Progresses with the IDC Infrasound system

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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

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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

International Staff

over 260 staff from 70 countries

3 Technical Divisions

International Monitoring System (IMS)
International Data Centre (IDC)
On-Site Inspections (OSI)

Executive Secretary

Dr Lassina Zerbo

Headquarters

Vienna

Seismic: 170

Listening underground

**Hydroacoustic: 11**

Listening to the oceans

Infrasound: 60
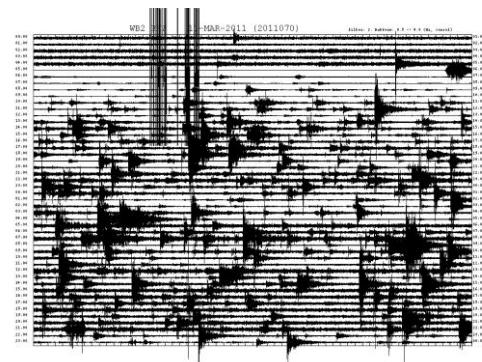
Listening to the atmosphere

Radionuclide: 80

Sniffing the atmosphere for radiation

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→ 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)
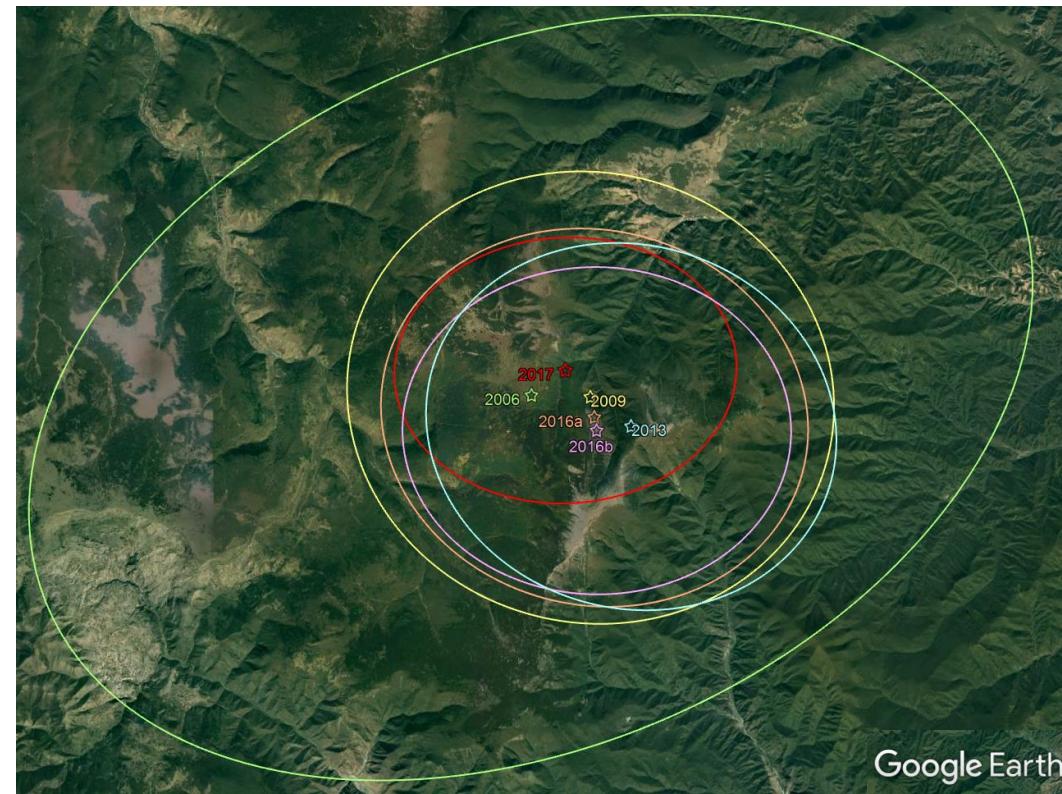
Depth: 0.0 km (fixed)

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

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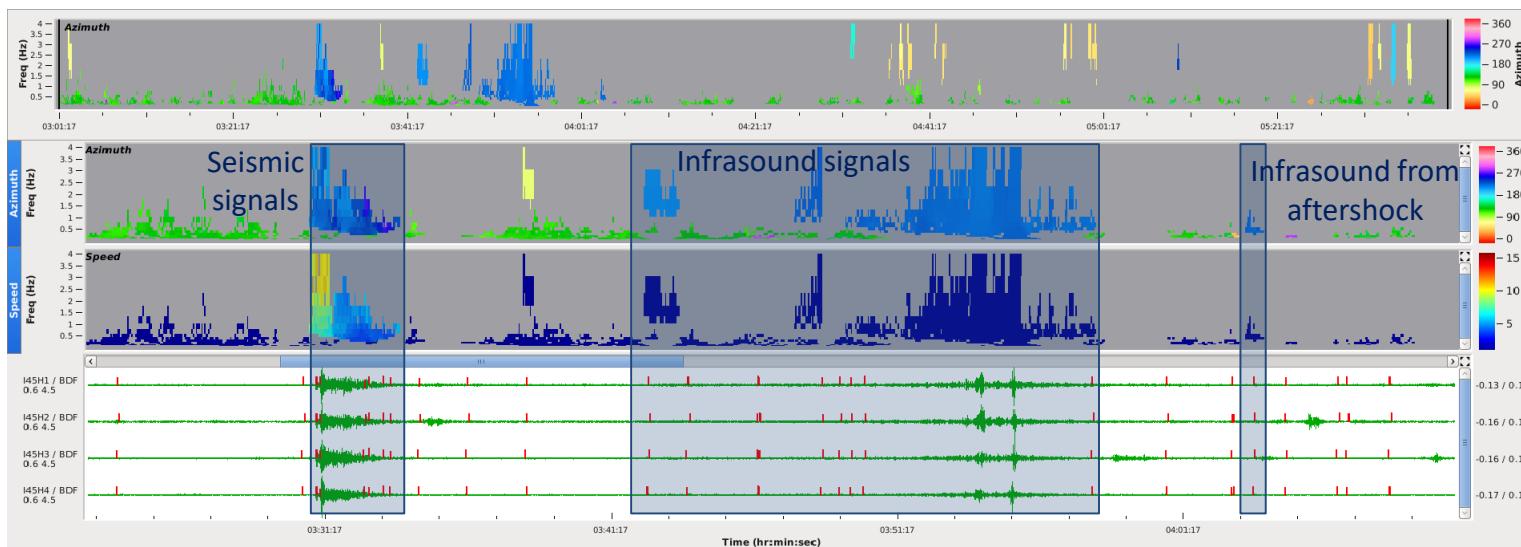
IDC Infrasound results for the DPRK event:

