# 25 years of infrasound monitoring: achievements and new challenges

**Elisabeth Blanc**

Alternative Energies and Atomic Energy Commission (CEA)
CEA/DAM/DIF, Arpajon, France

Vienna Institute for CTBT Science and Technology

# Outline

## Early story

The microbarography, first networks, atmospheric nuclear tests

## CTBT verification : renaissance of infrasound technology

Network specifications
Detection and location predictions

## Development of the IMS

New image of the atmosphere and disturbances
Effect of the stratospheric disturbances on infrasound propagation

## Reducing uncertainties in simulations

Improving stratospheric observations
Infrasound inversions, gravity waves characterization, synergy with lidar systems

## Infrasound observations and weather forecasting

Interest of infrasound observations for medium range weather forecasting

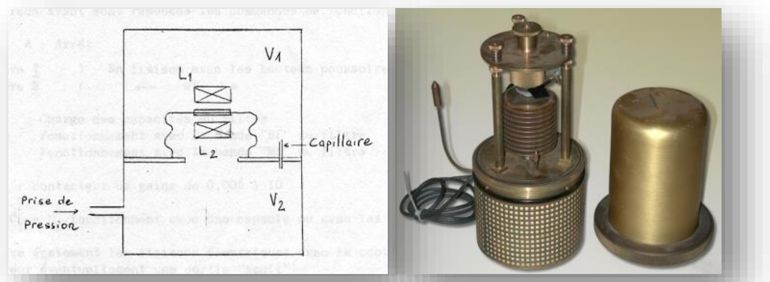
## Scientific applications

Volcano remote monitoring

# Early story: the microbarography, first networks, nuclear tests

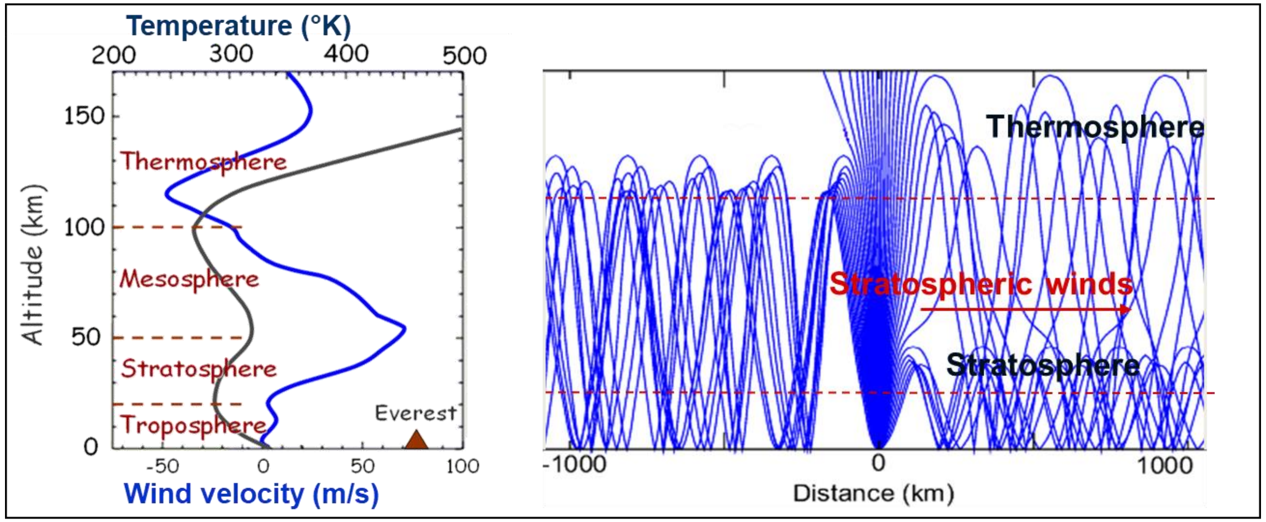
## 1950-1970 : first microbarographs, first station networks

- Infrasound system Lamont-Doherty Earth Observatory (Columbia University USA) Rind and Balachandran
- Infrasounds system in France and French Polynesia (CEA/LDG, FR) Prof. Rocard
    - Signal catalogs (nuclear tests, volcanoes, explosions)
    - Pionner work: detection, localisation, identification




First microbarometer in France 1956 (CEA, FR)

Infrasound: acoustic waves (10 Hz-0.01 Hz)
Infrasound long range propagation in the atmospheric wave guide formed by the temperature and wind variations in the different atmospheric layers.




## 1980-1991 : USA High Explosive (HE) Campaigns

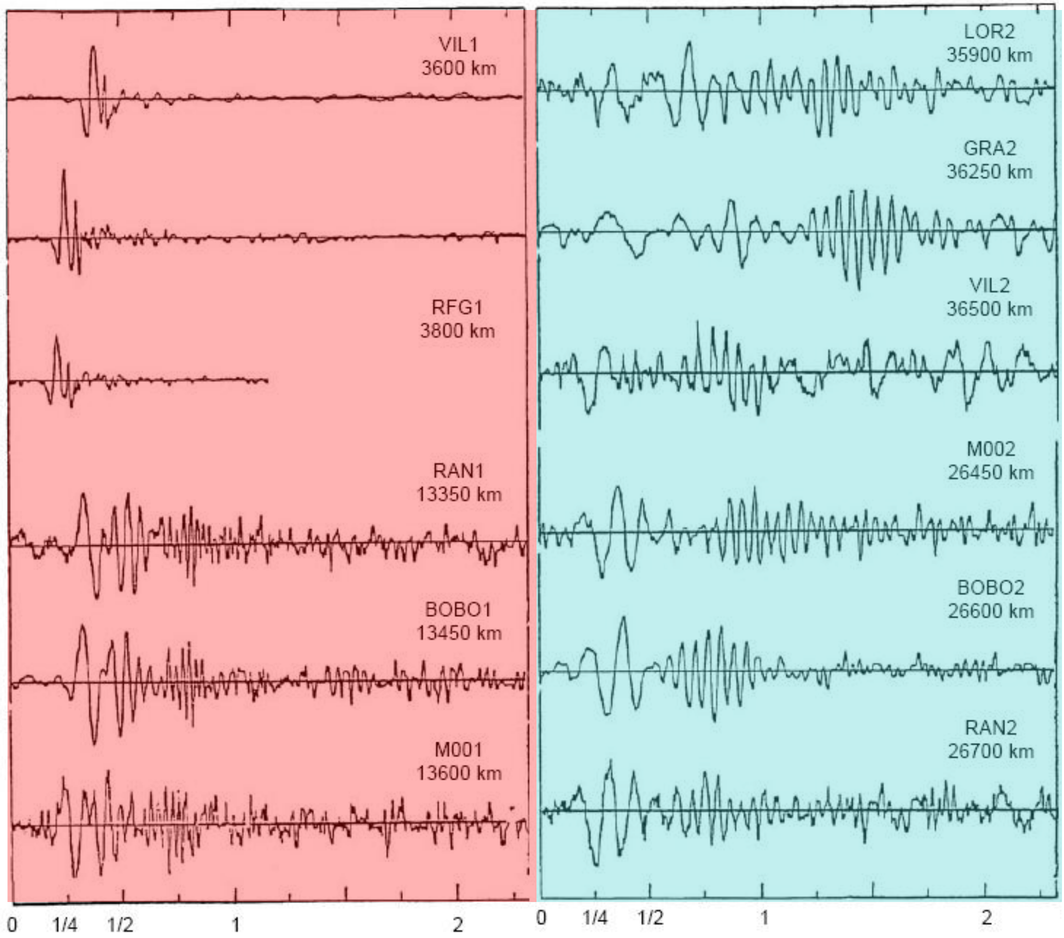
- At the end of nuclear atmospheric tests, HE tests for calibrations (LANL, USA)
    - Atmospheric profiles measured by rockets
    - ANFO explosions: 2 to 4 ktons

# Observations of the atmospheric nuclear tests

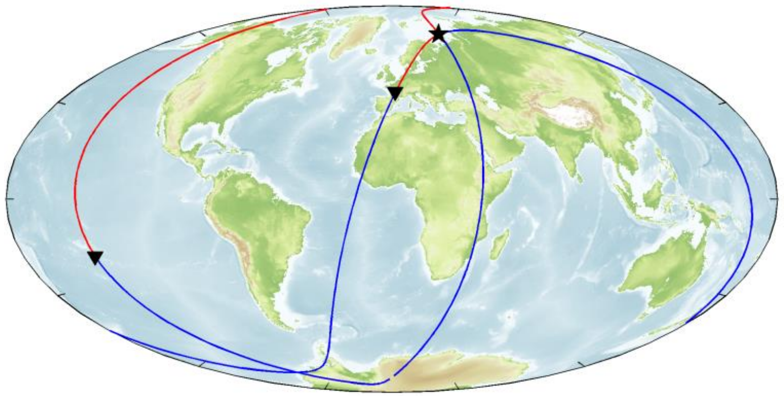
**>10 Mt in the Soviet Union**

1962/09/27, USSR
Y > 10 Mt

**short** great-circle path **long**




relative time [h] relative time [h]



- huge atmospheric nuclear explosions had generated strong pressure wave trains, dominated and headed by Lamb waves (period: >5mn) and followed by acoustic waves (infrasound ~0.01s to 100s)

- signals of such explosions were recorded several times in France and French Polynesia

*ISS 2009*

# Long range propagation of infrasound from nuclear explosions

## Theory

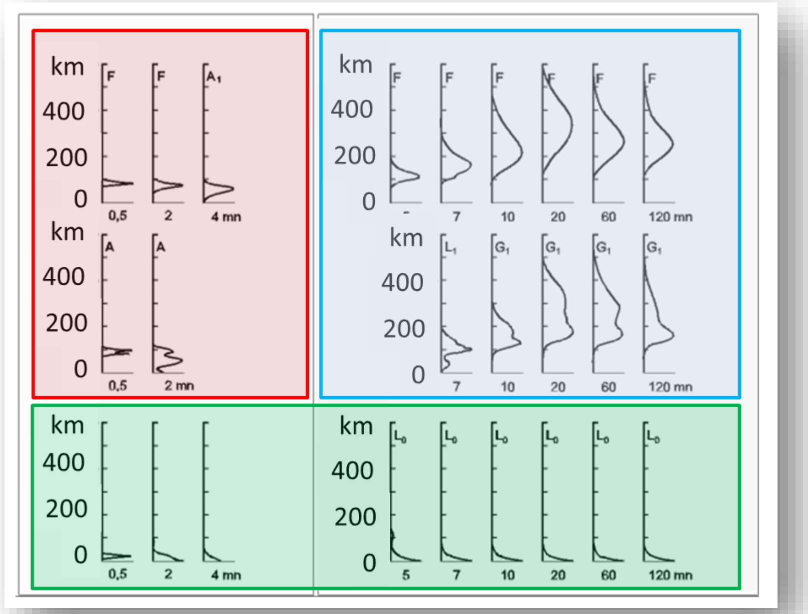
**Modes ducted in the atmospheric wave guide**

Effets of a 10Mt nuclear explosion at 10000 km *(Pierce and Posey, 1973)*

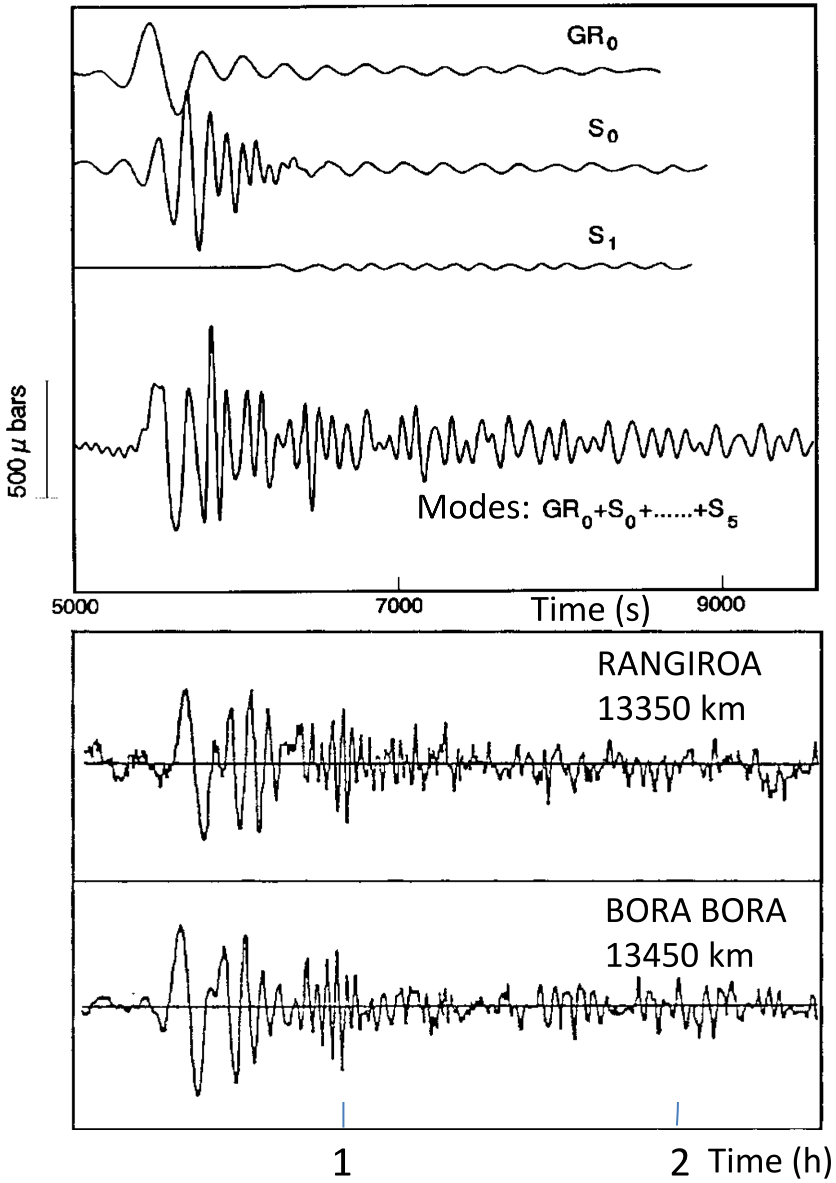
Acoustic modes (S)

Gravity modes (GR)

Lamb modes (L)



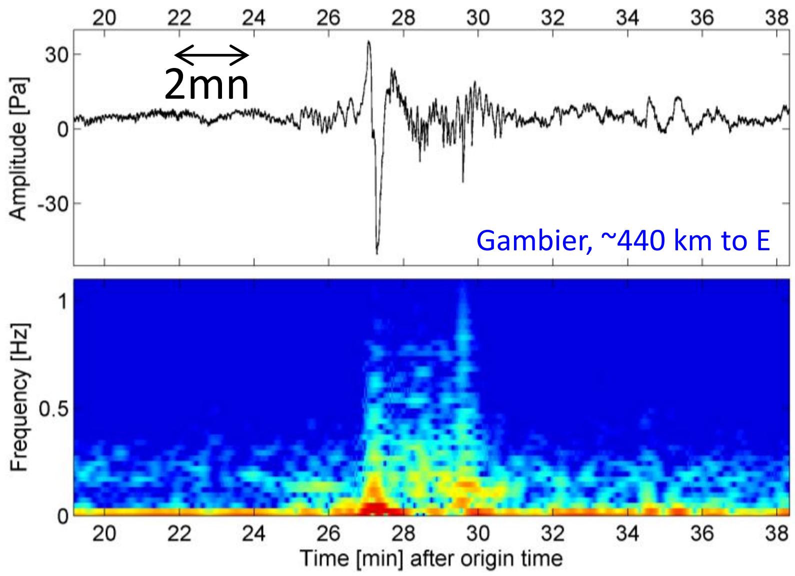

*(ref: Georges, Yeh and Liu, Françis, Kato, etc. )*

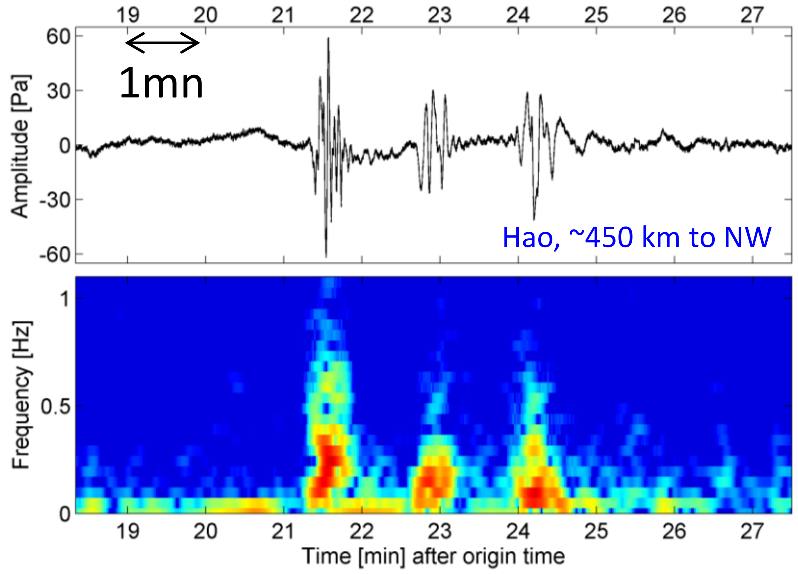



## Observations

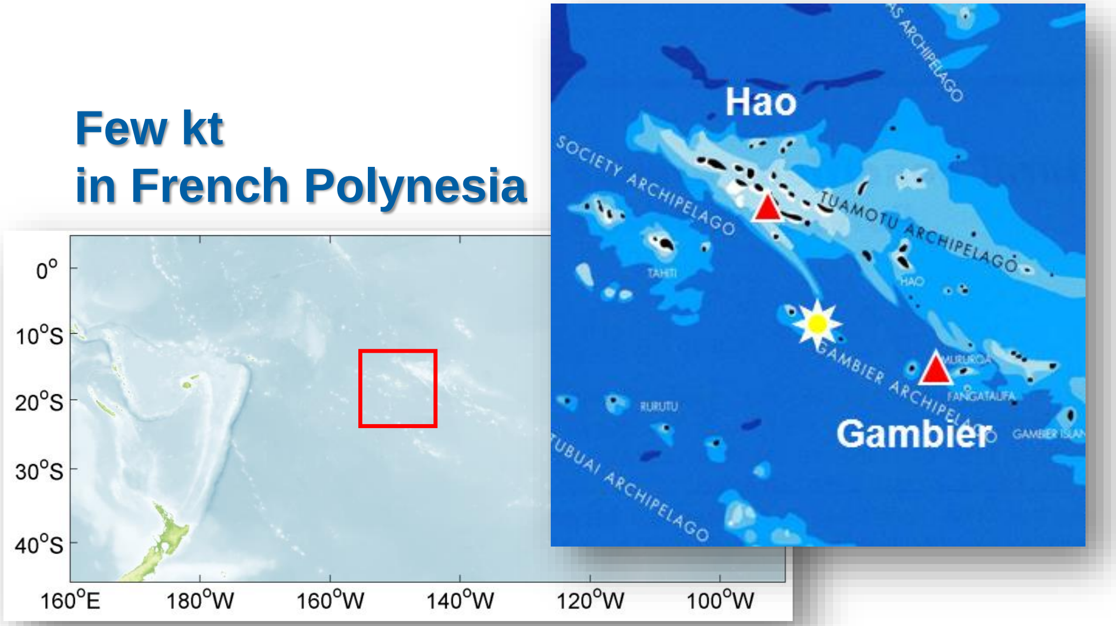
Examples of signals from a nuclear explosion (*CEA/LDG, FR*)

# Propagation complexity observed at shorter distances and lower yields




**Few kt in French Polynesia**




- infrasound propagation is directional both in regard of travel-time and dynamics

- dominating periods range from 30 to 2 s for a few kt explosion conducted near the surface

# The 1990s: CTBT verification, renaissance of infrasound technology

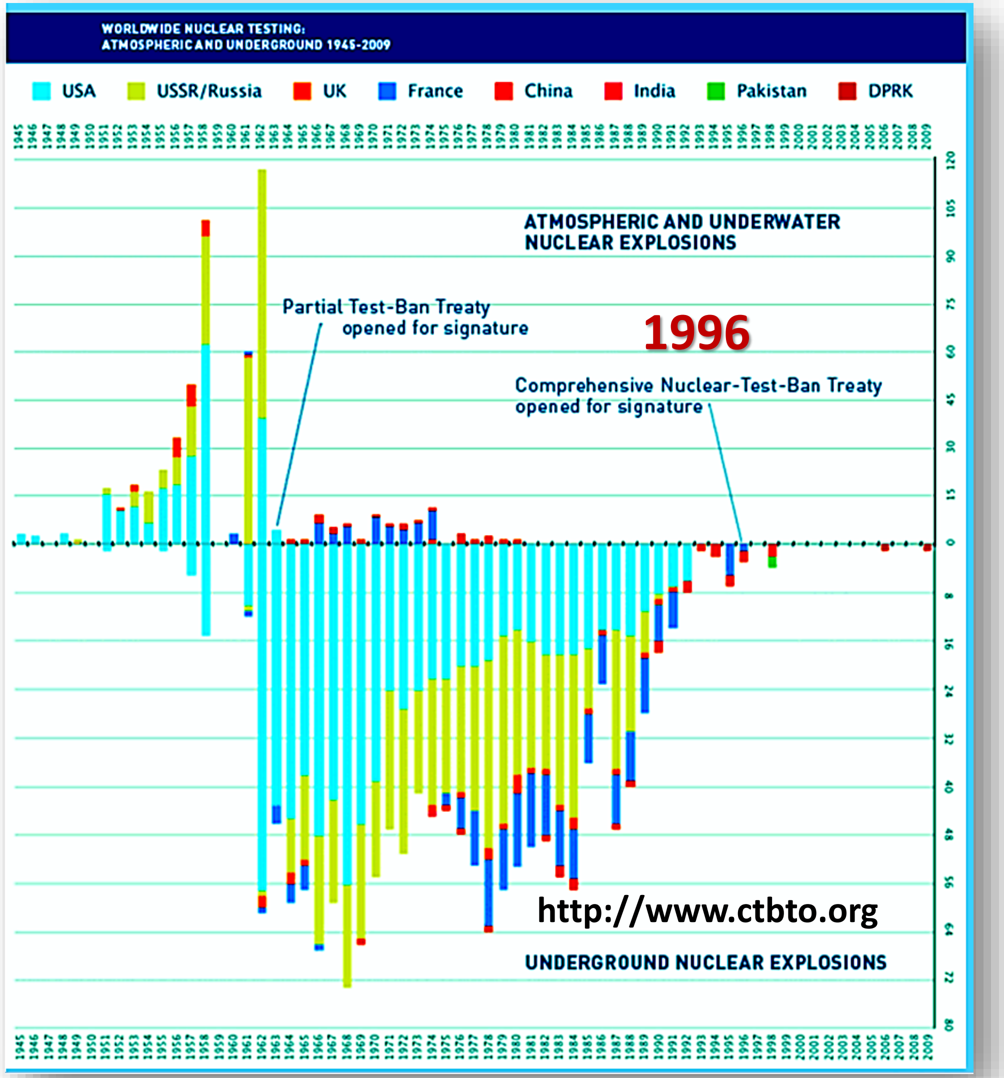
## 1993-96: Conferences on disarmament (Geneva)

- Would it be possible **to detect 1kt worldwide** with the infrasound technology?
- Which kind of signal?
- Which kind of stations?
- What about noise filtering?

## 1996: CTBT signature by 71 States Signatories

## 2001: First certified IMS station in Germany

The system specifications were determined based on the experience of different teams in nuclear explosion infrasound monitoring



# First computations of the network detection capability

**Method:** determination for each point of the Earth the lower explosion yield able to be detected in different atmospheric conditions

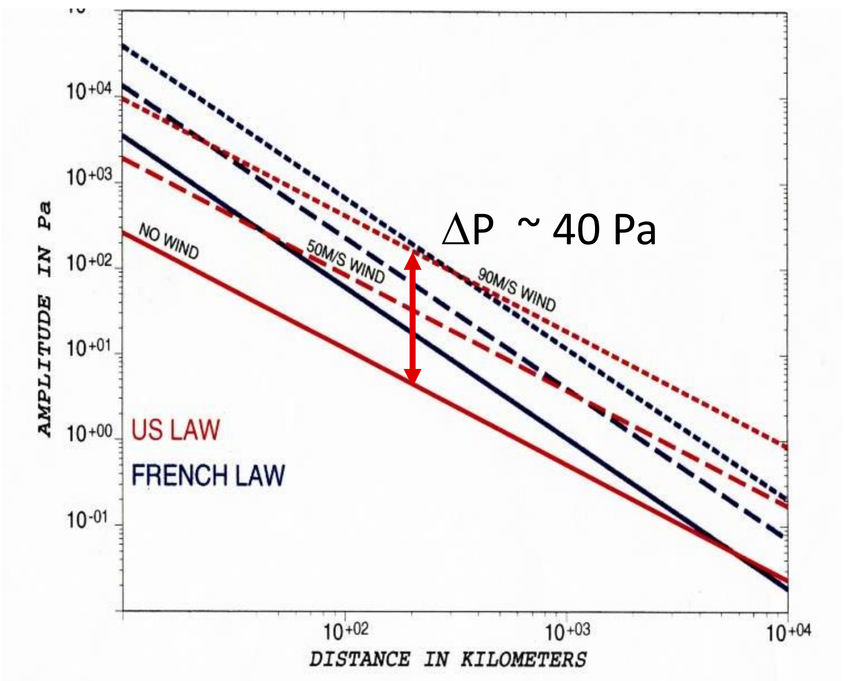
- **Attenuation law of the nuclear/HE explosions amplitude versus range including:**

**zonal stratospheric winds** (climatological models)

$$\log P = 1.33 + 0.68 \times \log E - 1.36 \times \log R + 0.019\, V_s$$

P: pressure amplitude (in Pa),
E yield (t TNT equivalent),
R: distance (in km),
Vs stratospheric wind speed at 50 km altitude (in m/s).

