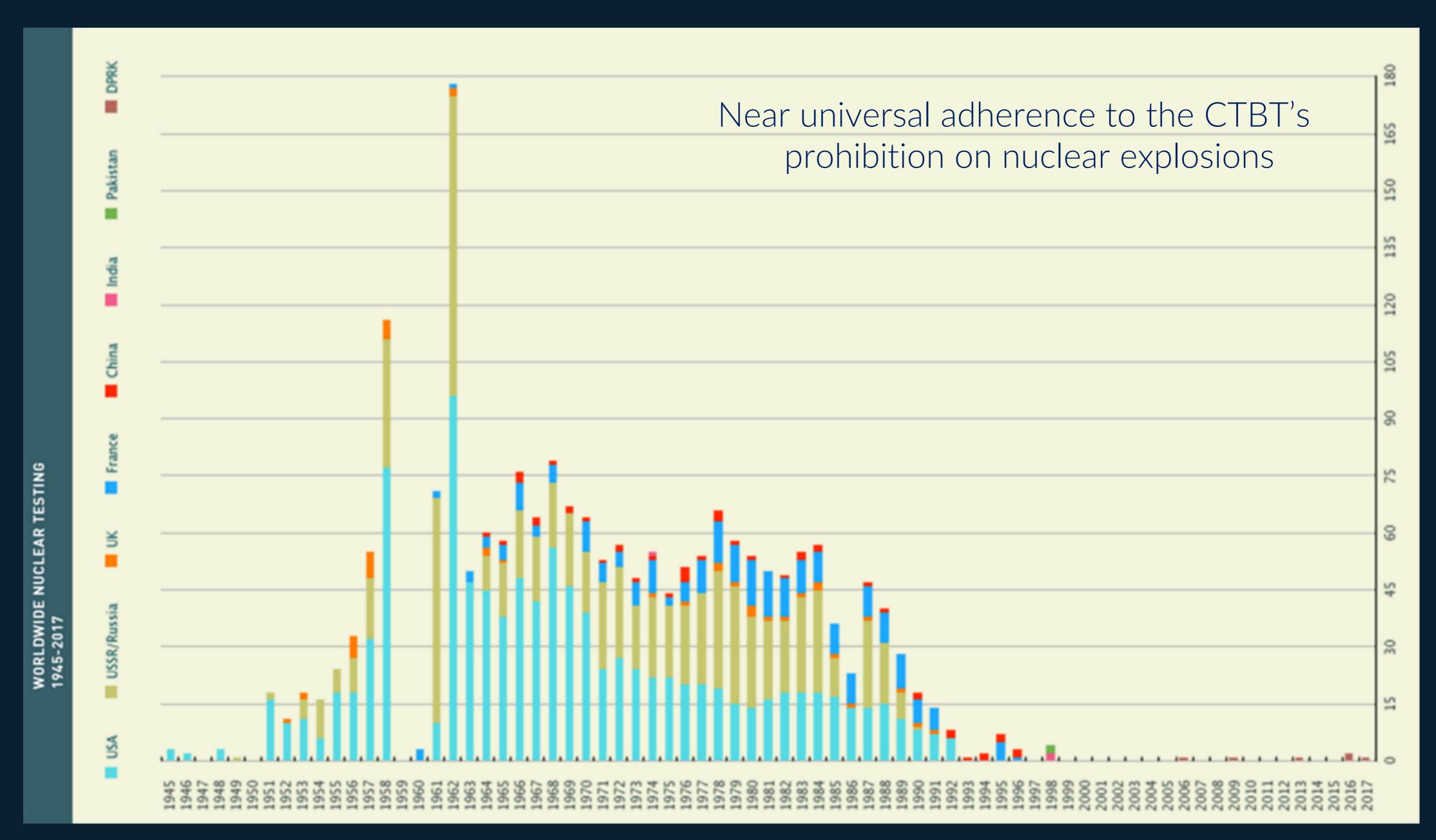


Putting an end to nuclear explosions through science: Infrasound technology, an overview

Pierrick Mialle<sup>1</sup> and CTBTO colleagues

<sup>1</sup> International Data Centre

# Worldwide Nuclear Testing 1945 - 2017



# CTBTO, at a glance





**Staff** over 260



**Headquarters**Vienna



5 Divisions

Administration
Legal and External Relations
International Monitoring System
International Data Centre
On-Site Inspections

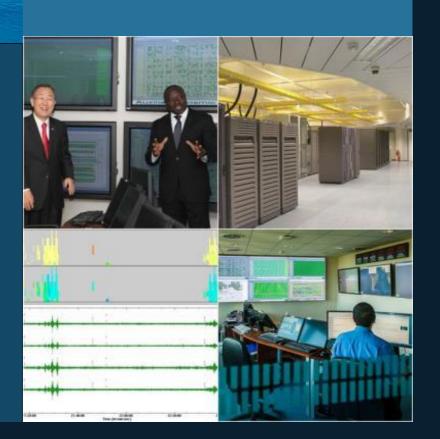




International
Staff from 70
countries



Budget 120.000.000 Euro









# **4** Monitoring Technologies



Seismic: 170
Listening underground



Hydroacoustic: 11

Listening under water



Infrasound: 60
Listening above ground

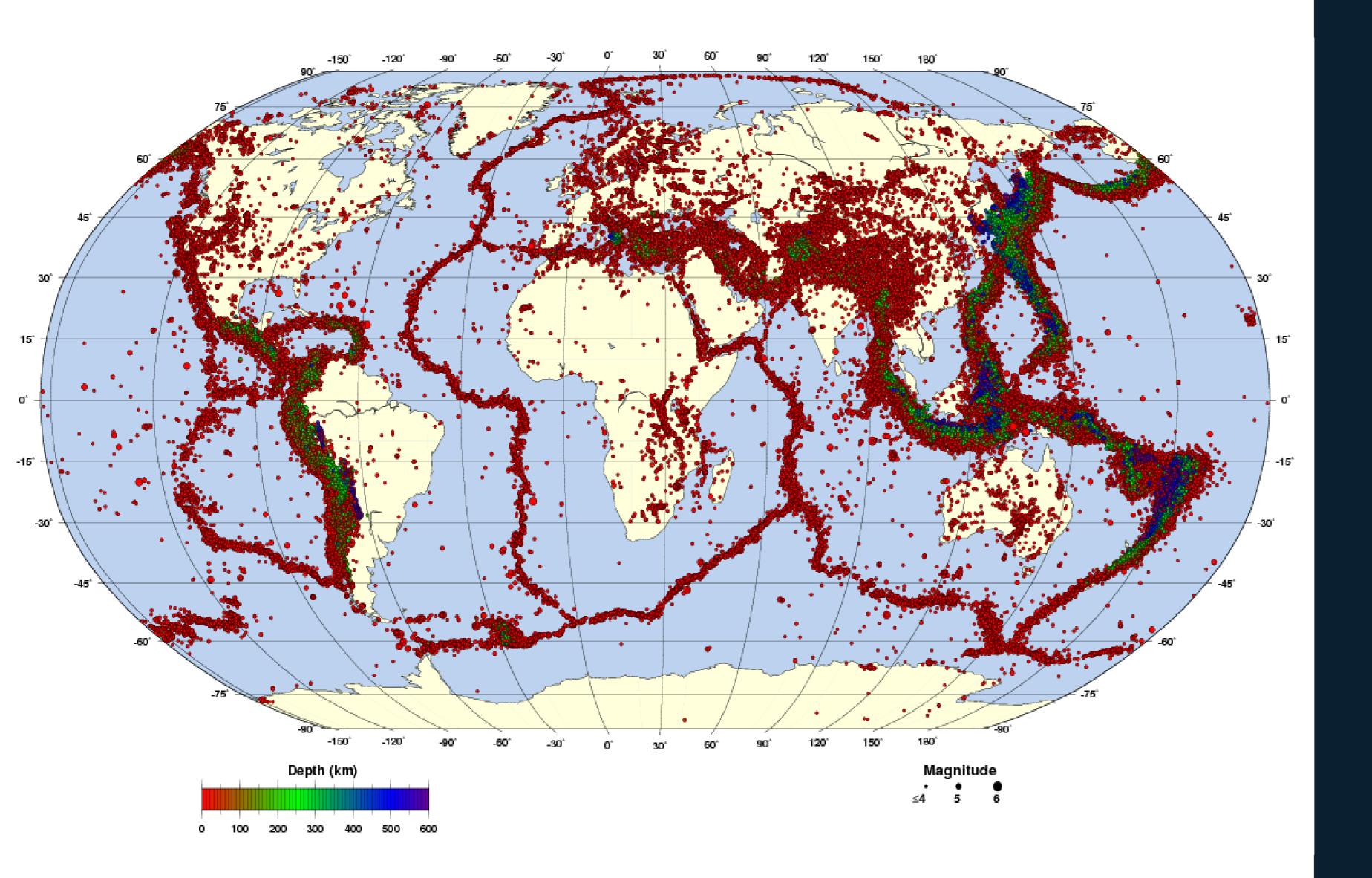


Radionuclide: 80

Sniffing for radiation









# Over 740,000

Seismic-Acoustic events located by the International Data Centre since February 2000

