting together with mechanical stresses propagation and relaxation. In the near zone the signal is bay like up to several nT having about the same time duration as the signal registered in the focus zone. The next, middle, zone the bay like signal reaches up later with a time shift and has lower value than in first zones have been mentioned, amounting as much as 1 nT by order of magnitude. In the far zone the signal is else lower and because of tangible distortion of crust deformation waves' propagation through inhomogeneous geological medium there are no evident regularities in correlation of values, space and time signal's parameters with epicenter distance.

In the focal and near zones signal reveals short-range propagation, in the middle and far zones - long-range one. According to the tectonomagnetic researches in Tajikistan's seismic areas the main impact to local geomagnetic field variations in brings the electrokinetic phenomena, stipulated by underground fluids filtration under mechanical stresses contrast between focal zone and outer vicinities. The sufficient impact of electrokinetic phenomena in local geomagnetic field variations has been proved by observations near the large

water reservoirs, rivers and hydro geochemical bore holes in Tajikistan, where the field anomalies have been found correlating with underground waters filtration and physical and chemical properties variations as well.

The alternative geomagnetic techniques can also be applied, for instance using electromagnetic induction effects in the earth crust stipulated by daily solar geomagnetic variations or spectral analyses.

For the tasks of identification of the local geomagnetic field variations the high sensitive magnetic gradientometers and variometers are applicable as well besides magnetometers.

OSI-40/B: Regional geopotential field effects of underground nuclear explosions

Ralph R.R.B. von Frese[1], Jeong Woo Kim[2], Hyung Rae Kim[3], Timothy E. Leftwich[1], and Elena Rangelova[2]
[1]School of Earth Sciences, The Ohio State University, Columbus, OH 43210, USA; [2]Dept. of Geomatics Engineering, University of Calgary, Calgary, Alberta T2N 1N4, CANADA; [3]Dept. of Geoenvironmental Science, Kongju National University, 182 Shinkwan-dong, Gongju, ChungNam-do, 314-701, Republic of Korea
Contact: vonfrese@osu.edu

Abstract: Telemetry from the Russian INTERCOSMOS 24 satellite recorded ELF and VLF electromagnetic disturbances in the outer ionosphere from an underground nuclear explosion that was detonated at Novaya Zemlya Island on 24 October 1994. The IC24 satellite observations were obtained at about 900 km altitude within a few degrees of ground zero. The disturbances were attributed to magnetohydrodynamic excitation of the ionosphere's E layer by the acoustic wave. Electrons accelerated along magnetic force lines amplify longitudinal currents and generate magnetic disturbances that may be measured by geomagnetic observatory and satellite magnetometers. The underground nuclear test in the vicinity of P'unggye, North Korea on 9 October 2006 provides an important opportunity for studying the utility of ionospheric disturbances for characterizing ground zero. In particular, we investigate this effect in the magnetic records from the nearby Daejon geomagnetic observatory of the Korea Institute of Geosciences and Mineral Resources (KIGAM) and the CHAMP and Ørsted satellite orbits that crossed near ground zero at altitudes of about 400 km and 650 km, respectively. GPS signal delays at receivers near ground zero were also checked for correlative ionospheric total electron count (TEC) variations. In addition, superconducting microgravity records were investigated for pore pressure and related ground water level effects and other mass changes of the ground related to the North Korean explosion.

OSI-41/B: Visual observation and initial overflight at the IFE

Bernd Ludwig et al
Contact: Malcolm.coxhead@dfat.gov.au

Abstract: Gaining a thorough overview of the inspection area is an important early step in CTBT on-site inspection. Visual reconnaissance of the inspection area, including observations from the air, could directly detect anomalies indicative of a nuclear explosion – but in any case is necessary for planning and directing the inspection as a whole. The treaty provides for an *initial* overflight of the inspection area, and inspectors must make the most of this opportunity to familiarise themselves with the area.

RADIONUCLIDE MONITORING

RN-01/E: Overview on sources of atmospheric radioxenon and their emission strengths

Martin Kalinowski, *Carl Friedrich von Weizsäcker Center for Science and Peace Research University of Hamburg Room 02/024, Beim Schlump 83, 20144 Hamburg, Germany*
Contact: martin.kalinowski@uni-hamburg.de

Abstract: Besides of potential radioxenon signatures released from a nuclear explosion there are many legitimate sources of radioxenon due to civilian nuclear activties. This poster presents and overview over civilian sources and compares their source threngths with possible activities released from underground nuclear explosions.

RN-02/E: Measurements of the atmospheric radioxenon background at four locations in Asia and Africa

A. Ringbom[1)], P.R.J. Saey[2)], T. Bowyer[3)], P. Andersson[1)], M. Aldener[4)], D. Al Ajmi[5)], M. S. Al-Rashidi[5)], A. Becker[2)], E.-G. Brunke[6)], M.W. Cooper[3)], L.-E. De Geer[1)] ,K. Elmgren[1)], A. Faanhof [7)], J.C. Hayes[3)], B. Hosticka[3)], C. Labuschagne[8)] , L.S. Lidey[3)], H. van der Linde[7)], K. Lindh[1)], N. Mumba[7)], R.F. Payne[3)], J. Peterson[1)], M. Shalash[5)], C. Söderström[1)], R.C. Thompson[3)], U. Tippawan[9)], N. Wilson[2)], and M. Zähringer[2)]
[1)] Swedish Defence Research Agency (FOI), SE-164 90, Stockholm, Sweden; [2)] Preparatory Commission for the Comprehensive Nuclear-Test-Ban Treaty Organisation (CTBTO), Provisional Technical Secretariat, PO Box 1200, 1400 Vienna, Austria; 3) Pacific Northwest National Laboratory, P.O. Box 999, Richland, WA 99352, USA; 4) Gammadata Instrument AB, P.O. Box 15120, 750 15 Uppsala, Sweden; 5) Kuwait Institute for Scientific Research, P.O. Box 24885 Safat, 13109 Kuwait; 6) South African Weather Service, Cape Point GAW Station, Jan Cilliers Street, P.O. Box 320 7599 Stellenbosch, South Africa; 7) North-West University, Mafikeng Campus, Private Bag X2046, 2735 Mmabatho, South Africa; 8) South African Weather Service, 442 Rigel Avenue South, Erasmusrand, Pretoria, South Africa; 9) Fast Neutron Research Facility, Department of Physics, Chiang Mai University, 239 Huay Kaew Road - Muang District, Chiang Mai 50200, Thailand
Contact: anders.ringbom@foi.se

Abstract: A detailed knowledge of the global radioxenon background is essential in investigations of the performance of the radioxenon part of the International Monitoring System (IMS), as well as in the development of techniques to discriminate radioxenon signatures from a nuclear explosion from other sources. Through the establishment of the radioxenon part of the IMS the knowledge of the background in Europe, North-America, and parts of Asia, today are reasonably well known. In other parts of the world, information is still missing.

This paper describes measurements performed in areas not earlier studied with respect to atmospheric radioxenon. Using two different SAUNA II radioxenon systems, measurements were performed in Kuwait City, Kuwait; Mafikeng and Cape Point, South Africa; and Chang Mai, Thailand. Altogether, about 350 12-hour atmospheric samples were collected and analyzed. The results are a good illustration of the variability of the ambient radioxenon concentrations around the world, with Cape Town as a "zero" location, Kuwait having low ^{133}Xe background originating mainly from European nuclear facilities, Mafikeng dominated by a nearby isotopic production facility resulting in detection of several xenon isotopes, and Chang Mai having several pure ^{131m}Xe detections.

RN-03/E: Environmental characterization of a major radioxenon source in Europe

Ringbom[1)], P.R.J. Saey[2)], P. Andersson[1)], S. Ban[1)], A. Becker[2)], K. Elmgren[1)], J. Camps[3)], L.-E. De Geer[1)], K. Lindh[1)], N. Paquet[4)], J. Peterson[1)], C. Söderström[1)], M. Sonck[5)], T. Taffary[6)], K. van der Meer[3)], B. Verboomen[4)] and M. Zaehringer[2)]

[1)] Swedish Defence Research Agency (FOI), SE-164 90, Stockholm, Sweden; [2)] Preparatory Commission for the Comprehensive Nuclear-Test-Ban Treaty Organisation (CTBTO), Provisional Technical Secretariat, PO Box 1200, 1400 Vienna, Austria; [3)] Belgian Nuclear Research Centre (SCK-CEN), Institute for Environment, Health and Safety, Boeretang 200, 2400 Mol, Belgium; [4)] National Institute for Radioelements (IRE), Internal Service for Prevention and Protection, Avenue de l'Espérance 1, 6220 Fleurus, Belgium; [5)] Belgian Federal Agency for Nuclear Control (FANC-AFCN), Department of Control and Supervision of the Territory, Ravensteinstraat 36, 1000 Brussel, Belgium; [6)] Commissariat à l'Energie Atomique (CEA), BP 12, 91680 Bruyères-le-Châtel, France

Contact: anders.ringbom@foi.se

Abstract: It has recently been realized that radiopharmaceutical isotope production facilities are major contributors to the global radioxenon background. The daily International Monitoring System (IMS) noble gas measurements are influenced from such anthropogenic sources that could hide relevant radioxenon signals.

In order to gain further understanding in the noble gas contribution from such facilities, radioxenon measurements have been conducted in and around the IRE radioisotope production facility in Fleurus, Belgium. In total 38 air samples were collected in the stack and at various distances (1-100 km) around the facility using a mobile SAUNA sampling system. Atmospheric ^{133}Xe concentrations in the range 0.7 – $4x10^5$ mBq/m^3 was detected. The stack samples had concentrations in the range $2x10^9$ – $4x10^{10}$ mBq/m^3. This is compatible with the reported total release. In addition to ^{133}Xe, all other CTBT relevant xenon isotopes were detected in several samples. The obtained isotopic ratios suggest different production lines in the plant. If a simple model is fitted to the measured concentrations versus distance from IRE, the resulting source term agrees reasonably well with the concentration of the measured stack samples. The measurements are also compared to long distance measurements made in Germany and France.

When a radioxenon signature is at hand in a suspicious situation it will be of prime importance for member states to understand as much as possible how the measured radionuclide mix can be interpreted in relation to different realistic emission scenarios. There are many possibilities as the test can have been performed in a vertical shaft at varying depths, in tunnels drilled into a mountain ridge of varying overburden or even performed close to the water surface at sea or a lake during a heavy rain storm. The mechanisms for gas emissions can vary greatly with different bedrocks and strata at different sites and the engineering of the shaft or tunnel as well as the operational mode will also have a decisive impact. The four xenon nuclides will act exactly the same way in all scenarios but as the decay dynamics of the three chains vary and the xenon precursors, most notably the iodines, are not inert gases and subject to filtration and even condensation the total xenon mix strongly depends on local circumstances.

In the present paper the different scenarios are parametricized by what can be described as an iodine disconnection time, defined as the time after the explosion when the xenon isotopes separate from their precursors and the in-growth via iodine is effectively stopped. This is of course a simplification as the disconnection can happen gradually and can also be different in different routes underground that finally combine (possibly at different times) to a xenon cloud that leaves the site and is the basis for detections off-site by e.g. the CTBT network. It does, however, provide a parameter space for characterizing samples and it will serve the object of defining some standard emission scenarios. Seen in a ^{135}Xe/^{133}Xe versus ^{133m}Xe/^{131m}Xe plot these scenarios are represented by different trajectories within the explosion envelope to the right of a distinct reactor/explosion separation line.

The paper presents updated chain decay data, it describes a decay-dynamics software and it shows a number of figures (produced by this software and data) that can be used to conveniently characterize radioxenon signatures from what is believed to be nuclear explosions. The figures use data from the 2006 North Korean test as an example.

RN-04/E: Evaluation of environmental radioxenon isotopical signals from a singular large source emitter

Saey P.R.J.[1], T. Bowyer[2], M. Aldener[3], A. Becker[4], M.W. Cooper[2], K. Elmgren[5], A. Faanhof[6], J.C. Hayes[2], B. Hosticka[2], L.S. Lidey[2], N. Mumba[7], R.F. Payne[2], A. Ringbom[5], R.C. Thompson[2], H. van der Linde[7], G. Wortmann[8], and M. Zähringer[4]

1:Vienna University of Technology, Atomic Institute of the Austrian Universities, Stadionallee 2, 1020 Vienna, Austria; 2:Pacific Northwest National Laboratory, P.O.Box 999, Richland, WA 99352, USA; 3:Gammadata Instrument AB, P.O. Box 15120, 750 15 Uppsala, Sweden ;4:Preparatory Commission for the Comprehensive Nuclear-Test-Ban Treaty Organisation (CTBTO), Provisional Technical Secretariat, PO Box 1200, 1400 Vienna, Austria ; 5:Swedish Defence Research Agency (FOI), Division for Defence and Security, Systems and Technology, 172 90 Stockholm, Sweden; 6:South African Nuclear Energy Corporation (NECSA), Pelindaba Nuclear Institute, Nuclear Technology, P.O. Box 582, 0001 Pretoria, South Africa 7:North-West University, Mafikeng Campus, Private Bag X2046, 2735 Mmabatho, South Africa; 8:NTP Radioisotopes Ltd., P.O.Box 582, 0001 Pretoria, South Africa

Contact: paul.saey@ati.ac.at

Abstract: In the framework of the verification of the Comprehensive Nuclear-Test-Ban Treaty (CTBT) the atmospheric background of environmental radioxenon is been studied near areas that could be affected by man-made sources. It was recently shown that radiopharmaceutical facilities (RPF) make a major contribution to the general background of ^{133}Xe and other xenon isotopes both in the northern and southern hemisphere. The daily IMS noble gas measurements around the globe are influenced from such anthropogenic sources that could mask radioxenon signals from a nuclear explosion.

To distinguish a nuclear explosion signal from releases from civil nuclear facilities, not only the activity concentration but also the ratio of different radioxenon isotopes (^{131m}Xe, ^{133m}Xe, ^{133}Xe and ^{135}Xe) plays a crucial role, since the ratios can be used to discriminate source types.

Theoretical release and ratio studies were recently published, but no measurements close to radiopharmaceutical facilities have ever been performed.

The world's fourth largest radiopharmaceutical facility, NTP Radioisotopes Ltd, is located in Pelindaba, South Africa. Other than a small nuclear power plant, located 1300 km southwest, near Cape Town and a small research reactor in the DR of Congo, located 2700 km northwest, this is the only facility that is known to emit any radioxenon on the African continent south of the Equator. This source is likely very dominant with respect to xenon emission. This makes it a point source, which is a unique situation, as all other worldwide large radiopharmaceutical facilities are situated in regions surrounded by many other nuclear facilities.

Between 10 November and 22 December 2008, radioxenon was measured continuously with a radioactive xenon measurement system, at the North-West University, Mafikeng, South Africa, which is situated 250 km northwest of Pelindaba. Fifty-six 12-hour samples were measured with a beta-gamma coincidence detector, of which 55 contained ^{133}Xe with values between 0.11 and 27.1 mBq/m^3. Eleven samples contained ^{135}Xe and three samples ^{133m}Xe. It is furthermore worth mentioning that none of the samples contained ^{131m}Xe.

In parallel, stack samples were taken at the NTP facility on an almost daily basis and measured with a high purity germanium gamma detector nearby at a local laboratory of NECSA. These stack measurements correspond to a daily release of around 1-10 TBq. This is consistent with typical release rates published for this type of facility and well below exposure guidelines thus not dangerous to the public. On the other hand it is expected to be high enough to increase the radioxenon background in wide regions around such facilities and has a potential impact on the monitoring capability of the highly sensitive CTBT xenon monitoring systems.

This paper will report on the activities measured at the facility stack and in Mafikeng, which allows for analysis and comparison with activity predictions based on atmospheric transport modelling. Finally the activity ratios measured shall be discussed in view of their implication for the xenon monitoring capability of the CTBT verification regime.

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RN-05/D: A decade of Radon222 measurements at Cape Point, South Africa

C. Labuschagne1, E-G. Brunke1, B. Parker(1) and H.-E. Scheel(2)
(1)South African Weather Service; (2)Forschungszentrum Karlsruhe, IMK-IFU, 82467 Garmisch-Partenkirchen, Germany
Contact: clabusch@weathersa.co.za

Abstract: Since March 1999, 222Rn measurements have been conducted at the South African Global Atmosphere Watch station, located at Cape Point, using a custom built ANSTO detector. Radon measurements are of particular interest at this site, because of the large source distribution discrepancy between land surfaces and oceans (~100 : 1 difference). This noble gas (half-life 3.8 days) is therefore an excellent tracer to characterise air mass types into marine; continental or mixtures of both (Kritz, 1990; Whittlestone et al, 1992; Schmidt et al. 1996). When used in combination with air trajectory analyses, it provides useful insight into the origin of the air parcels encountered at Cape Point. A statistical analysis of the data shows that within the high spatial resolution, marine air can be classified as essentially having a radon concentration of less than 250 mBq m-3 and continental air > 1200 mBq m-3 (Brunke et al, 2004). When 222Rn is compared with other trace gas species, in particular CO, an interesting yet small, systematic latitudinal dependence was observed when covering the 20oS to 90oS latitudes, signifying a continental influence (fingerprint) from South America to some degree.

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RN-06/D: Spurious Iodine-131 detections at remote IMS radionuclide stations

K Murray Matthews*, Christchurch, New Zealand*
Contact: murray.matthews@xtra.co.nz

Abstract: Iodine-131 is one of the more significant particulate radionuclides in CTBT verification because of its likelihood of detection soon after an above-ground explosion. It is also potentially detectable following underground explosions, and is the only such nuclide likely to be collected in the particulate network. An understanding of the sources of I-131 detected routinely by the IMS is therefore of paramount importance. Over the last four years the IDC has reported over 180 detections of I-131 across the IMS network. While most of these can be explained as radiopharmaceutical releases in major urban areas, approximately 10% have occurred at remote stations where such an explanation is not plausible. This paper describes the incidence of such detections, discusses whether or not the signals interpreted as being due to I-131 are indeed "real" (even if the nuclide identity may be unconfirmed), and raises questions as to the source of such signals. If interpreted as being due to I-131, the atmospheric concentrations reported could cause confusion through misinterpretation as being due to releases from underground nuclear explosions. A satisfactory explanation for these spurious signals has not yet been found, and the paper highlights the need for further work in this area.

RN-07/D: The influence on the radioxenon background during the shut-down of three major radiopharmaceutical production facilities in the Northern Hemisphere and during the start-up of a radiopharmaceutical production facility in the Southern Hemisphere

Paul R.J. Saey[1], Matthias Auer[2], Andreas Becker[3], Emmy Hoffmann[4], Mika Nikkinen[2], Anders Ringbom[5], Rick Tinker[6], Clemens Schlosser[2], Michel Sonck[7]

1:Vienna University of Technology, Atomic Institute of the Austrian Universities, Stadionallee 2, 1020 Vienna, Austria; 2:Bundesamt für Strahlenschutz, (BfS), Rosastr. 9, 79098 Freiburg, Germany; 3:Preparatory Commission for the Comprehensive Nuclear-Test-Ban Treaty Organisation (CTBTO), Provisional Technical Secretariat, PO Box 1200, 1400 Vienna, Austria; 4:Australian Nuclear Science and Technology Organisation (ANSTO) Safety and Radiation Protection, Environmental Monitoring, PMB1, 2234 Menai, NSW, Australia; 5:Swedish Defence Research Agency (FOI), Defence and Security, Systems and Technology Division, 172 90 Stockholm, Sweden; 6:Australian Radiation Protection and Nuclear Safety Agency (ARPANSA), 619 Lower Plenty Road, 3085 Yallambie, VIC, Australia ; 7:Federaal Agentschap voor Nucleaire Controle (FANC), Ravensteinstraat 36, 1000 Brussel, Belgium

Contact: paul.saey@ati.ac.at

Abstract: Atmospheric radioxenon monitoring is a key component of the verification of the Comprehensive Nuclear-Test-Ban Treaty (CTBT). Radiopharmaceutical production facilities (RPF) have recently been identified of emitting the major part of the environmental radioxenon measured at globally distributed monitoring sites deployed to strengthen the radionuclide part of the CTBT verification regime. Efforts to raise a global radioxenon emission inventory revealed that the global total emission from RPFs is 2-3 orders of magnitude higher than the respective emissions related to maintenance of all nuclear power plants (NPP).

Given that situation we have seen in 2008 two peculiar hemisphere-specific situations:

In the northern hemisphere, a joint shutdown of the global largest four radiopharmaceutical facilities revealed the contribution of the normally 'masked' NPP related emissions.

Due to an incident, the Molybdenum production at the "Institut des Radioéléments" (IRE) in Fleurus, Belgium, was shut down between Monday 25 August and 2 December 2008. IRE is the third largest global producer of medical isotopes. In the same period, but for different reasons, the other three worldwide largest producers (CRL in Canada, HFR in The Netherlands and NTP in South Africa) also had scheduled and unscheduled shutdowns.

The activity concentrations of ^{133}Xe measured at the Schauinsland Mountain station near Freiburg in Germany (situated 380 km SW of Fleurus) which have a mean of 4.8 mBq/m^3 for the period February 2004 – August 2008, went down to 0.87 mBq/m^3 for the period September – November 2008.

In the southern hemisphere, after a long break, the only radiopharmaceutical facility in Australia started up test production in late November 2008.

In the period before the start-up, the background of radioxenon in Australia (Melbourne and Darwin) was below measurable quantities. During six test runs of the renewed RPF at ANSTO in Lucas Heights, up to 6 mBq/m^3 of ^{133}Xe were measured in the station at Melbourne, 700 km SW from the facility.

This paper confirms the hypothesis that radiopharmaceutical production facilities are the major emitters of radioxenon first of all. Moreover it demonstrates how the temporal shut down of these facilities indicates the scale of their contribution to the European radioxenon background, which decreased 6 fold. Finally we have studied the contribution of the start-up of a renewed RFP to the build up of a radioxenon background across Australia and the southern hemisphere.

Disclaimer -The views expressed in this publication are those of the authors and do not necessarily reflect the views of the Vienna University of Technology or any of the participating institutions.

RN-08/D: A noble gas inventories and xenon and krypton isotopic signature study of the primary coolant of CANDU nuclear power plant to enhance CTBT verification

K. Ungar, W. Zhang, I. Hoffman and R. Lawrie, *Radiation Protection Bureau of Health Canada, 775 Brookfield Road, Ottawa, Ont, Canada K1A 1C1*

Contact: kurt_ungar@hc-sc.gc.ca

Abstract: To support interpretation of observed atmospheric ^{135}Xe, ^{133}Xe, ^{133m}Xe, ^{131m}Xe and ^{85}Kr a database of noble gas in the primary coolant of CANDU reactors has been established. This database is comprised of 40000 records of high-quality xenon and krypton radioisotope analyses. Records from the database were retrieved by a specifically designed data-mining module and subjected to further analysis. Results from the analysis were subsequently used to study isotopic ratios of observed xenon and krypton radioisotopes in the CANDU reactor primary coolant. These studies provided novel and practical information on the characterization of CANDU reactor xenon and krypton radioisotope, which can be used to discriminate between reactor effluence and underground nuclear test releases, also can potentially be used to discriminate between reactor effluence and fuel reprocessing for nuclear safeguard ^{85}Kr monitoring applications.

Key words: noble gas, reactor primary coolant, database inventories, krypton and xenon radioisotope.

RN-09/D: Ultra-low background measurements of decayed aerosol filters (LOG 403)

Craig E. Aalseth1, Erica Andreotti2, Dirk Arnold3. Joan-Albert Sanchez Cabeza4, Detlev Degering5, Andrea Giuliani2, Raquel Gonzales de Orduña6, Rodolfo Gurriaran7, Mikael Hult6, Marty E. Keillor1, Matthias Laubenstein8, Gilbert le Petit9, Romul Mircea Margineanu10, Murray Matthews11, Harry S. Miley1, Iolanda Osvath4, Monica Pellicciari2, Wolfango Plastino12, 13, Hardy Simgen14, Marc Weber14, Robert Werzi15 *Pacific Northwest National Laboratory1, Università dell'Insubria2, Physikalisch-Technische3, IAEA Marine Environment Laboratory4, Verein für Kernverfahrenstechnikund Analytik Rossendorf5, EC-JRC Institute for Reference Materials and Measurements6, IRSN/DEI/STEME / Environmental Radioactivity Measurement Laboratory7, Laboratori Nazionali del Gran Sasso8, CEA/DAM Ile-de-France9, National Institute of Research and Development for Physics and Nuclear Engineering10, Radioactivity Specialists Ltd.11, University of Roma12, National Institute of Nuclear Physics13, Max-Planck-Institut für Kernphysik14, CTBTO/IMS Division15*
Contact Craig.Aalseth@pnl.gov

Abstract: To experimentally evaluate the opportunity to apply ultra-low background measurement methods to samples collected, for instance, by the Comprehensive Test Ban Treaty International Monitoring System (IMS), aerosol samples collected on filter media were measured using HPGe spectrometers of varying low background technology approaches. In this way, realistic estimates of the impact of low-background methodology can be assessed on the Minimum Detectable Activities obtained in systems such as the IMS. The current measurement requirement of stations in the IMS is 30 microBq per cubic meter of air for ^{140}Ba, or about 10^6 fissions per daily sample. Importantly, this is for a fresh aerosol filter. One week decay reduces the intrinsic background from radon daughters in the sample allowing much higher sensitivity measurement of relevant isotopes, including ^{131}I. An experiment was conducted in which decayed filter samples were measured at a variety of underground locations using Ultra-Low Background (ULB) gamma spectroscopy technology. The impact of the decay and ULB is discussed.

RN-10/D: The PRDS Radiation Detector: An Electromechanically Cooled Germanium Detector Designed for Field Search Applications

Arden D. Dougan[1], William H. Dunlop[1], Brian Adlawan[2]
Lawrence Livermore National Laboratory, Textron Systems, IST Operations
Contact: adougan@llnl.gov

Abstract: Field search of radionuclides will be needed for On-Site Inspections require high resolution gamma-ray detectors that are robust, lightweight, hands-free and fieldable. We will discuss a new electromechanically cooled high purity germanium (HPGe) detector, Portable Radiation Detection/Identification System, PRDIS that has recently been developed. This detector includes a segmented BGO detector to enhance search and active Compton background suppression on the HPGe detector to increase the signal-to-noise. The many features of the detector and initial testing will be described in this paper.

RN-11/D: Development of improved equipment for measurements of xenon radionuclides in atmospheric air

***Yuri V. Dubasov, Sergey A. Pakhomov.**, Khlopin Radium Institute, St. Petersburg, Russia*
Contact: s_a_pakhomov@mail.ru

Abstract: The Radium Khlopin Institute have developed the mobile (vehicle based) equipment attended for the providing of the monitoring of radioactive xenon isotopes in atmospheric air on territories, neighboring with NPP. This equipment comprises the improved sampling installation with sample-processing unit and specialized spectrometer of β-γ-coincidences.

The principal specificity of sampling installation is the using of the gas-cooling machine attended for the reaching of the cryogenic temperatures, which works without helium, using for cooling the processed air itself. The capacity of sampling reaches 20 cubic meters per hour with the xenon extraction factor of 75%. The duration of the sampling cycle forms 3 - 7 hours depending of the xenon volume requirements.

The sample-processing unit is designed on preparative gas chromatograph scheme. Duration of sample-processing procedure does not exceed one and half hour. The volume of the prepared sample is around half liter, it contains 3 - 7 cubic centimeters of the xenon, depending of sampling cycle time.

For measurements of xenon radioisotopes containing in obtained sample, was developed a β-γ-coincidences spectrometer on the base of the "ORTEC" HP Ge detector equipped with scintillation β-detector designed as Marinelli chamber of 700 cm^3 volume. This spectrometer allows to reduce the ambient background more than in 20 times, with γ-channel efficiency reduction not more than in 1.5 times. The minimum detectable activity of ^{133}Xe (MDA), evaluated by Currie formula for probability 95 % is 0.05 Bq at the exposition of 20 hours.

Spectrometer is also intended for determination of the stable krypton and xenon concentrations in β-chamber by X-ray-fluorescent method. Therefore, in a shield of the spectrometer collimating pinhole is made and ^{241}Am source is installed.

To improve the sensitivity of the analysis beryllium window is made in β-chamber wall, adjoining to the HPGe detector. X-ray-fluorescent analysis allows to surely define Xe volumetric concentration of 0.05% in β-cell, that is equivalent less then 0,5 cm^3 of Xe.

The first approbation of described equipment was fulfilled in St. Petersburg at autumn of 2007 year and has shown that the spectrometer allows to measure ^{133}Xe concentration at the level of 2 mBq/m^3, and this value is in a good agreement with the results of other measurements.

Described equipment was practically approbated in field conditions on 2008 year during the expeditionary work carryout in Sosnovyi Bor, Udomlya and Polyarnie Zori – the cities of North-West of Russia, which are located in close neighboring with acting NPP.

