Using infrasound from explosions for probing internal gravity waves in the middle atmosphere

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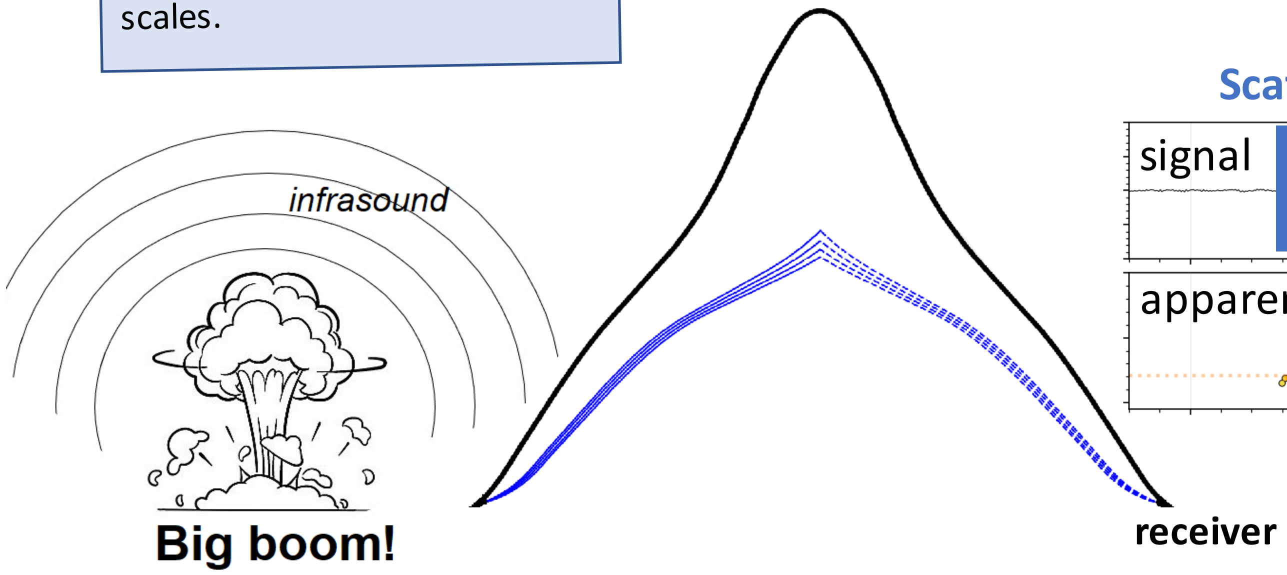
Sharing is encouraged

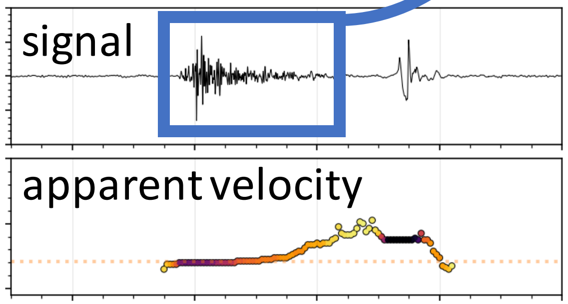
The OSPP talk

Main message: Infrasound can provide a complementary technique to extend the observational range of atmospheric gravity wave scales.

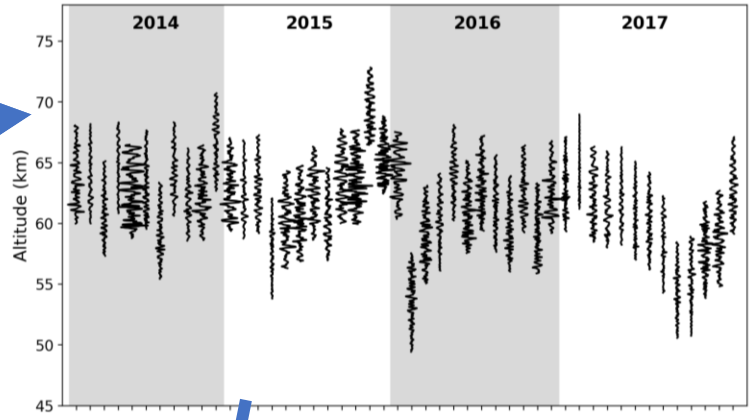


Signals in the shadow zone due to infrasound scattering on small-scale inhomogeneities

Scattered signal

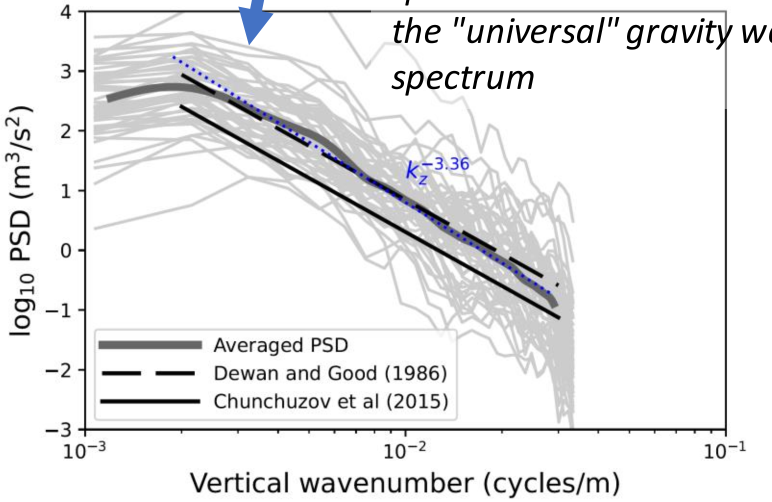


Inversion allows us to retrieve the effective sound speed fluctuations that caused the scattering



Explosions in 2014 - 2017

Vertical wavenumber spectra are associated with the "universal" gravity wave spectrum



