NUCLEAR EXPLOSION AND INFRASOUND EVENT RESOURCES OF THE SMDC MONITORING RESEARCH PROGRAM

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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 R&D. This presentation focuses on some recent enhancements to the infrasound, seismic, and hydroacoustic resources, which can be accessed from the RDSS website at http://www.rdss.info. In particular, ongoing developments and improvements are related to (1) the nuclear explosion database (NEDB) and (2) infrasound signals and associated source information.

The RDSS project has traditionally maintained an archive of information on source parameter data and waveforms from worldwide nuclear explosions. A major revision and update of the NEDB includes newly published or revised source information about historical explosions, access to additional or corrected waveform data for some explosions, and new data from more recent nuclear tests (viz., North Korea). New web tools for accessing the NEDB archive include GoogleMap visualization of alternative event locations, displays of recording station information (e.g., data availability and station parameters), seismic travel time residual displays, and new waveform display and retrieval options, which include options for simple prefiltering and signal rescaling during data review prior to download.

Identification of infrasound events for the RDSS infrasound database has continued. The effort is based primarily on seismic-event bulletins, volcanic activity reports, meteor observations, announcements on rocket launches and information appearing in the news media. The search for infrasound signals associated with events in these reports and bulletins is utilizing the automatic detection lists of International Monitoring System (IMS) stations augmented with the processing of waveform data from the SMDC waveform archive. The detectability at IMS infrasound stations I26DE (Freyung, Germany) and I18DK (Qaanaaq, Greenland, Denmark) of a large series of explosions in northern Finland to destroy ammunitions was also analyzed with regard to propagation conditions and station noise. During favorable conditions, low signal-to-noise ratio (SNR) signals were detected at the two stations, which are located at much larger distances than stations in Fenno-Scandia, for which infrasound signals have previously been reported for these events.

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 NEDB has historically provided access to source parameter data and associated waveforms for worldwide nuclear explosions, online at www.rdss.info and documented in a series of reports (e.g., Yang et al., 2000). As described in Bahavar et al. (2007), access to those data is being upgraded; and, in some cases, events are being added or the associated source parameters are being updated utilizing new information sources (e.g., Springer et al., 2002; Khalturin et al., 2005; Bennett et al., 2006; DTRA, 2007; Kim and Richards, 2007). In addition to performing a range of QA/QC checks on the source data (e.g., comparisons with satellite imagery), station calibration and response information have been improved to make archived waveform data from the NEDB more useful to the research community. The focus of this paper is on (1) recent improvements to NEDB event documentation, (2) expanded event analysis options (e.g., display of station travel-time residuals), and (3) improved display, review, and retrieval of waveform data.

The NEDB includes source parameter data for some 2,154 announced or presumed nuclear explosions (1,628 underground, 518 atmospheric, 8 underwater) conducted by 8 countries in more than 43 distinct geographic regions (Figure 1). Access to the NEDB is provided under the Research Databases menu option at the RDSS home

