CTBT: SCIENCE AND TECHNOLOGY 2017 CONFERENCE

Uncertainties in atmospheric dynamics and infrasound monitoring

Elisabeth Blanc[1], Alexis Le Pichon[1] , Doriane Tailpied[1]
Alain Hauchecorne[2],
Andrew Charlton Perez[3],
Pieter Smets[4]

1- CEA DAM DIF F-91297 Arpajon France
2- LATMOS, IPSL, Guyancourt, France
3- Department of Meteorology, University of Reading, Reading, United Kingdom
4- KNMI, Seismology and Acoustics, De Bilt, Netherlands

Outline

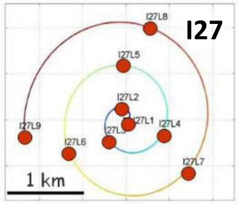
Uncertainties concern errors in models and simulations …
In infrasound monitoring uncertainties are mainly related to the variability of the middle and upper atmosphere

- Atmospheric variability was considered in the IMS network specifications
- Determination of the variability from identified calibration sources
- Complementary multi-instrument observations: Quantification of model uncertainties and effects of large scale disturbances
- Quantification of uncertainties in detection capability
- Perspective: Reducing uncertainties by innovative observations and future assimilation of new data sets in models

Infrasound monitoring

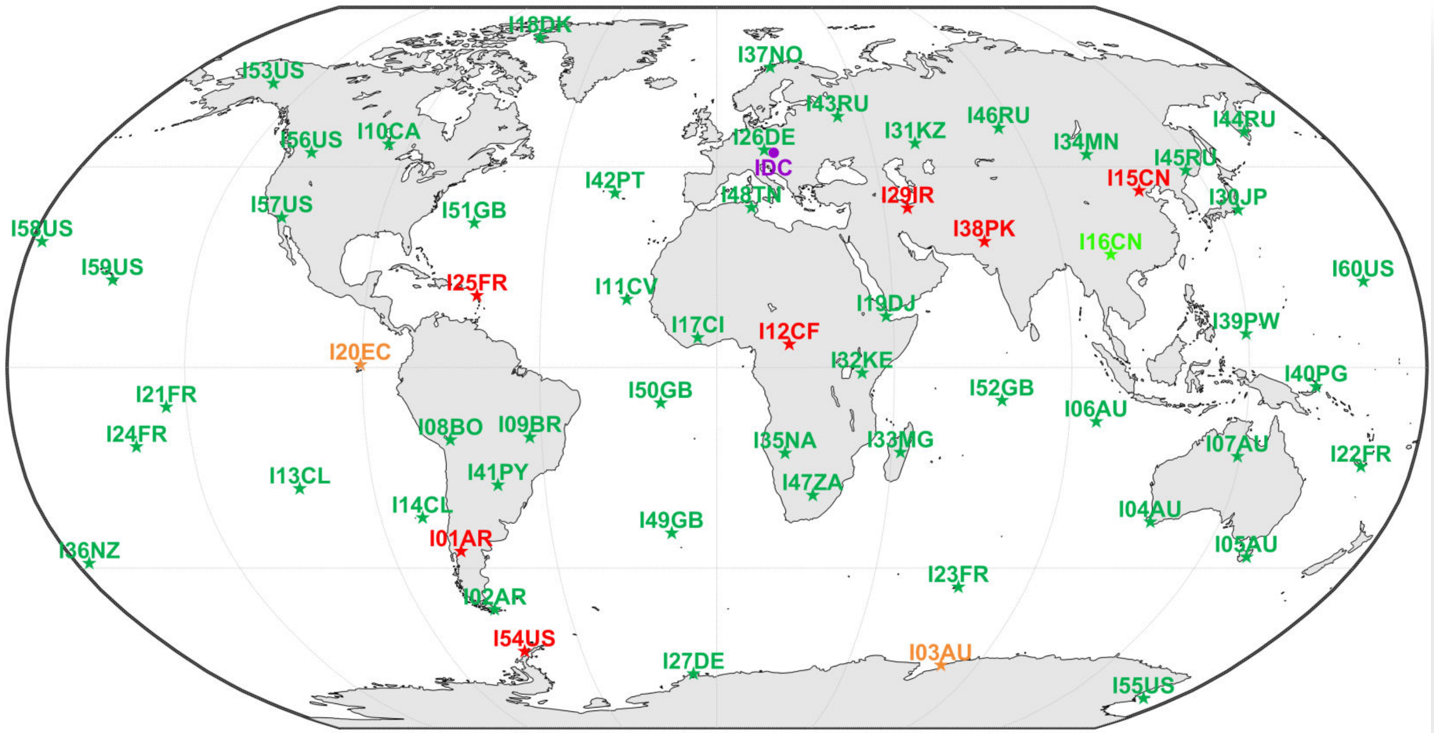
Broadband Microbarometers
(CEA –MB2005 and MB3)

Noise reduction systems



Station configuration

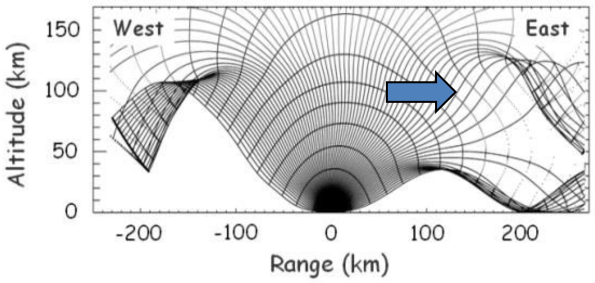
Station mini-arrays
⇒Very sensitive acoustic antennas



International infrasound Monitoring System for the verification of the CTBT

Marty, 2017

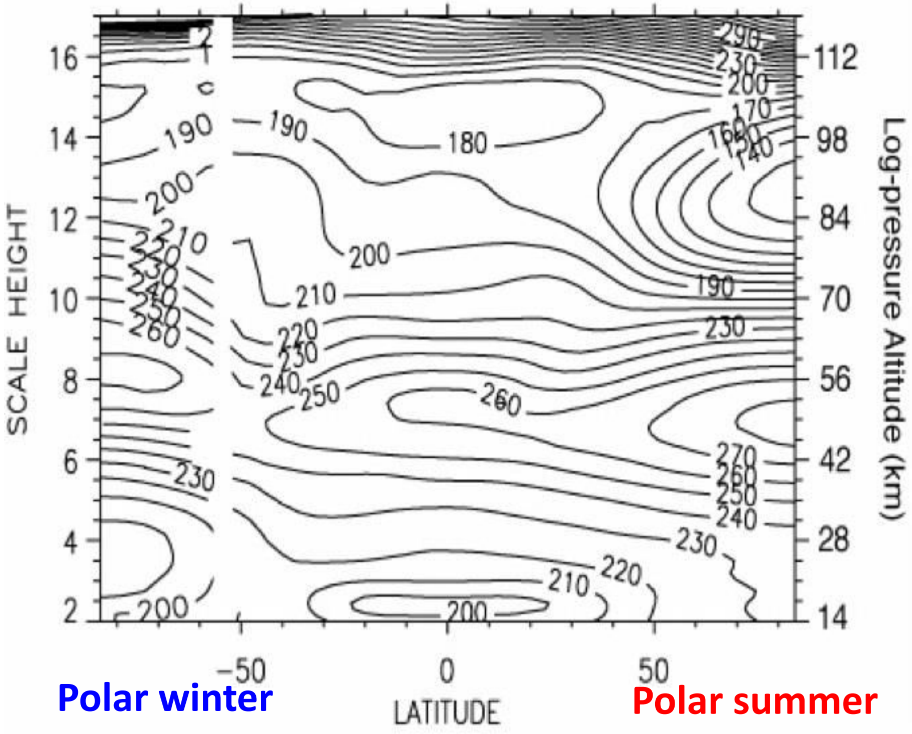
- ☐ 60 infrasound stations (when completed) provide permanent, homogeneous global observations of most atmospheric disturbances
- ☐ Opportunity to calibrate the network using well identified sources and promote civil and scientific applications



Infrasound propagates in the stratospheric wave guide of the atmosphere. Long range propagation is controlled by the stratospheric winds