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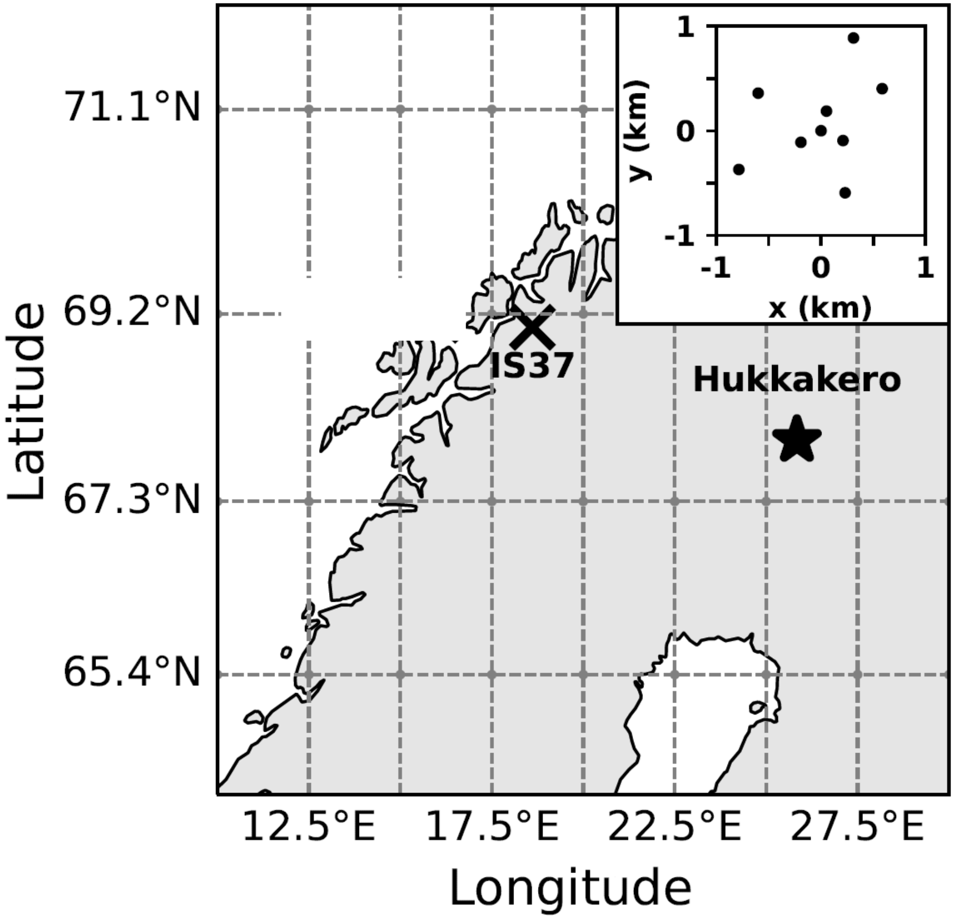
Motivation

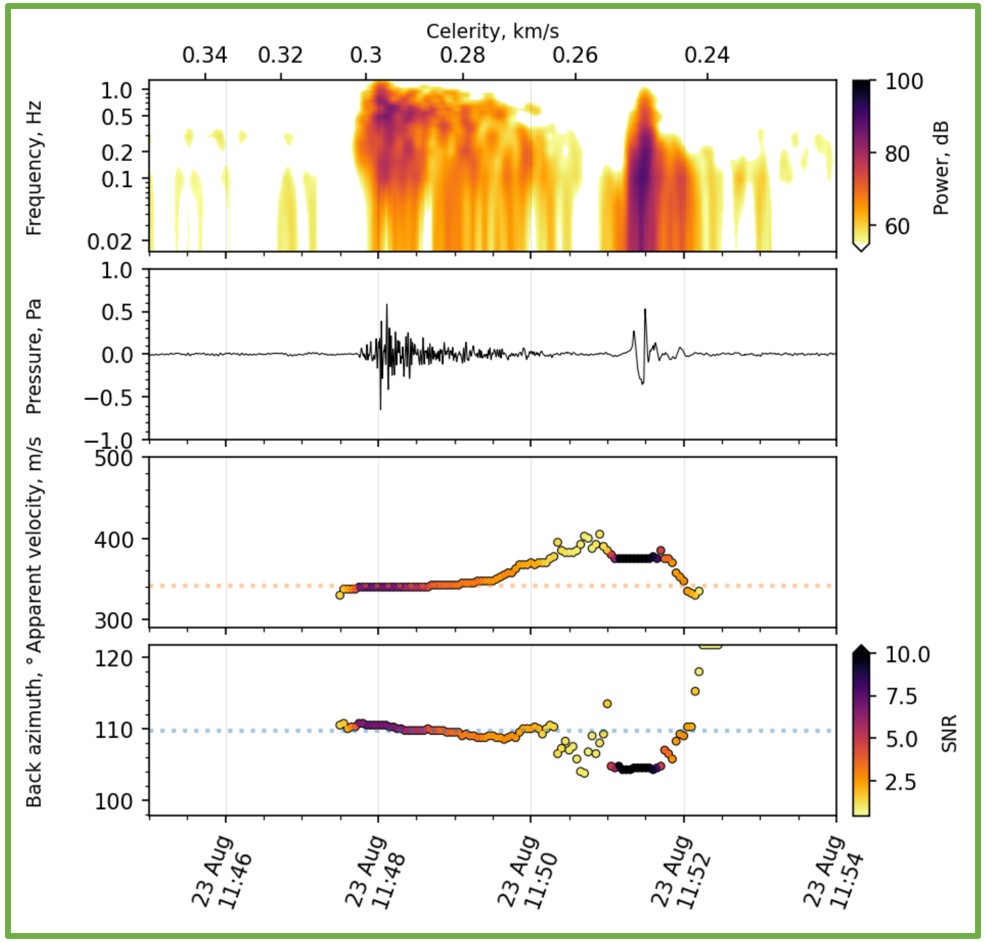
- Hukkakero explosions occur in **August-September** when the atmosphere experiences transition from summer to winter;
- Possible to clearly identify **arrivals from different** altitudes;
- **Recurring nature of events** → day-to-day variability of the middle atmosphere dynamics;



