A unique global network

that detects very low frequency sound waves in the atmosphere

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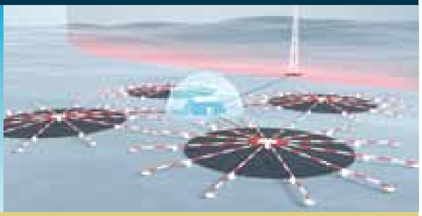
This article describes the experiences gained by the infrasound network, part of the International Monitoring System (IMS), from the Sayarim Calibration Experiment in the Negev desert in Israel, as well as from collaboration with the Japanese National Data Centre (NDC-1). Both cases allowed the Preparatory Commission for the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO) to test its equipment and detection capabilities. The article also explains how 15 IMS infrasound stations around the world recorded the meteoroid that exploded above Sulawesi, Indonesia, in October 2009, making it the largest event detected by the IMS infrasound network to date.

THE INFRASOUND NETWORK



When complete, the International Monitoring System (IMS) will comprise 337 facilities, including 60 infrasound stations. The infrasound network is unique in terms of the volume and the uniform distribution of its monitoring stations. Forty-two of the infrasound stations are already transmitting data continuously to the International Data Centre (IDC) in Vienna for processing and analysis.

The infrasound stations measure micropressure changes in the atmosphere generated by the propagation of infrasonic waves (low frequency sound). These waves are produced by a variety of natural sources such as exploding volcanoes, earthquakes, and meteors, as well as man-made sources, which include nuclear, mining and large chemical explosions etc.

With 70 percent of its stations fully operational, the infrasound network is able to register very large events at a number of stations around the globe. The recent extensive use of IMS infrasound data by the IDC has posed questions about the minimum size of an event (which may occur at any location) that can be detected by the IMS infrasound network. Questions also arise about the extent to which this minimum size varies over time due to constantly changing environmental conditions at the location. In order to address these questions, the CTBTO is participating in international infrasound experiments and is also collaborating with National Data Centres interested in advancing the infrasound technology used to monitor compliance with the Comprehensive Nuclear-Test-Ban Treaty (CTBT).

