ENHANCED RESOURCES OF THE SMDC MONITORING RESEARCH PROGRAM FOR SOURCE INFORMATION AND DATA ACQUISITION

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ABSTRACT

The Research and Development Support Services (RDSS) project of the Space and Missile Defense Command (SMDC) provides a range of resources and services for use in nuclear explosion monitoring research and development. R&D. This presentation focuses on recent developments and enhancements to the infrasound, seismic, and hydroacoustic resources, most of which can be accessed from the RDSS website at www.rdss.info. In particular, on-going and recent developments and improvements are related to (1) the nuclear explosion database archive and (2) infrasound signals and associated source information.

The RDSS project has traditionally maintained an archive of information on source metadata and seismic waveforms from worldwide nuclear explosions. These resources were previously documented in the year 2000, and we are now completing a major revision and update which includes newly published or revised information about historical explosions, access to additional or corrected waveform data for some explosions, and new data from more recent nuclear tests (e.g., North Korea). In addition to maintaining these research data archives, we have been developing a number of web tools which enable visualization of and easier access to these explosion resources, including tabular-, map-, and imagery-based event selection and comparisons, station coverage and response information, as well as review of data quality and acquisition of the available seismic waveform data.

Identification of infrasound events for the RDSS infrasound database has continued. This is based on a search of the RDSS waveform archive for signals that can be associated with recent events from seismic bulletins, volcanic activity reports, and reports in the press of accidental explosions, bolides, etc. Signal processing with Infratool and simple modeling with InfraMap are also used in the association. During the last year waveform data have been added to the archive from new infrasound stations in Asia and North Africa. Many events were identified with signals recorded at these stations which provide several new repeated source-receiver paths, particularly in central Asia, for modeling atmospheric propagation. RDSS has also continued its responsibility for collecting, compiling, and distributing data and metadata for the three rocket experiments in 2005–2006 at White Sands Missile Range (WSMR), including a number of quality control checks on the waveform data.

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OBJECTIVE

The RDSS project of the SMDC has the objective to support the nuclear explosion monitoring research and development community providing a range of data, state-of-the-art data access tools, and value-added datasets. This paper focuses on recent developments and enhancements to the seismic and infrasound resources, which can be accessed from the RDSS website. In particular, recent developments have been directed at (1) the nuclear explosion database archive and options for display and retrieval of the associated data resources, and (2) identification of infrasound events and association of the related signals.

RESEARCH ACCOMPLISHED

Nuclear Explosion Database

The SMDC Nuclear Explosion Database (NEDB) has historically provided access to source metadata and associated waveforms for worldwide nuclear explosions. This activity was documented in a series of reports (Yang et al., 1997, 1998, 1999, 2000) and in the online nuclear explosion research database provided at www.rdss.info. In recent years supplemental information has become available describing many of the explosion sources (e.g., Springer et al., 2002; Khalturin et al., 2001, 2005; DTRA, 2007; Bennett et al., 2004) from historical events plus source and waveform data from a new nuclear explosion—the October 2006 North Korea test (Bennett et al., 2006; Richards and Kim, 2007; Kim and Richards, 2007). These source data have now been added to the NEDB. In addition, we have performed a variety of QA/QC checks on both source data (including comparisons of published locations with satellite imagery) and station information to improve the database and ensure accuracy of the available waveforms. We have upgraded our station database to ensure that station names and station coordinates best match those contained in the official International Registry of Seismograph Stations. We have also been collecting additional station calibration and instrument response information that will be helpful for users who would like to do additional processing of the waveform data.

The prior version of the NEDB (Yang et al., 2000) included metadata from underground/underwater US nuclear explosion sources based on Springer and Kinnaman (1971, 1975) which only included events prior to October 1973. The corresponding complete listing describing all US underground/underwater explosions (Springer et al., 2002) has been digitized, checked for errors, and incorporated into the NEDB (Figure 1a). Errors in the Springer list include precision differences (e.g., Figure 1b)—related to location roundoff, which we have not yet attempted to correct, as well as some accuracy errors (e.g., Figure 1c)—mainly event names or in a few cases event locations, which we have corrected. In addition, we conducted a thorough and careful analysis of US atmospheric nuclear explosions, based on information from historical reports newly available from the Defence Threat Reduction Agency (DTRA) website (www.dtra.mil/rd/programs/nuclear_personnel/atr.cfm), and generated revised or more complete information on origin times, locations, and yields than those contained in the previous version of the NEDB.