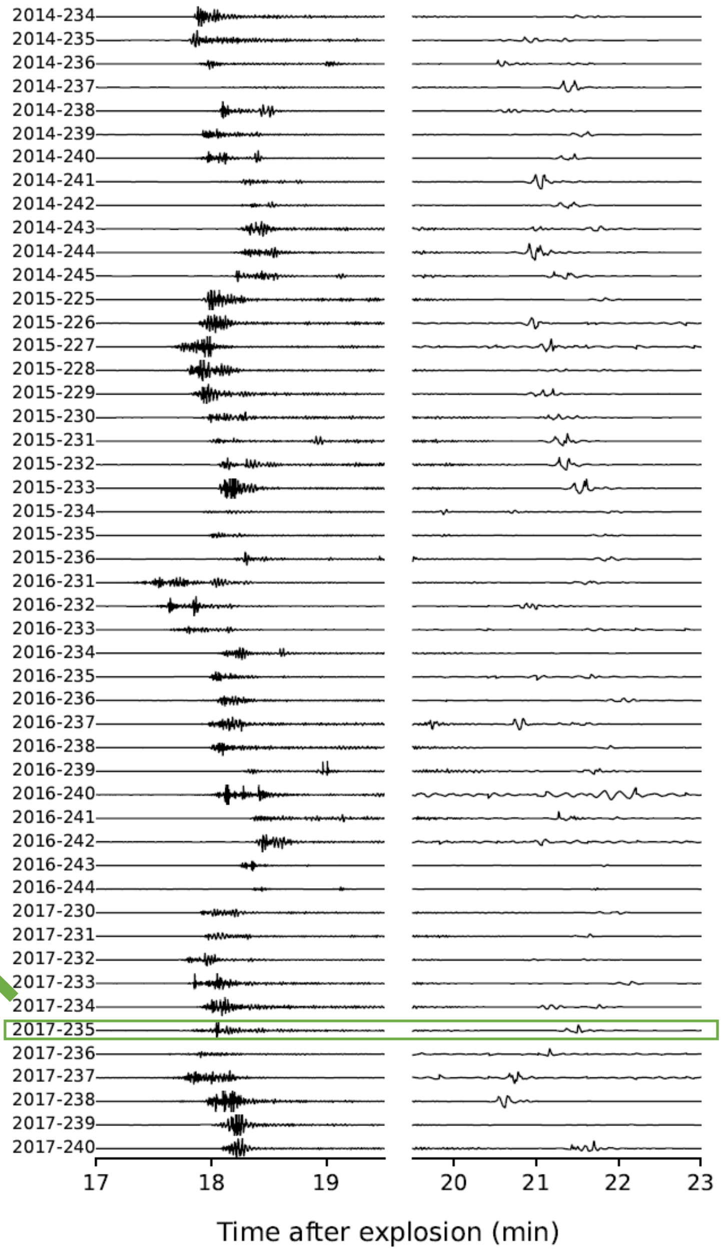
Introduction

- During the years **2014 - 2017**, **57 explosions**;
- 8 significantly weaker → **analyze 49** explosions;
- Typically, **two arrivals**: within **17-19 min** and within **20-22 min**;

Single event

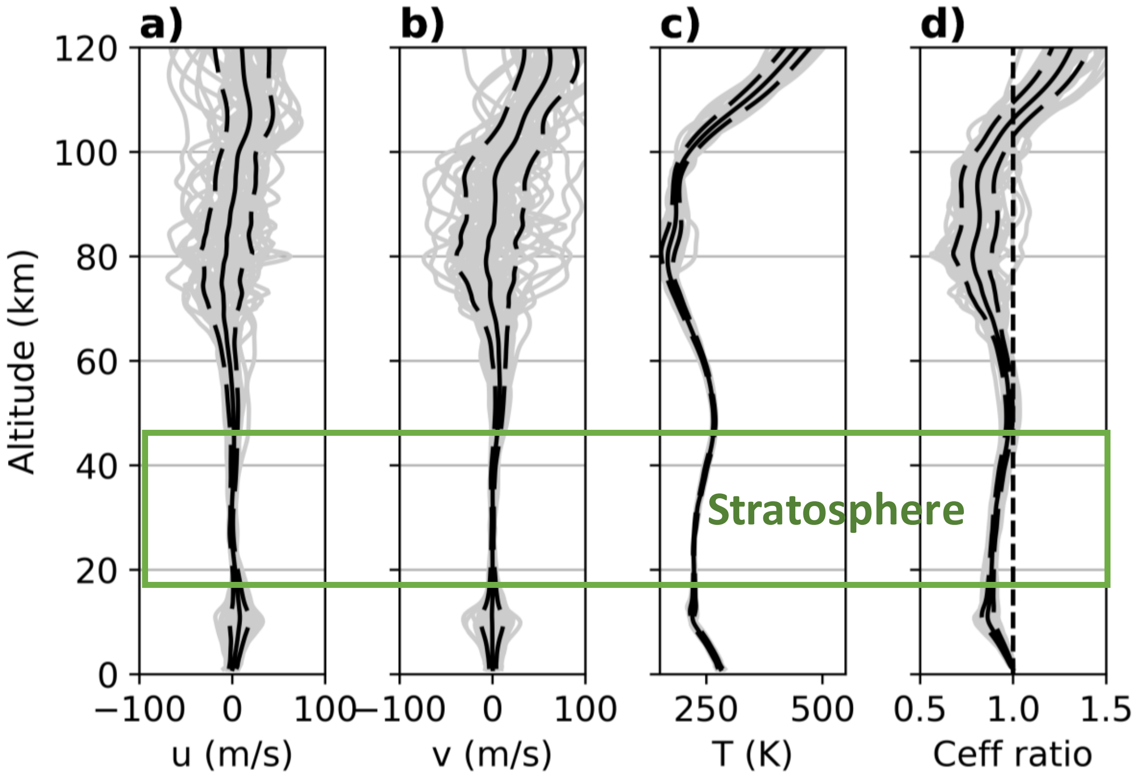


Four years of events



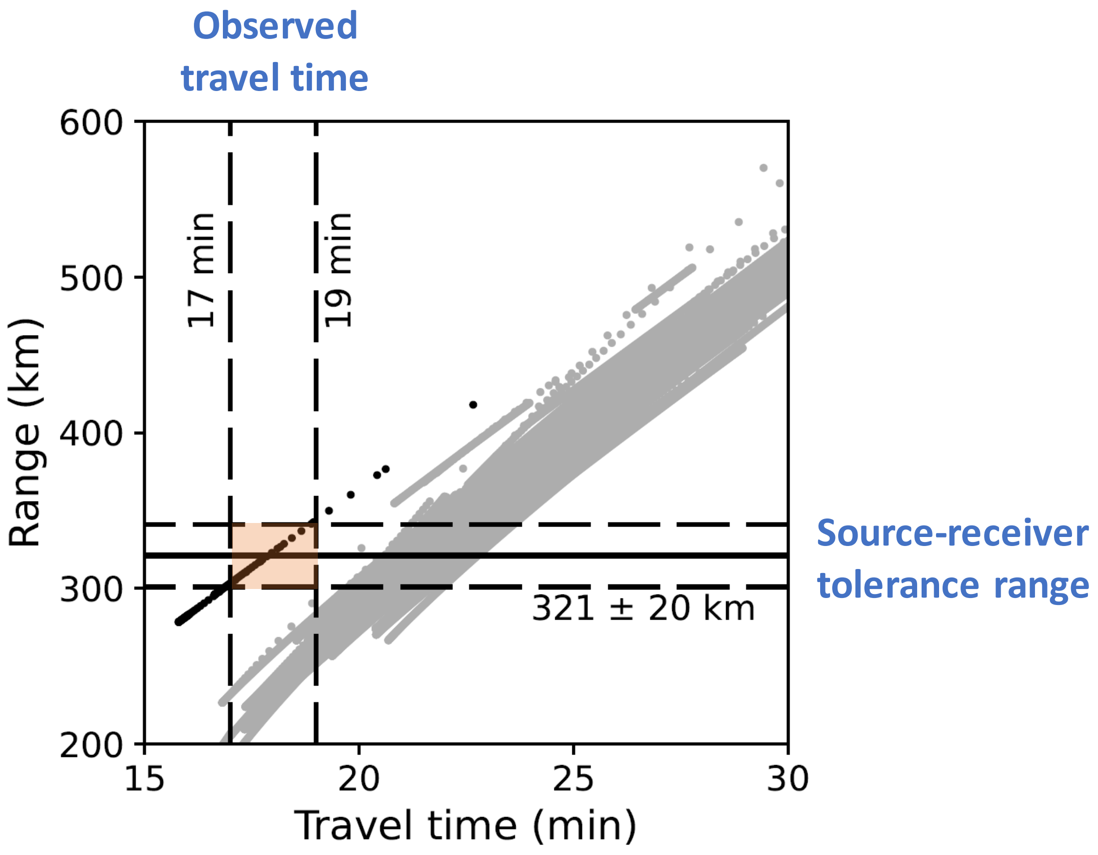
A single consistent atmospheric model (WACCM)