Dynamics of the middle and upper atmosphere: seasonal effect

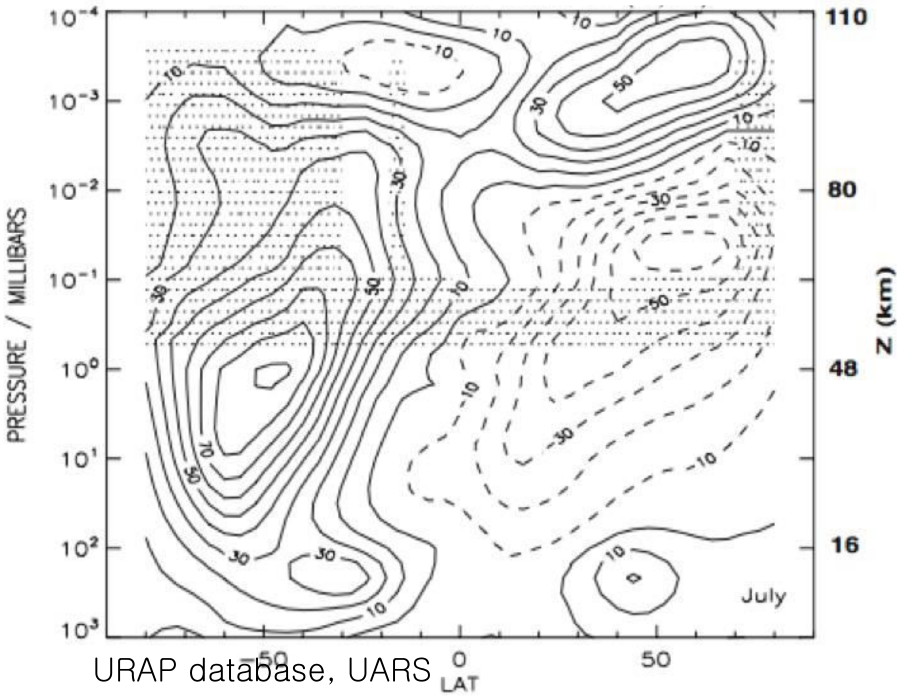
Mean temperature (K) July



Polar winter

Polar summer

Mean zonal wind (m/s) July



URAP database, UARS

Polar winter

Polar summer

The seasonal variations of the meridional temperature control the zonal flux

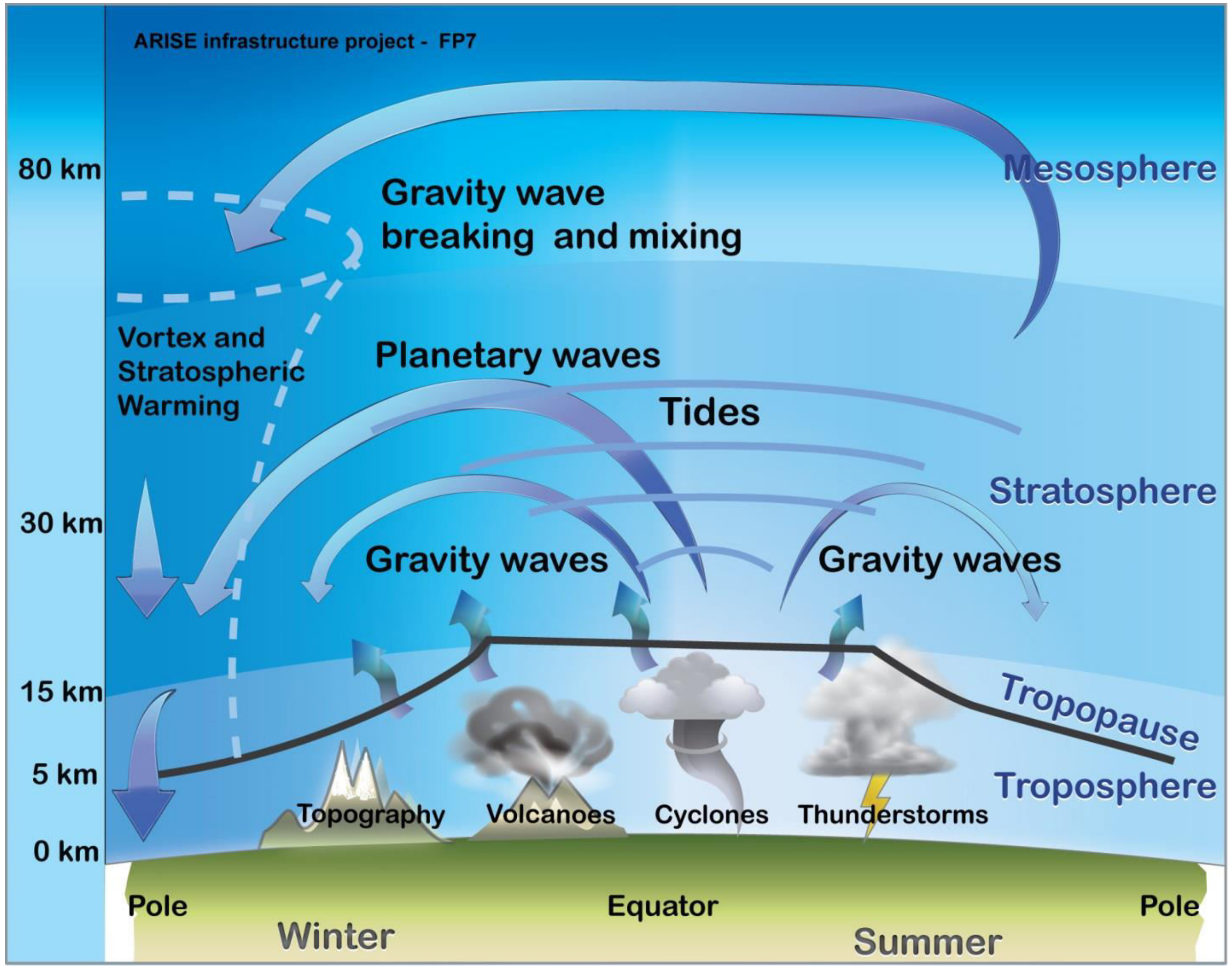
The wind direction is perpendicular to the temperature gradient

Winter: low latitudes warmer than polar regions: Eastward wind

Summer: polar regions warmer than equator: Westward wind

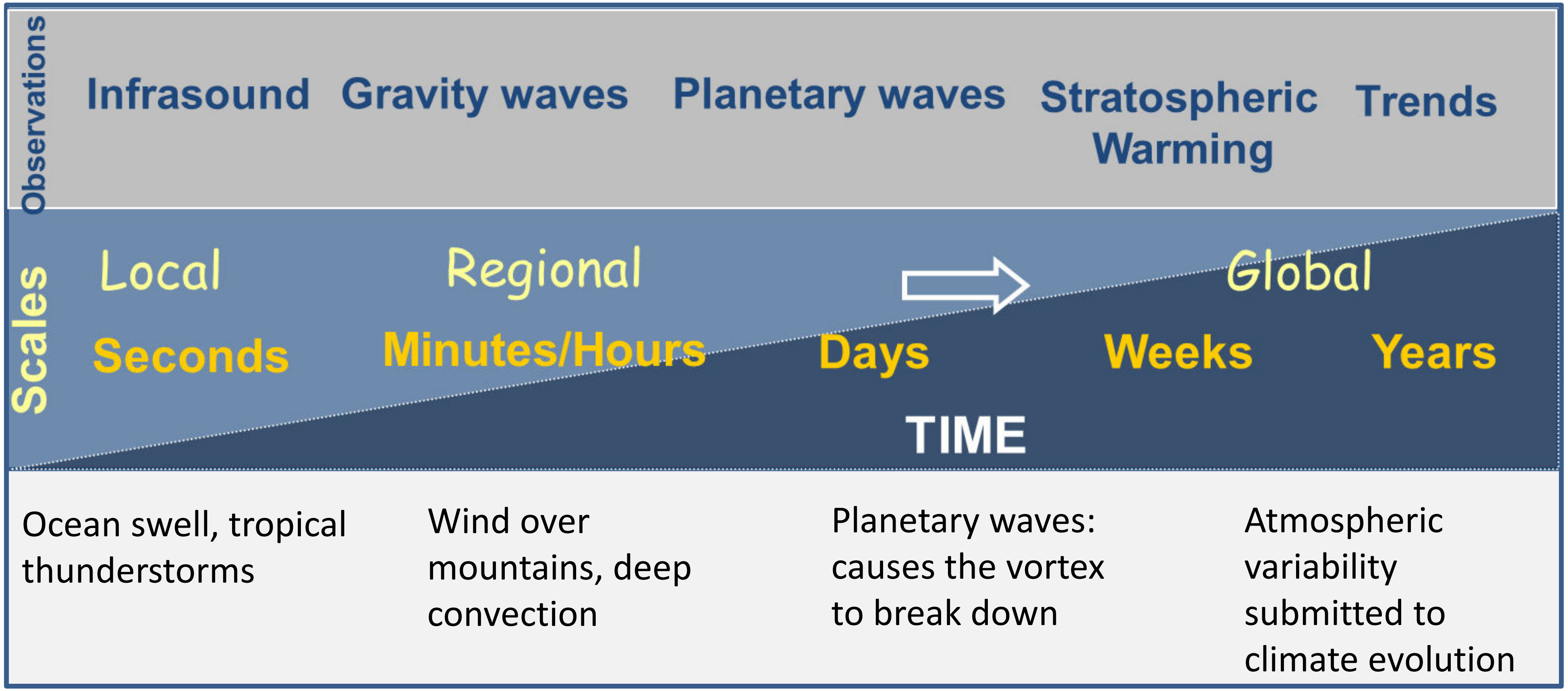
Brasseur and Solomon (2006)
SABER, Garcia et al (2005)

Atmospheric dynamics in the stratosphere and lower thermosphere



The temperature seasonal variation also controls the general circulation which is mainly driven by atmospheric waves originating from the troposphere at low altitudes

Atmospheric dynamics affects broad time scales



Observations

Infrasound **Gravity waves** **Planetary waves** **Stratospheric Warming** **Trends**

Scales

Local Regional → Global

Seconds **Minutes/Hours** **Days** **Weeks** **Years**

TIME

Ocean swell, tropical thunderstorms

Wind over mountains, deep convection

Planetary waves: causes the vortex to break down

Atmospheric variability submitted to climate evolution

The seasonal variability is well represented by the models, however the variability produced by gravity waves, planetary waves, stratospheric warming in the stratosphere and lower thermosphere is a large source of uncertainties.

Atmospheric variability in the first computations of the network detection capability

The atmospheric variability was integrated by:

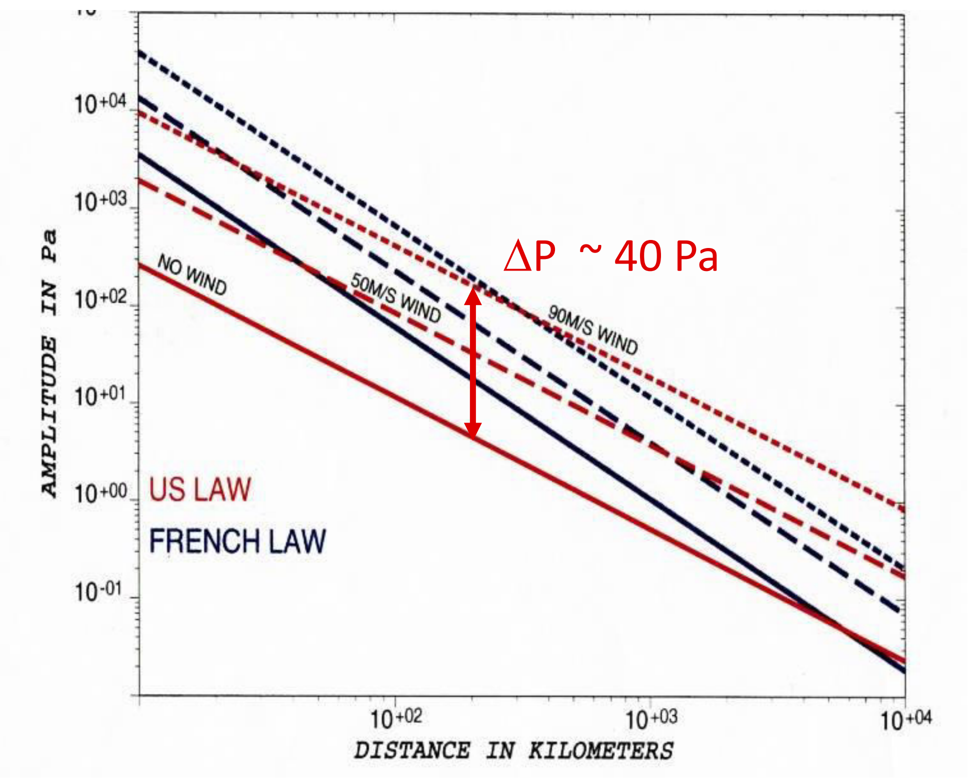
- **zonal stratospheric winds in the attenuation relation (climatological models)**

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

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).

