Progresses with the IDC Infrasound system

Pierrick Mialle, Seismic-Acoustic Officer, CTBTO/IDC
Nimar Arora, Bayesian Logic, USA
And colleagues from the International Data Centre (IDC)

Preparatory Commission
for the Comprehensive Nuclear-Test-Ban Treaty Organization
Provisional Technical Secretariat
Vienna International Centre
Vienna, AUSTRIA
The CTBT is an international treaty that bans all nuclear explosions, by anyone, anywhere, for ever: 183 States have signed, 164 ratified.

Not yet in force – needs action
4 Monitoring Technologies

Seismic: 170
Listening underground

Hydroacoustic: 11
Listening to the oceans

Infrasound: 60
Listening to the atmosphere

Radionuclide: 80
Sniffing the atmosphere for radiation
6th announced nuclear test by DPRK on 3 September 2017

→ A functioning system that swiftly, reliably and precisely detected all six DPRK declared nuclear tests (2006 – 2017)

2017 event information (REB*)

Date: 3 September 2017

Origin Time:
03:30:01.08 UTC ± 0.18 seconds

Latitude: 41.3205 degrees North
Longitude: 129.0349 degrees East

Approximate Location Accuracy:
± 6.7 km (109 km²)

Depth: 0.0 km (fixed)

Body Wave Magnitude mb (IDC): 6.07

Number of SHI Stations Used: 125

Issued: 5 September 2017 17:40:22 UTC
(within Entree Into Force timeline)

*Reviewed Event Bulletin
IDC Infrasound results for the DPRK event:

- **I45RU** (Ussuryisk, 400km): Seismic & infrasound detections associated to automatic and interactive products.

- **I44RU** (Kamchatka, 2500km): Infrasound detection.

_Fusion of waveform technologies at IDC helps to improve confidence and accuracy_
2001 – 2018: 50 IMS infrasound stations certified out of 60
Latest certification: I20EC, Ecuador (December 2017)
IDC bulletins for waveform technologies (Seismic/Hydroacoustic/Infrasound), event location for period:

Since February 2000

Over 580,000 REB events

IDC bulletins for infrasound technologies (since infrasound are in IDC Operations), event location for period:

Since February 2010

Over 22,000 LEB infrasound events

REB and LEB are IDC products. REB: Reviewed Event Bulletins – LEB: Late Event Bulletins
Infrasound data

**Station Processing**
- Detection: DFX-PMCC
- Categorization: StaPro

**Network Processing**
- Association & conflict resolution: GA
- SEL detections

**Interactive Review**
- Review: ARS / Geotool-PMCC
- SEL origins

Supported by Google Earth and InfraNet
Infrasound data

Station Processing
- Detection: DTK-PMCC
- Categorization: StaPro*

Network Processing
- Association & conflict resolution, with infrasound model
  Net-VISA

Interactive Review
- Review
  ARS / DTK-GPMCC*

Seismic & Hydro-acoustic data
- Seismic and Hydro-acoustic processing: DFX
  SEL detections

* And other specialized plugins and tools for SH
DTK-(G)PMCC – software evolutions

- PMCC\* algorithm reorganization to improve modularity and flexibility - *Re-engineering*
- method incorporate a 3D algorithm to allow for accurate computation of wave attributes for non-planar arrays - *Re-engineering*
- DTK-PMCC execution for distributed computation on multi-core computers - *IDC requirement*
- DTK-GPMCC evolved to integrate communication with single-station detection visualization software (DTK-Diva) - *NDC-in-a-box, distributed to CTBTO users since July 2016*

IDC integration

- real-time processing in development environment
- full integration to be completed in 2018

[Cansi, GRL, 1995]
NET-VISA Network Processing Vertically Integrated Seismic Analysis*

1. Initial Research (2009-2010)
   Towards the development of a Bayesian inference system (to replace legacy software, GA)