- The Whole Atmosphere Community Climate Model with thermosphere and ionosphere extension (**WACCM-X**);
- **Nudged** by the MERRA-2 from the ground **up to ~ 50 km** (SD-WACCM-X);
- Zonal and meridional **winds in the stratosphere are weak** due to the summer-to-winter transition in the stratospheric polar vortex;
- The C_{eff} ratio < 1 at 50 km altitude, except for two events → **strong stratospheric returns not expected** at IS37.

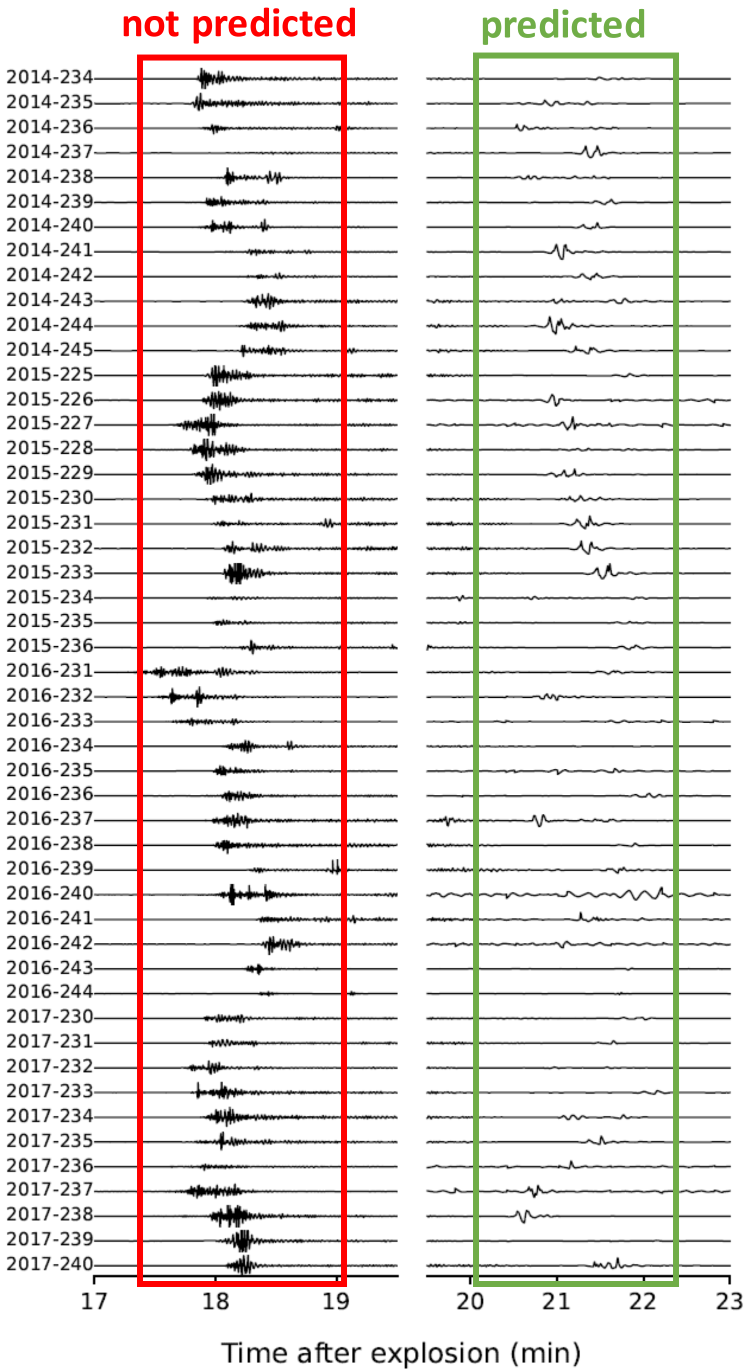


Ray-tracing

Simulate infrasound propagation using SD-WACCM-X atmosphere and InfraGA ray tracer → **only thermospheric arrivals are predicted** for 47/49 events.