We have also drawn upon a number of other published resources for nuclear tests from the former Soviet Union (FSU). For FSU events near Semipalatinsk (Figure 2a), we compared previously reported underground event locations (e.g., Leith., 1998, and Trabant et al., 2002, for the Degelen mountain area; or Thurber et al., 1993, 1994, and National Nuclear Center of Kazakhstan Republic (NNCKR), 1999, for the Balapan test area) with imagery analysis to ascertain the best location ground truth. Some systematic errors were identified (e.g., Figure 2b) and are now corrected in the revised NEDB, by sorting the previously reported event locations and using the one closer to features apparent on the available satellite imagery. The corrected explosion data, along with previously published location information (including ISC bulletin data) from the alternative references, are now provided in the NEDB and enable comparisons between the different source locations and related information. The NEDB also includes results from similar analyses of previously published event locations for peaceful Nuclear Explosions (PNEs) (Sultanov et al., 1999) and for Novaya Zemlya nuclear tests (Richards, 2000; Khalturin et al., 2005; Khristoforov, 1996).

Table 1 summarizes source reference information for the various countries and test areas included in the NEDB. After reviewing and comparing the source data from each of the events in the database, we formed the preferred source origin time, location (latitude and longitude), depth/height, yield/yield range, and type (e.g., underground, underwater, surface, tower, airdrop, balloon, high-altitude) for each event with an associated reference authority for each parameter. For most countries and test areas, one or two reference authorities (as indicated in the table) provide the bases for most of the preferred source solutions. It should also be noted that the preferred source origin time and location are in many cases independent of seismic information and for such cases may not agree with seismic location solutions. As noted above, to provide a relatively stable connection to the seismic source information for nuclear explosions, the NEDB includes International Seismological Centre (ISC) seismic solutions (or for some of the older events, Preliminary Determination of Epicenters solutions) along with the corresponding network magnitudes and other complete bulletin information. It is anticipated that comparisons of the preferred solutions and seismic solutions will enable a number of interesting analyses. In addition, we include in the NEDB travel-time residuals measured from stations reporting in the ISC bulletin with respect to predicted times for the preferred nuclear explosion locations and origin times. Such measurements should provide additional opportunities to investigate some features of global and regional velocity models.

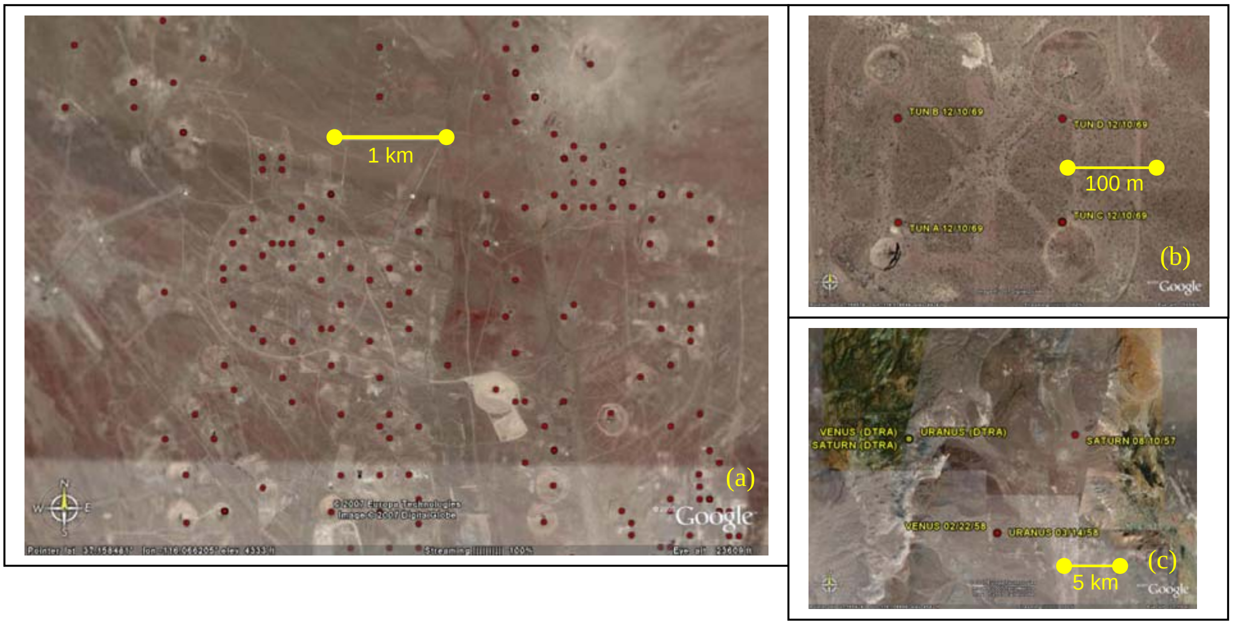

Figure 1. Springer et al. (2002) locations of US underground nuclear tests at the Nevada Test Site from the northern part of Yucca Flat (a). Comparison of the TUN series Springer locations (red) with satellite imagery illustrating roundoff error in Springer locations (b). Comparison of Rainier Mesa tunnel location of VENUS, SATURN, and URANUS tests (yellow) with locations reported by Springer (red) illustrating apparent location errors (c).