*Whitaker, LANL, 1995*

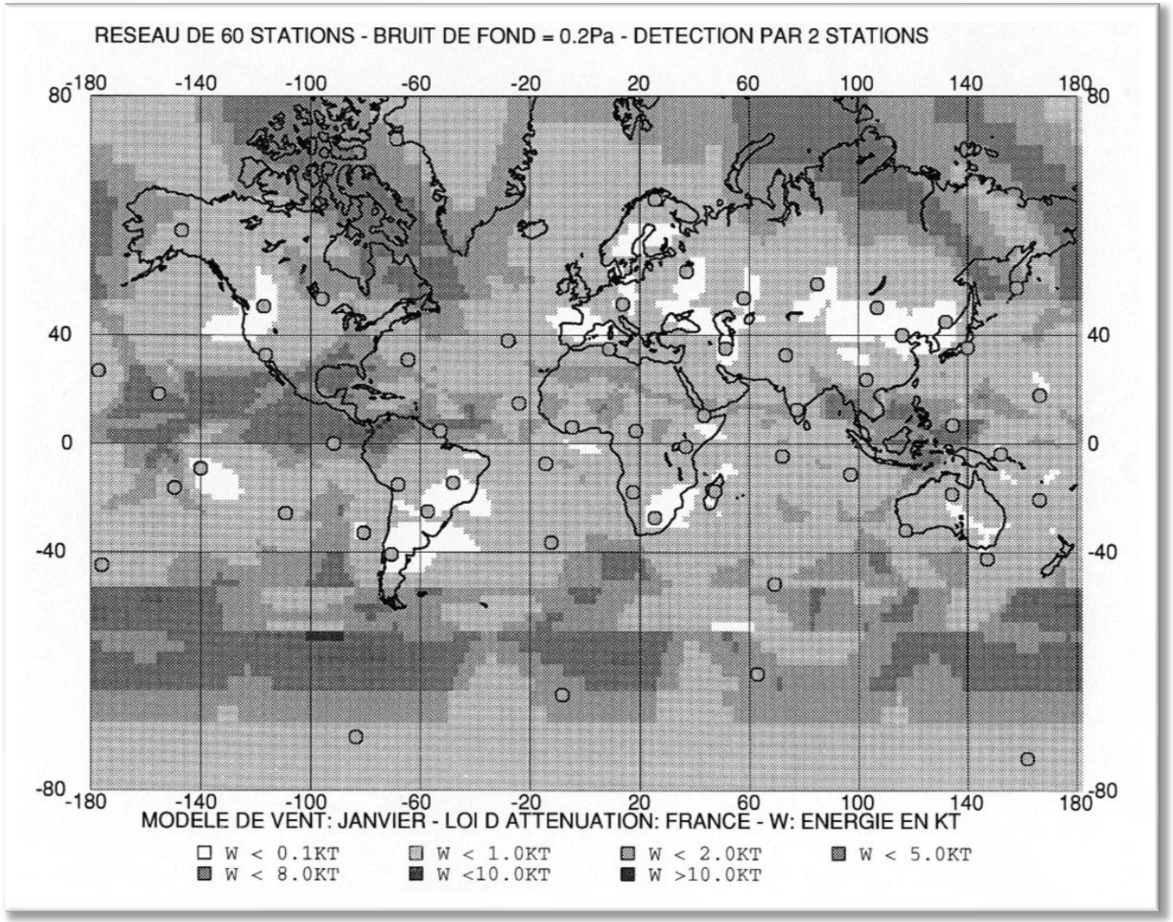



High variability of the signal amplitude, partly corrected by introducing stratospheric wind effects

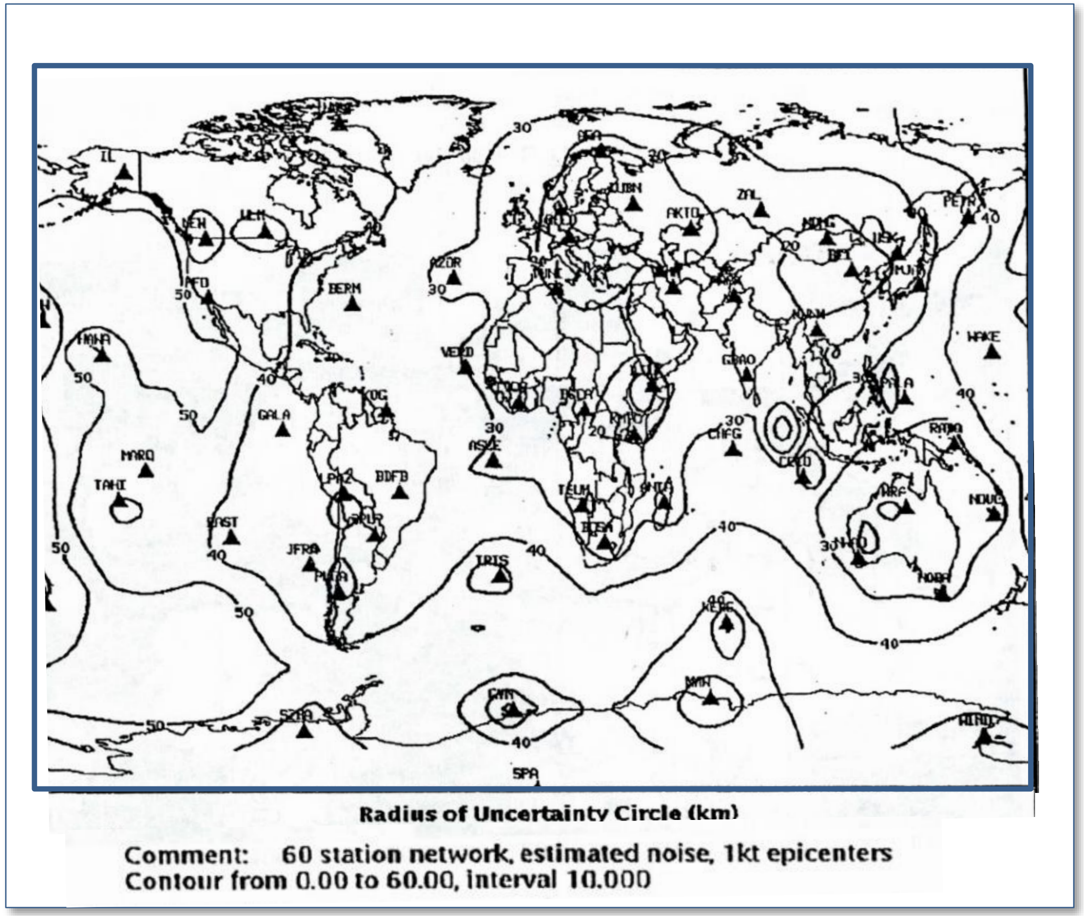
- **Noise level depending on the wind speed near the sensors, inducing wind turbulences**

**surface winds** (meteorological observations at the stations)

# First detection capability maps (60 stations system)




Deterministic approach (FR)



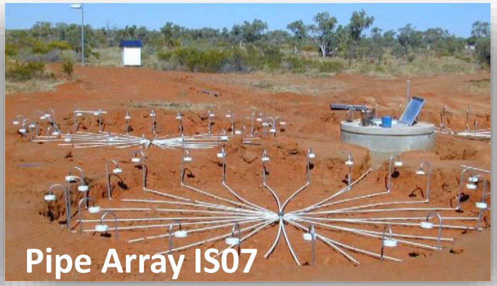

Probalistic approach (USA)

From the **Report of the Infrasound Expert group to the Ad Hoc Committee on a Nuclear Test Ban Working Group on Verification** (15 December 1995)

# Renaissance of the infrasound technology

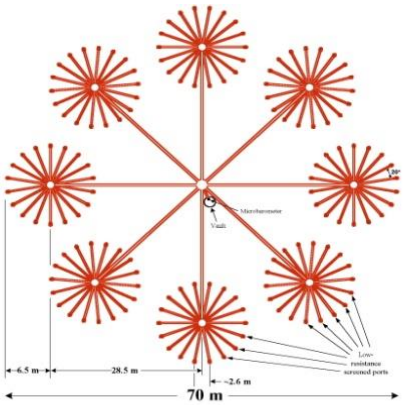
- **Examples of array element equipment**



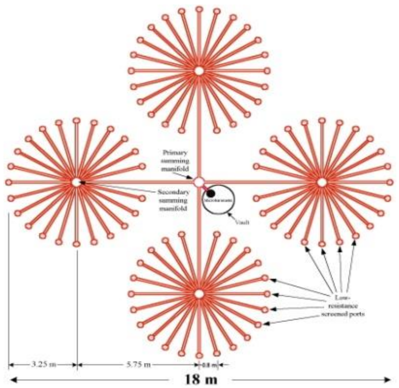




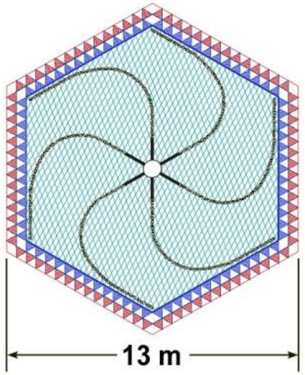
- **Noise reduction systems**



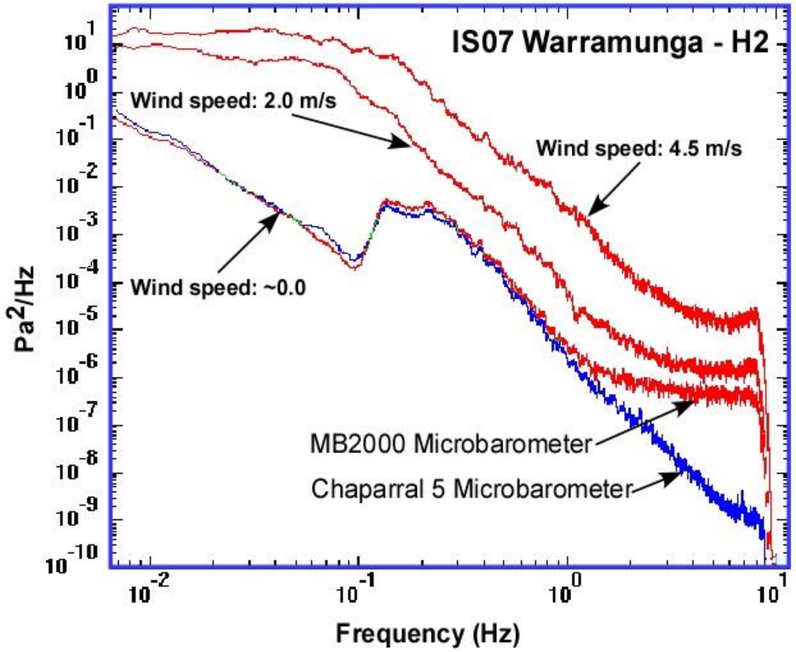

70-m diametre, 144 ports




18-m diametre, 96 ports




6 arm porous hose pipe+ + walls



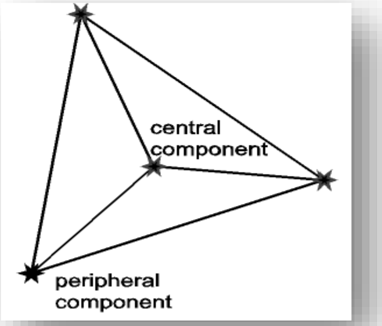

Examples of systems. Dimensions are increased in windy stations

*Bowman, 2005, Christie, 2006, 2007, Alcoverro 2006*

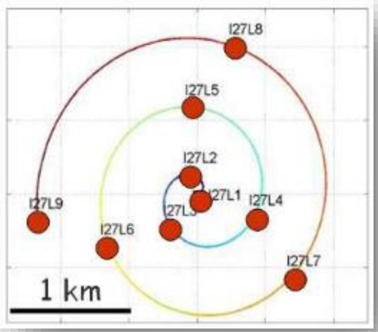
# Infrasound Stations : Very sensitive acoustic antennas

- **Stations : mini-arrays**

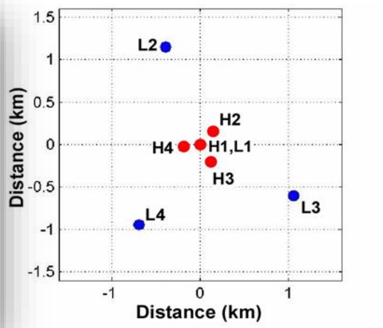
  The sensor number is increased in stations where winds are strong



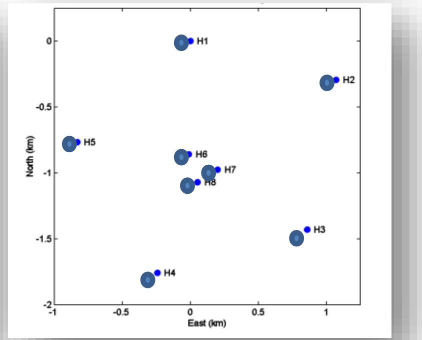

Basic configuration




I27DE (Antarctica)
*Hartmann, 2003*

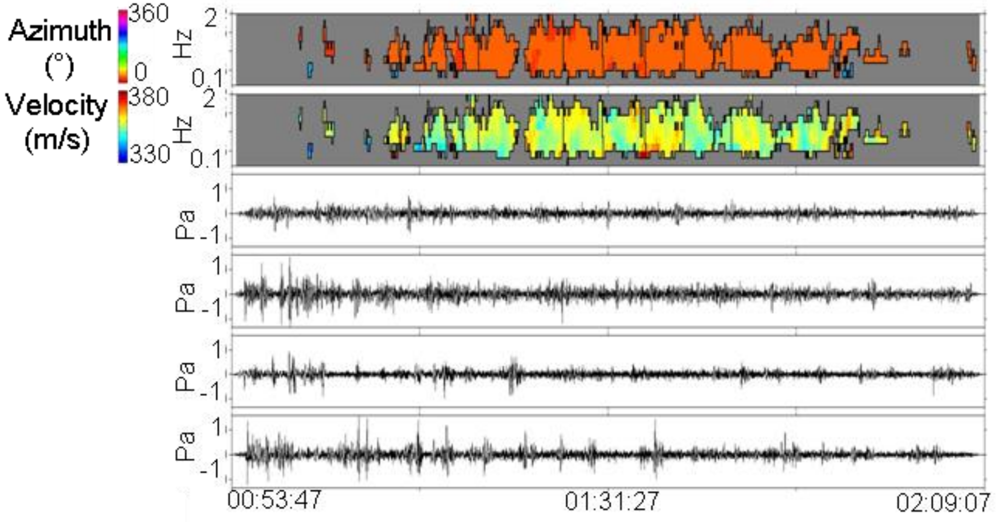



I07 (Australia)
*Christie, 2007*




I53US (Alaska)
*Olson et al, 2002*

- **Data processing methods, bulletins**



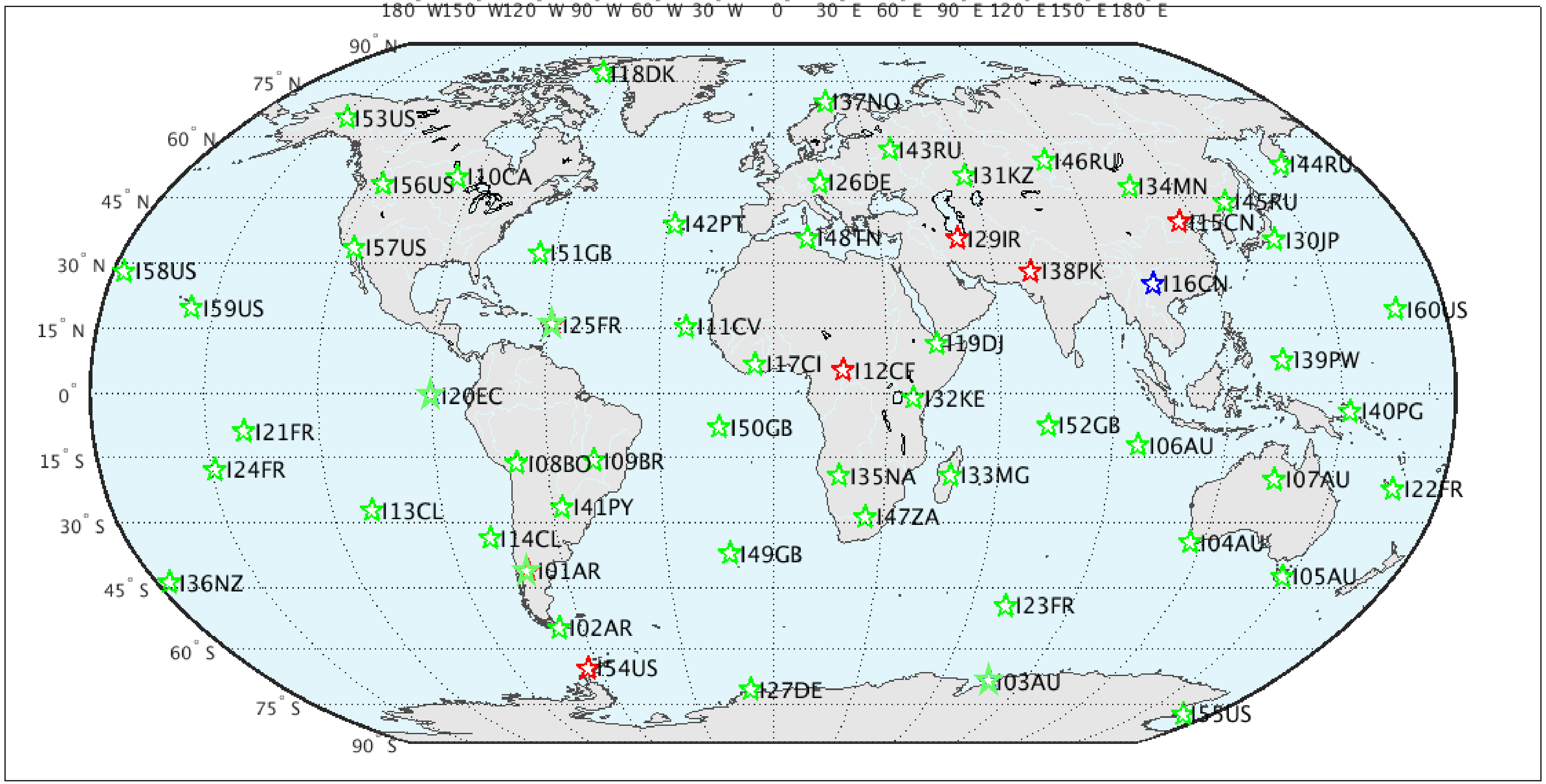

- Measured parameters:
  - azimuth,
  - phase velocity
  - amplitude
  - wave frequency

Progressive Multi Channel Correlation (PMCC) detections *(Cansi, 1995*)
Other method: F-detector (*Fisher, 1992*)

# International infrasound Monitoring System (IMS) for the verification of the CTBT






- Permanent, homogeneous global observations: explosions, ocean waves, bolides, earthquakes, volcanoes, hurricanes…
- Opportunity to calibrate the network from observed Ground Trust Events and to promote civil and scientific applications

*Mialle, 2019*
*www.CTBTO.org*

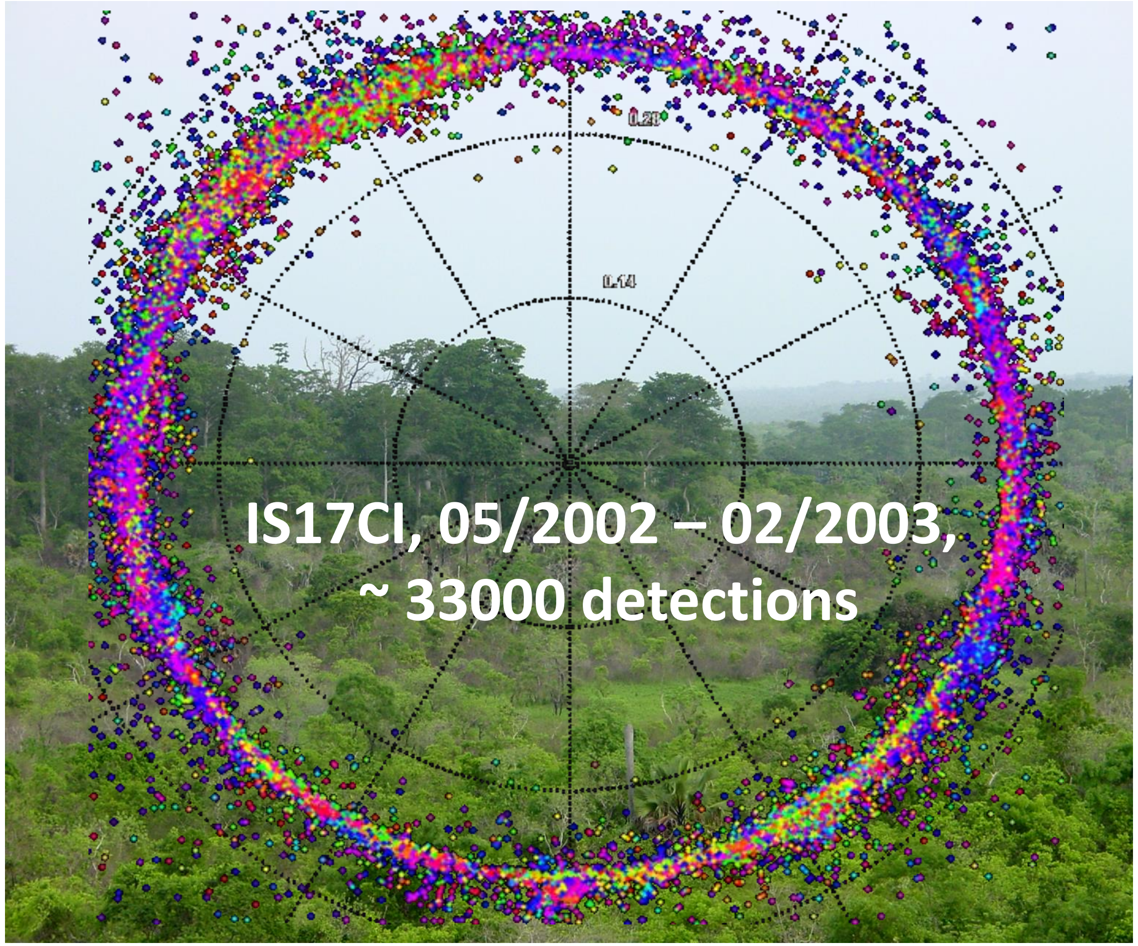
The IMS infrasound network (53 certified stations, 60 when completed) provides relevant global observations of most atmospheric disturbances

# The 2000s: Development of the IMS infrasound network

**2001:** First certified station IS26 in Germany

**2004:** 17 certified stations

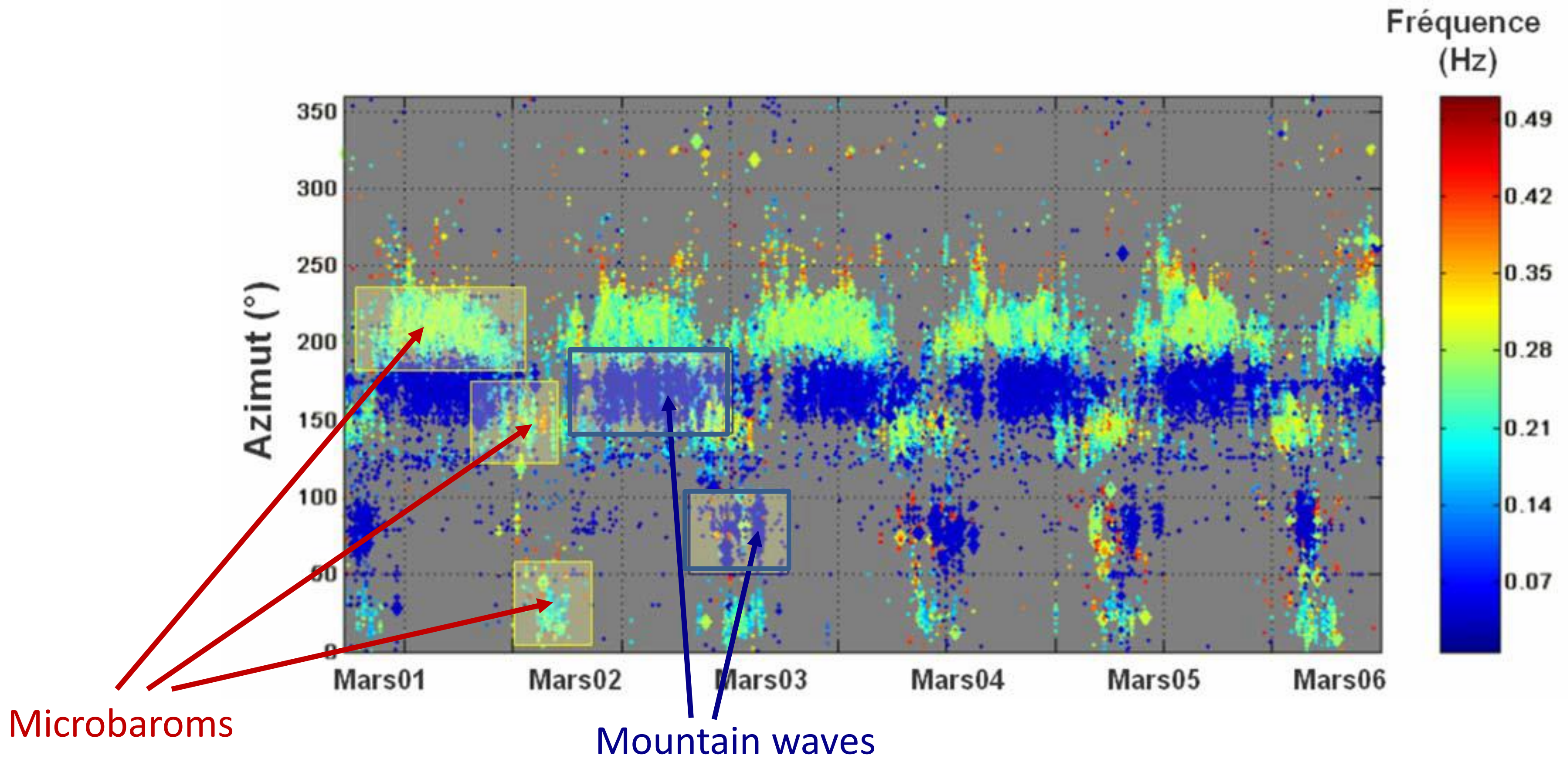


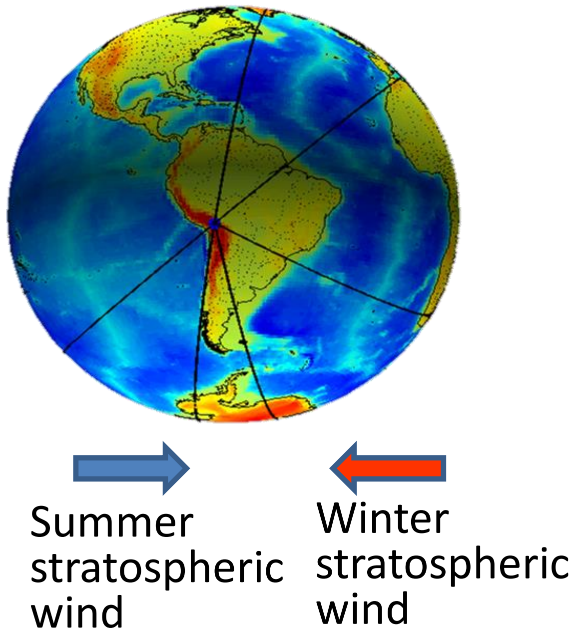



*Le Pichon, 2001*

**Challenge of the event identification and simulations of the infrasound propagation**

# Examples of detections in the Bolivia I08BO station



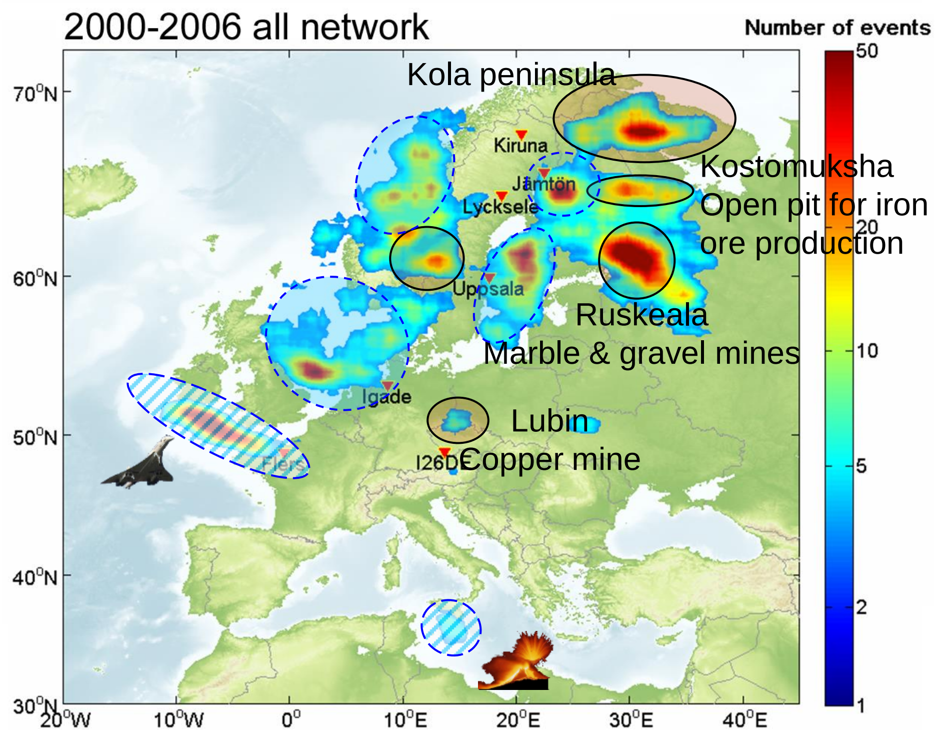




Two main events submitted to seasonal variations :