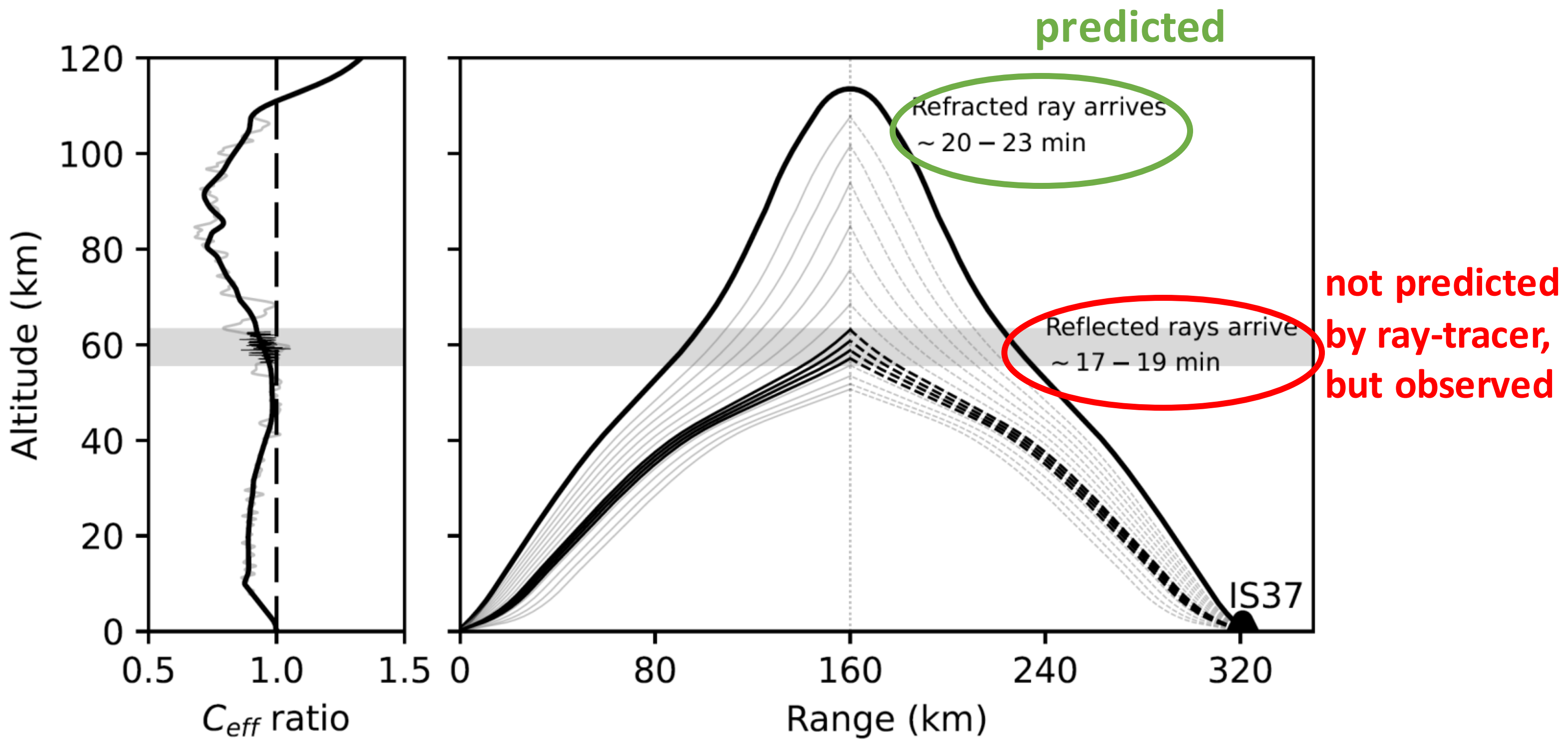


Grey – turning heigh ~100 km;
Black – turning heigh below 60 km.



Ray-tracing

Two typical infrasonic arrivals at IS37 after Hukkakero explosions:



From ray-tracing simulations:

- refracted infrasound reaches the station via **thermospheric ducts;**
- IS37 is located in a **stratospheric shadow zone** for most cases;
- The **reflected rays are** not predicted by the classical ray theory but are instead **constructed** using a mirroring procedure.

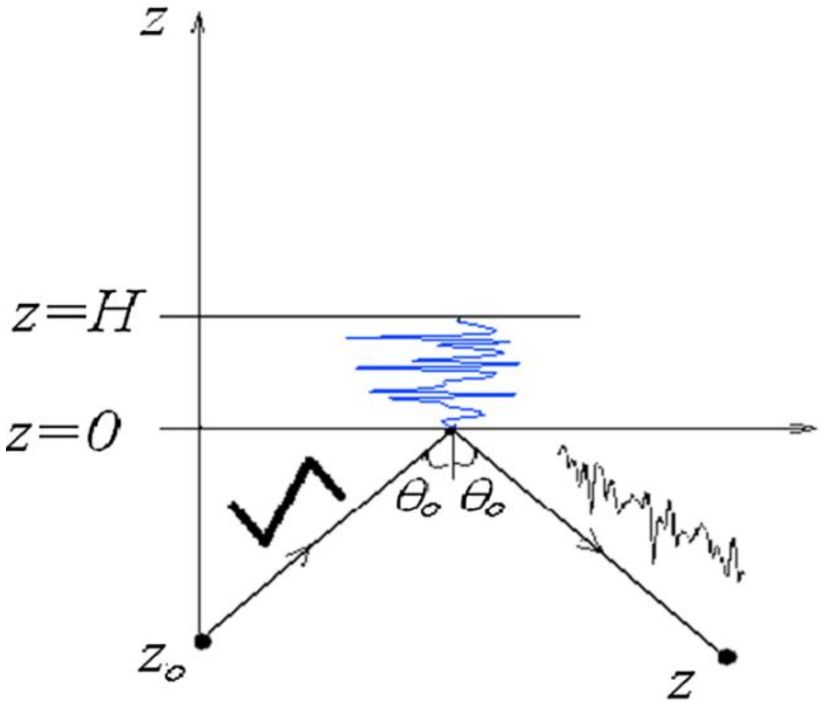
Inverse problem

- Assume **infrasound scattering on an inhomogeneous atmospheric layer** with fine-scale $C_{eff}(z)$;
- Want to retrieve fine-scale effective sound speed variations → **approach by Chunchuzov et al.**;
- The approach establishes a **relation between the waveform** of the scattered infrasound signal **and the $C_{eff}(z)$ fluctuation profile** in an inhomogeneous atmospheric layer.
- Yet, more information is needed:

1) Altitude range and incidence angle. Matching the travel time predicted by ray-tracing to the observed travel time.

2) Signal amplitude and duration close to the source. Use Kinney & Graham (1985) model based on the explosion yield.