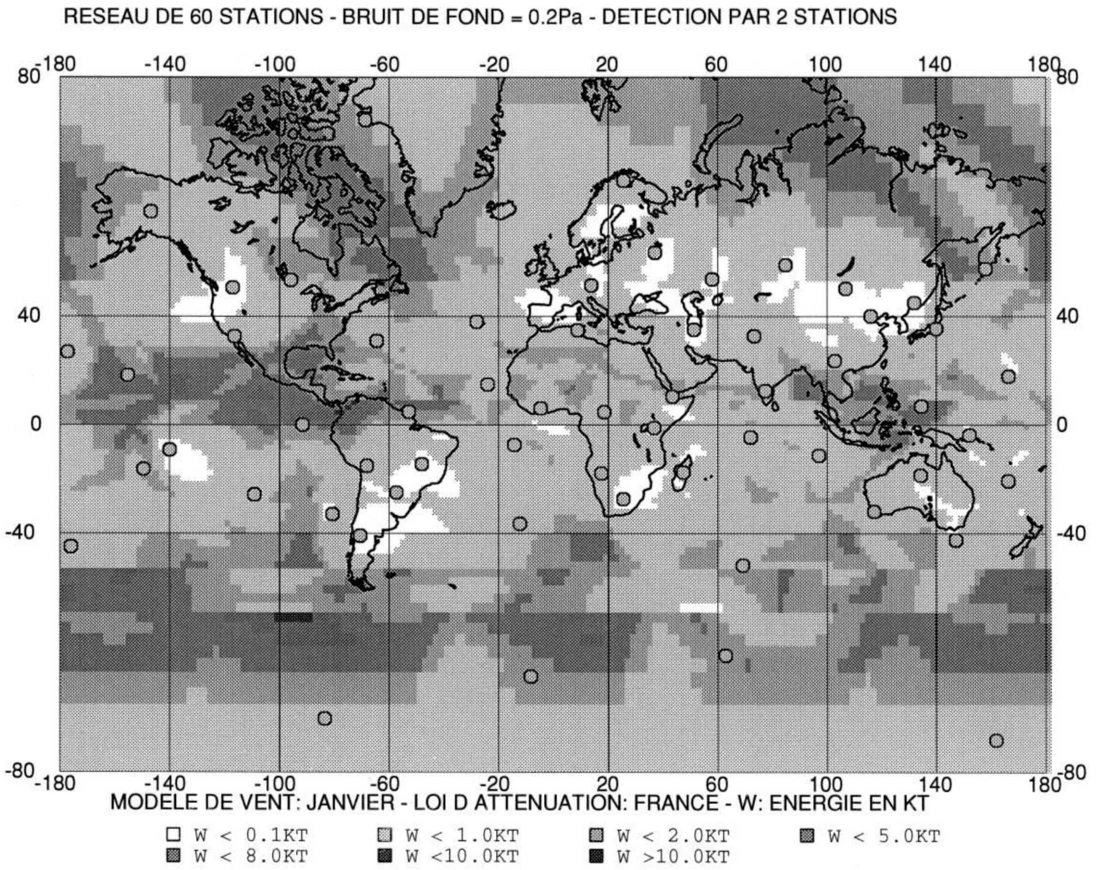
Whitaker, 1995

- **surface winds in the noise determination (meteorological observations)**

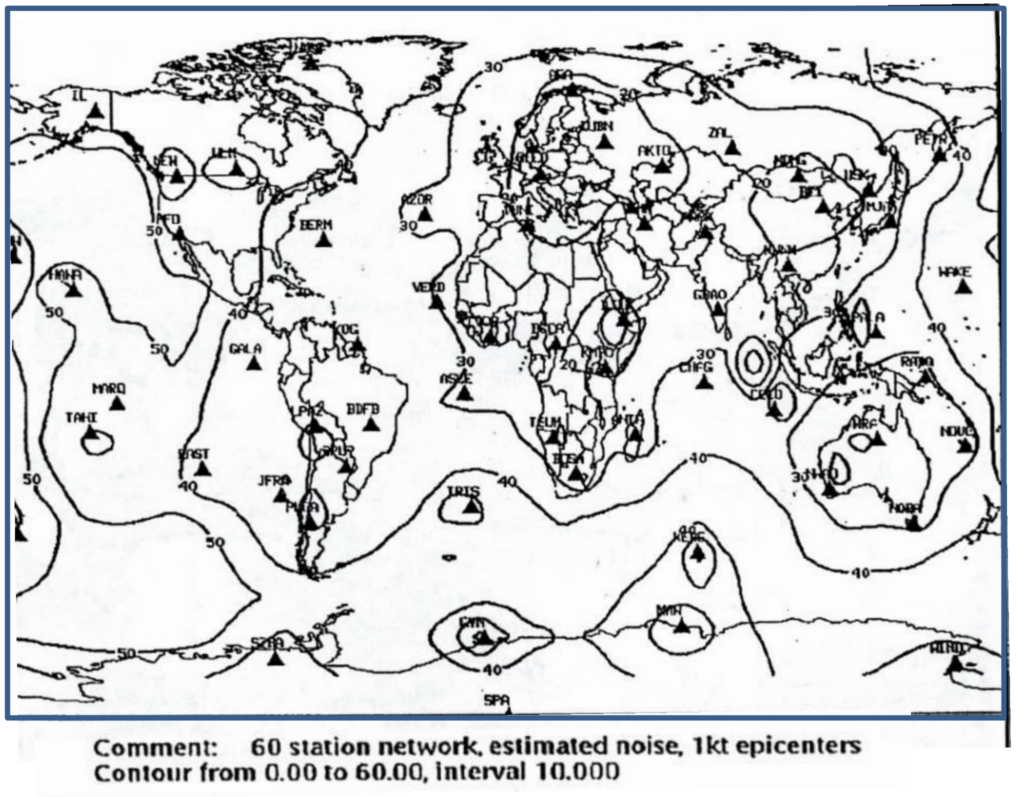


The determination for each point of the Earth the lower explosion yield able to be detected provided detection capability maps

First detection capability maps



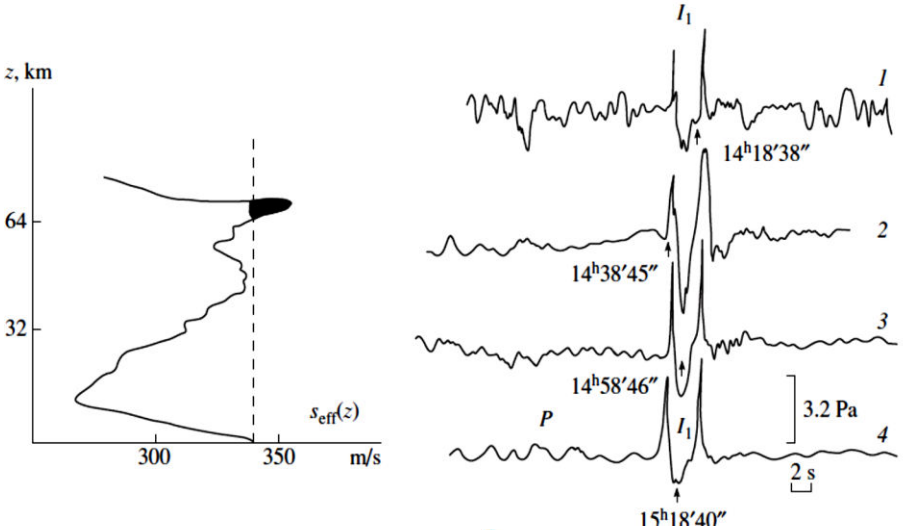
Deterministic approach (FR)

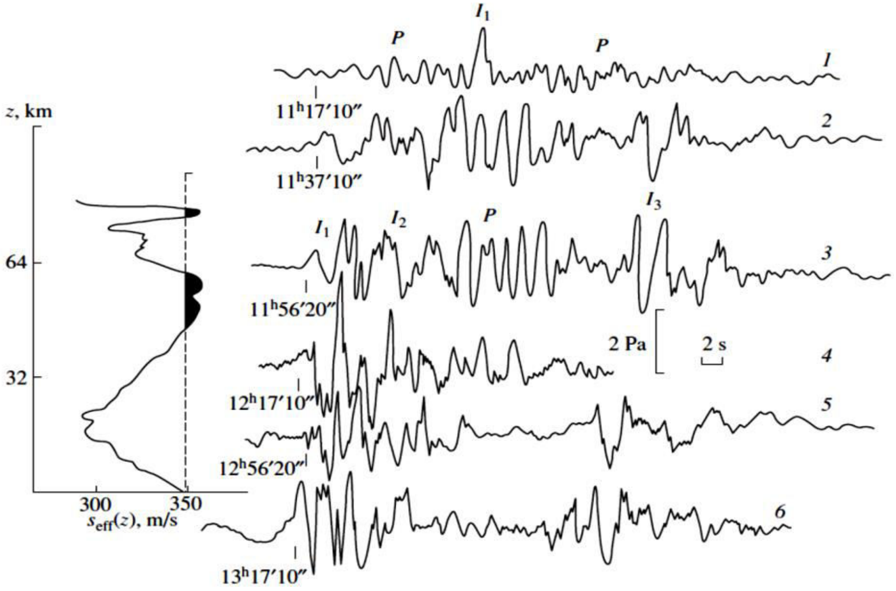


Probalistic approach (USA)

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)

Calibrations using repetitive sources (explosions)





Calibrations using successive explosions showed a large variability in the detected signals, identified as produced by changes in the atmospheric structure of the stratosphere

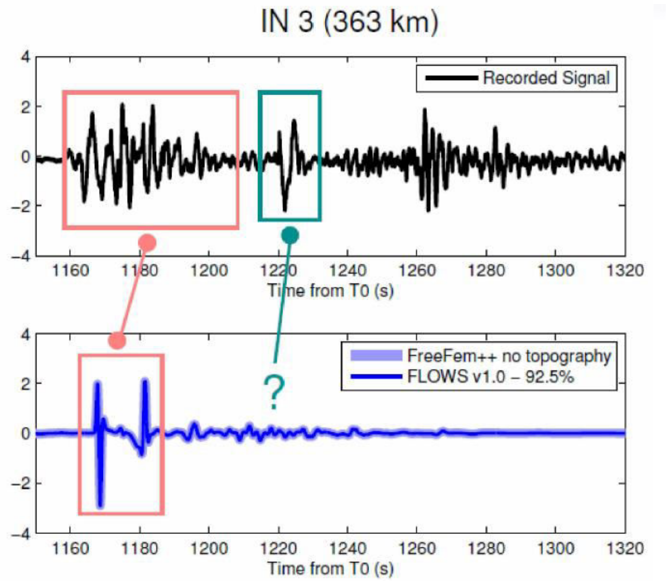
Kulichkov et al, 2010

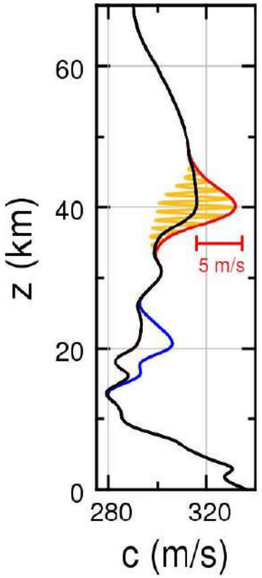
Small scale structures mainly originating from gravity waves, produce partial reflections of infrasound and strongly modify the observed signals