- 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
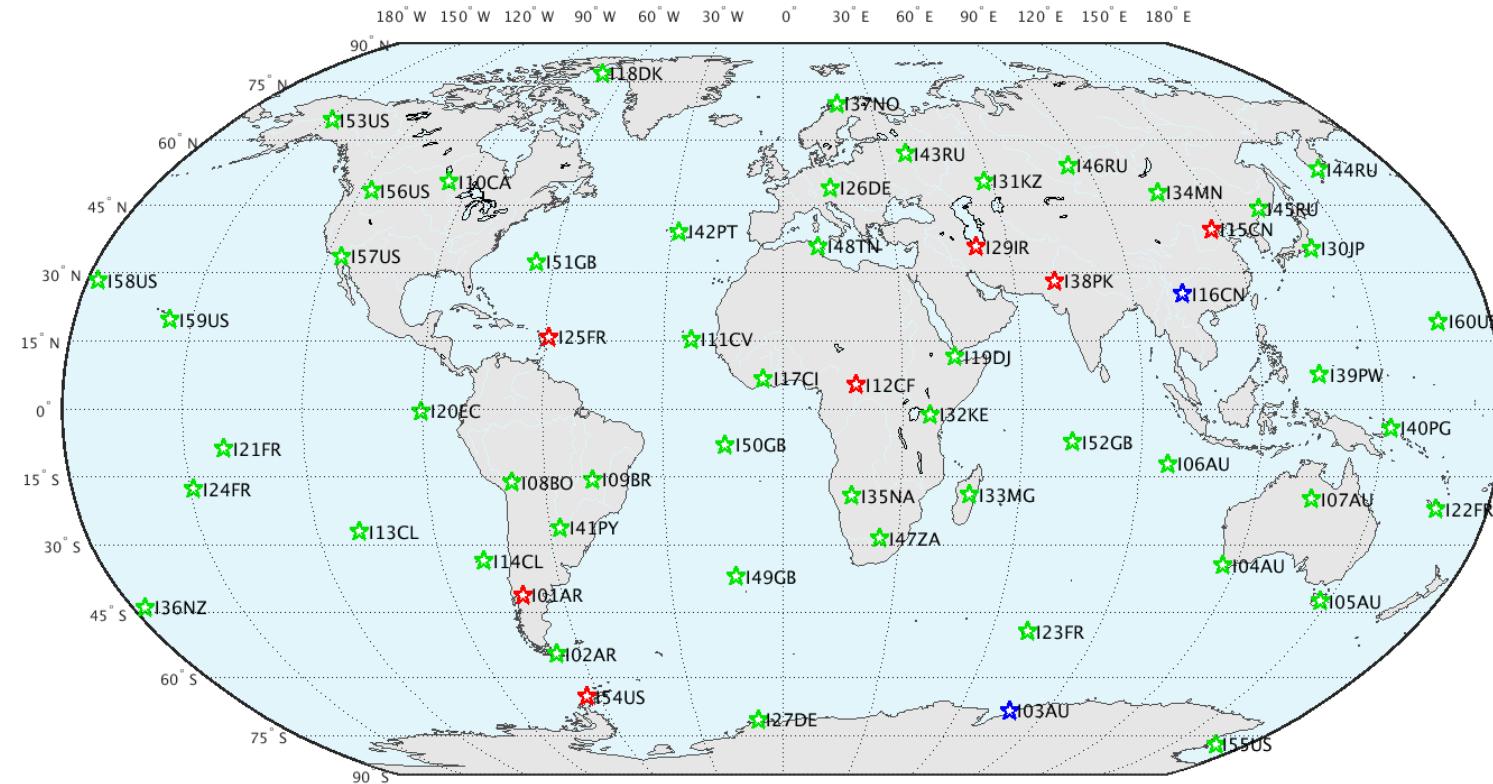
IDC review bulletin (extract)

Ev=14801040 (orid 14812788) 2017/09/03 03:30:01 41.32N 129.03E 0.0km mb=6.1 ml=5.2 Ell=6/5/88
Allocated to: wanghj Infra Review : none

Arid	Sta	Delta	Phase	Arrival time	Tres	Az	Azres	Tr.Vel	Cel	CFreq	Fstat	SNR	Amp
125944164	I45RU	3.6	Pn (ISx)	2017/09/03 03:30:58	0.2	228.4	10.4	5.2 km/s	6990 m/s	1.04	26.0	6.2	0.17
125969062	I45RU	3.6	Pg (P)	2017/09/03 03:31:05	-1.1	218.1	0.1	7.5 km/s	6202 m/s				
125969061	I45RU	3.6	Lg (P)	2017/09/03 03:31:53	-2.1	216.1	-1.8	4.8 km/s	3565 m/s				
125944808	I45RU	3.6	I (I)	2017/09/03 03:48:05	-270.5	215.0	-3.0	354 m/s	369 m/s	0.94	24.2	5.8	0.26
125943937	USRK	3.6	Pn (Pn)	2017/09/03 03:30:58	-0.2	222.4	4.3	8.2 km/s	7039 m/s	1.50	206.9	3263.7	4548.94
125945982	USRK	3.6	Pg (P)	2017/09/03 03:31:06	-0.6	223.7	5.6	7.4 km/s	6151 m/s				8998.83
125944292	USRK	3.6	Lg (Sx)	2017/09/03 03:31:54	-1.5	213.1	-5.0	4.3 km/s	3546 m/s	1.00	40.6	5.6	15120.67
125944564	USRK	3.6	PKIKP (P)	2017/09/03 03:46:33	-2.0	270.0	51.9	77.1 km/s	404 m/s	1.50	17.4	5.1	3.43
126007508	USRK	3.6	LR (LR)	2017/09/03 03:32:09	0.8	213.8	-4.3	3.1 km/s	3110 m/s				3409.81
125943922	KSRS	4.0	Pn (Pn)	2017/09/03 03:31:03	0.1	12.3	-0.4	8.4 km/s	7090 m/s	2.25	32.8	7672.3	2755.32
125946868	KSRS	4.0	Pg (P)	2017/09/03 03:31:13	-0.1	14.8	2.2	6.3 km/s	6106 m/s				1970.83
125957545	KSRS	4.0	Sn (Sn)	2017/09/03 03:31:50	-1.2	354.7	-17.9	4.2 km/s	4041 m/s				838.50
125944257	KSRS	4.0	Lg (Sx)	2017/09/03 03:32:07	0.4	12.5	-0.1	3.8 km/s	3488 m/s	1.12	6.1	6.3	1418.74
125944505	KSRS	4.0	PKIKP (P)	2017/09/03 03:46:34	-1.6	309.7	-62.9	145.7 km/s	445 m/s	1.50	50.8	12.9	4.37
125945341	KLR	8.1	Pn (Pn)	2017/09/03 03:32:01	0.9	188.5	-6.0	8.8 km/s	7525 m/s			1593.6	742.21
125945348	KLR	8.1	Lg (Pg)	2017/09/03 03:34:18	-1.0	289.6	95.0	5.4 km/s	3512 m/s			4.2	1705.65
126007283	KLR	8.1	PKIKP (P)	2017/09/03 03:46:34	-1.4	296.6	102.0	24.6 km/s	911 m/s				2.86
125945356	JNU	8.3	Pn (P)	2017/09/03 03:32:02	0.0	325.1	-25.3	39.0 km/s	7584 m/s			676.9	151.11
125957656	JNU	8.3	Sn (Sn)	2017/09/03 03:33:39	0.3	352.8	2.5	6.2 km/s	4238 m/s				54.98
125957657	JNU	8.3	Lg (Lg)	2017/09/03 03:34:27	2.4	283.2	-67.2	6.4 km/s	3467 m/s				49.31
126007465	JNU	8.3	LR (LR)	2017/09/03 03:35:07	5.7	350.0	-0.4	3.0 km/s	3013 m/s				8497.19
126007520	MJAR	8.6	LR (LR)	2017/09/03 03:35:01	16.5	334.5	28.0	3.2 km/s	3181 m/s				11797.18
125944268	MJAR	8.6	Pn (Pn)	2017/09/03 03:32:06	-0.3	303.2	-3.3	8.0 km/s	7623 m/s	2.25	8.2	192.7	58.91
125944526	MJAR	8.6	PKIKP (Sx)	2017/09/03 03:46:34	-2.2	242.2	-64.3	42.6 km/s	965 m/s	2.25	5.2	8.4	1.44