- Microbarom (green): from South Pacific (200-230°) during the austral winter and from the South Atlantic (130-180°) or North Atlantic (10-30°) during the austral summer.
- Mountain waves (blue): at longer periods (~ 20 s), generated over the Andes

# Synergy with seismology:
# Identification of human activity across Europe

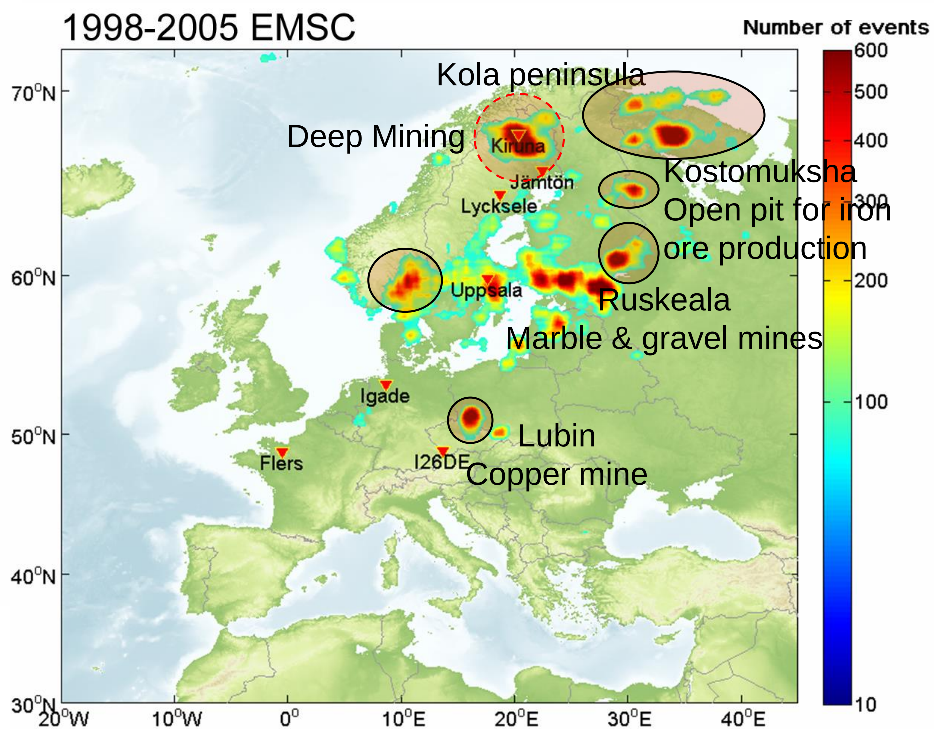
*Le Pichon et al. 2008*




Infrasound-bulletin (2000-2006)

**4 874 events**

*Godey et al. 2006*

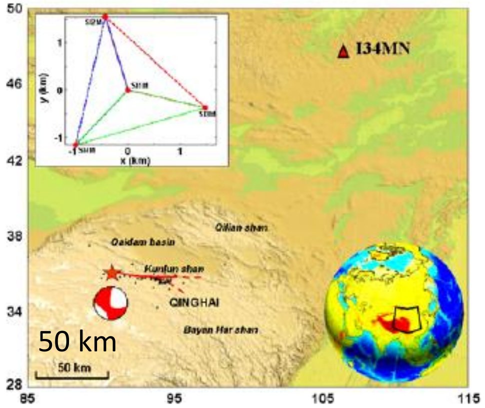


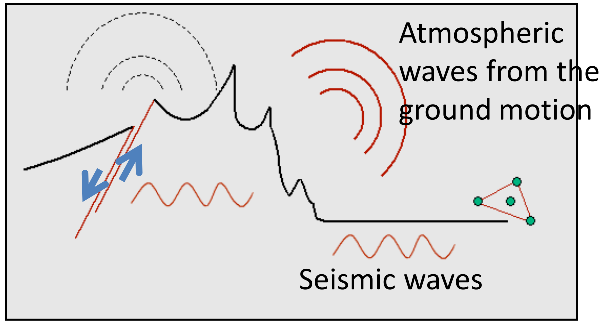

EMSC-bulletin(1998-2005)
artificial events

**18 160 events**

# Infrasound generated by Earthquakes

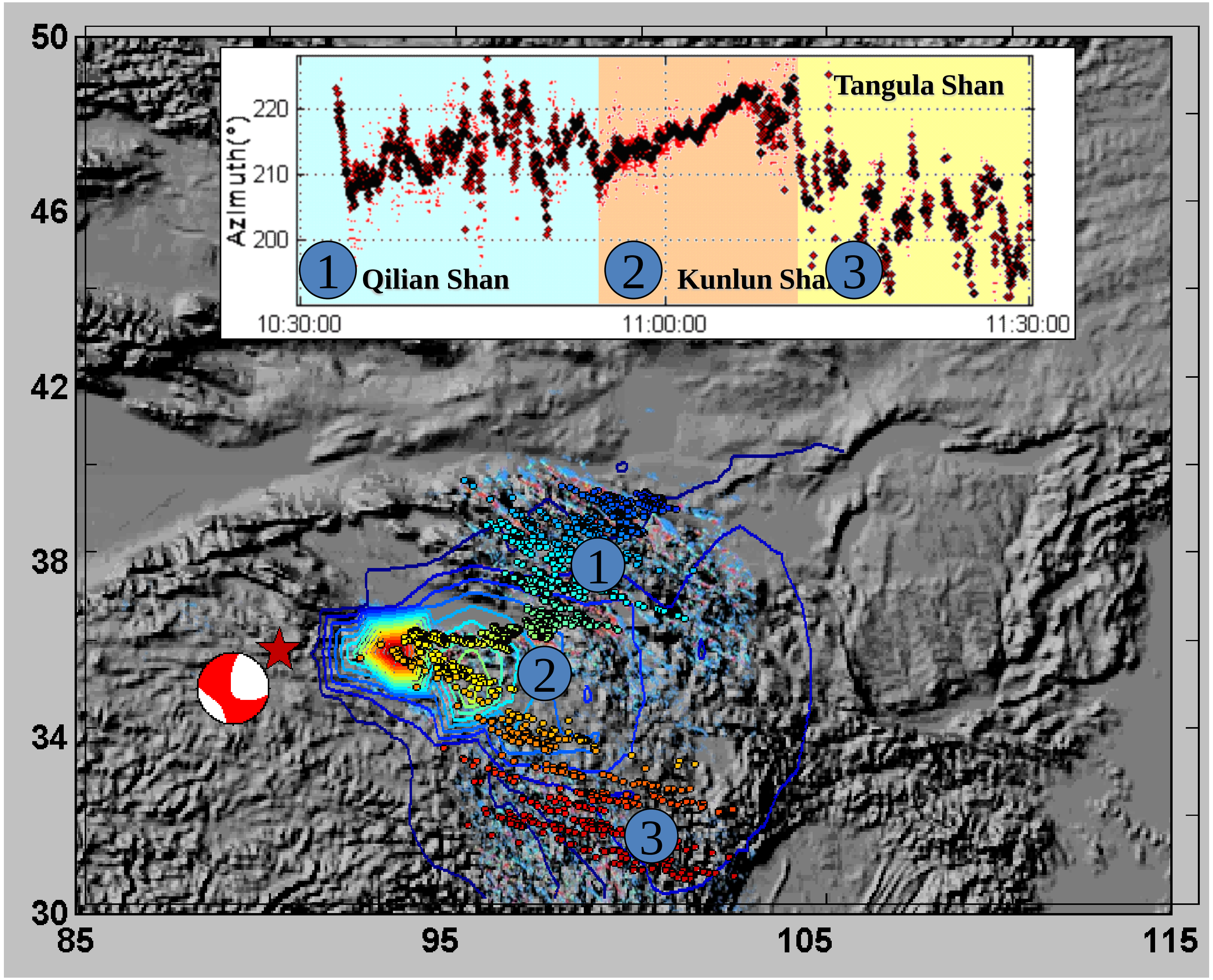
M7.8 China earthquake, 2001/11/14
observed in Mongolia



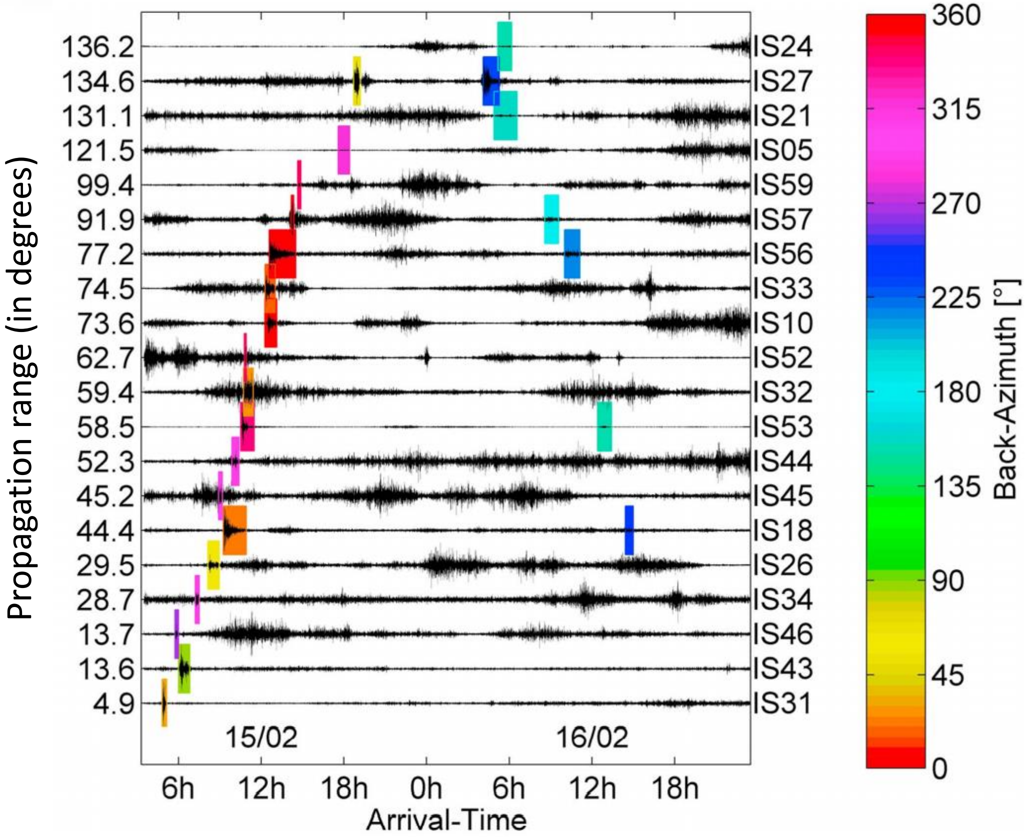




Earth-atmosphere coupling

*Le Pichon et al., 2002*



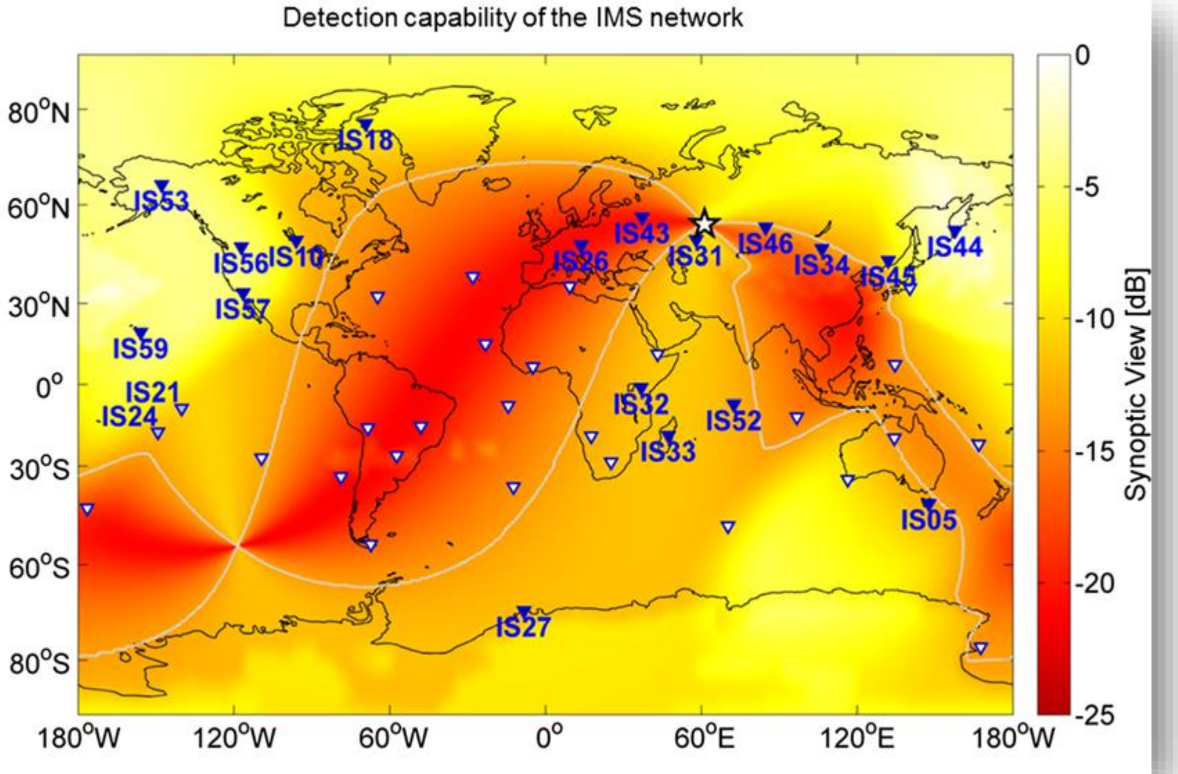
# Chelyabinsk meteorite (15 Feb 2013)




PMCC detections with color-coded back azimuths.

*Le Pichon et al. 2013*

## Detection capability of the IMS network



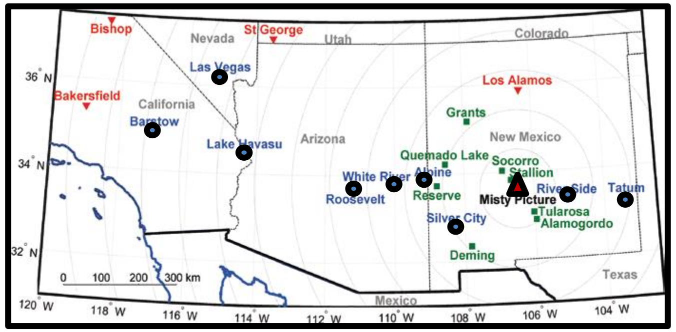

*Pilger et al. 2015*

**The most energetic event recorded by the infrasound IMS,** globally detected by 20 out of 42 operational stations.

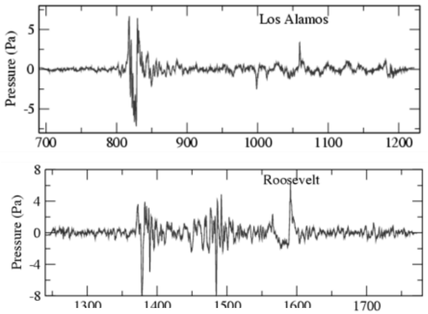
- Period : 20-80 s, Max distance : 86,600 km
- **Explosive Yield : ~450 kt of TNT**
- Diameter : ~20 m, mass : ~10,000 t
- Expected to occur every 100 years

*Brown et al., 2013*

# Calibration of infrasound propagation models: Misty Picture

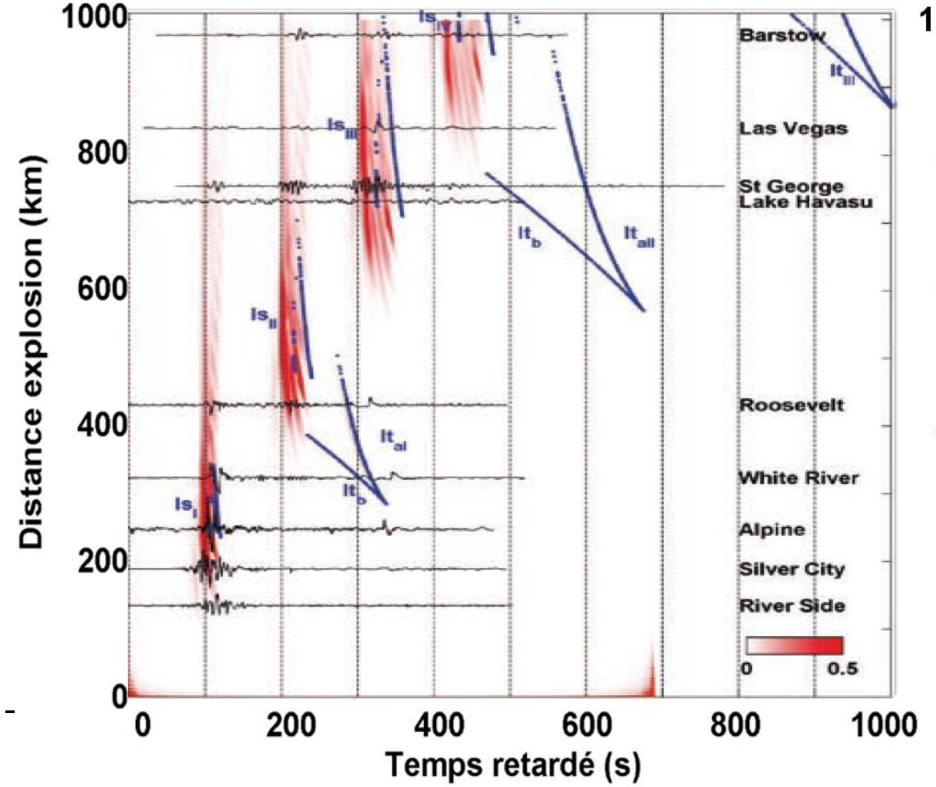


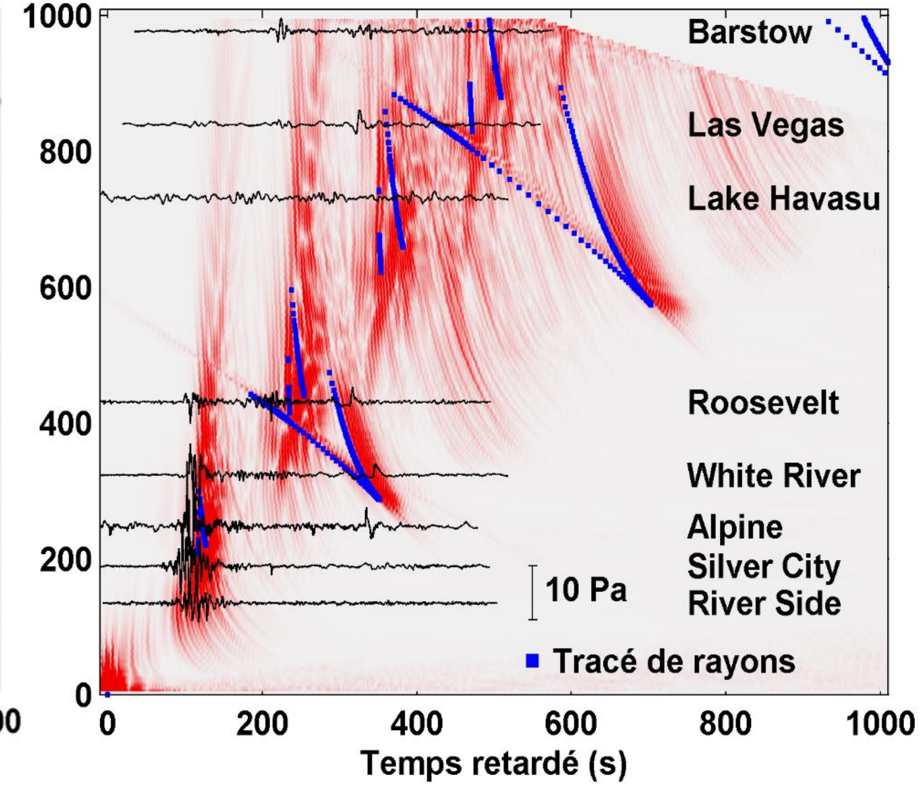

Misty Picture : 14 May 1987 (USA) 4685 tons ANFO. Sandia National Lab.(*Reed et l 1987*), LANL *(Whitaker, et al, 1990*), CEA (*Blanc et al., 1987*). **Rocket atmospheric profiles up to 70 km.**




Comparison between :

- ray tracing ●
- parabolic -
- observations -




*Gainville et al. 2005, 2010, Despres et al., 2006*

- HPC– TGCC (CEA)

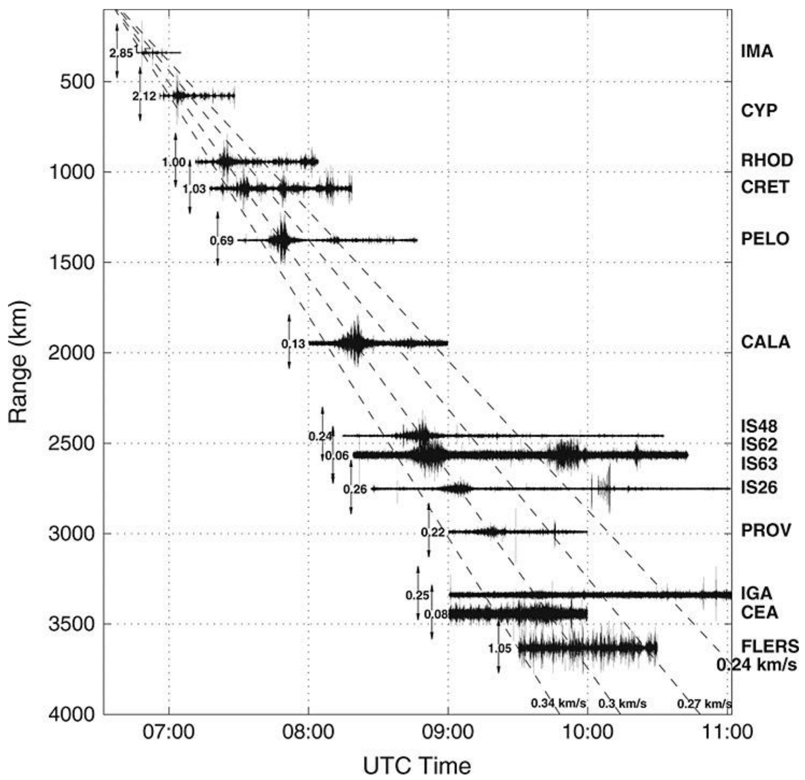
3D Euler simulations

Calibration of different propagation models performed at CEA, using Misty Picture signals recorded up to 1000 km.