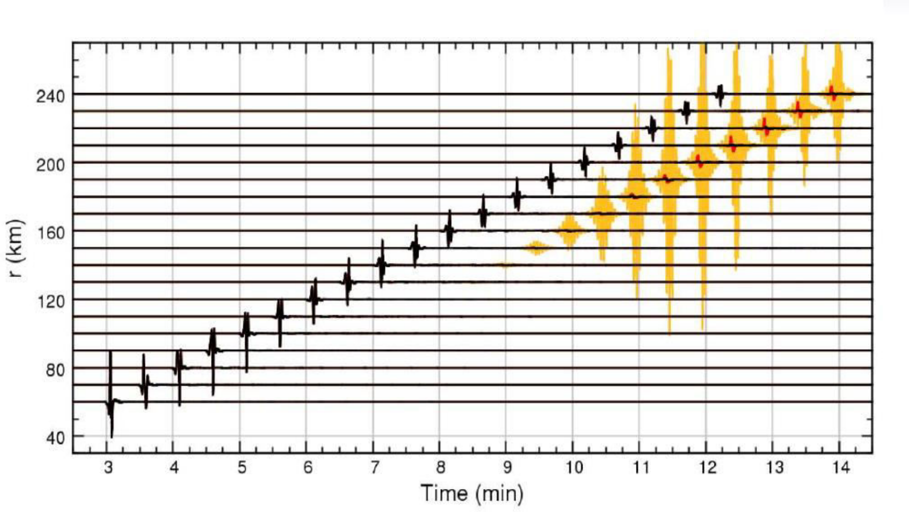
Strong variability is also observed in systematic observations of ground truth events (repeating explosion sources) in Northern Europe

Gibbons et al., 2015

Simulation integrating the effets of small scale stratospheric structures







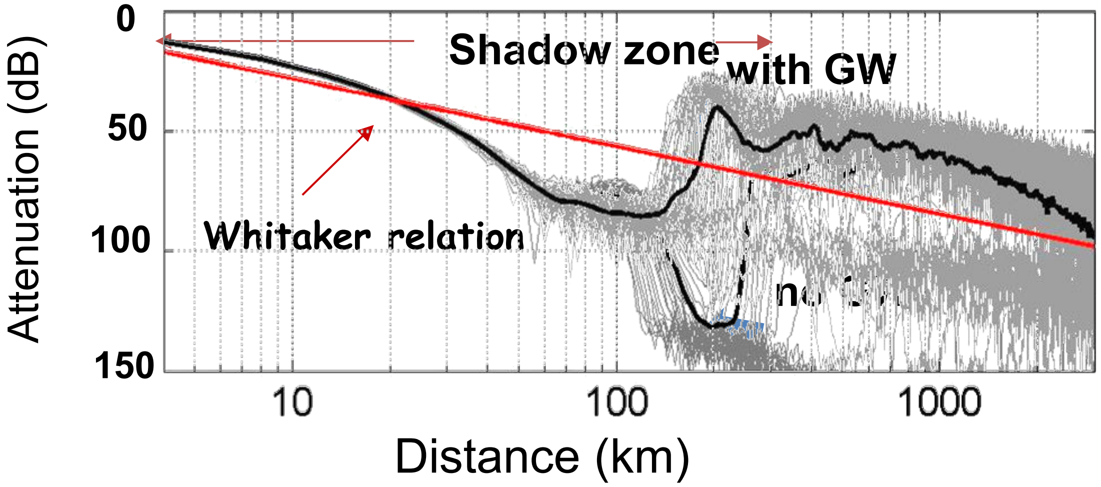
The observed signals are not represented by the simulation. The integration of irregularities in the model produces additional partial reflections and a better agreement with the observations

Realistic representation of small-scale dynamics is needed to accurately represent the infrasound recorded in the IMS stations.

Gravity waves are generally represented by small scale oscillations along the ECMWF profile

Ribstein et al., ARISE workshop, 2016

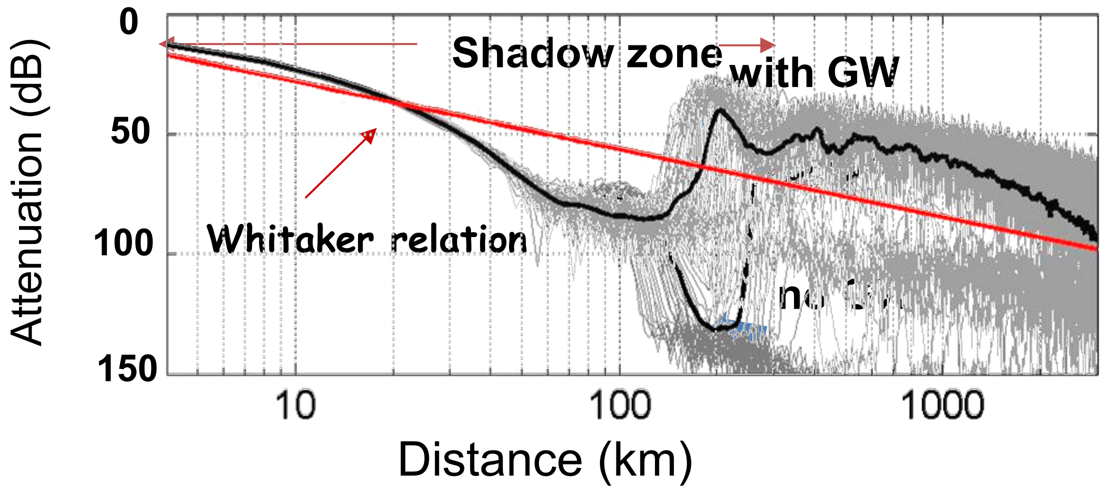
Determination of the detection capability using models rather than empirical attenuation relations



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

New simulations were developed using updated atmospheric models in 2009-2010, including a gravity wave model

Determination of the detection capability using models rather than empirical attenuation relations



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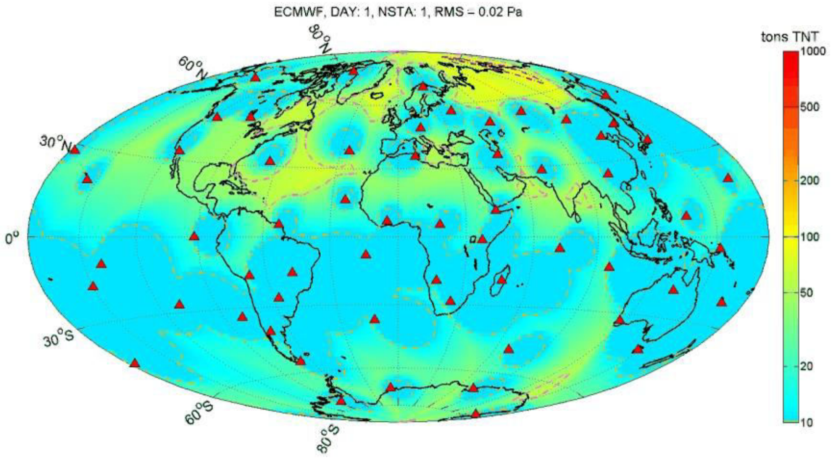
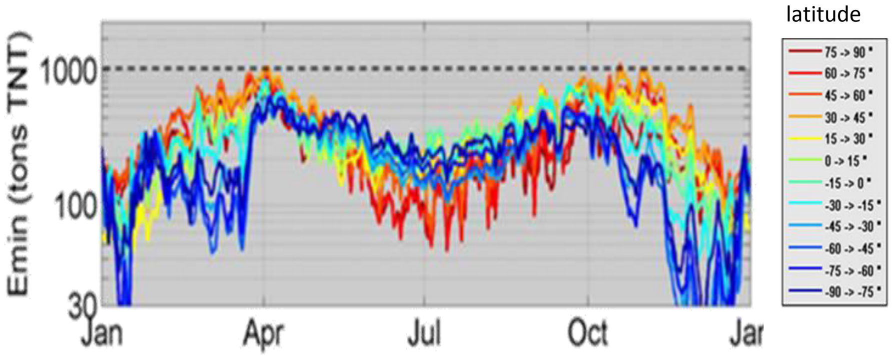
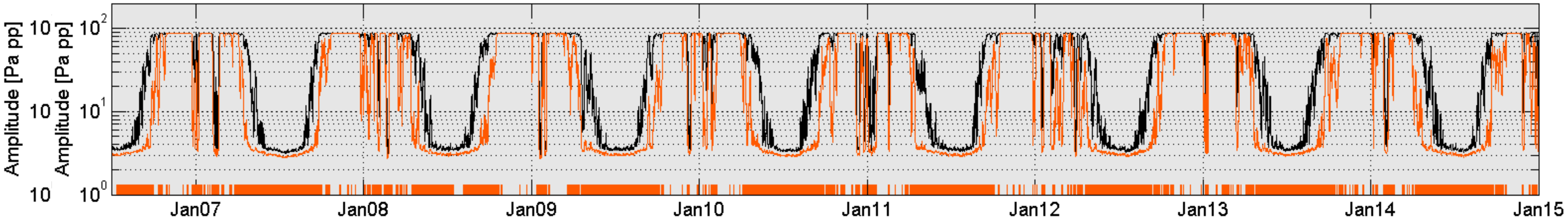




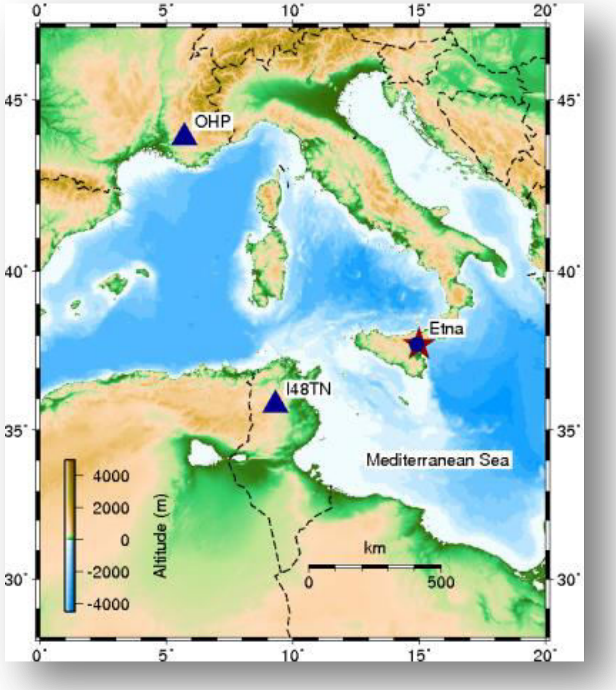
Deterministic approach (Le Pichon et al., 2009, 2012)