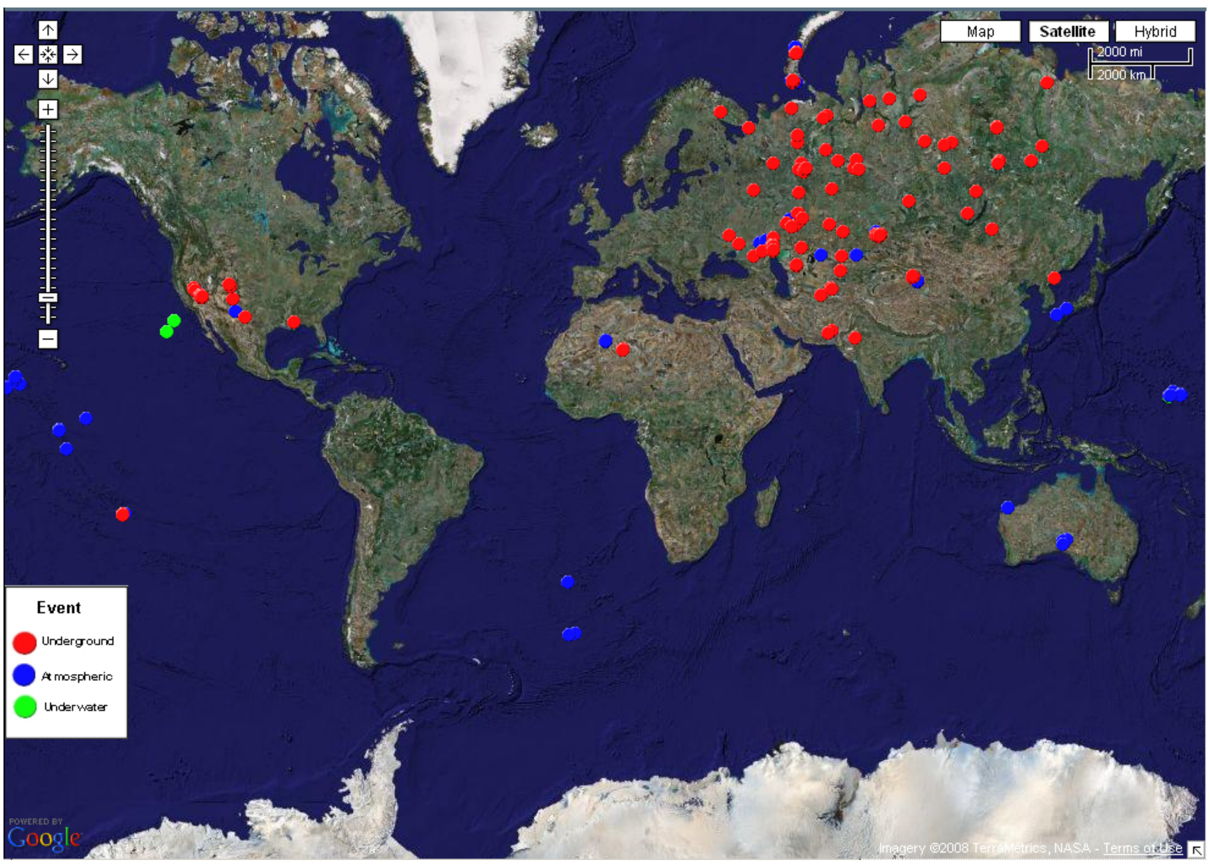
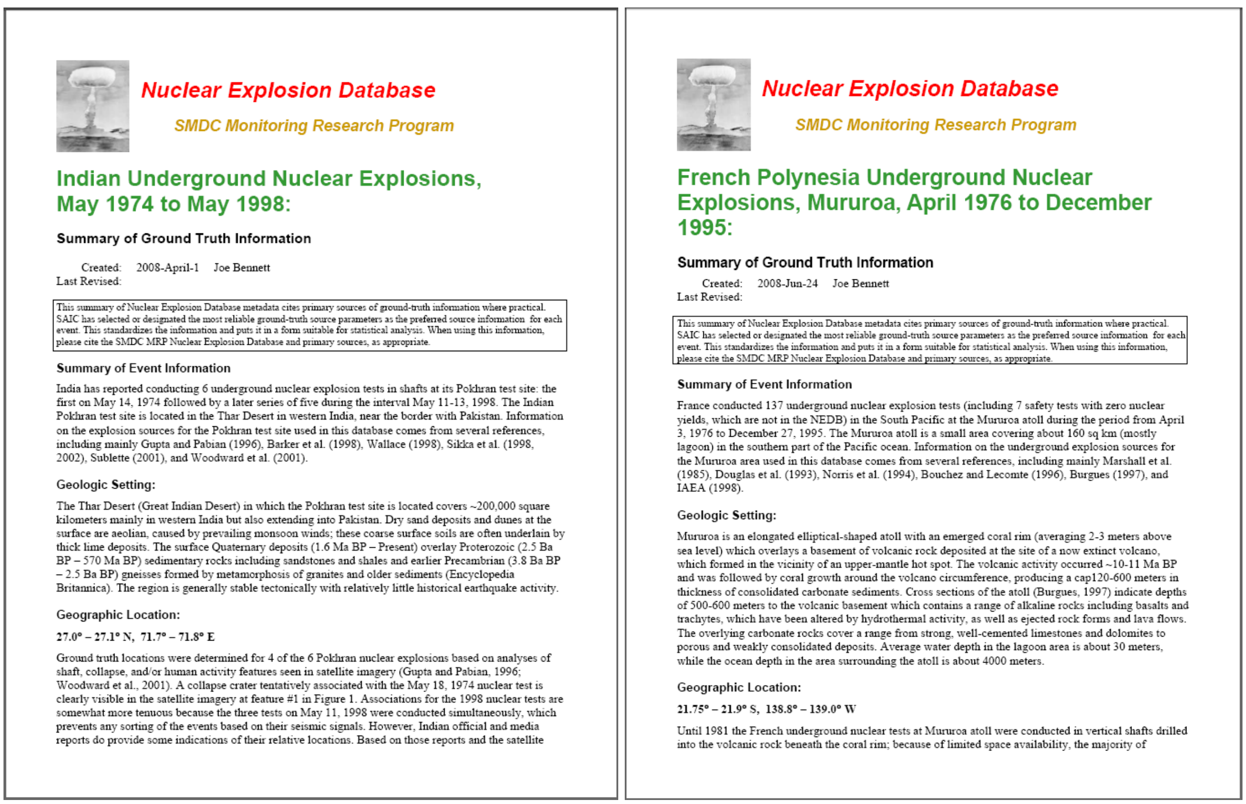