# 6<sup>th</sup> announced nuclear test by Democratic People's Republic of Korea (DPRK) on 3 September 2017

## 2017 event information (REB)

Date: 3 September 2017

Origin Time: 03:30:01.08 UTC  $\pm$  0.18 seconds

Latitude: 41.3205 degrees North

Longitude: 129.0349 degrees East

Approximate Location Accuracy:  $\pm 6.7 \,\mathrm{km} \,(109 \,\mathrm{km}^2)$ 

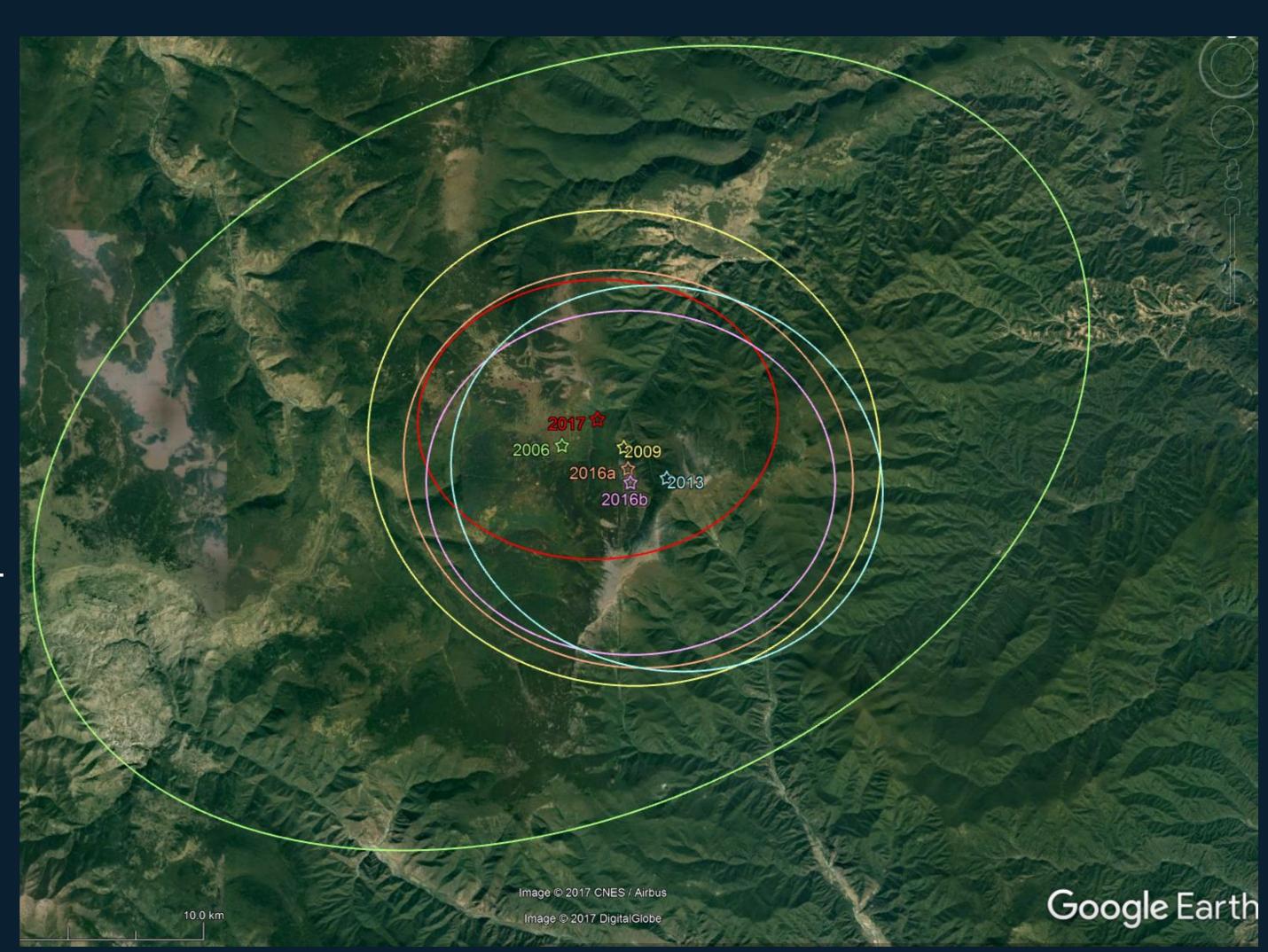
Depth: 0.0 km (fixed)

Body Wave Magnitude mb (IDC): 6.07

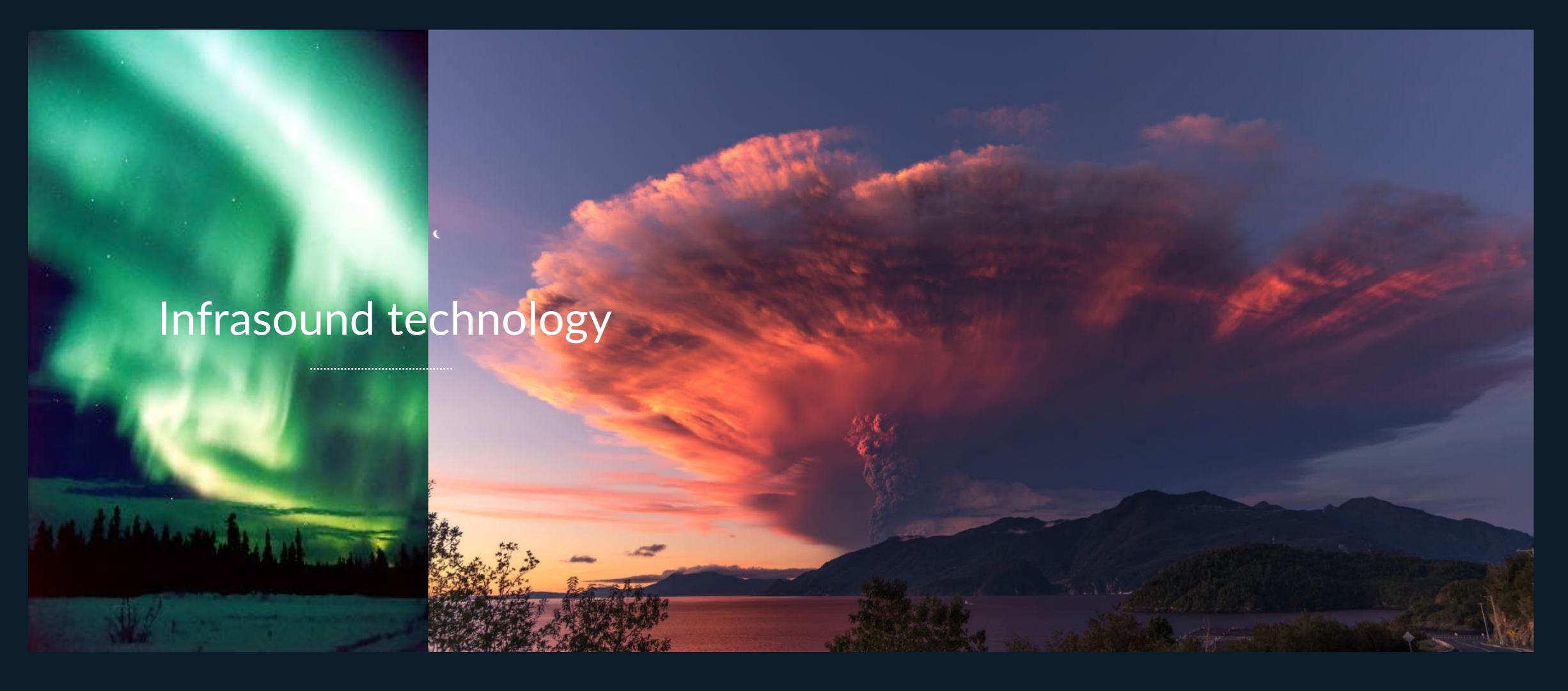
Number of Seismic-Acoustic Stations Used: 125

Issued: 5 September 2017 17:40:22 UTC (within Entry-

Into-Force timeline)

