CTBTO PREPARATORY COMMISSION

Atmospheric dynamics Research InfraStructure in Europe ARISE

Towards a Volcanic Notification System With Infrasound Data

Use of infrasound data in support of the VAACs in the Framework of ARISE Project

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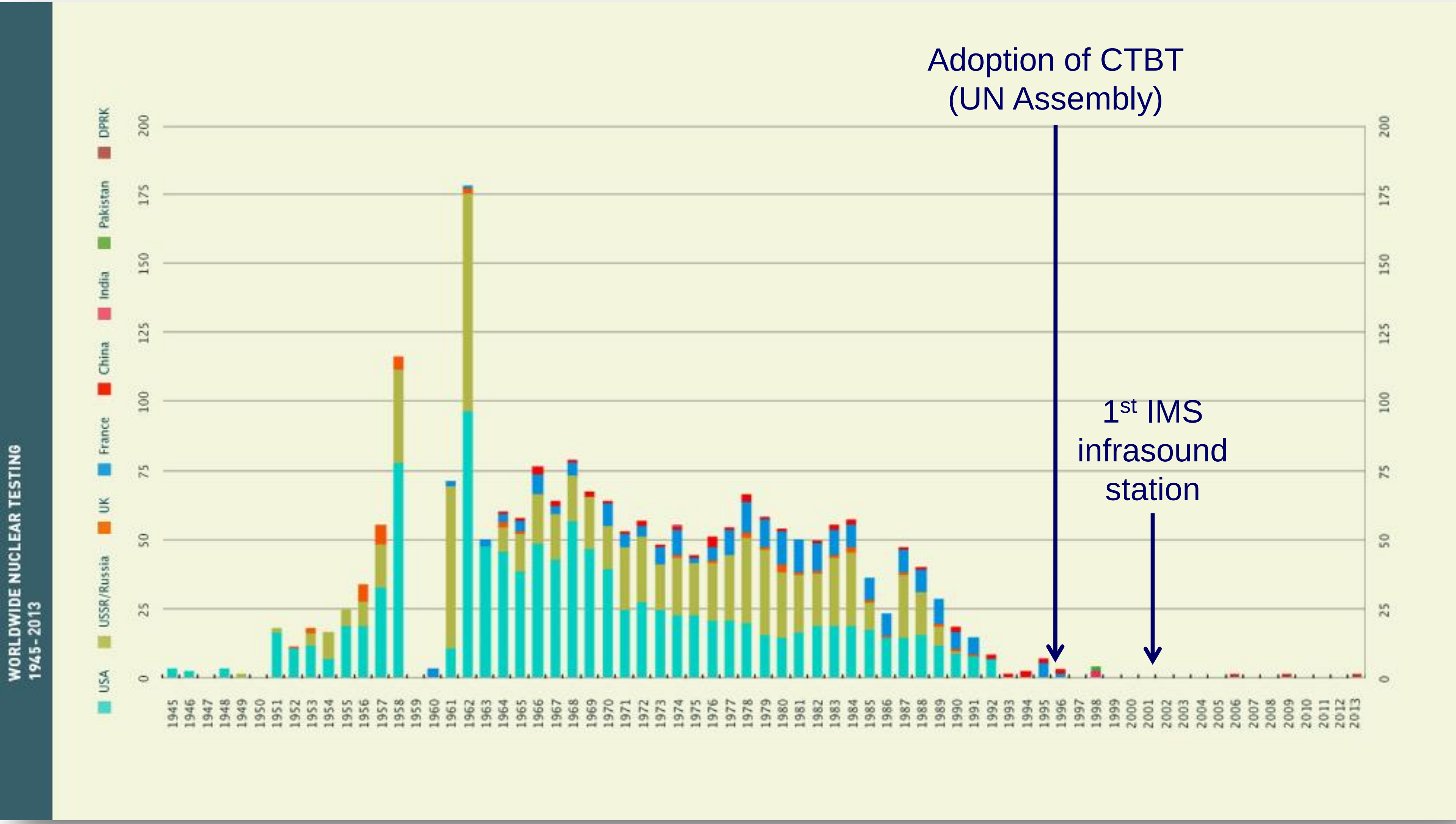
IVAW-7 ANCHORAGE | 19-23 OCTOBER 2015