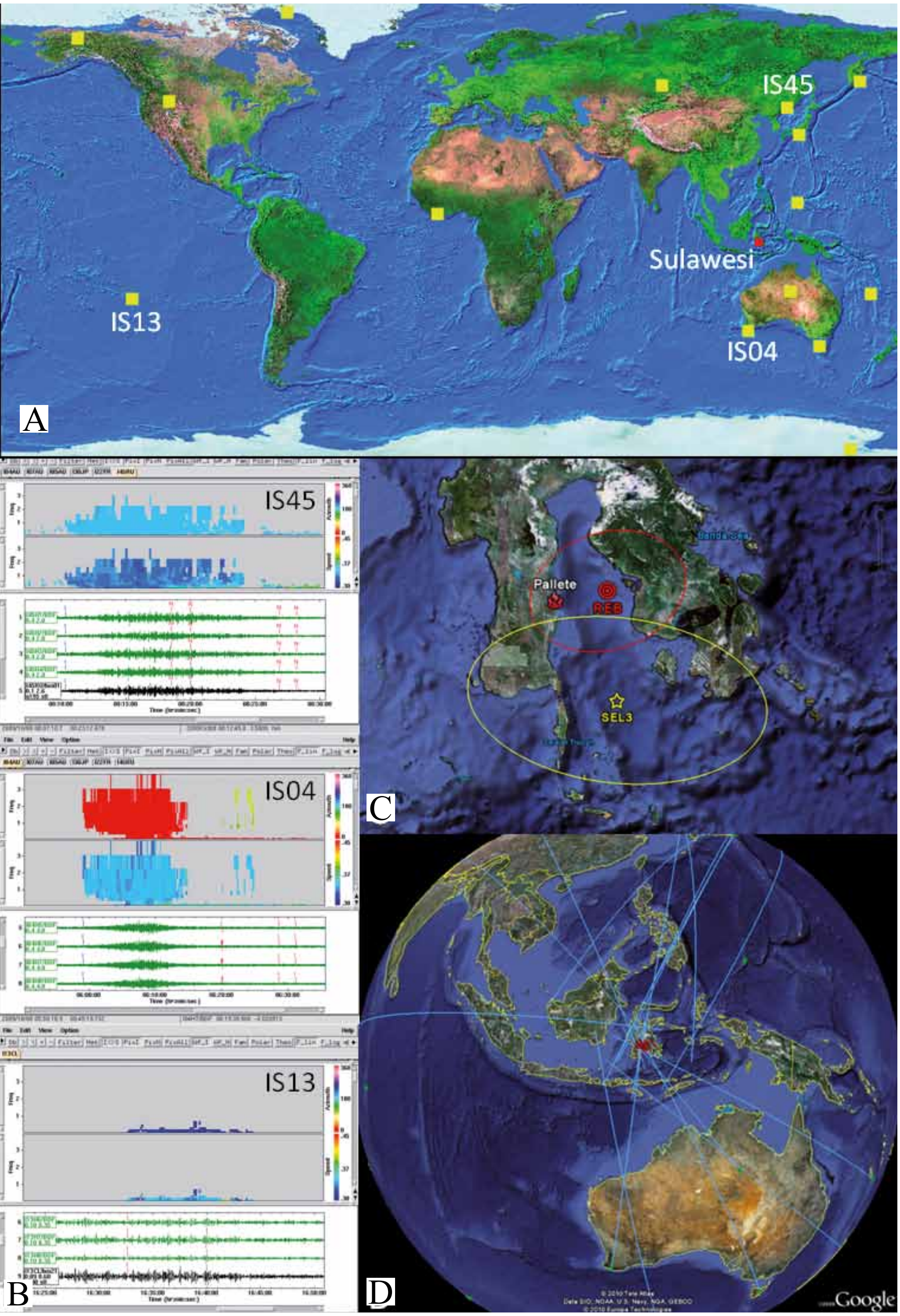
THE SULAWESI METEOROID

On 8 October 2009 at 02:58 UTC, a large meteoroid hit the Earth's atmosphere above South Sulawesi, Indonesia, and exploded. The only information came from local Indonesian authorities, who reported hearing a loud air blast up to 17 km from Pallete, Bone district, South Sulawesi, at around 03:00 UTC.

A couple of hours after the explosion, a number of IMS infrasound stations, which send monitoring data automatically to the IDC in Vienna, started recording infrasound waves from the blast. The IDC's automatic processing system recognized the data as originating from an acoustic disturbance in the Indonesian region.

EFFICIENT PERFORMANCE OF THE IDC'S AUTOMATIC PROCESSING SYSTEM

Based on assumptions about the source origin and infrasound propagation characteristics, the IDC scanned the IMS data interactively



FROM TOP LEFT TO BOTTOM RIGHT:

A) Map showing the Sulawesi event and the IMS infrasound stations that detected it (yellow).

B) Three examples of processing results: the upper two panels show the time versus frequency pixels with back-azimuths and trace velocity (the apparent speed at which the infrasound signal travelled across the array); the lower panel displays some of the filtered waveforms.

C) IDC automatic location and its error ellipse (in yellow), refined location and its ellipse (in red) and the village of Pallete.

D) Overview of the event location with the projected azimuth from all stations (green automatically associated, blue interactively associated).

and found 14 infrasound signal detections created by the automatic system and one manually detected related arrival. No related detection was found by the IMS seismic network.

The IDC's automatic system performed according to expectations by publishing an automatic bulletin that was interactively reviewed and refined by detections from stations up to 14,000 km – about three quarters of the way around the world – from the source. Considering the global distribution of stations involved, as well as the distance of detection and the signals' characteristics, the most probable source hypothesis was an exploding meteoroid, at high altitude, as indicated by local observations. As expected, most of the detections had stratospheric properties: stratospheric winds (about 50 km altitude) favour long-range infrasound propagation whereas thermospheric (about 100 km altitude) or tropospheric winds (around 10 km altitude) do not propagate over such large distances.

PROCESSING DATA AT THE IDC

Upon arrival at the IDC, the infrasound data from each station are processed automatically and independently using the Progressive Multi-Channel Correlation (PMCC) algorithm. PMCC estimates the signals' characteristics to determine whether the detections were infrasonic, seismic or spurious.[1]

Since an event may be recorded at more than one IMS station, the next step at the IDC is to determine which signals from different stations originated from the same source. All available detections are examined, eventually associated with an event, and then published in the IDC's automatic bulletins. A clearer picture of what actually occurred then begins to develop.

IDC analysts review the automatic bulletins and improve, correct or discard the events. The reviewed events are listed in timely and high quality Reviewed Event Bulletins (REB), which are made available to the Preparatory Commission for the Comprehensive Nuclear Test Ban Treaty Organization's (CTBTO) Member States.

REBs are produced using the three waveform technologies: seismic, hydroacoustic and infrasound. In February 2010, the IDC successfully reintroduced the routine analysis of infrasound data and events for inclusion in its daily products[2].