RN-12/D: evaluation of cooling technologies for HPGe detectors

Joel Forrester[1], Mike Yocum[2], George Rybicki[3], Robert Werzi[4], Ethan Hull[5]
Pacific Northwest National Laboratory1, Canberra Industries2,
Air Force Technical Applications Center3, Provisional Technical Secretariat4, PHDs Co.5
Contact: laura.wilhelm@pnl.gov

Abstract: High purity germanium (HPGe) is employed widely in radiation and nuclear material detectors. Prized for its high resolution and resulting ability for isotopic identification, HPGe must be maintained at very low temperatures during operation. The simplest and most common cooling method is liquid nitrogen (LN). However, the unavailability of commercial LN supplies prohibits its use at many remote radionuclide stations or reduces the efficiency gains available from the use of automatic radionuclide stations in the International Monitoring System (IMS) operated in support of the Comprehensive Nuclear Test-ban Treaty (CTBT). This paper will explore the several alternative mechanical cooling options presently available and/or under development for HPGe cooling. Both lower-tech and more complex technologies, e.g., LN generators and Stirling coolers, respectively, will be addressed. All available Mean Time Between Failure (MTBF) and operational data, particularly from IMS usage, will be presented. Particular emphasis will be given to the IMS and On-Site Inspection (OSI) applications.

RN-13/D: A method for lessening filter clogging on atmospheric aerosol samplers at IMS

Liu Longbo, Tang Hanbin, Liu Shujiang, Wu Yanmin, Wang Xuhui
Northwest Institute of Nuclear Technology, P. O. Box 69-14, 710024, Xi'an, China.
Contact: lomboliu@live.cn

Abstract: Atmospheric aerosol samplers are important devices at stations of the International Monitoring System (IMS) for sampling radioactive particulate matters. The requirements about the samplers by the Preparatory Commission for the CTBTO involved the flowrate as high as 500~1000 m^3/h and downtime less than seven days continually and fifteen days annually. Filter clogging, often taking place at stations where air pollution is severe, is one of the main factors that cause downtime more than required. PTS have given advice of installing pre-separators such as cyclones to solve the problem in "*Certification of IMS Radionuclide Stations*". However, design and performances of pre-seaprators were not mentioned by PTS. The performance of pre-separators including cyclones and impactors, as well as the characteristics of atmpspheric aerosol pollution were investigated in our lab. The results showed that: (1) the cutoff diameter of pre-separators should be about 15 μm to meet the global collection efficiency of no less than 80% at 10 μm required by the Preparatory Commission, and (2) the amout of atmospheric aerosols with diameter lower than 10 μm was usually no lower than that of larger than 10 μm during severe air pollution even sandstorms in Beijing and Lanzhou, China, where IMS radionuclide stations were located. As a result, we concluded that pre-separators may assist to lessen filter clogging but can not solve the problem, and more, they would cause loss of radionuclides in larger aerosols. A novel method then has been proposed in this paper to solve the problem. An impactor with about 2 μm cutoff diameter is used to separate aerosols. The larger aerosols are collected by substrate of the impactor and the smaller ones are collected by the filter. The substrate with particles in is combined with the filter as a whole sample after sampling. The filter, in this method, only collects a small part of aerosols so filter clogging can be postponed to the most extent. There is no obvious radionuclide loss since both parts of aerosols are collected. The preliminary experiments have shown that the method was feasible.
Keywords: Atmospheric aerosol samplers, Filter clogging, Impactor

RN-14/D: Production and characterization of enriched 133mXe samples

K. Peräjärvi[1], V.-V. Elomaa[2], T. Eronen[2], J. Hakala[2], A. Jokinen[2], A. Kankainen[2], P. Karvonen[2], I.D. Moore[2], H. Penttilä[2], J. Rissanen[2], A. Saastamoinen[2], H. Toivonen[1], J. Turunen[1, 2], J. Äystö[2]
[1] STUK - Radiation and Nuclear Safety Authority, P.O. Box 14, Helsinki FI-00881, Finland
[2] University of Jyväskylä, Department of Physics, P.O. Box 35 (YFL), FI-40014 University of Jyväskylä, Finland
Keywords: ^{133m}Xe source, noble gas sampling station
Contact: Kari.Perajarvi@stuk.fi

Abstract: The isotope ^{133}Xe and its isomeric state ^{133m}Xe are important indicators used by the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO) to detect clandestine nuclear weapon tests. Isomeric state ^{133m}Xe ($T_{1/2}$=2.19 d) solely decays to the ground state of ^{133}Xe ($T_{1/2}$=5.243 d) which further beta-decays to stable ^{133}Cs. Due to the central role of $^{133, 133m}$Xe for the Treaty verification we study the possibility to prepare pure ^{133m}Xe samples using IGISOL/JYFLTRAP facility in Finland [1]. The ^{133m}Xe samples may be used in the future for calibrating and characterizing xenon detection instruments and analysis algorithms.

Intense mass separated beam of A=133 including $^{133, 133m}$Xe can be produced through proton-induced fission, coupled with the Ion Guide Isotope Separator On-Line (IGISOL) technique [2]. In ref. [2] this beam was implanted without any additional purification into a thin aluminium-foil. It was also shown that implanted xenon did not diffuse extensively out from the foil during the experiments that lasted several days. A 30 keV implantation energy was used. Reference [3] demonstrates that the isobaric purification of above mentioned A=133 beam is possible using JYFLTRAP device.

Produced samples are examined both at the University of Jyväskylä and at STUK. Six xenon samples are made. Four samples are needed for the release studies of xenon from aluminium. These samples are measured right after their production with a single high purity germanium detector (HPGe) and with an array of silicon detectors. After that they are baked at different temperatures and measured again using same detectors. Remaining two samples are counted for several days at STUK using HPGe detector starting as soon as possible after finishing the sample production. The purpose is to study in detail the time evolution of these samples. This study tells precisely the number of xenon atoms escaping the foil before their radioactive decay if nothing is done for the sample. Data from the above described measurements are also used for the general characterization of samples (^{133m}Xe sample size, ^{133m}Xe/^{133}Xe atom ratio at the end of implantation etc.). Finally, the JYFLTRAP setup itself is also used for the diagnostics of out-coming xenon beam.

The experiments are performed in May 2009. Preliminary results of these studies will be reported.
[1] V.S. Kolhinen et al., Nucl. Instr. and Meth. in Phys. Res. A 528 (2004) 776.
[2] K. Peräjärvi et al., Applied Radiation and Isotopes 66 (2008) 530.

[3] H. Penttilä et al., To be published.

RN-15/D: A novel measuring system for detecting and characterizing radioactive particles

Jani Turunen, Kari Peräjärvi, Roy Pöllänen, Harri Toivonen, STUK - Radiation and Nuclear Safety Authority, P.O. Box 14, FI-00881 Helsinki, Finland
Contact: Jani.Turunen@stuk.fi

Keywords: non-destructive analysis, particle analysis, isotope ratios, novel detection technology

Abstract: A novel device for non-destructive sample analysis has been designed and built. This device is called PANDA (Particles And Non-Destructive Analysis). PANDA broadens the prospects on measurements and analysis of radioactive samples by applying techniques and instruments normally used in basic research. These are, for example, double-sided silicon strip detectors, event mode data acquisition and software-based coincidences.

PANDA has two measurement positions inside a vacuum chamber. Measurement position 1 (MP1) hosts a High Purity Germanium (HPGe) detector and a Double-Sided Silicon Strip Detector (DSSSD). These two detectors are facing each other and the distance between them is adjustable from zero to a few centimetres. The samples are placed between these detectors with a linear feedthrough. The HPGe is used to detect photons and the DSSSD to detect alpha and possibly also beta particles. The MP1 is primarily meant to screen large-area samples such as air filters.

The DSSSD is used to locate interesting radioactive particles. After the location and partial analysis of the particles, studies can be continued in measurement position 2 (MP2). It is currently under development. The detectors of MP2 are smaller and have better energy resolution than the ones in MP1. These detectors will also be capable of detecting conversion electrons.

PANDA records data in event mode. Events are also timestamped. This storage format brings along a lot of flexibility and additional benefits to the final data analysis. We have, for example, already shown that an alpha-gated gamma-spectrum related to an air filter is nearly free of background [1]. Notice that the analysis of the alpha-gated gamma-spectrum is quite straightforward since all peaks in the spectrum are created by alpha-decaying nuclides. Similar capability is possible for beta-decaying nuclides.

PANDA is a measurement setup that can greatly improve the analysis of air samples in Certified Laboratories. However, the sampling and subsequent sample preparation must be non-destructive, similar to sample treatment at Cinderella-type IMS stations.

[1] J. Turunen et al. PANDA - A novel instrument for non-destructive sample analysis, Nucl. Instr. and Meth. in Phys. Res. A, to be submitted.

RN-16/D: A study on the global detection capability of IMS for all CTBT relevant xenon isotopes

Réal D'Amours[1] and Anders Ringbom[2]
[1)] Canadian Meteorological Centre (CMC), Environment Canada, Dorval QC, Canada
[2)] Swedish Defence Research Agency (FOI), SE-164 90, Stockholm, Sweden
Contact: Real.D'Amours@ec.gc.ca

Abstract: Previous studies of the measurement capability of the radioxenon part of the International Monitoring System (IMS) for CTBT monitoring have all been made using simple assumptions with regard to the detection limits of the measurement systems and without taking the existing background into account. Furthermore, all earlier studies have been done for ^{133}Xe only. The recent development of sensitive radioxenon systems and the build-up of the network within the International Noble Gas Experiment (INGE), has substantially increased the possibility to perform a more realistic study of the network performance in the case of a nuclear explosion.

In this work, analyzed data from 18 noble gas systems within IMS collected during 2006-2009, as well as some other measurements, have been used to define a station dependent detection threshold for all four relevant xenon isotopes (^{133}Xe, ^{131m}Xe, ^{133m}Xe, and ^{135}Xe). The threshold takes into account both the performance of the detection systems, as well as the local radioxenon background. In combination with atmospheric transport models, these data have been used to evaluate the global isotopic dependent radioxenon detection capability of the network. The study has been conducted for both the proposed 40 NG stations network and the full 80 stations network; it looks at the effect of seasonal variations, and attempts to take into account the modelling uncertainties.

RN-17/D: Global capabilities to detect locate and characterize radionucleide radio-xenon sources and radionuleide particulates advancements in worldwide aerosol particulates monitoring

Ricardo Muñoz, *Nuclear Sciences Department of ESCUELA POLITÃ‰CNICA NACIONAL. ECUADOR*
Contact: ricardo.munoz@epn.edu.ec

Abstract: The Department of Nuclear Sciences of Escuela Politécnica Nacional, before called Institute, started to measure the radioactivity due to the fallout after a nuclear explosion made either on the earth, or on the sea. Samples collected in surrounding areas of Quito were measured daily, mainly in air, water, milk and vegetables. Samples of water, milk and vegetables collected at the Galapagos islands were also analyzed, because the ocean current call Cronwell, crosses these islands coming from the South Pacific were France was testing their nuclear pumps. In fact, on 29 of April 1986, we detected the radioactivity developed during Chernobyl accident in a Russian reactor. After a meeting held the 6 May, 1986 at Copenhage, I personally received a copy of the document that was produced at that date. In that occasion we had detected Zr-95, Nv-95, Cs-137 amd Ce-144 as major contaminants.

RN-18/D: Usage of industrial air separation plants as an extension to the noble gas IMS network

Khrustalev K. V., Popov Yu. S., Popov V. S., Prelovskij V. V.
Contact : popov@khlopin.ru

Abstract: Using industrial air separation plants with low and medium productivity can greatly simplify the process of obtaining high volume (10-100 cm3) xenon samples. Such plants are available in almost every major city or industrial center throughout the world. We have developed a prototype of a mobile beta-gamma coincidence xenon measurement system capable of measuring large volume samples with high sensitivity (5.5 mBq MDA for Xe-133).

This allows fast deployment for measurements at or near such plants, making possible sampling at more locations without building permanent measurement stations, thus extending the IMS verification capabilities.

RN-19/D: Characterization of the global isotopic distribution of atmospheric radioxenon using 13000 atmospheric samples from 23 locations

A. Ringbom[1)], H. Henriksson [1)], M. Auer[2)], I. Hoffman[3)], C. Schlosser[2)]
[1)] Swedish Defence Research Agency (FOI), SE-164 90, Stockholm, Sweden; [2)] Bundesamt für Strahlenschutz, Rosastr. 9, D - 79098 Freiburg, Germany; [3)] Verification and Incident Monitoring Radiation Protection Bureau, 775 Brookfield Road, AL6302D1, Ottawa, Ontario, Canada
Contact: anders.ringbom@foi.se

Abstract: The recent development of sensitive radioxenon systems and the build-up of the radioxenon network within the International Monitoring System (IMS), offers a unique opportunity to gain new knowledge of the global atmospheric distribution of radioxenon. A detailed knowledge of this distribution is essential in investigations of the performance of IMS, as well as in the development of techniques to discriminate radioxenon signatures from a nuclear explosion from other sources.

In this work, analyzed concentration data from 18 noble gas systems within the International Monitoring System (IMS) collected during 2006-2009, as well as from five non-IMS locations, have been reviewed to remove false detection caused by systematic errors, as well as peaks caused by calibration spikes or other activities not associated with the normal radioxenon background. In total, about 13000 samples were reviewed and sometimes reanalyzed.

Following the review, data from the different stations was put on a common format, and statistical parameters and frequency distributions for all four relevant xenon isotopes (^{133}Xe, ^{131m}Xe, ^{133m}Xe, and ^{135}Xe) were extracted. The frequency distributions were fitted to Gaussian or Lognormal functions folded with detector response. The results show that the ^{133}Xe radioxenon background in many cases can be well described by a lognormal distribution, which results when the measured concentrations are a product of many independent random parameters. It was also found that in at least one case, the same was true also for ^{131m}Xe.

The analysis approach allows the radioxenon activity concentrations at most measurement sites to be characterized by two parameters only, describing both the ambient radioxenon background at the site, as well as the detection capability of the station. This technique greatly simplifies the description of the global radioxenon background, and provides easy input to studies of the radioxenon part of IMS.

RN-20/D: The operational status of the IMS Radionuclide Particulate Network

R. Werzi[1]

[1]*CTBTO/PTS/IMS/MFS, VIC, PO Box 1200, A-1400 Vienna*
Contact: Robert.Werzi@ctbto.org

Abstract: A worldwide radionuclide network of 80 stations, 40 of which with noble-gas-detection capability, and part of the International Monitoring System (IMS) has been designed to monitor compliance to the Comprehensive Nuclear-Test-Ban Treaty (CTBT). Pending entry into force of the Treaty, the certified stations are provisionally operated. With about 70% of the network operational global coverage has been reached and an overall operating experience of more than 250 station year for the particulate network has been accumulated. To ensure minimum down time any operational problems are addressed within the organizations' Operations and Maintenance Support System. Within this support system the operational performance is continuously assessed as well as particular problems identified. To address these problems, equipment failures, operational procedures, maintenance and sparing plans, and equipment obsolescence are continuously reviewed and improved. The current operational status of the network as well as the support strategy is presented.

RN-21/D: Supporting the CTBT Radionuclide Monitoring System at the Canadian Meteorological Centre
Nils Ek, Réal D'Amours, Serge Trudel, Alain Malo, René Servranckx, Richard Hogue, ***Canadian Meteorological*** *Centre, Environment Canada, Dorval Qc, Canada*
Contact : Real.D'Amours@ec.gc.ca

Abstract: The Canadian Meteorological Centre (CMC) has been actively supporting the CTBTO radionuclide monitoring activities, since the early stage. It has participated in all major CTBTO exercises providing Source Receptor Sensitivity Coefficients as requested by the PTS. The CMC is also actively supporting the Canadian National Authority for the CTBT as well as the Canadian National Data Centre (NDC). The CMC played a key role in promoting the WMO collaboration and support of the CTBT through its WMO/RSMC role, which recently resulted in a formal cooperation arrangement between the WMO and the CTBTO.

At the request of, and to increase the support to the Canadian National Data Centre for radionuclide monitoring, the CMC is calculating SRS's for the full CTBT monitoring network, operationally, on a continuing basis. Updated SRS's data are always available to the Canadian NDC and to the CTBTO PTS as well.

The poser describes the operational implementation of the system, its coupling with CMC's operational meteorological suite, and the connectivity with the Canadian NDC. Examples of product outputs are shown based on recent exercises. The potential benefits of the system for non-CTBT related activities are discussed briefly.

RN-22/D: RADIOXENON SIGNATURES FROM UNDERGROUND NUCLEAR EXPLOSIONS
Lars-Erik De Geer, Swedish Defence Research Agency (FOI), Stockholm, Sweden
Contact: ledg@foi.se

Abstract: The announced nuclear test in North Korea in the morning (10:35 local time) of Monday 9 October 2006 was quite an eye opener for many in the CTBT community for the importance and relevance of the CTBT radioxenon verification sub-system. Seismic signals revealed a suspicious event at Mount Mantap some 40 km NNW of Kilchu town, but soon discussions started whether this really was a nuclear explosion or not. Only with several radioxenon detections that could be tied to a source in the same area those suspicions came to an end.
For the verification system it is important to be able to differentiate between possible leaks from underground nuclear explosions and in certain areas quite common emissions from civilian nuclear enterprises. The obvious difference in the radioxenon signature ($^{131m, 133m, 133, 135}$Xe), between nuclear power plants and an explosion, is that the former during routine production contain radioxenon that due to the equilibrium built within a few weeks from start-up is enhanced in the longer-lived ^{131m}Xe and ^{133}Xe. This can conveniently be expressed in a scattering plot of the ^{135}Xe/^{133}Xe and ^{133m}Xe/^{131m}Xe ratios where emissions from most reactor operations and from nuclear explosions are to be found in disparate domains. As demonstrated in recent years radiopharmaceutical plants are more problematic for the verification system, but they are few and their emissions can with moderate efforts be practically extinguished.

Another problem arises when there are good reasons to suspect that an explosion really has happened. There can be many different such scenarios ranging from the North Korean one where the country wants to be seen as nuclear capable (and the suspicions naturally turn around; did they just pretend?) to a country that has ratified the CTBTO and does its utmost to hide a test. The latter has with high confidence not yet happened.

RN-23/D: SWEDISH EXPERIENCE OF DETECTING LEAKAGES FROM FOREIGN UNDERGROUND NUCLEAR EXPLOSIONS

Lars-Erik De Geer, Swedish Defence Research Agency (FOI), Stockholm, Sweden
Contact: ledg@foi.se

Abstract: The Swedish Defence Research Agency (FOI, formerly FOA) has since the early 1950s run a national network of sampling stations for collection and analysis of debris from nuclear weapons explosions. It was established during a time when Sweden kept the option to develop her own nuclear weapons and its goal was then to learn about foreign nuclear developments, but also to learn about the characteristics of fallout as a military preparedness for nuclear war.

In the early 1960s very high-yield atmospheric nuclear tests were carried out in our vicinity and the network then played the role of a warning system for radiation. In 1963 the Moscow Treaty or the Partial Test Ban Treaty was signed and adhered to primarily by the three major nuclear testers, the Soviet Union, United Kingdom and the United States. This Treaty banned all nuclear explosions in the atmosphere, in space, under water and underground if radioactive debris could be detected outside the borders of the testing country. During the 1960s Sweden abandoned its nuclear weapons plans and then the surveillance system changed its goals into help stopping others to test and develop nuclear weapons. It became a disarmament tool by disclosing violations of the Partial Test Ban and to make public the doings of the nuclear weapon states, France and China, who had not signed and ratified the Partial Test Ban. All of this, together with efforts in seismic detections and a lively participation in the Conference of the Committee on Disarmament in Geneva was designed to promote a Comprehensive Nuclear Test Ban, which we all learned as time passed with weekly underground nuclear tests, was necessary to curb the development of ever better and effective nuclear swords.

This presentation summarizes the findings of the Swedish radionuclide surveillance system where leakages have been detected from underground nuclear testing and it puts it into the perspective of different emission scenarios from underground nuclear explosions. Since the Partial Test Ban in 1963 this network has detected particulate debris from four underground nuclear test explosions in former Soviet Union and two in the United States. Tritium was detected from a six charge salvo in a tunnel at the Novaya Zemlya site in 1975. On one occasion in 1990, actually the last test by the Soviet Union, 133Xe was detected, again from a salvo in a tunnel at the same site. The Swedish xenon system had then just been re-established after being moth-balled since the initial testing period during 1979 – 1982. In preparation for the CTBT the Swedish xenon system was further developed in the 1990:s, improved and also industrialized. In October 2006 a Swedish transportable machine (now under the brand name Sauna II) was rapidly brought to South Korea where it managed to collect on Thursday 11– Saturday 14 a series of radioxenon samples that derived from the North Korean nuclear test on Monday morning of the same week.

RN-24/D: Discrimination of nuclear explosions against civilian sources based on atmospheric xenon isotopic activity ratios

Martin Kalinowski, *Carl Friedrich von Weizsäcker Center for Science and Peace Research University of Hamburg Room 02/024, Beim Schlump 83, 20144 Hamburg, Germany*
Contact: martin.kalinowski@uni-hamburg.de

Abstract: The isotopic ratio plots have been proposed some time ago as one of several methods for categorization of noble gas samples. This poster demonstrates the concept and its applicability based on data from different test stations.

RN-25/D: Measurement of isotopic ratio Xe133m/Xe133 at very low level counting using Bayesian statistical approach

Gilbert Le Petit[1], Alain Vivier[2], X.Blanchard[1]
[1] CEA, DAM, DIF, F-91297 *Arpajon, France ;* [2] CEA, INSTN, *Centre de Saclay*, BP68, F-91192 *Gif-sur-Yvette, France*
Contact: gilbert.le-petit@cea.fr

Abstract: For Comprehensive Test Ban Treaty verification purposes some specific systems have been developed to extract, purify and concentrate xenon from air and measure the four relevant isotopes ^{133}Xe, ^{135}Xe, ^{133m}Xe, ^{131m}Xe. The ratio ^{133m}Xe/^{133}Xe plays an important role to distinguish civil sources from nuclear weapon test.

When a net count value is below the type 1 error decision threshold it is usual to declare that the activity is "below the detection limit". The content of this declaration is particularly impoverished, incapable for example of discriminating between a net measurement just below the decision threshold, but positive, and a negative net measurement; two types of information that it is legitimate and intuitive to think do not have the same weight of information. In the case of a spectral measurement of ^{131m}Xe and ^{133m}Xe certain information is available according to the various X and gamma emissions, which might all be below their respective decision thresholds. A Bayesian probabilistic approach can be used, without considering the decision thresholds, to obtain (i) anti-correlated maximum likelihood values taking all the information into account jointly and (ii) a powerful and pertinent information in the form of the absolute probability that the sample contains ^{131m}Xe and/or ^{133m}Xe, all possible activity values combined. Consequently xenon isotopic ratios involving metastable isotopes, especially ^{133m}Xe/^{133}Xe, are liable to be achieved at very low level counting.

RN-26/D: Measurements of radioxenon in ground level air in South Korea following the claimed nuclear test in North Korea on October 9, 2006

Anders Ringbom[1)], Klas Elmgren[1)], Karin Lindh[1)], Jenny Peterson[1)], Ted Bowyer[2)], James C. Hayes[2)], Justin I. McIntyre[2)], Mark Panisko[2)], and Richard Williams[2)]
[1)] Swedish Defence Research Agency (FOI), SE-164 90, Stockholm, Sweden
[2)] Pacific Northwest National Laboratory, Richland, Wa, USA.
Contact: anders.ringbom@foi.se

Abstract: Following the claimed nuclear test in the Democratic People's Republic of Korea (DPRK) on October 9, 2006, a mobile system for sampling of atmospheric xenon was transported to the Republic of South Korea (ROK) in an attempt to detect possible emissions of radioxenon in the region from a presumed test. Five samples were collected in the ROK during October 11-14, 2006 near the ROK-DPRK border, and thereafter transported to the Swedish Defense Research Agency (FOI) in Stockholm, Sweden, for analysis. Following the initial measurements, an automatic radioxenon sampling and analysis system was installed at the same location in the ROK, and measurements on the ambient atmospheric radioxenon background in the region were performed. These measurements were performed during November 2006 to February 2007. The obtained atmospheric activities of ^{133}Xe and ^{133m}Xe strongly indicate that the explosion in October 9, 2006 was a nuclear test. The conclusion is further strengthened by atmospheric transport models.

RN-27/D: Natural lithospheric radioxenon background in soil gas samples

Simon HEBEL, Martin KALINOWSKI*, Carl Friedrich von Weizsäcker Centre for Science and Peace Research, University of Hamburg, Germany*
Contact: shebel@physnet.uni-hamburg.de

Abstract: During the on-site inspections (OSI) for Comprehensive Nuclear-Test-Ban Treaty (CTBT) verification, soil gas sampling is a fundamental instrument to detect and characterise emissions from an underground nuclear test explosion (UNE). Due to their volatile nature, noble gases are the most likely products to migrate close to the surface where they can be sampled.

In order to efficiently evaluate subsoil gas measurements, the background must be known. The noble gas isotopes of interest for CTBT verification are argon-37 and the four xenon isotopes 131m, 133, 133m and 135. Despite great interest in noble gas sampling and the detection of radionuclides being essential to characterise the nuclear nature of a UNE, only a few rough estimates exist on the natural background of the relevant xenon isotopes. Most efforts so far have concentrated on the assessment of the anthropogenic atmospheric background, whereas the background of Ar-37 is generally considered to be negligible.

This study aims to assess the natural radioxenon background by explicitly addressing all possible production paths, including spontaneous and neutron induced fission of uranium and thorium, neutron reactions with lithospheric elements and muon reactions. Realistic spectra of cosmic and fission neutrons are considered. In

addition to comparing the importance of different production methods, the consequent xenon concentration equilibrium is determined for a range of different rock and soil types based on geological data from literature. The isotopic ratios are also evaluated and compared to those of UNEs and the anthropogenic background.

From these results the influence and detectability of the natural background is inferred, in order to provide a comparison for and guide prospective xenon background measurement activities.

RN-28/D: Detection and activity leveles of natural Ar-37 in soil air

Riedmann, R., Purtschert, R.[1]
[1]Physics Institute, University of Bern, Switzerland,
Contact: riedmann@climate.unibe.ch

Abstract: The radioactive noble gas isotope Ar-37 is produced in the underground due to neutron activation of calcium by the Ca-40(n,α)Ar-37 reaction (LEHMANN and LOOSLI, 1989). Ar-37 is a definitive and unambiguous indicator of a underground nuclear exposion (UNE) because the anthropogenic background is very low. A further advantage of Ar-37 compared to the CTBT relevant radio-xenon isotopes is the longer half-life of 35 days which enhances the likelihood that detectable concentrations reach the shallow soil zone.
However, the rather short half-life also implies an efficient and fast Ar separation both on- & off-site. Therefore a new gas processing unit was constructed resulting in a separation capacity for argon of up to three samples per day with a sample size up to 100 L air. Ar-37 is then measured by LLC in the underground laboratory in Bern (33 m below surface).

The identification of an artificial event requires the knowledge of the range of natural activities in the specific environmental settings.

We present results of measured subsurface Ar-37 profiles at different locations. It is shown that natural Ar-37 levels in soil air exceed background concentrations found in the atmosphere by several orders of magnitude.
The natural Ar-37 background concentration in shallow soils depends mainly on the diffusive gas exchange rate from the soil to the atmosphere and the production by cosmic rays.

Lehmann B. and Loosli H. H. (1989) Subsurface production of 3He, 4He, 36Cl, 37Ar, 39Ar, 40Ar, 129I and 222Rn in the cristalline.

RN-29/D: Proficiency Test Program for CTBT Radionuclide Laboratories

E. B. Duran X. Shen, E. McWilliams, L. Cella and R. Werzi
IMS Division, Comprehensive Nuclear-Test-Ban Treaty Organization Preparatory Commission, Wagramerstrasse 5, P.O. Box 1200, A-1400 Vienna, Austria
Contact: Emerenciana.Duran@ctbto.org

Abstract: Sixteen radionuclide laboratories in various parts of the world support the network of radionuclide air sampling stations being established for verification of the Comprehensive Nuclear-Test-Ban Treaty (CTBT). These laboratories corroborate the data provided by these stations, as part of the QA/QC program of the network and in particular to confirm by gamma spectrometry, the presence of fission products and/or activation products in air samples. Since 2000, the Provisional Technical Secretariat (PTS) of the CTBTO Preparatory Commission has organized annual Proficiency Test Exercises (PTE) as part of the quality assurance program for these laboratories. The poster presents a snapshot of the IMS laboratory network, the basis and process for certification of radionuclide laboratories, design of the PTE and criteria for assessment of PTE results. General trends in the performance of laboratories in the PTE since the first exercise in 2000 are presented.