Worldwide Nuclear Testing
1945-2013



Nuclear testing & monitoring technologies

Atmospheric tests

Infrasound

Underwater tests

Hydro-acoustic

Underground tests

Seismic

Radionuclides and noble gas

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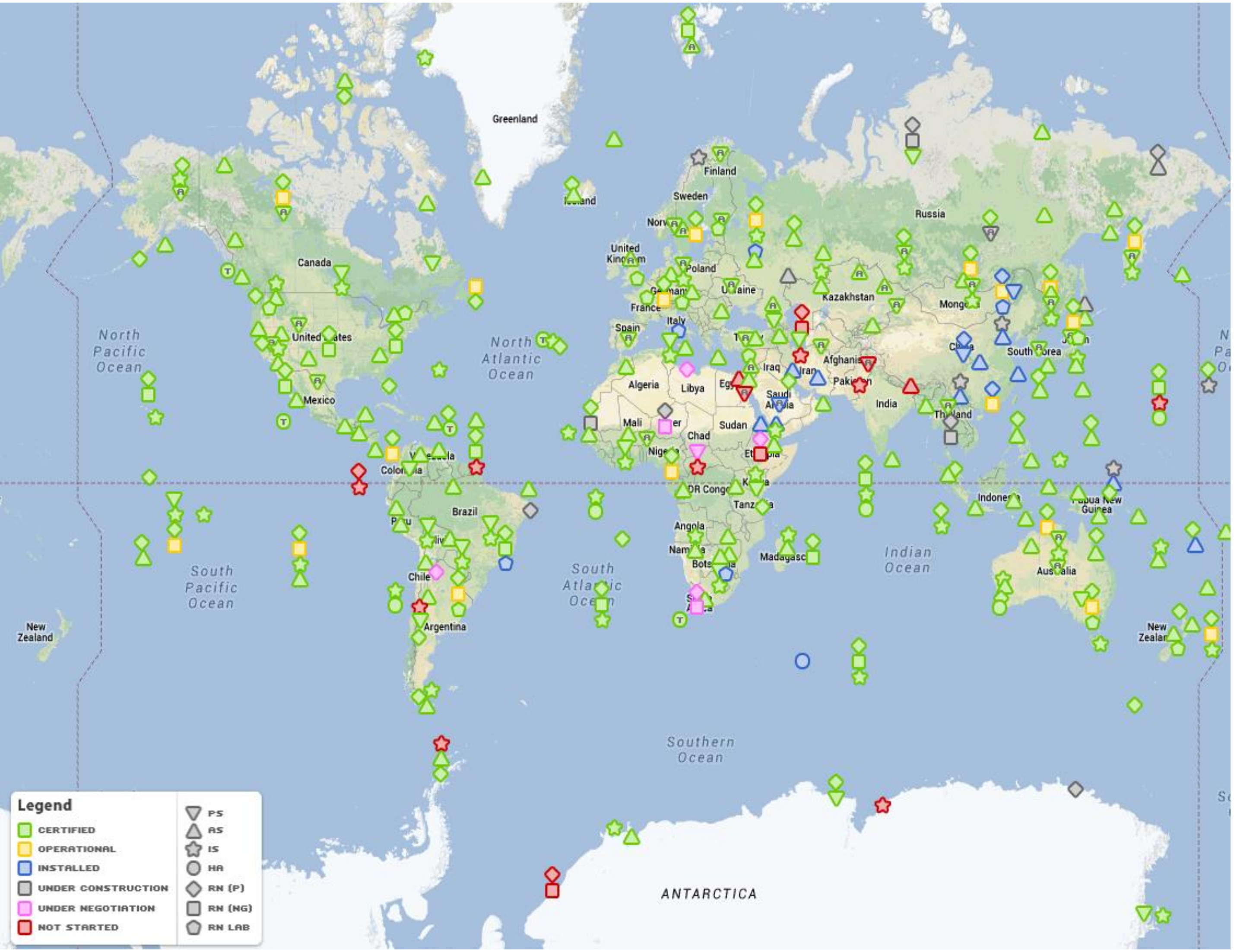
International Monitoring System
Prospective: 377 Facilities

ARISE
Atmospheric dynamics Research InfraStructure in Europe



2015 status: ~90% complete

Four monitoring technologies

Seismic:
- 50 primary stations
- 120 auxiliary stations

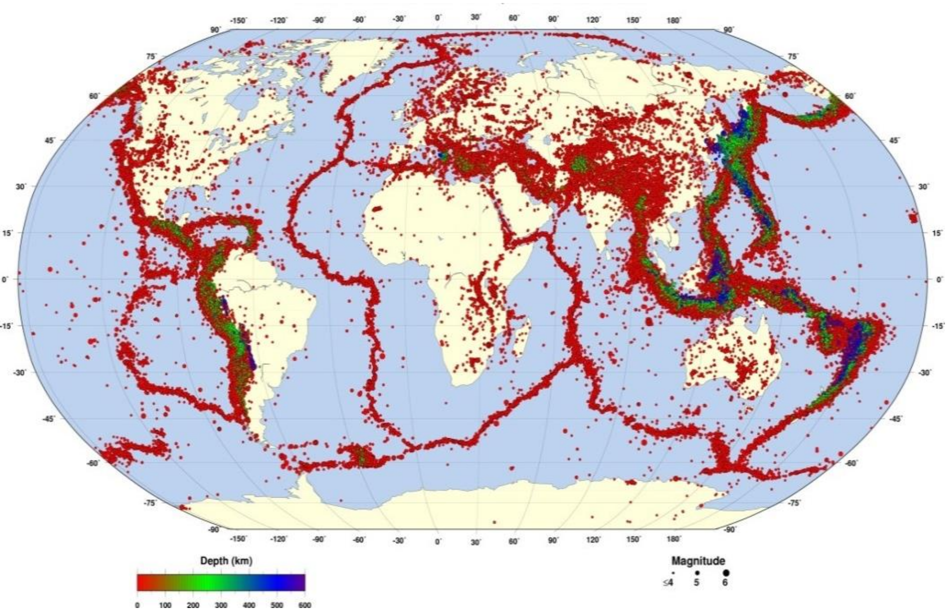
Infrasound:
- 60 stations

Hydroacoustic:
- 11 stations

Radionuclides:
- 80 particulate stations
- 40 nobles gas stations
- 16 radionuclide laboratories