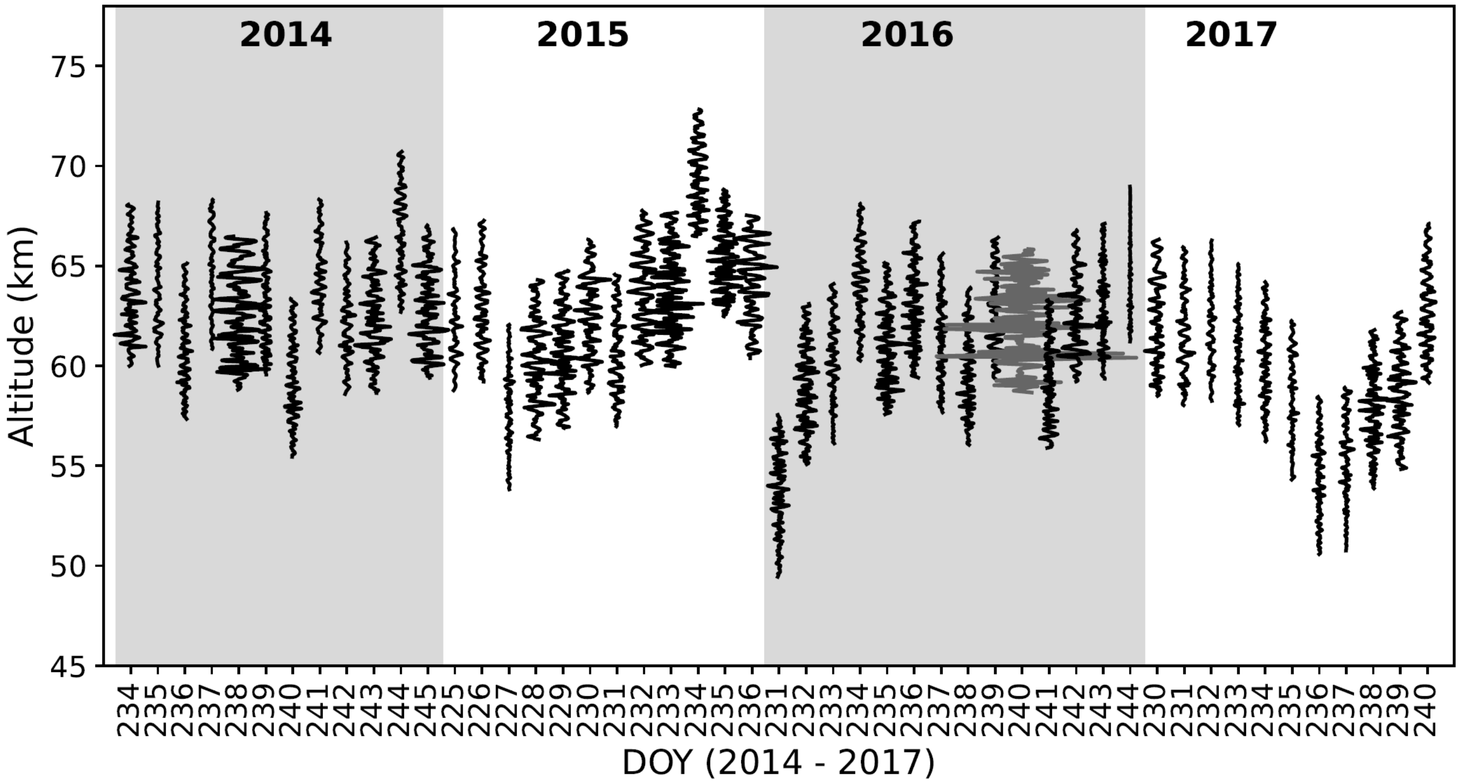
3) N-wave duration at the reflective layer altitude. Period lengthening is simulated using InfraGA weakly non-linear propagation simulations.



The initial waveform has N-wave shape near the source and duration T at the reflective layer altitude

Chunchuzov, I., et al. (2015), "Study of the wind velocity-layered structure in the stratosphere, mesosphere, and lower thermosphere by using infrasound probing of the atmosphere."