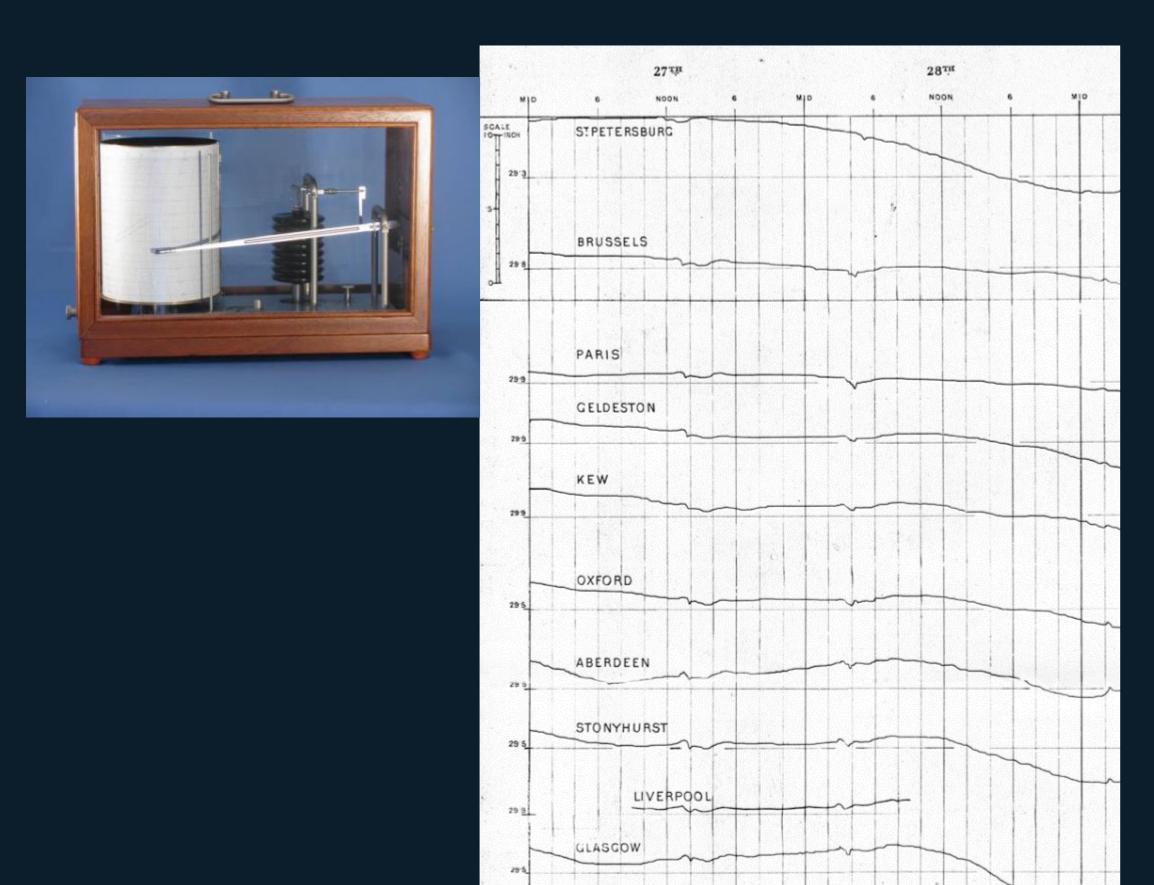




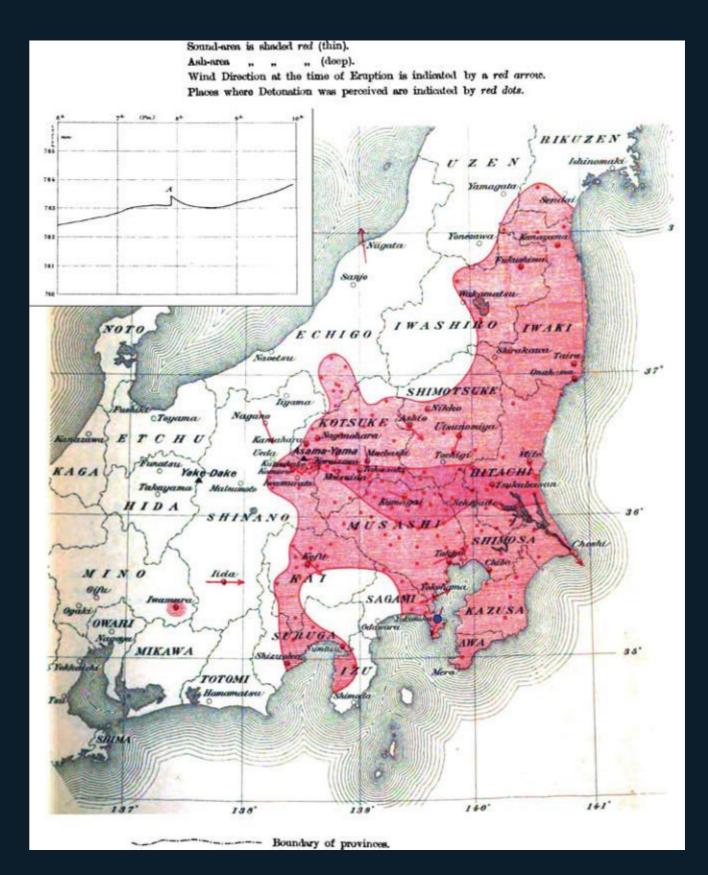


#### What is infrasound?





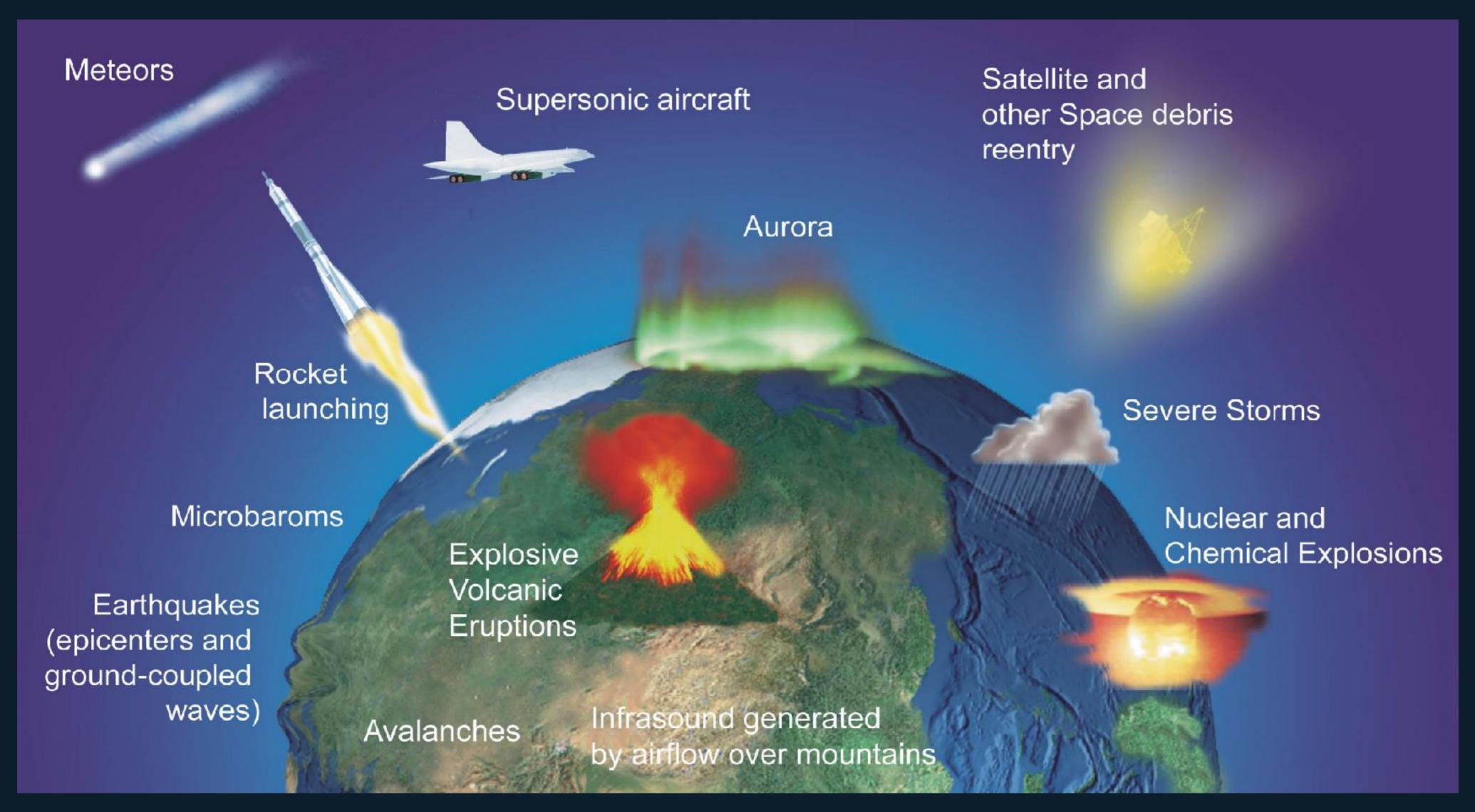




Zone of audibility of "detonation" sound from a 7 December 1909 explosion of Asamayama, Japan (Figures reproduced and modified from Omori 1912)

## Infrasound technology – Sources



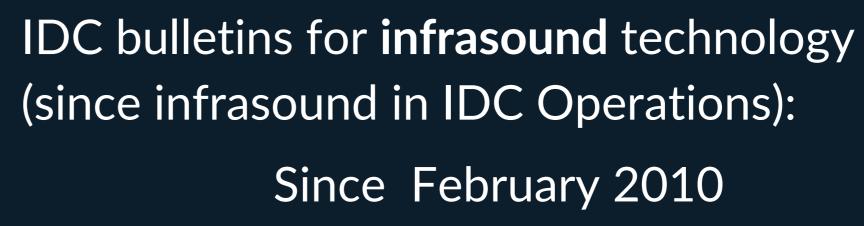


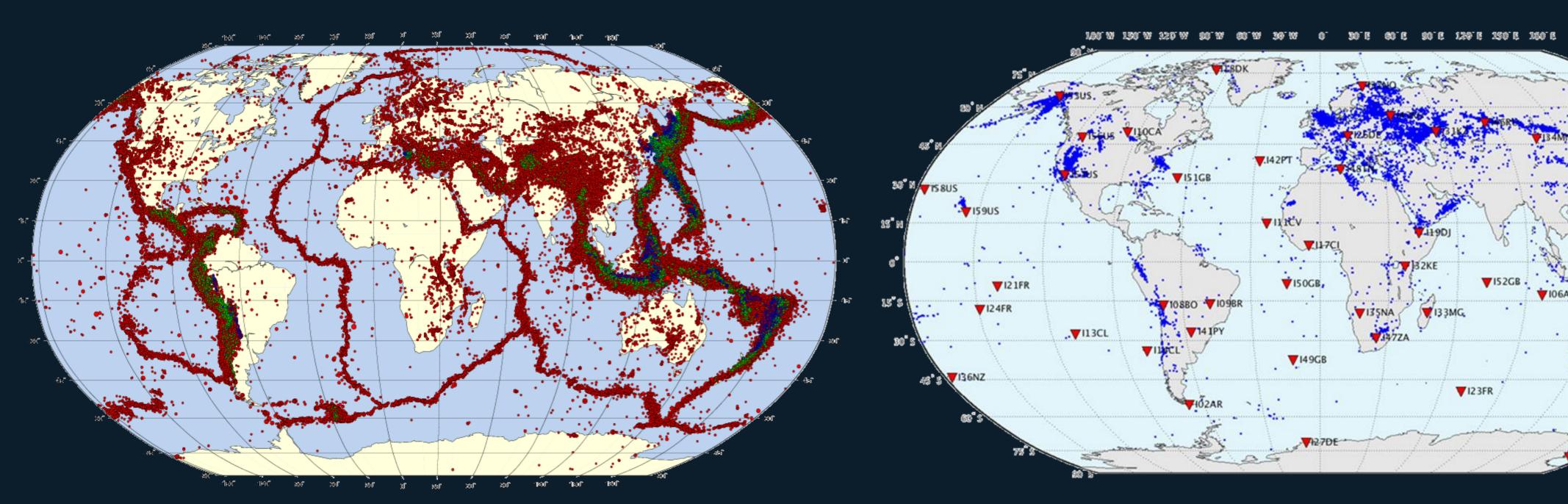
#### **IDC** bulletin – Event Location



IDC bulletins for waveform technologies (Seismic / Hydro-acoustic / Infrasound):

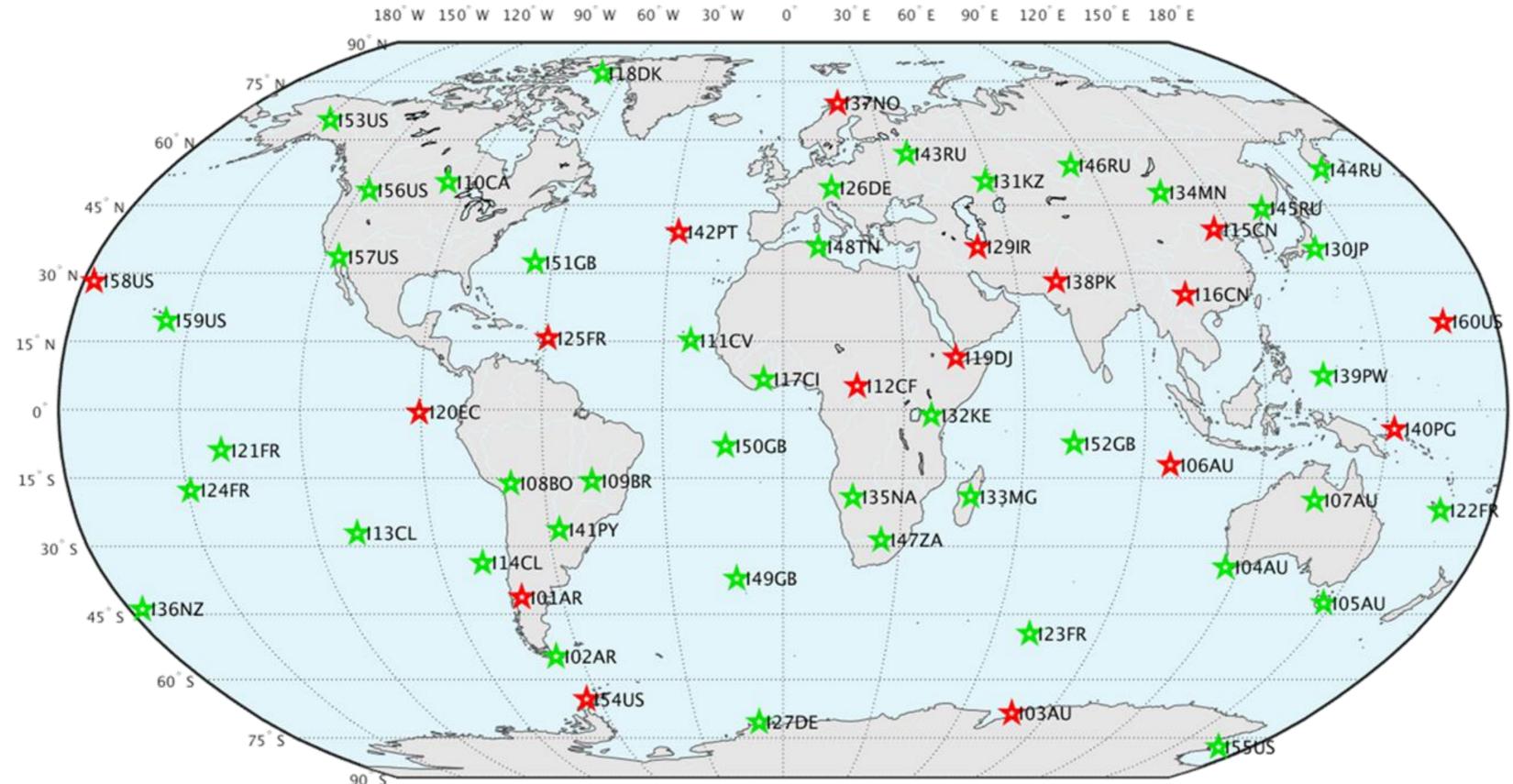
Since February 2000





> 740,000 REB events >880,000 LEB (& 580,000 since 02/2010 >130 events/day)