Figure 1. Locations of 2154 announced or presumed nuclear explosions included in the NEDB.

page using GoogleMap interaction, which enables comparisons between events or subsets of events, review of alternative source locations (e.g., the International Seismological Centre [ISC] or other seismic bulletins), assessment of relationships to terrain features visible in imagery, and analysis of seismic travel-time residuals.

Ground-truth information about explosion sources in the NEDB is quite variable and depends on many factors, including country of origin, age of the event, reliability and openness of documentation and record keeping, and region- or event-specific background knowledge. New emphasis has been placed on compiling the best available documentation regarding these nuclear explosions. As noted above, in some cases this information comes from newly published sources; in other cases review and cross-checking of previously reported source information has revealed discrepancies in the data, as noted previously (e.g., even recent reports such as Springer et al. (2002) include some errors in precision and accuracy). In compiling the revised NEDB, we have been attempting to provide the best available information for nuclear explosion source parameters along with the appropriate documentation to support the source description or allow the user to understand the uncertainties. This documentation is being provided in the form of event summary pages, accessible through links from the NEDB website.



Nuclear Explosion Database

SMDC Monitoring Research Program

Indian Underground Nuclear Explosions, May 1974 to May 1998:

Summary of Ground Truth Information

Created: 2008-April-1 Joe Bennett
Last Revised:

This summary of Nuclear Explosion Database metadata cites primary sources of ground-truth information where practical. SAIC has selected or designated the most reliable ground-truth source parameters as the preferred source information for each event. This standardizes the information and puts it in a form suitable for statistical analysis. When using this information, please cite the SMDC MRP Nuclear Explosion Database and primary sources, as appropriate.

Summary of Event Information

India has reported conducting 6 underground nuclear explosion tests in shafts at its Pokhran test site: the first on May 14, 1974 followed by a later series of five during the interval May 11-13, 1998. The Indian Pokhran test site is located in the Thar Desert in western India, near the border with Pakistan. Information on the explosion sources for the Pokhran test site used in this database comes from several references, including mainly Gupta and Pabian (1996), Barker et al. (1998), Wallace (1998), Sikka et al. (1998, 2002), Sublette (2001), and Woodward et al. (2001).

Geologic Setting:

The Thar Desert (Great Indian Desert) in which the Pokhran test site is located covers ~200,000 square kilometers mainly in western India but also extending into Pakistan. Dry sand deposits and dunes at the surface are aeolian, caused by prevailing monsoon winds; these coarse surface soils are often underlain by thick lime deposits. The surface Quaternary deposits (1.6 Ma BP – Present) overlay Proterozoic (2.5 Ba BP – 570 Ma BP) sedimentary rocks including sandstones and shales and earlier Precambrian (3.8 Ba BP – 2.5 Ba BP) gneisses formed by metamorphosis of granites and older sediments (Encyclopedia Britannica). The region is generally stable tectonically with relatively little historical earthquake activity.

Geographic Location:

27.0° – 27.1° N, 71.7° – 71.8° E

Ground truth locations were determined for 4 of the 6 Pokhran nuclear explosions based on analyses of shaft, collapse, and/or human activity features seen in satellite imagery (Gupta and Pabian, 1996; Woodward et al., 2001). A collapse crater tentatively associated with the May 18, 1974 nuclear test is clearly visible in the satellite imagery at feature #1 in Figure 1. Associations for the 1998 nuclear tests are somewhat more tenuous because the three tests on May 11, 1998 were conducted simultaneously, which prevents any sorting of the events based on their seismic signals. However, Indian official and media reports do provide some indications of their relative locations. Based on those reports and the satellite

Nuclear Explosion Database

SMDC Monitoring Research Program

French Polynesia Underground Nuclear Explosions, Mururoa, April 1976 to December 1995:

Summary of Ground Truth Information

Created: 2008-Jun-24 Joe Bennett
Last Revised:

This summary of Nuclear Explosion Database metadata cites primary sources of ground-truth information where practical. SAIC has selected or designated the most reliable ground-truth source parameters as the preferred source information for each event. This standardizes the information and puts it in a form suitable for statistical analysis. When using this information, please cite the SMDC MRP Nuclear Explosion Database and primary sources, as appropriate.