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

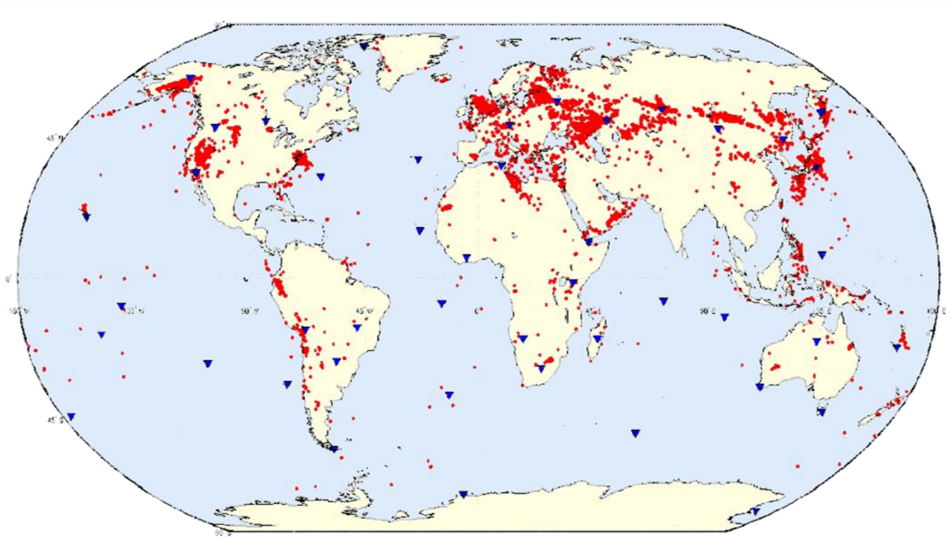
Since February 2000



481,510 REB events

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

Since February 2010

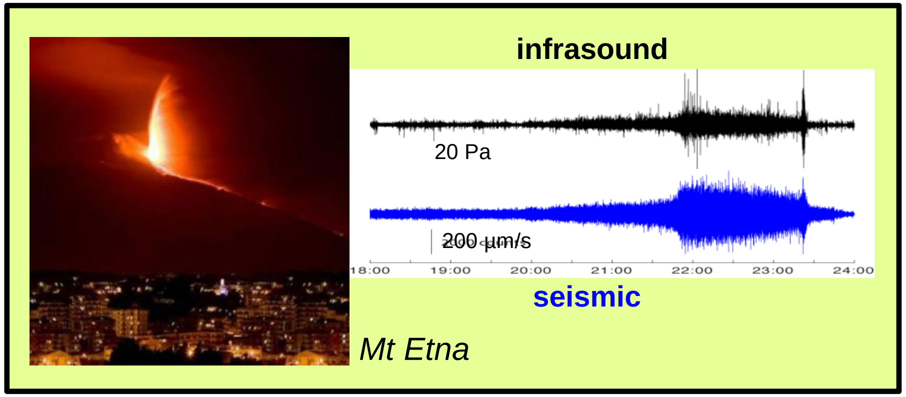


15,054 LEB infrasound events

REB and LEB are IDC products. REB: Reviewed Event Bulletins – LEB: Late Event Bulletins ; figures as of 05 October 2015

Motivation

- Large scale volcanic eruptions may eject ash and hazardous gas high into the atmosphere
- Ash encounters represents a serious threat to the safety of aircraft
- Volcanic Ash Advisory Centers (VAACs) are mandated by the International Civil Aviation Organization (ICAO) to coordinate and disseminate information on volcanic ash clouds
- Timely availability of reliable information is crucial to mitigate the risk of aircraft encountering volcanic ash
  - Volcanic and seismological observatories
  - Remote sensing
  - Pilot report
- Infrasound (<20Hz) may supplement other techniques for monitoring volcanic activity, especially in remote areas that are poorly instrumented

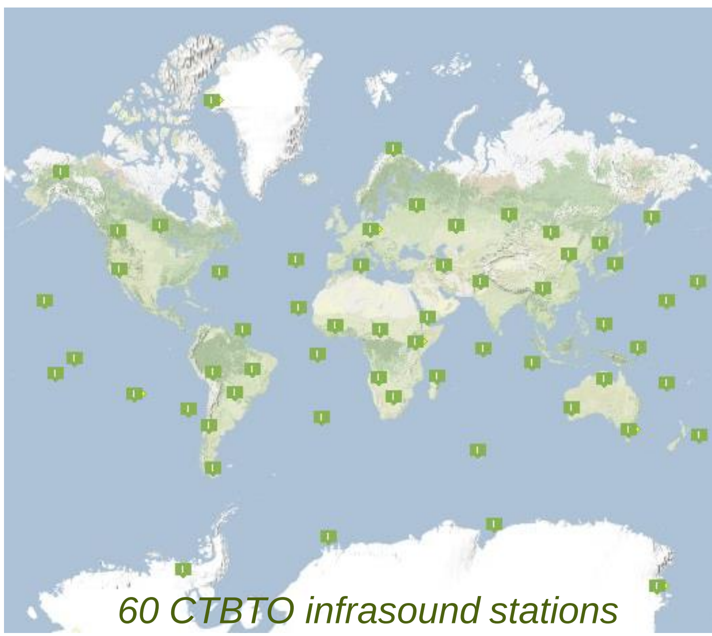


CTBTO Operational system

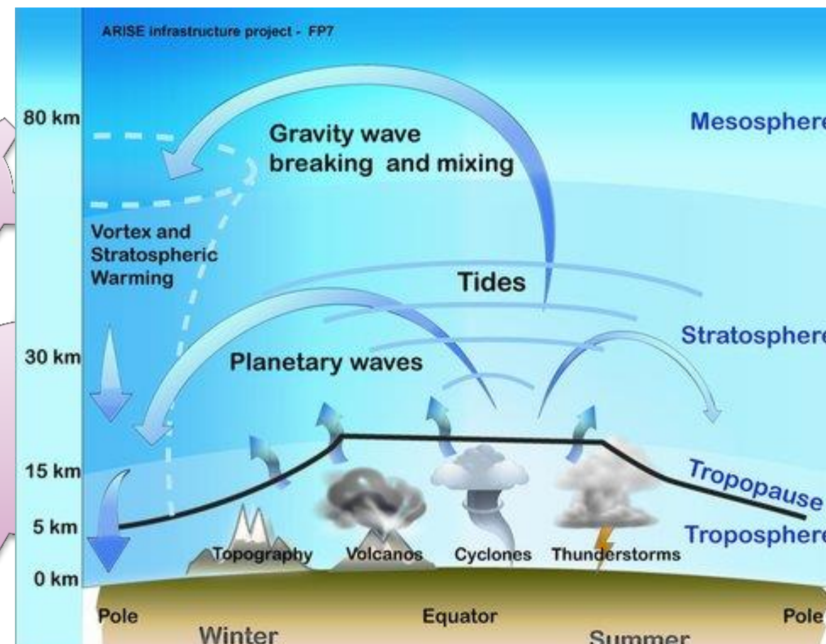
- The Organization ensures the build-up of a global verification regime capable of detecting nuclear explosions underground, underwater and in the atmosphere
- CTBTO-WMO/ICAO collaboration

ARISE: Applied science

- Atmospheric dynamics Research Infra-Structure in Europe, H2020 project funded by EU (2015-2017)
- 24 international partners working with CTBTO on characterization of atmosphere and monitoring of extreme events