> 45,000 LEB infrasound events 9.9 LEB events/day with infrasound association



# 2010

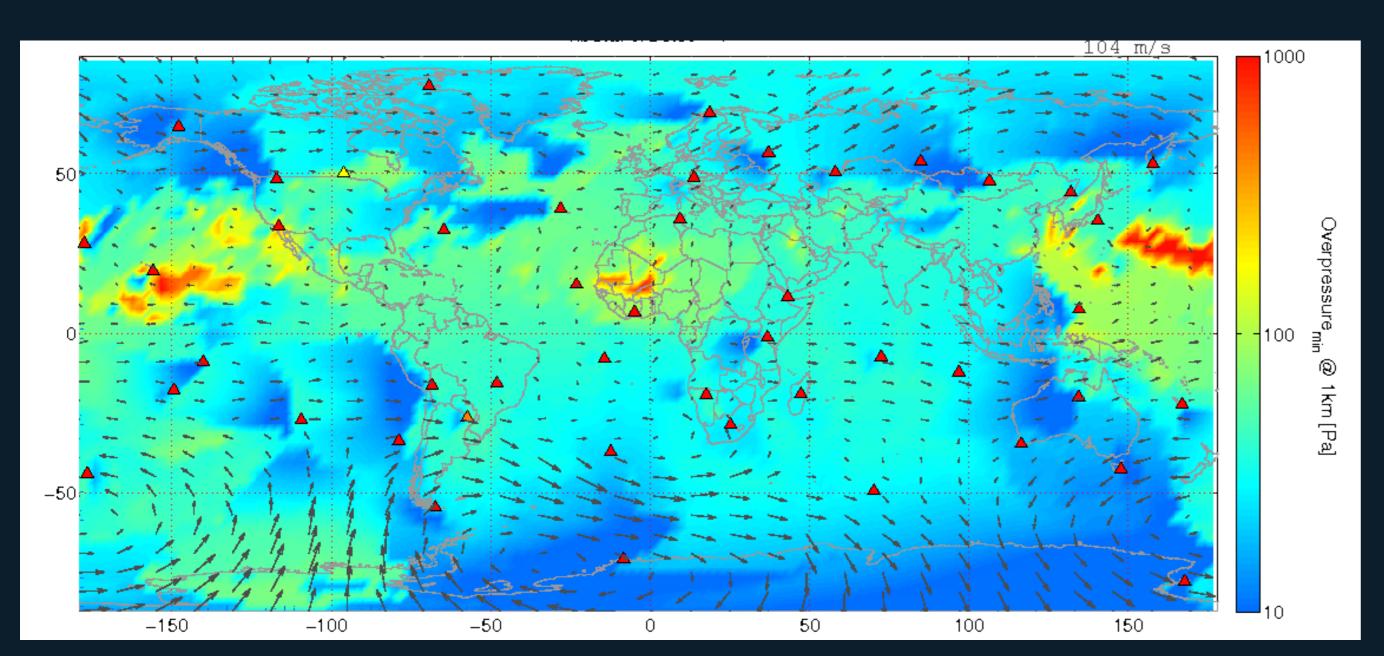
# Introduction of infrasound technology in IDC bulletins

## IDC infrasound – 2013, an interesting year

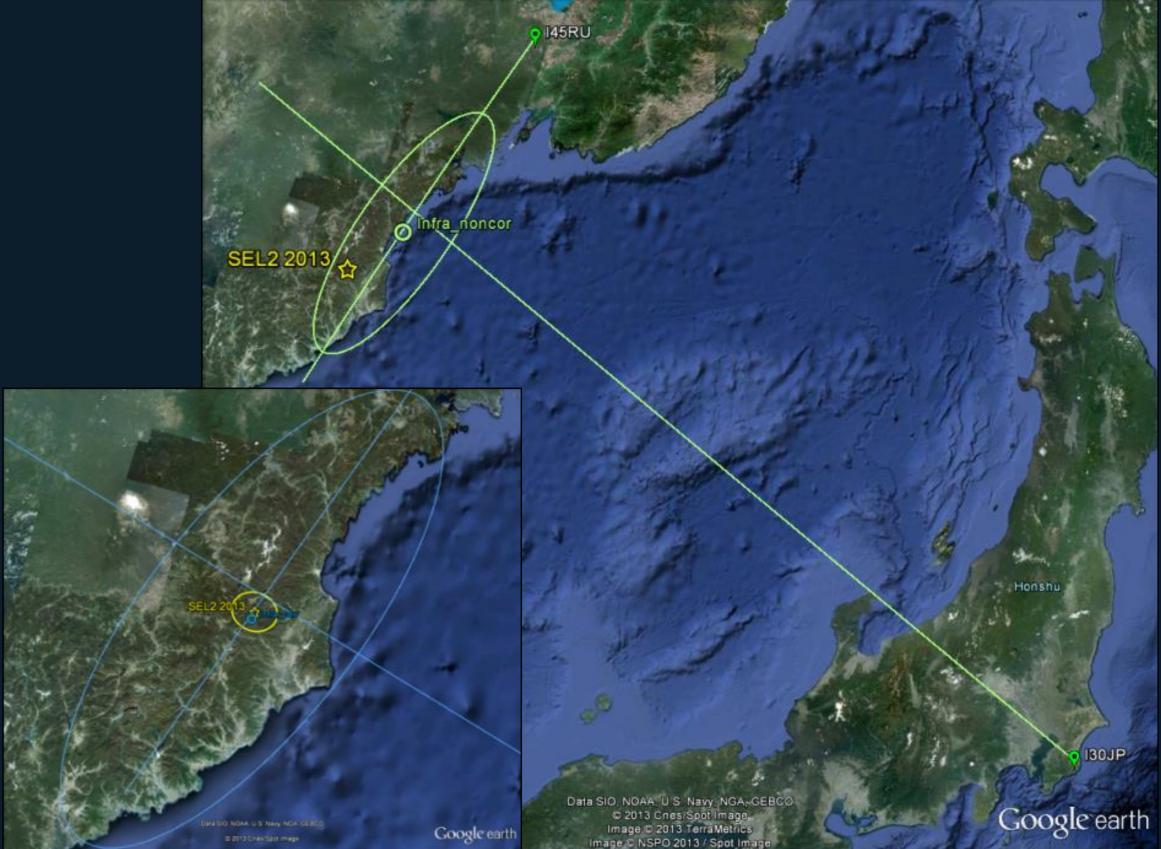


#### 2013 Monitoring production

- Network performance and network maintenance need QC of the whole system
- 3<sup>rd</sup> announced nuclear test by DPRK, 12 February 2013



Infrasound technology Network Performance – highly dynamic



Infrasound detection of 2013 DPRK announced test

ctbto.org

## IDC infrasound – 2013, an interesting year



## 2013 Monitoring production

- Network performance and network maintenance need QC of the whole system
- 3<sup>rd</sup> announced nuclear test by DPRK, 12 February 2013
- Chelyabinsk superbolide, 15 February 2013
  - ... The biggest infrasound event recorded by IMS... at the time