[1] For further reading, please see Brachet, N., Brown D., Le Bras R., Mialle P., and Coyne J. (2009). Monitoring the Earth Atmosphere with the Global IMS Infrasound Network. Chapter 3, *Infrasound monitoring for atmospheric studies*, Le Pichon A. et al. Published by Springer Science.

[2] Between 2004 and February 2010, the IDC redesigned the automatic infrasound system, introduced analyst procedures, and trained analysts with new infrasound review tools.

SAYARIM INFRASOUND CALIBRATION EXPERIMENT
A debris cloud rising high into the atmosphere above the Sayarim Military Range in the Negev desert, Israel, 26 August 2009. Photo courtesy of Dr Yefim Gitterman, Geophysical Institute of Israel

LARGEST EVENT EVER RECORDED BY INFRASOUND NETWORK

Once the infrasound waves were recorded at the more distant IMS infrasound stations, the final IDC event location was refined to about 45 km off the coast of Sulawesi in the Pallete region. The Sulawesi meteoroid is an interesting and, to date, unique case for infrasound automatic processing and interactive review because it presented such a high number of observations at IMS infrasound stations. This makes the event the largest recorded so far by the IMS infrasound network in terms of the number of stations and the distance of the observations.

THE SAYARIM INFRASOUND CALIBRATION EXPERIMENT

A large debris cloud rose high into the atmosphere above the Sayarim Military Range in the Negev desert, Israel, on 26 August 2009 at around 06:30 GMT. The cloud was the result of a large-scale calibration experiment carried out by the Geophysical Institute of Israel (GII) and sponsored by the U.S. Army Space and Missile Defense Command (SMDC). The experiment involved the upward detonation of about 82 tons of high-energy explosives.

The experiment aimed to:

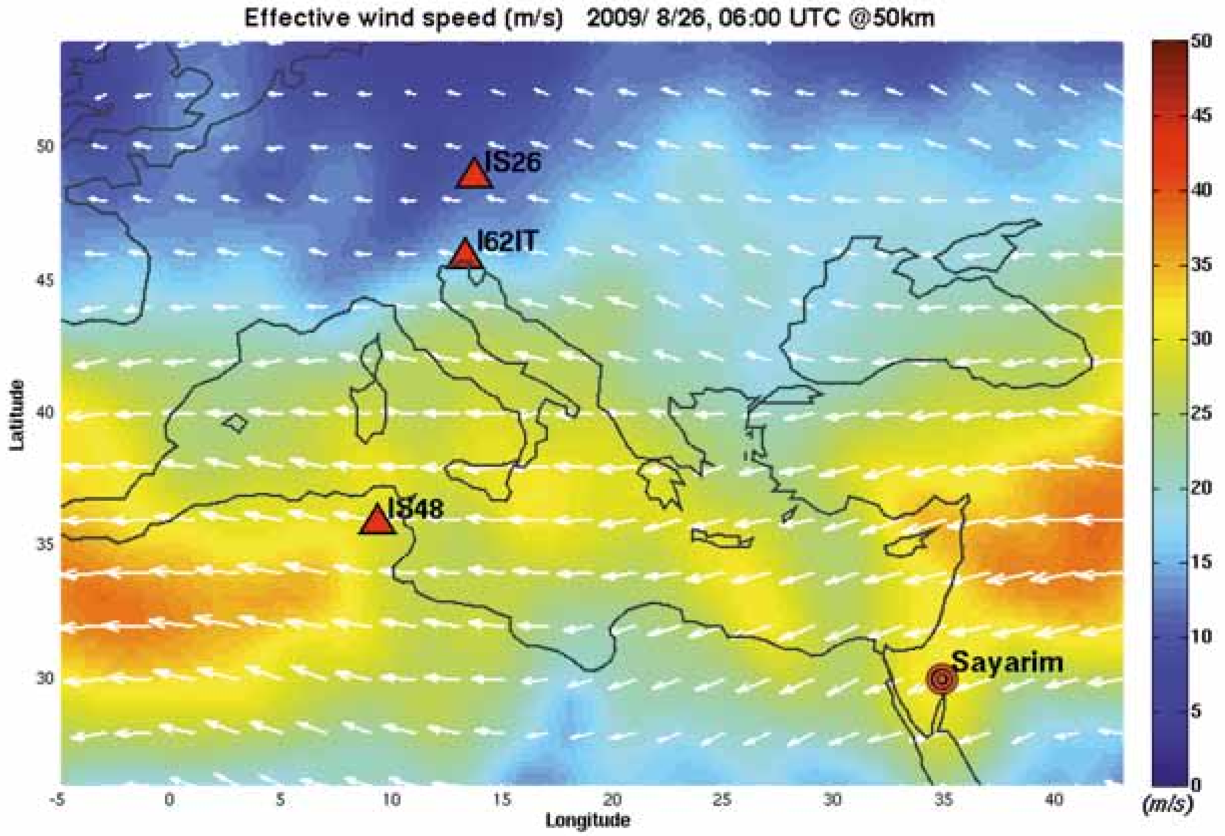
- Observe infrasound signals at a number of stations at distances up to 3,000 km from the explosion, thus establishing a Ground Truth infrasound dataset for the Eastern Mediterranean region
- Enhance the understanding of infrasound signals and propagation.