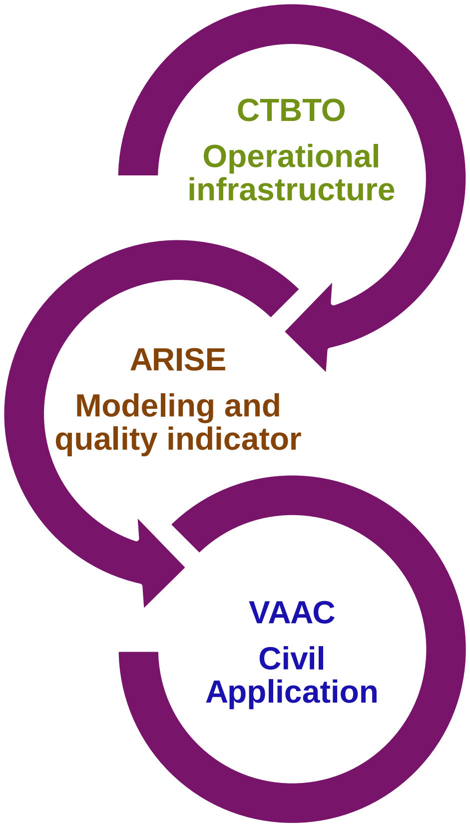


60 CTBTO infrasound stations (upon completion)



Establishment of a Volcanic Notification System (VNS)

The synergy CTBTO / ARISE offers a unique opportunity for the establishment of a VNS using infrasound data from a global station network

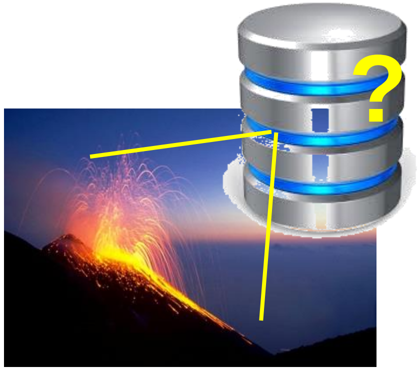


- The VNS makes best use of the infrasound component of the IMS together with the operational capabilities of the IDC
- ARISE advanced products provide valuable parametric inputs on the atmosphere dynamics that drives the infrasound wave propagation.
- These results may serve as quality indicators increasing the VAACs confidence when receiving notification messages.
- The proposed approached is tested with VAAC Toulouse, mandated by the ICAO, to demonstrate the usefulness of infrasonic data to International Airways Volcano Watch.
- Formalization through a future CTBTO-ICAO/WMO agreement

Basic steps for the VNS

Search for infrasound detections matching with a known volcano

Infrasound detections

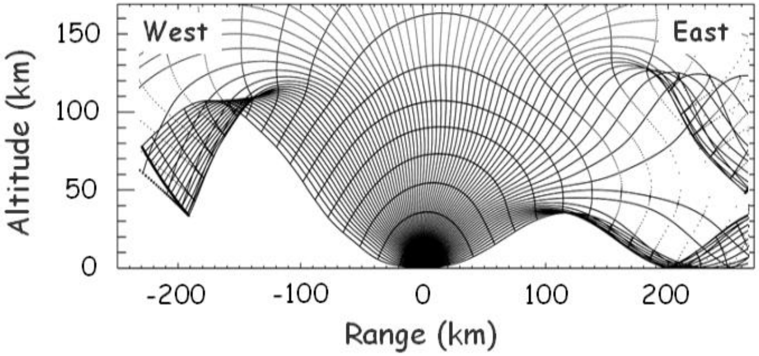


Query the IDC/ARISE databases, search criteria

- **Distance** source-stations < MAX_DISTANCE (4000 km)
- **Azimuth** +/- ΔAZIM (10 deg)
- **Central frequency (attenuation with distance)**
  cfreq < 4-0.055*Δ for Δ<60 deg
  and cfreq < 0.5 Hz for Δ>60 deg (*Brachet et al. 2010*)

- **Effective sound speed ratio (favorable ducting conditions for propagation)**
  Ceff-ratio = MEAN (MAX_i [Ceff-ratio 30-60 km]) > MIN_CEFF_RATIO (0.95)

$C_{eff\text{-}ratio} < 1$ $C_{eff\text{-}ratio} > 1$



A "binary"-like pattern

- $C_{eff\text{-}ratio} < 1$: signals strongly absorbed for f>1Hz
- $C_{eff\text{-}ratio} > 1$: stratospheric duct efficiently propagates acoustic energy