Seismic signals

Infrasound signals

Infrasound from aftershock

DTK-GPMCC

I47ZA, South Africa

I14CL, Juan Fernandez

I55US, Antarctica

I04AU, Australia

2001 – 2018: 50 IMS infrasound stations certified out of 60

Latest certification: I20EC, Ecuador (December 2017)

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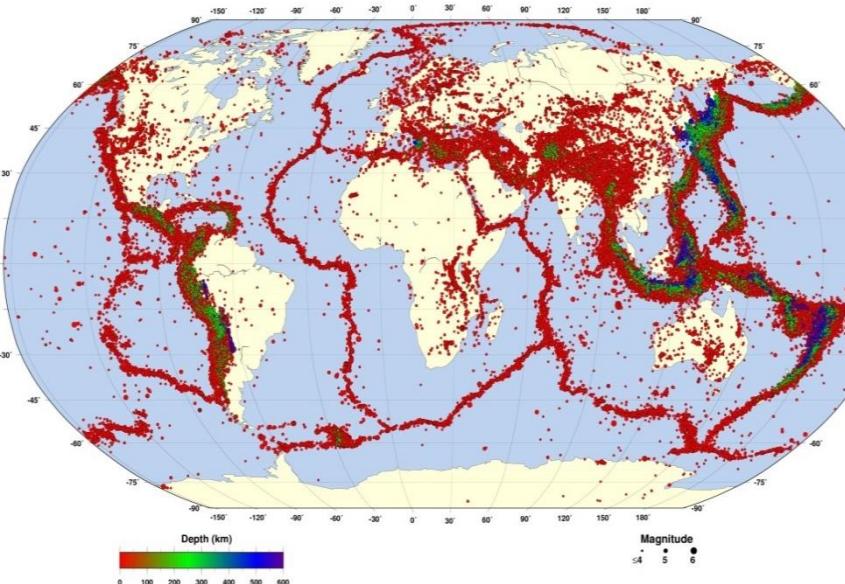
IDC bulletins for waveform technologies (Seismic/Hydroacoustic/Infrasound), event location for period:
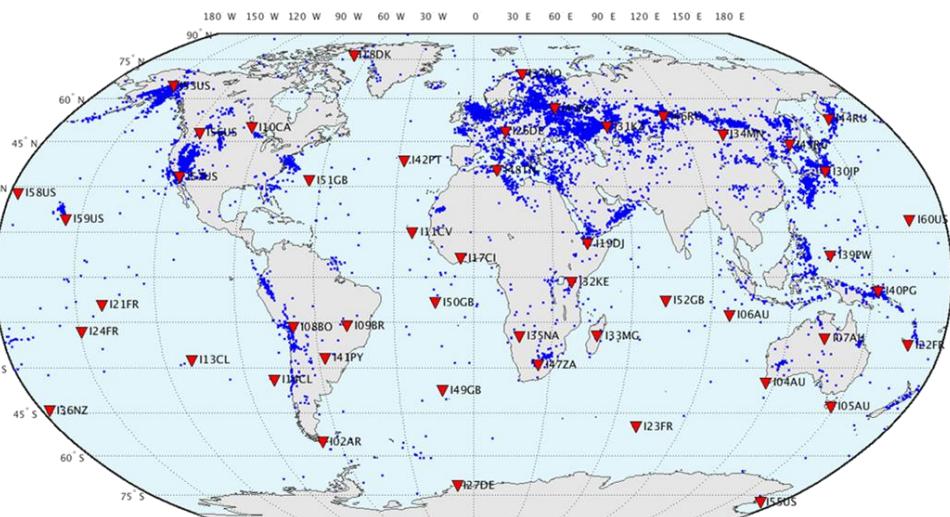
Since February 2000

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

Since February 2010

Over 580,000 REB events
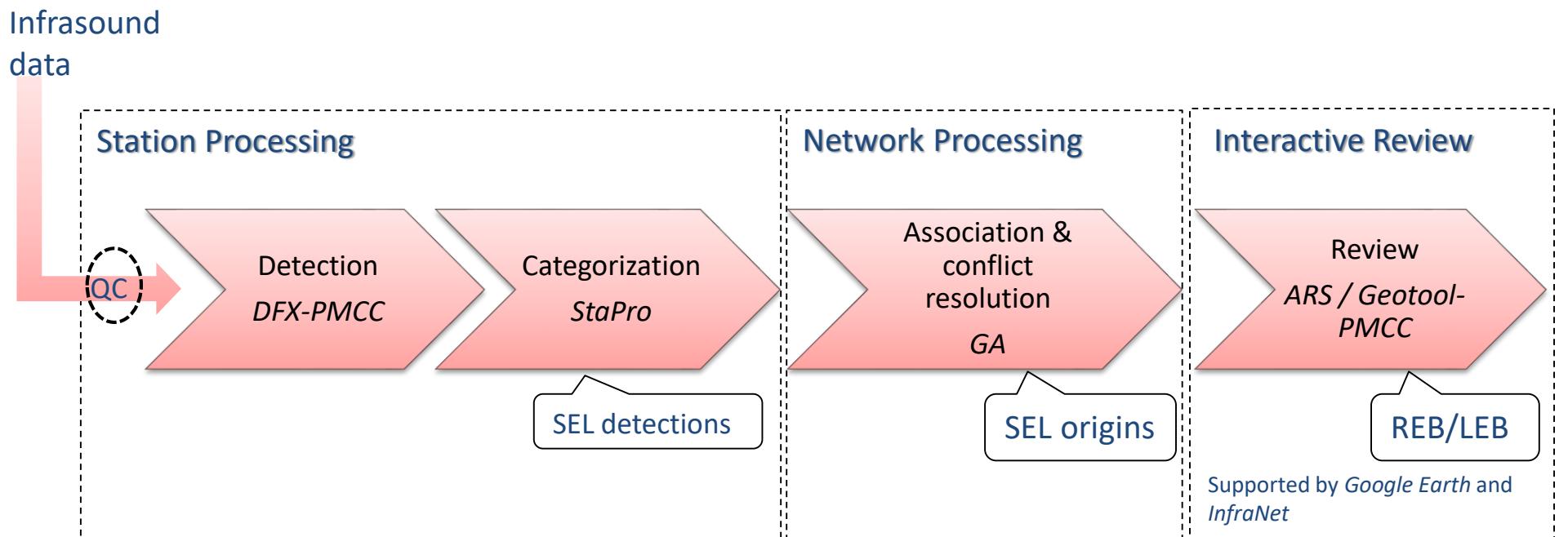
Over 22,000 LEB infrasound events