INFRASOUND DETECTION DEPENDENT ON REGIONAL WEATHER CONDITIONS

Since infrasound propagation is seasonally affected, the experiment was conducted in the summer when atmospheric conditions would be favourable for detections at IMS infrasound stations IS26 (Germany) and IS48 (Tunisia) as a result of the westerly stratospheric winds.

Numerous permanent infrasound arrays are installed in the Eastern Mediterranean region. Of particular interest for the CTBTO were the two stations IS26 and IS48, located closest to Sayarim. In order to achieve all of the experiment's objectives, technical and support teams from various institutes were also deployed to establish temporary infrasound arrays in Israel, Greece, Cyprus, Italy and France at distances of between 50 and 3,000 km from the detonation site. In addition to the permanent IMS infrasound arrays, the CTBTO set up its portable infrasound array, I62IT, in Friuli-Venezia, Italy. The site was selected to complement the IMS network and

The atmospheric model shows the stratospheric winds (at 50 km altitude) for the Euro-Mediterranean region on 26 August 2010 at 6:00 GMT. The model predicted a relatively strong eastward stratospheric wind. The IDC simulated the infrasound propagation using ray tracing software to evaluate and validate its simulation capacities. Meteorological data were provided by the European Centre for Medium-Range Weather Forecasts.



to provide knowledge on regional sources that might be observed in Germany and Tunisia.

MOST ENERGY FROM THE BLAST RELEASED INTO THE ATMOSPHERE

High-pressure values and strong ground motions were measured at distances up to 600 metres around the blast zone. A seismo-acoustic analysis of the explosion confirmed that most of the energy was released into the atmosphere and a minimum amount was transmitted to the ground.

The explosion was detected by the two regional IMS stations: IS26 (2750 km from Sayarim) and IS48 (2460 km away) as well as by I62IT (2560 km away).

EXPERIMENT OF GREAT INTEREST TO INFRASOUND COMMUNITY

The Sayarim calibration explosion was detected by several European arrays and temporary arrays located at ranges of between 300 and 3,500 km from the detonation site as well as by the two IMS infrasound stations. While no primary IMS seismic stations detected the explosion, further analysis showed that the local seismic network and an IMS auxiliary station picked up seismic arrivals.

The results of the experiment are of major interest to the infrasound community as they will be used for in-depth analysis and research. The experiment provides a unique Ground Truth infrasound dataset for the Eastern Mediterranean region during the summer.

COLLABORATION WITH JAPANESE NATIONAL DATA CENTRE (NDC-1)

The CTBTO attaches great importance to capacity building activities, particularly in terms of assisting National Data Centre (NDC) staff in the CTBT-related verification technologies.

An area of interest to many NDCs is the deployment of portable infrasound equipment. The CTBTO has recently collaborated with several NDCs in this field, offering NDC staff a range of opportunities. In addition to receiving CTBTO training in relevant hardware and software, participants improve their understanding of atmospheric propagation and help to validate regional atmospheric models. NDC staff also study regional and distant infrasound sources, which supports IDC routine analysis.

FOLLOW-UP ACTIVITIES PLANNED FOR 2011

An infrasound Ground Truth calibration experiment in the Eastern Mediterranean is scheduled for the beginning of 2011, with the following objectives:

- **Repeat the 2009 Sayarim experiment during a different season**
- **Test the infrasound propagation model**
- **Calibrate the yield measurement methods**
- **Cooperate with regional participants to identify and study additional infrasound sources in the region**

Location of Sayarim Military Range in Israel. IMS detecting stations IS26, (5 elements, Freyung, Germany), IS48 (8 elements, Kesra, Tunisia) and the CTBTO's portable array I62IT (4 elements, Strassoldo, Italy). Blue lines represent the back-azimuth extracted from the detected signals for each infrasound array.

In March 2010, the CTBTO embarked on a six-month project related to infrasound technology with the Japanese NDC-1[3], which comes under the responsibility of the Japan Weather Association (JWA).