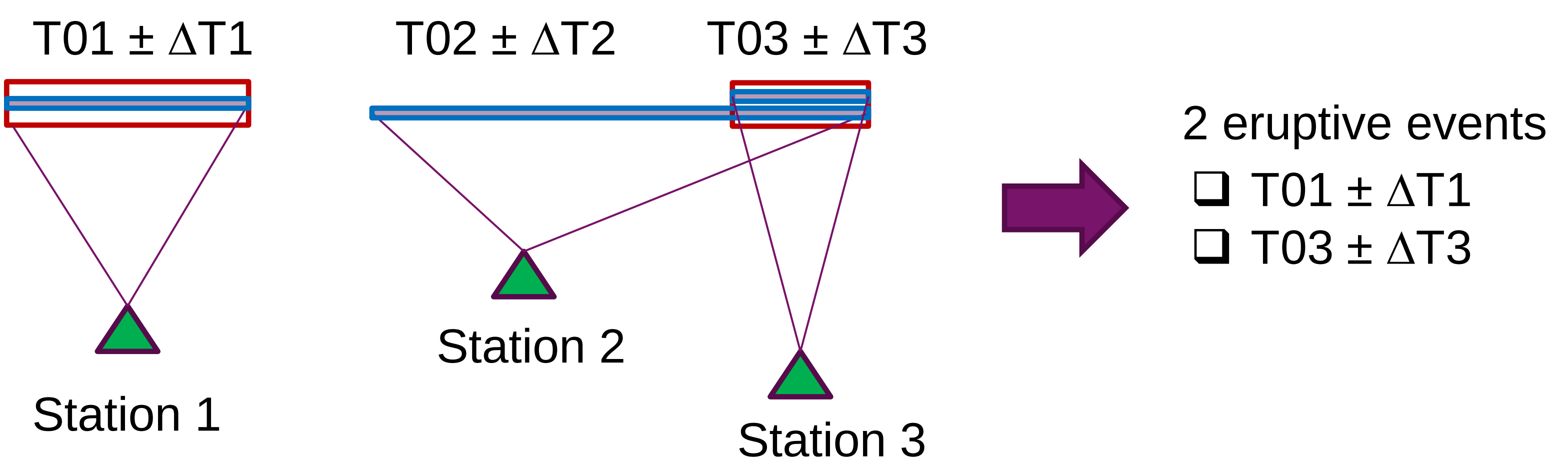
Basic steps for the VNS

Build eruption events from detections

- **Group detections**: the origin time of the eruption corresponds to the period overlap T0 +/- ΔT for the detecting stations

  T0 = Δ/REF_SPEED (REF_SPEED=300m/s)

  ΔT = Δ*[1/MIN_SPEED - 1/MAX_SPEED] (RANGE_SPEED=270-330m/s)



- **Eruptive sequences**: Origins belong to a same event if they are separated by less than ΔT_CLOSE (6 hours)
- **Filter out smallest events** (optional) based on MIN_NBSTATIONS, MIN_MAX_DURATION

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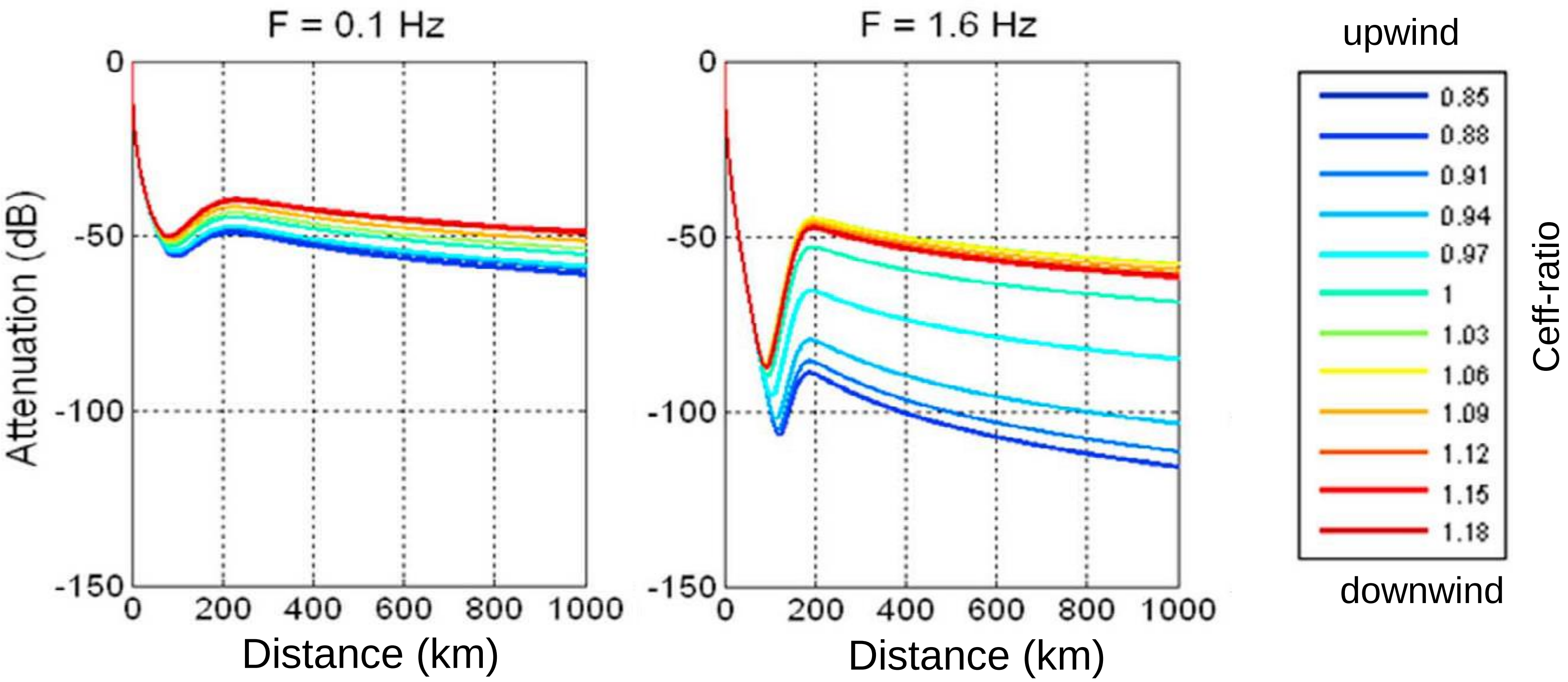
Attenuation is function of the frequency and wind conditions



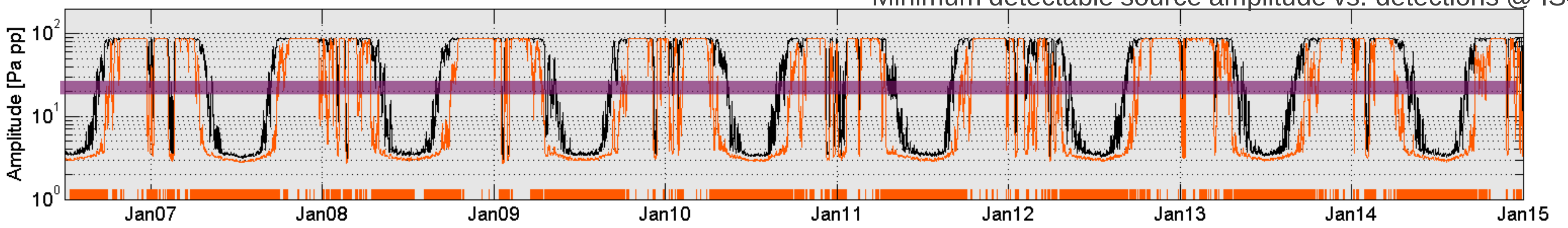
Low frequency: Attenuation weakly depends on $C_{eff\text{-}ratio}$