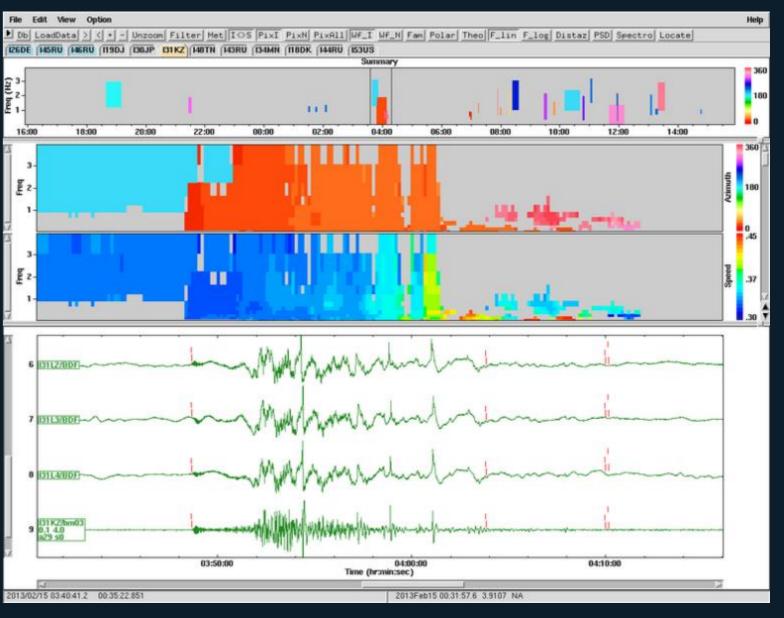


# Infrasound – Civil & Scientific Applications Chelyabinsk Fireball – 2013/02/15





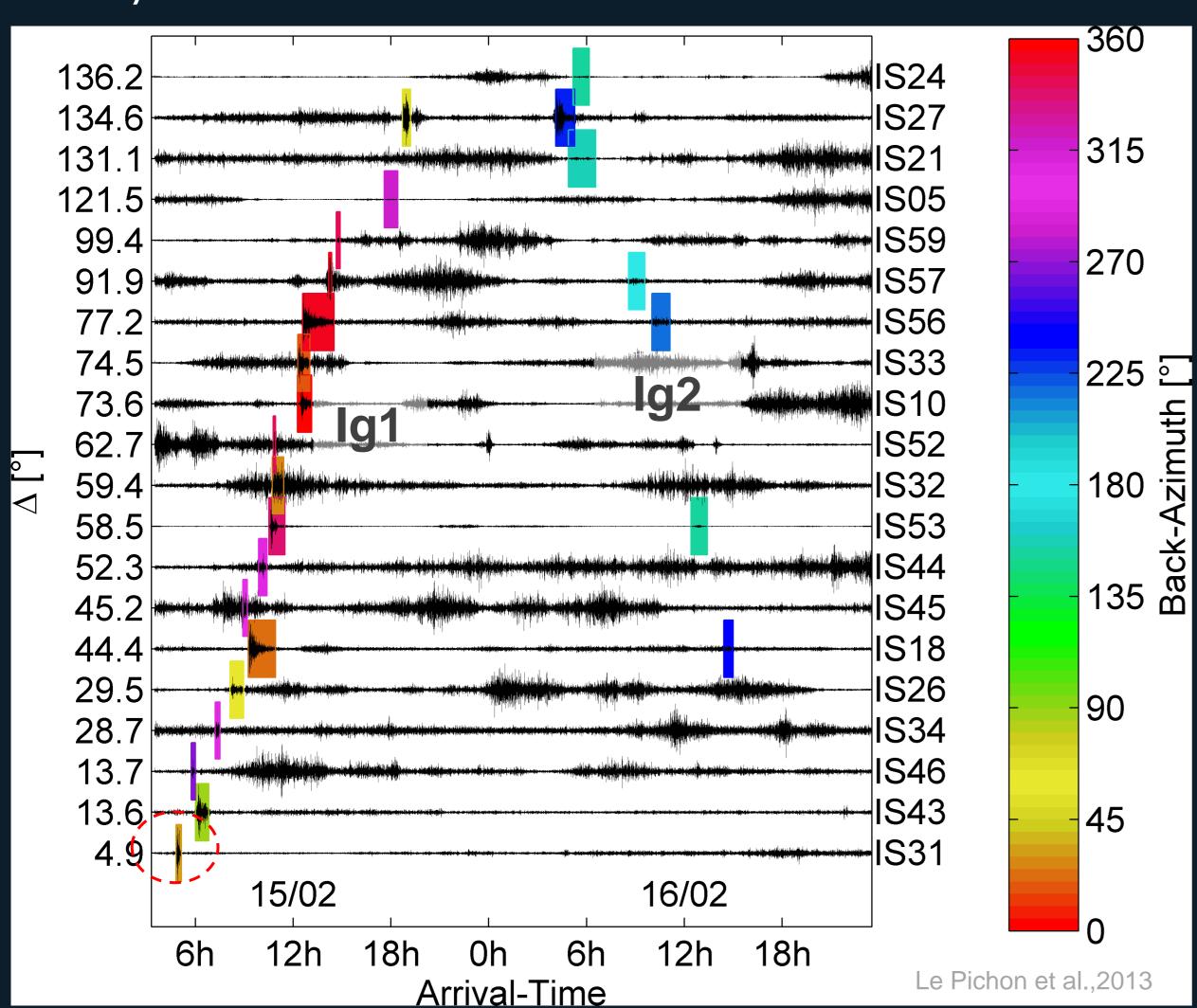




Detection by I31KZ (Kazakhstan)

Fireball detected by half of the IMS infrasound network operational at the time of the event (20 out of 42 stations)

# Infrasound – Civil & Scientific Applications Chelyabinsk Fireball – 2013/02/15





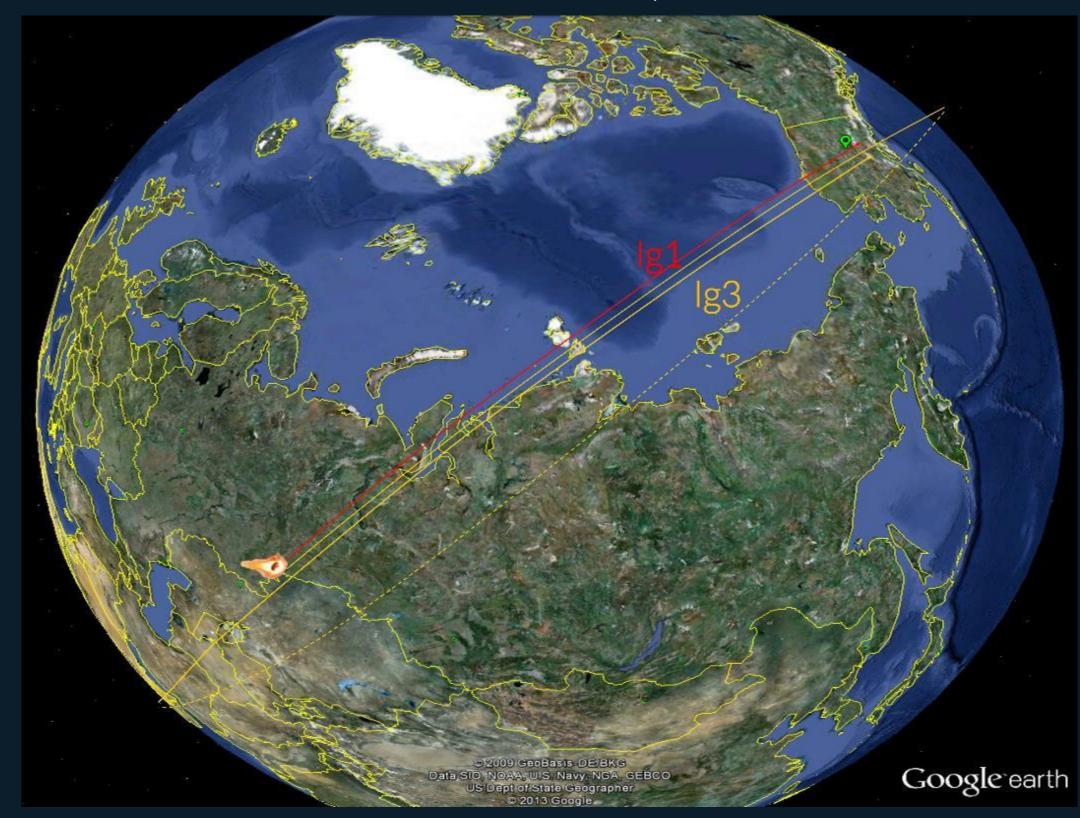




#### Detection summary:

- 20 observing IMS infrasound stations
- 30 detections due to global multi-path
- Multiple circumnavigation

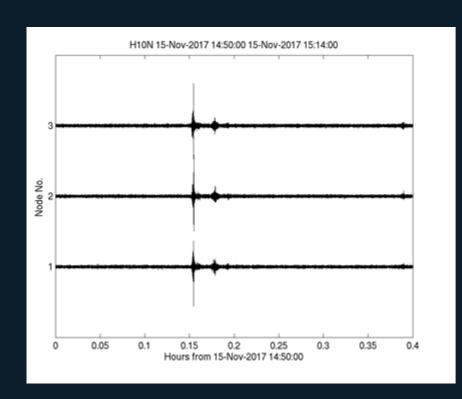
Detection by IS53 (Fairbanks, Alaska)

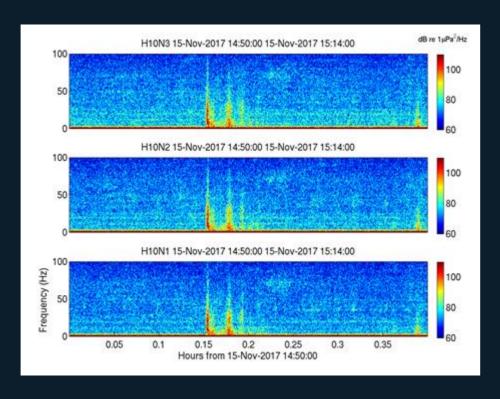


## Array processing software – other applications with SHI

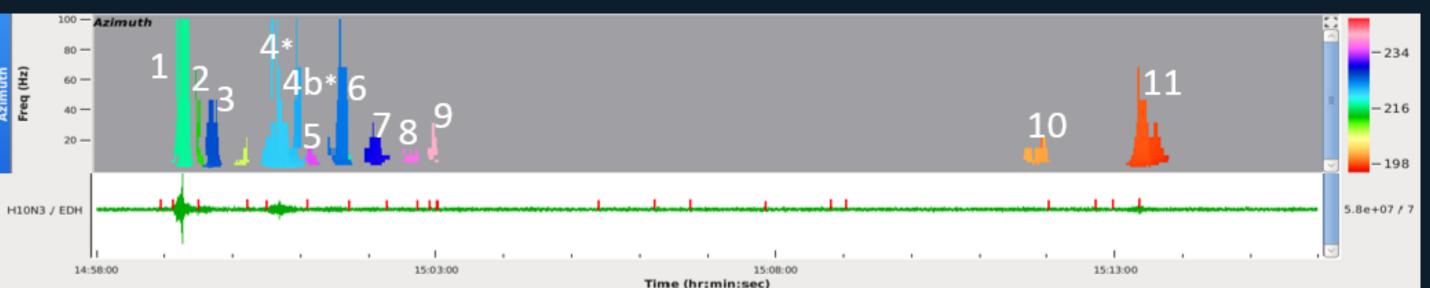


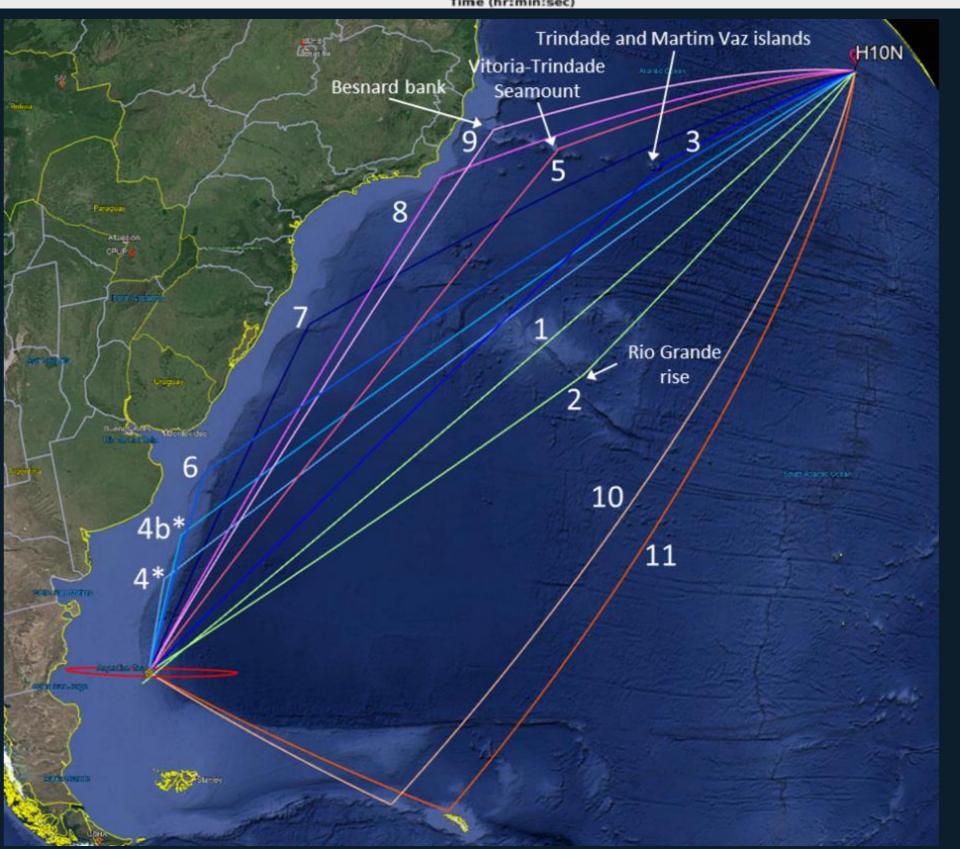
- Processing software to estimate wave attributes for SHI technologies
- Application to loss of San Juan submarine, November 2017
  - Signal detection of unknown origin received on H10N
  - A sequence of 10 late arrivals following the direct main arrival
  - Late arrivals attributed to reflections off underwater bathymetric features