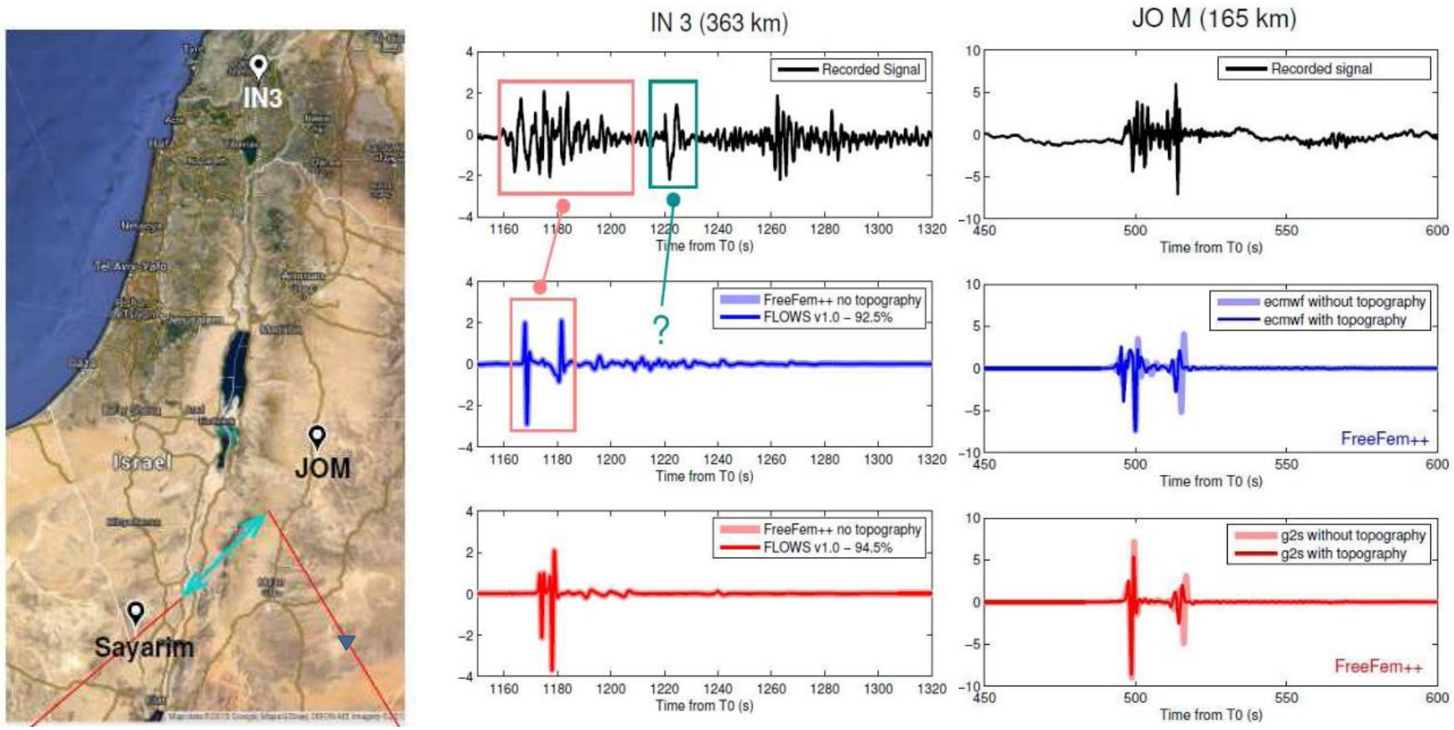
# Calibration specific experiments: Sayarim 2009-2011

Supports: University of Mississippi, Weston Geophysical, Israel NDC, Geophysical Institute of Israel
18 portable infrasound arrays deployed by CTBTO

26 August 2009 (96t), 24 January 2011 (7t), 26 January 2011 (77t)
Sayarim Military Range, Israel.
Infrasound is detected out to and ~6300 km in 2011



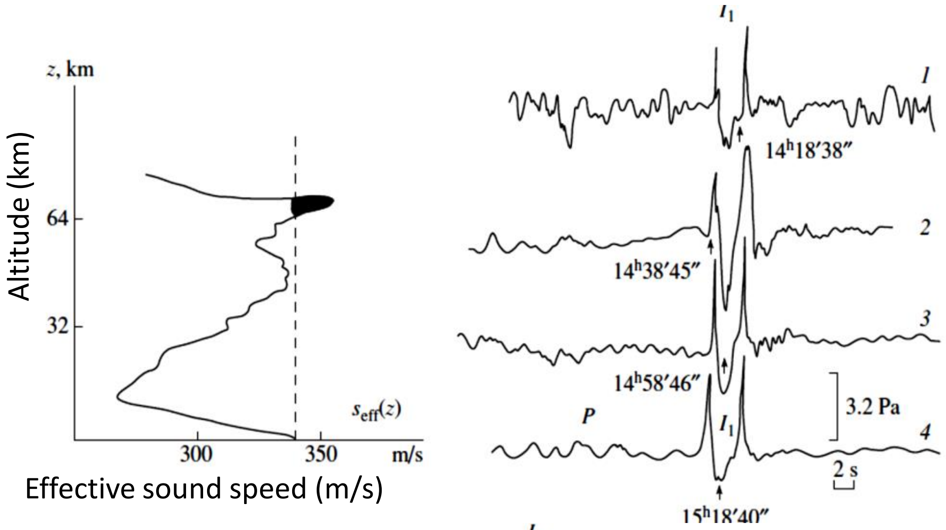

*Fee et al., 2013*

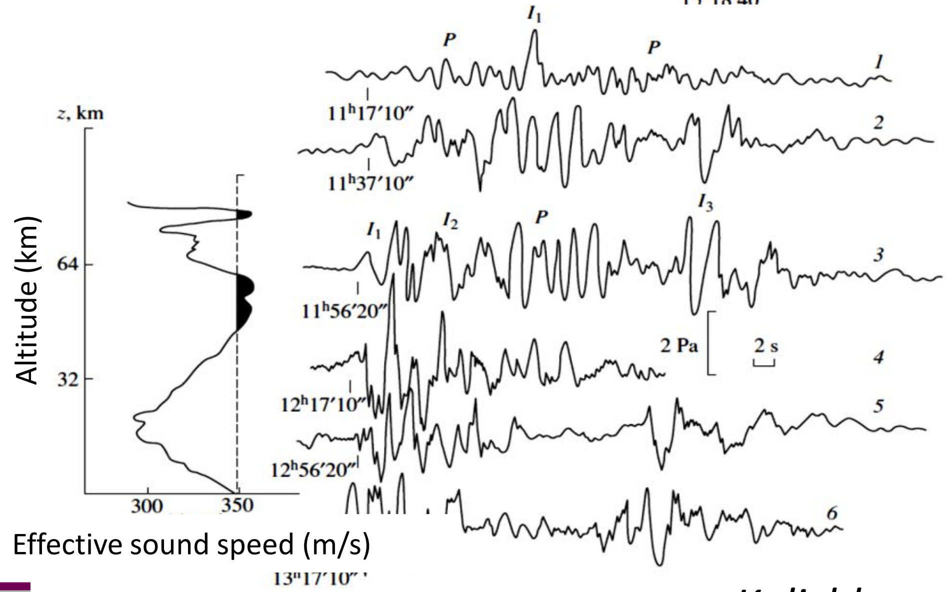



*Ribstein et al., 2016*

- ❑ Observations are well explained at a first order
- ❑ Differences come from fine structures in wind profiles not represented by models

# Calibrations using repetitive sources (explosions) and rocket atmospheric pro




*Kulichkov et al, 2004, 2010*

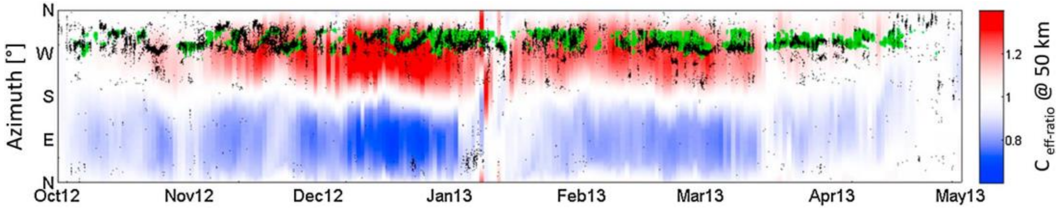
Calibrations using successive explosions showed a large variability in the detected signals, produced by fluctuations in the atmospheric profile

Such fluctuations are not fully described by the models. Improving their representation is needed for accurate infrasound simulations

$V_{eff}$ ratio= ratio between the effective sound speed at 30 to 50 km altitude and the sound speed at the ground level

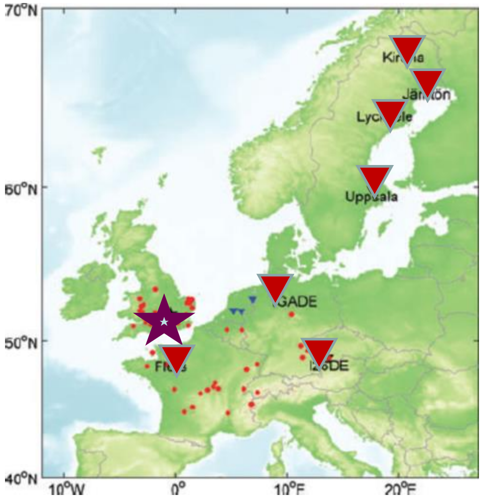
Veff ratio: used as criterion to characterize the infrasound propagation in routine processing and many infrasound studies

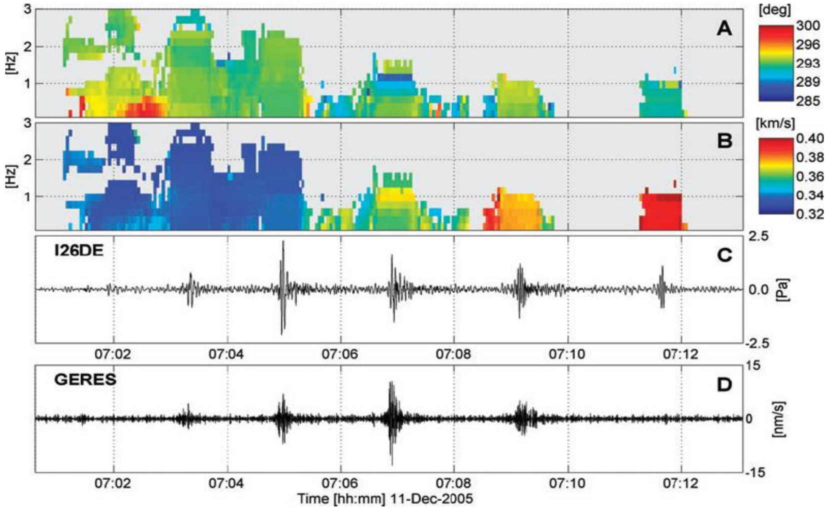
Propagation: Veff ratio >1 (in red)




*Le Pichon et al., 2015*

# Calibration by using the Buncefield accidental explosion

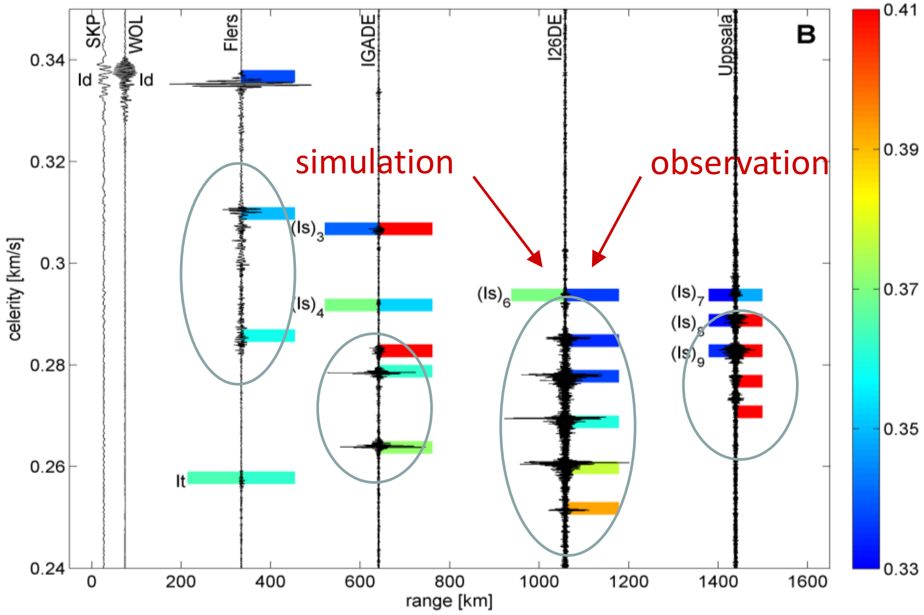


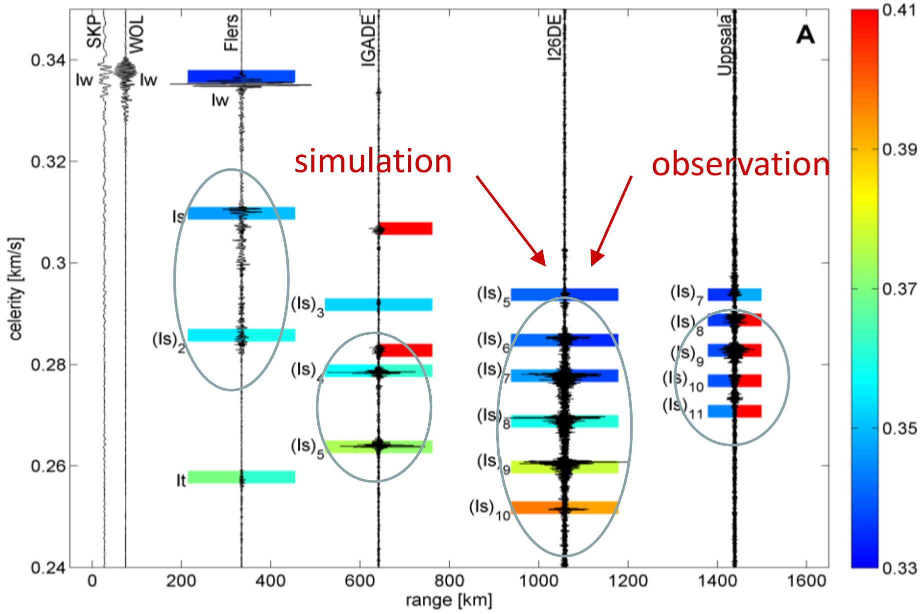

2005 December 11
~300 t petrol in UK

Role of the atmospheric models in the representation of the observations

*Le Pichon et al., ITW, 2006*
*Ceranna et al., JGI, 2009*

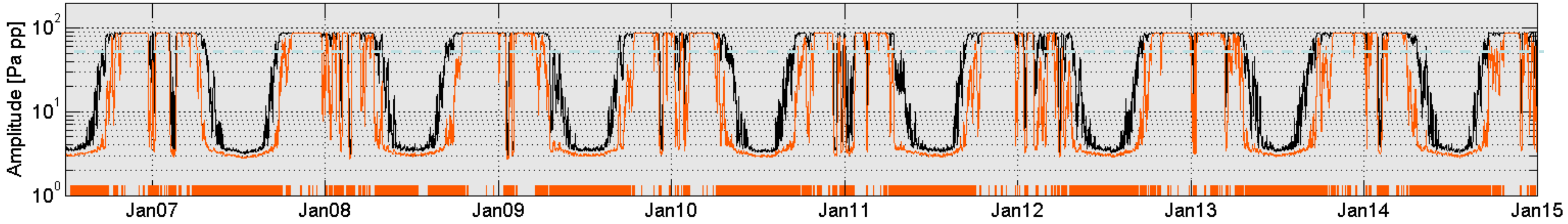



Semi-empirical climatology **Horizontal Wind Model model: HWM-93** (Hedin et al., 1996)

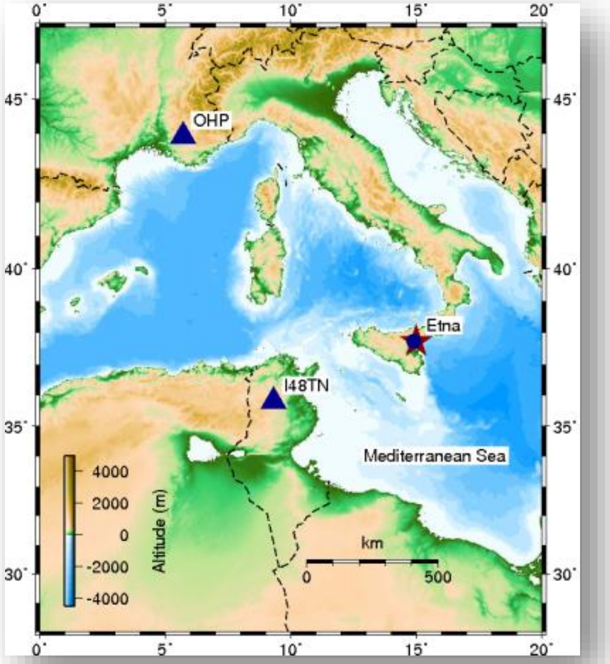



Semi-empirical **NRL-Ground to Space (NRL-G2S)** model (Drob et al., 2003)

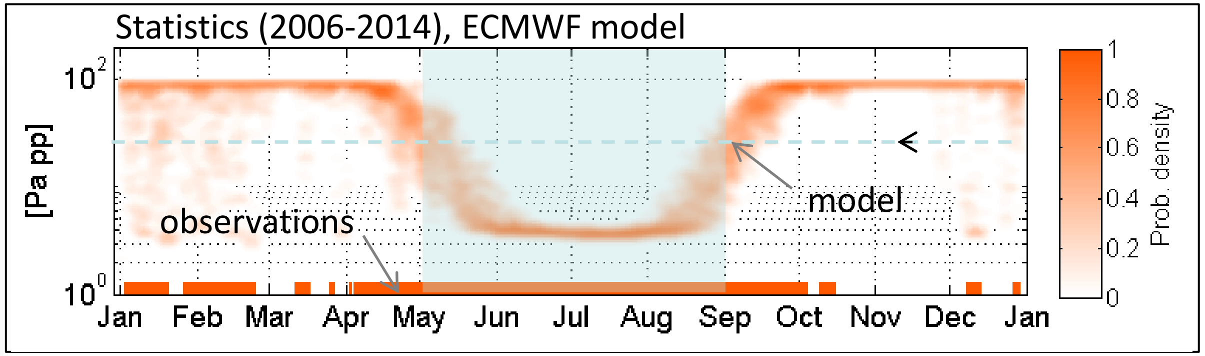
# Incomporing gravity waves in infrasound simulations  using Etna volcano

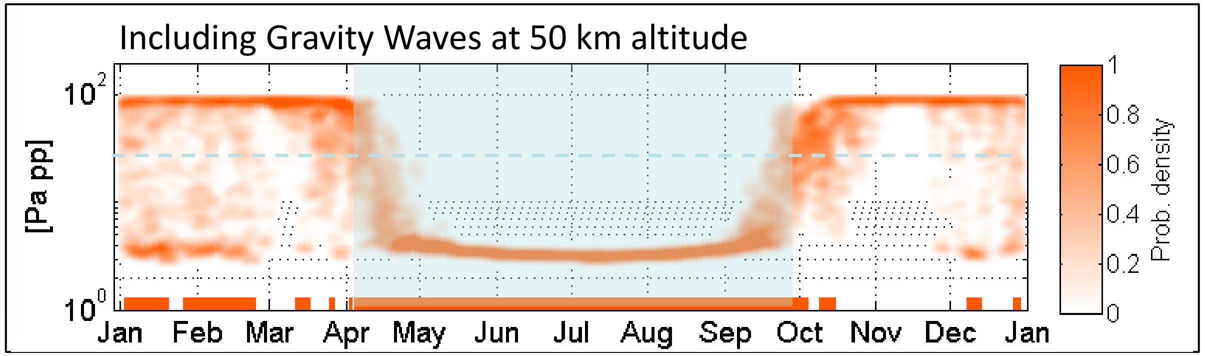



Probabilistic predictions using empirical attenuation relation and atmospheric uncertainty estimates




Etna detected in Tunisia at 550 km



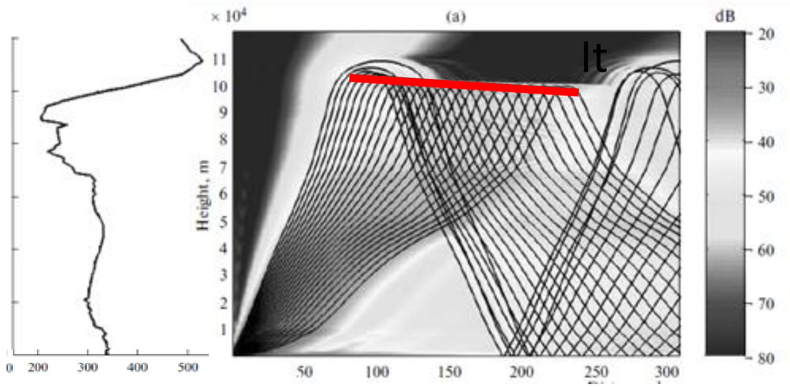




Gravity waves in the stratosphere induce quasi continuously fluctuations in stratospheric wind and temperature profiles, at the origin of partial reflections and increasing the number of detected signals

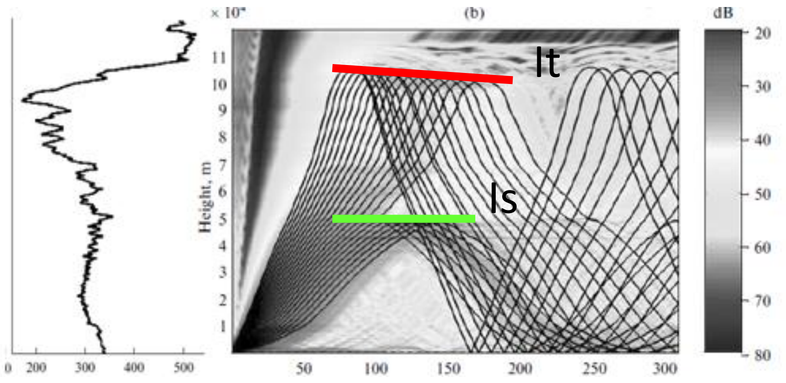
*Le Pichon et al., 2015, Blanc et al., 2017*

# Including gravity waves in the infrasound attenuation laws

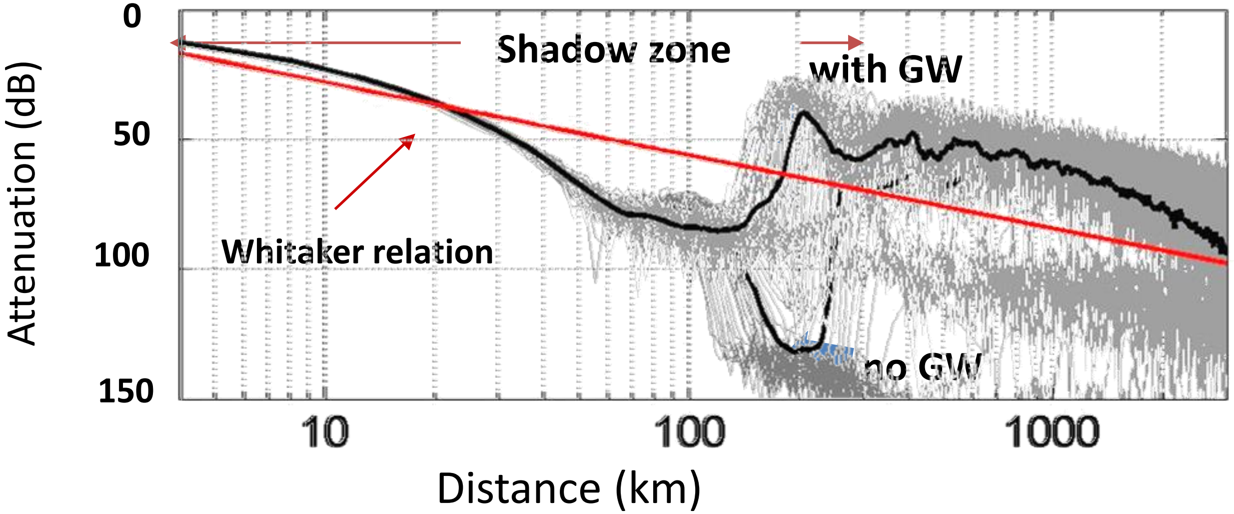
**Standard mean profile**




**Partial reflections from gravity waves**




*Kulichkov et al., 2010*




*Ceranna et al., 2011*
*Le Pichon et al, 2012*

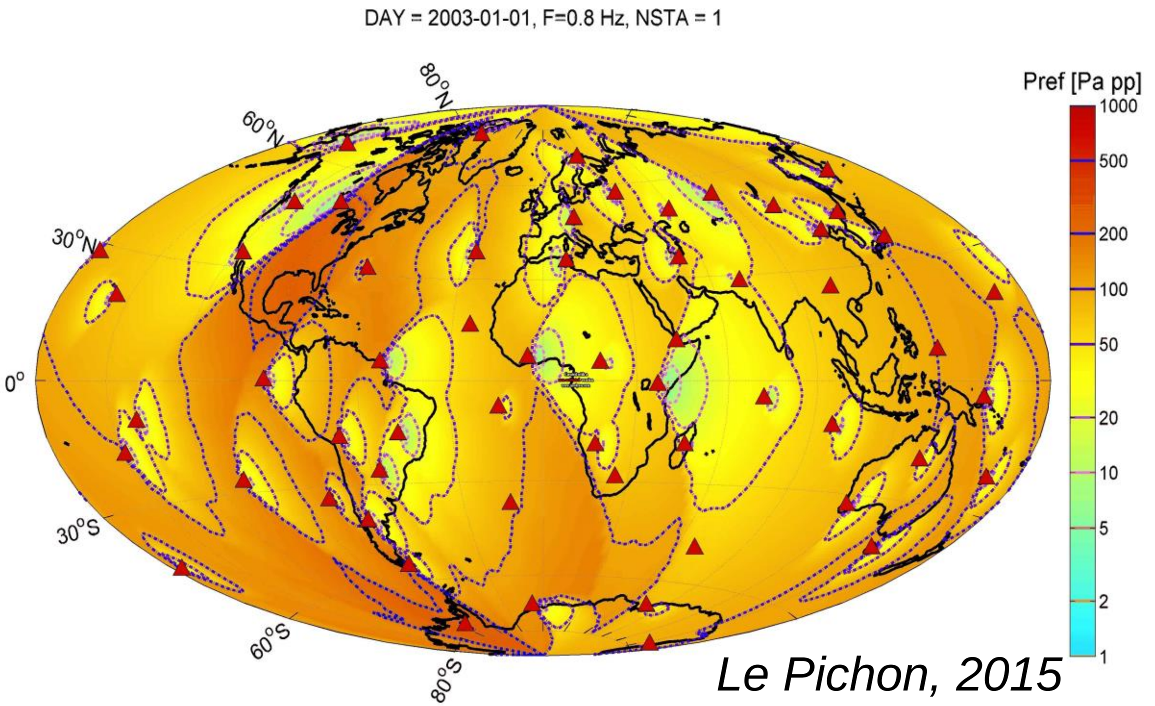
Attenuation law versus distance with and without gravity waves

# Performances of the verification technologies as computed 25 years later

Quantification of detection capability thresholds in space and time :

- ❑ New attenuation laws
- ❑ Meteorological routine models
- ❑ Noise in the stations (Brown et al, 2014)
- ❑ ARISE disturbances (gravity waves)