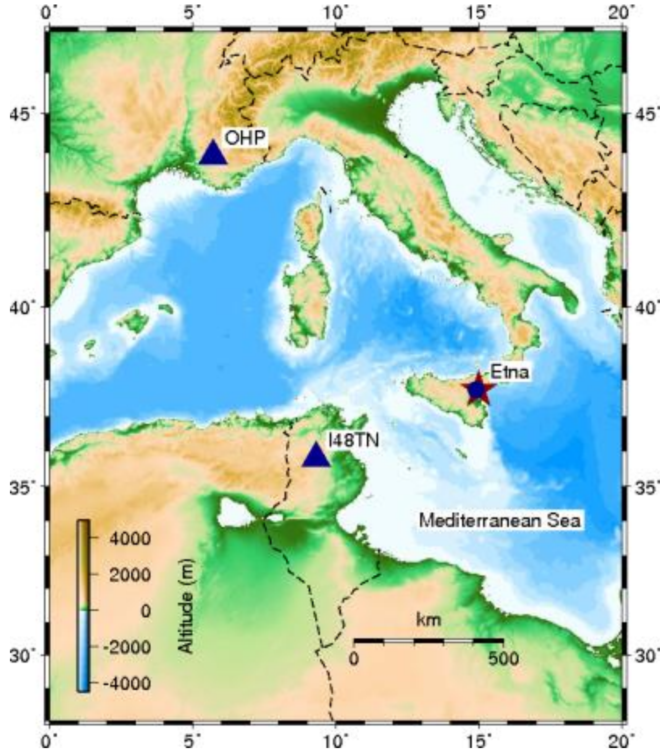
High frequency: Higher attenuation in upwind conditions (low $C_{eff\text{-}ratio}$)

ATMOSPHERIC MODELING (ARISE INPUT)

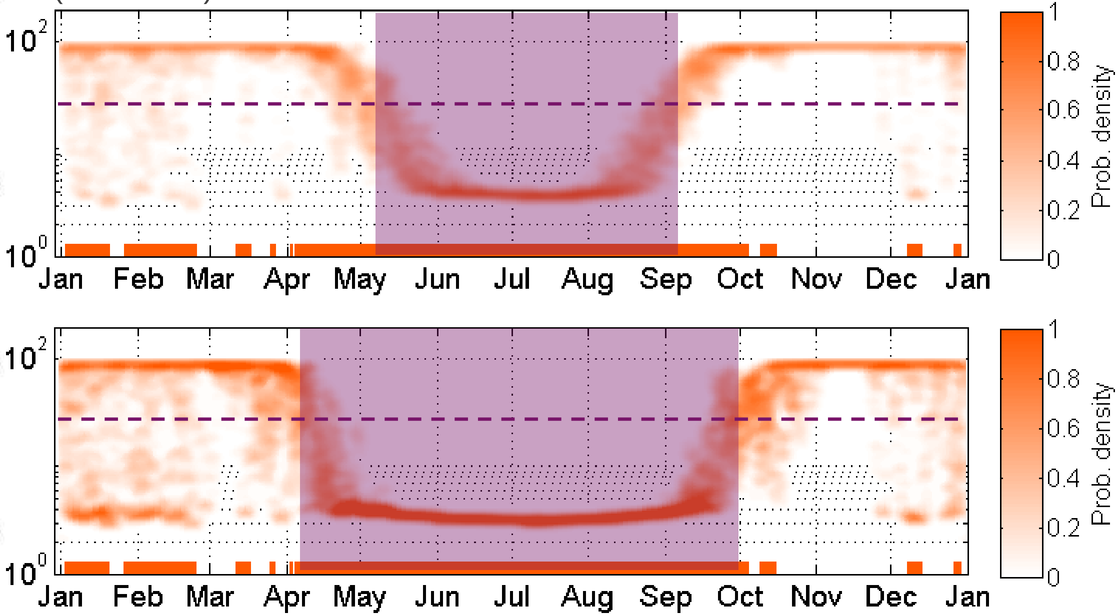
- Probabilistic predictions (Etna detected at IS48) using empirical attenuation relation and atmospheric uncertainty estimates (from OHP campaign)

Minimum detectable source amplitude vs. detections @ IS48





Probabilistic predictions without (top) / with (bottom) wind perturbations (2006-2014)