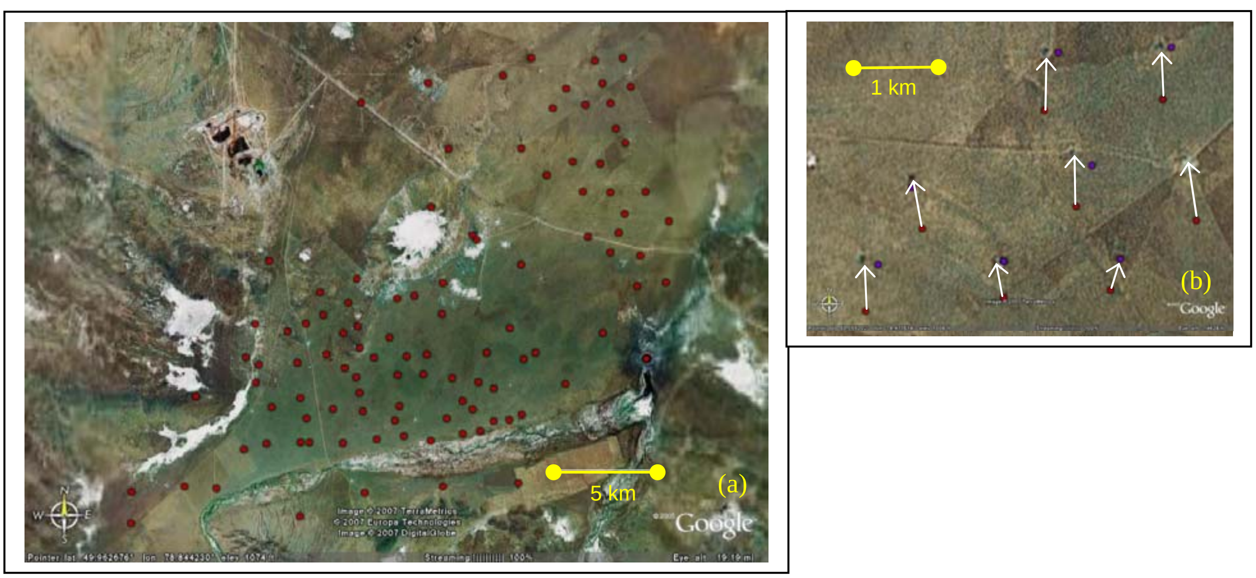

Figure 2. NNCKR locations of FSU underground explosions in the Balapan area of Semipalatinsk (a). Comparison of event locations reported by NNCKR (red) and Thurber et al., 1994 (purple), with satellite imagery from northeast Balapan (b) shows systematic location offsets relative to imagery features.

Table 1. Summary of principal nuclear explosion source reference information used in the NEDB.

Country	Region/Source	Reference/Authority*
China	Lop Nor	Gupta; Fisk; Bennett et al.; AWE
Former Soviet Union	Semipalatinsk	Mikhailov; Bocharov; NNCKR; Khalturin et al.; Leith;Thurber et al.; Trabant et al;Adushkin/Leith; Stevens et al.; AWE
	Novaya Zemlya	Mikhailov; Khristoforov; Richards; Khalturin et al.; Adushkin/Leith; Skorve; AWE; IAEA
	PNEs	Mikhailov; Sultanov et al.; Khalturin et al.; Adushkin/Leith
	Other	Mikhailov; Haave et al.; Zmuda et al.
France	Sahara	Burrows et al.; Bolt; IAEA
	South Pacific	Burrows et al.; Bolt; IAEA; AWE
India	Pokhran	Gupta/Pabian; Norris/Arkin
North Korea	Mount Mantap	Richards/Kim; Bennett et al.
Pakistan	Chagai	Norris/Arkin; Pabian
United Kingdom	Australia	Bolt; MARTAC; AWE
	Pacific	Bolt; AWE
	Nevada (US)	DOE; Springer et al.
United States	Nevada (Atmospheric)	DOE; DTRA; Griggs/Press
	Nevada (Underground)	DOE; DTRA; Springer et al.
	Pacific	DOE; DTRA; Griggs/Press
	South Atlantic	DOE; DTRA
	Other	DOE; Springer et al.
Unknown	Western Indian Ocean	GlobalSecurity; Sublette; Wikipedia

* Complete reference list available at the RDSS website.

Enhancement of the access to the NEDB is part of a more general upgrade of the SMDC RDSS website designed to provide more options and more intuitive interaction and connectivity to the data resources. Access to the NEDB is provided under the Research Databases menu option at the RDSS home page. Figure 3 illustrates the main NEDB menu with a variety of options for table-based or map-based selections to retrieve source and station information and the related waveforms from the data archive.