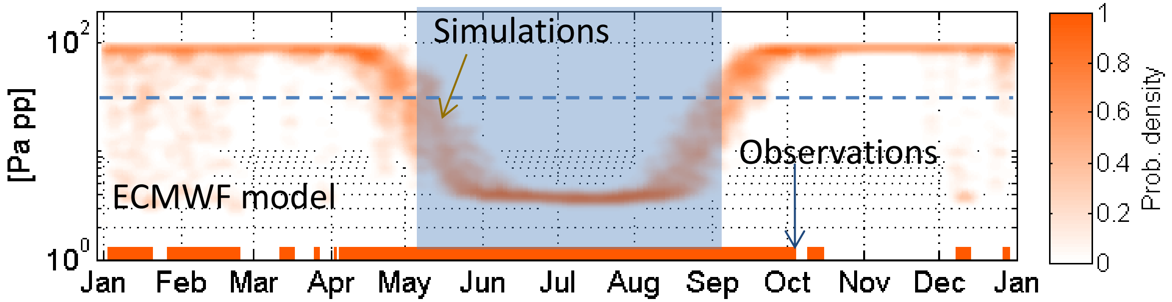
Probabilistic approach (Green et al., 2010) confirmed the efficiency of the IMS infrasound network

Quasi-continuous calibrations using eruptions of the Etna volcano

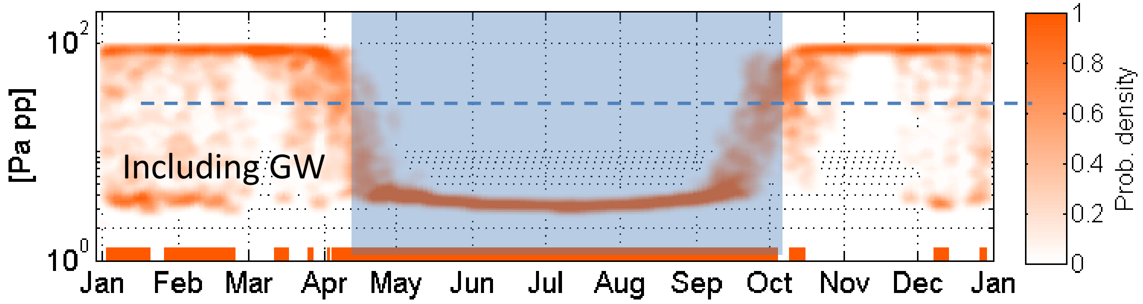


Comparison of Etna observations in Tunisia and predictions using the ECMWF model.





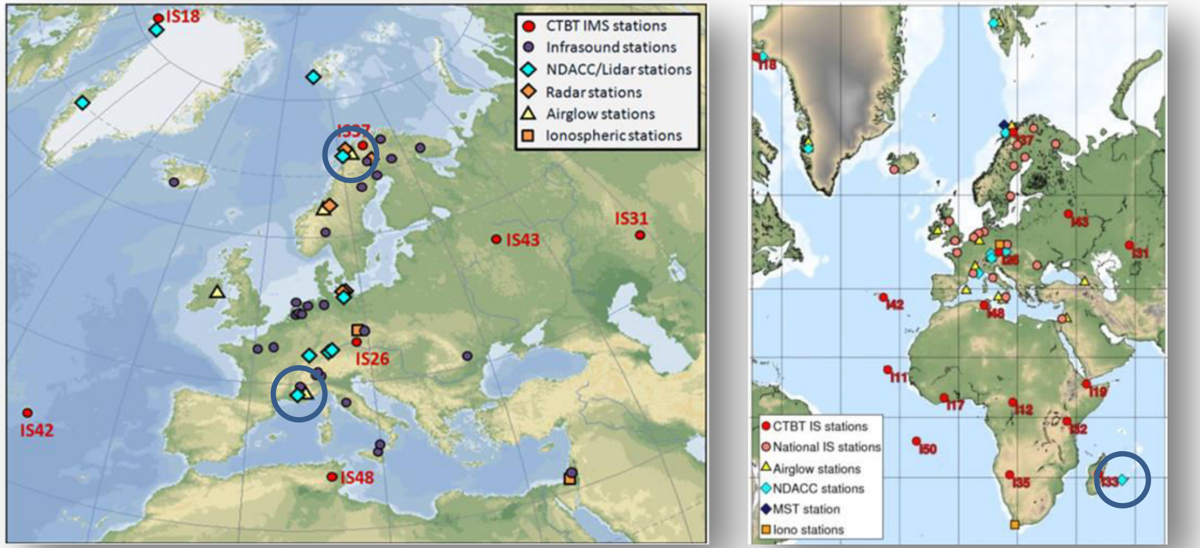
The integration of an empirical Gravity Waves (GW) model in ECMWF makes it possible to reproduce the observations



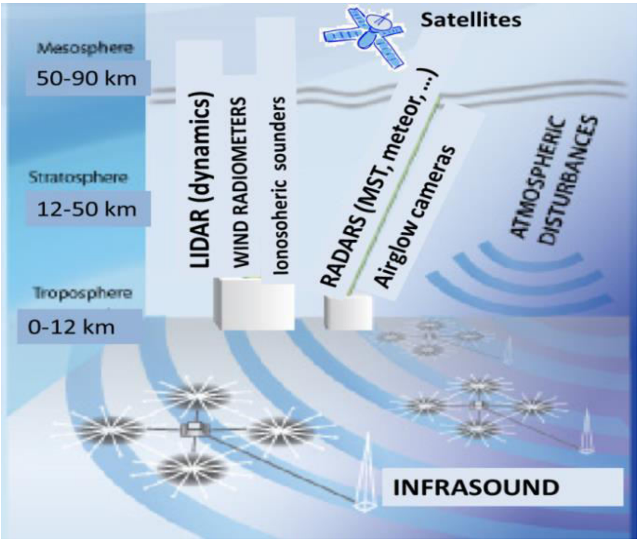
Uncertainty in simulations arises from the limitations of models to describe these disturbances

ECMWF: European Centre for Medium-range Weather Forecasts

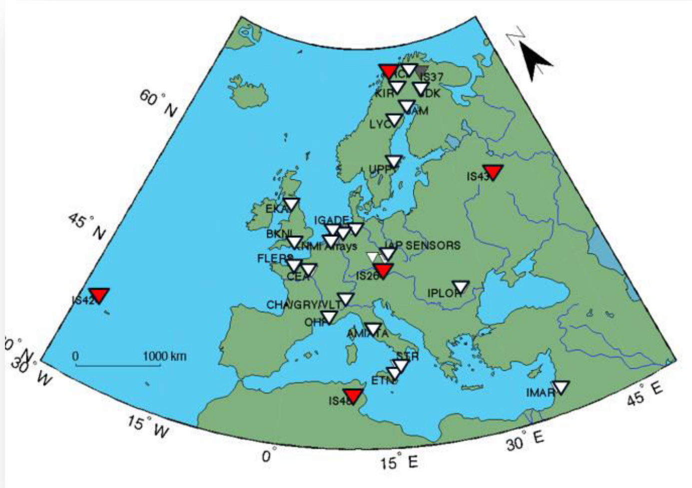
ARISE (Atmospheric dynamics Research InfraStructure in Europe)



ARISE station network



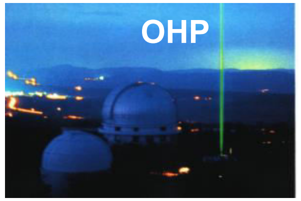
Complementary observations

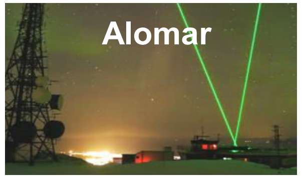


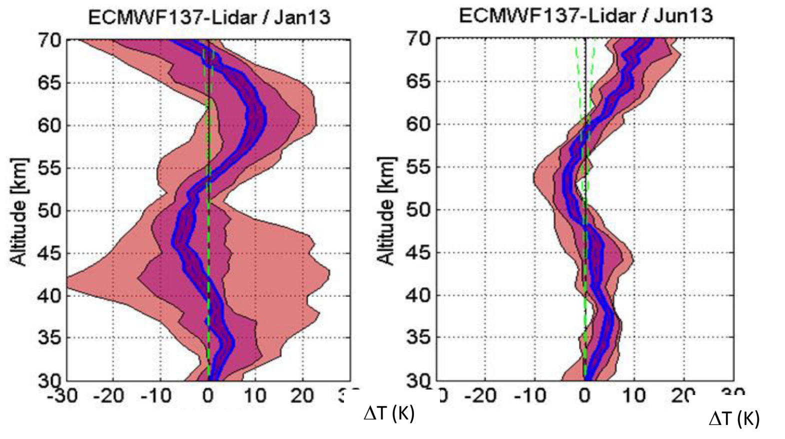
European ARISE infrasound stations

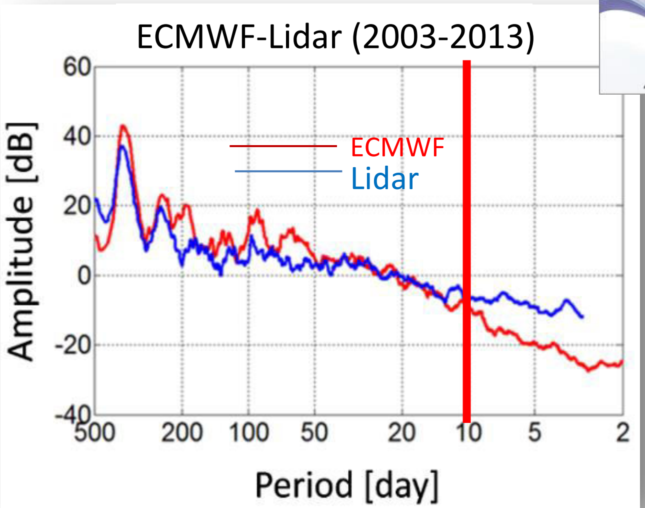
- The ARISE project combines complementary observations with theoretical and modelling studies to better understand and describe the dynamics of the middle and upper atmosphere.
- It uses the **IMS infrasound stations** associated to the **lidar NDACC network** and additional radars and complementary instruments. The **European infrasound network** well complement the system

Lidar observations for the determination of model uncertainties



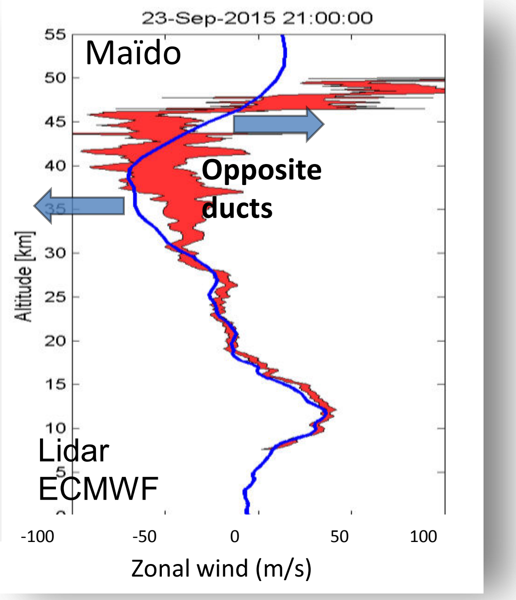






Distribution of temperature difference between ECMWF and Lidar at OHP in January and June 2013. The mean difference exceeds 5K for the temperature and 20m/s for the zonal wind.