Summary of Event Information

France conducted 137 underground nuclear explosion tests (including 7 safety tests with zero nuclear yields, which are not in the NEDB) in the South Pacific at the Mururoa atoll during the period from April 3, 1976 to December 27, 1995. The Mururoa atoll is a small area covering about 160 sq km (mostly lagoon) in the southern part of the Pacific ocean. Information on the underground explosion sources for the Mururoa area used in this database comes from several references, including mainly Marshall et al. (1985), Douglas et al. (1993), Norris et al. (1994), Bouchez and Lecomte (1996), Burgues (1997), and IAEA (1998).

Geologic Setting:

Mururoa is an elongated elliptical-shaped atoll with an emerged coral rim (averaging 2-3 meters above sea level) which overlays a basement of volcanic rock deposited at the site of a now extinct volcano, which formed in the vicinity of an upper-mantle hot spot. The volcanic activity occurred ~10-11 Ma BP and was followed by coral growth around the volcano circumference, producing a cap120-600 meters in thickness of consolidated carbonate sediments. Cross sections of the atoll (Burgues, 1997) indicate depths of 500-600 meters to the volcanic basement which contains a range of alkaline rocks including basalts and trachytes, which have been altered by hydrothermal activity, as well as ejected rock forms and lava flows. The overlying carbonate rocks cover a range from strong, well-cemented limestones and dolomites to porous and weakly consolidated deposits. Average water depth in the lagoon area is about 30 meters, while the ocean depth in the area surrounding the atoll is about 4000 meters.

Geographic Location:

21.75° – 21.9° S, 138.8° – 139.0° W

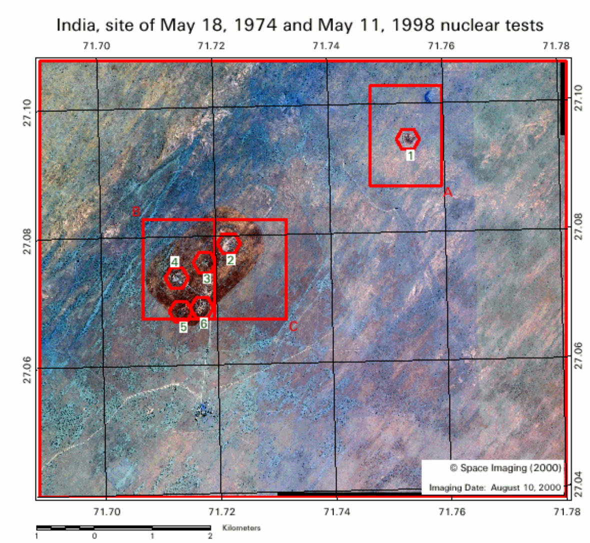
Until 1981 the French underground nuclear tests at Mururoa atoll were conducted in vertical shafts drilled into the volcanic rock beneath the coral rim; because of limited space availability, the majority of

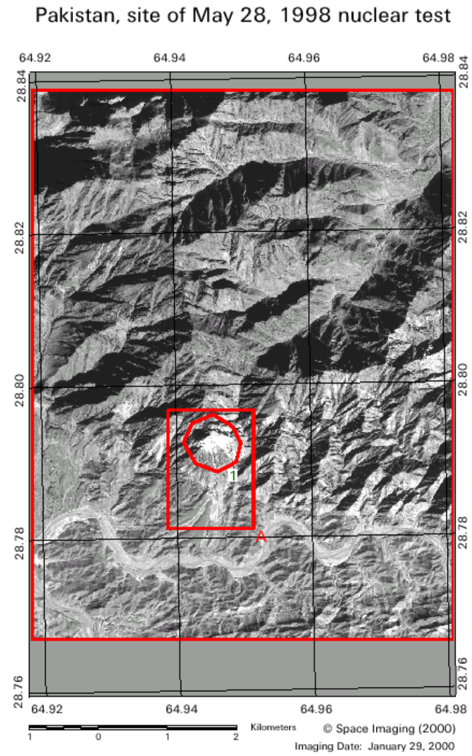
Figure 2. Examples of event summary reports accessible from the NEDB website.