Imagery and map access to the NEDB is provided through GoogleMap. An imagery-based rendition illustrating the regions and subregions worldwide where nuclear explosions have occurred is shown in Figure 4. The GoogleMap interaction enables a range of comparisons between events, ties between events and surface features visible in the imagery, alternative ground truth information, and distribution of recording stations, similar to those illustrated above in Figures 1 and 2.

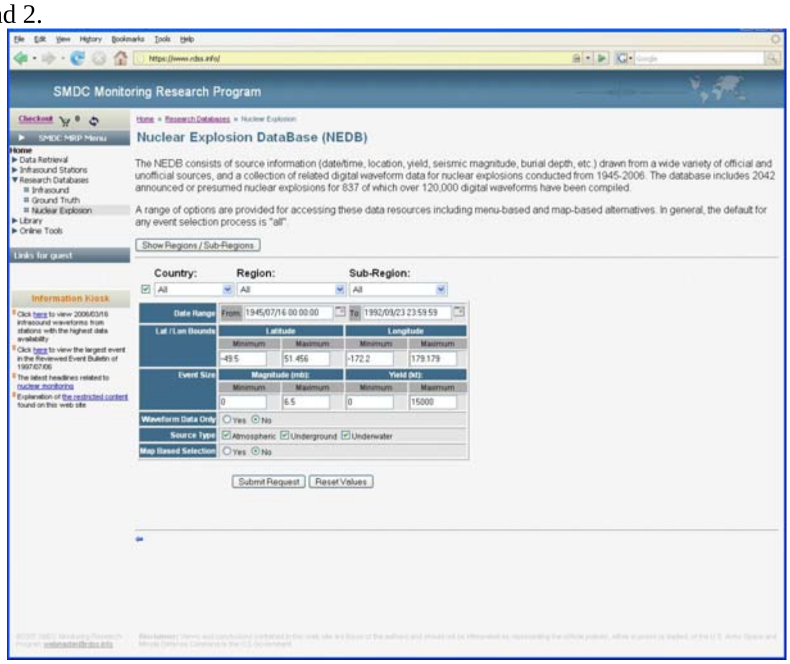

Figure 3. Homepage for the Nuclear Explosion Database at the RDSS website illustrating the menu options for refining nuclear explosion selections from the NEDB.

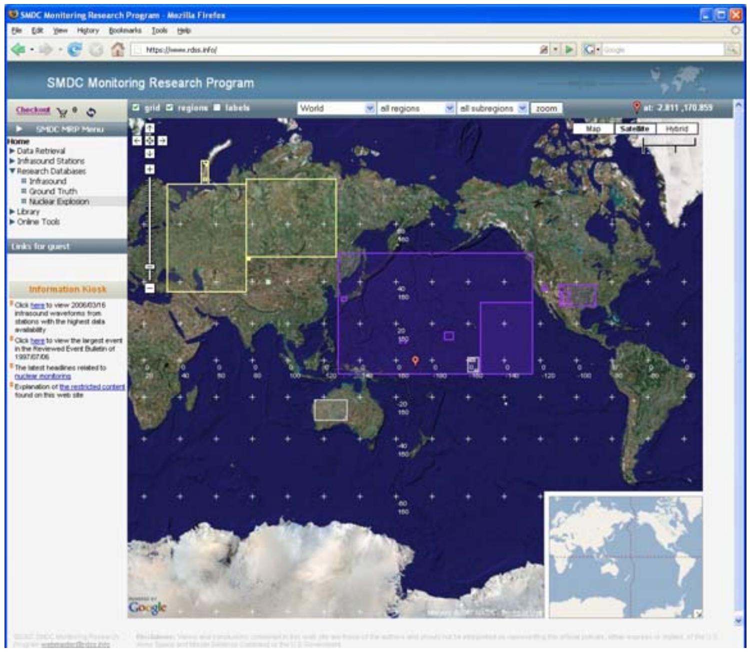

Figure 4. GoogleMap display of worldwide nuclear explosion region/subregions with boundaries color-coded by country; map and menus allow further drill-down to access source data and related waveforms.

The NEDB website provides an intuitive step-through process for accessing and retrieving the digital waveforms from the RDSS archive for nuclear explosions. The data retrieval options include selection based on individual explosions, groups of explosions, individual stations, groups of stations, and distance criteria. As summarized in Table 2, the NEDB archive is considered one of the most complete resources for digital waveforms from nuclear explosions. It currently includes more than 120,000 digital waveforms from 837 nuclear explosions recorded at the global network of seismic stations (Figure 5), covering distance ranges from near-regional to teleseismic. Available waveforms can be previewed and subjected to some basic processing (e.g., bandpass filtering) using the Waveform Viewer tool (illustrated in Figure 6) prior to actual selection and downloading.

Table 2. Summary description of NEDB data archive resources.