RN-30/D: The radionuclide processing system of the CTBTO

Mika Nikkinen, Matthias Zaehringer and Robert Werzi
Comprehensive Nuclear-Test-Ban Treaty Organization Preparatory Commission, Wagramerstrasse 5, P.O. Box 1200, A-1400 Vienna, Austria
Contact: Mika.Nikkinen@ctbto.org

Abstract: The Preparatory Commission for the Comprehensive Nuclear-Test-Ban Treaty Organisation is the international organisation establishing the global verification system under the provisions of the CTBT, which bans any nuclear weapon test explosion or any other nuclear explosion. The verification system includes the International Monitoring System (IMS), a global network of monitoring stations (radionuclide technologies: particulate and noble gases; waveform technologies: seismic, hydro-acoustic and infrasound), a global communications infrastructure, an International Data Centre and the capability to carry out on-site inspections.

IDC supports the verification responsibilities of the Commission by providing objective products and services for effective global monitoring. IDC collects data from the IMS network to detect, locate and analyse possible nuclear events. At the IDC, data are automatically processed and interactively analysed, and data and products are distributed in near real time to the State Signatories.

Radionuclide component has noble gas and particulate stations, all the particulate stations and part of the noble gas stations are equipped with HPGe detectors for high resolution gamma ray spectroscopy analysis of the samples. Part of the noble gas systems are using beta-gamma analysis, as well. The spectra are measured at the station and transmitted to the International Data Centre for analysis. The analysis software is used to calculate concentrations of the isotopes in the air and to categorize the samples. If needed, the samples can be reanalyzed in the certified laboratories. The presentation shall illuminate the capabilities of the radionuclide monitoring system and how the data is processed and results distributed to the state.

RN-31/E: IMS Radionuclide Laboratory GBL#15.

C L Comley A V Davies, P Thompson, J McLarty, M Ball, C Miles, J Collins.
Contact: Christine.Comley@awe.co.uk

Abstract: Introduction: Article IV of the CTBT Treaty states that the International Monitoring System shall comprise radionuclide monitoring including certified laboratories and this shall be placed under the authority of the Technical Secretariat and operated by the States hosting or otherwise taking responsibility for them in accordance with the protocol.

The protocol states that the radionuclide monitoring stations shall be supported by laboratories, which shall be certified by the Technical Secretariat in accordance with the relevant operational manual for the performance, on contract to the Organisation and on a fee for service basis, of the analysis of samples from radionuclide monitoring stations.

Role of Certified Laboratories: The certified laboratories role is to re-measure with better sensitivity any samples containing fission and activation products that are indicative of a nuclear test and to re-measure QA/QC samples collected at any of the 80 radionuclide particulate stations.

History and Progress of GBL#15: Experts from the UK participated in the negotiations at the CD, providing advice on the capability required by the treaty to monitor worldwide radionuclide's from a nuclear event. The laboratory contributed to the PIDC in Arlington USA, by sending weekly data from a particulate station located at UKAEA Chilton UK, operated by the UK Environment Agency for Department Environment Food & Rural Affairs and measured at GBL#15.

Progress to Certification: The existing laboratory had the expertise and relevant equipment to meet the specification of a CTBT laboratory. The experience and equipment of the laboratory including the staff was reviewed by PTS before progressing towards certification as the UK radionuclide laboratory. Following the preparation of relevant documentation to meet the specification in INF-96, participation in PTS proficiency tests and a visit by the PTS, addressing observations by the quality assessor and the PTS, the lab was certified in December 2004 and commenced working on a fee for service as part of the IMS. Two informal CTBTO radionuclide workshops have been hosted by GBL#15 (Jan/Feb 2001 and Dec 2008), where the 16 CTBT laboratories progress in the operations has been made.

SEISMOLOGY

SEISMO-01/I: The September 2005 volcanic episode in the Manda Harraro rift of the Afar Depression: potential resource for ground truth events

Atalay Ayele, *Institute of Geophysics, Space Science and Astronomy, Addis Ababa University*
Contact: atalay@geobs.aauedu.et

Abstract: In September 2005, a major diking episode occurred in the Manda Harraro rift of the Afar Depression and the associated earthquake swarm was captured by modern seismic instruments in the region. A number of earthquakes (>400) with magnitude ≥ 3.5 m_b occurred associated with the September eruption. Continuos earthquake activity, including a volcanic tremor, was observed on 24-26 September at FURI seismic station in the outskirt of Addis Ababa at ~450 km distance. A minor felsic eruption occurred along a 500-metre-long vent on the northeast flank of the Dabbahu volcano. Results from InSAR and seismology suggest that a rift segment of length > 60 km was activated in September 2005 with a maximum opening of 8 meters. However, seismic data shows that the activity started in April, 2005 and continued until the major eruption in September. The tightly relocated events using hypoDD software indicates multiple clusters which may indicate multiple dike sources. Most of the fault plane solutions show normal faults consistent with extensional stress field of the area.

Calibration of a seismic monitoring system remains a major issue due to the lack of ground truth information and uncertainties in the crust and upper mantle structure. The September 2005 earthquakes cluster in the Afar Depression can be exploited as ground truth events resource for structural calibration so as to imrove the seismic detection capability of IMS stations in the area.

Keywords: Dabbahu volcano, Seismicity, Afar Depression, ground truth earthquakes

SEISMO-02/I: Spot-checking of IMS location accuracy

Nils-Olov Bergkvist and Peder Johansson, *Swedish Defence Research Agency (FOI), Stockholm, Sweden*
Contact: nob@foi.se

Abstract: It is of the utmost importance that the IMS has a capacity to precisely locate shallow seismic events of low magnitude. The importance is easy to understand in the context of a possible on-site inspection as 1000 km^2 is the maximum allowed search area for an inspection. This poster gives an account of the current IMS location accuracy based on analysis of events from a number of source regions (spot-checking).

The current IMS network detects and locates hundreds of mining blasts and mining associated events per year on a global basis. These events can provide a good spot-checking of the IMS location accuracy as they are both shallow and in a magnitude range of high relevance for the CTBT - the generalized body wave magnitude (mb1) is mostly in the interval 2.8 to 4.2.

Around one hundred and fifty events from 8 mining areas and large enough to be included in the Reviewed Event Bulletin (REB), produced by the IDC, have been studied. Three areas are in Europe (Sweden and Poland), two areas in Africa (Republic of South Africa), two in Asia (Kazakhstan) and one in North America (Wyoming, US). Ground truth information has been obtained from various sources. Four areas are covered by regional bulletins with a stated accuracy of 2 to 6 km and the other four areas are single mines whose locations can be obtained from Google Earth. To check the current location accuracy recent events (mostly in 2007-2008) have been used.

The location accuracy varies from one area to another, both in terms of systematic errors and the "random" component.

Systematic errors in the REB locations can be seen in many of the areas. Surprisingly, the largest systematic error (around 20 km) is seen for events in Wyoming although source-specific station corrections are being used for IMS stations in North America.

The 90% confidence ellipses associated to the REB locations are less than 1000 km^2 for all areas except Wyoming where many are larger. In spite of being large only 4 out of 32 confidence ellipses in Wyoming cover the ground truth location. This can be compared to the other extreme, tremors in the mining areas of the Republic of South Africa where 11 out of 12 confidence ellipses cover the ground truth location and all have an area less than 1000 km^2. Averaging over all areas studied the 90% confidence ellipses cover the ground truth location in just around half the cases. This shows that they are often too optimistic and underestimate the location error.

Although in general the REB locations are useful for an on-site inspection for most of the areas, the locations can be very sensitive to the phase identification for stations at regional distances. One single phase change (Pn to Pg, Sn to Lg) can move the event location tens of kilometres. A few examples of this happening are seen in the events studied.

SEISMO-03/I: Analysis of the Location Capability of the International Monitoring System
[1]Eric A. Bergman and [2]E. Robert Engdahl, *[1]Global Seismological Services, [2]University of Colorado*
Contact: bergman@seismo.com

Abstract: The location capability of the International Monitoring System is investigated by comparing locations reported in the Reviewed Event Bulletin (REB) with locations of events that meet GT5 criteria (location error less than 5 km), based on a careful analysis of all available seismic data with a specialized algorithm based on multiple event location. The GT5 events are associated with about 75 clusters of earthquakes that are distributed globally and contain about 500 events in common with the REB during the period 2004-2008 that was chosen for the comparison. REB magnitudes are smaller on average by about 0.3 magnitude units than ISC-reported magnitudes. Events in common between the REB and GT5 catalogs have magnitudes generally between 3.5 and 5.5 (REB magnitude). The distribution of location differences between the REB and GT5 locations has a median of 14 km, but is quite heavy-tailed. The mean of location differences is about 18 km and the 90% level is about 32 km. For cases in which a non-zero depth is reported in the REB, they are typically several tens of kilometers deeper than the corresponding GT5 location, ranging up to ~60 km deeper. There is little correlation between location differences and magnitude. Location differences have a weak inverse correlation with number of stations, number of associated phases, and number of defining phases in the REB. The largest location differences (> 30 km) tend to occur when the secondary azimuth gap (largest azimuth gap closed by a single station) exceeds about 150°. There is a tendency for location differences to have consistent azimuths for individual clusters, reflecting the interplay between station geometry and unmodeled earth structure. When secondary azimuth gap is less than about 150°, location differences between the REB and GT5 catalogs are about 18 km at the 90% level. Azimuthal coverage is the strongest factor in controlling location differences.

SEISMO-04/I: Datasets for Monitoring Research at the International Seismological Centre
István Bondár, Dmitry Storchak, James Harris and Beatriz Vera. *International Seismological Centre*
Contact: istvan@isc.ac.uk

Abstract: The International Seismological Centre (ISC) is an independent, non-governmental, non-profit organization supported by more than 50 research and operational institutions around the world. The mission of the ISC is to produce the ISC Bulletin – the definitive and most complete summary of world seismicity based on seismic reports from over 120 institutions. The ISC collects and maintains various data sets that are useful resources for monitoring research and other seismic studies, such as the IASPEI Reference Event List of globally distributed GT0-5 events, the groomed ISC bulletin (EHB), the IDC REB, USarray data, and historical ISS (International Seismological Summary, 1918-1964) bulletins. The ISC, jointly with NEIC, maintains the International Seismographic Station Registry and provides a number of additional services available from its web-site.

The ISC has a substantial ongoing development program to ensure that the ISC data remains an important resource for seismologists. This program includes modernizing the ISC location procedures by incorporating depth-sensitive phases and to account for correlated model error structures to improve hypocenter determination and the corresponding uncertainty estimates, as well as making consistent amplitude measurements from waveforms to improve magnitude determination. The ISC also steps up its efforts in collecting reviewed provisional bulletin data from networks soon after events occur to improve the timeliness of the ISC Bulletin. The ISC development program will result in considerable improvements in the accuracy of the ISC Bulletin.

SEISMO-05/I: Multi-Reference Relocation Technique
Cichowicz, A.*, Council for Geoscience, Pretoria, South Africa*
Contact: artur@geoscience.org.za

Abstract: A relatively higher concentration of seismicity is found in the mining districts when compared other regions in South Africa. The mining districts are covered with very dense mining seismic networks. The accuracy of location by mining networks is, in most cases, better than 200 m. A recently conducted study shows that errors in locating mine-related events by the South African National Seismograph Network vary from 4 to 8 km and, in exceptional cases, the location error could be as much as 20 km. Numerous techniques are employed to accurately locate earthquakes such as the absolute location, the master event relocation, the joint hypocentral determination and the double difference relocation. This investigation proposes a new multi-reference relocation technique. The relocation technique compensates certain time anomalies caused by lateral velocity heterogeneities, thereby leading to good relative locations. In the relative location approach, each event is relocated relatively to the master event. The multi-reference method uses the accurate location of several events

to constrain the location of the new event in contrast to the relative locations method which uses only one master event. The multi-reference method uses the polygon velocity and not the apparent velocity. The apparent velocity between the master event and the station is the same as the velocity between a relocated event and the station. The ray path for regional events is controlled by the layered medium for which the velocity model is usually not well known. However, the velocity in the volume of the earthquake cluster can be simplified and characterised by the specific value of the velocity. The relocation process takes place in the polygon volume therefore the polygon velocity is more suitable for relocation than the apparent velocity between the reference event and the station. The exact dimensions of the polygon are delineated by the location of all reference earthquakes. The polygon velocity could be significantly different than the apparent velocities between the source and stations. The cross-correlation method is used to compute the time delay. The cross-correlation measurements provide more precise measures of relative arrival time differences than manual phase picks. The distance between two points on the earth's surface is calculated using an accurate ellipsoidal model of the earth with an iterative formula that gives complete accuracy of a few centimeters over lines of any length. The inversion is based on the neighbourhood algorithm. The newly recorded event in some cases has a high-quality P- or S-wave arrival time which is not connected to the reference events arrival time. In order to utilise additional arrival times the inversion has be extended to the absolute location component. The first tests with synthetic and real earthquakes showed that the method has the ability to reduce the errors in location. Location improvement through the relocation process is obtained only when at event and the reference events are observed by at least seven stations (seven links). Less than five links gives an unpredictable result.

SEISMO-06/I: Consistency of the IDC Reviewed Event Bulletin with other global seismological bulletins and its unique contribution to seismicity studies

F. Kebede & K. Koch, *CTBTO PrepCom, Provisional Technical Secretariat, Vienna International Centre, P. O. Box 1200, A-1400 Vienna, Austria*
Contact: (Fekadu.Kebede@ctbto.org

Abstract: As a final result of the processing and analysis of seismological and other waveform technology data, the International Data Center (IDC) issues the Reviewed Event Bulletin (REB), being made available to the States Parties to the Comprehensive Nuclear-Test-Ban Treaty (CTBT). This bulletin contains, in essence, the expression of global seismicity as detected by the International Monitoring System (IMS) network. The IDC started routine bulletin production on 21 February 2000. Since then the IDC, has issued daily REBs over the course of the last 9 years, except for a total of 28 days, containing now more than 230,000 events. This corresponds to more than 25,000 events per year or more than 2000 events per month, on average. In the context of civil and scientific applications, the REB is contributed to the International Seismological Centre (ISC) for inclusion in their seismological catalogue of global seismicity. For quality assessment and quality assurance, the REB for the years 2000 to 2008 has been compared to similar bulletins of global seismicity, issued by the ISC and the National Earthquake Information Center (NEIC) of the United States Geological Survey after about 2 years and 1-2 months, respectively, of event occurrence. These evaluations aim at: (1) the consistency of event locations for events found to be common in the REB and the bulletin of ISC or NEIC; (2) the extent to which the REB contains extra events compared to the other bulletin, possibly being bogus in nature; and (3) events in the ISC/NEIC bulletins missing from the REB. Compared to the REB the ISC (Published) bulletin contains about 45,000 events per year, of which some 25,000 event solutions are recalculated by ISC. The NEIC Preliminary Determination of Epicentres (PDE) Monthly and Weekly Listings contain about 30,000 events per year, of which some 17,000 events can be considered genuine NEIC solutions, as either the hypocentral solution or, at least, a magnitude is calculated by NEIC.

The REB consistency assessment with respect to the ISC bulletin for the years 2000 - 2006 indicates an average 94% of events common to both bulletins having location differences less than 1° (and about 85% even less than 0.5°). To the other extreme, only 0.25% of events are in disagreement of more than 5°, hence, are fairly rare cases. A significant number of REB events are unique solutions in the ISC bulletin. These IDC events are mainly in remote and oceanic areas. The number of events of significant magnitude missed by the IDC is small and related predominantly to lack of sufficient number of observed arrivals to define an event. The actual number of IDC events rejected by the ISC for incorporation in its bulletin has constantly decreased over time, from 43 events in 2000 to 5 events in 2006. Results towards the consistency of REB and PDE locations for 2001-2008 follow along the same lines; except that the percentage for smaller location differences is higher: 97% of common events differ less than 1° and 92% even less than 0.5°. On the other side, location differences larger than 5^{o} are found in ten times lesser cases than for the ISC. The number of IDC events not produced by NEIC is comparable to the number of common events. In contrast, NEIC events not produced by the IDC are low in number and are mainly related to small magnitude events not expected to be detected by the sparse teleseismic IMS network.

SEISMO-07/I: Comparison of IDC and National Seismic bulletins in the Italian Region

Alessandra Giuntini, Rodolfo Console, Roberto Carluccio and Massimo Chiappini
Istituto Nazionale di Geofisica e Vulcanologia, Rome, Italy
Contact: giuntini@ingv.it

Abstract: The performance metrics adopted in this study for the comparison between the IDC and national bulletins are basically those already used in the past years. Here we extend the analysis also to the application of the Double Difference Joint Hypocentral Determination (DDJHD) method to a cluster of seismic event srecorded by the IMS stations. The seismic bulletins available for the comparison are produced by the National Institute of Geophysics and Volcanology (INGV) from the recordings of the Italian Seismological Network composed by more than 200 telemetered broad-band and short period stations. The requirements adopted by the analysts during the bulletin preparation include that a minimum of six phases is associated to each event. The comparison was limited to the events located in the area of 36°-48° N latitude and 6°-20° E longitude.
This area corresponds to a part of the Central Mediterranean region where the INGV locations are supposed to be reliable enough to be used as a reference data set for testing the results obtained by the IDC. The standard deviation of the hypocentral coordinates for the INGV locations within the inland territory is, in fact, typically less than 2 *km* for earthquakes with magnitude equal to or larger than 2.0. In total, the national bulletins reported, for the selected period and in the selected area, 1795 events of magnitude (either MD or ML) equal to or larger than 2.0. For the same time and in the same area the IDC REBs reported 72 events. A simple check allowed us to recognize that 63 of these events were reported by both bulletins. Most of the events reported by the IDC, but not by INGV, are located outside of the Italian national territory densely covered by the stations of the national seismic network. Only one event has been located inside the Italian region by the IDC but not by INGV. Attention has been paid to investigate the nature of this event.

Most of the INGV events missed by the IDC REB have small magnitude. There were 4 events of magnitude equal to or larger than 3.6 missing in the IDC REB. The IDC REB reported 50% of the events equal to or larger than 3.2.

For the 63 events in common between the two bulletins, we have analysed the differences in location.
Some systematic differences point clearly to problems with the velocity model adopted at the IDC, which doesn't take into account regional variations. The application of the DDJHD method to a cluster of events occurred in northern Apennines with the constraint of the location coordinates for one reference event shows that, not only the systematic errors, but also the random errors can significantly be reduced by the method.

The performance metrics adopted in our analysis clearly shows an overall improvement of the system in time with respect to similar comparisons performed in the past years. Here are some of the most relevant conclusions:

- The 90% detection threshold of the IMS network in the Central Mediterranean area is Ml(INGV) 3.6.
- The number of events for which the IDC error ellipse area is smaller than 1,000 *km*2 is slightly less than 97%.
- 90% of the events are reported with an IDC-INGV mislocation smaller than 20 *km*.
- 52% of the INGV epicenters of common events appears to fall outside the IDC error ellipses.
- Depths larger than 200 *km* are reported by both bulletins in agreement, so that they can be used for event screening. However, the accuracy in depth determination is too low for using the depth criterion for event screening of shallow events.
- The use of regional velocity models, as well as the application of the DDJHD method could improve the IDC location accuracy.
- The comparison between IDC and INGV *Ml* magnitudes for common events doesn't show systematic discrepancies, but random differences exist with a standard deviation of the order of one magnitude unit.

SEISMO-08/J: Removing Periodic Noise to Detect Weak Impulse Events

Jürgen Altmann, Felix Gorschlüter
Experimentelle Physik III, Technische Universität Dortmund, D-44221 Dortmund, Germany
Contact: altmann@e3.physik.tu-dortmund.de

Abstract: For close-range localisation of an underground explosion, a local seismic network can be set up during a CTBTO on-site inspection in the area of interest determined from teleseismic signals. Extreme sensitivity is required to detect the weak aftershock signals. At the surface they can be masked by periodic noise from machinery, road traffic or propeller aircraft. Spectra of periodic noise consist of discrete lines at the fundamental frequency and its harmonics.

We have developed an algorithm to find lines in a spectrum and have derived a mathematical expression for the discrete Fourier transform of a Hann-windowed sinusoid. By non-linear fitting of the theoretical function to the highest spectral points in the line we determine the frequency, phase and amplitude of the underlying sinusoid. Applying these optimal values the theoretical one-line spectrum is calculated and subtracted, starting at the strongest line, then continuing with the highest line in the remaining spectrum etc. Tests with a measured acoustic impulse with a superposed synthetic harmonic series show that the latter can be removed effectively up to very high amplitudes: the impulse is above the remaining harmonic noise for line-series peak-to-peak values up to 150,000 times the one of the impulse. In the case of two lines in immediate vicinity their parameters have to be optimised simultaneously. This works well with synthetic spectra and some real vehicle signals. Further research is needed to understand the problems which occur with some of our vehicle signals. The procedure is generic and can be applied as well to teleseismic and acoustic (including infrasound) signals.

SEISMO-09/J: Analysis of Detection Capability of the International Monitoring System

E. Robert Engdahl and Eric A. Bergman
[1]Eric A. Bergman and [2]E. Robert Engdahl, *[1]University of Colorado [2] ,Global Seismological Services,*
Contact: Bob.Engdahl@Colorado.EDU

Abstract: The detection capability of the International Monitoring System (IMS) is investigated by comparing detections reported by selected seismic arrays in the IMS networks with catalogs from selected areas having dense local networks and low magnitude thresholds. The study has been focused on three areas, the Tehran, Iran region, northern Honshu, Japan, and offshore northern California, USA. For each area the completeness of the local catalogs are all less than local magnitude 2.5. The arrays selected, based on length of time in IMS operations and epicentral distance to the study areas, are Makanchi (MKAR), Kazakhstan, Warramunga (WRA), Australia, and Lajitas (TXAR), USA. At teleseismic distances MKAR is used to study its detection thresholds for the Tehran and northern Honshu areas, WRA for the northern Honshu area for cross comparison, and TXAR for offshore northern California. For each array any events missed at magnitudes well above its detection threshold for the areas studied are documented for further investigation by IMS staff. Other parameters that are documented for each array are the differences in observed to predicted ray parameter, azimuth, and travel-time residual.

SEISMO-10/J: Relative Contribution of IMS Stations to the Reviewed Event Bulletin of the IDC

J. Coyne (1), Y. Jia (2), and R. Brogan (3)
(1) CTBTO PrepCom, IDC, Vienna, Austria (2) CTBTO PrepCom, IDC, Vienna, Austria; , (3) ENSCO, Inc., USA
Contact: john.coyne@ctbto.org, yan.jia@ctbto.org, Brogan.Ronald@ensco.com

Abstract: The International Monitoring System (IMS) is being developed by the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO) as part of its global verification regime. The seismic component of the IMS includes 50 Primary Seismic and 120 Auxiliary Seismic stations. Continuous waveform data are sent from Primary Seismic stations, while waveform segments are retrieved from Auxiliary Seismic stations. About 70% of the stations are currently operating and sending data to the International Data Centre (IDC) in Vienna, Austria. Automatic processing is invoked upon receipt of the data at the IDC, which results in a series of bulletins, known as Standard Events Lists (SELs). The final automatic bulletin, produced 12 hours behind real time, is reviewed by analysts. The result of this review is published by the IDC in the Reviewed Event Bulletin (REB).

An observed event will appear in the automatic or reviewed bulletins only if certain criteria are satisfied, including observations from a sufficient number of stations. Events in the automatic bulletin must be observed by two or more primary stations, while events in the REB must be observed by three or more primary stations.

Due to a variety of factors, different stations are more sensitive than others to different regions of the world. Contributing factors include: near-surface geologic conditions under the station, station noise levels, station

design, global distribution of seismicity, and heterogeneities within the earth. The sensitivity of stations will be illustrated by a series of global maps which show the probability of a particular station to contribute defining phases for events for each region of the globe. The maps are based on historical contribution of each station to the REB. Based on these global maps, various criteria will be applied in order to identify the relative ranking of stations contributing defining phases to the REB.

The impact of magnitude on station sensitivity will also be investigated. In some areas of the world the REB contains events of very low magnitude, due to clustering of Primary Seismic stations and regional seismicity. It is unlikely that such events will be observed outside of this cluster of stations, and consequently may bias the resulting sensitivity maps. The influence of large magnitude events will also be investigated.

SEISMO-11/J: **Construction and Application of Time-Delay Correction Surfaces for Improved Detection and Estimation on Seismic Arrays**

Steven J. Gibbons, Jan Fyen, Frode Ringdal
Contact: steven@norsar.no

Abstract: Array stations are central to the seismic component of the International Monitoring System (IMS) for verifying compliance with the Comprehensive Nuclear Test-Ban-Treaty (CTBT). Delay-and-stack beamforming lowers the detection threshold for weak seismic signals and provides relatively reliable slowness and azimuth estimates for improved phase association and event location. Since the earliest days of seismic array operation, it has been appreciated that the predicted and measured slowness vectors can differ significantly. A plane-wavefront model often provides good alignment of coherent signals, such that Slowness and Azimuth Station Corrections (SASCs) may be applied to reduce bias.

For some arrays, the measured time-delays are not well modeled using a plane-wave formulation and beamforming according to theoretical arrival times results in significant waveform misalignment and beam loss. Beamforming on the large aperture NORSAR array (PS27) has to be performed using empirically determined time-delays, and iterative estimation techniques are required for optimal parameter estimation.

We have identified regions of slowness space for which PS27 phases in the Reviewed Event Bulletin (REB) display systematic residuals in slowness and azimuth, indicating that the current calibrated time-delay models for this array require review and modification.

Given an array of N sensors, our aim is to construct N-1 single-site correction surfaces which, for a hypothetical slowness vector (Sx,Sy), specify perturbations to the theoretical delay times which best preserve the alignment of coherent waveforms with respect to the array reference site.

Such correction surfaces should both provide delay-times for optimal beamforming and allow for one-step direct slowness estimates. Pointwise estimates for the correction surfaces are provided by the residuals between predicted and measured time-delays, calculated for well-observed phases. An initial set of surfaces for PS27, generated using kriging and least squares inversion, has been demonstrated to provide parameter estimates with smaller bias than in the REB for many regions of slowness space.

Some regions of slowness space are problematic due to waveform dissimilarity between sensors, and others are poorly constrained due to a lack of high-SNR calibration signals. A significant additional effort will be required to address the optimal processing of partially coherent signals and the extrapolation of correction surfaces to poorly-constrained regions of slowness space.

We note that significant deviations in time-delays exist for even closely spaced elements of PS27, indicating that a similar treatment may provide significant improvements for smaller aperture IMS arrays.

The scalar correction surfaces account for elevation effects as well as velocity heterogeneities and effectively circumvent the need to apply SASCs.

SEISMO-12/J: Capabilities of the IMS Seismic Auxiliary Network

David Hafemeister, *Center for International Security and Cooperation, Stanford University*
Contact: dhafemei@calpoly.edu

Abstract: The 2002 US National Academy of Sciences study, *Technical Issues Related to the Comprehensive Nuclear Test Ban Treaty*, concluded that increased monitoring confidence would be obtained at the 100-ton level if the auxiliary IMS network were utilized more fully. If there were evidence that an event may have occurred, the auxiliary network data would be examined to study the issue. It would be useful to know how the threshold level of the IMS seismic network would be improved by including the auxiliary data. This could be presented with global maps and contours by the ISS study, comparing the primary network alone versus the primary and auxiliary, together. **The NAS study concluded that thresholds "would drop generally by about 0.25 magnitude units in Europe, Asia, and North Africa, and by about 0.5 magnitude units in some regions** (such

as Iran)." The NAS study also discussed four additional enhancement approaches: (1) Augmentation with data from areas of concern, (2) correlation analysis that compares past data from near an event with new data, (3) Threshold Monitoring that combines signals from many IMS stations and (4) examine data from the Global Seismic Network and the International Seismological Center with about 3,000 seismic stations. It would be useful if the ISS study examined these conclusions.

This paper lists past estimates of the threshold detection levels for nuclear explosions for various seismic networks, showing how seismic detection has improved over time. **Our pedagogical calculation shows that the average reduction in threshold level is about 0.25 magnitude units for the Total IMS network of 170 seismic stations (Primary plus Auxiliary) as compared to the Primary network of 50 stations.** It would be useful if network simulations obtained threshold level maps for both the Total and Primary networks for the June 2009 ISS meeting. Since the Auxiliary network can be used in both a spotlight mode when needed or in continuous mode, it would be useful to have more accurate calculations of this affect.