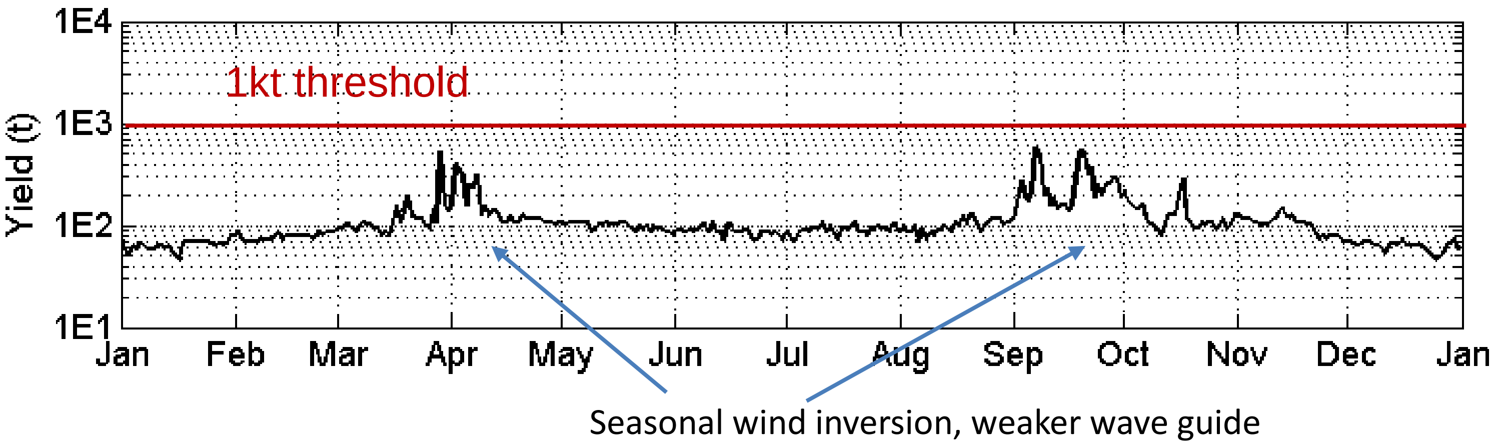
Validation by using observations of large scale events (meteors, explosions, volcanoes)




*Le Pichon, 2015*

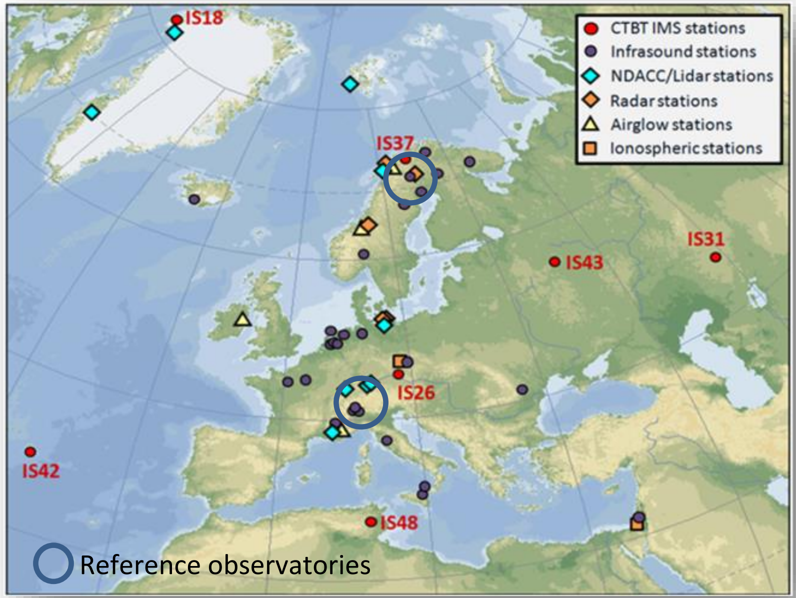
➔ **Implemented in automatic procedures: daily maps**

➔ **Operational products at IDC**



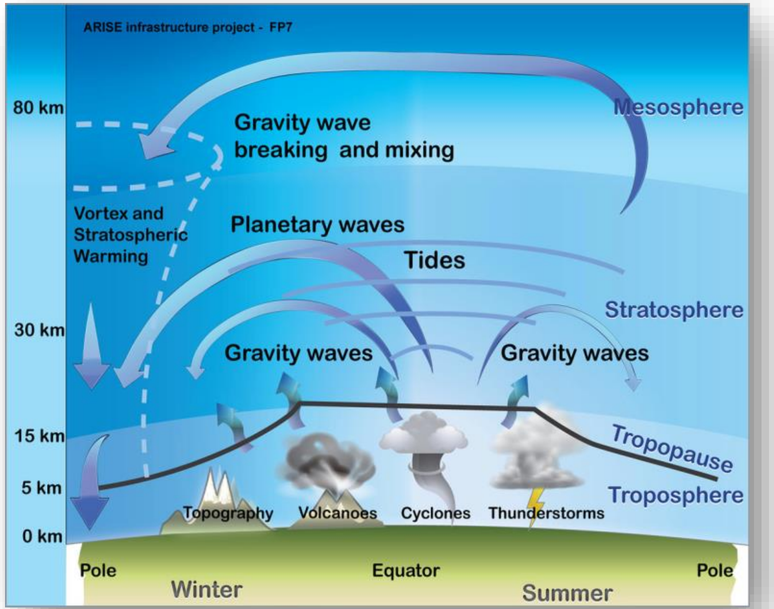
# Reducing model uncertainties by improving the knowledge of stratospheric dynamics

## ARISE station network





## Dynamics processes




**Complementary observation systems:**

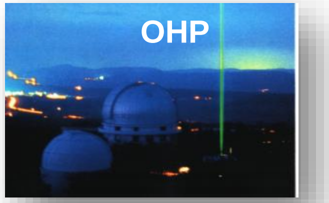
- IMS infrasound network
- Network for the Detection of Atmospheric Composition Change (NDACC) lidar stratospheric winds & temperature
- Mesospheric observations by OH spectrometers, Meteor radars, spectroradiometer

The ARISE **(Atmospheric dynamics Research InfraStructure in Europe)** project combines complementary observations with theoretical and modelling studies to better understand and describe the dynamics of the middle and upper atmosphere

ARISE was funded by the European Union’s 7th and H2020 Framework Programmes

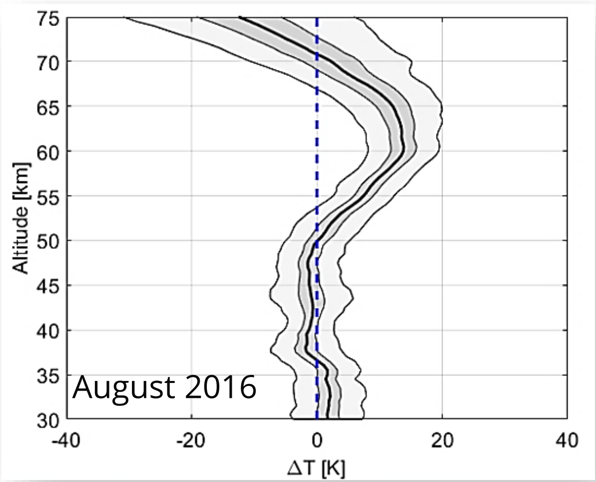
# Comparison between observations and ECMWF*

European Centre for Medium-Range Weather Forecasts

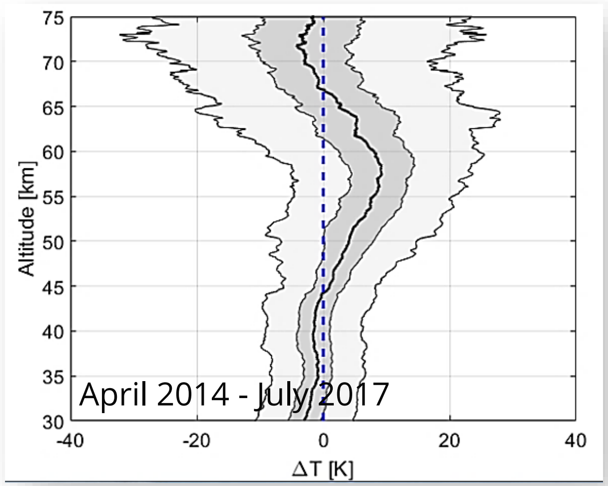





**Norway (Andøya, 69.3 16.E)**




**France (OHP, 43.9N 5.7E)**

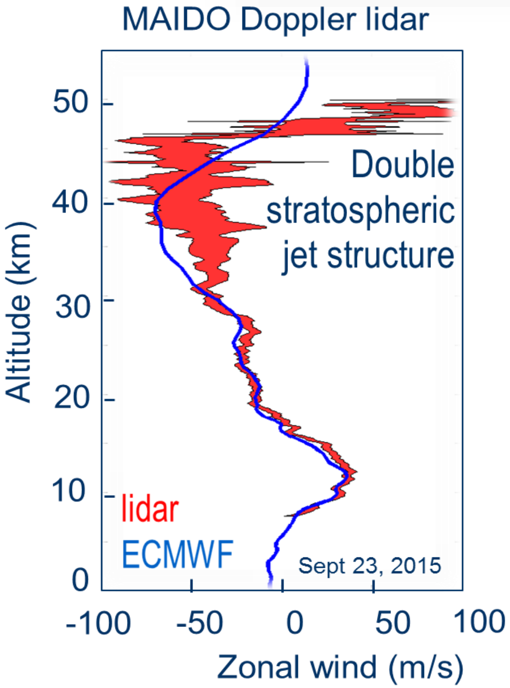


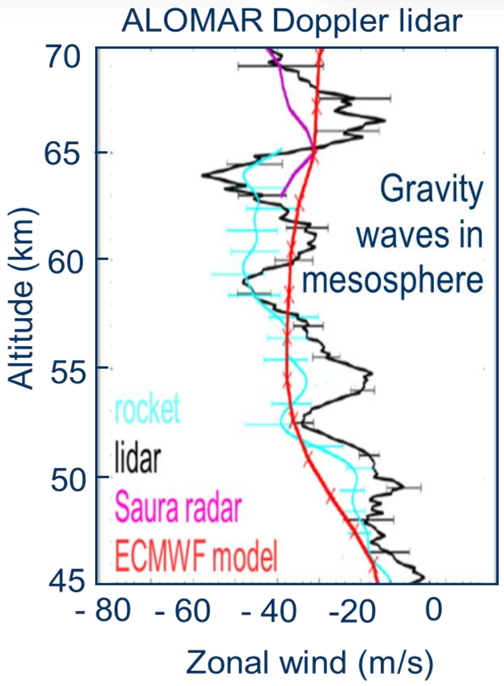

Differences between lidar observations and ECMWF temperature profiles exceeds 10K in the stratosphere and mesosphere.

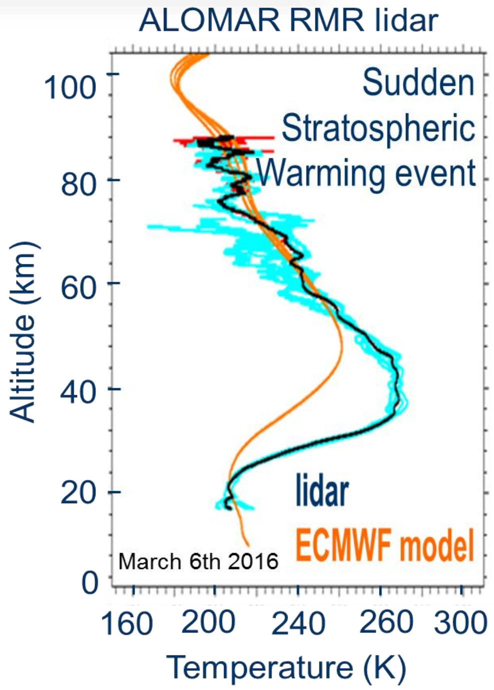
*Le Pichon et al, 2018*

- ❑ The models do not integrate short time scales (< few days) disturbances
- ❑ Interest of lidar observations associated to infrasound stations for routine processing

*Hauchecorne, 2016*



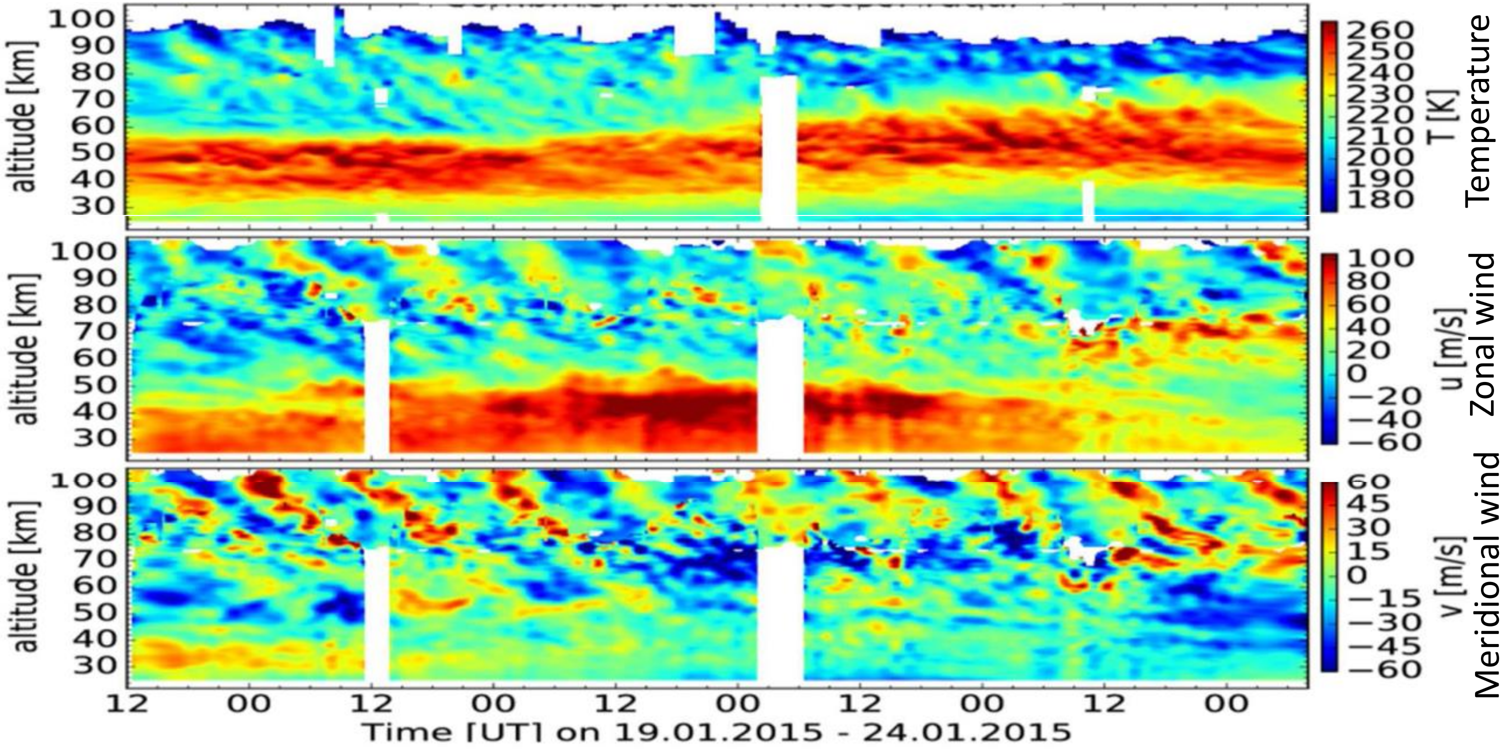



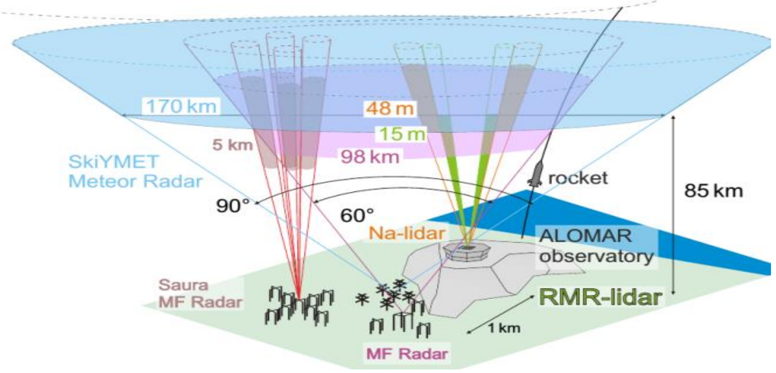

*Baumgarten, 2014, 2016*

# Challenge: How to accurately determine the fluctuations in the atmospheric profile?

High resolution combined temperature and wind observations by lidars and meteor radar in ALOMAR
Unique multi instrument campaign continuously during several days: full temperature and wind profile, in altitude and time revealing dynamical complex structures (gravity waves and solar tides)

**Lidar and radar observations**




- ALOMAR Rayleigh/Mie/Raman lidar,
- Mobile iron resonance lidar,
- Andenes meteor radar.

*Baumgarten, Stuber, Höffner , 2016*

Remarkable agreements between observations and models but also large differences: observed gravity waves and tidal signatures are not reproduced in the ECMWF estimates, neither in temperature nor in winds

# Challenge: How to accurately determine the fluctuations in the atmospheric profile?

High resolution combined temperature and wind observations by lidars and meteor radar in ALOMAR
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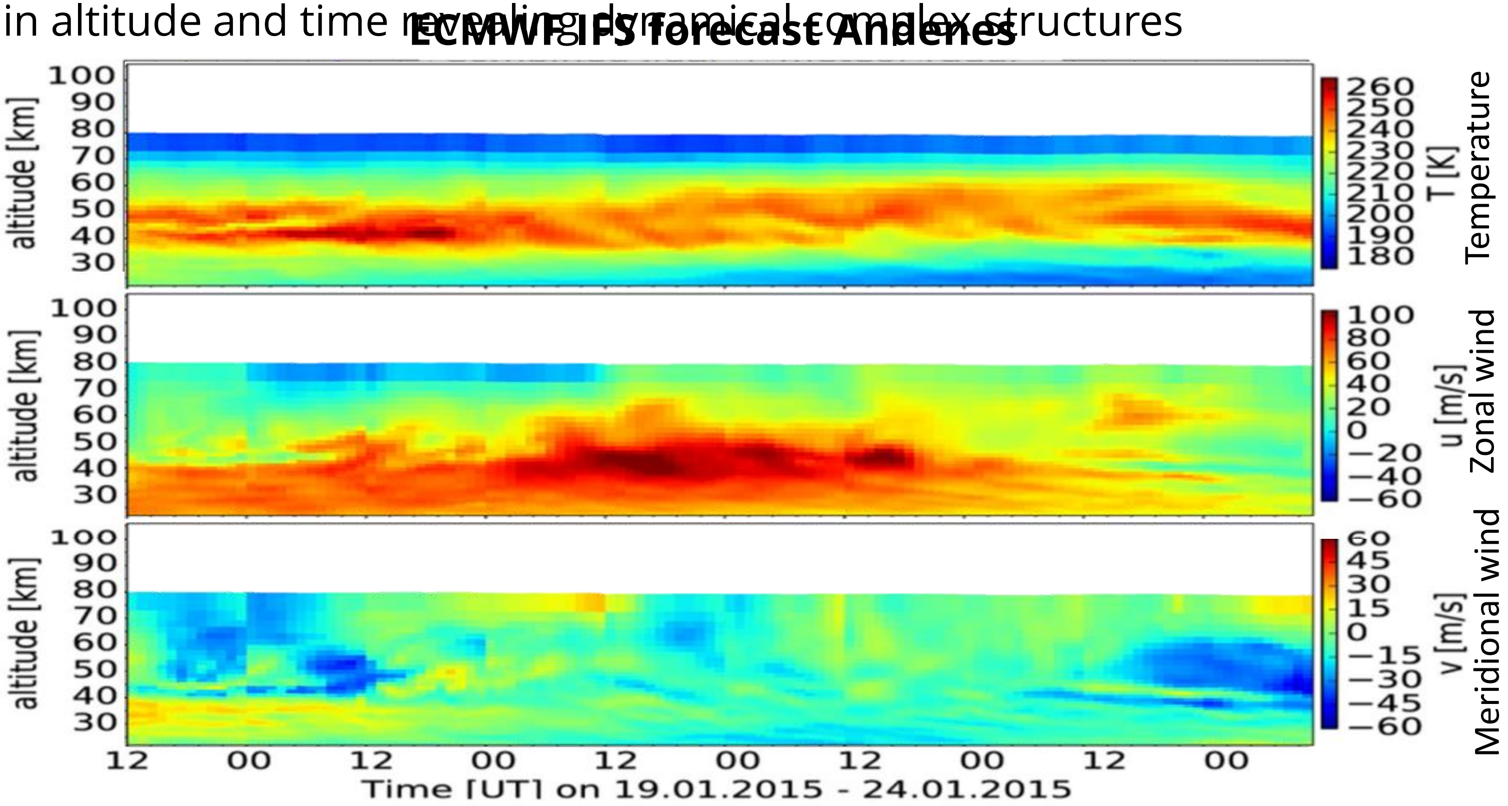


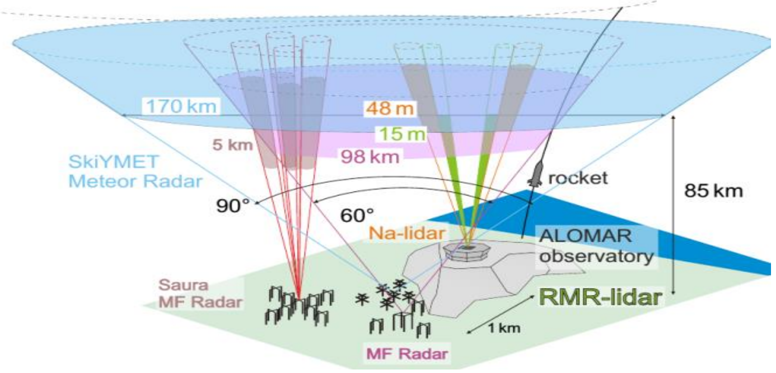


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*Baumgarten, Stuber, Höffner , 2016*

Remarkable agreements between observations and models but also large differences: observed GW and tidal signatures are not reproduced in the ECMWF estimates, neither in temperature nor in winds

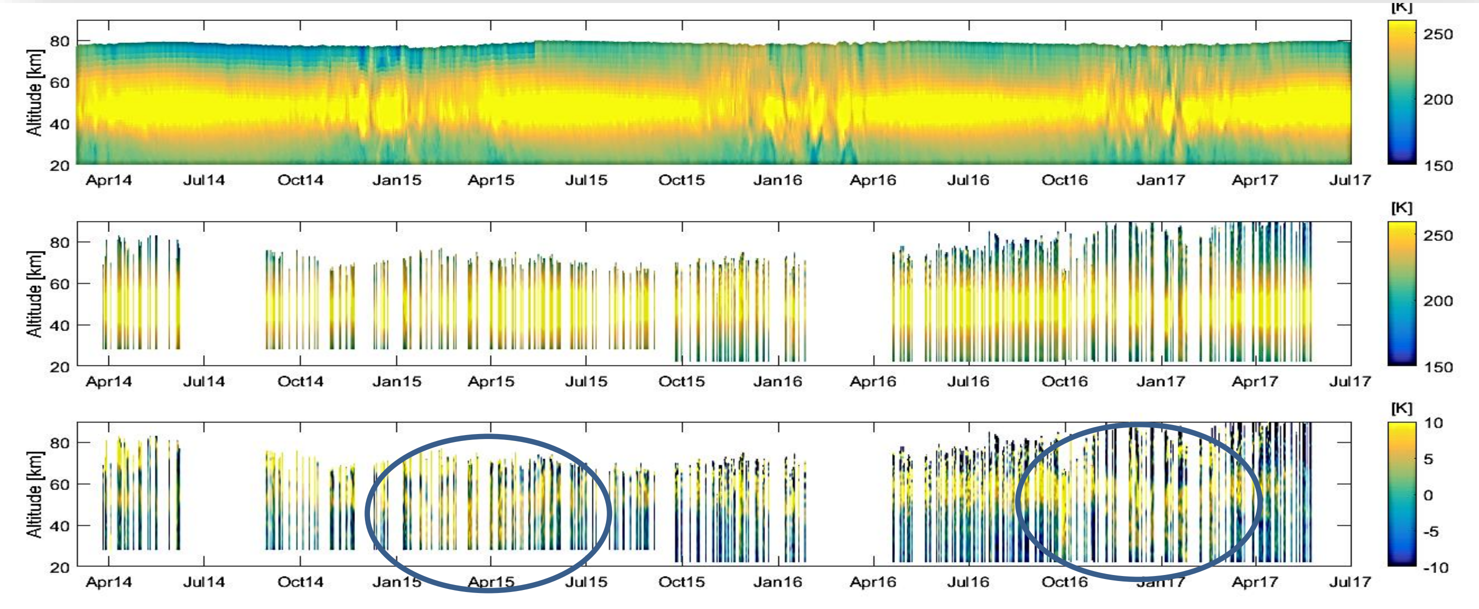
# Need of lidar routine observations: OHP observations

Difficulty of routine lidar observations
Improvement of observation duration and altitude range during the ARISE project

**ECMWF (IFS) cycle 38r2**

**Lidar (450 profils)**

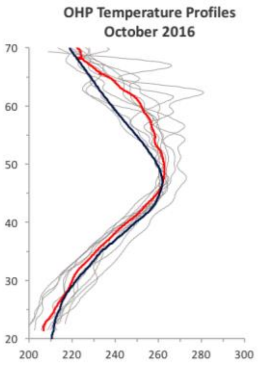
**Lidar-ECMWF difference**



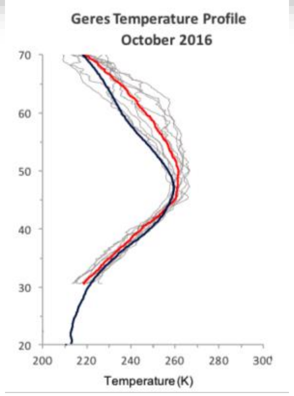

Nightly averaged lidar profiles routinely performed at the Observatoire Haute Provence (OHP)