Events with Digital Waveform Data	Stations with Digital Waveforms	Total Waveforms	Total Data Volume
~ 840	~ 570	> 120,000	~ 6 GBytes

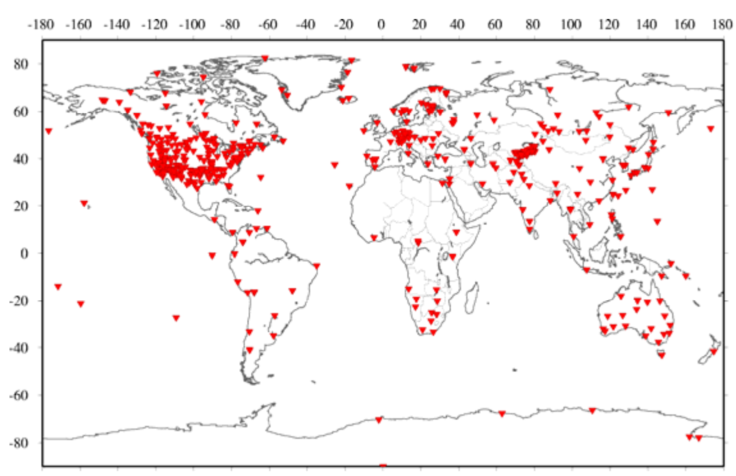

Figure 5. Map showing locations of seismic stations (N ≈ 570) for which there are digital waveform data in the NEDB archive.

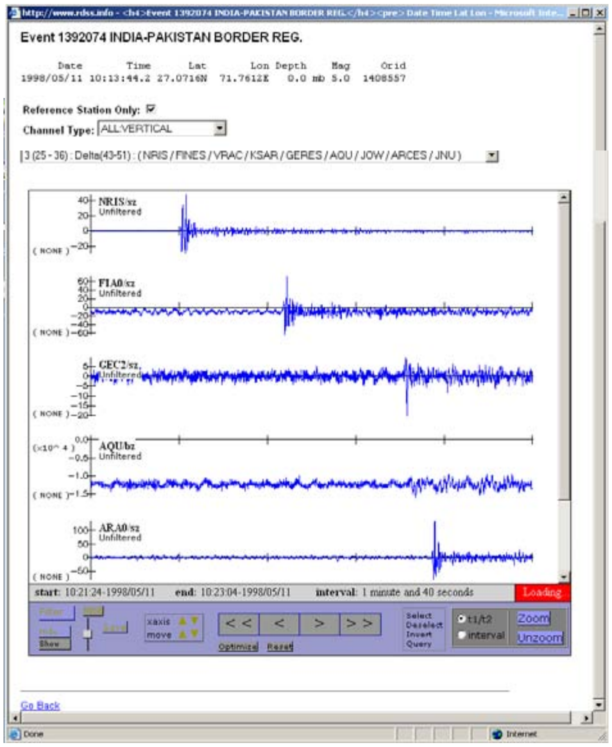

Figure 6. An example of available waveforms from a sample nuclear explosion displayed using the Waveform Viewer tool.

Infrasound Database

Identification of infrasound events for the RDSS infrasound database is based on a search of the RDSS waveform archive for signals that can be associated with recent events in seismic bulletins, volcanic activity reports, and media reports of events such as accidental explosions and bolides. Signal processing based on adaptations of Infratool and of the Maximum Cross-Correlation Method (MCCM) is used in this association. Modeling of atmospheric wave-propagation with InfraMap is also used in some cases. The search for candidate infrasound events has been focused on (1) mining events in Eurasia, (2) larger events with long paths and multi-station recordings of infrasound signals, and (3) cases with repeatable events during different times of the year for given source-station paths. Source data on infrasound events and their associated waveforms are also available to the nuclear explosion monitoring community in the research database provided at the SMDC RDSS website (www.rdss.info).

Mining events in Eurasia - Development of a database of presumed mining events in Eurasia to be included in the Infrasound Database (Bahavar et al., 2006) is based on a compilation of potential source areas by Kohl (2006) from analysis of satellite imagery and from reports in the literature such as Demin et al. (1996). Recent work on the Eurasian mining events has focused on recordings at the International Monitoring Station (IMS) four-element infrasound array at Zalesevo in Russia (I46RU), for which data became available in early 2007. So far, about 100 events have been identified in about 10 widely located areas with infrasound signals recorded at I46RU. Some of these events appeared in the International Data Centre (IDC) event bulletins (REB and SEL1), but most of the events were reported in the seismic bulletin of the Kazakhstan National Data Center (KNDC), which draws upon an extensive regional seismic station network. The map to the left in Figure 7 compares KNDC seismic locations of events, for which infrasound signals could be associated, with mining locations from Kohl (2006). There is a large concentration of events at ranges of 100–200 km in the vast Kuzbass mining district to the east of the station (Figure 7, panel to the right). There are also a number of mines located in a largely westerly direction from I46RU at varying distances up to about 3,000 km (Zaleznogorsk iron mine). Figure 8 compares infrasound signals recorded at I46RU and the Kazakhstan infrasound array (I31KZ) from an event at the Zaleznogorsk mine on April 4, 2007. Infrasound signals from two other Zalesnogorsk events during the winter and early spring were also recorded at I46RU.