Reference: [i]National Academy of Sciences, *Technical Issues Related to the Comprehensive Nuclear Test Ban Treaty* (National Academy Press, Washington, DC, 2002). www.nap.edu/catalog.php?record_id=10471
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[iii]D. Hafemeister, "Progress in CTBT Monitoring Since its 1999 Senate Defeat," *Science and Global Security 15,* 151-183 (2007). www.princeton.edu/~globsec/publications/SciGloSec.shtml. Presented at Article XIV EIF-CTBT Conference, Vienna, September 2007. D. Hafemeister, "The Comprehensive Test Ban Treaty: Effectively Verifiable," *Arms Control Today 38*(8), 6-12 (October 2008). www.armscontrol.org/act/2008_10/Hafemeister

SEISMO-13/J: Seismic event bulletin evaluation based upon probability

Wang Haijun, Liu Junmin, Wang Yan. *CTBT Beijing NDC & RNL, Beijing 100085,China*
Contact: wang.haijun@ndc.org.cn

Abstract: Matching events screening are the most important issues for comparing two different seismic event bulletins. Origin time, latitude and longitude of epicenter are used to construct eigenfunction. Suppose the eigenfunction obey normal distribution, events matching probability can be calculated with the corresponding probability density function. Matching events are screened out automatically based on events matching probability. The threshold of events matching probability is determined by analyzing the relation of events matching ratio and parameters of matching events. The new algorithm proposed here can be used in evaluation of network monitoring probability, analysis of data automatic processing system as well as seismic event bulletin comparison.

Key Words: Seismic , Bulletin , Evaluation , Probability

SEISMO-14/J: Anatomy of seismic records; detection and analysis of secondary phases like pP, sP, PmP and Lg.

E. S. Husebye; Bergen *Center of Computational Science. UNIFOB,UoBergen, Høyteknologisenteret, 5008 Bergen, Norway;* ***Yu. V. Fedorenko;*** *Polar Geophysical Institute, KSC RAS, Apatity, Russia; T. Matveeva: Dept. of Geoscience, Allegaten 41, 5007 Bergen, Norway.*
Contact:: esh@bccs.uib.no

Abstract: Seismology is the principal tool for exploring the interior of our dynamic Earth. This in turn depends on our ability to extract relevant information from the seismograph records. Despite great progresses on all aspects of CTBTO operations over the last 40 years remaining and outstanding problems in this context are reliable pickings and verification of secondary phases. Such phases are essential for accurate event location and focal depth estimation and hence seismic source discrimination.

2D signal detector: Most used is the 1D STA/LTA detector albeit the so-called F detector (semblance type) are often recommended alternative. For single stations the 1D STA/LTA detector is commonly used while including horizontal components substantial gains are feasible. Basic requirements are lack of noise coherency between waveform components and also for the component envelopes (STA-traces) and these assumptions were validated. A 2D detector performs well at a threshold of 3.0 while the 1D threshold is 4.0 conditions on similar false alarm rates. For teleseismic ranges 2D detectors are naturally less efficient.

Secondary phase pickings of pP, PmP and sP. This task is left to presumably experienced analysts and results are not fool-proof and the corresponding focal depth estimates are not to be trusted. What is lacking is a scheme for validating phase pickings that is testing phase features like particle motion, azimuth and incident angles when for a preliminary event location. We have developed a Bayesian methodology for dealing with complex nonlinear models of secondary phases which has been tested on local recordings from Karelia, NW Russia. It works well and an impressive feature here is the rejection of scattering pulses being more than 5 deg out of the azimuth plane. The ultimate verification test is to estimate jointly the focal parameters for any event using secondary phase pickings from a network of stations – work in progress.

Lg arrival time pickings. The Lg phase is shear waves travelling in the crustal waveguide and as such is a prominent seismogram feature at local and regional distances. However, Lg arrives in the P- and S-coda so its onset cannot be identified reliably due to a weak or gradual first onset. The Lg group velocity is around 3.60 km/s so its wavelengths are short and hence should be convenient for accurate epicenter locations. Rectifying seismogram records using the Hilbert transform procedure we were able to read consistently Lg peak amplitude arrival times for many stations in Europe and with group velocities reflecting various tectonic environments. Joint usage of P- and Lg-arrival times for location is not feasible since Origin Times (OT) are not necessarily the same. Complimentary to our Lg picking study is generating Lg synthetics for different sources and focal depths in order to illuminate the OT problem above.

At the Conference we would present updated results on the above research topics.

SEISMO-15/J: Analysis of the IDC Reviewed Event Bulletin for detection capability estimation of the IMS primary and auxiliary seismic stations

***Tormod Kværna, Frode Ringdal**, NORSAR, PO Box 53, 2027 Kjeller, Norway.*
Contact: tormod@norsar.no, frode@norsar.no

Abstract: We have investigated the IDC Reviewed Event Bulletin (REB) for the time period 1 January 2000 to 31 March 2009 to quantify the event detection capability of individual seismic stations of the International Monitoring System (IMS). For a specific target area, we can obtain estimates of the detection threshold of a given station by considering the ensemble of REB reported events in the area, and simply downscaling each event magnitude with the observed SNR at the station. However, there are some problem areas associated with this procedure such as:

- Possible biases in the REB magnitudes caused by non-detections
- Skewness in the distribution of threshold estimates, also caused by non-detections
- The validity of using the signal-to-noise ratio for downscaling the event magnitude

We address these issues by dividing the events into a binned global grid system and introduce a data censoring procedure to reduce these effects. A major result of this study is a quantification and ranking of the IMS primary and auxiliary seismic stations based on their capability to detect events within regional, teleseismic and core phase distance ranges. For each station, source regions with noticeable signal amplitude focusing effects (bright spots) and defocusing effects are conveniently identified and quantified. We will also present results from applying maximum-likelihood magnitude estimation techniques for validation of the censoring procedure

SEISMO-16/J: Enhancements of Seismic Detection Capabilities resulting from the Bilateral Cooperation of the NDCs of Austria and Czech Republic

Ulrike Mitterbauer[1], Josef Havíř [2], Jan Švancara[2], Peter Melichar[1], Wolfgang Lenhardt[1]
[1] Austrian National Data Centre at the Central Institute for Meteorology and Geodynamics, Vienna
[2] Czech National Data Centre at the Institute of Physics of the Earth, Masaryk University, Brno
Contact: wolfgang.lenhardt@zamg.ac.at

Abstract: The cooperation between the Austrian and Czech National Data Centres (NDCs) has been in existence since the establishment of the CTBTO Preparatory Commission in 1997. Among the goals of the bilateral cooperation are the improvements of seismic events location accuracy in the Central European Region utilizing all data collected by both NDCs and readiness to support the CTBTO with supplementary data and information which are formally not part of the IMS data as needed for the IDC and IMS evaluations.
Comparative studies of IDC and NDC event locations for the area of Austria and the Czech Republic have been carried out using the IDC event locations reported in the Reviewed Event Bulletins (REBs) for the period 2004 - 2008.

In this period 29 tectonic events with local magnitude ML=>3.0 were located by the Czech and Austrian NDCs within the area of interest. Due to higher seismicity in Austria there are more events from Austria than from the territory of the Czech Republic; the same pattern of more events from Austria is correctly reflected in the REB.

The comparison revealed that only 17 of the 29 events were included in the REB, the remaining 12 events were not located by the IDC. Most events which were not reported in REBs had local magnitude smaller then 3.3, the highest local magnitude of an event not included in the REB was 3.7. The magnitudes of these "missing" events are generally below or close to the expected average global detection capability of the IMS seismic network.

To assess the real IDC location accuracy 17 events have been analysed. These events were reported both in the REB and in the earthquake catalogues of the NDCs. Most events showed that a difference between the REB and NDC locations is smaller than 30 km, with an average difference of 18 km (median is 14 km). The largest difference occurred for an event at the Austrian/Hungarian border and amounted to 59 km.

Only weak correlations have been found between the location difference and the number of stations detecting the event, the event magnitude, and the azimuthal coverage. Based on the Protocol to the CTBT the on-site inspection should be carried out in the area where the triggering event occurred, the size of the on-site inspection area should not exceed 1000 km². The area of 1000 km² can be seen as an equivalent circle area with a radius of 17 – 18 km. Therefore the estimated location difference between the IDC and the NDC locations for the area of interest is at the edge of the uncertainty expected by the Treaty provisions for on-site inspection.

SEISMO-17/J: An approach for denoising waveform data by Auto-Regressive algorithm

Nobuo ARAI, Takahiko MURAYAMA, Makiko IWAKUNI and Mami NOGAMI
Japan NDC-1, Japan Weather Association
Contact: murayama@jwa.or.jp

Abstract: The waveform data observed by the CTBT IMS are mainly used for making the epicenter and characteristics of an observed event clear. Waveform data usually consist of the signal from natural phenomena or man-made phenomena and site specific noise from the ambient surrounding.

Unfortunately, if the dominant frequency of the signal would be within the frequency band of the site specific noise and the amplitude of the signal would be close to detection limit, the signal may be buried within the noise.

Bandpass filtering of data is often used to reduce the influence of the background noise (such as the site specific noise) and enhance signal-to-noise ratios. However, it would not be an adequate approach for extracting signals from raw data for distinguishing its nature of waveform in such case.

To remove site specific noise components from observed raw data, an Auto-Regressive (AR) algorithm is applied for extraction of the signal. The time series of the noise is simulated by AR algorithm, and then the signal would be extracted by removing the simulated noise from raw data.

Effectiveness of such algorithm has been tested by some infrasound data observed at the IMS.

In this symposium, we are both confident and delighted to exhibit possibility and capability of an AR algorithm for denoising waveform data observed.

SEISMO-18/J: Three-Component Waveform Cross-Correlation Detection Method and Its Implication to the Seismic Monitoring for CTBT

Hong-Chun Wang , Ping Jin and Yan He. *Northwest Institute of Nuclear Technology, Xi'an ,China*
Contact: wang.haijun@ndc.org.cn

Abstract: There are many industrial explosions of tens of tons TNT in mines all over the world. Such explosions normally generate seismic signals which can be detected at regional and sometimes even at some sensitive teleseismic stations. These explosions may cause false alarm for the CTBT monitoring, so an efficient method should be implemented to excluded them from the suspicious event list. Cross-correlation detection is an effective approach for the detection of these clustered explosions due to their similar waveforms and co-location. In this paper we report the test results of using waveform cross-correlation approach to detect explosions detonated within a coal mine which is located about 200km away from Urumqi, the capital of Xinjiang province, China. We use three regional stations' historical recordings of confirmed explosions within this mine area as reference signals. Records at regional stations are cross-correlated with reference signals for the same station and component. For each station, the resulted correlation waveforms of different components are summed together to detect signals of relative high correlation coefficients. The arrival times of detections at different stations are shifted with those of the corresponding reference signals. A detection of explosion is declared when detections at a given number of stations are triggered at the same time. Results obtained with this method show that small explosions within the concerned site may be detected while false-alarm rate is reduced to nearly zeros.

The dependence upon distance from the reference event for the above-mentioned method is also reviewed in this paper. Results obtained suggested that explosions within 3km away from the reference explosion may be reliably triggered and three reference explosions are sufficient to detect most of the mining detonations in the whole mine area given the combination of frequency band and window length of reference signals. For the routine detection of the industrial explosions, we develop a program for the cross-correlation detection based on the historical explosion waveform database.

SEISMO-19/J: Local / regional events discrimination using seismic main wavelet & Highlight of local conditions using seismic coda

ElHassan Ait ElAasri, Es-Saïd Akhouayri, Driss Agliz and Abderrahmane Atmani
Seismic signal processing team, Electronic, Automatic and Signal processing Laboratory Physics' Department, Faculty of Sciences, IBN ZOHR University, B.P. 8106, Agadir, Morocco
Contact: akhouayri@msn.com

Abstract: The Agadir seismic database was implemented on May 1998 by the design and implementation of an automatic station detection of seismic events, and then on November 2001 by installing a seismic local network managed at quasi-real time via an automatic central detection. The digital database is powered by two types of events, natural seismic events of tectonic origin and anthropogenic events incurred in shooting careers. Thus, a large quantity of data is currently available.

In this work we try to highlight the aspects that are similar to the events, regardless of the type and the distance to the source. The used function is the correlation, commonly used in signal processing; it can reflect the overall similarity of seismic events.

The main wavelet processing has shown that this function can quantify the non-correlation degree of local/regional events, and as a result differentiate events.

Similarly, this work has helped to highlight the effect of local characteristics whose sizes are contained in the seismic coda. By applying the correlation function to the seismic coda, we were able to identify the existence (or not) of a character depending on the source-station distance, non-depending on the type of the event, but on the site of registration.

Ultimately, we can conclude that the correlation might allow the classification in local and regional events since the events located at relatively long distances, it could provide a major factor correlation. This prompts us to talk about the concept of seismic network resolution. We believe that a distance not less than ten times the size of the network will give a perfect correlation, for an event recorded by the network. The only constraint is that the events are filtered during the journey and due to inadequate detection network by short period stations. Conversely the correlation is not a reliable tool for the classification of local seismic events.

The correlation of the seismic coda can unequivocally provide the information mainly on local conditions (soil type, heterogeneity, default…). The seismic coda may be regarded as the local signature, it depends a bit on the source type and the travelled path.

SEISMO-20/J: Testing the Applicability of P/S Amplitude Ratios for the Discrimination of Low Magnitude Seismic Events

Pan Chang-zhou, Jin Ping Wang Hong-chun, *Northwest Institute of Nuclear Technolog, Xi'an,China*
Contact: bullpan@126.com

Abstract: Applicability of regional P/S amplitude ratios for the discrimination of low-magnitude seismic events was tested and proved using earthquakes and explosions in central Asia. Here the term P/S amplitude ratios include Pn/Sn, Pn/Lg, Pg/Lg and Pg/Sn ratios computed within various frequency passbands. Results obtained show that regional P/S amplitude ratios which may discriminate medium or large magnitude events well are also applicable to low magnitude events. Their performances for low magnitude events are almost as good as that for medium or large events. Statistical comparisons based on P/S ratios of different types from the four seismic stations WMQ, BLK, MUL and MAK showed that the average misclassification rate for low-magnitude seismic events averagely was only 2 percent higher than that for medium and large magnitude seismic events.

SEISMO-21/J: Comprehensive Test Ban Monitoring: Contributions from Regional Moment Tensors to Determine Source Type and Depth

Hellweg, M., DREGER, D. and ROMANOWICZ, B., *UC Berkeley, Berkeley Seismological Laboratory, 215 McCone Hall #4760, Berkeley, CA 94720*

Contact: peggy@seismo.berkeley.edu

Abstract: Regional distance moment tensor analysis can be used, even for relatively small magnitude events (*M* > 3.4), to discriminate explosions from naturally occurring earthquakes. For earthquakes, MT analysis can provide insight into event size, depth and type of faulting, as well. Besides explosion monitoring, mechanism information is important for applications like assessing earthquake effects and tsunami warning. We apply the UC Berkeley full moment tensor code to a target region in Eurasia using data from broadband seismic stations operated by the International Monitoring System (IMS). We have selected the region from 30 – 70 degrees E and from 20 – 45 degrees N, for its seismicity and IMS station availability. Greens functions are calculated for two 1D velocity models. The first is the generic global model, iasp91. The second velocity model is a 1D model adapted from Pasyanos et al (2004) 3D model for the region. Seismic moment magnitude (M_w), depth and source mechanism are estimated using both Greens types of functions, for a subset of events of M >4 (and possibly M>3.5). These results will serve to support an assessment of magnitude estimation and screening capabilities of the IMS.

SEISMO-22/J: Development and testing of seismic regional discriminants

Valerio Materni[1],[2], Rodolfo Console[2], Stefano Chiappini[2], Massimo Chiappini[2] and Giada Adelfio[3]

[1]Dipartimento di Fisica "E.Amaldi", Università degli studi Roma Tre, Italy; [2]Istituto Nazionale di Geofisica e Vulcanologia, Rome, Italy; [3]Dipartimento di Scienze Statistiche e Matematiche "Silvio Vianelli", Università di Palermo, Italy

Contact: valerio.materni@ingv.it

Abstract: The routine process of the IMS data at the CTBTO International Data Center (IDC) is aimed at identifying in the seismological bulletins all the seismic events the source of which is certainly natural. This process, named screening out, is carried out on several tens of earthquakes per day. It is important that the methods used for the screening process are as reliable and efficient as possible, so as substantially reducing the number of suspicious events without classifying any explosion as natural events.

The principal identification method applied at the CTBTO IDC is based on the difference between the *Ms* magnitude, computed from the amplitude of the surface Rayleigh waves with period close to 20 s, and the *mb* magnitude computed from the amplitude of the body waves with period close to 1 s. The applicability of this method is, however, limited by the difficulty of detecting surface waves for events of low *mb* magnitudes, so as to allow the computation the *Ms* magnitude for such events, which are very numerous. For CTBT verification, in case of events of small magnitude, the use of stations at regional distances from the epicenter, is crucial. In this context, another category of seismological screening, the so-called regional discriminants, can be applied. This method is based on the amplitudes of the surface waves (*Lg*) at much higher frequencies (8-12 Hz). Unfortunately, these high-frequency waves are not easily detectable, and the method requires regional calibration curves for each specific site, calibrations that are not available on a global scale.

In this study we explore the capacity of a new discriminant, applying the classical *mb*-*Ms* method to surface waves of periods shorter than 20 s (6-12 s), more easily observable at regional distances. Rather than using the *Ms* magnitudes, this discriminant is directly based on the surface wave amplitudes, by comparison with the amplitudes expected through a theoretical model of explosive source. According to the study of Taylor and Patton, (BSSA 2006) this method is expected to reduce the false-alarm rate, i.e. the number of events detected but not screened out.

Before its application on routine basis, a discriminant method should be optimized and tested by means of rigorous statistical methods. In our work, we adopt a mathematical theoretical framework named "Discriminant Analysis". The Discriminant Analysis is known as a statistical tool in a variety of applications for classifying single observations in two or more sets through the search of the optimal linear functions of the parameters describing the observed data. In the learning phase, this method allows the adjustment of the contribution of each single parameter to the discrimination algorithm.

In our work, for the learning phase of the Discriminant Analysis we have taken *mb*, *Ms* and depths from the NEIC reports for 105 known explosions in former nuclear test sites (China, India, Pakistan, Nevada and Kazakhstan) and 263 natural earthquakes belonging to these areas or neighbouring regions. Then, for the test, we have considered *mb*, *Ms* and depths reported in REBs from 806 natural earthquakes distributed on the whole globe. Of these, the Discriminant Analysis has classified 798 events as earthquakes and left 8 events classified as explosions. The "false alarm" rate is quite smaller than that achieved by the standard IDC screening procedure, although we can not guarantee that the number of explosions missed by the method would be zero.

For comparison with the classical *mb-Ms* method, the new regional discriminant method, based on the theoretical surface wave amplitudes, has been applied to waveform data from 10 events selected in Indonesia, Kyrgyzstan, Greece, China (Xinjiang), China (Sichuan), Japan (Honshu), India, Kaukasus and Iran. In most cases, the regional investigation has led to a better detection of the seismic waveform, and then to a better event identification.

Our results show that these new methodologies seem capable of bringing advantages in the identification of seismic events, and that the development and testing of such procedures could be usefully implemented in the future verification system

SEISMO-23/J: Aftershock Characteristics of Explosions Relative to Earthquake Sequences

Sean R. Ford, William R. Walter and Jerry J. Sweeney, *Lawrence Livermore National Laboratory*
Contact: bwalter@llnl.gov

Abstract: The behavior of explosion aftershock sequences at the Nevada Test Site is quantitatively analyzed and compared with earthquake aftershocks in the southern Great Basin of the Western US (Ford and Walter, 2009). The regional earthquake catalog was taken from the Yucca Mountain Hazard Project where the estimated magnitude of completeness is M2.5 from 1968 to 1978 and M1.5 from 1978 to 1993. The aftershock model designed by Reasenberg and Jones (1989, 1994) allows for a probabilistic statement of earthquake-like aftershock behavior at any time after the mainshock. This model was used to investigate the degree to which explosion aftershock sequences behave like earthquake aftershock sequences. Generally, explosion aftershocks are not as large or as numerous as earthquake aftershocks. Of the 67 M>4 earthquakes in the study region, 63 of them produce an aftershock within the first seven days with a magnitude equal to or greater than is predicted by an aftershock model of the region. Conversely, only six of 93 M>4 explosions produce a predicted aftershock using the same model for the same period. Further, all but five earthquakes (92.5%) produce a number of events within seven days that is consistent with the aftershock model, whereas only 1% of the explosions reach a number of events that is predicted by the model in the same period. The greatest difference in behavior is seen in the number of aftershocks produced, but this observation requires a low magnitude of completeness for the given earthquake catalog. These results at NTS indicate clear differences between explosion and earthquake aftershock characteristics observed at regional distances. These observations should be evaluated at other nuclear test sites to understand the effects of differences in the geologic setting and nuclear testing practices on aftershock characteristics. These models provide a quantitative means to assess aftershock productivity for possible detection and characterization during an On-Site Inspection under the Comprehensive nuclear-Test-Ban Treaty.
Reference: Ford, S. R. and W. R. Walter, 2009. Aftershock Characteristics as a Means of Discriminating Explosions from Earthquakes, submitted to *Bull. Seism. Soc. Am.*

SEISMO-24/J: Satellite Earth observations support CTBT monitoring: case studies including the nuclear test in North Korea of Oct. 9, 2006 and comparison with seismic results

J. Schlittenhardt[1], M. Canty[2], I. Grünberg[1]
[1]Bundesanstalt für Geowissenschaften und Rohstoffe, Stilleweg 2, 30655 Hannover, Germany; [2]Forschungszentrum Jülich GmbH, 52425 Jülich
Contact: joerg.schlittenhardt@bgr.de

Abstract: The Comprehensive Nuclear-Test-Ban Treaty prescribes the use of seismic stations and arrays as the main measure for verification of Treaty compliance. Since the inception of the Treaty, a vast amount of open source earth observation satellite data has become available. This poster investigates the potential for combining seismic and satellite data for more effective monitoring and response.

Synergy between seismic and satellite based data for the characterization of underground nuclear testing in the CTBT monitoring context has been demonstrated through the application of the multispectral MAD (Multivariate Alteration Detection) technique to historical underground nuclear explosions detonated at the Indian Test Site and at the Nevada Test Site, USA, (Canty & Schlittenhardt, 2001; Canty et al., 2005). In continuation of this work, the ability of DInSAR (Differential Interferometric Synthetic Aperture Radar) techniques to reveal both co-seismic and post-seismic subsidence signals in the cm-range within the damage (spall) zone caused by underground nuclear explosions, as reported by Vincent et al. (2003), is revisited using ERS-data over the Nevada Test Site. Subsequent investigations at other test sites also showed limits of the DInSAR technique when mountainous topography and/or temporal and spatial baseline differences become critical factors (Schlittenhardt et al., 2008).

With data acquired before, during and after the alleged North Korean underground nuclear test on October 9, 2006, wide area change detection techniques using medium resolution optical/infrared satellite sensors are combined with localized high-resolution imagery to attempt to pinpoint the test location within the area

identified by the seismic measurements. Problems associated with the timeliness, degree of coverage and ambiguity of the remote sensing data are pointed out, but it is generally concluded that their integration into the CTBT regime would valuably complement the existing seismic observation network.

This work has been carried out in part within the framework of the Global Monitoring for Security and Stability (GMOSS) Network of Excellence initiated by the European Commission.

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SEISMO-25/J: Difference in seismic cepstrum between explosions and earthquakes

Fu-Sheng Wei and Zhong-Huai Xu
Institute of Geophysics, China Earthquake Administration, Beijing 100081, China
Contact: weifusheng@sohu.com

Abstract: The Fourier transform of the logarithmic power spectrum is known as the cepstrum of a signal. Usually, cepstrum of seismic records of explosions show an approximate linear variation trend with minor fluctuation, while that of earthquakes display significant variation with peaks and troughs. To express such difference quantitatively, we define an index C for each cepstrum as the sum of the squared residual amplitudes which deviate from the linear variation trend. In finding the linear trend we firstly normalized the cepstrum, then removed its peak value at the beginning time and made a least square fitting to the remained cepstrum with a linear variation model. According to our previous studies the C index thus constructed usually has a value lager than 1 for variable cepstrum of earthquakes, while it is smaller than 1 for explosions.

We analyzed the digital seismic records at northeastern China stations of 21 events, including 9 small to moderate earthquakes, 11 industrial explosions and 1 nuclear explosion of 9 Oct. 2006, occurred in Korea peninsula since 2000. Each event is well recorded by 4 to 12 stations. Epicentral distances of these events are less than 700 km.

Based on the waveform data of first arrived P wave train of vertical component we calculated the cepstrum of these events and found corresponding C value of each event. Our result indicates that, 9 natural earthquakes have a C value between 1.2 and 1.7, all lager than 1, with a mean C of 1.5; while the C values of 11 industrial explosions are between 0.1 and 0.7, all smaller than 1.0, with a mean C of 0.3. This means that the C criterion describing main feature of the cepstrum can be used to well discriminate industrial explosions from natural earthquakes in the area of Korea peninsula.

The cepstrum of the 6 Oct. 2006 Korean nuclear explosion displays a monotony decaying variation without remarkable peaks and troughs. The corresponding C values obtained from seismic records of 15 stations are all below 1.0, with a mean of 0.4. So by using our cepstrum C criterion this event is recognized as an explosion.

SEISMO-26/J: Dealing with Hard-to-Identify Seismic Events Globally and Those near Nuclear Test Sites

Lynn R. Sykes and Meredith Nettles, *Lamont-Doherty Earth Observatory and Department of Earth and Environmental Sciences, Columbia University, Palisades NY 10964 U.S.A.*
Contact: sykes@ldeo.columbia.edu

Abstract: Under the CTBT the identification of nuclear explosions and so-called either problem or anomalous seismic events is reserved for national CTBT authorities. Since their findings typically are classified, it is difficult to ascertain how well seismic events of various sizes can be identified in addition to being detected and located. We update through 2008 Sykes' 2002 study "Four Decades of Progress in Seismic Identification Help Verify the CTBT". Nevertheless, only about 70 events detected over the past 50 years were singled out in unclassified scientific and governmental publications or the media as problem events whose identification potentially compromises the verifiability of the CTBT. They are a tiny fraction of the many earthquakes that have been reported. Special studies of problem events using a variety of techniques identify nearly all of them as either nuclear explosions, earthquakes, chemical explosions or mine-associated events. The seismic magnitudes of problem events have decreased dramatically with time. Since many occurred either near nuclear test sites or in a few countries that may be seeking nuclear capabilities, they have been, and continue to be, of great importance to policy makers.

We also examine 36 seismic events located by the IMS and its predecessor from 2000 through 2008 within 100 km of 6 nuclear test sites. Most occurred near the test sites in China, Nevada and Pakistan. No events were reported by the IMS near the Russian site at Novaya Zemlya or that of India. Only two seismic events were reported within 100 km of the North Korea nuclear explosion of 2006. We examine events of magnitude > 4.0 using long-period body and surface waves, focal mechanisms (CMT), mb-Ms, depth phases and numerous foreshocks/aftershocks. CMT mechanisms, which clearly identify an event as an earthquake, now extend down to moderate-size events (for NTS to mb 3.4). Smaller events require an analysis of spectral ratios of regional seismic waves, which is the subject of a companion paper by Kim, Richards and Sykes (2009).

SEISMO-27/J: Discrimination of Earthquakes and Explosions near Nuclear Test Sites using Regional High-frequency Data

Won-Young Kim, Paul G. Richards and Lynn R. Sykes, *Lamont-Doherty Earth Observatory of Columbia University, Palisades, NY 10964, U.S.A.*
Contact: wykim@LDEO.columbia.edu

Abstract: We examine over 50 seismic events located by the CTBT IDC and its predecessor from 2000 through 2008 within 100 km of eight known test sites. Most occurred near the test sites in China, Nevada (U.S.A.) and Pakistan. No events were reported in the Reviewed Event Bulletin (REB) by the IDC near the Russian site at Novaya Zemlya or that of India. Only two seismic events were reported within 100 km of the North Korea nuclear explosion of 2006. The selected events are in the magnitude range of m_b(REB) 3.0 to 4.4. For seismic events of magnitude > 4.0, focal mechanisms (CMT), m_b:Ms, depth phases, and analysis of teleseismic body waves and long-period surface waves can be used to identify these events as reported in a companion paper by Sykes & Nettles (2009). However, regional phases *Pn*, *Pg*, *Sn* and *Lg* must be used to characterize the majority of small events with magnitude m_b(REB) < 4.0 (~75% of the selected events). We analyze regional three-component seismic records to characterize those events and to seek the best regional phases and frequency bands that can help us to discriminate an explosion from the earthquake population.