As well as the overall goals outlined above, the project aimed to:

- Assess the impact of anthropogenic activity near IMS infrasound station IS30
- Estimate the performance of the CTBTO's portable infrasound array equipment, I64JP, in relation to IS30
- Train JWA staff on equipment operation and maintenance, and on the software used for infrasound data processing

The project took place at three different sites: in Tsukuba[4], which is about 60 km from Tokyo; in co-location with IS30 at Isumi in Western Japan; and at the University of Hokkaido in northern Japan.

INFRASOUND REFERENCE EVENT DATABASE

Significant infrasound events have been included in the IDC's Infrasound Reference Event Database (IRED) since 2004

Its objectives are to:

- **Collect, review and document infrasound events of special interest**
- **Archive the data for each event into database tables**
- **Use this resource for training, testing and validation purposes**

The database currently contains 750 infrasound events generated by natural or anthropogenic sources. The database is available to CTBTO authorized users (through IDC Services services@ctbto.org). An updated IRED was released in July 2010.

[3] The Government of Japan has designated the JWA and the Japan Atomic Energy Agency as the NDCs dealing with waveform (NDC-1) and radionuclide data (NDC-2).

[4] Tsukuba was the original location of IS30, as foreseen in Annex 1 to the Protocol of the Comprehensive Nuclear-Test-Ban Treaty.

Installation of CTBTO's portable array in Tsukuba, Japan, March 2010

The portable equipment performed well at all three locations and its performance was comparable with that of IS30 when the arrays were co-located. When deployed at Tsukuba, the detection capability of I64JP was unaffected by activities at the nearby refinery at Tokyo Bay, which have negatively impacted IS30's processing results. The results demonstrated the importance of using such portable equipment together with IMS permanent arrays to study and understand regional infrasound background activity. The data collected were especially valuable for IDC infrasound routine analysis.

The collaboration has proven mutually beneficial. JWA staff gained experience in the use of portable infrasound equipment and IDC software, as well as on the scientific aspects of infrasound propagation. The CTBTO obtained valuable feedback on the use of its software and on the usefulness of the portable infrasound array. Both sides have expressed a strong interest in continuing their cooperation in infrasound technology.

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GLOSSARY

AZIMUTH:
A horizontal direction defined by an angle measured clockwise from true north. "Back-azimuth" involves reversing the bearing of the azimuth.

GROUND TRUTH:
Seismoacoustic sources whose location, depth and origin time (together with their uncertainties) are known to high precision, either from non-seismic evidence or using exceptionally good coverage of seismometers close to the event.

RAY TRACING:
Infrasonic ray tracing is a procedure whereby the most likely path of propagation that a sound wave takes is predicted based on assumed temperature and wind-speed profiles along the propagation path.

BIOGRAPHICAL NOTES

PIERRICK MIALLE
joined the CTBTO in 2008 and now works for the IDC as an Acoustic Officer. Prior to that, Dr Mialle worked for the Commissariat à l'énergie atomique (CEA) in France for four years on the atmospheric propagation of infrasound waves.

PAULINA BITTNER
worked at the IDC until Dec. 2009, latterly as Lead Analyst at the Monitoring and Data Analysis Section. Prior to this, Dr Bittner held an appointment at the Polish Naval Academy. She also worked at the Prototype IDC.

NICOLAS BRACHET
worked as Acoustic Officer at the IDC from 1998 to 2010. In August 2010, he rejoined the French National Data Centre at the Commissariat à L'Énergie Atomique (CEA) where Mr Brachet worked prior to the CTBTO in the fields of seismology and infrasound.

JOHN COYNE
has worked at the IDC since 1998, where he is currently the Programme and Project Coordinator for the IDC Division. Prior to this, Dr Coyne worked in nuclear monitoring for 10 years for a contractor in the United States.

DAVID J. BROWN
has worked at the IDC as a Software Engineer since 2008. Prior to that, Dr Brown worked as an Infrasonic Scientist in the nuclear monitoring group at Geoscience Australia and with Science Applications International Corporation at the Prototype IDC in Arlington, Virginia, United States.

JEFF GIVEN
joined the IDC in 2009 as Chief of the Software Applications Section. Dr Given has over 20 years experience supporting research and development for treaty monitoring for GSETT2, GSETT3*, the United States National Data Center, the Prototype IDC, and the IDC.

*Group of Scientific Experts Technical Test (GSETT): Technical experiments conducted by the Ad-hoc Group of Scientific Experts. This was done to test monitoring technologies and data analysis methods for the verification of a nuclear test ban. GSETT1 took place in 1984, GSETT2 in 1991, and GSETT3 in 1995.