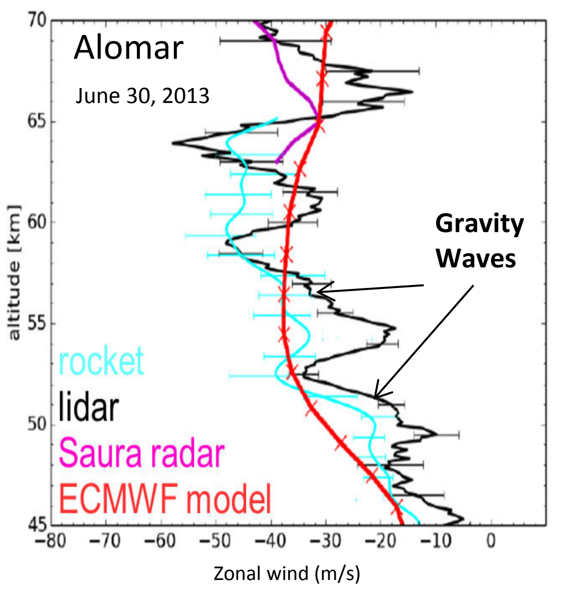
Le Pichon et al, 2015



Hauchecorne, 2016

Wind lidar and ECMWF present large differences in the presence of gravity waves or during equinox period when opposite ducts are expected

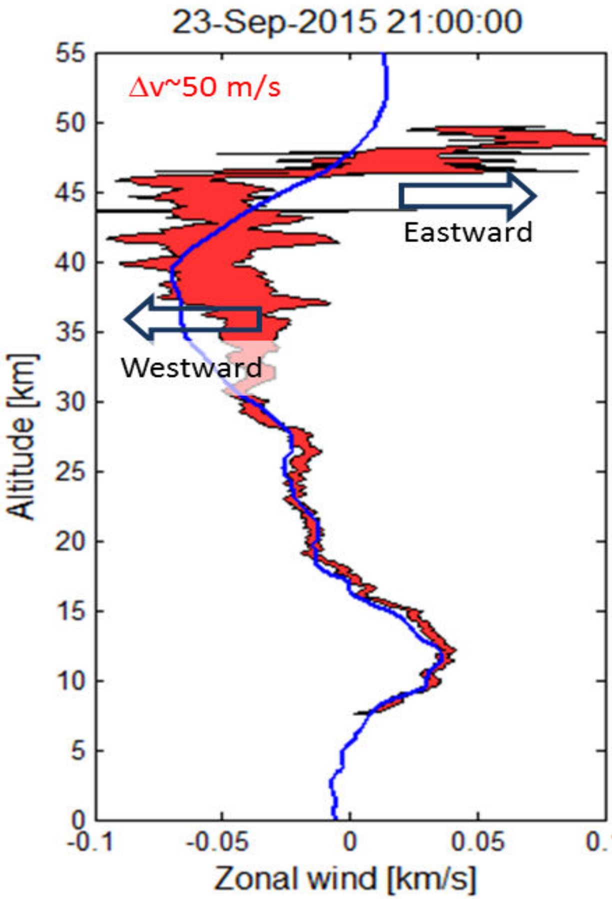
Interest of the new data sets for model improvement



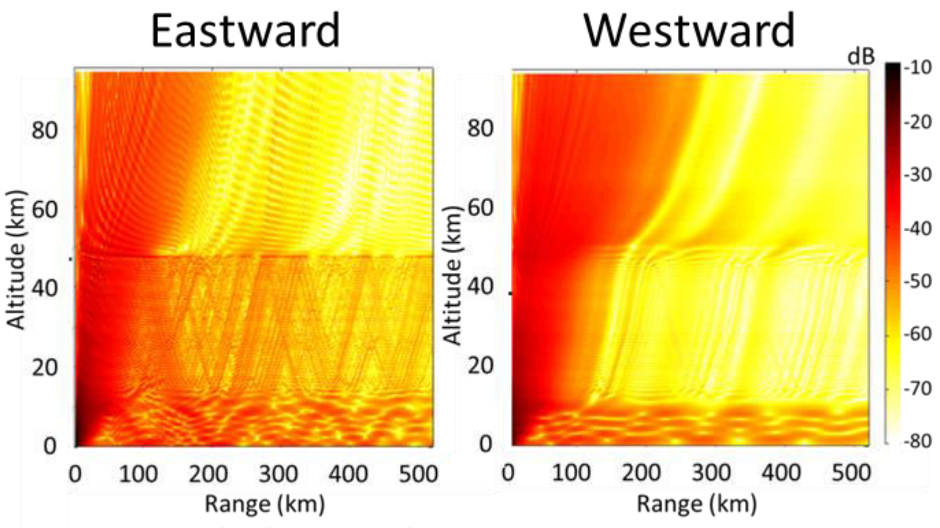
Baumgarten, 2014

Uncertainties in propagation
as observed at the Maïdo observatory by lidar

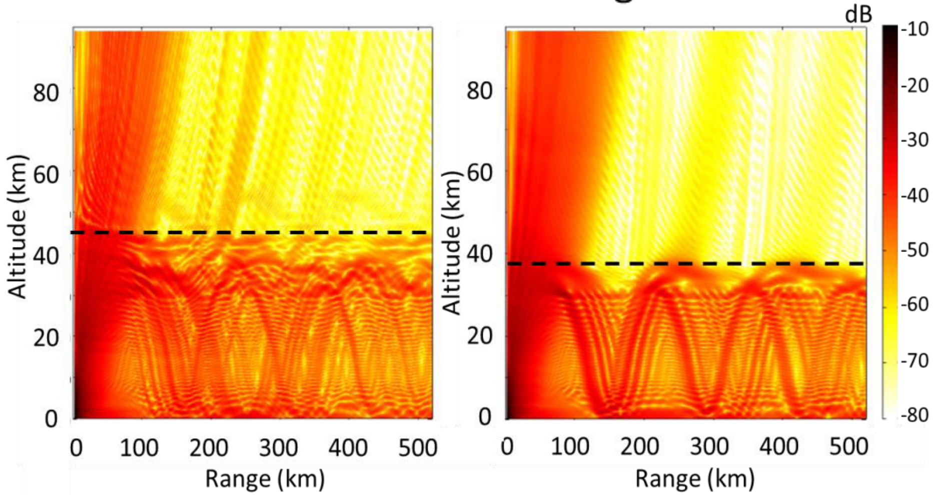
Atmospheric dynamics Research InfraStructure in Europe
ARISE



Lidar vs ECMWF (L137)



Parabolic simulations using ECMWF



Parabolic simulations using lidar observations

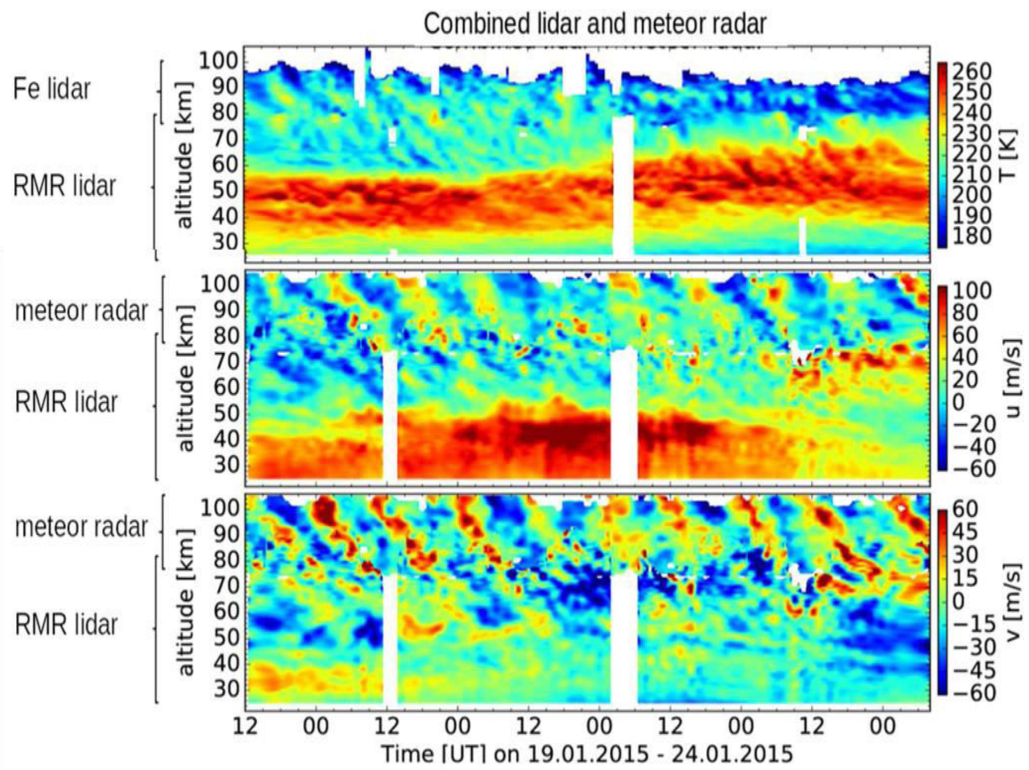
ECMWF does not allow to represent the observed double stratospheric guide