REB and LEB are IDC products. REB: Reviewed Event Bulletins – LEB: Late Event Bulletins
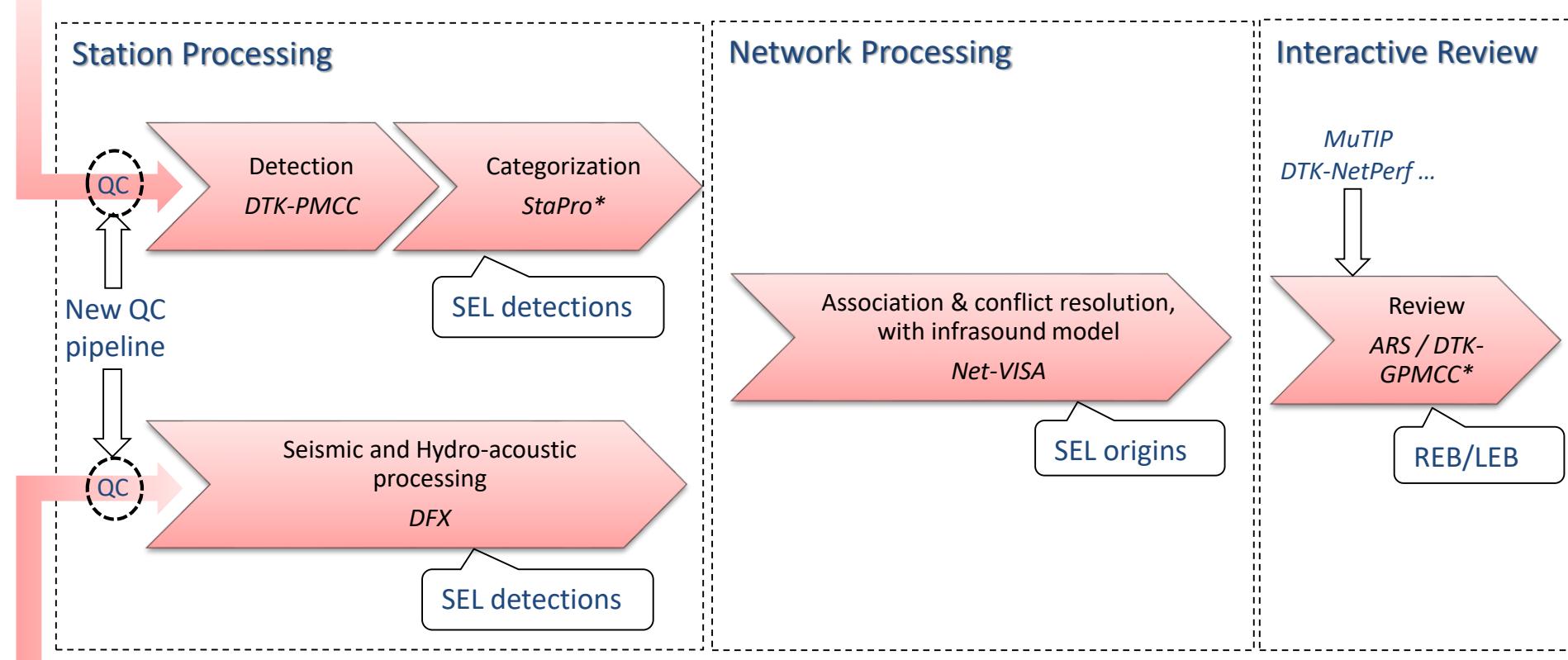
Processing pipeline currently in IDC Operational (and test) environment

Infrasound data

QC

Station Processing

Detection
DFX-PMCC

Categorization
StaPro

SEL detections

Network Processing

Association & conflict resolution
GA

SEL origins

Interactive Review

Review
ARS / Geotool-PMCC

REB/LEB

Supported by *Google Earth* and *InfraNet*

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Infrasound data

Station Processing

QC

New QC pipeline

Detection
DTK-PMCC

Categorization
StaPro*

SEL detections

QC

Seismic and Hydro-acoustic processing
DFX

SEL detections

Seismic & Hydro-acoustic data

Network Processing

Association & conflict resolution, with infrasound model
Net-VISA

SEL origins

Interactive Review

MuTIP
DTK-NetPerf …

Review
ARS / DTK-GPMCC*

REB/LEB

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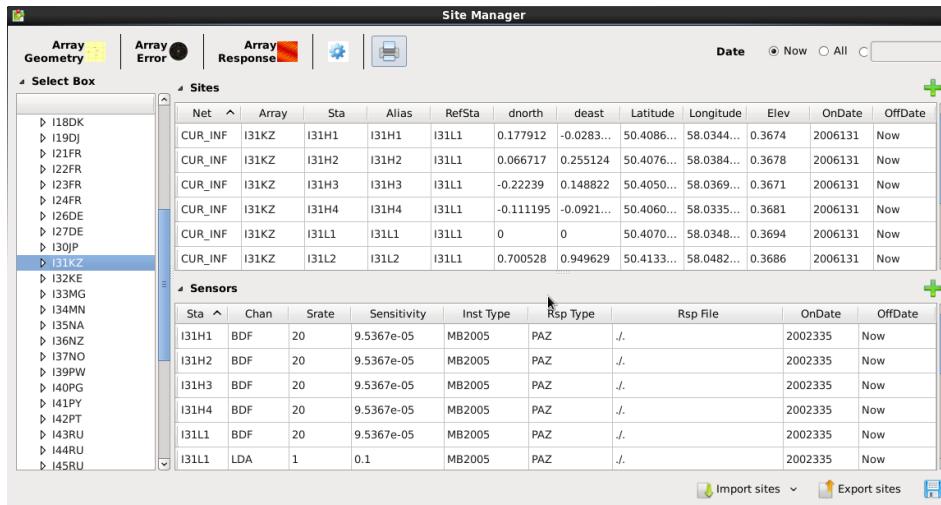
DTK-(G)PMCC – software evolutions

[Cansi, GRL, 1995]
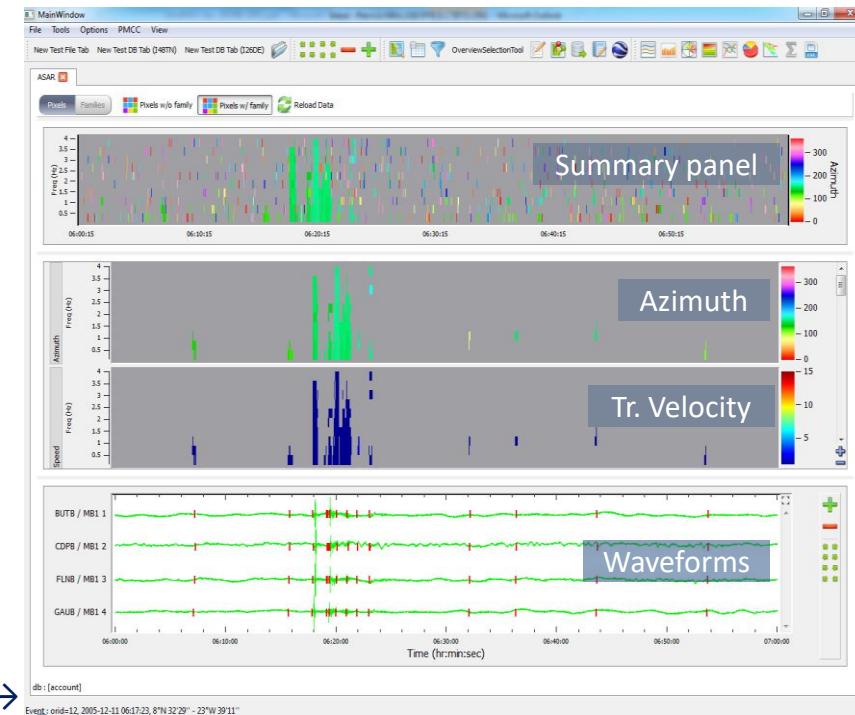
- PMCC* algorithm reorganization to improve modularity and flexibility - *Re-engineering*
- method incorporate a 3D algorithm to allow for accurate computation of wave attributes for non-planar arrays - *Re-engineering*
- DTK-PMCC execution for distributed computation on multi-core computers - *IDC requirement*
- 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