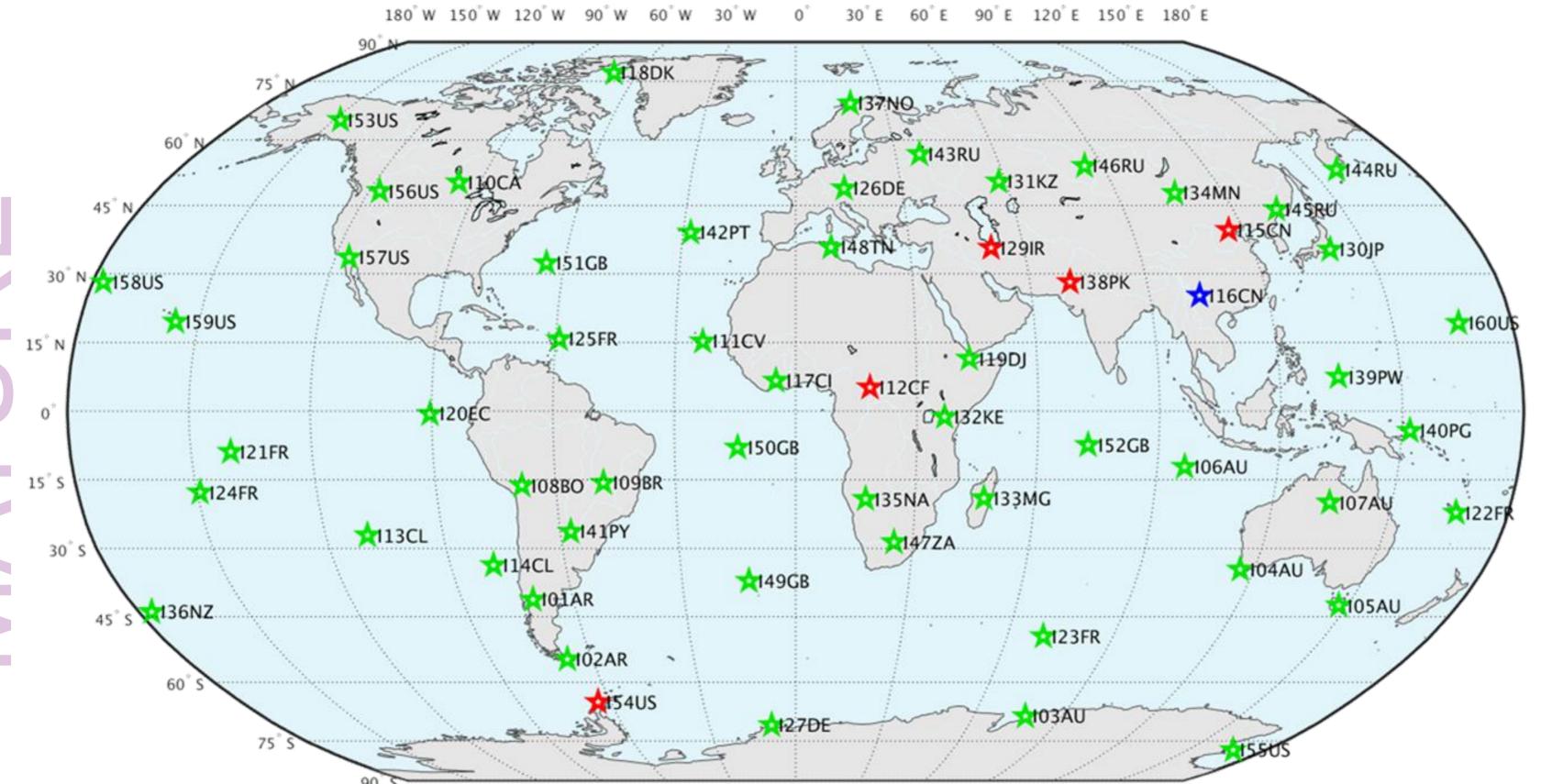


Time series for an unknown hydro-acoustic event: Recorded time series on H10N indicate an impulse-like event.









# 2022

# A 90% complete network for global studies

## IDC infrasound – where we are today

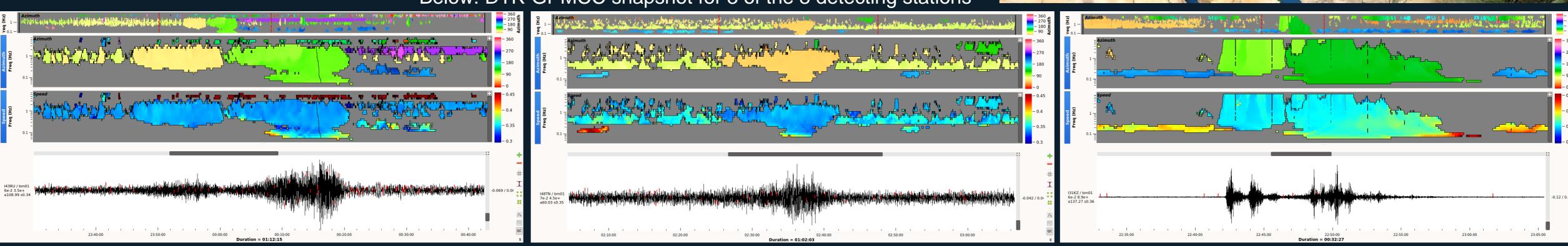


#### 2021 – 2022 The new generation of tools and methods ready for IDC Operations

- QC tools operational and sensor calibration efforts
- Net-VISA, Bayesian method, ready for SHI network processing
- Major upgrade of the infrasound processing pipeline
- NDC-in-a-Box regular releases and continuous user support

Largest infrasound REB of 2021: Soyuz-2 launch from Baikonur, Kazakhstan 21 August 2021

Below: DTK-GPMCC snapshot for 3 of the 8 detecting stations









## Data archiving and distribution



#### IMS Data / IDC Products



Users in State Signatories



- ~10 GB Daily
- >40 TB Archived

## Civil applications

Tsunami warning centers with agreements

Radiolog. and nuclear emergencies (IACRNE)