The content of the event summary reports includes information on source locations, origin times, emplacement depth or height, surface elevation, magnitude, yield, and geologic and geographic setting along with the pertinent references used as the bases for preferred and alternative explosion source data included in the NEDB.

One of the most basic of the nuclear explosion source parameters described in the NEDB is source location. In general, for the NEDB we have sought to determine ground truth rather than seismic bulletin locations, where that information was available. In some cases, the preferred locations come from government or other official sources (e.g., Springer et al., 2002; DTRA, 2007; IAEA, 1998); while in others the locations are based on indirect analyses, including comparisons with features seen in satellite imagery (e.g., Thurber et al., 1993, 1994; Woodward et al., 2001). As examples of the latter, Figure 3 shows results (Woodward et al., 2001) of satellite imagery analyses at the Indian Pokhran test site and the Pakistan Ras Koh mountain test site, respectively. Based on analyses of shaft, collapse, and/or human activity features seen in the satellite imagery, ground-truth locations were determined for the Pokhran tests in India as well as for the explosions at Ras Koh mountain in Pakistan.

Figure 3. Satellite imagery analyses were used to establish ground-truth locations for nuclear explosions at the Indian Pokhran test site (below) and the Pakistan Ras Koh mountain test site (right), which are included in the NEDB as preferred solutions.





The NEDB website enables comparisons of these ground-truth source locations with surface features visible in the GoogleMap satellite imagery as well as with seismic bulletin locations (e.g., ISC). In addition, the website provides options for further review and analysis of ISC bulletin data in terms of travel time residuals for stations reported in the bulletin relative to the preferred ground truth explosion source locations. In particular, for all historical nuclear explosions from ISC bulletins, seismic travel-time residuals have been calculated for the reported station travel times relative to the times predicted for an iasp91 velocity model using the preferred ground-truth locations and origin times from the NEDB as the source. The results for the individual explosions can be easily displayed and compared using the website tools, which provide opportunities to investigate a variety of features in global and regional travel-time and velocity models.

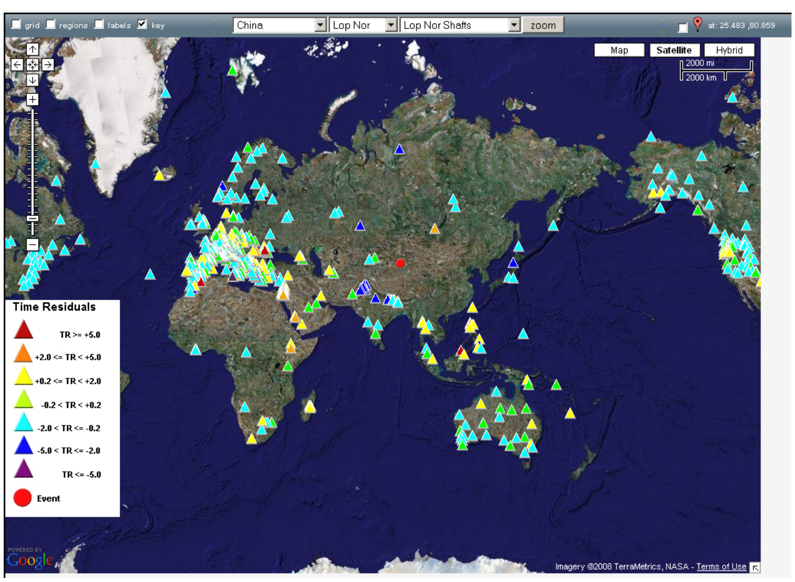


Figure 4. Travel-time residuals at ISC bulletin stations (N ~700) relative to ground truth origin for 1996/06/08 Lop Nor China nuclear test.

Figure 4 shows an example of the travel time residual display from the website for an underground nuclear test from the shaft area at Lop Nor China. Observed travel times tend to be somewhat fast or average in most of the world relative to the iasp91 model from this event; some of the most apparent slow areas in this plot are in the eastern Africa/Red Sea region, the Philippine islands, and parts of the western U.S. (Cascades area).