↑DTK-GPMCC station manager

DTK-GPMCC main widow →

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

3. Operational Testing (2016-2018)

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
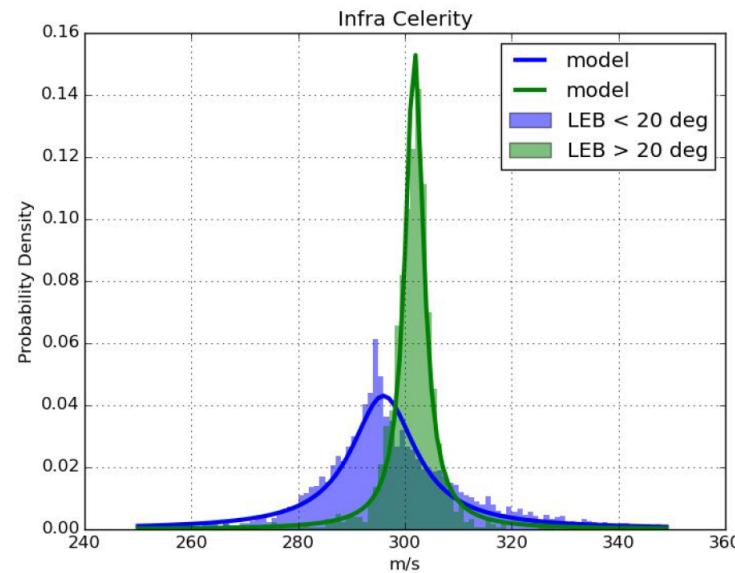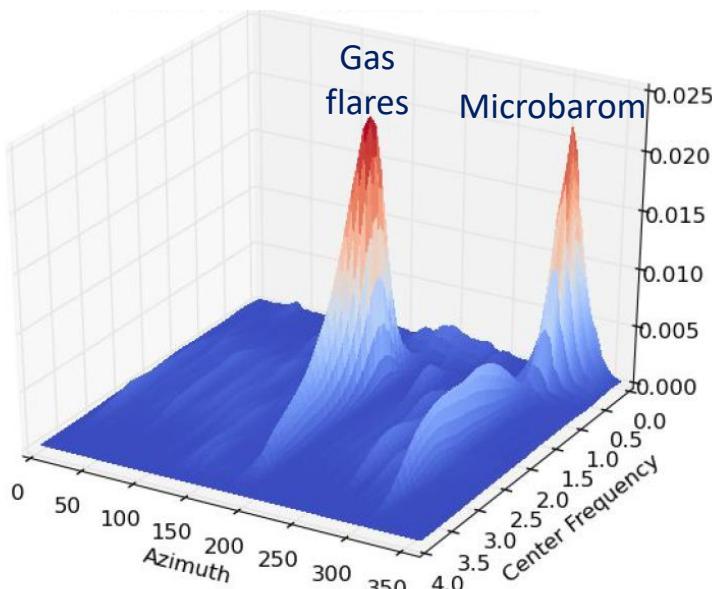
Static prior

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

Comparison of performances between GA* (SEL3) and NET-VISA implementation over 2013 data (offline)

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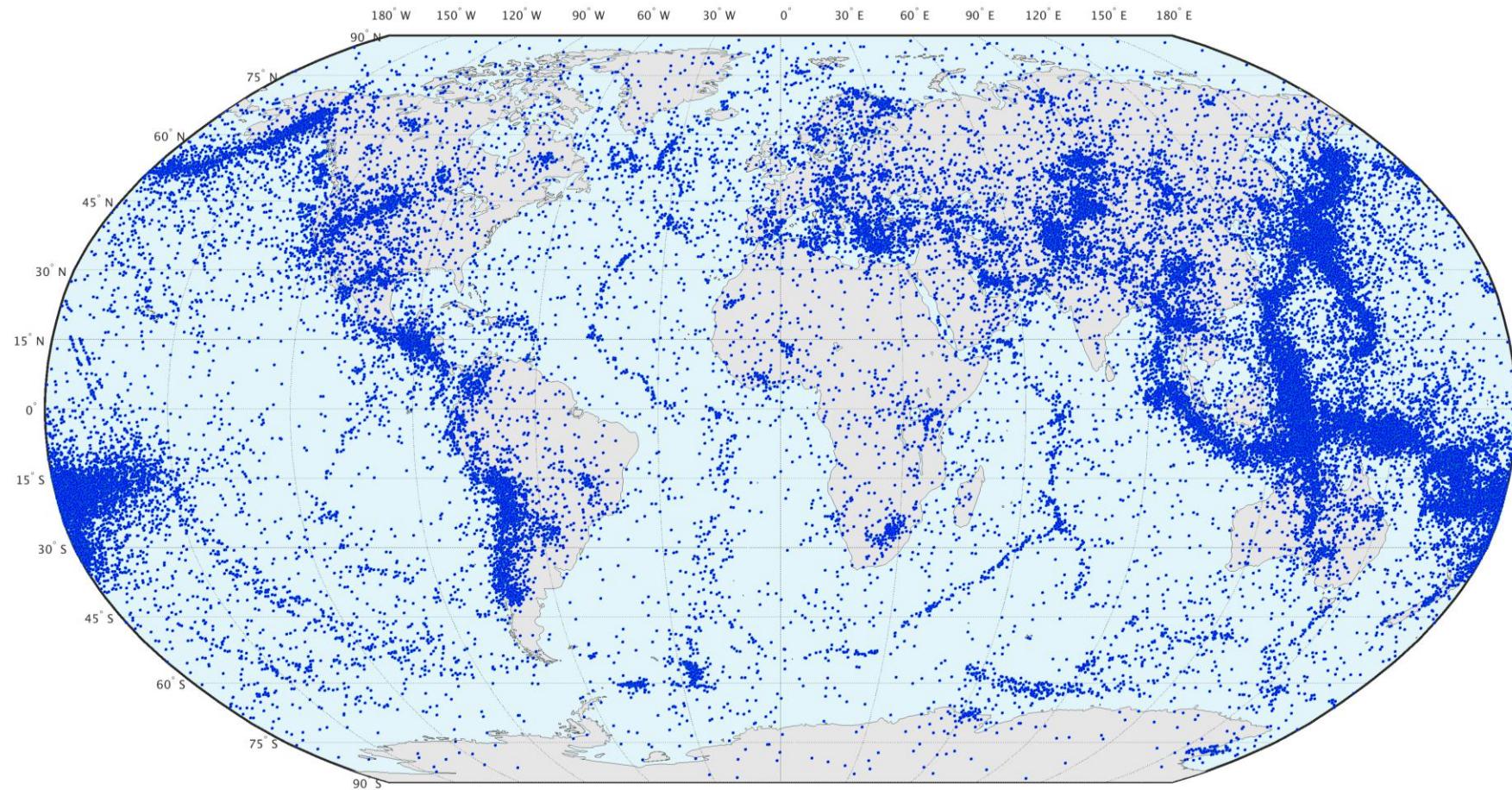
- Reducing spurious seismo-acoustic associations
- Improving false alarm rate & reducing analyst workload

*Global Association   (with NET-VISA 2.2.48)