2. Software Development (2011-2016)
   a. Seismic
      Seismic model development (2011)
      Continuous seismic model improvements
   b. Hydro-acoustic
      Introduction of Hydro-acoustic processing (2013)
   c. Set up a framework for bulletin comparison (2013)
   d. Pipeline processing (2014-2015)
      Semi-continuous single pipeline processing on OPS data
      Simulation of full pipeline processing (data made available to Member States)
   e. **Infrasound**
      Introduction of Infrasound processing (2015)
      Continuous model improvements


Under normal circumstances, NET-VISA produces a bulletin more complete and accurate than IDC’s automatic bulletin

[Arora et al., BSSA, 2013]
NET-VISA Event Formation Criteria

An event is real if the probability of the event occurring and generating its associated detections and mis-detections is higher than the probability of those same detections being generated by noise (including repetitive clutter) sources.

Infrasound specificities

- **Static prior** using a whole year’s worth of data (built with event location and detection rate prior)
- **Clutter model** to avoid building events from long-lasting local sources
- **Disentangling** seismo-acoustic vs. pure infra associations
- Identified minimal set of **infrasound detection features** (using back-azimuth, celerity, trace velocity, energy, frequency)

Difference between Infrasound and Seismic technologies

- Prior on number of events artificially inflated (vs learned from data in seismic)
- Event time is uncertain due to dynamic of the atmosphere
- Nuisance (N) phases at infrasound stations not considered
Static prior
Detection probability, the first element of the model (learned empirically)

Distributions obtained from 2012 interactively reviewed events (LEB):
- Celerity
- Noise phases proportion per stations
- Centre frequency of associated phases

Clutter model
- Example: I31KZ (Kazakhstan) – a rather “typical” station

Net-VISA for infrasound
Static prior & clutter model
Comparison of performances between GA* (SEL3) and NET-VISA implementation over 2013 data (offline)

Objectives

• Reducing spurious seismo-acoustic associations
• Improving false alarm rate & reducing analyst workload

Results highlights:

• LEB overlap for pure infrasound event from GA 24.7% to NET-VISA 46.5%
• Inconsistency high 85.3% but reducing → fewer false events while keeping miss event rate
• 90% reduction in spurious seismo-acoustic associations
Network processing
Event formation - GA

SEL3 bulletin 2013 54,327 events
Interactive review results (LEB)

LEB bulletin for 2013 for all waveform technologies: 42,782 events
NET-VISA bulletin for 2013: 62,487 events total, with 3,383 events containing infrasound phases
Events from NET-VISA for 2013 infrasound events by types

Green 1I – Blue 2I – Red at least 3I

NET-VISA bulletin 2013 Events with infrasound phases 3,383 events
Station impact to global infrasound bulletin

Overall better agreement between NET-VISA and LEB

(with NET-VISA 2.2.48)
Event comparison for 2013
LEB vs NET-VISA

Blue LEB – Red NET-VISA

NET-VISA bulletin 2013 Events with infrasound phases 3,083 events vs 1,767 LEBs
Infrasound needs
Areas for future developments and possible collaborations

**Station processing** progresses

- Implementation into IDC Operation
- Continuous inclusion of new functionalities
- Infrasound phase categorization redesign

Enhancement of Infrasound *network processing*

- Full implementation into IDC Operation and continuous improvements
- Further refining priors and clutter model
- Inclusion of meteorology / propagation criteria
- Objective: improving performance of association algorithms: GA – NET-VISA

Infrasound *propagation* tools

- *Benchmarking* of propagation tools (possible project)
- Needed for special event and interactive review analysis
- To support network processing enhancements and performance objectives
2010: Infrasound Monitoring for Atmospheric Studies, editors Le Pichon A., Blanc E. and Hauchecorne A.

2018: Infrasound and middle-atmospheric monitoring: Challenges and new perspectives, editors Le Pichon A., Blanc E. and Hauchecorne A.

Advances in operational processing at the International Data Center, Mialle et al.
Event comparison for 2013
SEL3 vs LEB

SEL3 bulletin 2013 Events with infrasound phases 5,117 events vs 1,767 LEBs