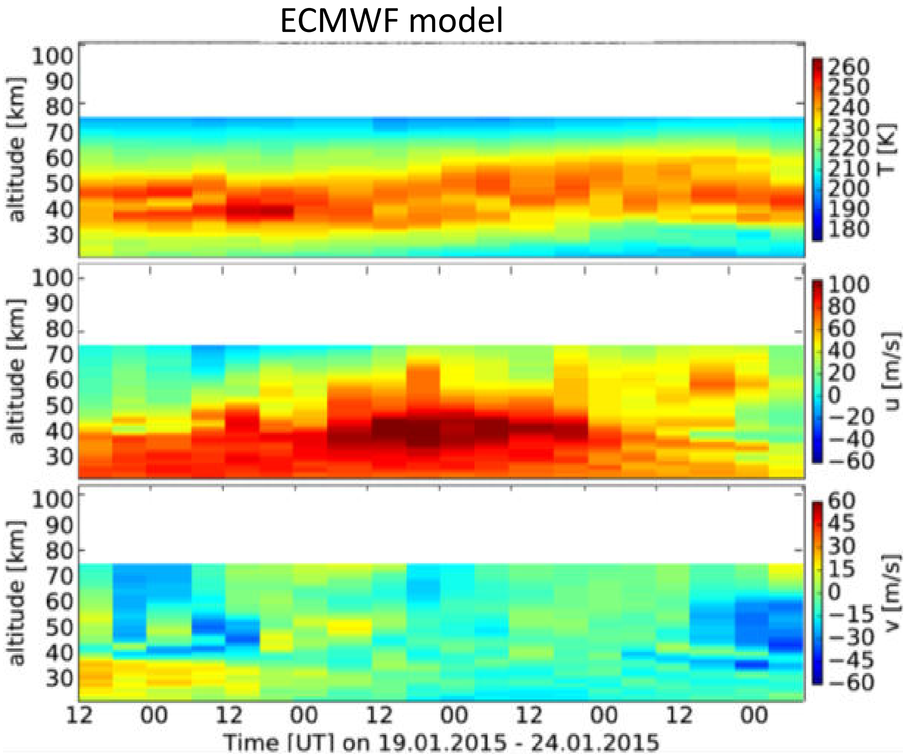
Interest of lidar observations for the interpretation of infrasound signals

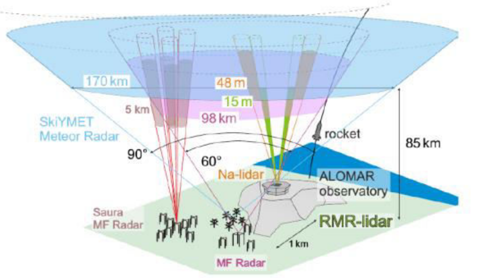
Blanc et al., 2017

Quantification of the uncertainties in ECMWF

Continuous observations by lidars and radars during several days at ALOMAR (NO)







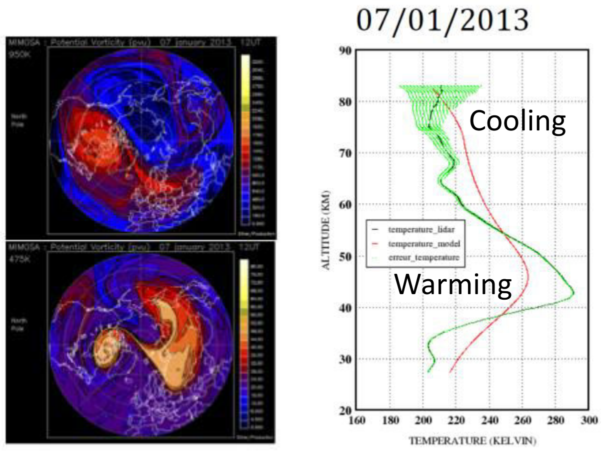
Combined and simultaneous high resolution temperature and wind observations with the ALOMAR RMR lidar, the mobile iron resonance lidar, and the Andenes meteor radar

- Simultaneously measurement of temperature and wind at high temporal resolution
- Daylight capability
- Tides and gravity waves characterization

Baumgarten, Stuber, Höffner , 2016

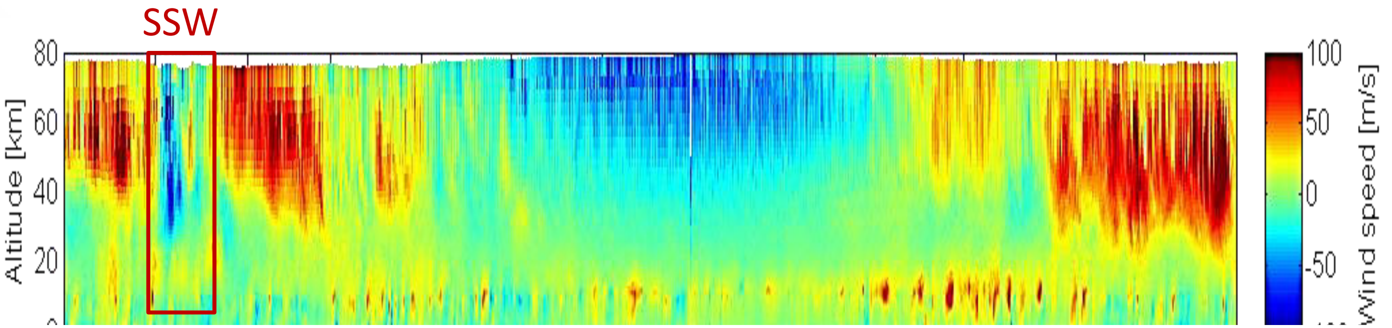
Sudden Stratospheric Warming

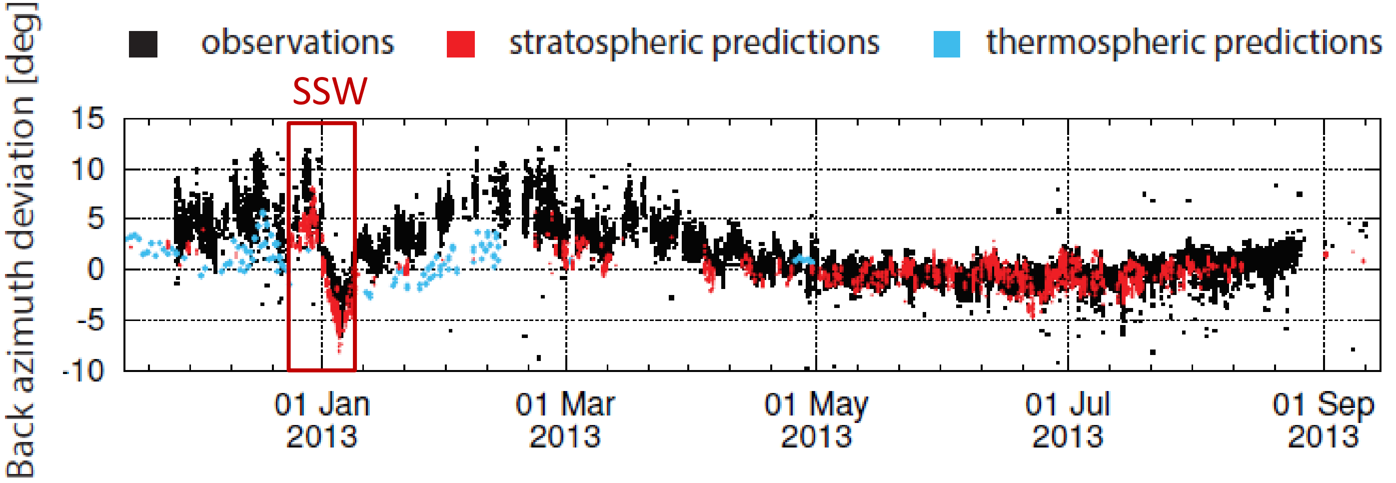
Sudden Stratospheric Warming events(SSW): polar vortex breaking, stratospheric warming, mesospheric cooling, inversion of the zonal stratospheric wind.



Hauchecorne et al, 2014

Volcano Mount Tolbachik (Kamchatka, Russian Federation)





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

The back azimuth deviations represent the seasonal variation of the stratospheric winds. The SSW produced in winter conditions observed in summer.

Deviation of of several degrees are observed between simulations and observations during and after this event showing the effect of SSW related uncertainties in simulations

Smets, et al., JGR, 2016

Integration of uncertainties in detection capability simulations: effects on detection thresholds

Uncertainty factors: {α(f), β($V_{eff\text{-}ratio}$,f) , δ, σ(f)}

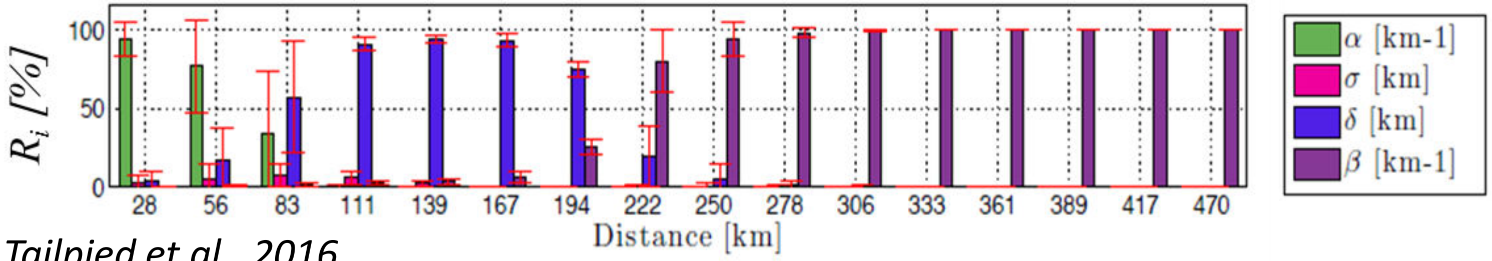
$$\sigma(A_P) = \sqrt{\sum_{i=1}^{N} \left(\frac{\partial f}{\partial x_i}\right)^2 . \sigma^2(x_i)}$$

Sensitivity index

$$R_i = \frac{\left(\frac{\partial f}{\partial x_i}\right)^2 . \sigma^2(x_i)}{\sigma^2(A_P)} . 100$$

α: dissipation direct wave,
β (f): geometrical spreading and dissipation of stratospheric and thermospheric paths