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
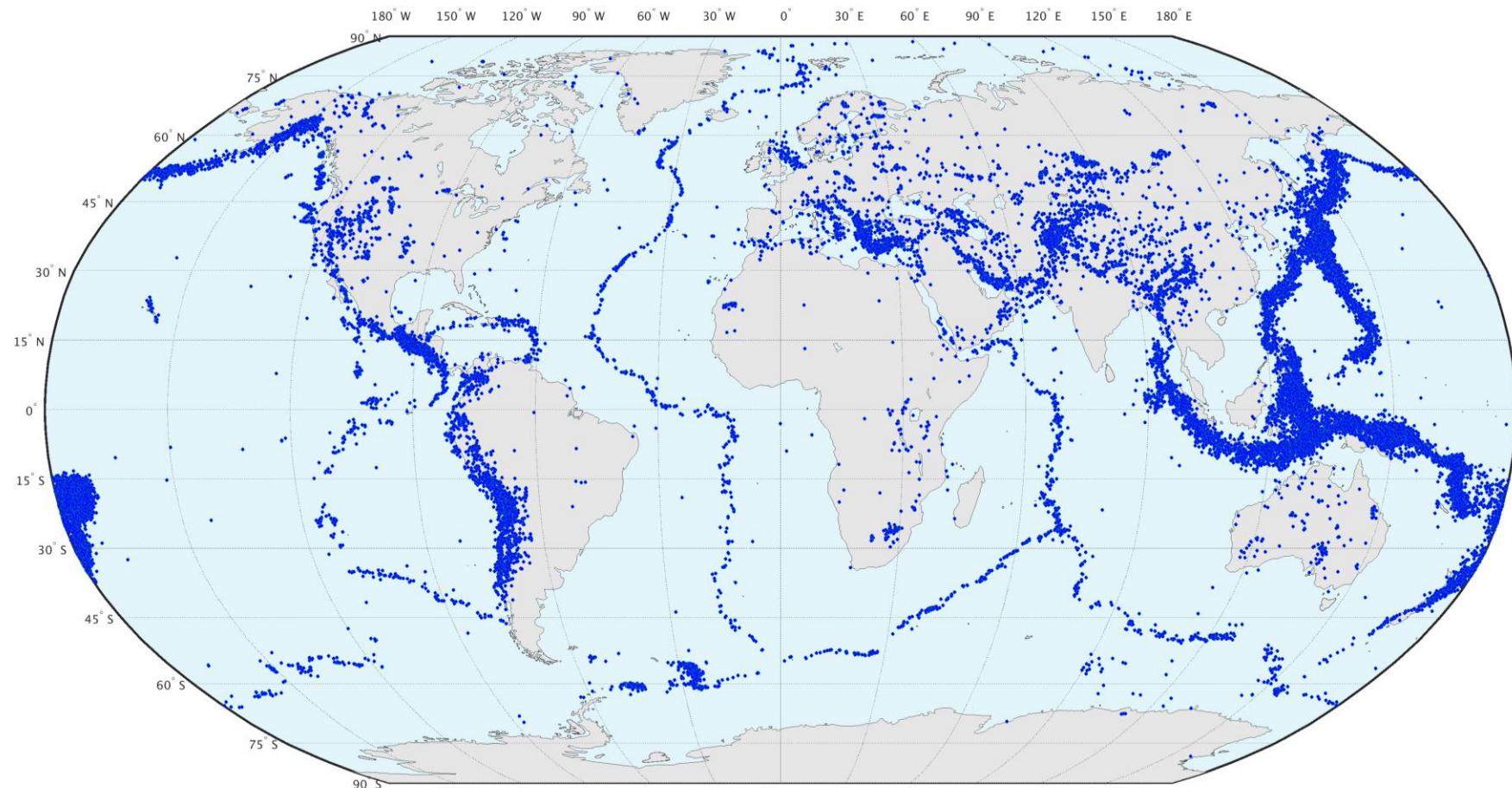
SEL3 bulletin 2013 54,327 events
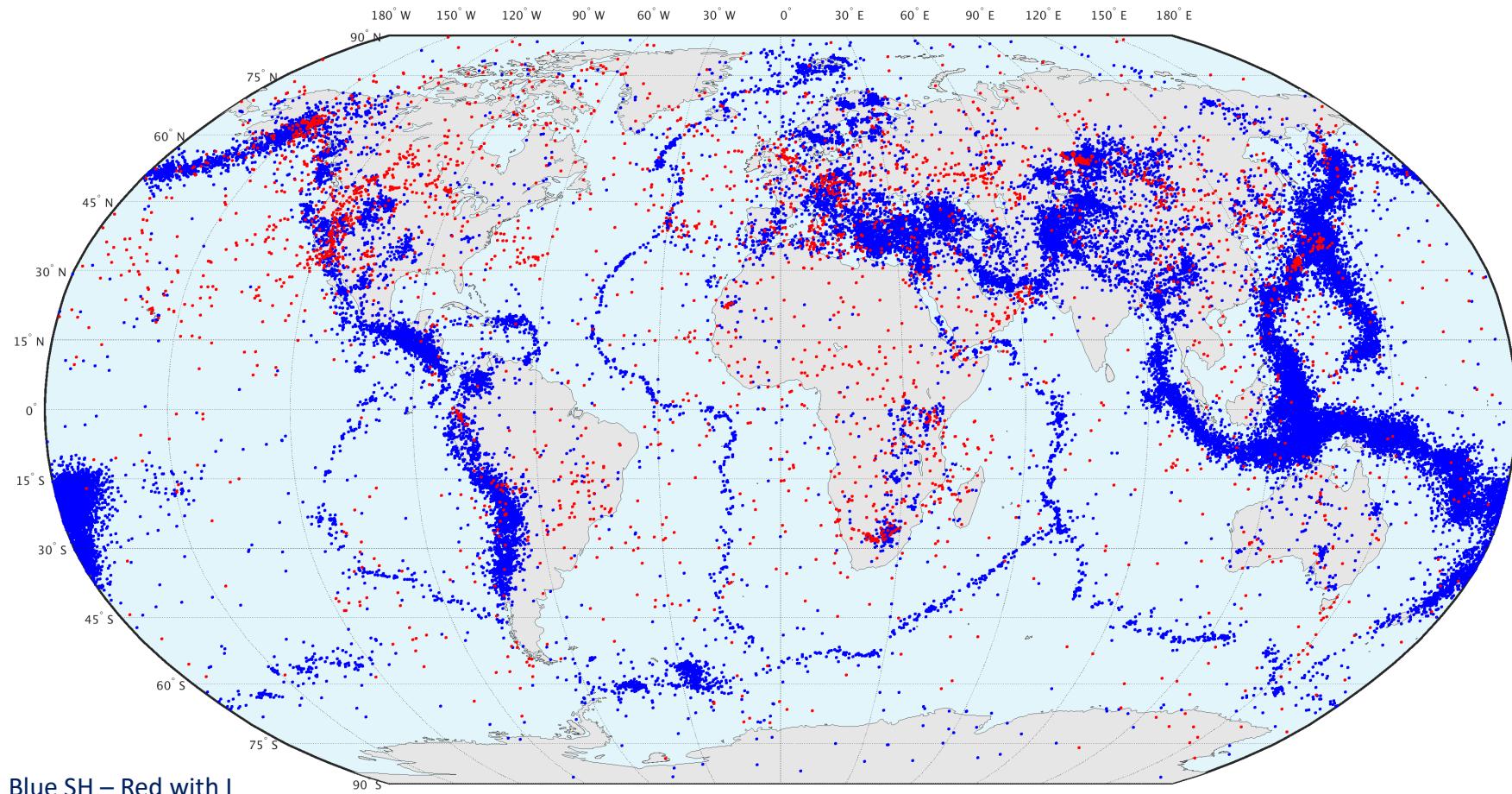
LEB bulletin for 2013 for all waveform technologies: 42,782 events