The NEDB website also provides an intuitive step-through process for accessing and retrieving digital waveform data from the RDSS archive, one of the most complete resources for digital waveforms from nuclear explosions. This archive includes more than 120,000 analyst-reviewed digital waveforms recorded at regional and teleseismic distances from the global network of seismic stations for 837 events from the NEDB. The options for previewing, selecting, and downloading waveforms from the website have recently been upgraded and simplified. The website now incorporates a simple and intuitive tool which provides for viewing waveforms, comparing signals between stations, and interactive display options (e.g., alternative filter choices, amplitude rescaling, time shifting) prior to selecting and downloading data. These new NEDB website waveform viewing options are illustrated in Figure 5 for the waveform data from the North Korean nuclear test of 2006/10/09.

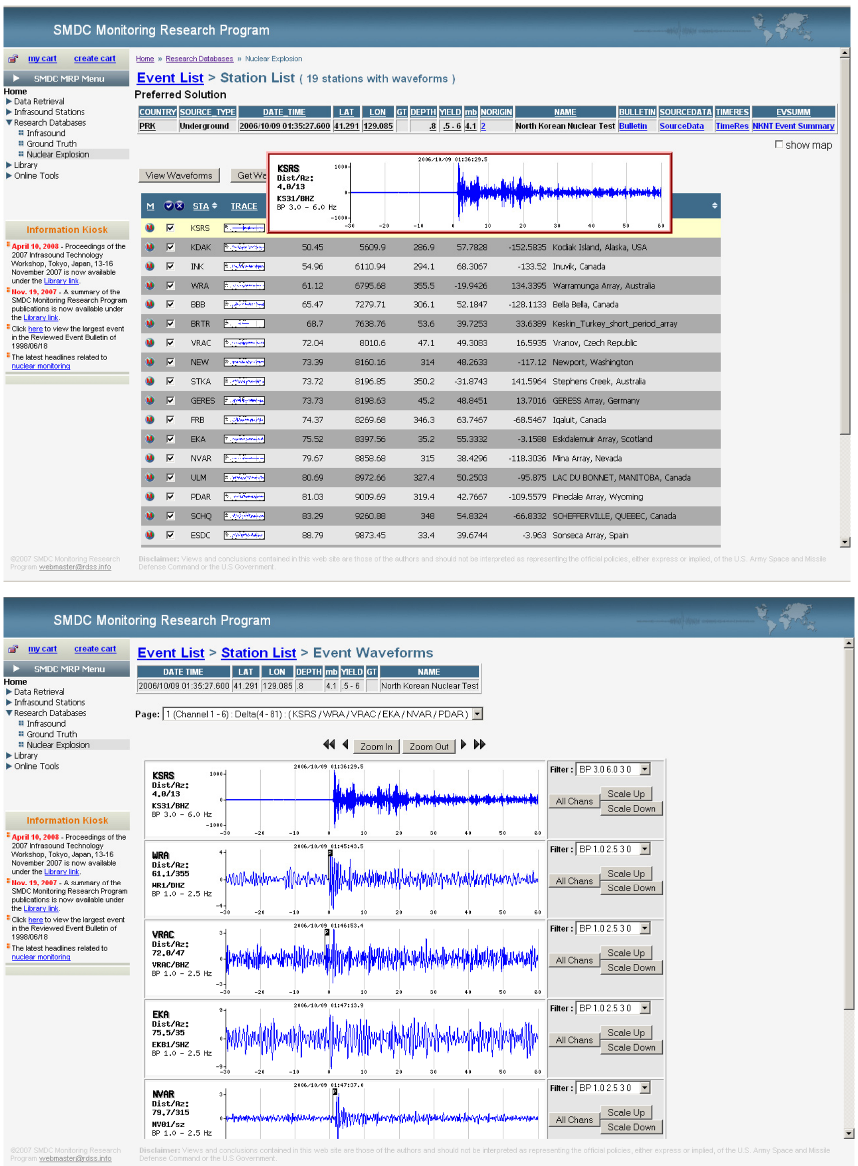


Figure 5. NEDB waveform selection and downloading tools enable previewing and menu selection of station data (top), as well as some simple options for alternative filtering, amplitude rescaling, and time shifting of selected waveforms (bottom) prior to downloading.

Infrasound Database

Identification of infrasound events for the RDSS Infrasound Database is based on a search of the International Data Centre (IDC) automated detection list and 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 is also available to the nuclear explosion monitoring community in the research database provided at the SMDC RDSS website (www.rdss.info). Access to the Infrasound Database (IDB) is provided under the Research Databases menu option at the RDSS website.

The Infrasound Database contains information on events in the atmosphere for which there are associated microbarograph recordings. The database includes hundreds of events for different source types, including historical nuclear explosions, and contains, in addition to the associated waveform data, information on available source locations with related metadata and the available associated parametric data, such as arrival times of detected signals. The waveforms recorded at over 25 stations represent propagation along more than 500 distinct paths, with broad geographical coverage.