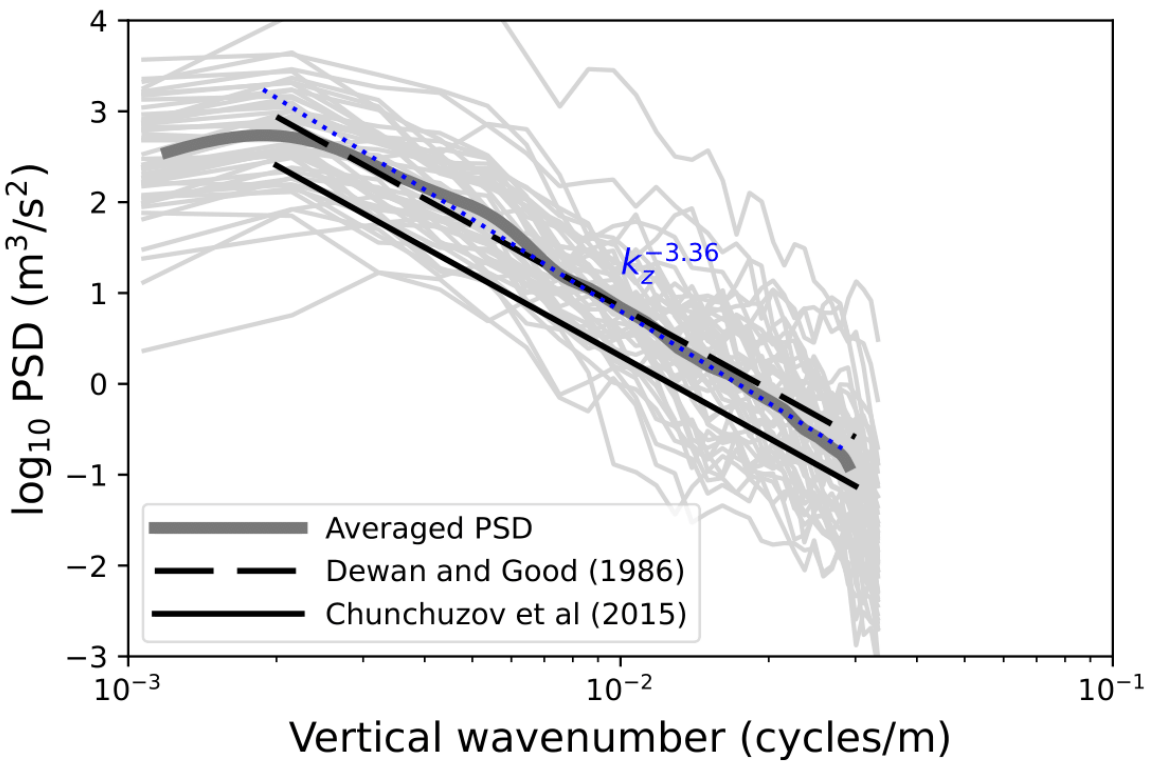
Results

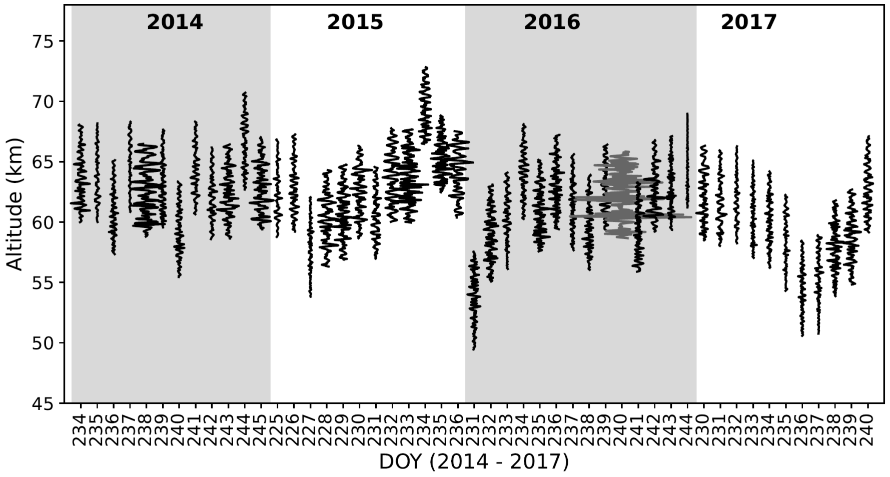


- First time Chunchuzov's approach is applied to a large dataset;
- Retrieving along one source-receiver path;
- **Altitude range**: stratopause-lower mesosphere (50 - 75 km)**;**
- **Average layer depth**: 7.75 ± 0.38 km;
- Effective sound speed fluctuation **amplitudes** up to 15 m/s;

Results

- **Power spectral density** of the retrieved effective sound speed fluctuations;
- Negative slope establishes at $\mathbf{k_z = 2.15\ 10^{-3}}$ **cycles/m;**
- Vertical scale of fluctuations that infrasound is sensitive to: L_{in} = **33 - 37 m**, L_{out} = **386 - 585 m**.
- Slope is close to the $\mathbf{k_z^{-3}}$ **power law** → GW saturation?

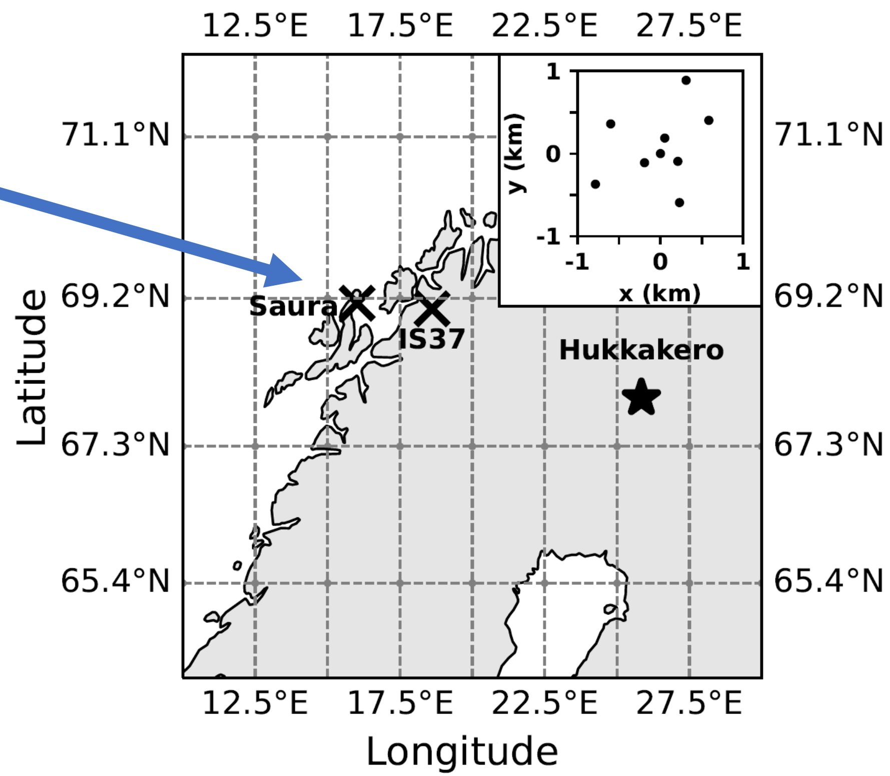




Results

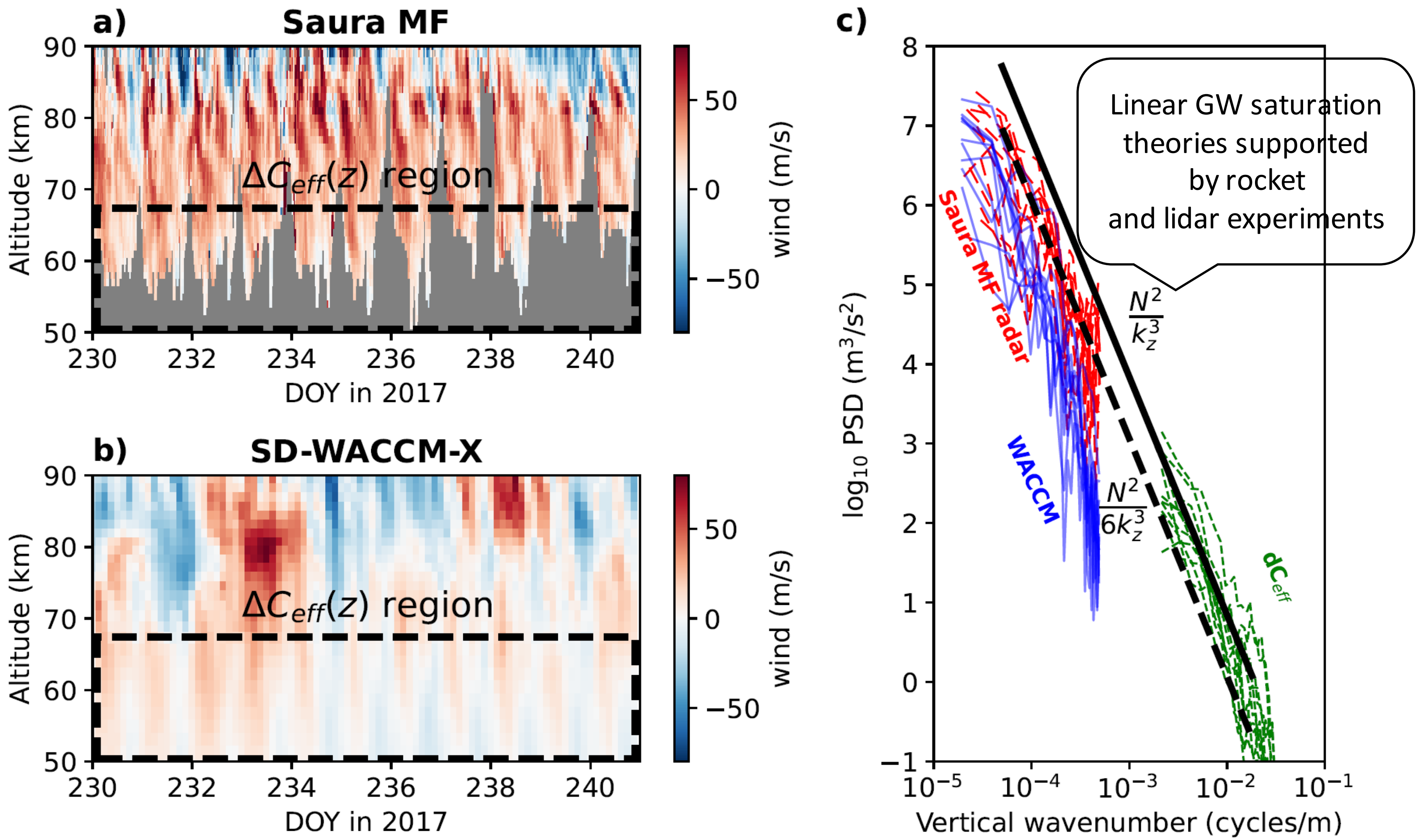
Validation against independent radar wind measurements for 2017