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Blue SH – Red with I
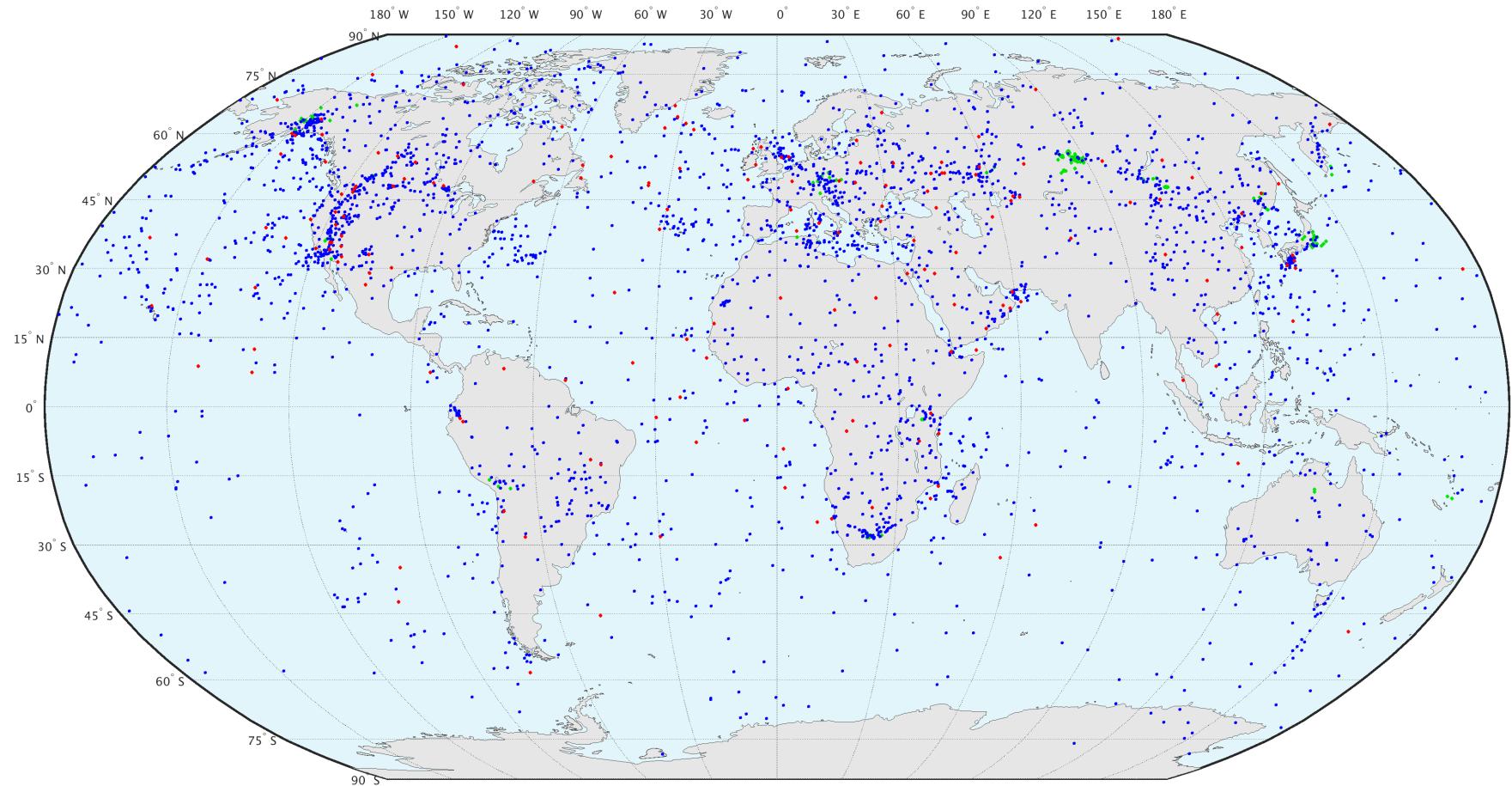
(with NET-VISA 2.2.48)

NET-VISA bulletin for 2013: 62,487 events total, with 3,383 events containing infrasound phases
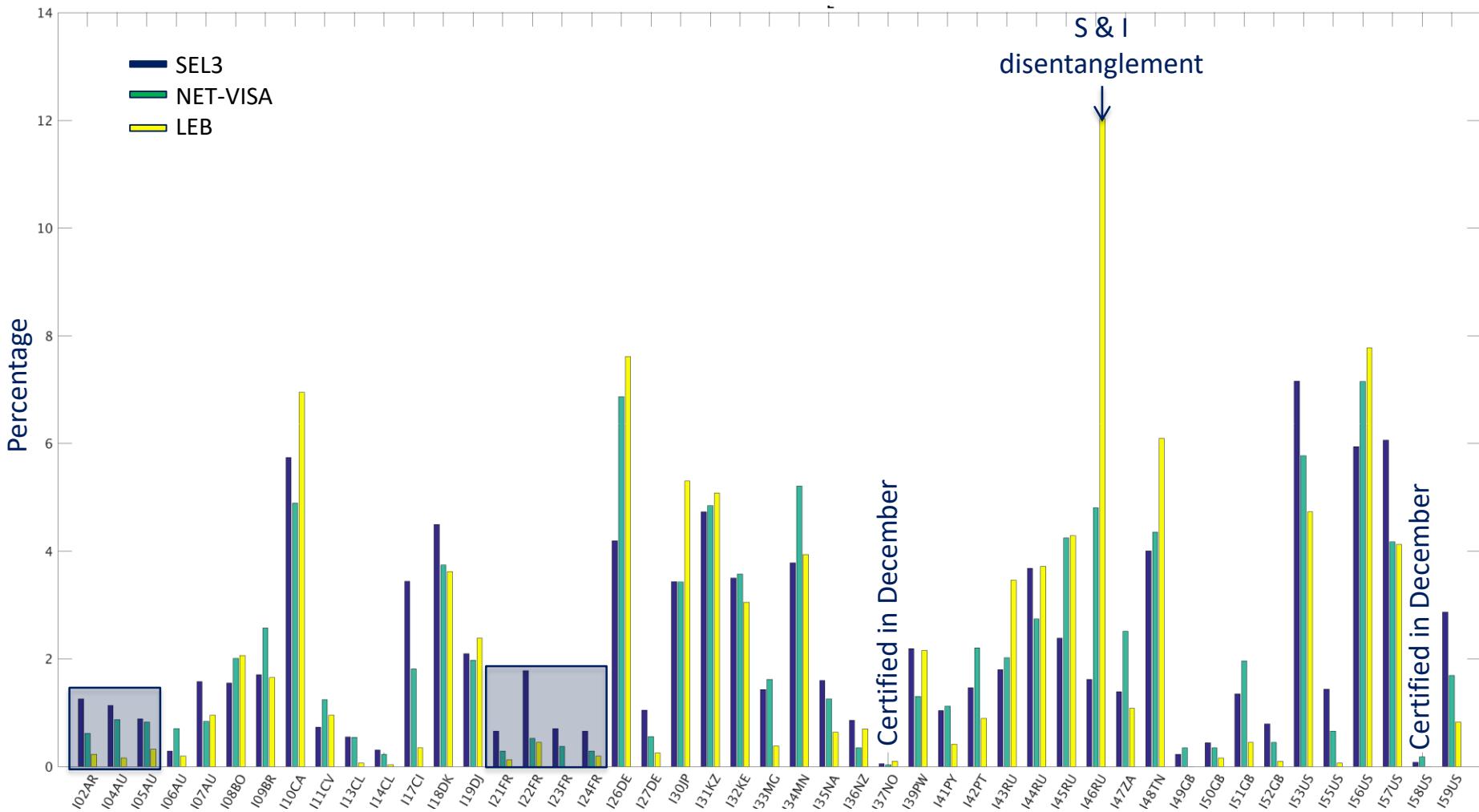
Green 1I – Blue 2I – Red at least 3I