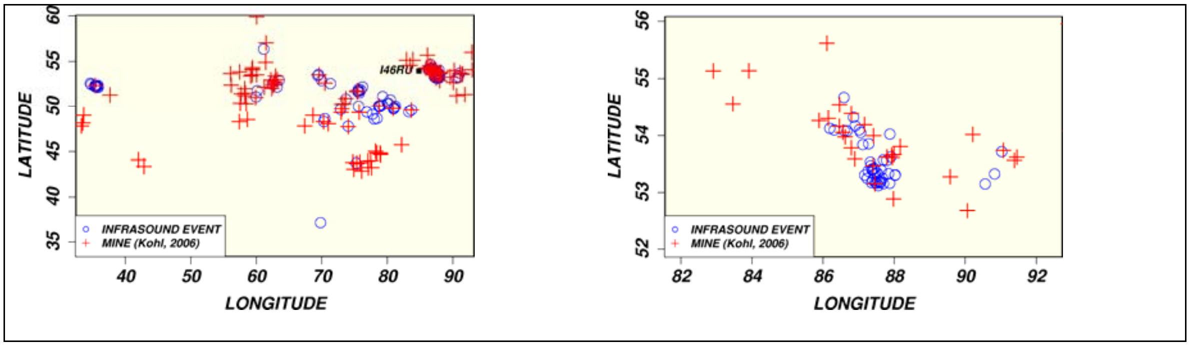

Figure 7. The left plot shows mines (red crosses) in Eurasia compiled by Kohl (2006) together with events (blue circles) with associated infrasound signals recorded at the IMS station Zalesevo (I46RU) indicated in upper right. The events occurred between January and June of 2007. The large number of mines just to the east of the station is in the Kuzbass mining district. The plot to the right shows mines and events with infrasound signals in the Kuzbass district and surrounding areas. Most of the Kuzbass events were located near two mines in the extreme southern part of the district.