Preliminary analysis of 20 earthquakes that occurred within 100 km from the Lop Nor Chinese test site reported in the REB indicates that vertical *P* wave to *S* wave ratios (*Pn/Lg*) of earthquakes are around 1.0 in the frequency band 1-16 Hz, whereas the same spectral ratios from six underground nuclear tests conducted at the Lop Nor test site during the 1990s are about 5.0 in the same frequency band. This suggests that the high-frequency *P/S* spectral ratios can be an efficient method to distinguish between explosions and earthquakes in the Lop Nor region, western China. Regional records in the distance range 200 – 2,000 km are used for the preliminary analysis. The stations used include an IMS primary network station MKAR and three surrogate stations, NIL, ABKT and ULN as well as four IMS auxiliary stations in central Asia. In the case of the earthquakes and explosions around the North Korean test sites, the *P/S* spectral ratios from the earthquake and explosion population overlap significantly at frequencies of 1-7 Hz, but the spectral ratios from the two populations are fairly well separated in the range 9-15 Hz. These preliminary studies indicate that high-frequency *P/S* spectral ratio provides an efficient method to identify seismic source types for seismic events of magnitude < 4.0.

SEISMO-28/K: Citizen Seismology: an experience feedback

Rémy Bossu, Sébastien Gilles and Gilles Mazet-Roux. *The European Mediterranean Seismological Centre*
Contact: bossu@emsc-csem.org

Abstract: The European Mediterranean Seismological Centre (EMSC) provides rapid earthquake information on its web site (www.emsc-csem.org) by collating parametric data from 66 networks originating from 49 different countries. Our web site is now well identified by the public as a source of information in case of earthquakes and attracts an average of 15 000 daily visitors.

During the last few years, the EMSC developed a number of tools to rapidly collect in-situ observations of the earthquake effects and better evaluate the reaction of the population. The first tool is an original development by EMSC. It uses the observed surge of traffic on EMSC web site to rapidly (within 5 to 10 minutes of the earthquake's occurrence) map the area where an earthquake was felt and it determines whether there has been significant widespread damage. When an earthquake is felt, people rush on the Internet to find out the cause of the shaking generating brutal surge of traffic on our web site. The area where the earthquake was felt is determined by locating the IP addresses and identifying the localities which exhibit a significant increase of visitors. Damaged areas are characterised by a lack or an absence of connections. This approach, which is the fastest way to collect in-situ observations on earthquake effects, is being implemented in several institutes in Europe.

Online macroseismic questionnaires in more than 20 languages complement this first approach. It provides a refined description of the effects and shaking levels through a quantitative scale, however it takes 60 to 90 minutes to collect enough questionnaires to draw a reliable map.

Witnesses have also the opportunity to share their pictures of the damage. Once validated by a seismologist they are shared on the EMSC web site. This proves valuable to provide local constraints on the actual damage but also for documenting the earthquake phenomenon and rare pictures have already been collected from Chile to Greece.

After a present of these different tools, we will present the experience feedback on this approach: what are the limitations, the advantages and what can be further developed.

SEISMO-29/K: The training course "Global Seismological Observation"

Tatsuhiko Hara, International Institute of Seismology and Earthquake Engineering, Building Research Institute, Tatehara, Tsukuba, Ibaraki, 305-0802 JAPAN
Contact: thara@kenken.go.jp

Abstract: The International Institute of Seismology and Earthquake Engineering of the Building Research Institute (hereafter referred as the IISEE) has been providing a training course entitled "Global Seismological Observation" in cooperation with Japan International Cooperation Agency (JICA) and Japan Meteorological Agency since 1995. The course objective is to nurture personnel who have knowledge and advanced techniques of global seismological observation and are able to play important roles in the monitoring system for nuclear tests. The overall goal is to contribute to promotion for the Comprehensive Nuclear Test Ban Treaty (CTBT) to take effect. In this presentation, we would like to introduce our training course.

Course Duration and Number of Participants: The course duration is about two months and the IISEE gives this training once every year for participants from developing countries who apply to this course through JICA local offices. The number of participants is around ten every year. In total, 139 participants from 69 countries have participated in our training course by March, 2009.

Course Outputs: We set the following four expected outputs for participants of this course: (1) acquiring knowledge of the CTBT regime and the role of seismology in the International Monitoring System (IMS), (2) understanding global seismological observation technologies for monitoring nuclear tests and earthquakes, (3) acquiring data analytical techniques to discriminate nuclear tests from natural earthquakes, and (4) making action plans on ways how they utilize their knowledge after the training course.

Course Program: The course program has the following subjects: (1) the CTBT, the IMS, and National data center, (2) Seismological observation, (3) Data analyses (hypocenter determination, array analyses, source mechanism, discrimination techniques, etc.). Participants have lectures and intensive practices.

Since 2003, lecturers from the IMS and/or the IDC (International Data Center) have visited us to provide a lecture entitled "Characteristics and Progress Status of the International Monitoring System of the CTBTO", which are very effective to improve understanding of participants on the CTBT, the IMS and the IDC.

SEISMO-30/K: On the Composition of Earth's Short Period Seismic Noise Field

Keith D. Koper and Kevin Seats, Dept. of Earth and Atmospheric Sciences, Saint Louis University, St. Louis, MO 63130, USA; **Harley M. Benz**, United States Geological Survey, Box 25046, MS966, Denver, CO 80225, USA
Contact: koper@eas.slu.edu; seatsk@slu.edu

Abstract: It is well known that Earth's surface continuously vibrates in response to natural processes such as ocean waves and anthropogenic activities such as road traffic. Study of this ambient noise is a classic topic in seismology and has been ongoing for more than a century. Because of the recent recognition that ambient seismic noise can be used to image Earth's crust and provide 4D monitoring of important geologic structures such as fault zones and volcanos, there is renewed interest in locating and describing sources of ambient seismic noise. Characterization of ambient seismic noise also contributes to verification seismology by providing the basis for time- and direction-dependent detection thresholds. In the classic microseismic band of 4-20 s seismic noise consists mainly of fundamental mode Rayleigh and Love waves; however, at shorter periods seismic noise also contains a significant amount of body wave energy and higher-mode surface waves. In this work we perform a global survey of Earth's short period seismic noise field with the goals of quantifying the relative contributions of these propagation modes, and geographically locating prominent sources of seismic noise.

We examined a year's worth of vertical component data from 18 arrays of the International Monitoring System that were sited in a variety of geologic environments. The apertures of the arrays varied from 2-28 km, constraining the frequencies we analyzed to 4.0-0.4 Hz. Using frequency-wavenumber analysis we identified the apparent velocity for each sample of noise and so classified its mode of propagation. The dominant component was found to be Lg, occurring in about 50% of the noise windows. Since Lg does not propagate across ocean-

continent boundaries this energy must be created in shallow water areas near coastlines. The next most common component was P wave energy, which accounted for about 28% of the noise windows. These were split between regional P waves (Pn/Pg at 6%), mantle bottoming P waves (14%), and core sensitive waves (PKP, 8%). This energy is mostly generated in deep water away from coastlines, with a region of the north Pacific centered at 165W 40N being especially prolific. The remainder of the energy arriving in the noise consisted of Rg waves (28%), and so in contrast to the classic microseismic band of 4-20 s, at shorter periods fundamental mode Rayleigh waves are the least significant component.

SEISMO-31/K: Observations from EarthScope's USArray

Robert Woodward and Robert Busby
Incorporated Research Institutions for Seismology Washington DC, USS
Contact: simpson@iris.edu

Abstract: The geographical extent of USArray allows unprecedented observations of geophysical targets over a range of scales. The three seismic observatory components of USArray presently span the contiguous United States. The Transportable Array (TA) component of USArray has already occupied over 700 sites in the western United States, from the Pacific coast through the Rocky Mountains, and continues its multi-year migration towards the Atlantic coast. The three component broadband TA stations are deployed in a grid-like arrangement, with 70 km separation between stations. At any given time there are approximately 400 station sites operating, occupying a ~1900 km by 800 km "footprint." Each TA station is operated for two years. The Flexible Array (FA) component of USArray provides a pool of instruments, ranging from high frequency geophones to three-component broadband sensors, and are typically deployed for focused geological targets at spatial scales two to four orders of magnitude less than the TA, and for time periods ranging from days to years. Finally, the Reference Network provides a fixed, permanent reference frame for the TA and FA, with approximately 100 broadband stations deployed across the contiguous US, at roughly 300 km spacing between stations. USArray also includes a magnetotelluric (MT) component. The MT observatory includes seven permanent backbone stations distributed across the US, as well as a pool of instruments deployed campaign-style each summer, and which have now occupied 170 distinct sites.
The data collected by USArray have supported a wide range of studies and have been processed in numerous ways. For example, the spatial extent and density of the TA deployment allows visualization of the seismic wavefield. These visualizations allow direct observation of seismic amplitude variations and off-great-circle wave propagation. A number of standardized data products are produced from the USArray data, including analyst reviewed phase picks, wave-field animations, and comprehensive compilations of ambient noise field measurements.

SEISMO-32/K: Seismology: Endless Frontier

Wu Zhongliang and Peter Suhadolc*, International Association of Seismology and Physics of the Earth's Interior (IASPEI), www.iaspei.org*
Contact: wuzl@cea-igp.ac.cn

Abstract: IMS is an international facility for large-scale scientific projects originally aiming at the monitoring of a Comprehensive Nuclear Test Ban Treaty. Whether IMS would like to be concerned also with the fundamental scientific problems of seismology and physics of the Earth's interior depends to much extent on its interest on the state-of-the-art and future progress of this scientific branch. Such a concern is quite reasonable, since generally it is not possible for a scientific branch to be always in a fast-growing period. In this poster presentation we show that at present seismology is in a period of fast development. A new series of discoveries is underway, following the first series in the 1910s to 1930s which led to a clear picture of the Earth's interior, and the second one in the 1950s to 1970s which led to the establishment of global plate tectonics. Among the driving engines of the new progress in seismology and physics of the Earth's interior we can certainly list: meeting the increasing needs of society for the reduction of earthquake disasters and the exploration of resources; the interdisciplinary discussions on the physics of the Earth's interior and the physics of earthquakes; the continuous accumulation of high-quality observational data; application of new technologies in seismological observation and data analysis; debates on several unsolved fundamental problems related to earthquakes and the Earth's interior, and most importantly, the study of important earthquakes that provide opportunities for new discoveries in seismology. In the perspective of seismology, IMS is by no means merely a machine simply applying well-established technologies. Similar to the role of the Hubble Space Telescope in astronomy, IMS provides a well-functioning global observation facility and has the potential to contribute to the new development of seismology and physics of the Earth's interior. A long-term cooperation between IMS and seismological communities will leave the fingerprints of IMS on the history of basic science.

SEISMO-33/K: Recent Improvements to Earthquake Reporting at the USGS National Earthquake Information Center

Ray Buland, Harley Benz, Paul Earle, and William Leith,
U.S. Geological Survey, Golden, Colorado, USA
Contact: buland@usgs.gov

Abstract: The U.S. Geological Survey's National Earthquake Information Center (USGS NEIC) is the U.S. seismic monitoring system federally mandated to provide earthquake information worldwide. NEIC and its predecessors have produced authoritative global earthquake locations and magnitudes since the 1930s. Operating 24x7 since January 2006, NEIC on average reports a magnitude and location for any M5 or larger earthquake within 20 minutes of its occurrence, locates over 30,000 earthquakes a year in coordination with USGS-supported regional seismic networks, and maintains a comprehensive bulletin of earthquake source parameters and felt effects. NEIC accomplishes its mission requirements and meets its performance goals by using real-time seismic waveforms from more than 650 broadband and 300 short-period stations, worldwide. Currently, NEIC strives to produce a reviewed seismic event bulletin complete to M4.5 or larger globally and is developing processing systems and procedures to be automatically complete worldwide to approximately M4.5. Recently, NEIC implemented continuous beam-forming of 21 of the International Monitoring System (IMS) arrays for improving its automated event detection and association processing.

For its earthquake response mission, the USGS's primary mechanism for distribution of earthquake information products is through the world-wide-web. Our principal portal (earthquake.usgs.gov) averages approximately 7 million hits per day; peak traffic reached as high as 35 million hits in 4 hours following an M5.4 San Francisco Bay Area earthquake in 2007, and the site received more than 500 million hits in the 30 days following the M7.9 Sichuan earthquake on May 12, 2009. In addition, NEIC distributes automated e-mail notifications to more 145,000 individuals and organizations, and produces reviewed body-wave, surface-wave and W-phase moment tensor solutions for all M5.5 or larger earthquakes worldwide, and regional MT solutions for all M4.0 and larger earthquakes within the United States.

Following the 2004, M9.1 Sumatra earthquake and tsunami, NEIC began a significant development project to more rapidly estimate the impact of potential large damaging earthquakes. Based on rapid estimates of earthquake locations and source characterizations, NEIC now produces a suite of higher-level response and map products. Maps of estimated ground shaking are produced by the ShakeMap system for all M5.5 or larger earthquakes globally: M3.5 or larger within the U.S. To improve estimates of ground shaking, finite fault inversions that show the temporal slip history along a ruptured fault are computed for all earthquakes M7.5 or larger. In addition, the "Did You Feel It?" system collects public observations of shaking intensity via the Internet and uses them to supplement the construction of detailed intensity maps. Rapid impact assessment of significant earthquakes is estimated using the Prompt Assessment of Global Earthquakes for Response (PAGER) system. PAGER currently estimates the number of people exposed to potentially damaging shaking and distributes alerts automatically within approximately 30 minutes (?). Future enhancements of the PAGER system will include fatality and building collapse estimates. More information can be found at *http://earthquake.usgs.gov/*.

SEISMO-34/K: CTBTO Contributions to Tsunami Warning

Capacity Building and Training Section, IDC
Contact: Lynda@Lastowka@ctbto.org

Abstract: Following the tsunamigenic earthquake of 26 Dec 2004 in Sumatra, delegations were moved to consider whether it would be useful if IMS data and/or IDC Products were made available for tsunami warning purposes. A Decision by PrepCom 24 on 4 March 2005 (CTBT/PC-24/1/Annex I) allowed exploratory tests requested by National Authorities and by International Tsunami Warning Organizations recognized by UNESCO. PrepCom in November 2006 established policy for provision of data to tsunami warning organizations. Currently data is forwarded to four organizations, such as PTWC (Pacific Tsunami Warning Center), NWPTAC (Northwest Pacific Tsunami Advisory Center), MMD (Malaysian Meteorological Department) and ATWC (Australian Tsunami Warning System).

IMS Seismic Data can contribute to reducing earthquake and tsunami risk with the following ways,

- filling gaps in existing global station coverage:
  - reducing detection times and thresholds and increasing location accuracy
  - more reliable locations and depths (including from array processing)
  - IMS network provides key stations in some areas
- Improving the broad-band recording of large seismic sources:

  - better earthquake focal mechanisms; moment, displacement and energy release determinations; and improved rupture models
- Rapid determination of source depth, rupture length and duration (current research using array data)
- Reliable station operation and communications infrastructure

Earthquake detection and characterization have been improved. For example, USGS has evaluated the improvements that can be achieved by incorporating IMS primary network broadband data fully into NEIC operations

- Detection/location capabilities can be reduced by 0.5-1.0 magnitude units in broad areas
- Detection times can be reduced by 1 – 5 minutes, with broad areas showing reductions of 2 minutes or more
- Also important is improved station distribution on the focal sphere, allowing higher-confidence source mechanisms
- IMS seismic data also increase sampling of the Earth's crust and upper mantle for research -and calibration- purposes

In 2008 agreements or arrangements have been made between the PTS and the six tsunami warning centres. In these centres, forwarding to Indonesia Tsunami Early Warning System and Australian Tsunami Warning Centre has already started and they are receiving data. Technical arrangements with Philippines and Japan are currently underway. An agreement has been signed by the ES of CTBTO and the counterpart of PTWC and WC/ATWC of USA. With Thailand, an agreement has been signed by the Thai Meteorological Department. This agreement is being finalized by the PTS.

SEISMO-35/K: A new approach of the rupture process of the great earthquakes using images derived from array processing

Guilbert J.[1], A. Le Pichon[1], J. Vergoz[1], M. Vallée[2]
[1] CEA, DAM, DIF, F-91297 Arpajon, France.; [2] Géosciences Azur, IRD, Nice, France
Contact: Jocelyn.guilbert@cea.fr

Abstract: The study of the source of major earthquakes is of great interest for the scientific community because the parameters derived from have a major importance for the rapid estimation of associated effects (destruction or tsunami). In the framework of these studies, we have identified the array processing as a modern tool that can provide vital information on the geometry and the kinematics of the rupture. Thanks to the various technologies implied in the CTBT, we have brought these studies in the field of seismology, infrasound and hydroacoustic. These different approaches have resulted in either a direct visualization of the rupture thanks to the analysis of variations of azimuth with time of direct waves from the source or indirectly by obtaining the scope of radiation pattern of surface waves. This type of image is very innovative because it allows provide information on geographic areas which are not instrumented. We show multiple images of treatment PMCC (Progressive Multi Channel Correlation) associated with different major earthquakes as Sumatra Mw=9.3, Nias Mw=8.7, Kokoxoli Mw=7.8 and how we can constrain the rupture of these events.

These studies show the interest of the CTBT network and more precisely the dense arrays of sensors. These arrays offer the unique opportunity for a multi-technological approach of the seismic source and, perhaps, ultimately, the improvement of early warning systems to strong earthquakes and their consequences.

SEISMO-36/K: Continuous seismic scanning in the region of the Mendocino Triple Junction, California

Aurelie Guilhem and Doug Dreger. Berkeley Seismological Laboratory, UC Berkeley
Contact: aurelieguilhem@gmail.com; Aurelie Guilhem aurelie@seismo.berkeley.edu

Abstract: The Mendocino Triple Junction (MTJ) region is tectonically complex resulting in a variety of anomalous seismic events that include repeating earthquakes, slow/low-stress-drop earthquakes, and non-volcanic tremors, in addition to typical inter- and intra-plate seismic activity. The MTJ is the most seismically active region of Northern California with the seismicity extending to 40 km depth and including potential large earthquakes (M7+) on the Mendocino fault and intra-plate events occurring in the offshore Gorda/Juan-de-Fuca plates.

In order to more effectively monitor the offshore region, particularly for slow/low-stress-drop or large possibly tsunamigenic events, we implement an automatic scanning of the continuous long-period (> 10 sec) broadband seismic records to detect, locate and determine moment tensors of events using the method developed by Kawakatsu (1998), independent of current operational applications. The method works by continuously performing the cross-correlation of Green's functions computed with suitable velocity models and every 2 seconds inverting for the seismic moment tensor for sources distributed over a spatial grid. When a defined level

of fit is reported the algorithm has detected, located, and determined the scalar seismic moment and focal mechanism.

We plan on inverting for full moment tensors including the isotropic component of the source. Ford et al (2009) demonstrated that regional full moment tensor inversion (deviatoric and isotropic) was successful in identifying isotropic events in western United States.

Because the analysis is done continuously every two seconds it offers the possibility of rapidly identifying large damaging and potentially tsunamigenic events rapidly as the latency is only the time that it takes for the complete low frequency wavefield including surface waves to propagate across the network. For stations located in the 100-300 km distance range it should be possible to detect, locate and determine moment tensors of events 1 to 3 minutes after their occurrence. We will present the design performance of the method for the Mendocino region.

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SEISMO-37/K: Seismicity and focal mechanism solution Of Yemen

Naji Ahmad Saleh Husain, *Geophysical Department , Center of Observation and Seismic Study, PO Box 187, Dhama, Yemen Republic*

Contact: naji_husaini@yahoo.com

Abstract: Yemen is located on the southwestern corner of the Arabian plate on the eastern margin of the Red Sea and on the northern margin of the Gulf of Aden, The western part of Yemen represents a typical volcanic margin resulting from the magmatic activity of Afar since 30 Ma. The Tertiary volcanic and granites are related to the Afar mantle plume which impacted the Arabia-Africa area during the Oligocene (Fig. 1). the seismic activity in the form of recurring low to moderate magnitude earthquakes is generally observed in the different parts of Yemen . The hug and moderate activity has also been observed in the Gulf of Aden and red sea.

The activate in this regions related to the location in the south west Arabian drift ,which located under the accumulative stress and strain forces by the continental shoulders of Africa and Eurasian [Barberi and Varet, 1977].

The Separation of Arabian plate from Africa, Have rotate Clockwise and propelling it northeast wards to under thrust and suture with Eurasia along Taurus and Zegros zones.] The historical earthquakes have taken care by Arab and Islamic history, they had been observed and documented many Reviewer and references, based on the effected it and damaged on live and earth. Most of events were documented after the eight-century (N.N AMRASES, C.P. MELVILE AND R.D. ADAMS).

In the present work, this suggested seismo-tectonic feature was investigated through the observation, spatial distribution and analysis of local earthquake hypocenters. When comparing the available information including the 13 December greet event 1982 and 22 November main shock and aftershock (swarm activity) in Audyin region 29 km west of Ibb governorate , with documented seismicity of Yemen we came to find clusters of epicentres located not far from the epicentres region of past major earthquakes.

Through out the statistical analysis and spatial distribution mapping of these smaller events we came across a set of facts based on data related to small magnitude earthquakes that could only be detected. Among the important results reached, we could clearly identify a pattern of moderate to high seismic activity in the Yemen.. In behalf the determination of the fault plan solution for significant regions, zones depend of the YSN which including 12 digital station.

The Tertiary volcanics of Yemen are related to Afar mantle plume which impacted the Arabia-Africa area during the Oligocene.

Analysis seismic Digital data, hypocenter determination are distribute the epicenter seismic mapping and to study the structures and tectonic evolution of Yemen. Focal mechanism solution give some clear evidence cumbering with result of Remote sensed results, as most of them with normal fault plane solution by E-W and NE-SW trending faults. The result of Yemen seismic observation, from the end of 1990, confirms that the Gulf of Aden and Red Sea, are highly seismogeic regions, cambering with other regions inland.

We also expected that relation between the time period of seismic activity in land and offshore area (Red sea and gulf of Aden) , as the opposite relation ,as we noted that when the seismic activity occur with huge seismic recording events inland ,we mention that the offshore regions

Characteristic with quite limited number of seismic events, however the other hand when we recorded renew activity in the offshore regions.

SEISMO-38/K: Evaluation of Seismic Monitoring Capability of IMS in Some Regions

Liu Junmin, Wang Haijun, Wang Xiaoming, Wang Hong, CTBT Beijing NDC & RNL, Li Zhenfu, Northwest Institute of Nuclear Technology
Contact: liu.junmin@ndc.org.cn

Abstract: This paper is focused on evaluation of monitoring capability of seismological monitoring network of IMS in some regions. The evaluation is based on last year IDC REB and seismic stations of IMS which has been in operation. The regions include Mid & South Asia (Indian & Pakistani Test Site, Lop Nor Test Site and Semipalatinsk Test Site sit in),and North America (Nevada Test Site sits in). The evaluation involves comparison of seismic event magnitudes and locations in bulletins of IDC, NEIC and ISC, etc. then introduction of monitoring capability evaluation methods, finally monitoring capabilities of the network to the nuclear test site regions. In general, magnitude of an event listed in NEIC bulletin is 0.4 units greater than in IDC REB in North America, 0.3 units in Mid & South Asia. Magnitudes of NEIC bulletin are more coincident with ISC respectively. There is 31 km and 16 km in average between the location of an event in NEIC and IDC bulletin respect areas. In some regions, monitoring capability of IMS seems weaker than it should be. Some interesting discoveries will be presented in this paper.

SEISMO-39/K: The last developments of the national seismological observation network of turkey, 2009

Karakisa, S., Kadirioglu, F.T., Kaplan, M., Zünbül, S., Kartal, R.F., Hologlu, N., Kiliç, T., Baran, B., Türkoglu, M., Yanik, K., Tezel, T., Baykal, M., Oztürkakca, C., Yatman, A., Ravul, Y., Tüzel, B.
Turkish Republic, Ministry of Public Works and Settlement, General Directorate of Disaster Affairs, Earthquake Research Department, Eskisehir Yolu 10. km, 06530, Lodumlu, Ankara, Türkiye
Contact: salih@deprem.gov.tr

Abstract: In order to mitigate disaster losses, it is necessary to establish an effective disaster management and risk system. The first step of the management is constituted by preparedness studies before the earthquake (disaster). In order to determinate disaster and risk information it is necessary to have a seismological observation network.

Turkey is always in danger of being ruined by an earthquake because it's on the active fault zone, as it was seen in the last ten years.That's why a seismological observation network having good coverage is needed to research the reasons of earthquakes and reduce their damage.

For this purpose, the stations which was established on the NAFS (North Anatolian Fault System) in 1989 were spread across all country.and currently observation are made with 147 stations. According to years distrubition of the number of seismological observation network is examined; between 1989-2004 19 stations was established and removed depending on the circumstances of the day. 31 stations in 2004, 47 stations in 2005, 61 stations in 2006, 135 stations in 2007 and 147 stations in 2008 (6 Three Component Short Period, 63 Broad-band, 13 One Component Short Period stations, 65 Local Network- Broad-band) have been operated by our ministry. Aim of the project, to increase of the number of stations from day to day.This number will be 156 at the end of the year 2009.

All of the stations transmit continuously their signal to the ERD (Earthquake Research Department) seismic data center in Ankara. Capability of the network is to determine an earthquake which is minimum local magnitude ML= 2.8 generally, in some region local magnitude threshold is ML=1.5 (the places where the stations are concentrated).

Earthquake activity in Turkey and surrounding region has been observed 7 days / 24 hours, in ERD data center in Ankara. After the manuel location of an earthquake, If the magnitude is over 4.0, system sends to SMS message automaticaly to the authorized people and immediately press, public and national-local crisis center, scientific institutions are informed by fax and e-mail. Data exchange has been carried out to EMSC-CSEM and ORFEUS.

SEISMO-40/K: Tsunami early warning using earthquake rupture duration

Anthony Lomax[1] and Alberto Michelini[2]
1) ALomax Scientific, Mouans-Sartoux, France; 2) Istituto Nazionale di Geofisica e Vulcanologia, Roma, Italy
Contact: anthony@alomax.net

Abstract: Effective tsunami early warning for coastlines near a tsunamigenic earthquake requires notification within 5-15 minutes. We have shown recently that tsunamigenic earthquakes have an apparent rupture duration, T0, greater than about 50 s. Here we show that T0 gives more information on tsunami importance than moment magnitude, Mw, and we introduce a procedure using seismograms recorded near an earthquake to rapidly determine if T0 is likely to exceed T=50 or 100 s. We show that this "duration-exceedance" procedure can be completed within around 10 min after the earthquake occurs, depending on station density, and that it correctly identifies most recent earthquakes which produced large or devastating tsunamis. This identification forms a complement to initial estimates of the location, depth and magnitude of an earthquake to improve the reliability of tsunami early warning, and, in some cases, may make possible such warning.

Evolution for 10 min after OT of the T0>50 s exceedance level (L50) calculation for: (upper) 2006.07.17, Mw7.7, T0=180 s, It=18, Indonesia tsunami earthquake, and (lower) 2008.04.09, Mw7.0, T0=23 s, It=0, Loyalty Islands interplate thrust. Blue lines show P-arrival times for each station; red, yellow or green horizontal bars show the station exceedance levels, l50, starting at its first reported time (about 60 s after the corresponding P time). Histogram shows l50 values at 600s; the median (50 percentile) and bounds (20 and 80 percentile), respectively, for L50 are indicated by solid and dotted white lines on the main plot and as a colored diamond and error bar. Red indicates l50(or L50)≥1 (likely that T0>50 s and It≥2); yellow indicates 0.7≤l50(or L50)<1 (possible that T0>50 s and It≥2); green indicates l50(or L50)≤0.7 (unlikely that T0>50 s or It≥2). For both events the L50 values have stabilized by 4-6 min after OT. For real-time monitoring, comprehensive information about exceedance level could be provided by a time-sliding display similar to the above.

SEISMO-41/K: IMS stations of CTBT for INA-TEWS as the Regional Tsunami Early Warning Centre in Asia

Sugeng Pribadi, *Indonesian Agency of Meteorology Climatology and Geophysics (BMKG)*
Contact: sugengmsc@gmail.com

Abstract: After the most horrify disaster in this decade – 2004 Sumatra Tsunami (Mw 9.0) which caused more than 280.000 people died, Indonesia was denoted as the most risky country because of the closest location to tsunami generation of Indian tectonic plate. Therefore the wide seismic network is necessary to cover prone areas in the country and also Asia region. The IMS stations of CTBT give contribution by supporting some auxiliaries stations and sharing the international data seismic through IDC for Indonesia Tsunami Early Warning System (Ina-TEWS). Ina-TEWS is supported by several donor countries and global agencies. It is provided by the high concept of processing system, the broadband seismograph network, sufficient facilities, technical improvement and quick information dissemination. Gradually the false alarm of tsunami can be reduced within multi verification of tide gauges, GPS, and DART-Buoy networks and tsunami modeling database. Therefore the earthquake parameter could be quickly determined within 5 minutes after origin time. The earthquake information through facsimiles, telephones, websites, short message services (SMS), and radio-internet (RANET) is disseminated into the recipients such as local governments and also Asian countries. Then it is carried on into the people in prone areas. Earthquake and tsunami countermeasures are already made in several local governments to minimize the victims. The programs are conducted such as education training and evacuation drill. The regulation of disaster mitigation is established which consisted of building regulation, operational disaster information, community and self emergency response. Tsunami Drill Day is held every year every on 26 December as an implementations of Ina- TEWS readiness, run well and get positive responses from both government and community disasters Keywords : IMS Stations, Ina-TEWS, BMKG, Eartquake and Tsunami Information

SEISMO-42/K: Probabilistic Estimates of Monitoring Completeness of Seismic Networks

D. Schorlemmer, *Southern California Earthquake Center, University of Southern California, 3651 Trousale Parkway, Los Angeles, CA 90089 USA*
Contact: ds@usc.edu

Abstract: The monitoring completeness of seismic networks is heterogeneous in space and time. It strongly depends on station distribution and recording quality per station. We present a probabilistic method to estimate the capability of seismic networks to spatially and temporally monitor completeness based on phase data, station information, and the network specific attenuation relation.