APPLICATION: ERUPTION OF CALBUCO CHILE, 22-23 APRIL 2015

Source: Marcelo Utreras ©DR

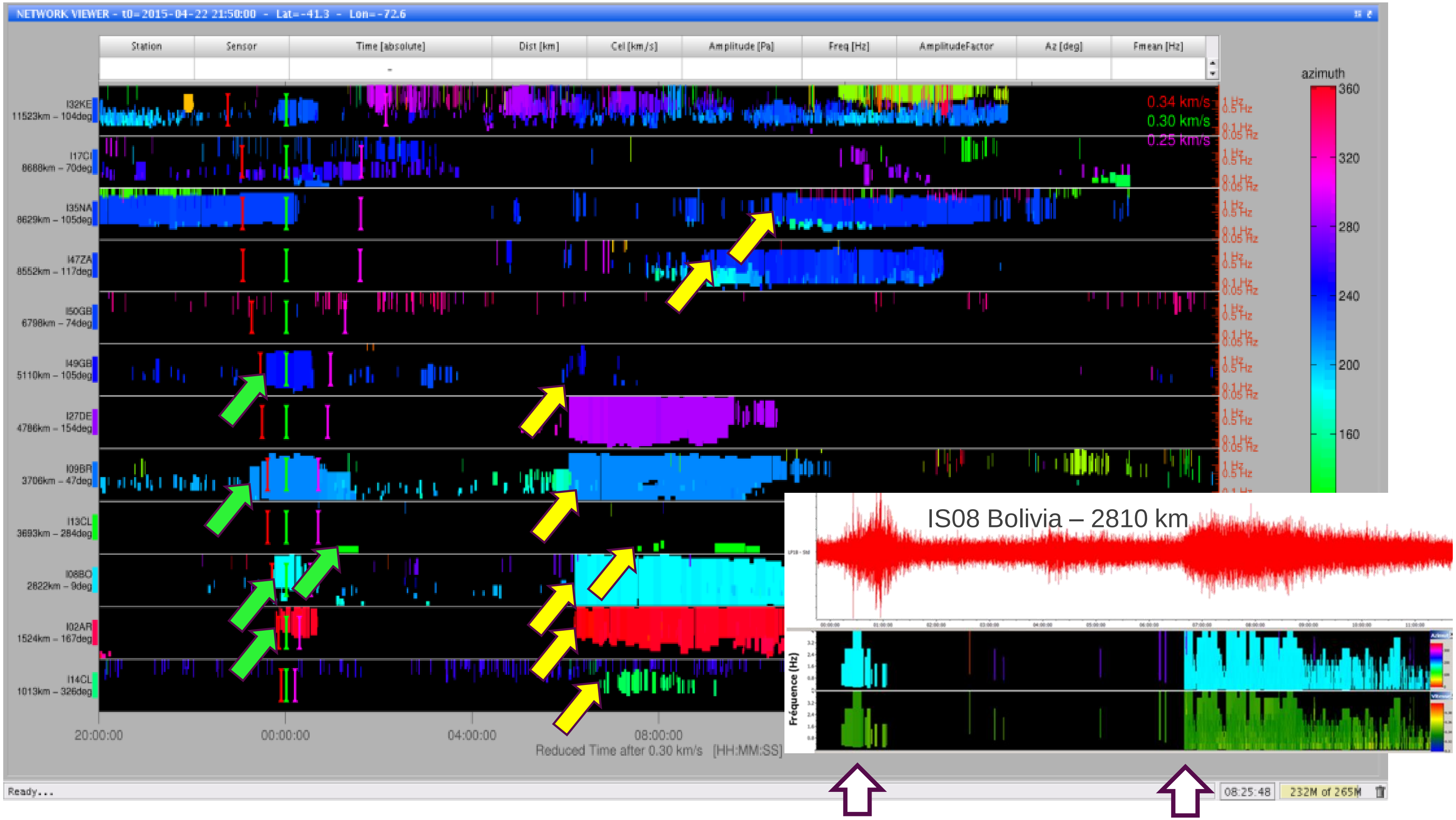
Stations	Distance (km)	Théor. Az (°)	Arriving Time (TU)
IS02 Argentina	1525	343	22:50:59
IS08 Bolivia	2810	187	00:09:19
IS13 Eastern Island Chili	3695	125	02:19:00
IS09 Brazil	3700	215	00:35:09
IS49 Tristan de Cunha United Kingdom	5120	245	02:10:30
IS50 Ascension United Kingdom	6795	230	04:18:00
IS35 Namibia	8640	230	04:51:30
IS17 Ivory Coast	8675	225	05:13:00
IS32 Kenya	11525	227	08:20:10

Table 1: *Event associated with the first eruption on 22 April 2015 at 21:50 UT.*

Stations	Distance (km)	Théor. Az (°)	Arriving Time (TU)
IS14 Robinson Crusoe Chili	1010	149	05:39:14
IS02 Argentina	1525	343	05:32:19
IS08 Bolivia	2810	187	06:43:55
IS09 Brazil	3700	215	07:23:05
IS27 Neumayer Antarctic	4800	277	08:22:55
IS13 Eastern Island Chili	3695	125	10:26:24
IS49 Tristan de Cunha United Kingdom	5120	245	08:39:19
IS47 South Africa	8570	230	11:52:04
IS35 Namibia	8640	230	12:01:04
IS17 Ivory Coast	8675	225	12:26:00
IS32 Kenya	11525	227	15:10:00

Table 2: *Event associated with the second eruption 23 April 2015 at 04:22 UT.*

APPLICATION: ERUPTION OF CALBUCO CHILE, 22-23 APRIL 2015



APPLICATION: ERUPTION OF CALBUCO CHILE, 22-23 APRIL 2015

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METEO FRANCE

VOLCANO NOTIFICATION TO VAAC

Prototype volcano notification system

cea

Message

NOTIVAAC : 20120401.1
ISSUED : 2015/06/11 17:02:50
ISSUED BY : CEA (ARISE-PROTO)
RECIPIENT : TOULOUSE VAAC (METEOFRANCE)
NO.PAGES : 1

Volcano

VOLCANO NAME : CABULCO
VOLCANO ID : 358020
LATITUDE : 41.3°S
LONGITUDE : 72.6°W
ELEVATION : 0 M

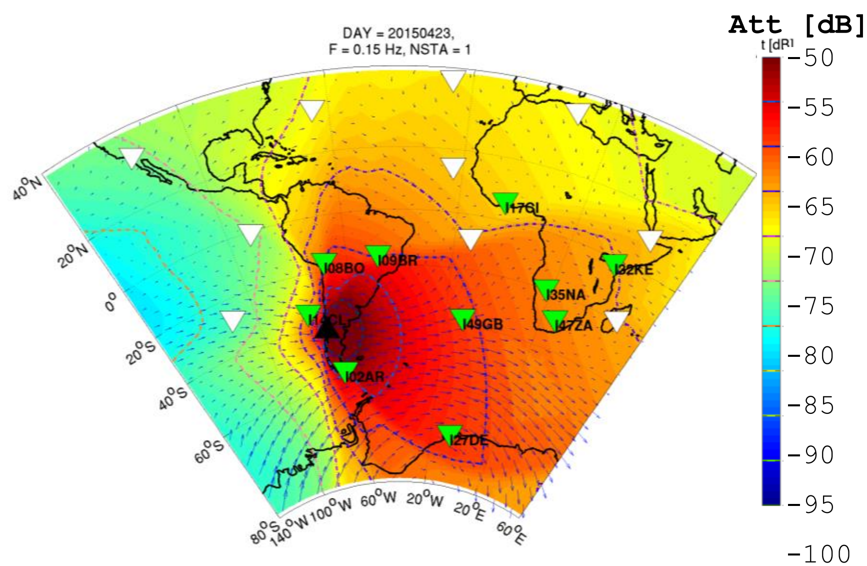
Summary

START TIME : 2015/04/23 03:50:00 UTC
END TIME : 2015/04/23 09:34:00 UTC
DETECTIONS :