With the revival of infrasound as a monitoring technology, and the ongoing installation of the IMS infrasound network, an increasing number of infrasonic events, both natural (bolides, earthquakes) and man-made (planned and accidental explosions, rocket launches and re-entries, etc.) are being reported and recorded by a growing global network of sensors. Source locations are well-known for the explosions, and generally less well-defined for the bolides and rockets. The RDSS infrasound database provides a valuable resource for accessing and understanding the waveforms and effects of source and propagation on the measured signals.

The RDSS infrasound database is constantly being updated with additional waveforms. Over 800 infrasound-only or seismo-acoustic events were detected globally in 2007 (Figure 6). As seen in the figure, these new events provide a broad range of source locations and propagation coverage, supplementing the existing database.

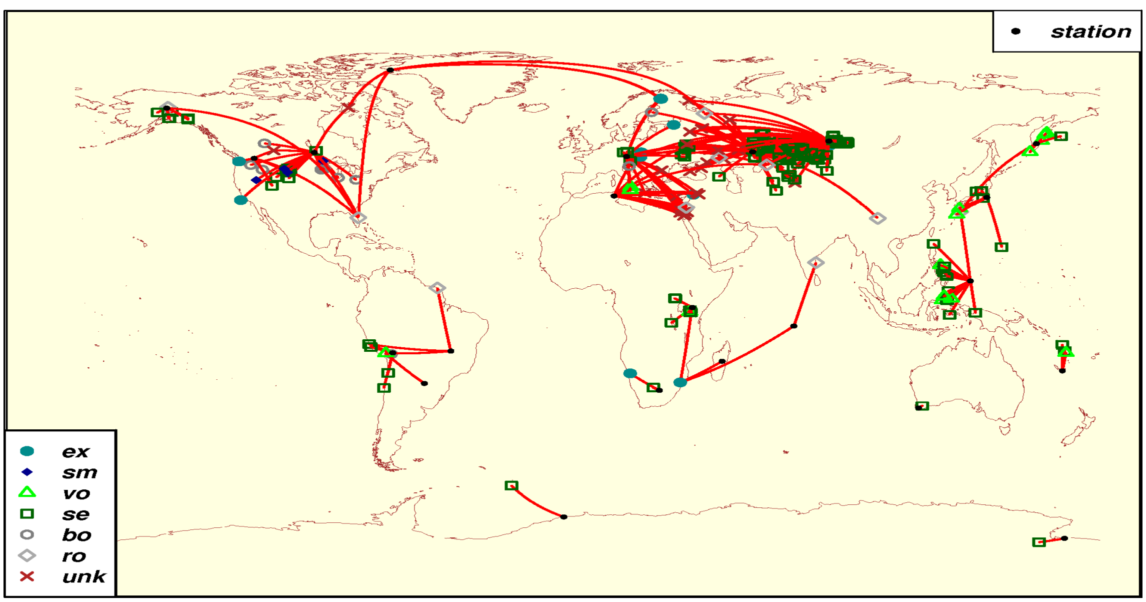


Figure 6. More than 800 infrasound or seismoacoustic events detected in 2007 are candidates for inclusion in the RDSS infrasound database.

Many of the events come from repeating sources (including mining events). Bahavar et al. (2007) reported infrasound and seismoacoustic observations from repeating mining events in south-central Russia and eastern Kazakhstan, and those have continued (Figure 7). Such repeating sources provide additional opportunities for a detailed study of a range of waveform processing tools, including alternative signal-detection methods.