(with NET-VISA 2.2.48)

NET-VISA bulletin 2013 Events with infrasound phases 3,383 events
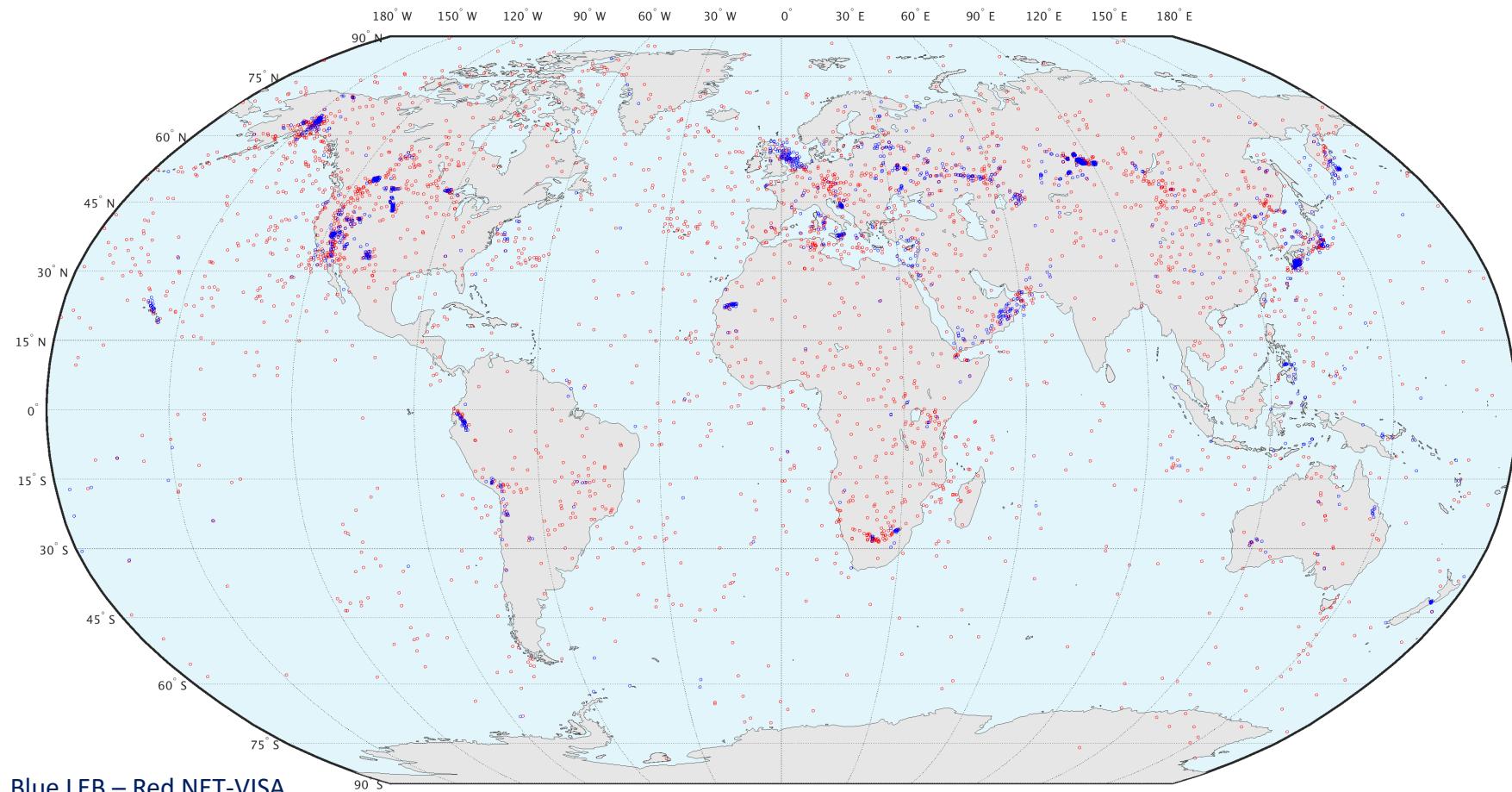
→ **Overall better agreement between NET-VISA and LEB**

(with NET-VISA 2.2.48)

Blue LEB – Red NET-VISA

(with NET-VISA 2.2.48)

NET-VISA bulletin 2013 Events with infrasound phases 3,083 events vs 1,767 LEBs

Station processing progresses
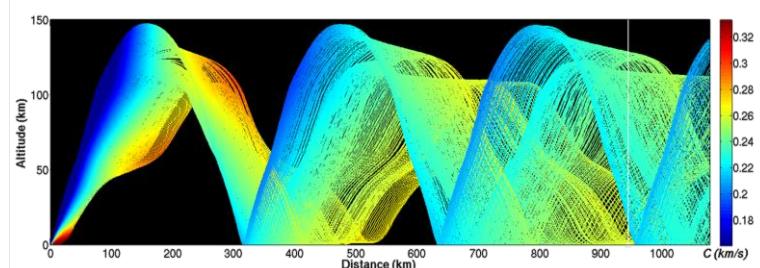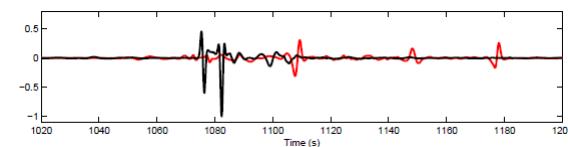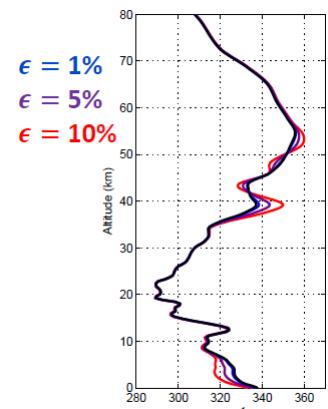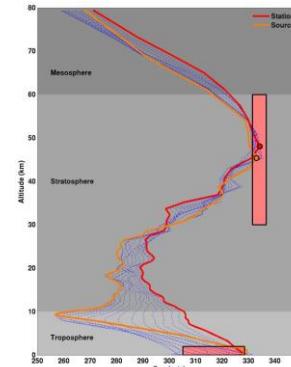
→ Implementation into IDC Operation

→ 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
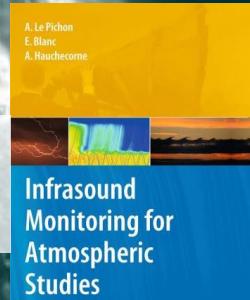
→ *Benchmarking* of propagation tools (possible project)

→ Needed for special event and interactive review analysis

→ To support network processing enhancements and performance objectives

the comprehensive nuclear-test-ban treaty
putting an end to nuclear test explosions

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.
 The IMS Infrasound Network: Status and State-of-the-Art Design, Marty et al.
 Advances in operational processing at the International Data Center, Mialle et al.

Blue SEL3 – Red LEB

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