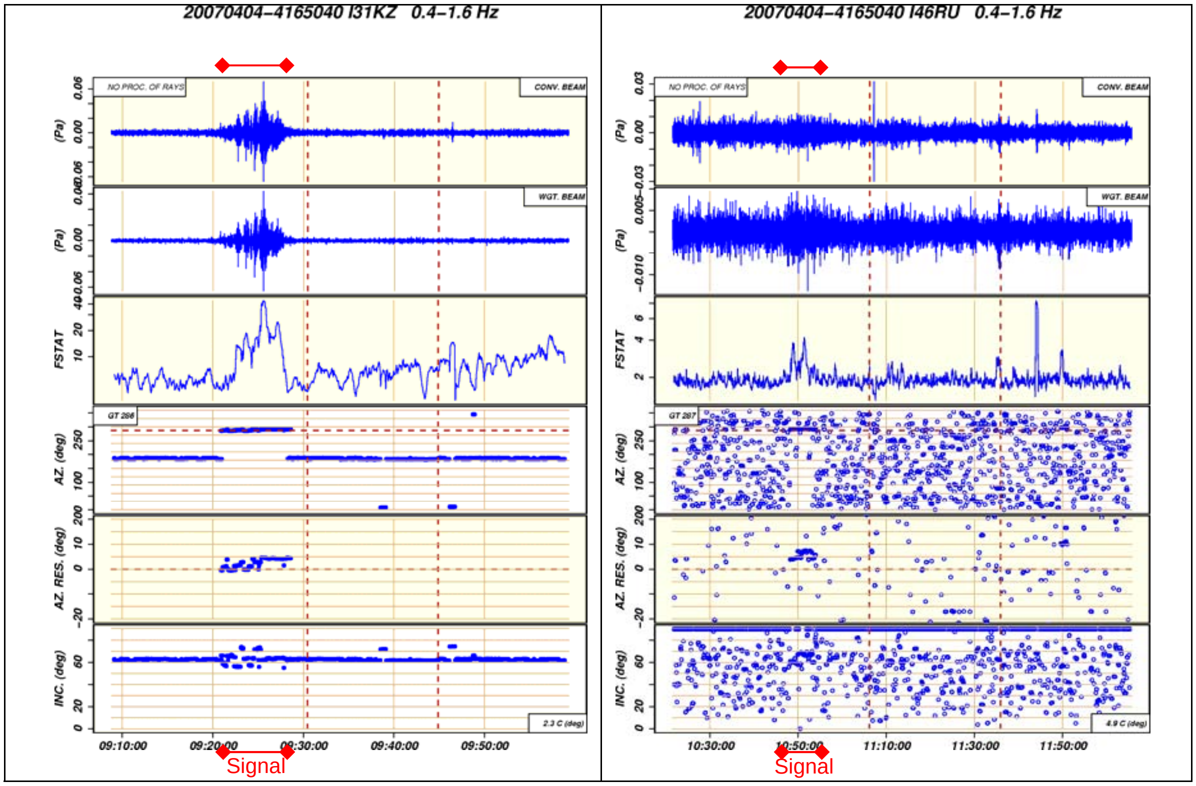

Figure 8. Example of signals recorded for an event from the Zalesnogorsk mine (IDC solution 2007 April 4 08:00:13 52.29 N 35.63 E) recorded at the two IMS stations Aktyubinsk (I31KZ, to the left) and Zalesevo (I46RU, to the right) at distances about 1,500 and 3,200 km respectively. The coherent signal energy (azimuth around 180 degrees) before and after the signal for the mining event on the I31KZ recording (left panel) originates most likely from gas flares at the Zhanazkol Oil and Gas field about 240 km to the south of the station (Smirnov, 2006). The signal at I46RU (right panel) is barely visible on the beams (top traces) but has a clear increase in the F-statistic with an azimuth around the expected back-azimuth. The red dashed vertical lines correspond to celerities of 0.29 and 0.25 km/s.

Multi-station and long path events—The addition of stations to the IMS network has broadened the coverage of infrasound signals recorded across longer paths (> 500 km) in various parts of the world. It has also increased the number of events for which signals were recorded at more than one station. Figure 9 shows great-circle event-station paths for infrasound signals during the last year recorded at large distances and/or at more than one station. There are paths on all continents except Antarctica.

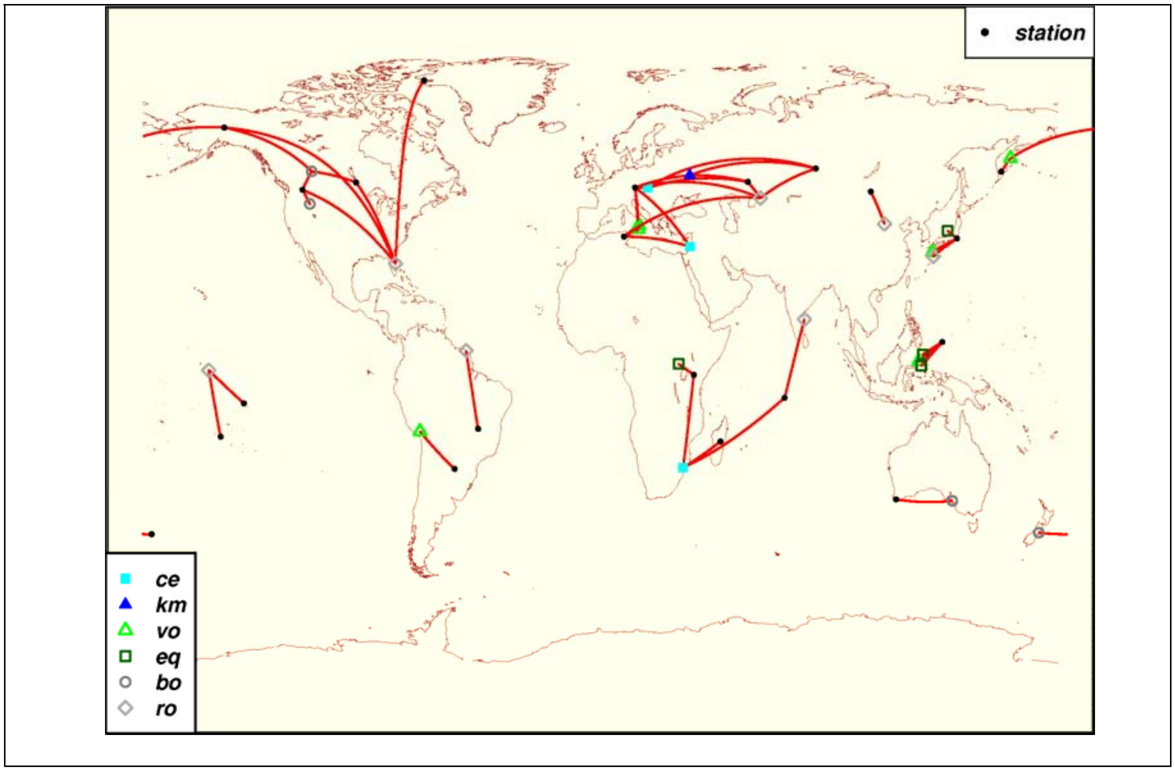

Figure 9. Great circle paths for selected events between June 2006 and June 2007 with associated infrasound signals recorded across long propagation paths and/or at multiple stations. Source types are chemical explosions (ce), known mines (km), volcanic eruptions (vo), large earthquakes (eq), bolides (bo), and rocket launches (ro).