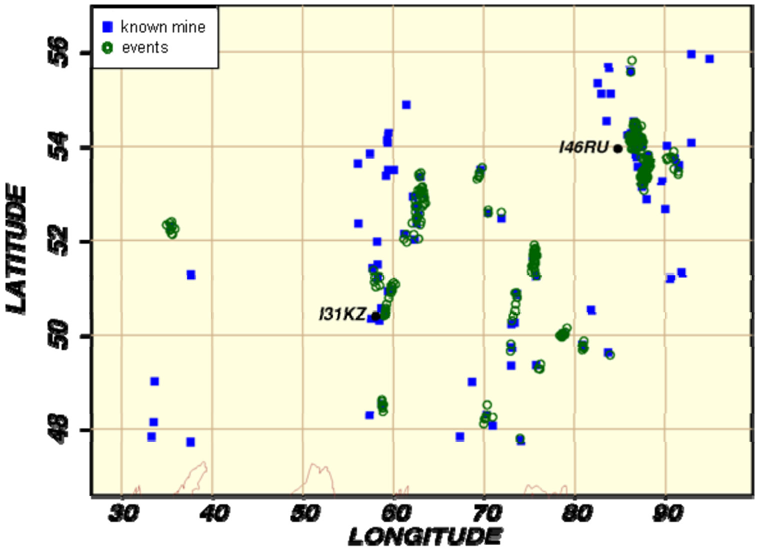


Figure 7. Dozens of detected infrasound signals from seismoacoustic events associated with known mines in south-central Russia and eastern Kazakhstan were observed in 2007-2008.

A valuable set of repeating events (under preparation for inclusion in the IDB) comes from sources in northern Finland. Suites of seismic events, confined to a small area in northern Finland, have occurred between mid-August and mid-September during the last several years (Ringdal et al., 2007). The events have been reported in the seismic bulletins of Helsinki University (http://www.seismo.helsinki.fi) and have been attributed to explosions carried out to destroy outdated ammunition (Ringdal et al., 2007). Seismic as well as infrasonic signals have been observed at the seismic array ARCES about 175 km due north of the source area (Ringdal et al., 2007). Events have also been recorded with high SNR at infrasound stations in Fenno-scandia at distances between 50 and 1,200 km (http://www.umea.irf.se). Data recorded at the two IMS infrasound arrays, I26DE (Freyung, Germany) and I18DK (Qaanaaq, Greenland, Denmark) located at about 2,500 and 3,000 km from the source area were analyzed for detections of events in the area between mid-August and mid-September in 2007. The map in Figure 8 shows the two IMS arrays, I18DK and I26DE, in relation to the source area. Data for all 46 events reported in the daily automatic bulletins of the Helsinki Seismological Institute (HEL) with local magnitudes between ML (HEL) = 0.9 and 1.5 have been analyzed.

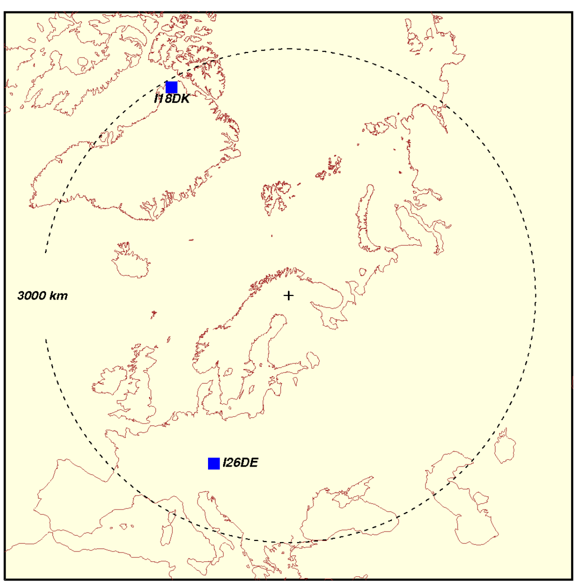


Figure 8. Map showing the locations of the two arrays I18DK (Qaanaaq, Greenland, Denmark) and I26DE (Freyung, Germany) in relation to event area centered at 67.93N 25.80E (cross symbol in center).

Automatic detections in the IDC detection list were associated with events from this data set. The IDC detections are based on the Progressive Multi Channel Correlation, PMCC (Cansi, 1995), which is followed by phase categorization (Brachet et al., 2006 and Brachet et al., 2007), during which a detection is classified as signal (I) or noise (N) depending on duration, frequency content, and repetitiveness. Even though automatic IDC detections (both I and N phases) were associated with all 46 events, only a fraction of the events produced associated I detections at the two stations (7 at I18DK and 10 at I26DE) when more rigorous analyses of the waveforms were performed. The infrasound data from these events have provided an opportunity to investigate alternative detection schemes at the two infrasound arrays based on frequency-wavenumber (fk) processing and the F-statistic. The results of comparing the alternative detection processing schemes indicate station-dependent differences which could be related to differences in the number of array elements at the two stations.

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 and documentation for the NEDB has been enhanced to include a range of search options 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, and retrieving nuclear explosion digital waveform data from the NEDB archive. The waveform display options have been improved to make them more useful, more intuitive, and faster. 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. Infrasound signals from a repeating series of sources in northern Finland have provided a useful resource for comparing alternative infrasound signal-detection processing schemes.

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