*Le Pichon et al., 2018, Keckhut, Hauchecorne 2018*

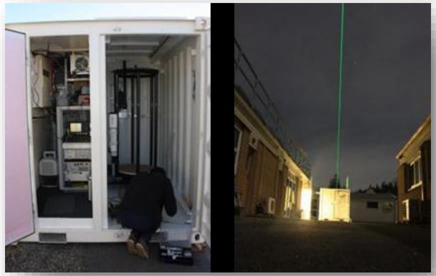
OHP




GERES



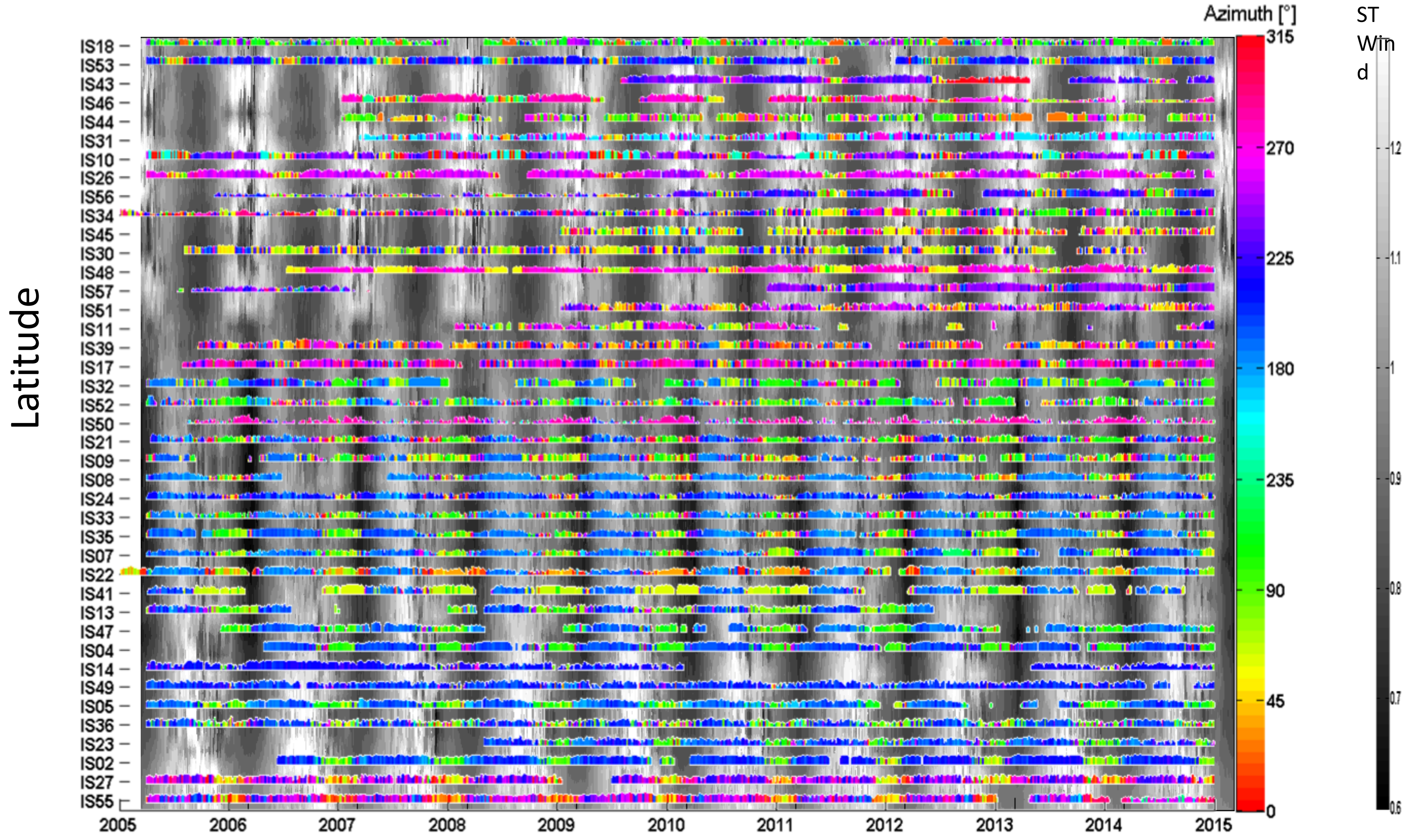

Compact Rayleigh Autonomous Lidar (Coral) at Geres station
Automatic high-resolution observations facilitating routine observations campaigns and synergy with infrasound observations



*Kaifler B and N, 2019*

*CORAL lidar*

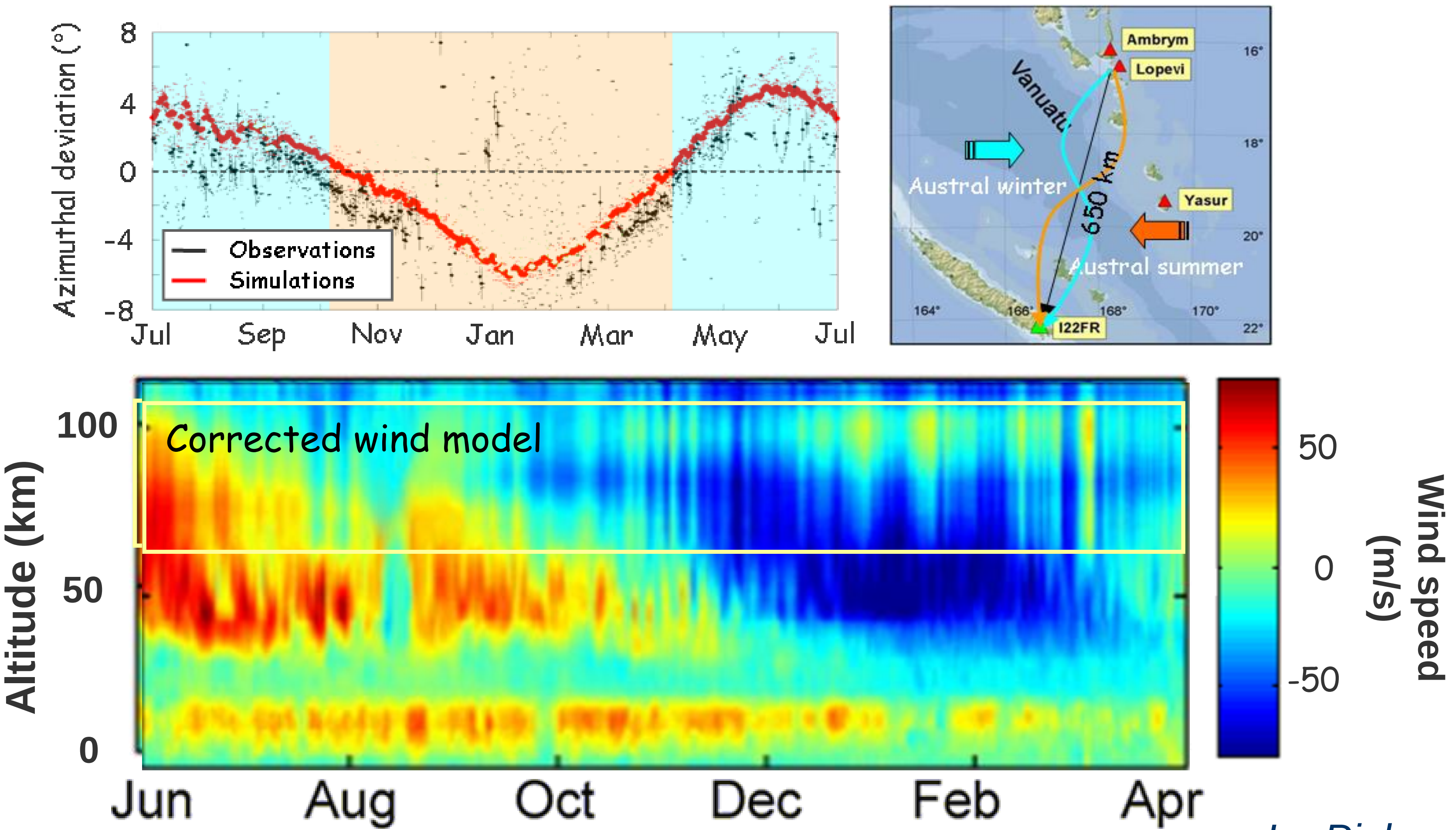
# IMS infrasound global observations for determining the stratospheric dynamical structure




Infrasound propagation in the atmospheric wave guide is strongly controlled by the stratospheric zonal wind

- ❑ 15 years of data in many infrasound stations
- ❑ The observed microbarom signals are submitted to seasonal variations controlled by the stratospheric winds
- ❑ A large potential for the improvement of stratospheric winds difficult to be dermined in the stratosphere

# Probing high altitude winds by using infrasound repetitive sources

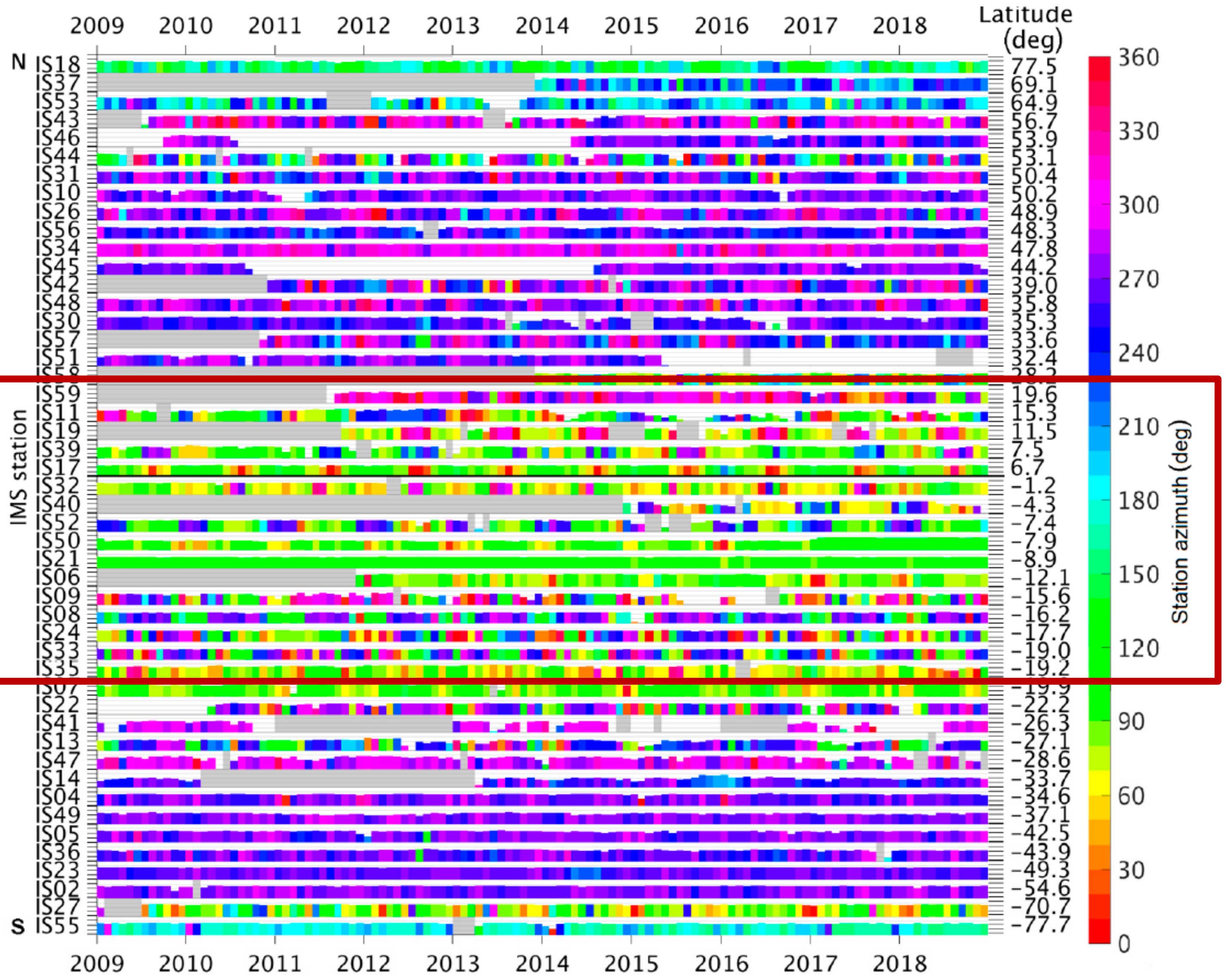



*Le Pichon et al., 2005a,b*

- The observed azimuth deviation is larger than explained by models
- This indicates that the wind effect is stronger than expected.

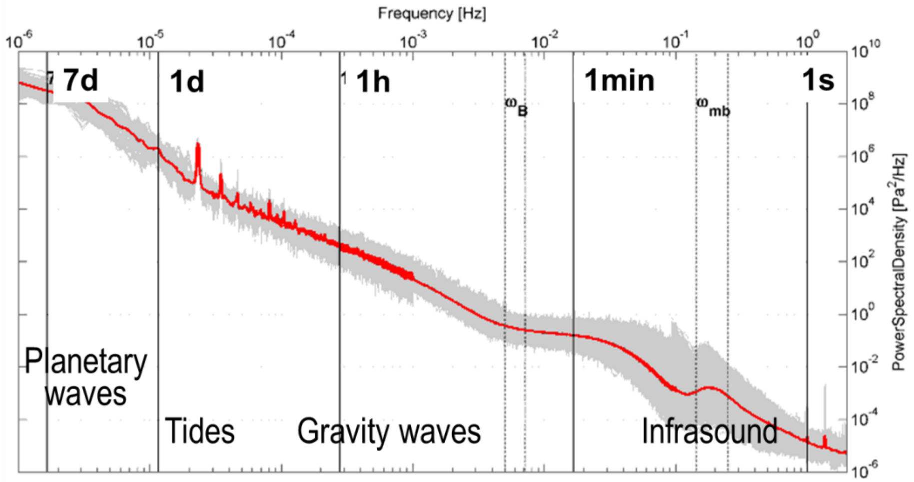
- Relevant atmospheric parameters can be extracted from infrasound monitoring when the source is well identified

# Gravity waves globaly observed with the IMS infrasound network

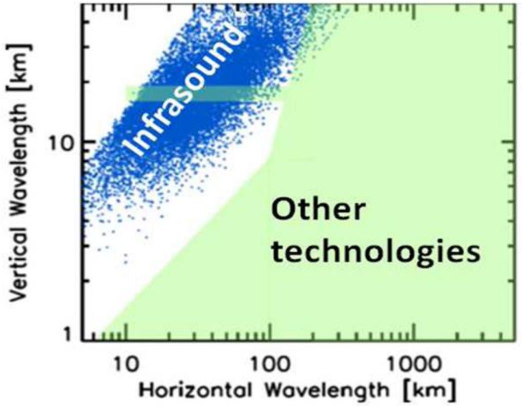



*Hupe et al., 2019*

Direct observations in the lower part of the observation spectrum

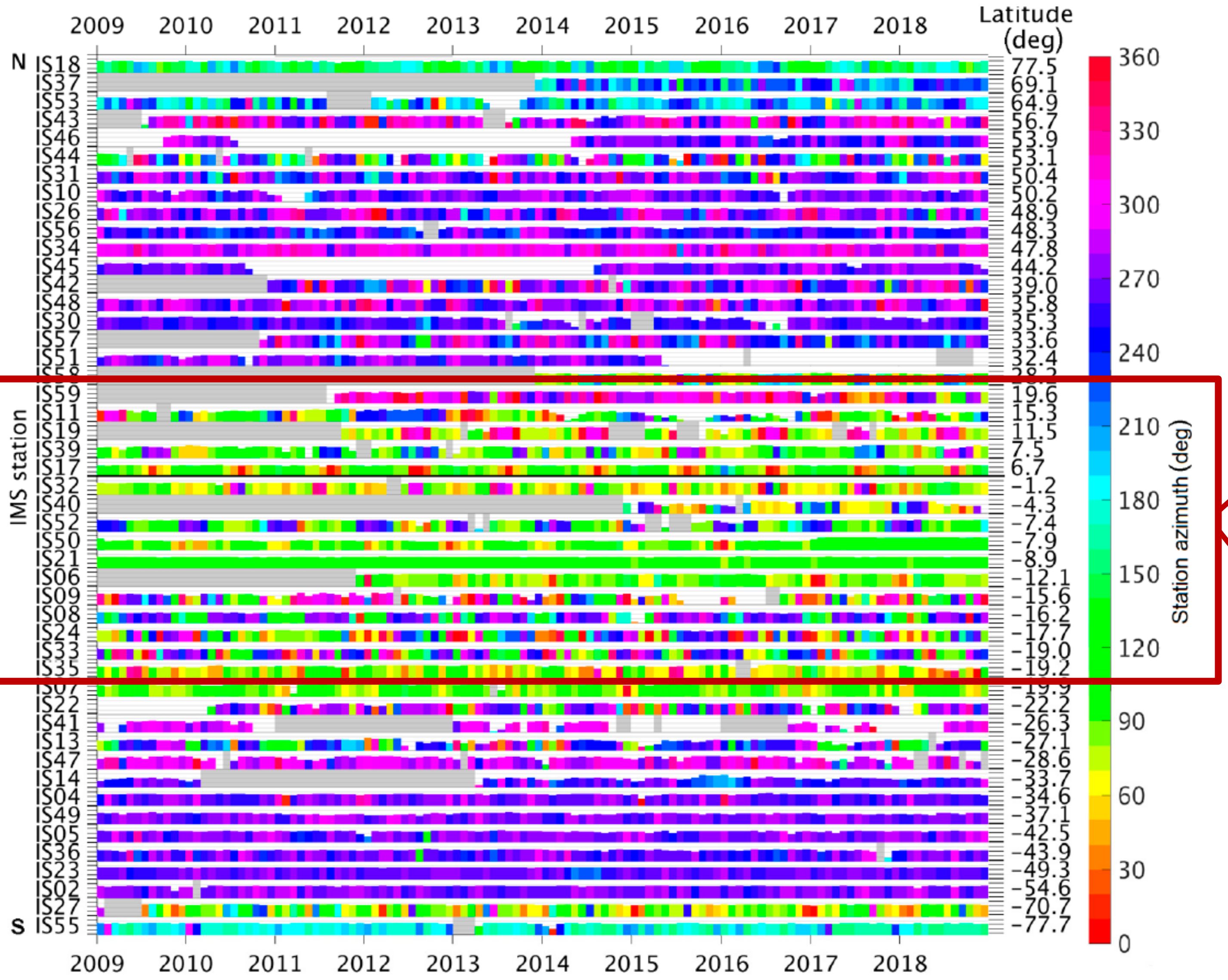



*Hupe, Ceranna, 2016, 2018*



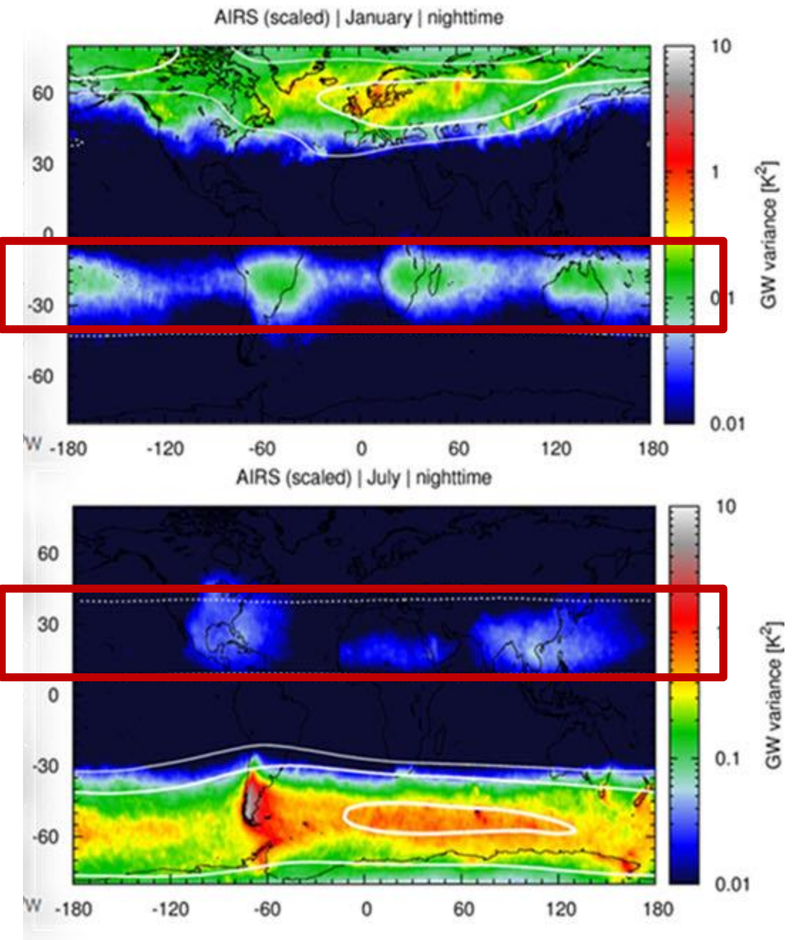

*Charlton Perez et al., 2014*

# Gravity waves observed with the global IMS infrasound network

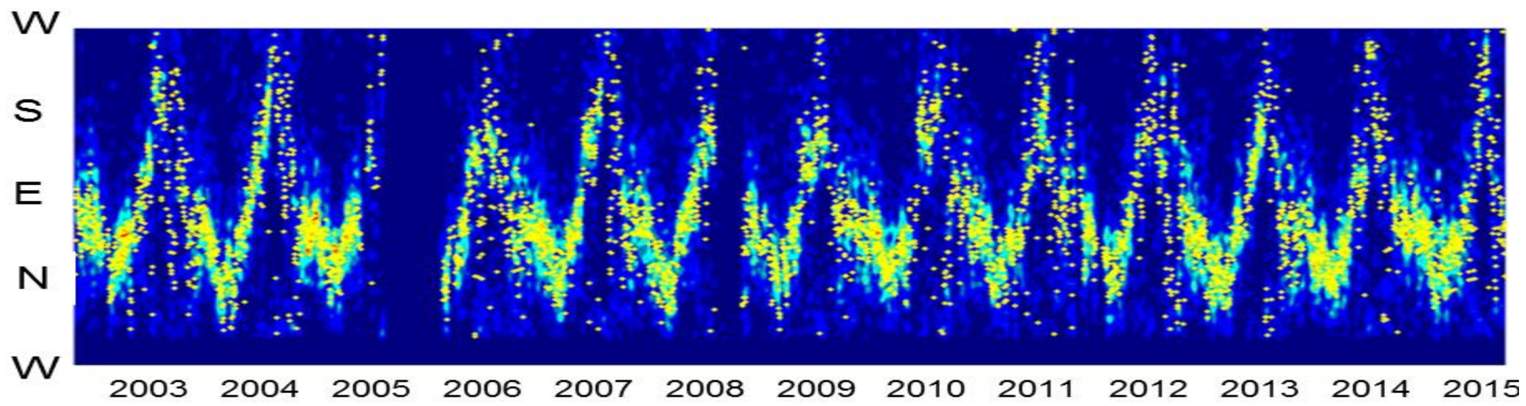


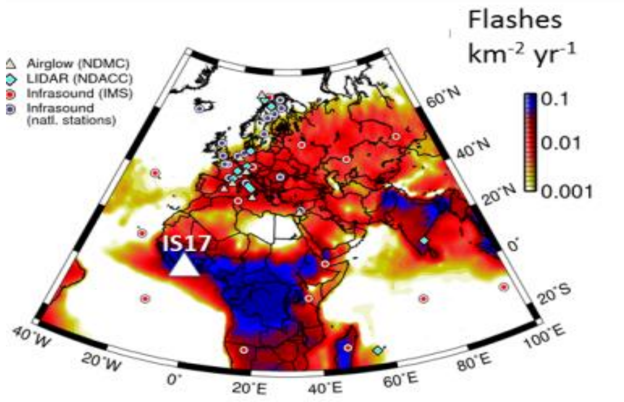

*Hupe et al., 2019*

Main gravity wave origins : deep convection in tropics or mountain waves

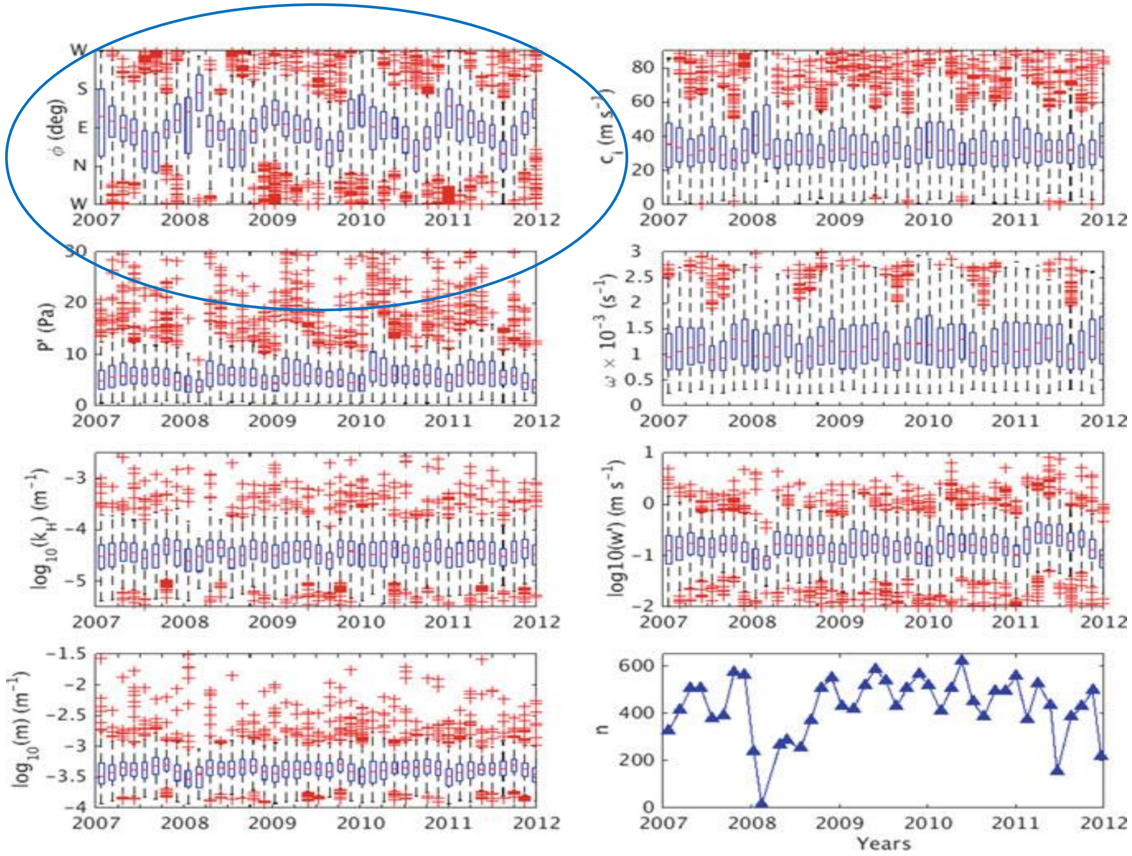


# Gravity waves from convection observed in I17CI (Ivory Coast)




*Blanc et al., 2014*




**Seasonal variation related to the motion of the Intertropical convergence zone of the winds**, which drive thunderstorms, precipitations and convection seasonal motion.