Seasonal differences in repeatable events—A previous study (Israelsson and Kohl, 2006) showed reasonable agreement between observed and modeled seasonal patterns of detection and non-detection of infrasound signals from mining events in the Powder River Basin, WY at the IMS station I10CA (Lac Du Bonnett). I10CA is about 1,000 km to the NE from the mining area (see map in Figure 10). The IMS station I56US (Newport, OR), is also at a distance of about 1,000 km and similarly equipped as I10CA, but lies in a NW direction from the mining area. Due to the seasonal variation of the horizontal wind, the I56US station has a detection pattern almost opposite that of I10CA, with infrasound signals being detected at I56US primarily in the summer months. These opposite detection patterns for infrasound stations at similar distances are somewhat similar to those reported by Bahavar et al. (2006) for Zalesnogorsk at the two stations I31KZ and I26DE. The lower diagram in Figure 10 compares detections and non-detections of infrasound signals at the two stations from 126 mining events distributed fairly evenly throughout 2006 and located within an area with a diameter of about 25 km in the Powder River Basin. The ambient noise levels at expected arrival times or prior to observed arrival times of infrasound signals show no obvious correlation with these detection patterns (lower diagram Figure 10).

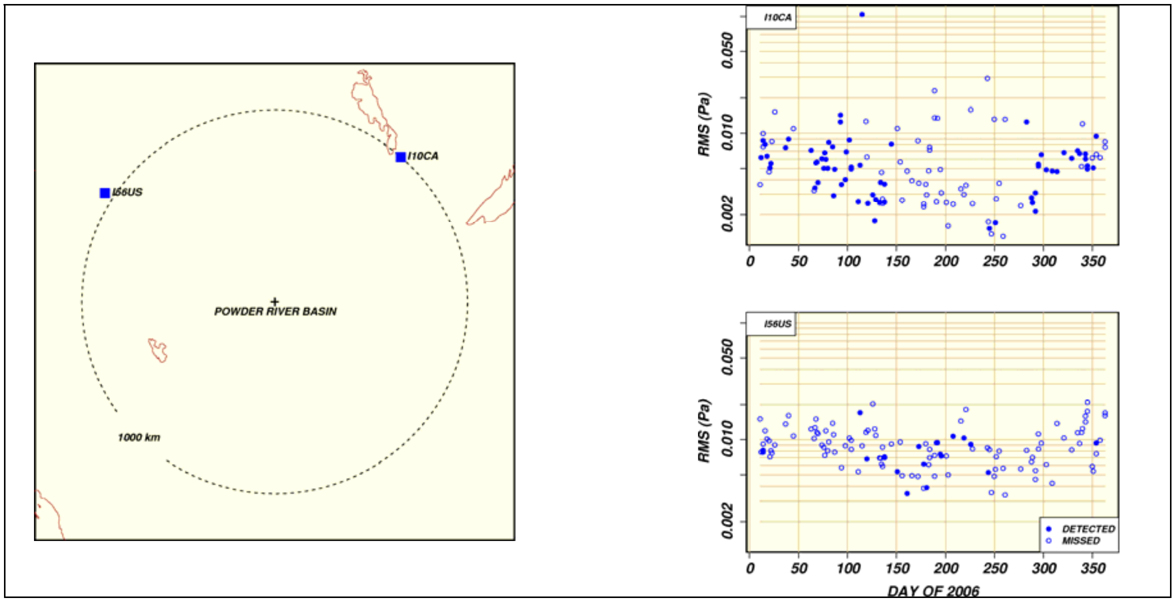

Figure 10. Map with relative locations of IMS stations I56US (Newport, OR) and I10CA (Lac du Bonnett, Canada) and the Powder River Basin mining district (left) and pattern of detection/non-detection (filled/open circles) of infrasound signals from 126 events during 2006 (right).

CONCLUSIONS AND RECOMMENDATIONS

The NEDB for the SMDC RDSS has been updated to include newly published or revised information about historical nuclear explosions, access to additional or corrected waveform data for some explosions, and new data from more recent nuclear tests. Access to the data archive for the NEDB has been upgraded to include options for table- and map-based searches and comparisons between events, alternative locations, and surface features visible in satellite imagery through an integrated GoogleMap tool. The website also provides an intuitive step-through process for accessing, displaying (using the Waveform Viewer tool), and retrieving nuclear explosion digital waveform data from the NEDB archive. For infrasound, comparisons of RDSS waveform archives with event bulletins (seismic and volcanic) and media reports have resulted in new infrasound events and their associated waveforms being added to the database. Mining events from Eurasia and the US include repeatable events and multiple-station recordings over several paths which can be used to analyze seasonal dependence in signal propagation and station noise and their effects on infrasound signal detection.

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