Test ban monitoring

Authorized users

Scientific use

Scientists with cost-free contract



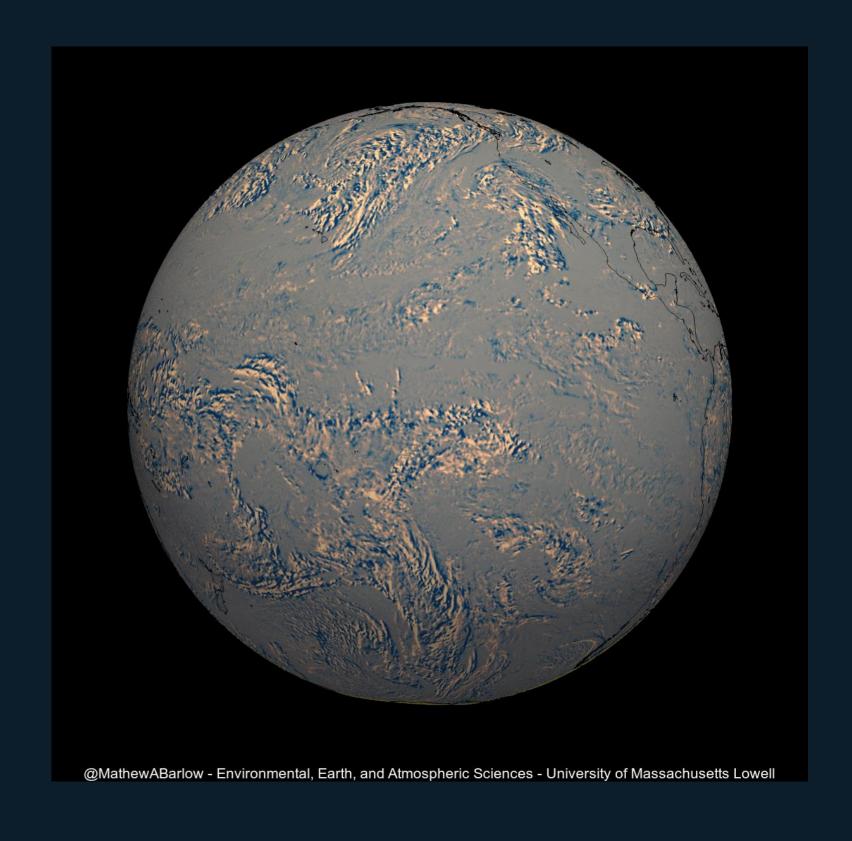
2022 Hunga Tonga-Hunga Ha'apai eruption



# Infrasound – Civil & Scientific Applications Hunga eruption – 2022/01/15





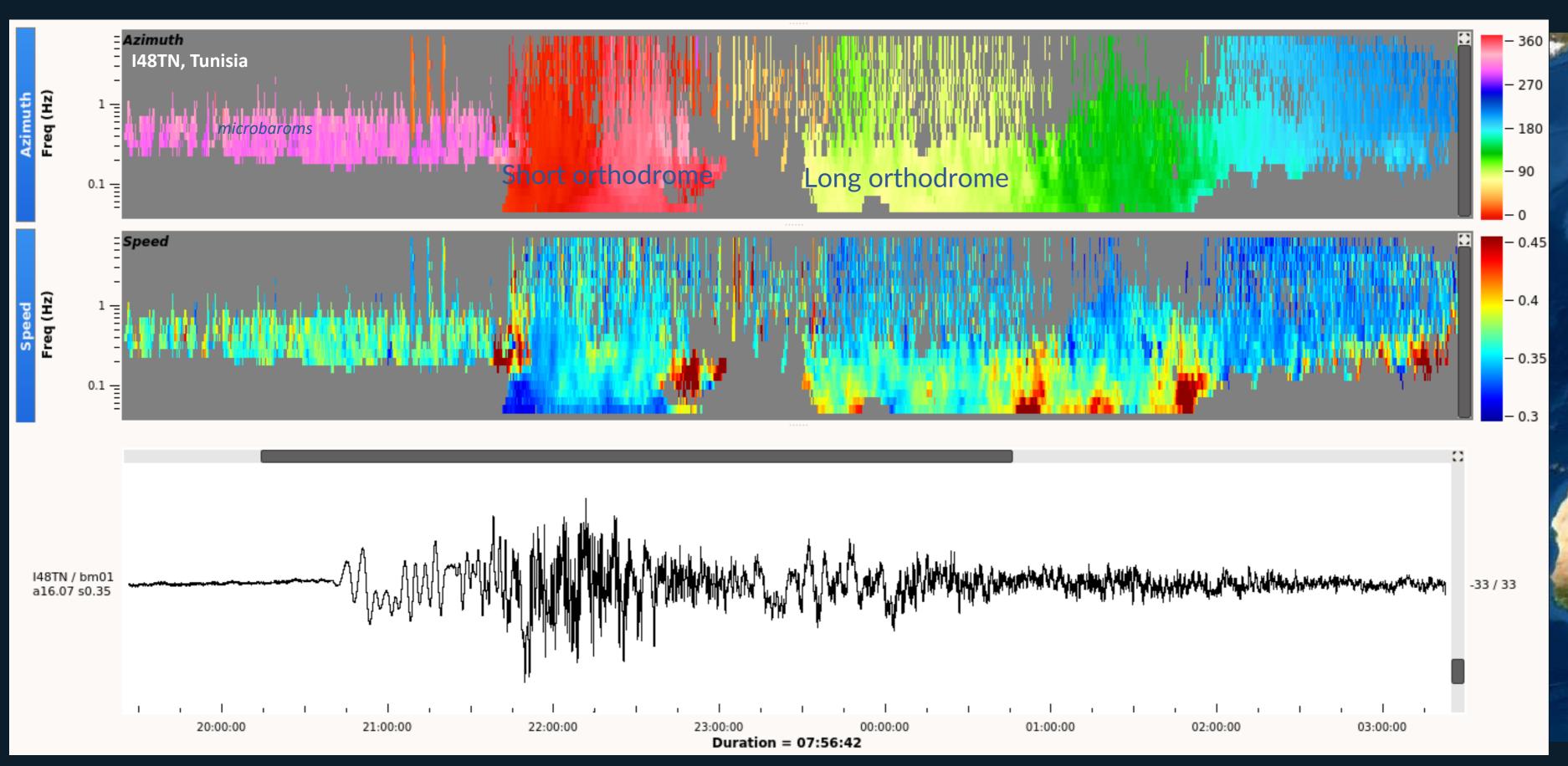


Eruption detected by 53 out of 53 operational IMS infrasound stations at the time of the event

# Infrasound – Civil & Scientific Applications Hunga eruption – 2022/01/15



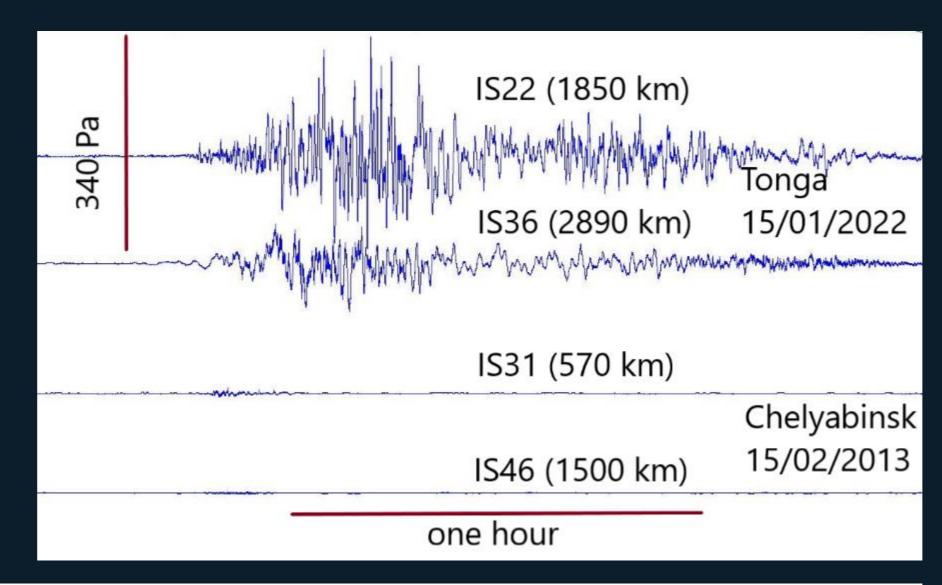
Complex global propagation patterns

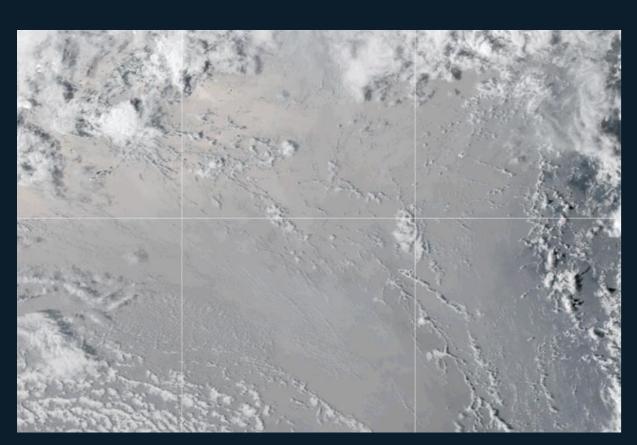




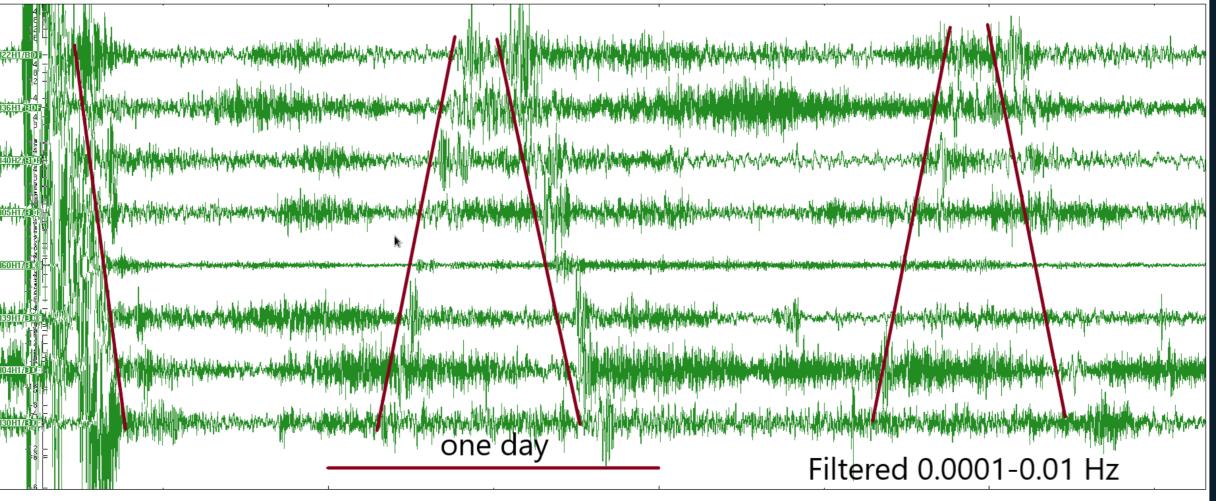
# Infrasound – Civil & Scientific Applications Hunga eruption – 2022/01/15

- Waves circumnavigating the Earth for days
- Exceptional dataset acquired by seismic, hydroacoustic & infrasound networks
- Several publications making use of CTBTO data and products (unprecedented collaborative effort)





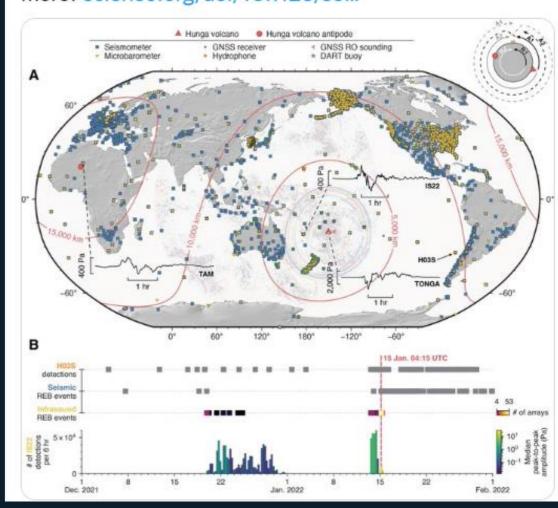
Credit: Visible Earth/NASA







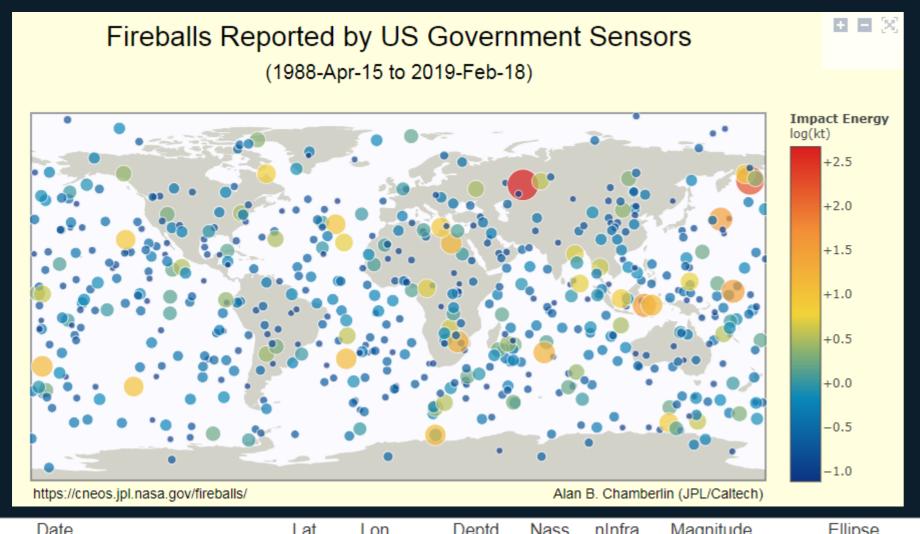
Hunga volcanic eruption, #Tonga was a once-in-acentury event producing extraordinary atmospheric waves recorded globally by #IMS. The eruption triggered a collaborative effort w/76 experts from 17 states involving #CTBTO, NDCs, Station Operators & more: science.org/doi/10.1126/sc...