We derive probability distributions in the magnitude/distance space for each station. From these, we compute either completeness maps for a particular probability level or probability maps for the detectability of earthquakes with a particular magnitude.

This approach has several advantages over alternative ways in completeness estimation: Contrary to estimating completeness based on the Gutenberg-Richter distribution, our approach does not assume any event-size distribution and is based solely on empirical data. Because the method does not rely on earthquake samples, no averaging over space and time occurs. It also offers the possibility of estimating the completeness in low-seismicity areas where methods based on parametric earthquake catalogs fail due to sparse data. Additionally, the probability distributions per station allow to analyze single station performances, intrinsically including site effects.

We present studies of regional networks from California, Switzerland, Italy, Japan, global studies, and compare the result with estimated completeness levels of other methods. We report on the time evolution of monitoring completeness in these regions and show the depth dependence of detection probabilities. Scenario computations show the impact of different possible network failures and offer estimates of possible network optimization strategies. All presented results are published on the CompletenessWeb (www.completenessweb.org) from which the user can download completeness data from all investigated regions, software codes for reproducing the results, and publication-ready and customizable figures.

Because the only ingredients to the probabilistic estimates of monitoring completeness are the phase data, the station list, and the networks attenuation relation, this approach is easy to adopt to other seismic networks. We envision this method to become a viable additional tool for the design and management of seismic networks from local to global scales and to provide further insights into station site conditions.

SEISMO-43/K: Seismological Approach to Earthquake Forecast in Western Nepal Himalaya & its adjoining Indian Region

D. Shanker[1], Harihar Paudyal[2], H.N. Singh[3]
[1]Department of Earthquake Engineering, Indian Institute of Technology Roorkee, Roorkee-247667, India; [2]Department of Physics, Birendra Multiple Campus, Bharatpur, Chitwan, Nepal; [2]Department of Geophysics, Banaras Hindu University, Varanasi-221005
Contact: dayasfeq@iitr.ernet.in

Abstract : Seismological approach to earthquake forecast is the method to predict an earthquake with former seismic activities. The previous and former earthquakes will be the mirror to the future earthquake due to the succession of tectonic movement. Anomalous seismicity is first to take place as compared to other precursory phenomena due to formation of various ruptures where considerable strain energy are accumulated, hence it may be an important parameter for the prediction of long-range earthquake related hazards in a region. Anomalous seismic activity associated with major earthquakes in the Western Nepal Himalaya and its adjoining Indian region have been studied in an area bounded by 28.0^{o}-31.0^{o} N and 79.5^{o}-82.2^{o} E, using seismicity data from 1963-2006. In the present study, anomalous/precursory swarm seismicity and the delineation of preparation zones (~1.1×10^4 km^2) are carried out for the future earthquake hazard using the temporal and the spatial distribution of events considering the total events and the events with $m_b \geq 4.3$ in four anomalous episodes: Normal/ background (N); Anomalous/ swarm (A); Precursory gap (G) and Mainshock sequence (M), respectively. Five cases of anomalous seismicity have been identified: prior to three earthquakes that have already occurred and two cases for which quiescence episodes still continues. Three medium size earthquakes of 1980 (m_b 6.1), 1984 (m_b 5.6) and 1999 (m_b 6.6) occurred in the Western Nepal and its adjoining Indian region were preceded by well defined patterns of anomalous seismicity/ precursory swarm. The first of these was the Bajhang earthquake of which most of its preparatory processes during 1967-1980 were confined approximately in the central part of the area between the MCT and the MBT. Subsequently, the seismic activity shifted towards east in the northeast-southwest direction which produced another mainshock of 1984 (m_b 5.6). Seismic activity started concentrating in and around Chamoli area (India) since 27 November 1995 which was preceded by a quiet low seismicity in the region. After Chamoli earthquake in 1999, a low seismic activity was observed in the region which continued for the next two years till 14 April 2001. The seismic activity again shifted towards

southeast and started concentrating in the region east-northeast of Bajhang earthquake, since April 2001, in which anomalous pattern in seismicity is observed on two occasions. On analyzing the seismicity data from 1999 to 2006, two additional cases of characteristic seismicity patterns were observed: (1) 1999-2006, and (2) 2003-2006. In these two cases, though the anomalous seismicity exists, no mainshock has occurred so far. After critical analysis of the data, it is observed that the seismicity from 1999 onwards fluctuates in the order as low-high-low phases. The analyses suggest that a shallow focus ($h \leq 30$ km) earthquake of about M 6.5 and more may occur at any time in the delineated preparatory area (29.4^o-30.6^o N and 81.3^o-81.8^o E) in its southern part till 2011.

SEISMO-44/K: Proposal on the Organization in Armenia of Complex Monitoring of Nuclear Explosions

Hektor Babayan, *Institute of Geological Sciences (Armenia)*
Contact: hektor.babayan@gmail.com

Abstract: The Caucasus lie between the Black and Caspian . The relatively high geodynamic activity within the region, expressed as both seismic and aseismic deformations, are the result of ongoing convergence of lithospheric plates and northward propagation of Afro-Arabian continental block at a rate of several cm/year. This has been identified through numerous paleoseismodislocations, contrasting neotectonic movements and related seismic activity.

In spite of long-standing investigations in the field of geology and seismology in the Caucasus, a number of problems still remain unclear or insufficiently studied because of the complicated mosaic of geologic structures of the region.

To address the problem of seismic hazard it is also necessary to establish a modern regional monitoring network comprised of highly-sensitivity digital seismographs.

Regular instrumental seismological observations have been conducted in Armenia since early 50-s of the last century. Presently, a few local telemetry networks are in operation, and there are also individual analog short-period stations, as well as advanced digital stations (GURALP).

One seismic station of IRIS seismological network, which is an auxiliary station of the International Monitoring System of CTBT, is installed and operates in the gallery of GARNI Geophysical Observatory of the Institute of Geological Sciences of Armenia.

The Garni Observatory ($\varphi=44.74^0$ E, $\lambda=40.13^0$ N) is situated in the settlement of Garni, 18 km east of Yerevan, the capital of Armenia, on the northern edge of the Ararat depression. The Garni Observatory was built in 1976 and covers an area of 25 hectares.

The observatory has: a) a three-storey laboratory building with the area of 1,620 m^2; b) a hotel for 16 rooms with the total area of 610 m^2; c) infrastructure (boiling-house, garage, warehouses, etc.);d) an underground part. The underground part of the observatory is a horizontal tunnel with the total length of 325 m, laid in volcanogenic-sedimentary rocks to a depth of 68 m from the ground surface. The cross-section of the tunnel is 3 x 3.5m, and the area is 1,475 m^2. The tunnel has a closed P-shape contour and 10 observation chambers on the sides with a total area of 500 m^2. Concrete with plastic reinforcement isolates the tunnel and the chambers from the surrounding rocks. Temperature and humidity within the chambers are kept constant. There is a vertical, 10m–long shaft in the tunnel, which allows one to estimate tensor values for offsets caused by deformation. A 1.2 km-deep observation well is near to the observatory, and 1 km far from it, there is another well, drilled to a depth of 3.5 km, which can be also used for stationary observations.

Considering the geographic position of Armenia, and the unique features and capabilities available at GARNI Geophysical Observatory, it is proposed to install in its area equipment to perform infrasound and radionuclide monitoring along with the seismic observations. Another possibility to involve the Republic of Armenia in the ISS Project is related to the coordination of activities on the installation and maintenance in Armenia of seismic array used on a global scale and in the seismic verification and monitoring of the CTBT.

SEISMO-45/K: Efficient and accurate calculaton of ray theory seismic travel time through variable resolution 3D earth models

Sanford Ballard, James R. Hipp and Christopher J. Young, *Sandia National Laboratories*
Contact: sballar@sandia.gov

Abstract: We describe a fully 3D global Earth model representation and a compatible travel time calculator based on the ray pseudo-bending algorithm that together provide a practical means to efficiently and accurately calculate travel times for infinite frequency rays through variable resolution 3D Earth models. This approach provides a potentially operational monitoring-compatible means to take advantage of the large number of 3D models that have been created in recent years, some of which have already been proposed to improve the location of seismic events. The approach can leverage standard multi-processor computing hardware that is readily available to monitoring agencies and researchers, but does not require it.

This work represents the next logical step in travel-time prediction beyond the radially symmetric 1D models that have been used for many years, and the new Regional Seismic Travel Time (RSTT) "2.5D" approach for regional phases. RSTT achieves dramatic improvements over 1D models in the accuracy of regional travel times while maintaining reasonable computational performance, even on single-processor computers. However, the RSTT model can only be used for shallow, regional events because it makes an approximation for upper mantle structure that breaks down outside these bounds. The approach proposed here uses a single, realistic model that is valid for all body wave phases (regional and teleseismic) over the entire Earth

The 3D model representation is based on a 2D (geographic), multi-level tessellation of triangles with each tessellation level completely covering the surface of a unit sphere without gaps or overlaps. Low levels of the tessellation consist of relatively large triangles and are associated with slowness discontinuities deep in the Earth. Triangles are subdivided into ever smaller triangles at progressively higher levels of the tessellation which are associated with discontinuities closer to the Earth's surface. At the vertices of the triangles Earth properties are defined along radial profiles that extend from one of the major discontinuities up to the surface of the model, which corresponds to the topographic/bathymetric surface of the solid Earth, referenced to the GRS80 ellipsoid. Variable resolution in both geographical and radial directions is achieved by specifying appropriate criteria for triangle subdivision at each tessellation level.

The implementation of the Um and Thurber Pseudo-bending algorithm presented here quickly and accurately computes the travel time of infinite frequency seismic rays through 3D Earth models. The new implementation modifies Zhao's method of handling discontinuities by implementing a 2D minimization algorithm that searches for the point on the velocity discontinuity surface where Snell's Law is satisfied. Further, the new implementation reduces the likelihood that the pseudo-bending algorithm will return a local minimum by starting the ray calculation from several different starting rays. Specifically, interfaces are defined that include first order discontinuities plus additional interfaces at levels of the model where local minima are anticipated. Rays are computed that are constrained to bottom in each layer between these interfaces. The computed rays might be reflected off the top of the layer, turn within the layer, or diffract along the interfaces at the top and/or bottom of the layer. The computed ray that is seismologically valid and that has the shortest travel time is retained. To evaluate accuracy, travel times computed with the new bender are compared to those calculated with the 1D TauP method and the Fast Marching Method.

Performance of the bender for realistic Earth models is currently on the order of tenths of seconds per ray for single processor hardware. To meet operational requirements without requiring significant computer resources, we describe methods to interpolate travel time predictions from pre-computed, optimally tessellated 3D lookup tables.

Reference: Ballard, S., J. R. Hipp, and C. J. Young (2009). Efficient and accurate calculation of ray theory seismic travel time through variable resolution 3D earth models, submitted to *Seism. Res. Lett.*

SEISMO-46/K: Crustal Investigations of Northern Iraq from Seismic Studies

Roland Gritto, Matthew Sibol, Pierre Caron, Kathryn Quigley, Hafidh Ghalib, Youlin Chen
Array Information Technology, 5740 Hollis Street, Emeryville, CA 94608
Contact: Roland.Gritto@arrayinfotech.com

Abstract: The Northern Iraq Seismic Network (NISN) has operated 10 broadband stations in north-eastern Iraq since late 2005. In the current paper, we present the latest results of our crustal studies obtained with seismic data recorded by NISN and surrounding networks.

At present, over 1 TB of NISN seismic waveform data have been recorded and analyzed. The aim of the present study is to derive models of the local and regional crustal structure of north and north-eastern Iraq, including the northern extension of the Zagros collision zone. This goal is achieved by estimating local and regional seismic velocity models using 3-D joint inversion for hypocenter locations and velocity structure, receiver function- and surface wave dispersion analyses and to use these velocity models to obtain accurate event focal mechanisms. Our analysis of phase arrival times yielded over 27,000 phase picks, comprised of 9,000 Pg, 5,000 Pn, 10,000 Sg/Lg and 3,000 Sn arrivals. Our analysis of hypocenter locations produces a clear picture of the seismicity associated with the tectonics of the region. The largest seismicity rate is confined to the active northern section of the Zagros thrust zone, while it decreases towards the southern end, before the intensity increases in the Bandar Abbas region again.

Our analysis of waveform data indicates clear propagation paths from the west or south-west across the Arabian shield as well as from the north and east into NISN. Phases including Pn, Pg, Sn, Lg, as well as LR are clearly observed on these seismograms. In contrast, blockage or attenuation of Pg and Sg-wave energy is observed for propagation paths along the axis of the Zagros-Bitlis zone from the south, while Pn and Sn phases are not affected. These findings are in support of earlier tectonic models that suggested the existence of multiple parallel listric faults splitting off the main Zagros fault zone in east-west direction. These faults appear to attenuate the crustal phases while the refracted phases, propagating across the mantle lid, remain unaffected. We will present surface wave analysis in support of these findings, indicating multi-pathing for surface waves from events located to the south-east of NISN, indicating the complex structure of the Zagros fault zone. In combination with receiver function, our preliminary structural model of the crust beneath north-eastern Iraq indicates a crustal depth of 40-50 km for the foothills, which increases to 45-55 km below the core of the Zagros-Bitlis zone.

SEISMO-47/K: Large-scale array use for phase identification and waveform determination

George Helffrich, James Wookey. *Earth Sciences, University of Bristol*
Contact: george@gly.bris.ac.uk

Abstract: The early experiments of seismic array use for discrimination purposes led, in the mid-1970s, to the view that large scale arrays were undesirable due to the loss of wavefield coherence at scales larger than a few tens of kilometers. Consequently, small aperture arrays were preferred for detection, location and discrimination, and are an element of the present IMS.

A variety of large-scale national seismic monitoring networks for seismic hazard reduction and basic research are a new, and a readily available resource usable in some seismic array roles. They comprise hundreds of stations with apertures up to a thousand km. The aperture and the station density enhance the utility of simple methods such as delay-and-sum to suppress noise and enhance waveform features. However, the large station spread and independent station time bases virtually guarantee that crustal structure and instrument timing variations will make absolute time measurements problematic.

Relative time and slowness measurements, after adjustment for receiver statics, are quite feasible given this constraint. While losing an absolute time base impairs regional array use for event location, it is still beneficial for wavenumber- and waveform-based event study.

We show two examples of how regional seismic arrays benefit earth structure studies: in subduction zones and in the inner core of the earth. The regional network in the United Kingdom (~100 stations; slowness resolution 2 × 10−3 s/km) provided data with which the seismic discontinuities at 410 and 660 km were traced through the Izu-Bonin subduction zone in the western Pacific. Array processing of nearby earthquakes illuminating the discontinuities revealed their locations by reflections and conversions of direct waves at the discontinuities. Hi-Net in Japan (~800 stations; slowness resolution 5 × 10−4 s/km) provided data with which high frequency records of the inner core shear wave, PKJKP, were obtained by array processing methods. Compared to PKKP and PKiKP, also recorded by Hi-Net, the PKJKP waveform has extra pulses in it that suggest shearwave splitting in the inner core.

These studies show the potential that regional array use has for discrimination work. Greater waveform fidelity enhances detectability of depth phases associated with natural events. Relative slowness estimates between direct and later arriving phases provide azimuth and range information that constrain source locations.

The free availability of data also means that the analyses may be replicated by any national agency. The factors are all beneficial as an element of a global seismic event monitoring facility.

SEISMO-48/K: Seismic tomographic mapping of the Earth's interior - the ACH inversion revisited

A. Christoffersson, *Dept.Information Sci.;Div. Statistics, UoUppsala, Box 513, SE-751 20 Uppsala, Sweden*
E. S. Husebye, *Bergen Center of Computational Science. UNIFOB, UoBergen. Høyteknologisenteret,5008 Bergen, Norway*
Contact: anders.christoffersson@dis.uu.se

Abstract: The CTBTO monitoring system collects huge amounts of high quality seismic data which are eminently suitable for exploring and mapping the Earth's interior. Such information is in turn needed for further refining and improving the CTBTO monitoring system. A versatile and flexible analysis technique is that of seismic inversion or tomography published by Aki, Christoffersson and Husebye (ACH) in JGR, 1977. At that time, convenient observational data were P-wave travel time residuals reported for the 2 large aperture arrays Norsar and Lasa. In many subsequent studies the ACH inversion technique has been refined and extended to whole Earth data observations for many kinds of seismic observations. In 1970-ties computer resources were meagre relative to present days so the complex inversion calculations were hampered at that time - hence our motivation for the ''ACH inversion revisited''.

Inversion issue. In our past tomographic study of 1977 we discussed two separate solution strategies namely the so-called stochastic and general inverse. The former one was considered with some sceptics simply because it involved vertical smoothing of model blocks. Physically this is not strictly valid since velocity anomalies in one layer may differ from those in another layer. However, the stochastic inverse is more easy to compute and besides gives relative small standard errors for the unknowns. The general inverse does not involve vertical block weigthing but smoothing is still desirable and we
failed to develop proper procedures here.

Revised ACH inversion. We present the basic formulations for the stochastic and generalized inverse and discuss their relative merits a new. In addition we introduce a novel weighting approach, the Gauss-Markov scheme, for the generalized inverse. Using the original Norsar lithosphere & ray sampling we compute velocity anomalies for a synthetic model – here we know a priori the correct solution. The stochastic inverse
proved to be a disaster that is unable to reproduce the 'true' model. The generalized inverse is OK while the Gauss-Markov smoothing gives the best results here. On this basis we recalculated the velocity anomalies in the lithosphere beneath Norse.

Other inversion schemes. Tomographic mapping has also been undertaken for tomographic mapping of the deep interior of the Sun – termed helioseismology. Here a computationally fast variant of the Backus-Gilbert scheme was introduced by Pijpers -Thompson. We discuss these approaches and demonstrate that the Gilbert-Backus scheme cannot be used for Norsar data inversion while that of Pijers-Thompson is similar to our Gauss

SEISMO-49/K: 1-D Shear Wave Velocity Structure of North Kore

Tae Sung Kim, Ik-Bum Kang, Geun-Young Kim, Jin-Soo Shin and Heon-Cheol Chi
Earthquake Research Center, Korea Institute of Geoscience and Mineral Resources
Contact: tskim@white.eq.kigam.re.kr

Abstract: One dimensional shear wave velocity structure of North Korea was constrained using 2- to 37-sec Rayleigh waves generated from a seismic event in China. Surface waves from the M4.2 event was recorded at the three broadband seismic stations (BRD, CHNB, KSA) which are located near the boundary between North and South Korea. Group velocities of fundamental-mode Rayleigh waves were estimated with the Multiple Filter Analysis and refined using the Phase Matched Filter. Group velocity dispersion curves range from 2.75 to 3.57 km/s. The dispersion curves were inverted to constrain the shear wave velocity structures. The average shear wave velocity model was composed of 11 layers and half space. Low velocity zone was found along the path between the event to BRD at the depth of 3 km and 7 km, which may be related to the sedimentary basin in the Yellow Sea. The variation of the shear wave velocity for different propagation path was from 3.15 to 3.9 km/s at the depth 15 and 23 km. At depth below 23 km, the velocity is almost same for all the paths.

SEISMO-50/K: Using IMS Seismic Arrays to Constrain the Structure of Earth's Deep Interior

Keith D. Koper and Yan Xu, *Dept. of Earth and Atmospheric Sciences, Saint Louis University, St. Louis, MO 63130, USA*
Contact: koper@eas.slu.edu

Abstract: The seismic arrays of the International Monitoring System (IMS) provide an excellent means of inferring the structure of Earth's deep interior. Many of these arrays have apertures of 5-25 km and so are effective at recording teleseismic P waves at frequencies around 0.5- 2 Hz. The seismometers are often sited in boreholes in regions with low cultural noise. In general, arrays offer two significant advantages over traditional three component stations. First, they dramatically increase signal-to-noise ratios, in some cases by much more than the pN predicted by classic linear processing. Second, arrays enable the apparent velocity and backazimuth of the seismic energy to be determined. These two properties allow exotic body wave phases, that are sometimes unobservable at three component stations, to be confidently identified and modeled with IMS array data.

In this work, we review the many recent contributions to inferring deep Earth structure that have been made using IMS seismic data. Hundreds of new observations of precritical reflections from Earth's inner core (PKiKP) have been made that have yielded new constraints on the density jump across the inner core boundary. This value is important because the segregation of light element between the inner and outer core is thought be the major driving force for the compositional convection that generates Earth's magnetic field. The scattered coda waves that follow PKiKP have also been used to detect and characterize the distribution of individual grains of iron that exist in the inner core. Core reflected phases such as PcP and ScP have been observed and studied to determine the fine-scale properties of core-mantle boundary. In particular, a strong and variable ultra-low velocity zone beneath the southwest Pacific has been identified. This feature is most readily explained by the presence of a small amount of partial melt, similar to what exists in Earth's asthenosphere. Small and diffuse precursors to PKP have been studied to determine the location of small-wavelength chemical heterogeneities in the lower mantle beneath North America. In particular, these data indicate that pieces of oceanic crust from the ancient Farallon plate that subducted beneathWestern North America have penetrated to great depths. All of these and other related studies will be discussed in detail.

SEISMO-51/K: Trends of Earth Deep Structure Research and Its Implication to the CTBT Verification

Wenxue Liu, Hongchun Wang Xin Li Henglei Xu, *Northwest Institute of Nuclear Technology，PR China*
Contact: liuwx@mailst.xjtu.edu.cn

Abstract: The frontier of the earth deep structure research is the structure and evolution of mantle lithosphere, which has the strongest rheology feature in continental lithosphere. The better insight we have into this region at earth depth, the better we can improve our understanding to the evolution of continental lithosphere. On the other hand, the complex structure of upper most mantle complicates the seismic wave propagations for regional events, which is a great challenge for CTBT verification. So the structure of mantle lithosphere research takes a crucial role in continental evolution and CTBT verification. Today the trends of the research in mantle lithosphere characterized by observation regionalizing, data sharing, data process open source programming and inversion methods joining.

The portable seismic array is the way of observation regionalizing. The typical projects include PASSCAL of IRIS and USArray of EarthScope. With the number increasing of seismic stations/arrays around the world, the seismic data volume has been increasing everyday. Data sharing is the most effective way for taking full advantage of these data, such as DMC in IRIS has been providing seismic data for geoscientists all over the world. The huge volume of data needs efficiency tools to deal with it. Open source programming for seismic analysis is a promising and effective way to produce these tools. The observation regionalizing, data sharing and open source programming of data retrieve and processing may be classified as infrastructures of seismic research, and all kinds of techniques for mantle lithosphere researches are based on it. Surface wave dispersions and teleseismic receiver functions are two kinds of seismic tools for lithosphere structure studies. These techniques are advancing in their own ways. One of the most important improvements of receiver functions is the application of seismic exploration techniques (Chen *et al,* 2005a, b，Rondenay and Bostock *et al,* 2001a, b, c), because the dense portable seismic arrays around the world facilitate this application. On the other hand, one of the most promising techniques of surface wave dispersions extraction is ambient noise tomography (Shapiro and Campillo *et al,* 2004, Sabra *et al,* 2005, Lin *et al,* 2006). This technique extends the periods of surface wave dispersions to as short as several seconds, which is very important for shallow crustal structure constraint. Although these techniques provide good constraints for lithosphere structures in lots of regions all over the world, the distinctive nonuniqueness of the results need more improvements. One of techniques for complementing nonuniqueness of each technique is their joint inversion (Ozalaybey and Savage *et al,* 1997, Julia and Ammon *et al,* 2000, 2006, Ammon and Herrmann *et al,* 2002).

Except for improving our understanding of continental evolution, the results of the earth deep structure may improve the seismic capabilities in CTBT verifications.

SEISMO-52/K: Joint inversion of surface wave velocity and gravity observations and its application to Central Asian basins shear velocity structures

***Monica Maceira[1] and Charles J. Ammon[2]**, Los Alamos National Laboratory[1] and Penn State University[2]*
Contact: mmaceira@lanl.gov

Abstract: This paper describes a method to jointly invert surface-wave group velocities and gravity anomaly observations. Surface-wave dispersion measurements are sensitive to seismic shear-wave velocities, and the gravity measurements provide constraints on rock density variations. The goal is to obtain a self-consistent three-dimensional shear velocity-density model with increased resolution for shallow geologic structures. This method is applied to investigate the structure of the crust and upper mantle beneath two large central Asian sedimentary basins: the Tarim and the Junggar. These basins have thick sedimentary sections that produce substantial regional gravity variations (up to several hundred milligals). Gravity observations extracted from the global gravity model of the Gravity Recovery and Climate Experiment satellite mission were used. For a grid of locations across central Asia, the gravity anomalies are combined with high-resolution seismic surface-wave slowness tomographic maps derived from group velocity dispersion values in the period range between 8 and 100 s. To integrate these data, a relationship between seismic velocity and density was constructed by combining two empirical relations: one determined by Nafe and Drake, which is most appropriate for sedimentary rocks, and a linear Birch's law, which is more applicable to denser rocks (the basement). An iterative, damped least-squares inversion, including smoothing, is used to jointly model both data sets, using shear velocity variations as the primary model parameters. Results show high upper mantle shear velocities beneath the Tarim basin and suggest differences in lower crust and upper mantle shear velocities between the eastern and western Tarim basin.

Reference: Maceira, M., and C. J. Ammon (2009). Joint inversion of surface wave velocity and gravity observations and its application to central Asian basins shear velocity structures, *J. Geophys. Res*. 114: B02314, doi:10.1029/2007JB005157

SEISMO-53/K: A model and methods for the computation of regional seismic travel times

Stephen C. Myers[1], Michael L. Begnaud[2], Sanford Ballard[3], Michael E. Pasyanos[1], W. Scott Phillips[2], Abelardo L. Ramirez[1], and Charlotte A. Rowe[2]
[1]Lawrence Livermore National Laboratory; [2] Los Alamos National Laboratory; [3] Sandia National Laboratory
Contact: smyers@llnl.gov

Abstract: A Regional Seismic Travel Time (RSTT) model and method is developed for use in operational monitoring systems. The model captures the effect of the 3-dimensional crust and upper mantle on travel times of Pn, Pg, Sn, and Lg phases. By using a simple linear velocity gradient as a function of depth in the mantle (i.e. a 2.5D parameterization), a calculation speed of approximately 1 millisecond is achieved on a single computer processor. This calculation speed allows the model to be used in real-time seismic analyses. A tessellation of nodes provides global coverage with seamless sampling of ~1°. Although the model can return a travel time anywhere on the globe, the model is currently optimized for use throughout Eurasia and North Africa. Model optimization is accomplished using seismic tomography, whereby the average crustal velocity, mantle velocity at the Moho, and the mantle velocity gradient at each node is adjusted to better fit a high-quality data set. In the initial phase of this work, approximately 600,000 Pn arrivals from events with well-constrained locations comprise the tomographic data set. Ten percent of the tomography data are randomly selected and set aside for testing purposes. Across Eurasia and North Africa travel time residual variance for the validation data is reduced by 32%. Based on a geographically distributed set of validation events with epicenter accuracy of 5 km or better, epicenter error using 16 Pn arrivals is reduced by 46% from 17.3 km (*ak135* model) to 9.3 km for the RSTT model. Epicenter uncertainty ellipses are validated and found to contain the expected number of ground-truth epicenters within expected variations. Relative to the *ak135* model, the median area of epicenter uncertainty ellipses is reduced by 68% from 3070 km^2 to 994 km^2, and the number of ellipses with area less than 1000 km^2, which is the area allowed for onsite inspection under the Comprehensive Nuclear Test Ban Treaty, is increased from 0% to 51%.

Reference: Myers, S.C., M. Begnaud, S. Ballard, M. Pasyanos, S. Phillips, A. Ramirez, M. Antolik, K. Hutchenson, G. Wagner, J. Dwyer, C. Rowe, and D. Russell (2009). A crust and upper mantle model of Eurasia and North Africa for Pn travel time calculation, *Bull. Seismol. Soc. Am.,* In Preparation.