Unique global GW observations relevant for global GW climatologies and parameterization in models

**Gravity wave climatology**

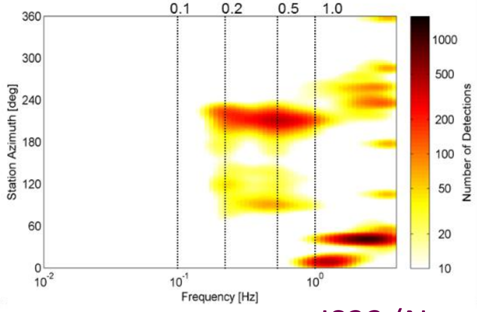
New parameters calculated for ECMWF needs by combining this infrasound data with meteorological data recorded at the array

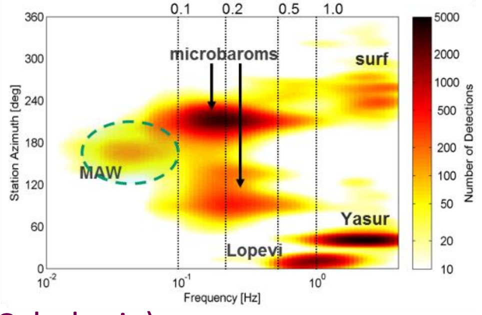
*Marlton et al., Springer book, 2019*

# Mountain Acoustic Waves: new information about the GW sources

Previous observations

New processing (logarithmic)



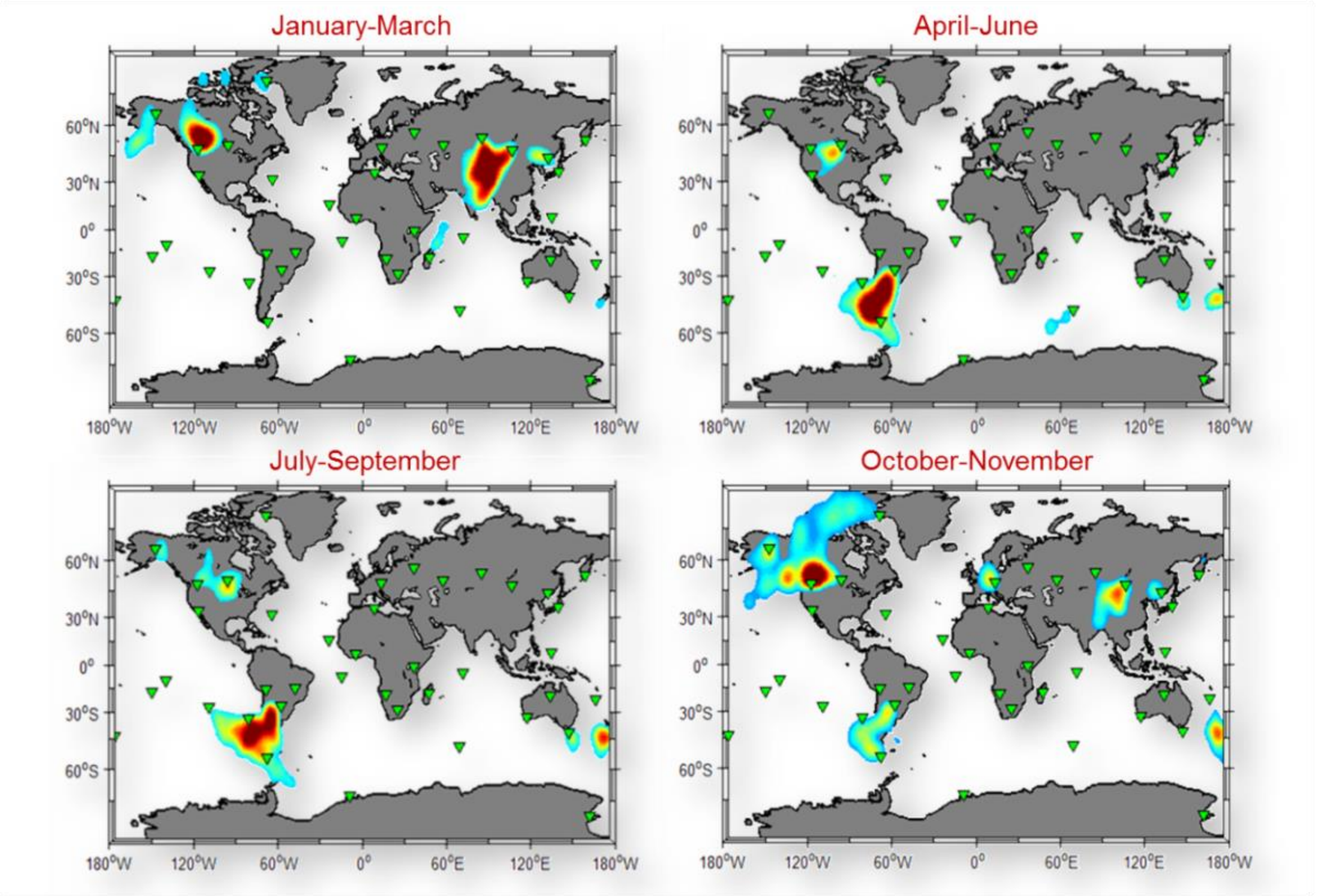




IS22 (New Caledonia)

Broadband PMCC processing provides a better description of the detected waves for a better source identification

*Le Pichon et al., 2015, Hupe et al., 2021*

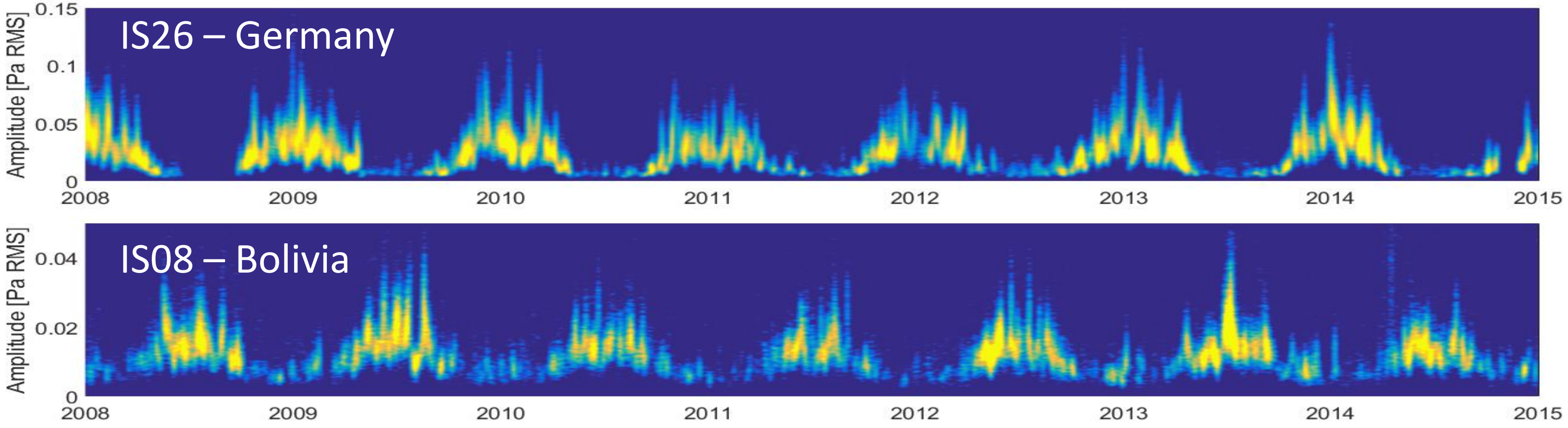
- ❑ Mountain Acoustic Waves are detected and localized from infrasound originating from mountain areas.
- ❑ They are related to mountain gravity waves
- ❑ They need to be accurately described for improving the atmospheric models
- ❑ The identification of the wave origin is more difficult with other technologies



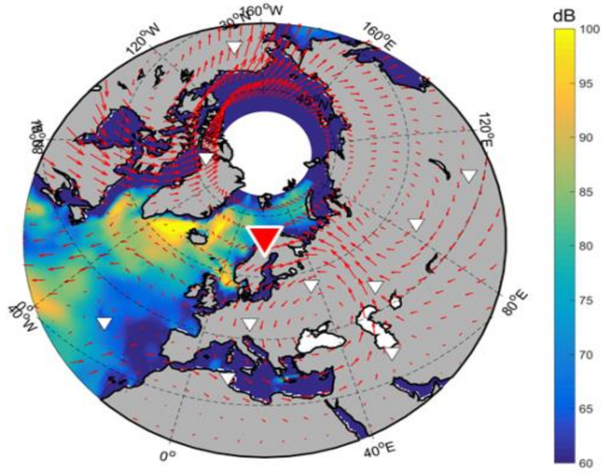

A global view of MAW activity @20-50 s

*Hupe et al, 2019*

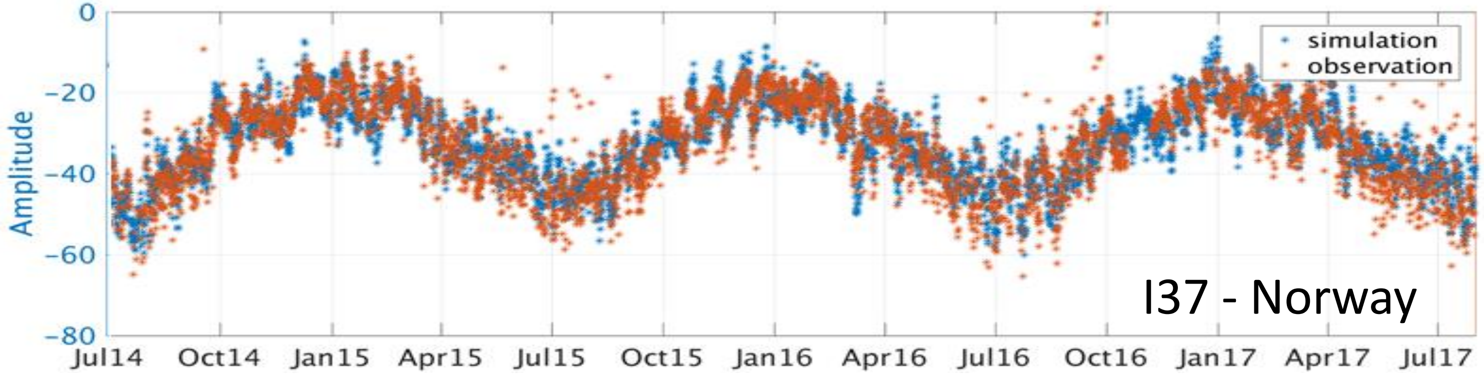
# Perspective: Using microbaroms for retrieving atmospheric parameters




Seven years microbarom observations. Planetary waves modulate the atmospheric wave guide and then the microbarom amplitude




Microbarom source (IFREMER ocean wave action model) *Ardhuin et al., 2013*

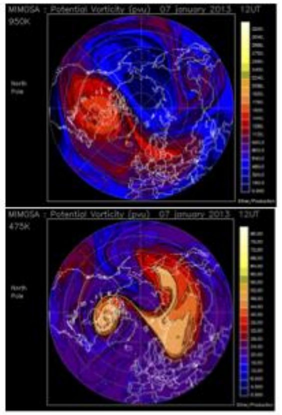


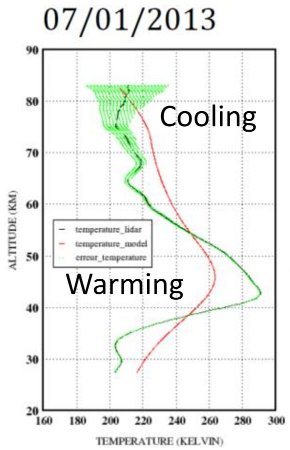

- ❑ Build of a global reference catalog of continous infrasound ambient noise
- ❑ Combine global microbarom source and propagation model to predict directional and amplitude informat
- ❑ Develop metrics to assess NWP models

*Le Pichon et al., 2018, De Carlo, 2020, Näsholm, 2020*

# Effets of Sudden Stratospheric Warming (SSW) events in infrasound monitoring

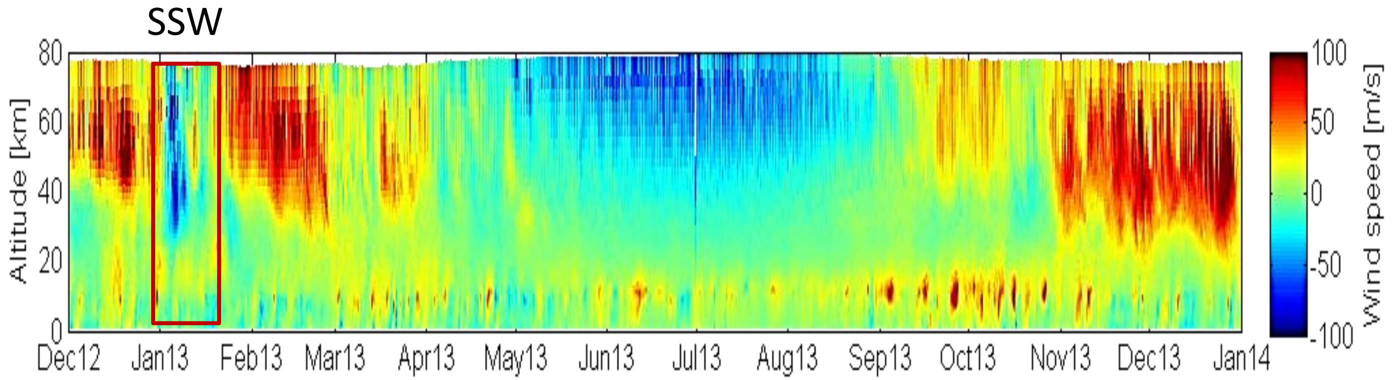
Sudden Stratospheric Warming events(SSW) are major atmospheric events producing polar vortex breaking, stratospheric warming, mesospheric cooling, inversion of the zonal stratospheric wind.






*Hauchecorne et al, 2014*

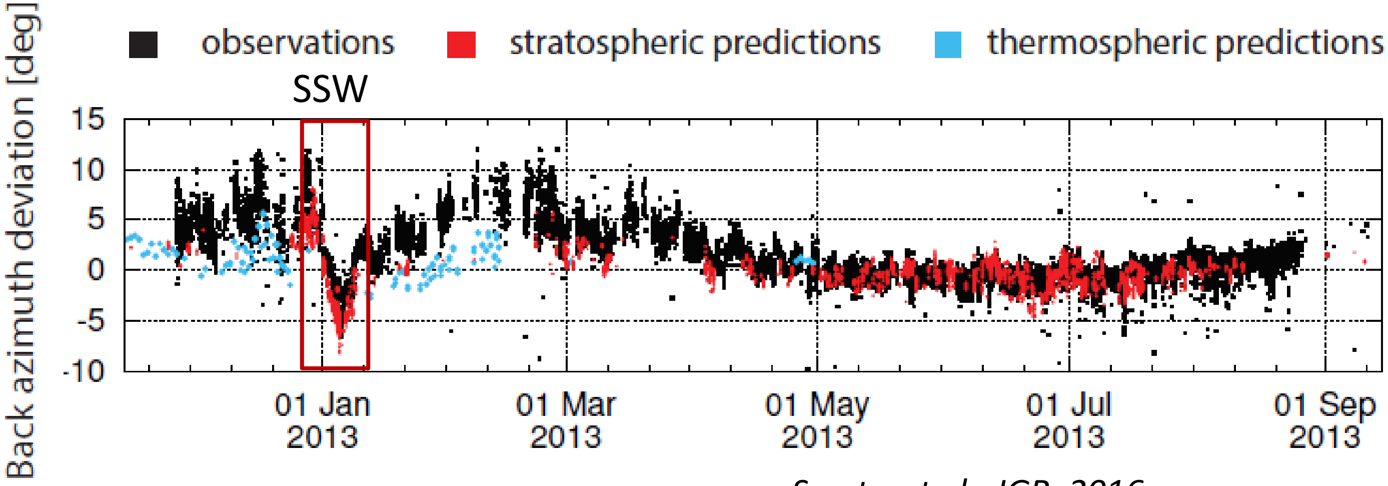
Volcano Mount Tolbachik (Kamchatka)




Quasi continuous infrasound detections at IS44 from the Mt. Tolbachik eruptions.

The infrasound azimuth deviations represent the wind variations. During the SSW are inverted, changing the direction of the wave guide.

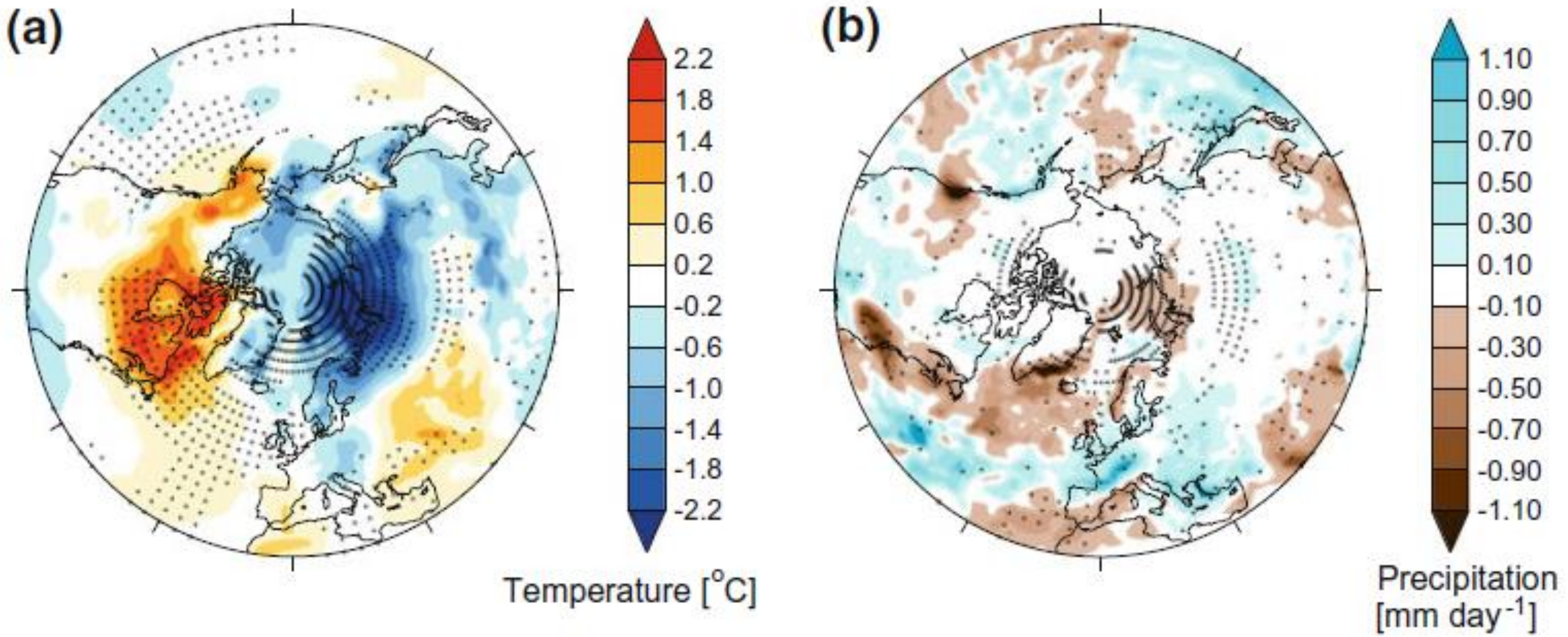
Deviations of several degrees are observed between simulations and observations during and after this event. Persisting effects are not represented in predictions




*Smets, et al., JGR, 2016*

# Sudden Stratospheric Warming events: effects of weather predictions

Surface temperature and precipitation anomalies over 15-30 days forecasts for 15 SSW



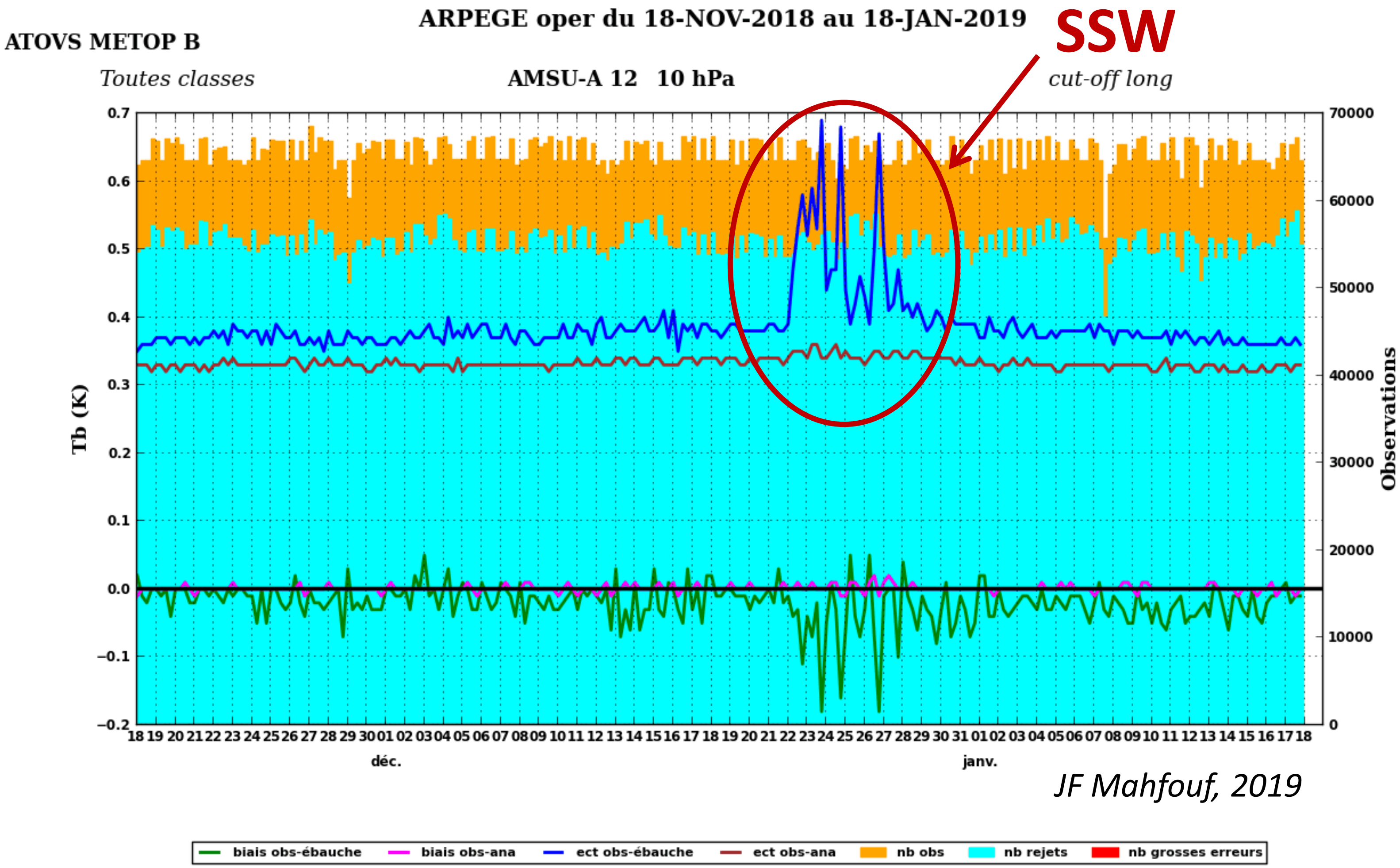

Average anomalies of (a) surface temperature, (b) precipitation, 15 - 60 days after the onset of 15 SSWs in a 50-year unconstrained climate run of the HadGEM2 Unified Model.

*Lee et al., 2019*

An abrupt shift in temperatures high up disturbed the jet stream and weather patterns, allowing cold air to seep southwards into parts of Europe


Major SSW events can be followed by cold weather that can affect Europe for several weeks

# Perspective: providing diagnostics for Numerical Weather Prediction models




*JF Mahfouf, 2019*

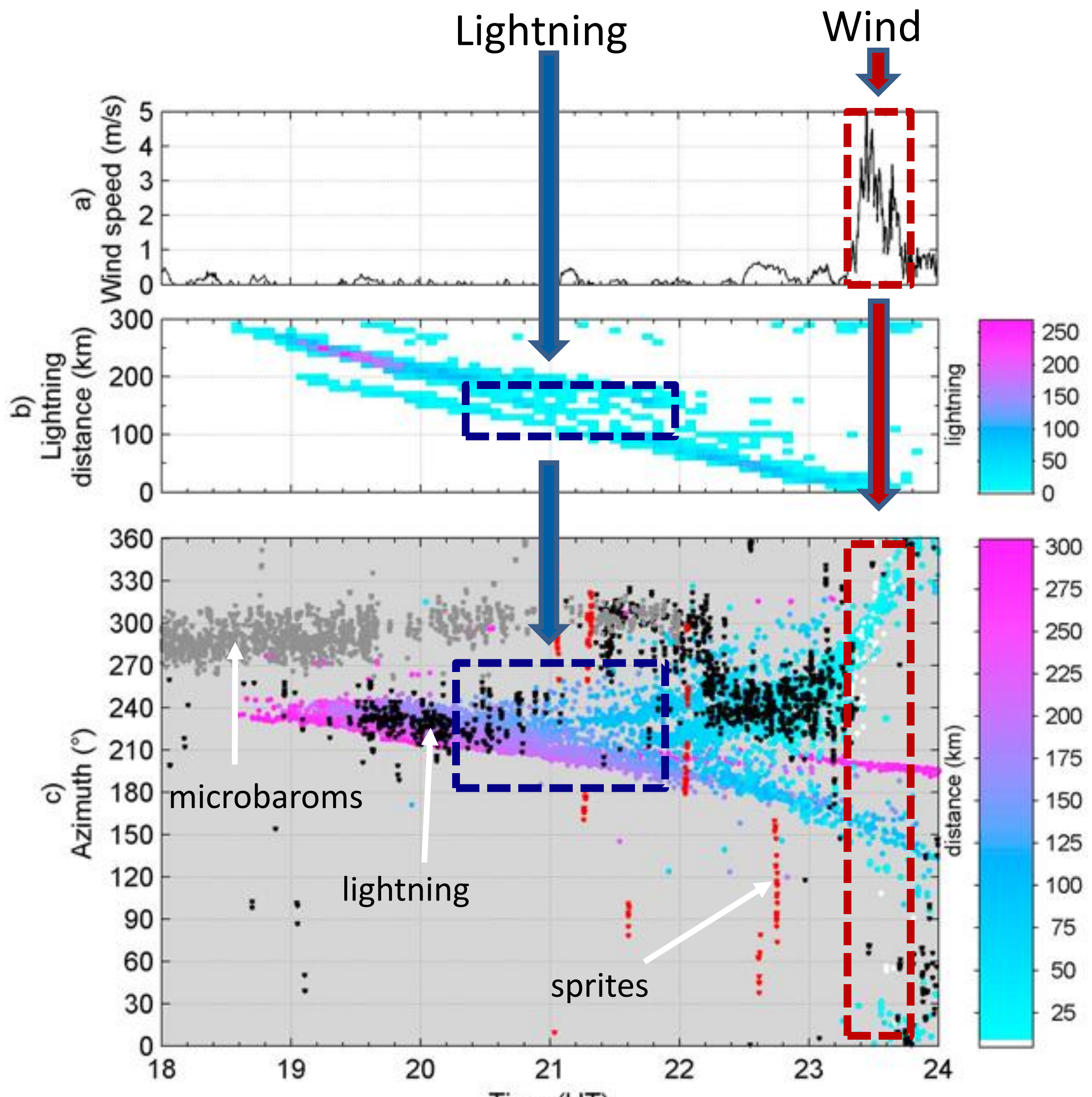
- During Sudden Stratospheric warming, large anomalies in the prediction model appear.
- The number of available routine observations of winds in the stratosphere is very small for assimilations in models.
- Other requested data concern low latitudes, and high altitudes (above the stratosphere) and other disturbances