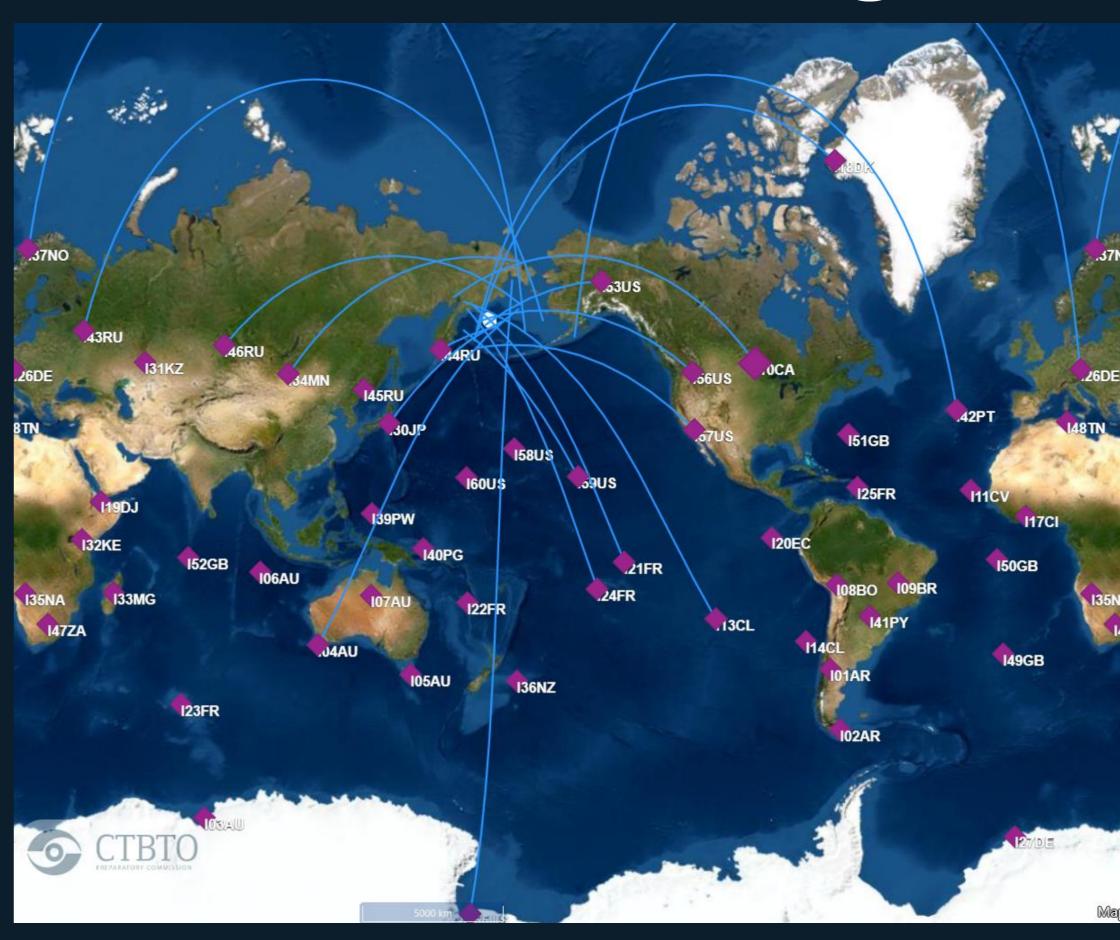
# Infrasound – Civil & Scientific Applications Bering airburst – 2018/12/18

CTBTO
PREPARATORY COMMISSION

• Scientific application: monitoring atmospheric for NEO impacts







- 3rd largest infrasound event recorded by IMS infrasound component (19 stations)
- Automatically detected and published in reviewed bulletins of IDC

Region

**BERING SEA** 

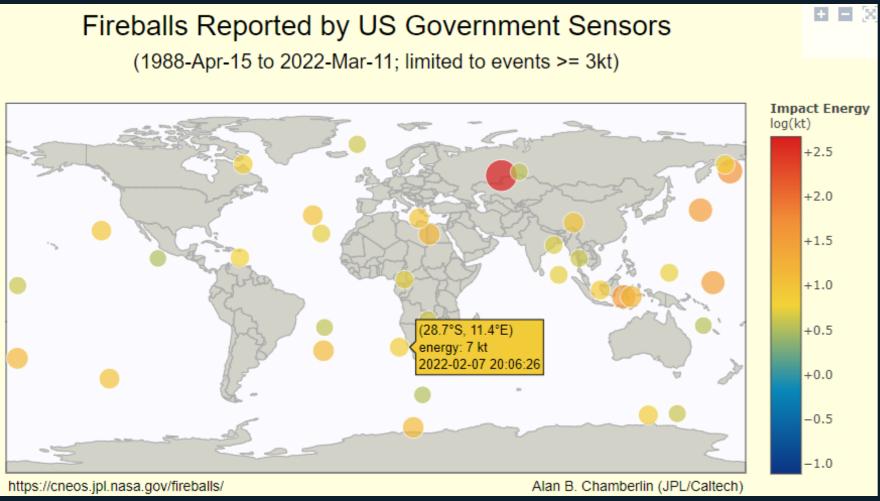
38655.6 km<sup>2</sup>

• Confirmed on NASA NEO fireball page 3 months later (on 8 March 2019, total impact energy 173kt, revised in 2022 to 49kt)

ctbto.org

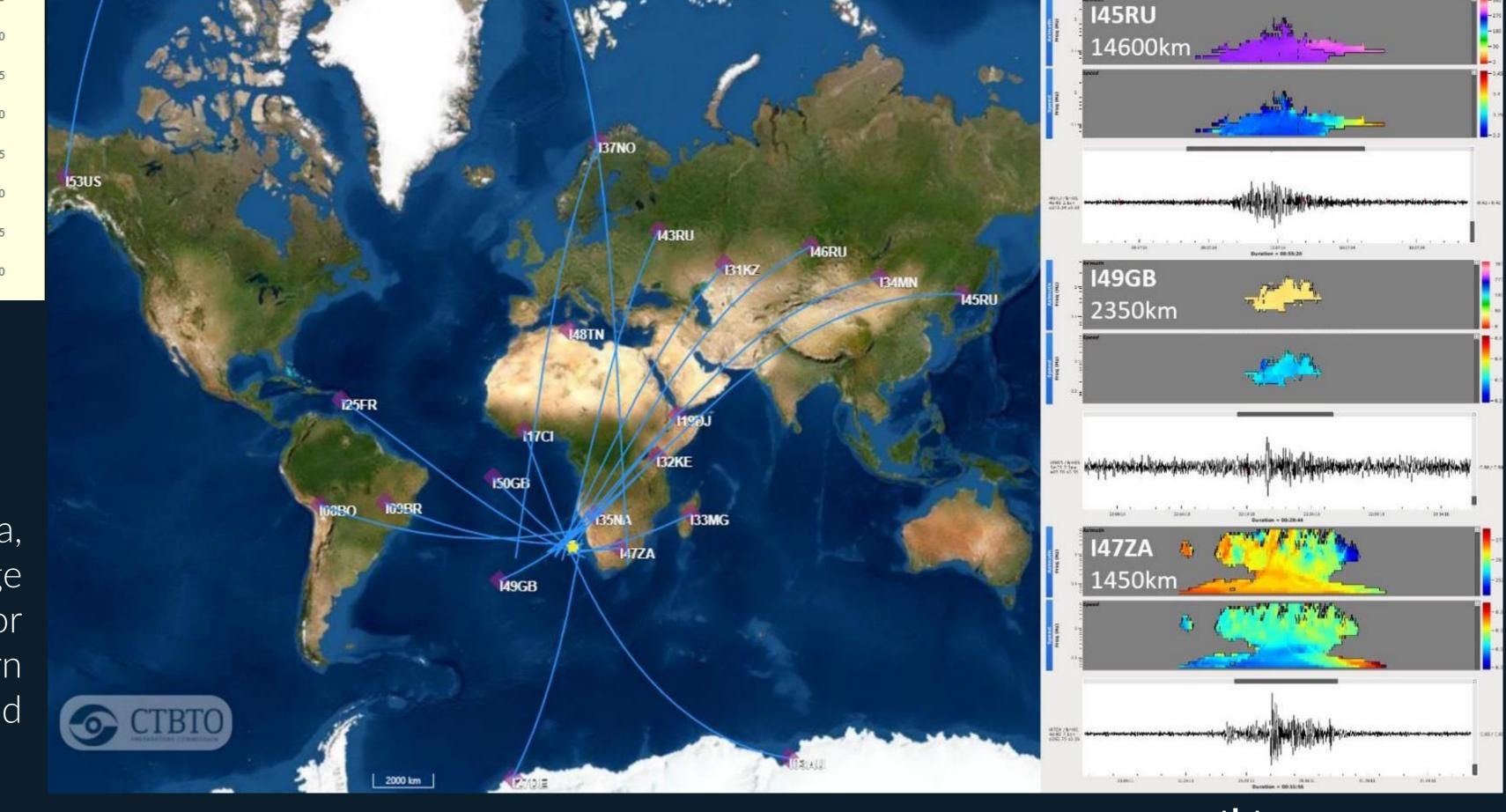
# Infrasound – Civil & Scientific Applications Southern Atlantic Ocean airburst – 2022/02/07





 Origin
 Date
 Lat
 Lon
 Depth
 Nass
 nInfra
 Magnitude
 Ellipse
 Region

 21771158 (2)
 2022-02-07 20:09:37
 -28.264839
 10.47754
 0
 20
 20
 mb - / ml 54690.5 km²
 SOUTH ATLANTIC OCEAN



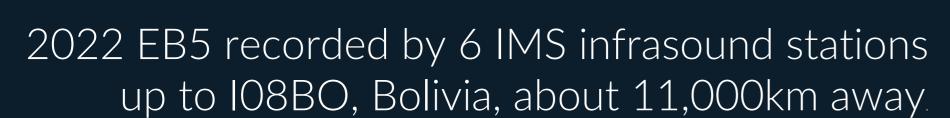
20 infrasound stations up to I53US, Alaska, 15,600km away, recorded a large atmospheric event related to a meteor airburst and located over the Southern Atlantic Ocean on 7 February 2022 around 20:09 UTC.

# Infrasound – Civil & Scientific Applications 2022 EB5 – 2022/03/11



Origin	Date	Lat	Lon	Depth	Nass	nInfra	Magnitude	Ellipse	Region
21936215 🖆	2022-03-11 21:31:57	69.660027	0.45271986	0	6	6	mb - / ml -	65808.5 km <sup>2</sup>	NORWEGIAN SEA

Arid	Sta	Delt	Phas	<b>IPhas</b>	Arrival time	Tres	Az	Azre	Tr.vel (m/s	Cel (m/s
16849209	137N	6.4	I .	I	2022-03-11 22:14:3	125.	283.	0.1	357.4	280
16849326	I18DK	19.8	I .	I	2022-03-11 23:35:3	-77.2	77.6	2.4	345.6	297
16849463	146R	39.1	I .	I	2022-03-12 01:30:3	-33.4	325.	-1.1	328.2	303
16849663	144R	56.4	I -	I	2022-03-12 03:32:3	929.	344.	-6.7	366.2	289
16849682	145R	61.0	1	I	2022-03-12 03:55:4	628.	337.	-5.5	341.8	294
16850089	108B	98.0	I	I	2022-03-12 07:33:5	160.	22.4	3.2	340.0	302







The Comprehensive Nuclear-Test-Ban Treaty

Putting an end to nuclear explosions through science and technology

Thank you