- Saura radar ~100 km west of IS37 and ~420 km north-west from Hukkakero;
- Measures **wind**, provides estimates of turbulent kinetic energy dissipation rates, electron density, as well as meteor observations;
- **50 – 100 km altitude** range;
- Vertical resolution 1 - 1.5 km;
- Can probe vertical variations at scales > 2 km.



Saura data can be requested via https://www.iap-kborn.de/forschung/abteilung-radarsondierungen/instrumente/mf-radare/saura-mf-radar/

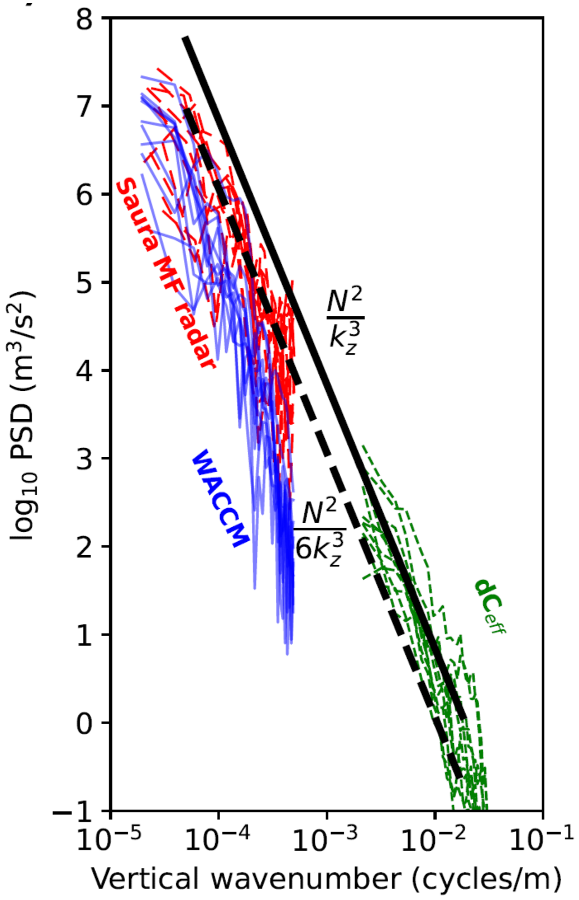
Results



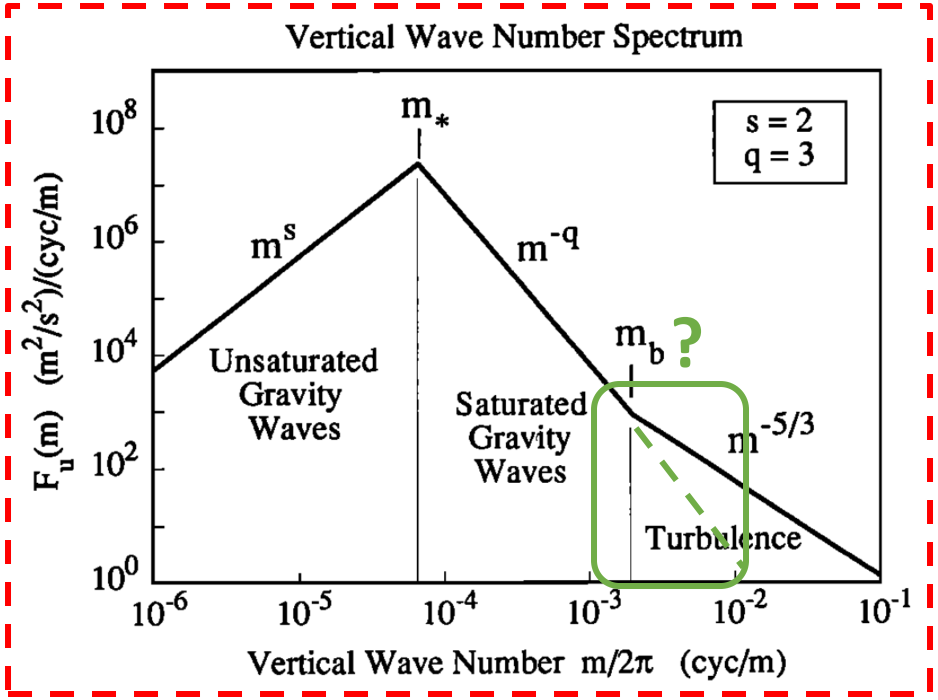
- Good agreement with **GW saturation theories**;
- Saura radar and infrasound-based ΔCeff profiles represent **low- and high-wavenumber parts** of the "universal" GW spectrum;
- **WACCM-X could be improved** by including smaller-scale processes in the parametrization.

Results

- **Infrasound is sensitive to very small vertical scales** compared to other measurement techniques.
- When does the transition to turbulence occur in the Gardner's spectrum?



Gardner et al (1993)



Summary

- IS37-Hukkakero is an attractive dataset for studying day-to-day middle atmosphere dynamics;
- Infrasound scattering occurs within 50 - 75 km altitude (gravity waves start breaking);
- Spectral analysis of retrieved effective sound speed fluctuations revealed that the tail of the mean spectrum corresponds to the "universal" spectrum of horizontal wind fluctuations induced by gravity waves;
- Infrasound can resolve atmospheric motions with very small vertical scales compared to other measurement techniques;
- ΔC_{eff} retrieved from ground-based infrasound measurements is of direct interest for studying GW activity and for potential improvement of GW parameterization schemes in numerical weather prediction models.

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Thank you for attention!
Questions?