Sobol & Kucherenko, 2009
Turányi & Rabitz, 2004

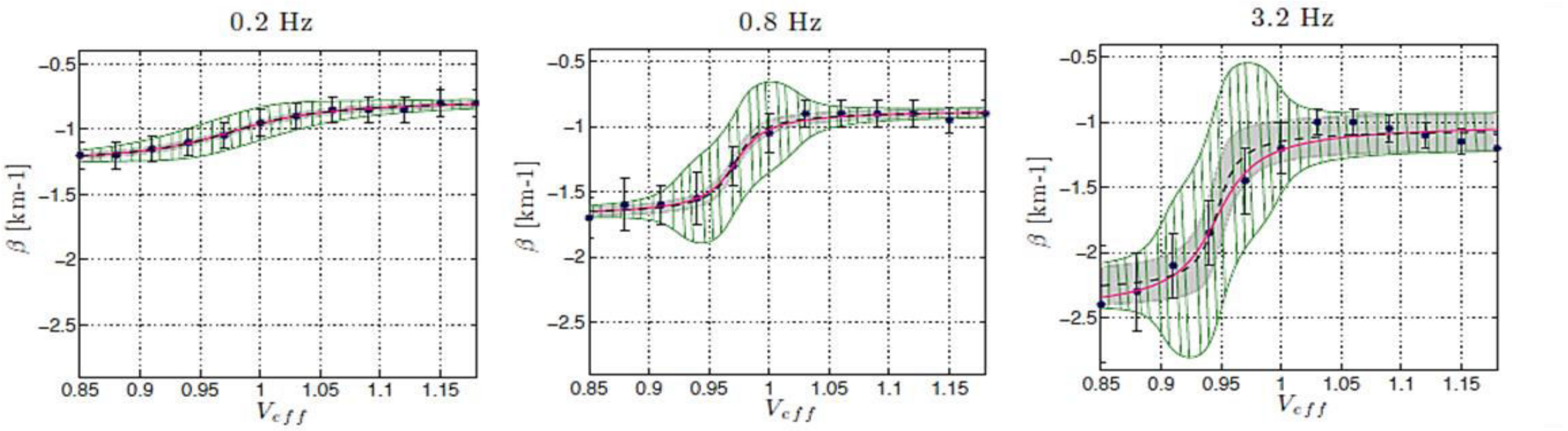


Tailpied et al., 2016

At far fields, uncertainty is dominated by β

■ Uncertainty from models

▥ Uncertainty from atmosphere

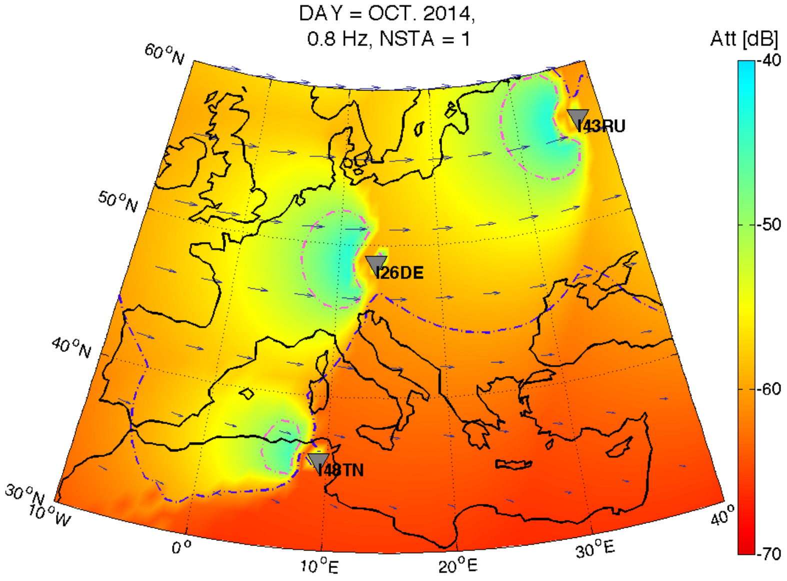


The uncertainty increases with frequency and when the stratospheric wind amplitude decrease

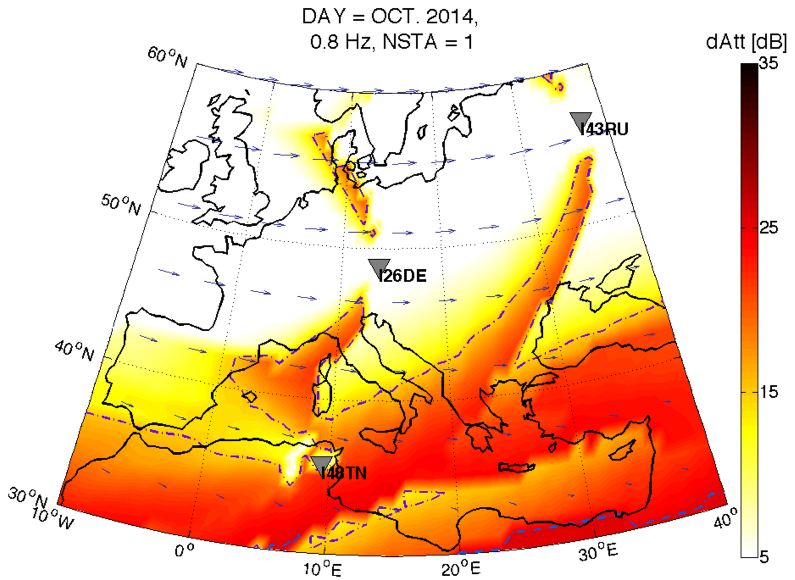
Performance of the detection capability networks

Effect of uncertainties on the detection thresholds (ARISE)

Regional study of sensitivity



Uncertainties of the detection thresholds

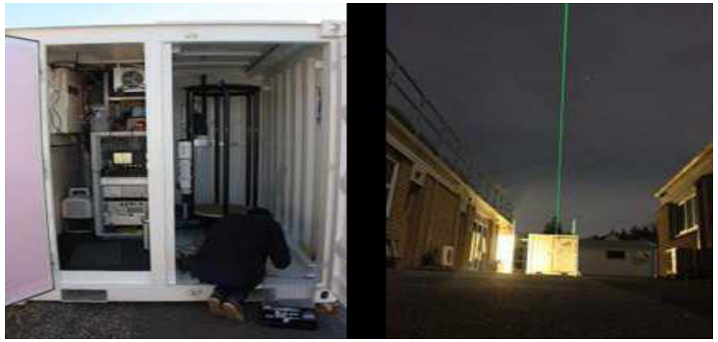


Interest for monitoring the network performances:
Provide a confidence interval on detection thresholds

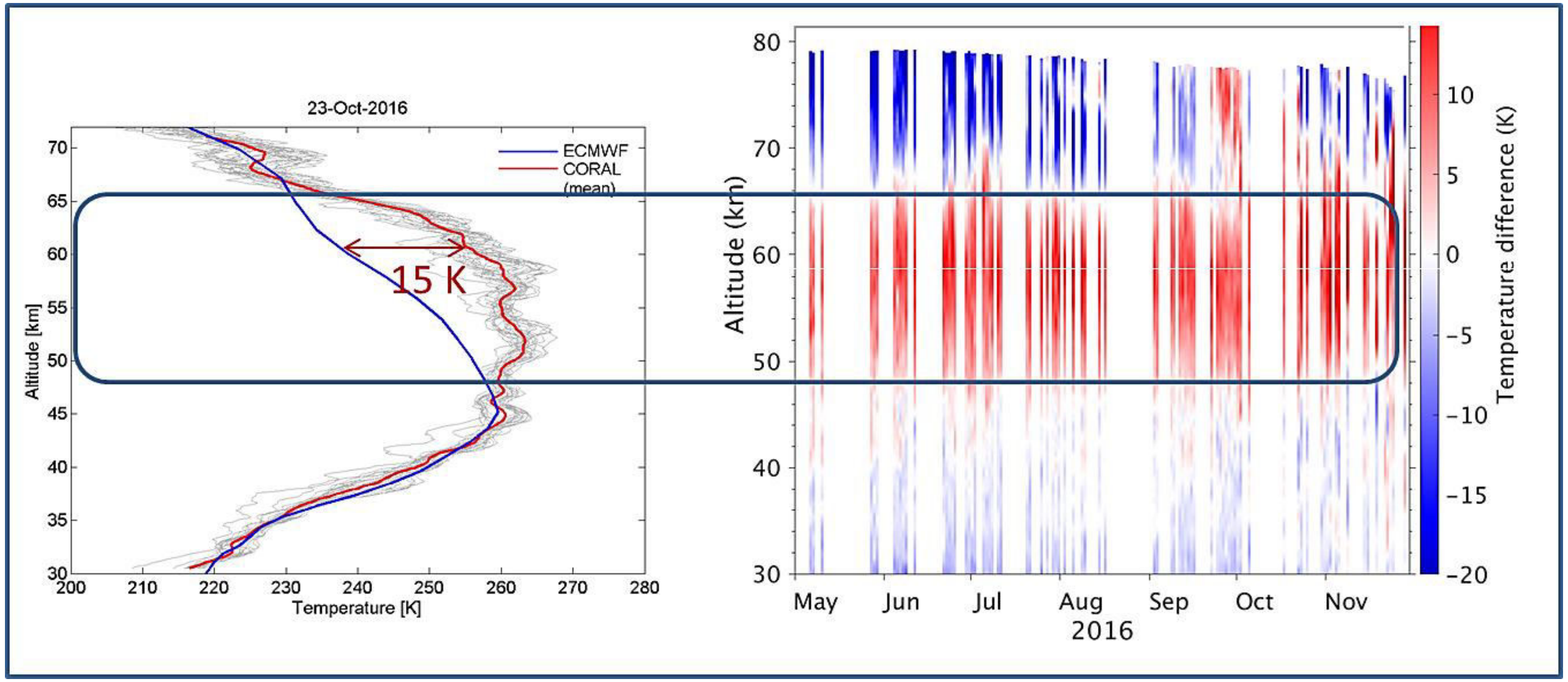
Tailpied et al., 2016

Interest of lidar associated to infrasound stations to reduce uncertainties in infrasound monitoring

High-resolution observations in the middle atmosphere by the mobile CORAL Lidar(DLR, DE) at the IS26DE infrasound station for an ARISE experiment campaign



Valuable middle-atmosphere observations for model validation (ECMWF IFS137)
– Good agreement up to 45 km
– Systematic difference between 45 and 68 km



Interest of quasi-real time processing (lidar + infrasound) for decreasing the uncertainties in models and improving operational monitoring

Result presented at the ARISE review (June 2017) by M. Rapp (DLR)

Summary and conclusion

- Uncertainties in infrasound monitoring are mainly related to atmospheric variability of the stratosphere and mower thermosphere.
- Seasonal variations are well represented by ECMWF. The uncertainty sources are mainly disturbances related to gravity waves (GW), sudden stratospheric warming events (SSW), planetary waves, solar tides .
- Comparison between multi-instrument observations (ARISE) with models (ECMWF) showed averaged differences of 5K and 20m/s in temperature and winds. Differences are larger in the presence disturbances
- ARISE observations are systematically used for characterization and parametrization of temperature and winds in the stratosphere and lower thermosphere.
- Challenge of quasi-real time processing of co-localized lidar and infrasound for decreasing the uncertainties in models and improving operational monitoring.
- Other challenge: data assimilation for improving infrasound and weather forecasting models

ARISE design study (http://arise-project.eu) is funded by the European Union within FP7, grant 284387,and the ARISE2 project within H2020, project 653980.