SEISMO-54/K: Testing the global capabilities of the Antelope software suite: fast location and Mb determination of teleseismic events using the ASAIN and GSN seismic networks

D. Pesaresi (1,2), M. Russi (1), M. Plasencia (1), and C. Cravos (1)
(1) OGS, Trieste, Italy, (2) INGV, Roma, Italy (
Contact: dpesaresi@inogs.it, pesaresi@ingv.it

The Italian National Institute for Oceanography and Experimental Geophysics (Istituto Nazionale di Oceanografia e di Geofisica Sperimentale, OGS) is running the Antarctic Seismographic Argentinean Italian Network (ASAIN), made of 5 seismic stations located in the Scotia Sea region in Antarctica and in Argentina: data from these stations are transferred in real time to the OGS headquarters in Trieste (Italy) via satellite links. OGS is also running, in close cooperation with the Friuli-Venezia Giulia Civil Defense, the North East (NI) Italy seismic network, making use of the Antelope commercial software suite from BRTT as the main acquisition system.
As a test to check the global capabilities of Antelope, we set up an instance of Antelope acquiring data in real time from both the regional ASAIN seismic network in Antarctica and a subset of the Global Seismic Network (GSN) funded by the Incorporated Research Institution for Seismology (IRIS). The facilities of the IRIS Data Management System, and specifically the IRIS Data Management Center, were used for real time access to waveform required in this study.

Preliminary results over a few months period indicated that over 80% of the earthquakes with magnitude M>5.0 listed in the PDE catalogue of the National Earthquake Information Center (NEIC) of the United States Geological Survey (USGS) were also correctly detected by Antelope, with an average location error of 0.05 degrees and average body wave magnitude Mb estimation error of about 0.1.
The average time difference between event origin time and the actual time of event determination by Antelope was of about 45': the comparison with 20', the IASPEI91 P-wave travel time for 180 degrees distance, and 25', the estimate of our test system data latency, indicate that Antelope is a serious candidate for regional and global early warning systems.

Updated figures calculated over a longer period of time will be presented and discussed.

SEISMO-55/K: Global upper mantle seismic tomography using the spectral element method.
Ved Lekic and Barbara Romanowicz, *Berkeley Seismological Laboratory, Berkeley, CA, 94720, USA.*
Contact: barbara@seismo.berkeley.edu

Abstract: The elastic structure of the upper mantle provides key constraints for determining the temperature, composition and dynamics of the mantle. Its accurate knowledge is also critical for performing path corrections in CTBT discrimination studies.
All existing tomographic models of mantle structure have been developed using approximate techniques that are insufficiently accurate in predicting the effects of the crust and sharp velocity gradients on seismic waveforms. We have developed a new approach to tomography in which the spectral element method (SEM) is used to accurately calculate the propagation of seismic waves through heterogeneous mantle and crustal structures. We have applied this method to a large dataset of long period (>60s) surface wave and overtone 3 component waveforms. Our retrieved shear wavespeed structure confirms the long-wavelength features gleaned using approximate techniques. However, our improved forward-modeling scheme allows us to image mantle structure with unprecedented resolution. We show how the addition of data from IMS broadband stations improves resolution in some regions of the world.

SEISMO-56/K: Open data exchange in support of CTBT research
David W. Simpson and Ray Willemann, *IRIS Consortium, Washington, D.C.*
Contact: simpson@iris.edu

Abstract: Seismological data from a variety of open sources can contribute to both research and monitoring related to the CTBT and complement the more formally structured and restricted data procedures of the International Monitoring System. In addition to providing an increasingly rich source of data for fundamental research programs and monitoring, the open exchange of data can encourage international and multi-disciplinary collaboration and lead to improvements in data quality and network practices.
As stated in its mission statement, the IRIS Consortium and its members commit to "promote exchange of geophysical data and knowledge, through use of standards for network operations, data formats, and exchange protocols, and through pursuing policies of free and unrestricted data access". All data collected through IRIS programs as supported by the US National Science Foundation are archived at the IRIS Data Management Center (DMC) from which they are freely and openly available to researchers and the public. Most of the continuous waveform data from the IRIS/USGS Global Seismographic Network and the EarthScope Transportable Array are available in real-time. Investigators using portable PASSCAL and the EarthScope Flexible Array equipment can request that access to their data be limited for a two-year proprietary period, following which all data must be archived at the DMC and made openly available.

In addition to data from IRIS programs, the DMC also provides archiving and distribution for data contributed by many other global networks (including members of the Federation of Digital Seismographic Networks), national networks in other countries and regional networks in the US. Expanding use of networked data services provides access to the archives of additional data centers worldwide. Data exchange with the USGS National Earthquake Information Center (NEIC), regional networks in the US and international mission agencies contributes to global and national earthquake monitoring. All of the data in the DMC can be accessed through a common set of data access tools, providing easy access to waveform data from thousands of sensors in hundreds of networks throughout the world, for studies of structure and source characteristics in varied tectonic and geographic environments. The archiving of continuous data, with well-maintained metadata and quality control, is becoming increasingly important in the investigation of long-term (decadal) changes in background noise (possibly related to climate change), studies of exotic sources and observing temporal changes in earthquake source characteristics.

SEISMO-57/K: The International Federation of Digital Seismographic Networks (FDSN): Thirty Years Dedicated to Seismological Research and High-Quality Seismological Data Production and Distribution

Gerardo Suárez[1], Torild van Eck[2], Jim Lyons[3], Tim Ahern[4] and Rhett Butler[5]

[1] Instituto de Geofísica, Universidad Nacional Autónoma de México (UNAM), México; [2] Observatories and Research Facilities for European Seismology (ORFEUS),; c/o KNMI, de Bilt, The Netherlands

[3] Geological Survey of Canada, Ottawa, Ontario, Canada; [4] Data Management Center, IRIS, Seattle, Washington, USA; [5] Incorporated Research Institutions in Seismology (IRIS), Washington D.C., USA

Contact: gerardo@geofisica.unam.mx

Abstract: The International Federation of Digital Seismographic Networks (*FDSN*) is a non-governmental organization formed by institutions dedicated to seismological research and seismic monitoring. The *FDSN* is a successful complement to the International Seismological Centre (*ISC*) in pursuing a more than a century old tradition of global seismic data exchange. The main goal of the *FDSN* is the production and dissemination of seismic waveform data from high-fidelity seismic observatories. The Federation is formed by 65 organizations from 52 countries that contribute data to three main data centers in the United States, Europe and Japan. A subset of the stations that participate in the *FDSN* send real-time to the Data Management Center (*DMC*) of the Incorporated Research Institutions of Seismology (*IRIS*) in the United States and the Data Center (ODC) of the Observatories and Research Facilities for European Seismology (ORFEUS). Data from this real-time network are crucial to the determination of the seismic parameters of large earthquakes in a very short time after their occurrence and to support the efforts of institutions that are responsible for disaster relief or prevention. Most notably, Tsunami Warning Centers use this information as a fundamental underpinning to issue warnings and alerts. Through the operators that are part of the *FDSN,* the Federation has been an active participant in verification issues for many years. Over half of the stations that comprise the auxiliary seismic network of the International Monitoring System (IMS) are part of the *FDSN* network. Operators of these stations have contributed their technical expertise to properly and effectively operate these stations and to facilitate the installation of the software and hardware necessary for the stations to conform to the *IMS* specifications in data format and authentication. The *FDSN* is actively working with the *CTBTO* to improve the collaboration in station-related issues and to promote the generation of high-quality data.

SEISMO-58/K: Sudan seismicty and the Sudan seismic network

Abd Alhadi Ibrahim Alhassan, Amani Elkhidir Belail, Hatim Siddig Hag Elbashir, Indira Abdel Rahman Mohamed, Mustafa Bashir Mohammed and Nada Bushra Eltahir, *Geological Research Authority of Sudan (GRAS), Khartoum , Sudan.*

Jens Havskov, *Department of Earth Science, University of Bergen, Norway*

Contact: nada_ahmed99@hotmail.com

Abstract: Though Sudan is characterized by low seismic activity, several big earthquakes have been recorded, which resulted in loss of life and damage to properties. The largest of these was probably the largest earthquake in Africa in the 20th century. It occurred on 20 may 1990 (Ms=7.1-7.4) near Juba in the southern part of Sudan. Other earthquakes whose effects caused major damage and even deaths, include the Suakin graben earthquakes (Ms= 5.8) of 12 May 1938, located in the Western margin of the Red Sea, the Jebel Dumpier event located in Central Kordofan (Ms=5.6), which occurred on 9th October 1966, and the Khartoum event (Ms=5.5) of August 1993.

In 2001, the Sudan Geological Research Authority (GRAS) established a three station seismic network to monitor earthquake activity in the region. The network is, for practical reasons, distributed around Khartoum and local, regional and distant earthquakes are recorded. Most of the local events are found to be correlated with the fault NW of Khartoum, which is thought to be the epicenter of the Khartoum earthquakes of August 1993. The SSN, is also able to detect and locate events from large distances.

The network is well calibrated, has low noise stations and seems to give very accurate Ms and Mb. SSN has started to report all readings to the International Seismological Centre (ISC) and should be able to make a significant contribution considering the scarcity of stations in the area and the accuracy of its observations.

SEISMO-59/K: A review of seismological studies in Bangladesh

Tahmeed M. Al-Hussaini*, Professor of Civil Engineering, Bangladesh University of Engineering & Technology*

Contact: htahmeed@yahoo.com

Abstract: Bangladesh is located in a seismically active region due to its proximity to the plate boundary of Indian plate and Eurasian plate. The collision of the Indian Plate moving northward with the Eurasian plate is the cause of frequent earthquakes in the region comprising Bangladesh and neighbouring India, Nepal and Myanmar. Some large magnitude (M>7) historical earthquakes have affected parts of Bangladesh in the past.

Unfortunately, few seismological studies have been carried out in this country. Due to the absence of large magnitude earthquakes in recent times in the region, people had been complacent about the threat of earthquakes. There was only one analog seismic recording station in the south east part of the country which also did not function properly. Only in recent years the occurrence of devastating earthquakes in India, Pakistan and Indonesia, occurrence of small to moderate earthquakes in the country and awareness campaigns by different groups of people including the government has resulted in some earthquake awareness among the people. The government has very recently installed modern digital seismological observatories in major cities of Bangladesh. Leading universities of the country (Bangladesh University of Engineering & Technology, Dhaka University) have been involved in installing and operating additional seismic recording stations. Very recently some foreign experts have undertaken some field trenching studies within the country to study the validity of some assumed active faults.

This paper will attempt to give a brief account of the different seismological studies carried out in Bangladesh. Available internet and library resources is used to collect information on such studies. The current status of seismological research in the country will be discussed. The possible outlook for such research appears to be good due to accumulation of earthquake recordings in Bangladesh and interested researchers within the country.

SEISMO-60/K: Neotectonics and Paleoseismoloy along the Dead Sea Fault in Jordan

Mahmoud Al-Qaryouti [*] ***and Khalid Momani*** [**]
[*] *Seismology Division, Natural Resources Authority, Amman, Jordan;* [**] *Geological Mapping, Natural Resources Authority, Amman, Jordan*
Contact: almah2010@yahoo.com

Abstract*:* The Dead Sea Transform (DST) fault system is well-defined by geological and geophysical studies. It is the active plate boundary between the Arabian plate and Sinai-Palestine subplate and is the main responsible of seismic source in the region. The geometry and formation of the Dead Sea basin and lake are controlled by a pull-apart basin that developed due to *en echelon* pattern of the major faults in this area. The Dead Sea is a deep saline lake located within the major on-land, pull-apart basin along the transform, between Jordan and Palestine. Holocene and late Pleistocene fan-deltas are very common deposits along the western margins of the Dead Sea and can record the areal and temporal distribution of significant earthquakes. Geological observations (Quennell, 1956; Garfunkel et al., 1981) as well as plate tectonic models (e.g. McKenzie et al., 1970; Joffe & Garfunkel, 1987; DeMets et al., 1994; Jestin et al., 1994) suggest that the DST accommodates the differential motion between Arabia and Sinai-Palestine by left-lateral slip. The modern slip rate is poorly constrained, however; geological observations suggest nearly pure strike-slip faulting and estimated rates range between 1 and 20 mm/y (e.g. Freund et al., 1968; Garfunkel et al., 1981; Gardosh et al., 1990; Ginat et al., 1998). By correlation with similar surfaces along the Dead Sea lake margin, Klinger et al. (2000) and Le Beon (2008) propose a chronology for their emplacement. Taken together, the observations suggest an average slip rate over the Late Pleistocene of between 2 and 6 mm/y, with other preferred value of 4 mm/y. This study focuses the new tectonics and paleoseismology related to the alluvial floor of the rift valley which cuts sharply along particular straight traces.

SEISMO-61/K: Large and Great Earthquakes in the Stable Continental Region of India: Seismotectonic Perspective

J. R. Kayal, *CSIR Emeritus Professor, Jadavpur University, Kolkata 700032, India*
Contact: jr_kayal@yahoo.com

Abstract: During the last few years, since 1993 three strong/large earthquakes, chronologically the 1993 Killari (m_b 6.3), the 1997 Jabalpur (m_b 6.0) in the central part of peninsular India shield area and the 2001 Bhuj (M_w 7.7) in the western part of the peninsular shield area, caused severe damages and large casualties. All these earthquakes and their aftershocks recorded by temporary seismic networks were well studied by various national and international organizations (Kayal, 2007). These investigations have been very useful to understand the seismicity and seismotectonics of the stable continental region (SCR) earthquakes in India. While the Killari event was a typical shallow (depth <10 km) shield earthquake, the Jabalpur and the Bhuj events were identified as the deeper (25-35 km) *paleo-rift* events with inverse tectonics.

Further, recent broad band seismic data in the Shillong plateau in northeast India have shed light on seimotectonics of the 1897 great Shillong earthquake, revised Ms ~ 8.0. This great earthquake, though initially believed to be a Himalayan thrust earthquake, is now argued to be a shield intra-plate earthquake generated by *pop-up* tectonics of the Shillong plateau in the northeastern part of the Indian shield (Kayal et al., 2006).

Reference:

Kayal, J.R., Arefiev, S.S., Baruah, S., Hazarika, D., Gogoi, N., Kumar, A., Chowdhury, S.N. and Kalita, S., 2006. Shillong Plateau earthquakes in northeast India region: Complex tectonic model, ***Curr. Sci.***, 91(1), 109-114.

Kayal, J. R. 2007. Recent large Earthquakes in India: Seismotectonic Perspective, **Int. Asoc.** Gondwana Res. Mem., 10, 189-199.

SEISMO-62/K: Muzaffarabad Earthquake of October 8, 2005: Source Parameters using Empirical Green's Function Technique

M. Tahir*, Javed Iqbal*, M. Qaisar, M. Ali Shah, Tariq Mahmood and Shahid A. Khan
**LGIT, 1381, rue de la Piscine, Grenoble FRANCE Micro Seismic Studies Programme (MSSP), P.O., Nilore Islamabad.*
Contact: mtyousafzai@yahoo.com

Abstract: Source parameters of Muzaffarabad earthquake of October 8, 2005 were estimated using small events as Empirical Green's Function, which include path, site and instrumental effect on Pwaveforms. The relative source time functions (RSTF's) for the main event at different stations were estimated using iterative deconvolution method. Source parameters such as seismic moments at different stations vary from 1.08 to 9.07 x 1020 Nm with average value as 2.65 x 1020 Nm calculated from duration of RSTF's. The pulse width and amplitudes of RSTF's variations with different azimuths show that rupture propagation were not unilateral. Fault

length as 36 km and rupture velocity as 3.5 km/s were calculated using directivity effects. The fault length might be smaller but comparable with fault calculated using Sato and Hirasawa Model.

SEISMO-63/K: Focal Mechanism Solution of the 15th March 2008, Nyamandlovu Earthquake using CTBTO SeismicSstations

Blessing Tawanda Shumba[1], Dumisani John Hlatywayo[2], Vunganai Midzi[3]
[1]Goetz Observatory, P.O.Box AC65, Ascot, Bulawayo, Zimbabwe; [2]Physics Department, National University of Science and Technology, P.O.Box AC 939, Ascot, Bulawayo; [3]Seismology Unit, Council for Geoscience, P. Bag X112 Pretoria 0001 South Africa
Contact: shumbamajachani@yahoo.co.uk

Abstract: Focal mechanism solution of the 15th March 2008 earthquake (mb = 4.3) that occurred in the Nyamandlovu area, northwest of Bulawayo City, Zimbabwe, has been determined from P-wave first motion polarities. CTBTO stations and some regional seismic stations were employed in this study. Results show normal oblique left lateral faulting. The earthquake mechanism bears a signature that is almost synonymous with that for events in the Zambezi branch of the East African Rift zone. Synthetic seismograms compared with observed data from regional stations were employed for depth determination. This event had a shallow depth of 5km. Earthquakes in the area tend to occur either after a significant drought or a wet season of considerable length. The area is underlain by thick Karoo sandstones that form an aquifer of high potential water storage. These events are therefore most probably induced by pore – pressure differentials in the underlying rock.
Key words: focal mechanism, P-wave polarity, depth, Nyamandlovu

SEISMO-64/K: Results from IMS Seismic Array in Niger

C. Estabrook[1], B. Bergsson[1], S. Soumana[2], O. Boureima[2], M. Moumouni[2]
[1]Comprehensive Nuclear Test-Ban Treaty Organization/ IMS Division, PO Box 1200, 1400 Vienna, AUSTRIA
[2]Institut des Radio-Isotopes, Abdou Moumouni University, B.P. 10727, Niamey
Contact: charles.estabrook@ctbto.org

Abstract: The International Monitoring System (IMS) of the Preparatory Commission of the Comprehensive Nuclear Test-Ban Treaty Organization (CTBTO) has built a sixteen element broadband seismic array in southwestern Niger near the town of Torodi. This is the first array to be built in West Africa. The array has a diameter of 6 km (three rings with a central element), contains twelve vertical and four 3-component broadband sensors, all with identical instrument responses (Guralp CMG-3TB broadband sensors, flat to velocity from 100 seconds to 40 Hz). Many elements have seismic noise characteristics at or below Peterson's Low Noise Model at greater than 0.5 Hz. All of the sensors are emplaced in 50 m boreholes in crystalline rock.

The array is used to examine the North African Craton Structure and Seismicity. Receiver functions show that the crust is fairly simple with a Moho depth of about 38 km and Upper Mantle Discontinuities at 410 and 660 km. Because this is one of the few seismic arrays close to the Equator (array is centered at 13.2 N) and because its distance to Tonga-Fiji-New Zealand is 140-160 degrees, it could be used to look at temporal and spatial (north-south) variations in core phases. It is also used to look at Solid Earth Tides and long period diurnal signals. The array is capable of resolving and detecting events with magnitude (mb) less than 3.0 from events in Peru and Indonesia, showing that the array significantly adds to the IMS detection capabilities in the Africa region and world-wide.

SEISMO-65/K: CTBT Space-Based Monitoring: Interferometric Synthetic Aperture Radar and National Technical Means

David Hafemeister, Science Affiliate Center for International Security and Cooperation, Stanford University
Contact: dhafemei@calpoly.edu

Abstract: Interferometric Synthetic Aperture Radar (InSAR) is apromising new technology, which has detected and identified explosions of 1 kton at a depth of 500 meters at the Nevada Test Site. InSAR cannot detect all nuclear explosions under 1 kton at all locations, but if the test is roughly located by seismic or other data to a general location, InSAR can discriminate between explosions and earthquakes by the shape of the interference pattern. In addition, InSAR can determine absolute locations for onsite inspections to 100 meters, or 0.01 square kilometers. The larger the test the more useful InSAR becomes. National Technical Means can detect,

discriminate and locate nuclear tests at chosen sensitive locations with greater accuracy than that obtained by the IMS. An unclassified description of NTM technologies is included in this paper.

SEISMO-66/K: The DPRK event of May 25, 2009: a preliminary analysis carried out at INGV from a multidisciplinary perspective

M. Chiappini, R. Carluccio, S. Chiappini, R. Console, F. D'Ajello Caracciolo, K. Damiani,A. Giuntini, V. Materni and A.Nardi, Istituto Nazionale di Geofisica e Vulcanologia, Rome, Italy
Contact: carluccio@ingv.it

Abstract: On the early morning of May 25, 2009 INGV detected an event located in a predefined area of interest, including the DPRK. Such detection triggered the request of raw data from the seismological International Agencies that operate global seismic networks. Around 6:00 UTC of the same morning, the INGV staff started the standard procedures of seismological analysis on the data collected from such Agencies, in order to locate, identify and characterize such event from a National perspective. At the same time, the DPRK Government announced the conduction of an underground nuclear test in their territory, confirming the suspected explosive nature of the seismic event.

The seismological analysis carried out at the INGV included, as usual, hypocentral location, mb and Ms computation, application of discrimination criteria developed at the INGV, and estimation of a possible range for the yield. Here the basic parameters for the event, as obtained at the INGV are reported:

Origin time: 2009/05/25 00:54:43.039
Latitude: 41.286 deg. N +/- 12.214 km.
Longitude: 129.174 deg. E +/- 14.767 km.
Depth: 0 (fixed by the analyst)
mb: 4.5 +/- 0.1; Ms: 3.2 +/- 0.2

These parameters are consistent with those reported by the IDC in its SEL bulletins and later confirmed in the REB. The criteria adopted at the INGV for event screening has lead us not to screen out this event and to classify this event has an explosion with high probability. To reach this conclusion, a rigorous statistical method known as "Discriminant Analysis" has been applied (see also a poster entitled "Development and testing of seismic regional discriminants" submitted to this same meeting).

Particular care has been devoted to the comparison with the nuclear test announced by the DPRK on 9 October 2006. The two locations appear very close to each other (within a distance of the order of 10 kms), with the respective error ellipses nearly totally overlapping (the error ellipse area of the recent event is smaller due to the better quality and more numerous recordings). A more accurate relative location has been carried out by the application of the algorithm of DDJHD specifically developed at the INGV for these purposes (see also a poster entitled "Comparison of IDC and National seismic bulletins" submitted to this same meeting). In this case the epicentral distance drops to less than 3 kms, with an error of 3 kms. The depth comparison, obtained by the same DDJHD method shows a difference smaller than 4 km between the two depths.

The event appears to have occurred in a mountainous area of scarce natural seismicity, geologically belonging to a tectonic region constituted by granitic massifs and not far from volcanic structures, some of which still active at the present time. For a conversion of the mb magnitude into yield, numerous relations developed in the past are available. The proper relation to be used in specific cases, like this, depends on an accurate knowledge of the geological framework. Unfortunately, this is not our case, due to the vicinity of granitic intrusions to lava flows and pyroclastic material coming from the volcanoes present in the area. Adopting a relation obtained from the Nevada test site, the possible value of yield for an explosion of magnitude mb=4.5 is at least 3.0 kt.

SYSTEM PERFORMANCE

SP-01/C: Effective coping with uncertainties in evaluation of the compliance to international treaties

Y. Ermoliev, T. Ermolieva, M. Makowski*, International Institute for Applied System Analysis,, A-2361 Laxenburg, Austria*

Contact: ermoliev@iiasa.ac.at

Abstract: Evaluation of the compliance to an international treaty often involves an effective treatment of the related uncertainties, and incomplete and/or asymmetric information. We show on the example of the Kyoto Protocol to the UNFCCC how to effectively handle inherent uncertainties during the compliance evaluation in order to achieve environmentally safe and cost-efficient implementation. Moreover, the proposed approach has two additional features: (1) the solution is cost-effective not only globally but also for each party, (2) the parties need not to reveal complete cost information.

SP-02/C: Analysis of system performance applied to the territory of Romania (2004 - 2008)

Daniela Ghica[1], Mihaela Popa[1] and Victoria Oancea[2]

[1] National Institute for Earth Physics, National Data Center, Bucharest, Romania

[2] Science Applications International Corporation, McLean, VA, USA

Contact: daniela_ghica@yahoo.com daniela@infp.ro

Abstract: In support of the verification regime of the Comprehensive Nuclear-Test-Ban Treaty, the National Institute for Earth Physics (NIEP, Bucharest) hosts the National Data Centre of Romania (ROM NDC), and operates the auxiliary seismic station Muntele Rosu (AS081, MLR) as part of International Monitoring System (IMS) network. The paper presents results on evaluation of the performance of the International Monitoring System for a small geographical area, the territory of Romania. The analysis is carried out for the 2004-2008 period.

Seismic data from MLR station have been provided directly to the International Data Centre (IDC) upon request at any time through on-line computer connections and VSAT transmission. The paper discusses the GCI link availability and data availability for MLR, as well as the usage of MLR data in the IDC for the automated and reviewed products.

Daily event bulletins are produced by ROM NDC, including the events located on the territory of Romania, using seismic data recorded by the national seismic network. These bulletins, sent on a monthly basis to the IDC, provide ground truth solutions for many events located by the IDC in Romania, as they are based on data recorded with a dense local network.

The IDC automated and reviewed event bulletins include events in whole world, based on processing data recorded by a network of seismic, hydroacoustic and infrasound globally distributed IMS stations. It is very interesting to compare the solutions obtained using a globally distributed network and a local national network, for a set of events located in an area covered by the local network. There were 72 common REB-NDC events located on the territory of Romania during 2004-2008, and 70 common SEL3-NDC events. These solutions were analyzed, and conclusions resulted by comparing their epicentral location, depth, magnitude, error ellipse, and number of phases are presented. As a consequence of the superior coverage of stations on the Romanian territory, the ROM NDC locations are better constrained.

SP-03/C: Seismic monitoring – network problems

Hlompho Malephane, *Lesotho Highlands Development Authority*

Contact: hrmammile@yahoo.com

Abstract: The Lesotho Highlands Water Project (LHWP) is a bi-national engineering project, whereby dams are constructed in Lesotho for purposes of generating electricity locally and transferring water to South Africa. Currently, there are two large reservoirs at which seismic networks are set up to monitor induced seismicity.

This poster/presentation describes the seismic monitoring system of the Lesotho Highlands Water Project (LHWP) with regards to the dams/reservoirs. An overview of the seismic network setup, its operation and limitations are made and the problems encountered in running these networks are the key focus. It will be shown that most of the problems are topographic and climate related, as well as the nature of certain units of the networks and finally, investigations on how to resolve these problems will be made.

SP-04/C: Simulations of IMS Detection Effectiveness as Deployed vs. Planned

James Arzigian and Joseph Damico, Sandia National Laboratories
Contact: jsarzig@sandia.gov

Abstract: Some decisions regarding placements of sensors for the IMS were made using models to predict sensor detection effectiveness; other models attempted to integrate the combined predicted performance of radionuclide, seismic, hydroacoustic and infrasound networks to provide an overall systems effectiveness measurement. In the intervening years, most, but not all of the proposed sensors have been placed, a significant body of system performance data has been collected, and new models have been developed for specific system performance characteristics. An integrated systems model of IMS performance using individual performance evaluation modules based on technology current with the initial development of IMS was used to compare predicted performance of the sensors actually placed in IMS with the entire suite of proposed sensors. Estimates of detection probability are displayed for the combined as-deployed network. An outline is presented of a potential new combined systems analysis model that takes advantage of modeling approaches that have been developed since the inception of IMS, and benefits from the significant body of data now available.

SP-05/C: NDC Preparedness Exercises - Performance assessment of the CTBT Verification System by simulating realistic scenarios -

N. Gestermann and M. Henger, *Federal Institute for Geosciences and Natural Resources, Hannover, Germany*
Contact: henger@sdac.hannover.bgr.de

Abstract: The underground nuclear explosion conducted by the Democratic People's Republic of Korea (DPRK) on 9 October 2006 was the first real performance test of the CTBT verification system. The IDC and NDCs presented convincing results of their event analysis at the Kiev evaluation workshop in October 2006. However, doubts were raised whether similar processing results, in particular with respect to event characterization, would have been achieved if the DPRK had not announced this event. As a follow up of these discussions, NDCs agreed to carry out an event analysis exercise that simulates the scenario of a small event of unknown nature for which neither the location nor the time of its occurrence is known. The idea of the "NDCs Preparedness Exercise" (NPE) was born.

The NDCs expected from the NPE to reveal strengths and weaknesses of the verification system from the NDC perspective. Additionally the exercise promised to contribute both to the evaluation process of the PTS products and to provide a realistic assessment of the quality and performance of the processing and analysis procedures applied at each individual NDC.

An appropriate selection process was applied at the German NDC to SEL1 events which are routinely received from the IDC. The NPE candidate event was defined to be the first SEL1 event occurring after an agreed NPE start time for which the epicenter was located within one of a total of fourteen predefined areas. Additionally, the event location had to be based on phase picks from at least six seismometer stations and the magnitude was requested to fall into the range between $3.8 \leq mb \leq 5.0$. The application of this selection scheme produced an SEL1 event of magnitude mb=3.9 in Northern Iran in 2007. The automatic IDC processes for event location and mb-magnitude determination worked quite well as for the DPRK nuclear explosion, whereas surface magnitude determination and event classification were found to leave room for improvement. Better results would have been obtained if the IMS network had be completed at this time. Particularly data from non-operational seismometer stations at local and regional distances from the epicenter were missed. Therefore it was a challenging task for NDCs to classify this event unambiguously as an earthquake. A complete IMS network would have considerably facilitated the event classification process.