ARISE data are relevant for providing complementary relevant data in the framework of the ARISE project.
Near real time diagnostics are developed for assimilation in models

*Näsholm 2018*

*Statistics: observations minus models: in blue standard deviation with all observations, in brown with assimilated observations*

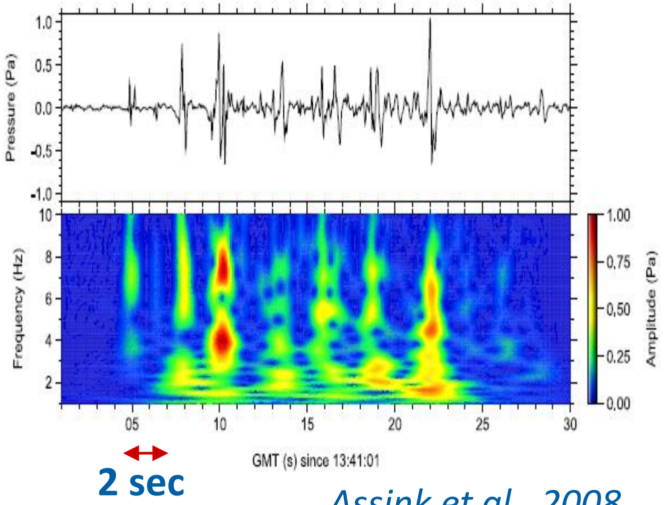
# Thunderstorms: from local noise to lightning characterization




*Farges and Blanc, 2010*

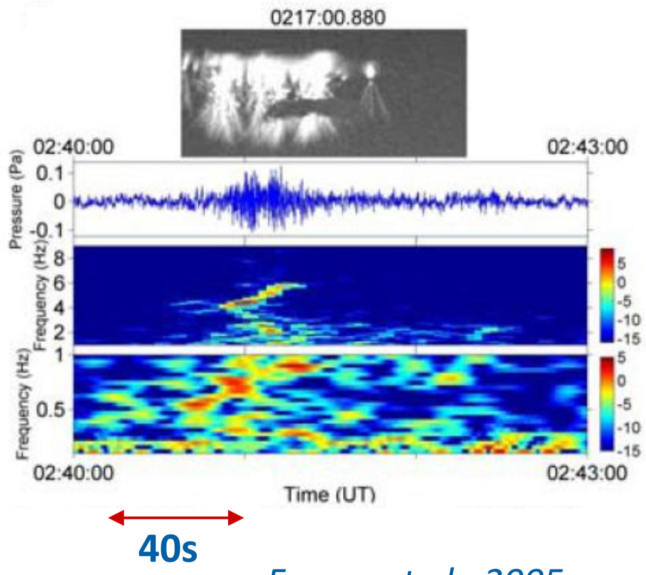
Thunderstorms noise is significant at distances lower than 60 km

Infrasound lightning




*Assink et al., 2008*

Infrasound sprite

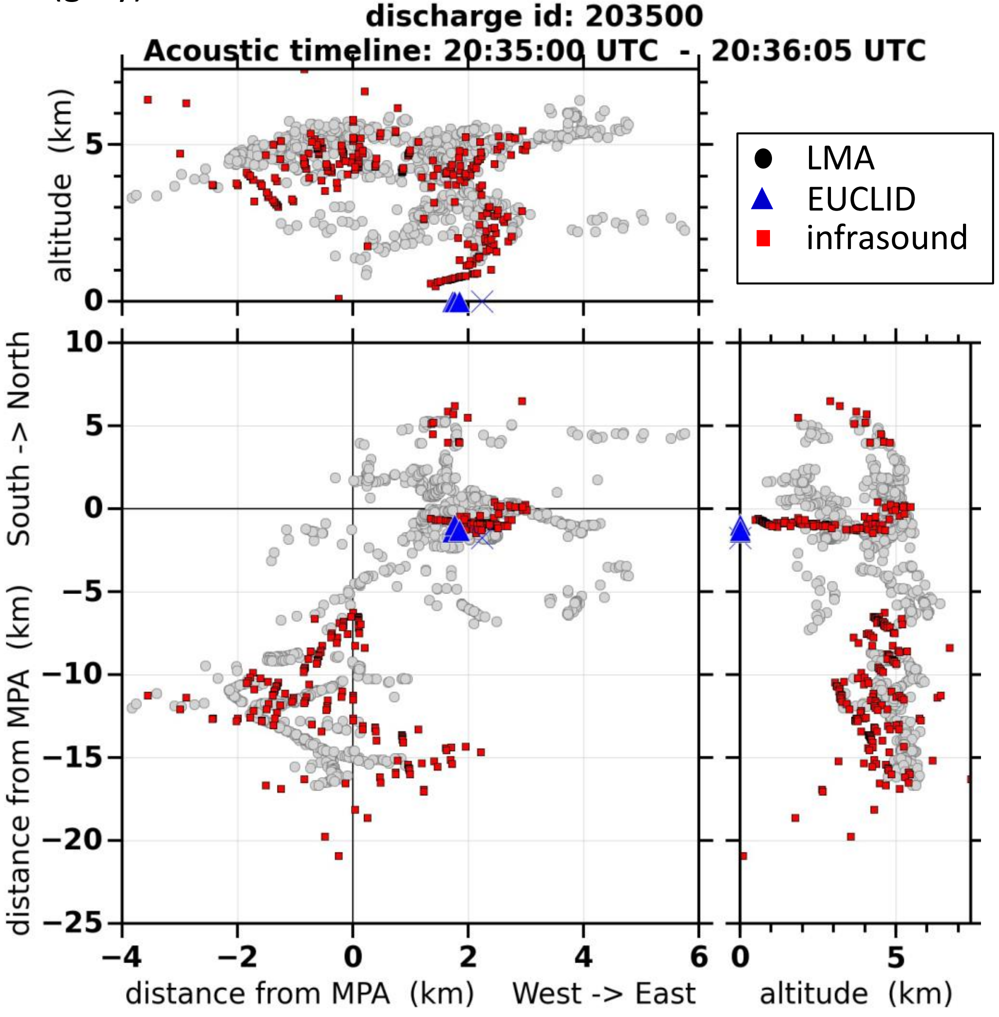



*Farges et al., 2005*

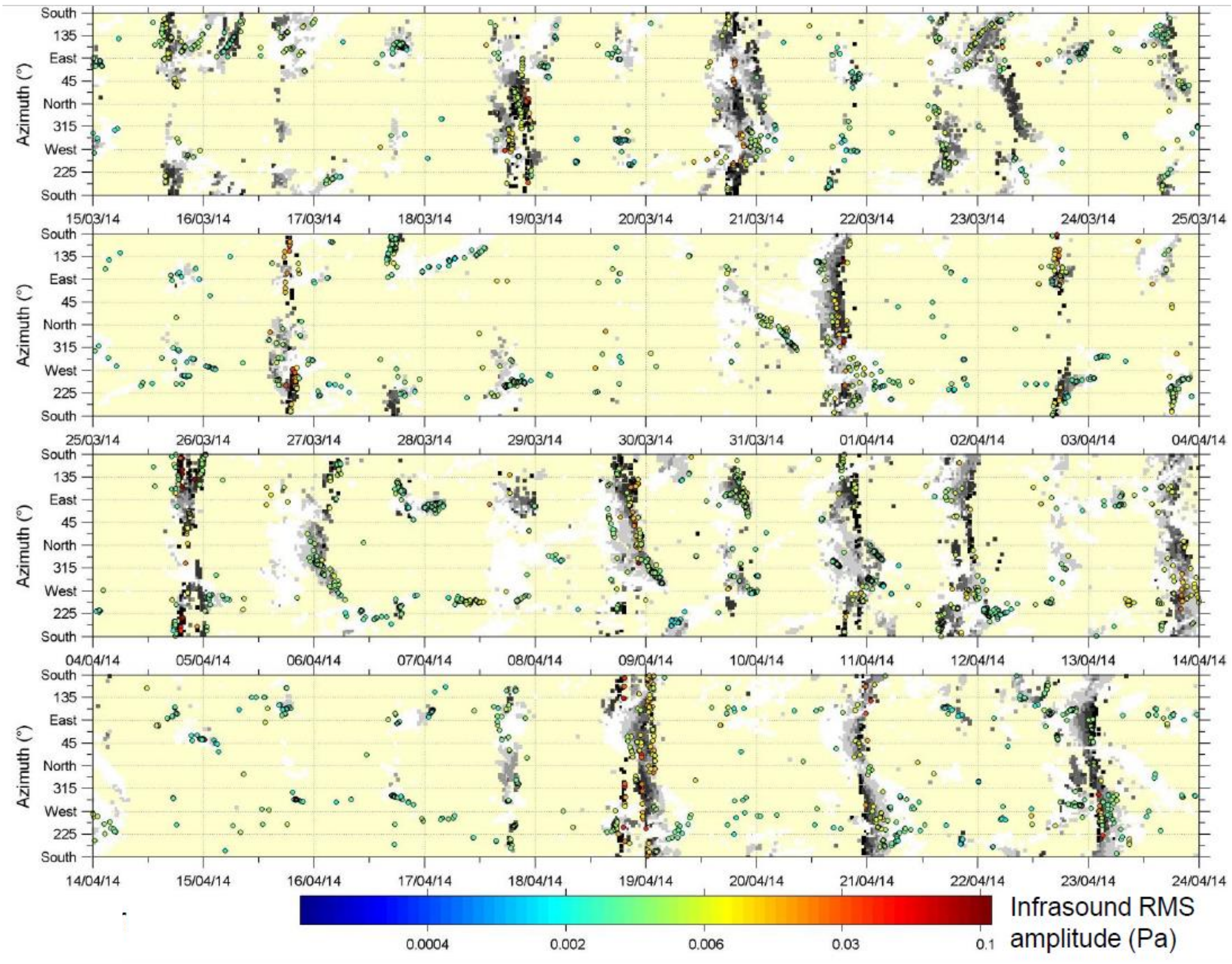
# Perspective: providing new lightning parameters

## Innovative method for lightning and sprite studies

Individual structure of a lightning from infrasound detections (red) compared with Lightning Mapping Array LMA (grey)

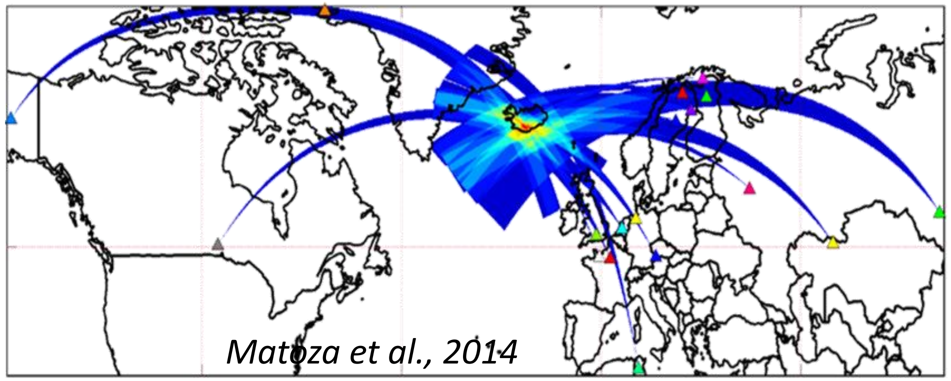


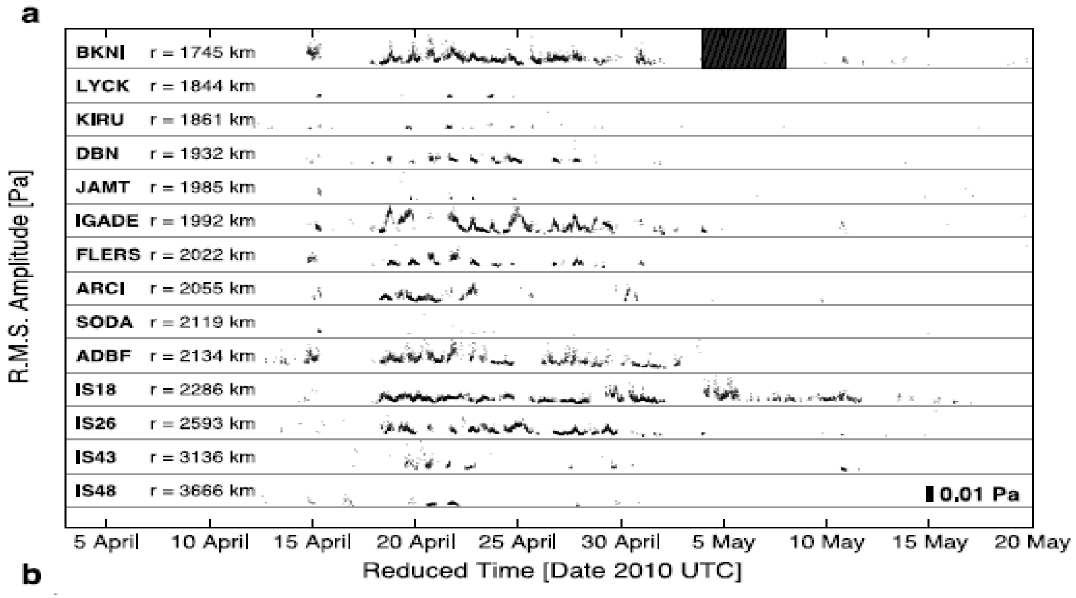

Infrasound lightning monitoring during 40 days 2014/15/03 to 2014/24/04



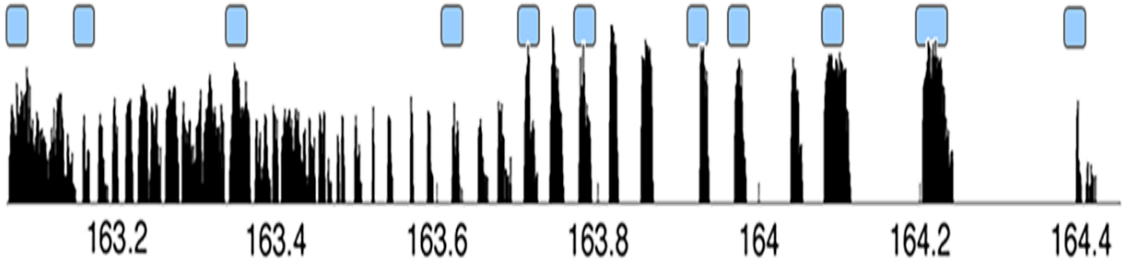
# Example of societal application: Remote monitoring of volcanoes

Long range observation of the infrasound produced by  the Eyjafjallajökull eruption 2011



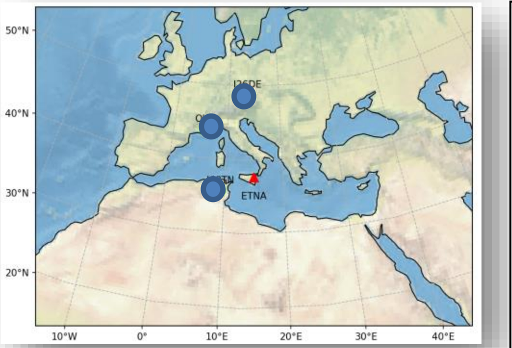

Infrasound observations (IS44, black) provide relevant observations in complement to satellite observations (SVERT, blue)



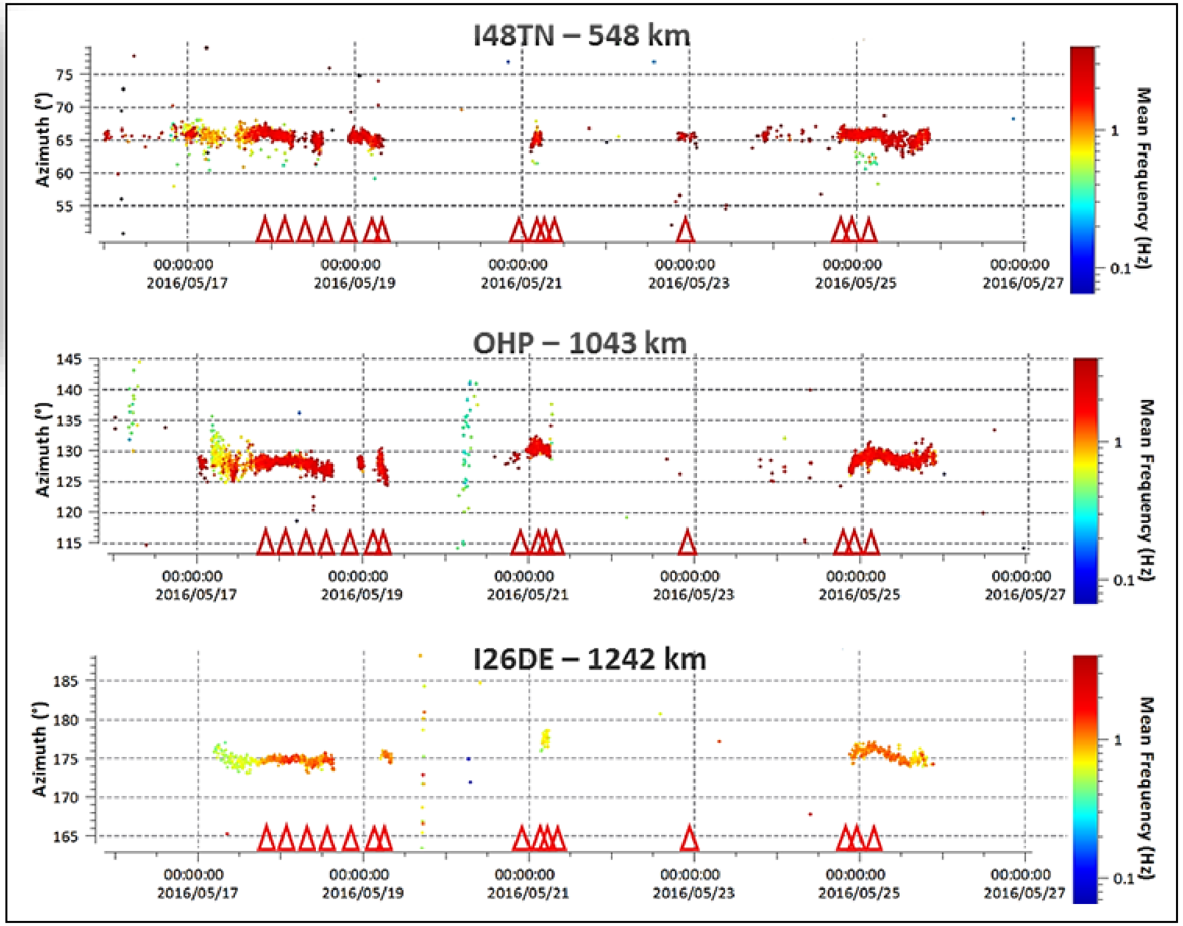

Eruption of the Sarychev Peak (june 2009)

*Matoza et al., 2014*

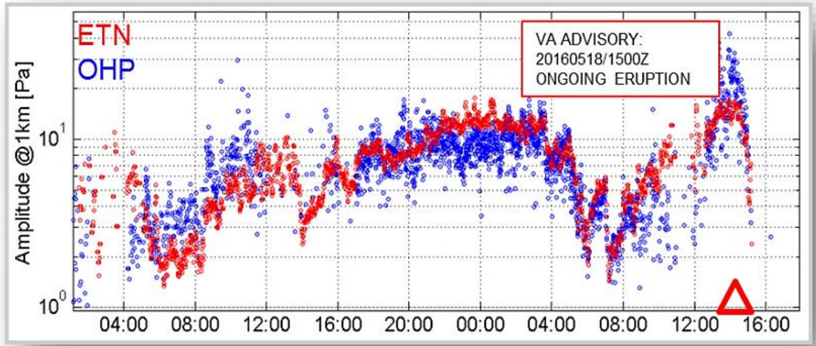
# Remote volcano monitoring




Example of infrasound signals from Etna eruption, recorded at IS48 (Tunisia), OHP (France) and IS26 (Germany) arrays for the period between May 15 and May 27, 2016.




Toulouse VAAC alerts



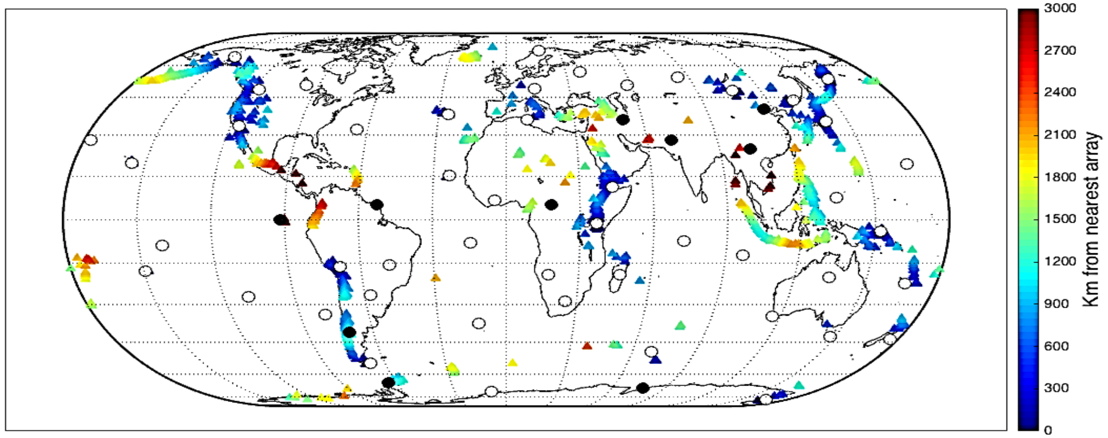

The eruption signature is similar at Etna and OHP stations, which shows the possibility to retrieve source characteristics at large distances.

*Marchetti et al, 2018,*
*Le Pichon, Brachet, 2018,*
*Mialle, Hereil (2018)*

Source: Marcelo Utreras ©DR

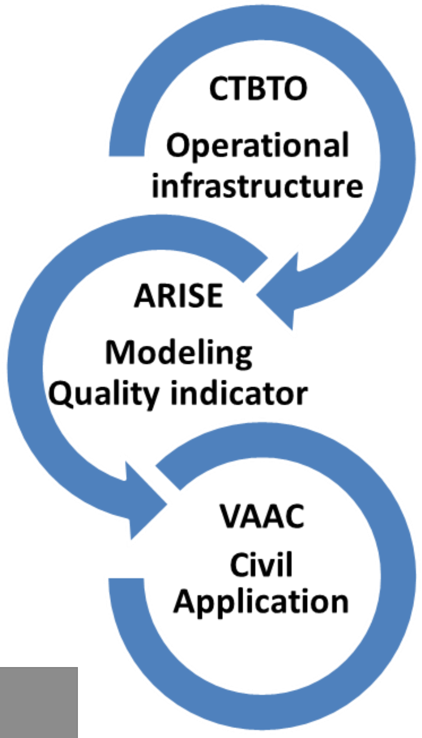
# Towards a Volcanic Information System (VIS) using Infrasound Data

## in support of the VAACs in the Framework of ARISE Project

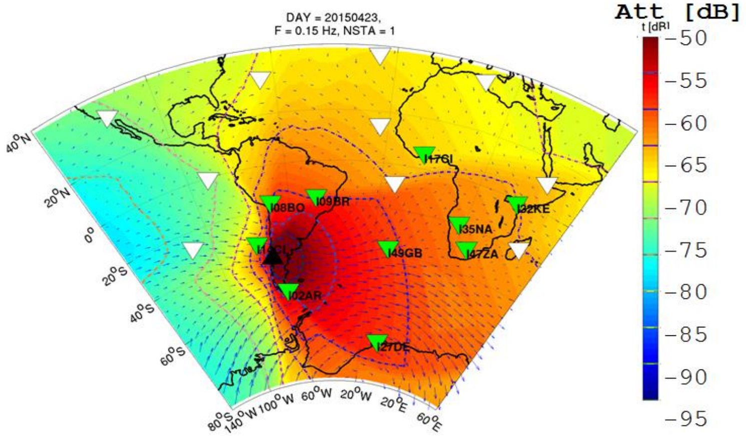



IMS stations and volcanic activity. Volcanoes are color-coded according to the distance from the IMS infrasound stations.

ARISE advanced products provide parametrization of distant volcanic eruptions in support of the civil aviation (Volcanic Ash Advisory Centre VAACs) in relation with the CTBTO (operational monitoring)




### CALBUCO VOLCANO, CHILE (22-23/04/2015)




Confidence index map

**VOLCANO NOTIFICATION TO VAAC**

Volcanic Information System v2018.2

**Notification**

ID : CABU2015112
ISSUED : 2018/08/20 09:27:59 UTC
REVISION : 6
ISSUED BY : CEA (ARISE)
RECIPIENT : VAAC TOULOUSE (METEO FRANCE)

**Volcano**

NAME : CABULCO
ID : 358020
LATITUDE : -41.33
LONGITUDE : -72.61
ELEVATION : 1974 m

**Summary**

START TIME : 2015/04/22 21:34:34 UTC
END TIME : 2015/04/23 09:35:08 UTC
STATUS : ENDED

| STATION | DISTANCE (km) | NB DETECTIONS | MAX AMPLITUDE (Pa) | EST. AMPLITUDE (Pa) |
|---|---|---|---|---|
| I14CL | 1011 | 1 | 0.03849 | 1217 |
| I02AR | 1524 | 9 | 0.1496 | 1030 |
| I08BO | 2809 | 175 | 0.09947 | 2796 |
| I09BR | 3698 | 181 | 0.09148 | 10681 |

SOURCE AMPLITUDE : 10681 Pa

*Le Pichon, Mialle, Husson, Brachet, 2019*
*Marchetti, 2019*

# Conclusion

- The infrasound IMS is unique. It provides a description of most atmospheric disturbances in broad scales in space and time.
- Progress in the understanding of atmospheric processes improve the detection capability of the network by better event identification and propagation modeling
- The atmosphere is a highly variable environment. The IMS infrasound network provides unique global observations of atmospheric fluctuations such as gravity waves, both by direct observations in the lower frequency part and by remote sensing using volcanoes and other sources such as ocean swell in future.
- Such disturbances control infrasound propagation and need to be integrated in routine monitoring tools. However, they are poorly represented in models, inducing uncertainties in simulations.
- Challenge: near-real time processing of co-localized lidar and infrasound stations (pilot stations) for model assessment and future assimilation in medium range weather prediction models and routine infrasound simulations

- The infrasound network is relevant for civil applications as monitoring of volcanoes (aviation safety) or other events (meteorites, thunderstorms, hurricanes …)
- It will also becomes very quickly essential for studies of atmospheric dynamics for improving weather forecasting and climate studies

# Thanks to my colleagues and the ARISE partners