STATION	*DIST. (km)*	*AMP. (Pa)*
I14CL	1012	0.37
I02AR	1526	0.27
I08BO	2811	0.22
I09BR	3700	0.14
I27DE	4802	0.47
I49GB	5124	1.07
I47ZA	8574	0.10
I35NA	8642	0.08
I17CI	8677	0.02
I32KE	11528	0.39

Detectability

DAY = 20150423,
F = 0.15 Hz, NSTA = 1



SUMMARY/PERSPECTIVES

- In the framework of ARISE project, the infrasound community develops a Volcanic Notification System (VNS) for Civil Aviation community
- As ARISE partner, CTBTO brings its operational infrastructure to support dissemination of information to VAACs through the VNS
- CTBTO and ARISE welcome participation from volcano-infrasound research community to enhance the VNS
- Ongoing work: Improve VNS reliability to reduce false alarms rate
  - Enhancement of atmospheric specifications (ECMWF) for modeling infrasound wave propagation
  - Improved accuracy and uncertainty of infrasound wave parameters using atm. modeling
  - Calculate source amplitude from long range infrasound measurements to estimate the acoustic energy (in relation with the flux of ash injection in the atmosphere → link to the volcano community)
- Once agreement is in place and the VNS is functional with Toulouse VAAC, this pilot project can be extended to other VAACs
- Scientific collaboration on VNS is an asset for ARISE (Research), CTBTO (Operations) and ICAO/WMO (Civil impact) communities

REFERENCES / PUBLICATIONS

More on infrasound & volcanoes

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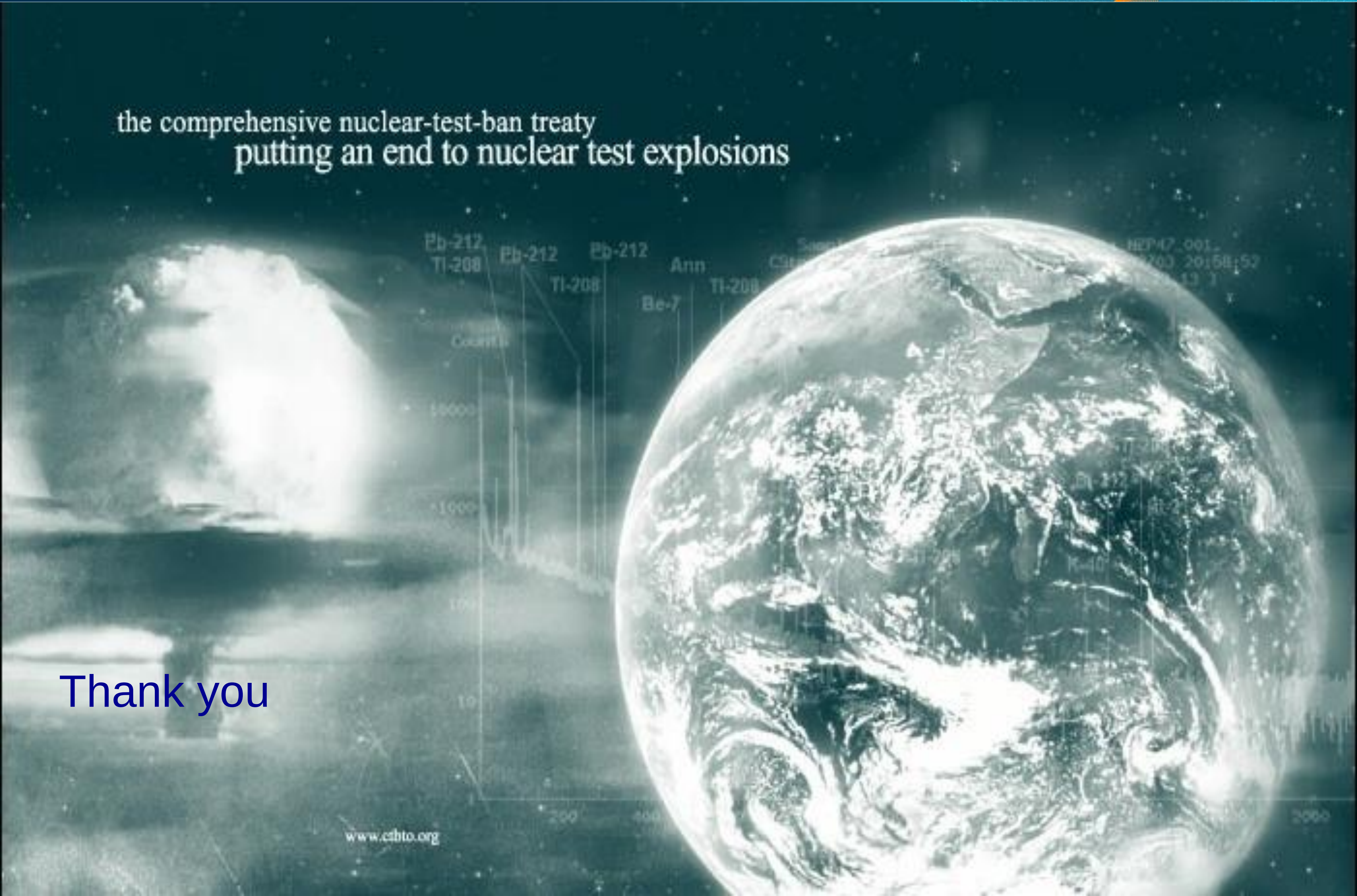

Thank you