Due to the usefulness of the first NPE in 2007 there was no doubt for NDCs to continue with this kind of testing in 2008. The selection criteria were slightly modified with respect to the number and extent of the selection areas and the magnitude range, for which the upper limit was reduced to mb=4.8. Moreover, a radionuclide component was added to this exercise. NPE08 started on 20 October 2008. The first SEL1 event that met the selection criteria happened to occur in the Chile-Bolivia border region on October 27. Although the automatic epicenter determinations of the SEL2 and SEL3 bulletins seemed to confirm the SEL1 location, the coordinates of the epicenter in the REB pointed to a location more than 150 km to the West to the Pacific coast of Northern Chile. With mb=3.9 the REB magnitude was somewhat lower as given in the SEL1. It was striking to see the REB location not coinciding with the epicenter of the Chilean Seismological Institute, which is based on data from a regional network.

This difference results from lack of data from a number of existing IMS stations in South America which did not work at this time. Although the results of NPE08 have not been discussed yet in detail, they indicate that the network performance of the verification system does currently not meet the requirements in South America. Only available and useful data from operational stations and good coverage of regional stations for each

individual event should be counted as key performance indicators of interest both for NDCs and for the assessment of the capability of the verification system with respect to event location and identification.

SP-06/C: Is there an identifiable human signature in the International Data Center Products?

***Y. Ben Horin*[(1)] *and D. Steinberg*[(2)]**
[(1)] *National Data Center Israel, Soreq NRC*
[(2)] *Department of Statistics and Operations Research Tel Aviv University*
Contact: tal@ndc.soreq-ndc.gov.il

Abstract: The International Data Center (IDC) regularly produces several bulletins as part of the Comprehensive Nuclear-Test Ban Treaty (CTBT) verification regime. The compilation of the Reviewed Event Bulletin (REB) is the only human intervention during the analysis of CTBT waveform technologies data. The aim of the work is to investigate, by using statistical methods, if there is an identifiable human signature in the REB analysis. In the first stage of the work three months of data from the IDC automatic bulletin (SEL3) and the REB where analyzed. In the data supplied by the IDC the analyst indicator is masked, so that this amounts to using unsupervised methods to search for an analyst signature. The analysis demonstrates that by analyzing the difference between SEL3 and REB several dependencies are revealed but none of them can be related to the analyst's work. In the next stage of the work the analysis will be repeated but this time the data set will include a training set in which the analyst indicator will be revealed (anonymously); thus supervised learning methods will be applicable to this next stage.

SP07/C-: Advances in data integration and quality control in support of ground-based nuclear detonation detection

Richard J. Stead, Michael L. Begnaud, and Julio Aguilar-Chang*, Los Alamos National Laboratory*
Contact: stead@lanl.gov

Abstract: The goal of the U.S. DOE NNSA Ground-based Nuclear Detonation Detection Research and Development program is to develop, demonstrate, and deliver advanced technologies and systems to operational monitoring agencies to support ground-based detection, location, and identification of nuclear explosions. This work is primarily conducted using relational database schemas (sets of table structures). The research conducted at the NNSA national laboratories to populate the schemas requires collection and integration of a remarkably large and diverse collection of geophysical data to develop the types of products needed to improve monitoring. The size and diversity of these data present substantial technical challenges to achieve complete, correct, consistent, useful, and accessible information. These data are processed by the national laboratories to produce the higher-level engineering products (e.g., travel-time correction surfaces) that are needed for operational monitoring, but the basic data must also be included in the schemas to fully test and verify the operational products. Los Alamos National Laboratory has developed and refined a substantial foundation of software, structures, and procedures to assure high-quality integration of diverse data sets. Software advances include generalized database interfaces and generalized quality assurance/quality control (QA/QC) software. Structural advances include a metadata abstraction of supporting structures (themselves metadata) that we refer to as the "schema schema." Procedural advances leverage the software and structures to create robust procedures for definition and transfer of data between groups.

The development and application of automated QC software is the primary topic of this paper. Attention to quality has been a subject of growing importance and focus. Dealing with data quality in an established system is difficult and time-consuming. A better approach is automated QC of supporting data before they are integrated. The first critical step in automating QC is to make the information about the schema readily available to the QC software, which has been done by developing a set of tables describing the schema itself, or a schema schema. The schema schema captures information about the content of each table (what the columns are), the relationships between the tables, and information about each column (definition, acceptable range of values). With this in hand, a Perl-based QC tool was developed to check the content of any set of tables against what is in the schema schema. The software performs three basic types of checks: 1) validity of column data within each table, 2) consistency of column data between related tables, and 3) more complicated consistency relationships between related tables. Because the software makes use of the schema schema, it was written in a generic manner and thus can be used for virtually any sort of check without modifying code. A user sets up a parameter file to designate the database tables that will be checked, writes the specific checks for #2 and #3 above, and then initiates the QC check. The output can then be used to direct the integrator to problems in the incoming data.
We believe the results of our research and development efforts discussed herein may be applicable to the work of the Comprehensive Nuclear-Test-Ban Treaty Organization International Data Centre (IDC). The schema schema can provide more easily and consistently maintained documentation of the IDC schemas used to support the

work of the IDC. The web interfaces may provide the mechanisms for this maintenance and easy access for reference and development purposes. And the QC software may provide a simple means to identify issues in the IDC databases and contributed information, which may need to be addressed.
Reference: Stead, R. J., M. L. Begnaud, and J. Aguilar-Chang (2006). Advances in data integration and quality control in support of the NNSA Knowledge Base, in *Proceedings of the 28th Monitoring Research Review,* Vol. 2, pp. 1028–1037.

SP-08/C: Bridging the missing link to strengthen CTBT verification regime

Isaiah Tumwikirize 1
1Geophysicist, Department of Geological Survey and Mines P. O. Box 9 Entebbe, UGANDA
Contact: isaiah.tumwikirize@gmail.com

Abstract: Since the establishment of the preparatory commission for the Comprehensive Nuclear Test Ban Treaty Organisation (CTBTO) by the Comprehensive Nuclear Test Ban Treaty (CTBT) in 1996, progress is acknowledged in the implementation of the treaty through the International Monitoring System (IMS) technologies inter alia: seismology, hydroacoustics, infrasound and radionuclide, with increase in number of IMS stations and more states signing and ratifying the treaty. This paper only focused on the missing link which in my opinion can strengthen the existing verification regime which is concerned about the high energy extreme nuclear tests or explosions based on the past experience.

However, we are confronted with the missing link in that with the changing nature of states and technological advancement which has made portability and laboratory-work mobile; suggest that small energy nuclear tests can be carried out in the background of intense volcanic activity where volcanic events characteristics match with low energy nuclear tests. In addition, the IMS network on seismological technology can locate global seismic events of M≥4.5 with reasonable accuracy in a radius of 5-20 km where as small magnitude events less than M=4.5 are recorded sparsely in the global IMS network. National seismic networks which are not well configured have problems of locating small magnitude events. In most seismic bulletins such events are left not located.

Realising the role the small magnitudes events can play in complementing CTBT through IMS capabilities and civil uses of data by state signatories in e.g seismic micro-zonation and detailed seismic hazard assessment, characterization of volcanic, tectonic events and nuclear explosions, Uganda is expanding the existing network of four (4) seismic stations in the first phase to a total of ten (10) broadband stations in order to obtain high quality reliable seismic data which will be transmitted to National Data Centre (NDC) 180 at Department of Geological Survey and Mines in near real time. The long-term development plan is to install additional twelve (12) in the North and North-Eastern to monitor the Aswa shear zone and the volcanic centres in the Eastern Uganda and Kisoro in the south western volcanic corridor. The seismic network will also monitor the induced seismicity and hazard assessment for critical facilities such as dams. In addition high quality data will promote international collaboration in research and monitoring of seismicity due to geothermal activity, mining, oil and gas fields. In order to achieve good detection levels in the network, the distance from one station to its closest neighbour should ideally not be more than 100 km.

In conclusion bridging the missing link in the verification regime means strengthening further the IMS network by complementing the efforts of local seismic networks of states and seismic monitoring of all potential volcanic centres using technologies installed both on land and in space.

SP-09/C: Overview of Standards Activities in Reliability and QoS for CTBTO's Evolving Global Communications Infrastructure

***Spilios E, Makris**, Ph.D., (Telcordia), Chair ATIS[1] Standards PRQC[1] Reliability Task Force*
***Percy Tarapore**, (AT&T), Vice-Chair ATIS Standards PRQC*
Contact: smakris@telcordia.com

Abstract: This paper deals with the evolving Global Communications Infrastructure portion (GCI) of the Comprehensive Nuclear-Test-Ban Treaty Organization's (CTBTO) International Monitoring System (IMS). It focuses on the reliability and Quality of Service (QoS) aspects of the GCI. Specifically, evolving network architectures and technologies pose interesting challenges in measuring the "end-to-end" reliability and QoS, two critical aspects regarding the resilience of the GCI/IMS. The GCI is a private data network that is largely based on satellite (VSAT) links. However, for the received information from remote stations located around the world to reach the International Data Center (IDC) in Vienna, a large number of terrestrial networks and submarine cables are involved after the initial VSAT uplink-downlink. Of particular interest is the terrestrial and submarine cable systems portion of the GCI and the independent sub-networks of various Member States used to exchange data with the CTBTO.

Following a technological migration path, the GCI will eventually be evolved to a Next Generation Network (NGN), which is a packet-based network that seamlessly supports data, voice, and video services. Currently, service providers and network vendors are re-using large telephone switch reliability and QoS requirements and applying them to many types of network elements in Voice over IP (VoIP) and Voice over ATM (VoA) network solutions regardless of the impact of their failure modes. This paper discusses various issues with this approach and also addresses NGN reliability & QoS.

Reliability and QoS (as discussed in this paper) have two perspectives: (i) the service view; and (ii) the network view. Generally, the service view will be important to both end users and other service providers using the network. The network view will be most important to the owner and operator (a.k.a "service provider") of the network. The service user experiences service outages, failed service attempts, etc., while the service provider experiences maintenance costs, as well as, OAMP (Operations, Administration, Management, and Provisioning) outages such as loss of the ability to diagnose. A significant amount of effort has been devoted at national and international standards bodies on the migration path to NGN and the associated reliability and QoS issues. This paper gives (i) a broad, high-level overview of the different Standards activities, and (ii) discusses the challenges for the evolving GCI in the pursuit to achieve high reliability and meet the appropriate QoS parameters. Examples of applicable standards activities include development of QoS classifications for IP-based services, admission control priority requirements for NGN, and reliability/availability metric definitions and methodologies for various networking technologies.

SP-10/C: Towards a reliable communication network for International Monitoring System
Senthil Kumar Chandran[1] and Sasikumar Punnekkat Mälardalen University, Västerås, Sweden
Contact: senthil.kumar.chandran@mdh.se, sasikumar.punnekkat@mdh.se

Abstract: Building a secure and reliable network system especially for safety critical applications is an extremely challenging task even when the scale of the application or physical boundaries of the system are small and well-defined. The complex issues in network communications, security and data quality apart from the high reliability requirements pose difficult scientific problems one has to tackle with. In the context of the international monitoring system, these challenges become much more daunting due to heterogeneous network topologies, mixing of private networks and internet as well as the enormity of geographical coverage.

This paper attempts to provide an overview of the various approaches followed internationally in dealing with reliable network communications. One of methods highlighted in this paper for a secure communication for the International Monitoring System is the usage of Virtual Private Networks (VPN) in the identified sensor locations to communicate data to desired local access server locations through unsecured public networks. This setup could be for nearby local stations within a specified radius. The data is routed through a tunnel to local servers in the VPN using protocols such as IPSEC, PPTP etc.

Multi-homed network that provides redundant links are cost effective and are proposed as means to ensure high reliability and end-to-end availability between the VPN servers to the centralized system located at Vienna. This paper also compares various communication technologies and dependability strategies available and recommends suitable combinations that overcomes the challenges such as malicious attacks, various failure modes, dynamic changing of the routing table to address dead links etc., to preserve data integrity and provide highly reliable information to the end users.

SP-11/C: Verifying Timing Quality of Seismological Stations Using Teleseismic Arrivals
Klaus Stammler, *Federal Institute for Geosciences and Natural Resources, Germany*
Contact: klaus@szgrf.bgr.de

Abstract: This presentation addresses the topic of timing quality of seismological stations. Usually this quality parameter is checked by reading and parsing the logging information of the digitiser, i.e. the state of health channel. However, an independent check of timing quality seems advisable, in case that the SOH info is not available or is doubtful.

We propose to use teleseismic arrivals as timing reference. Such events within a distance range between 40 and 90 degrees and magnitudes between 5.5 and 7.0 usually provide signals of sufficient coherency if recorded in a network extending not more than 1000km in diameter. This coherency can be exploited with a crosscorrelation method to measure relative arrival times within the network. If a reliable location of the event is available theoretical arrival times can be computed using a global earth model to be compared with the times observed. The resulting residuals of the relative onset times are driven by the location quality, the choice of the velocity model - and by timing errors on the channels. The scatter in the residuals caused by the inaccurate velocity model is in the order of about 1s. If we assume the location to be sufficiently precise then this 1s is the resolution we have for finding timing errors in single events.

The processing would include the computation of mean and standard deviation of the residuals for each station. An upper threshold on the standard deviation provides means to sort out inappropriate events (weak amplitudes and/or bad coherency) and bad locations. Outliers in the residual distribution would indicate timing errors on the corresponding stations. Reliably detectable are (constant) timing errors after 3 to 5 subsequent occurrences of such exceptional residuals on the same station. A limiting factor, however, is the occurency rate of the required events in the order of one per day, so that constant timing errors can be identified within a couple of days to a week. The algorithm can be automised completely if sufficiently precise automatic locations are avaiable and would complement the set of quality control functions of a data centre.

Other kinds of timing errors, like spurious or changing timing errors as well as smaller deviations than one second are detectable only after application of statistical methods on a large set of residuals. This, of course, can be achieved only in offline procedures operating on large data sets. This would be more of an evaluation of existing archives rather than an online processing tool.

SP-12/C: Sel1 vs. REB bulletins comparison: looking for underlying features.

***Roberto Carluccio, Rodolfo Console, Stefano Chiappini and Massimo Chiappini.**, Istituto Nazionale di Geofisica e Vulcanologia, Rome, Italy*
Contact: carluccio@ingv.it

Abstract: SEL1 bulletin are, among all IDC products, a fundamental tool for NDCs in their task of national assessment of compliance with the CTBT. This is because SEL1s are expected to be disseminated within 2 hours from the occurrence of any detected waveform event, and the National Authorities are supposed to take a political decision in a nearly real time, especially in the case when the event triggers the need of an on site inspection. In this context not only the rapidity, but also the reliability of the SEL1 is a fundamental requirement.

Our last years experience gained in the comparison between SEL1 and Italian Seismic Bulletin events has shown that SEL1s usually contain a big fraction of bogus events (sometimes close to 50%). This is due to many factors, all related to the availability of processing data and to the fast automatic algorithms involved. On the other hand, REBs are much more reliable as proved by our experience. Therefore, in spite of their relevant time delay by which they are distributed, which prevents their real-time use, REBs can be still useful in a retrospective way as a reference information for comparison with SEL1s.

This study tries to set up a sort of logical filter on the SEL1s that, while maintaining the rapidity requirements, improves their reliability. Our idea is based on the assumption that the SEL1s are produced by systematic algorithm of phase association and therefore some patterns among the input and output data could exist and be recognized.

Our approach was initially based on a set of rules suggested by human experts on their personal experience, and its application on large datasets on a global scale. Other approaches not involving human interaction (data mining techniques) do exist. This study refers specifically to a semi-automatic approach: fitting of multi-parametric relationships hidden in the data set, through the application of neural networks by an algorithm of supervised learning.

Full SEL1 and REB bulletins from Jan 2005 to Oct 2008 have been inserted in a database, together with IMS stations availability information. These data have been used to create two sets of independent data (learning and verifying) used to train a "feed-forward" supervised neural network.
The expectation of the analysis is to associate any new event with a reliability coefficient based on the training set. Preliminary results are shown.

SP-13/C: Towards a Portable Rule-Based Agent for Monitoring the Data of the International Monitoring System (IMS)

S. Laban[1], A.I. El-Desouky[2] *[1] Preparatory Commission for the Comprehensive Nuclear-Test-Ban Treaty (CTBT) Organization, Vienna International Centre, P.O. Box 1200, A-1400, Vienna, Austria*
[2] Computer Engineering and Systems Department, Faculty of Engineering, El-Mansoura University, El-Mansoura, Egypt.
Contact: Shaban.Laban@ctbto.org

Abstract: WorkFlow is one of the main tools used to monitor system performance of the International Monitoring System (IMS) of the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO). Processing Engineers need such tools to visualize the pipeline progress as well as monitor the underlying processes and servers. The tool should provide the capability to automatically detect anomalies and failures in the monitored data of such heterogeneous system. The tool needed to be proactive and to generate early warning alerts and exceptional reports in a timely manner. The current WorkFlow programs lack these capabilities, resulting in the consumption of critical (e.g. human) resources. Furthermore, existing tools are not portable. This paper discusses the challenges of monitoring real-time domains and presents the design and implementation of a generic rule-

based agent that minimizes these limitations and restrictions. A unified data representation model has been adopted and implemented to overcome structure irregularity of the different monitored data. The light weight agent is proposed to utilize custom rules for workflow monitoring and generating alerts and exception reports to the operators. The implementation of the proposed rule-based agent proved to be flexible, dynamically configurable, and platform-independent.

SP-14/C: On the reliability of the CTBT International Monitoring System

Richard A. Gustafson
Contact: gusjen@sccoast.net

Abstract: Although Article IV of the CTBT Treaty requires the establishment of a verification regime in order to verify compliance with the Treaty, the Treaty deferred the detailed specifications of the verification system to the Preparatory Commission (PrepCom). The PrepCom developed draft Operational Manuals for Seismic, Radionuclide, Hydroacoustic, Infrasound, and International Data Center (IDC) including availability requirements for the International Monitoring System (IMS). These availability requirements are at the IMS station level, the Global Communications Infrastructure (GCI) link level, and the IDC data forwarding and product level. There are no total IMS system (IMS consists of station, GCI, and IDC subsystems) or element level specifications.

This paper examines the implications of the IMS station subsystem and GCI subsystem availability on the reliability of the monitoring system and discusses the need for global reliability requirements. An IMS system availability model including the stations, communications, IDC, and National Data Center data and product delivery is developed and analyzed. Notional element level reliability models for seismic, radionuclide, hydroacoustic and infrasound stations as well as the IDC are presented and mission critical elements suggested. Series and parallel (redundant) reliability approaches are reviewed as well as the state representation model reflecting the dynamics of failure and repair. The collection of failure and repair quality indicators (time to failure and time to repair) is recommended to permit the development of Mean Time Between Failures and Mean Time To Repair statistics for the IMS system elements. It is suggested that these statistics be used in a system availability model to monitor and predict mean time to IMS system interruption and meantime to IMS system restoration.

SP-15/C: Physical Modeling as Quality Control Tool for Calibration, Instrument Responses and Orientation

Ronan Le Bras, Marina Malakhova (CTBTO), Jeffrey Given, Jeffry Stevens (SAIC)
Contact: Ronan.LeBras@ctbto.org

Abstract: As the IMS network is being deployed, hundreds of seismic instruments need to be calibrated, horizontal components oriented, and the instrument responses validated. This is a vast undertaking and it is expected from experience with previous networks that with such a large number of sensors, a small percentage of the sensor parameters such as calibration, instrument responses and horizontal component orientation will need some correction, adjustment and tuning after the initial deployment. The IDC of the CTBTO has conducted, and is currently conducting a number of projects to acquire modeling software that has proved useful in detecting anomalies in these parameters. The software acquired includes surface wave detection and moment tensor inversion and body wave moment tensor inversion and modeling.

We will present examples of applications of the body wave moment tensor modeling. The modeling technique helped ascertain that the majority of the IMS sensors are correctly calibrated and the instrument responses on file are compatible with the modeling. This was achieved through waveform modeling of the vertical broad band channels and comparison of the inverted moment tensor solutions with the published CMT solutions. In a few cases however, the initial use of the modeling technique on broad band data helped detect faulty instrument response files and served as a quality control tool for checking the instrumentation parameters. In particular a few cases of polarity reversal and lack of update of an instrument response file after instrumental upgrade were detected.

The surface wave detection and modeling technique also allowed us to verify the general correctness of the calibration of the network again by comparing the results with outside sources. A few detections of instrumentation problems in particular with orientation of the horizontal components of broad band instruments were made possible through the modeling technique.

This work outlines the importance of a feedback from modeling results to instrument parameterization checks. It opens the way towards possible automation of this feedback loop, but in the more immediate future, modeling techniques can be used as a manual quality control tool for instrumental parameterization.

SP-16/B: Making the CTBT work

Malcolm Coxhead (Australian Safeguards and Non-Proliferation Office), David Jepsen, Adam Yeabsley
Contact: Malcolm.coxhead@dfat.gov.au

After more than forty years on the drawing board, and a decade in development, entry into force of the Comprehensive Nuclear-Test-Ban Treaty may be in sight. A great deal has been done to prepare the verification infrastructure. This paper examines the practical application of the various elements of the CTBT verification regime, their interplay, and suggests a model for technical interaction among States Parties to facilitate verification.

The Treaty establishes a monitoring and analysis infrastructure that allows all States Parties equal access to objective data. A sensitive and highly reliable network of stations (the International Monitoring System- IMS), measures signals relevant to the detection of nuclear explosions. Analysis of those signals (by the International Data Centre - IDC) derives information on their origin and makes this available to States Parties. The Treaty also provides mechanisms to acquire more information on events of concern, including on site inspection (OSI).

The IMS and IDC should be understood as tools for detecting and screening events, and the key day-to-day challenge of CTBT verification is not the ability to detect a nuclear explosion, but the ability to separate it from the range of normal events detected on a daily basis.

States Parties have a central role as verifiers of the CTBT. Sound technical analysis at a national level will be crucial to investigating ambiguous events identified in IMS and IDC data (or data from national technical means), to assess their relevance to the object and purpose of the CTBT, and to instigating Treaty clarification procedures or OSI. Technical cooperation among States will enhance this important task, and strengthen the case for further action if this is required.

SP-17/B: Civil Society's Contributions to CTBT Verification

Annegret Falter, Dieter Deiseroth, Martin Kalinowski
Contact: martin.kalinowski@uni-hamburg.de

Abstract: To the extent that technical verification measures, applied by states or international organisations get increasingly unreliable, *societal verification* by civil society actors could gain importance.
Societal verification of the CTBT and its implementation may be needed, for example

- where official verification provisions prove fragmentary or otherwise not satisfactory
- to address the replacement of underground atomic tests by laboratory methods
- to compensate for barred on-site inspections
- to provide transparency for a broader public or countries without own National Technical Means
- to counterbalance biased verification findings

In these cases *societal verification* could partially substitute or complement technical verification by national or transnational actors, or be instrumental for deploying on-site verification in the proper locations. To encourage further *societal verification*, this paper looks at two preconditions more closely:

- how to provide legal protection measures for those citizens willing to report breaches of contract and
- how improved access of citizens and NGOs to novel technologies can be of benefit for CTBT verification.

SP-18/B: Promoting use of IMS data and IDC products through capacity building initiatives

Capacity Building and Training Section, IDC
Contact: Lynda.Lastowka@ctbto.org

Abstract: While interest among developing countries in the establishment of National Data Centres (NDCs) has grown significantly over the past two years - an increase of approximately 20% - many countries still do not have access to IMS data and IDC products and many of those that do have access are not participating as fully as they might.

For developing countries traditional training has generated only limited use of data and products from the IDC, which may affect their potential future participation in the verification regime. An analysis of this situation has identified a few key reasons:

- lack of infrastructure (computers, staff, software)
- lack of national commitment
- training not responding to the needs and interests of the State Signatory

In response, efforts are being taken to identify the needs and interests of the State Signatories through NDC Development Workshops, the Helpdesk, surveys, and country visits. Based on the information gathered, a new approach is being used to build capacity consisting of the following:

- use of e-learning courses to prepare trainees for hands-on training and to increase training availability and outreach;
- changing traditional regional training courses into 2-week courses focused on specific NDC operational issues and emphasizing hands-on practice;
- extended on-site technical expert stays at select NDCs to compliment the NDC training received in the regional course,
- establish procedures for download and analysis of IMS data and IDC products,
- find and implement solutions to merging that data with local data and processing solutions,

foster a culture of reporting to the National Authority and using the data and products for civil and scientific purposes;

- providing equipment where needed to increase the capability of the recipient states to participate in the verification regime;
- follow-up visits and analyses of the NDC activities to monitor sustainment of the NDC activities.

This approach is being implemented first in the Africa region where 29 of the treaty signatories do not have SSAs and very little data are sent.

Plans are to extend this programme to the LAC region next and a proposal is pending with the EU to support the effort. Other regional will be targeted in the future, depending on the availability of resources. As part of the new strategy, the PTS purchased computer systems in 2008 for use at NDCs to increase their capacity to participate in the verification regime. When installed, an active NDC can be supported. These systems are intended to be used where needed and where a strong commitment has been made by the host country to support sustainment of their NDC. The PTS commitment is to provide both the equipment and the training necessary to install, maintain and run both the hardware and software.

The capacity building project focuses on increasing use of data and products, which as a result increases participation by developing nations. Strengthening traditional classroom training with e-learning, extended technical visits, and equipment should produce tangible results that can be sustained.

SP-19/B: Performance Monitoring and Assessment

S. Alamo1, A. Anichenko2, E. Castillo2, J. Guarnizo1, G. Perez3, C. Wirawan1
(1 Evaluation Section-OES; 2 Operations Section-IDC; 3 Engineering and Development Section-IMS), PTS CTBTO Preparatory Commission - Vienna – Austria
Contact: Alexey.Anichenko@ctbto.org

Abstract: This poster presents an overview of the framework and tools used by the PTS for monitoring and assessing the performance of the verification system development and provisional operation activities. Paragraph 14 (l) in Article IV of the Treaty provides the mandate to monitor, assess and report on the overall performance of the IMS and the IDC. The PTS performance monitoring and assessment activities conform to present guidelines for technical testing and provisional O&M and allow gathering the necessary information to comply with the mandate of the Commission in the Resolution for establishing the Preparatory Commission for the CTBTO (CTBT/MSS/RES/1) to present a report on the operational readiness of the regime to the initial Session of the Conference of the States Parties. The draft IMS, IDC and OSI Operational Manuals and documents in the domain of the Policy Making Organs define the requirements for the CTBT verification system.

The PTS Quality Policy and Manual establish the customer focus and process-based framework, together with continual improvement as measured through performance indicators, to provide the States Signatories and the Commission with the necessary confidence in the functioning of the PTS and in its products and services.

The PTS performance monitoring and assessment system encompasses the following processes:

Continuous monitoring of specified parameters, such as data availability and quality, and periodic monitoring of aggregated values and trend analysis. Periodic assessments, namely related to product quality, through a structured quality assurance programme, including benchmarking with product users.

System transient analysis through testing procedures to assess system design parameters and requirements. A set of systems are being developed and used for continuous monitoring of performance indicators related to data acquisition (State Of Health System); data & products transport (State Of Health, NetVigil & Scrutinizer); data collection (scripts and workflows); and to the PTS processes supporting the development and provisional operation of the verification system (IRS, DOTS). Aggregated values of key indicators are collected and displayed in the Performance Reporting Tool (PRTool).

Relevant Abstracts From Other Topics

A. Atmospheric Transport Modelling

1. RN-21/D: Supporting the CTBT Radionuclide Monitoring System at the Canadian Meteorological Centre. (see p. 89)

B. Infrasound

1. DM-15/A: Swedish-Finnish Infrasound Network – The Research Program. (see p. 28)

C. Hydroacoustics

1. DM-06/A: Kernel-based machine learning techniques for hydroacoustic signal classification. (see p. 23)

D. Radionuclide Monitoring

1. ATM-10/E: A refined backtracking and source reconstruction for the noble gas measurements taken in the aftermath of the announced October 2006 event in North Korea. (see p. 15)

2. ATM-12/E: Radioxenon in a hypothetical world in which underground nuclear explosions are frequent. (see p. 16)

3. ATM-14/E: A long distance measurement of radioxenon in Yellowknife, Canada, in late October 2006. (see p. 17)

4. ATM-15/E: Changes in radioxenon observations in Canada and Europe during medical isotope production facility shut downs in 2008. (see p.17)

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