Simulating infrasound waveguides in the middle atmosphere with ICON and UA-ICON: comparison with the IFS and ground-based remote sensing.

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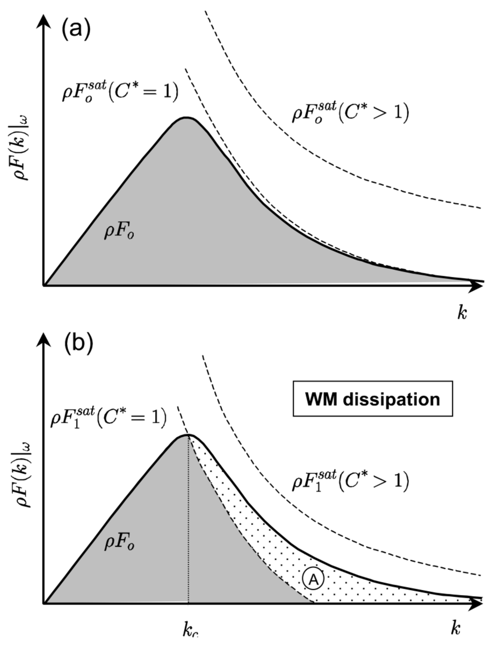
1. Introduction

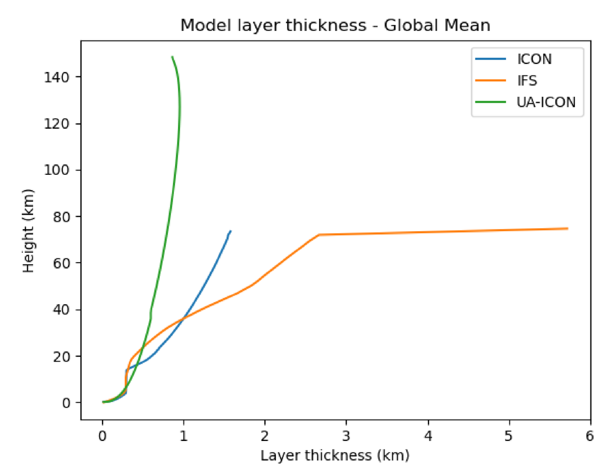
- Temperature and wind conditions in the middle atmosphere play an important role in infrasound propagation.
- Atmospheric wind and temperature profiles can acoustic wave-guides, which vary greatly throughout the year.
- Accurate atmospheric profiles up to the thermosphere are necessary to predict infrasound trajectories.
- Gravity Wave (GW) play an important role in atmospheric winds and temperatures.
- In the GW parameterization of NWP models considered here, C* regulates the height at which GW momentum and energy are deposited into the mean flow.
- GW momentum that is greater than the C* saturation level is deposited into the atmosphere at that level.
- Larger C* values increase the height at which momentum is deposited.



GW launch spectra and saturation levels (C*)
McLandress and Scinocca, (2005) https://doi.org/10.1175/JAS3483.1.

2. ICON Model

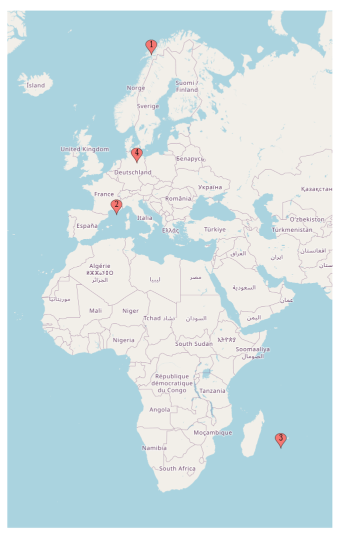
- The ICOsahedral Non-hydrostatic (ICON) model is a non-hydrostatic numerical weather prediction model jointly developed by the German weather service (DWD) and the Max Planck institute of Meteorology..
- Accurate atmospheric profiles up to the thermosphere are necessary to predict infrasound trajectories.
- Upper Atmosphere (UA)-ICON provides a means to predict these middle atmospheric wind and temperature profiles.
- UA-ICON height profile
  - Atmosphere top = 150 km (240 ML)
  - Sponge layer = 110 km
- Operational ICON height profile
  - Atmosphere top = 75 km (120 ML)
  - Sponge layer = 35 km
- Time step – 40 s
- Horizontal resolution = 13 km
- Nested domains are possible, which can increase the resolution 2/4 times.



3. Lidar

Lidar Sites

- Rayleigh/Mie/Raman Lidars measure wind and temperature profiles in the middle atmosphere (30-100 km).
- High vertical resolution allows for model validation, and resolution of atmospheric gravity waves.
- These four locations provide high latitude, mid-latitude, and tropical comparisons.

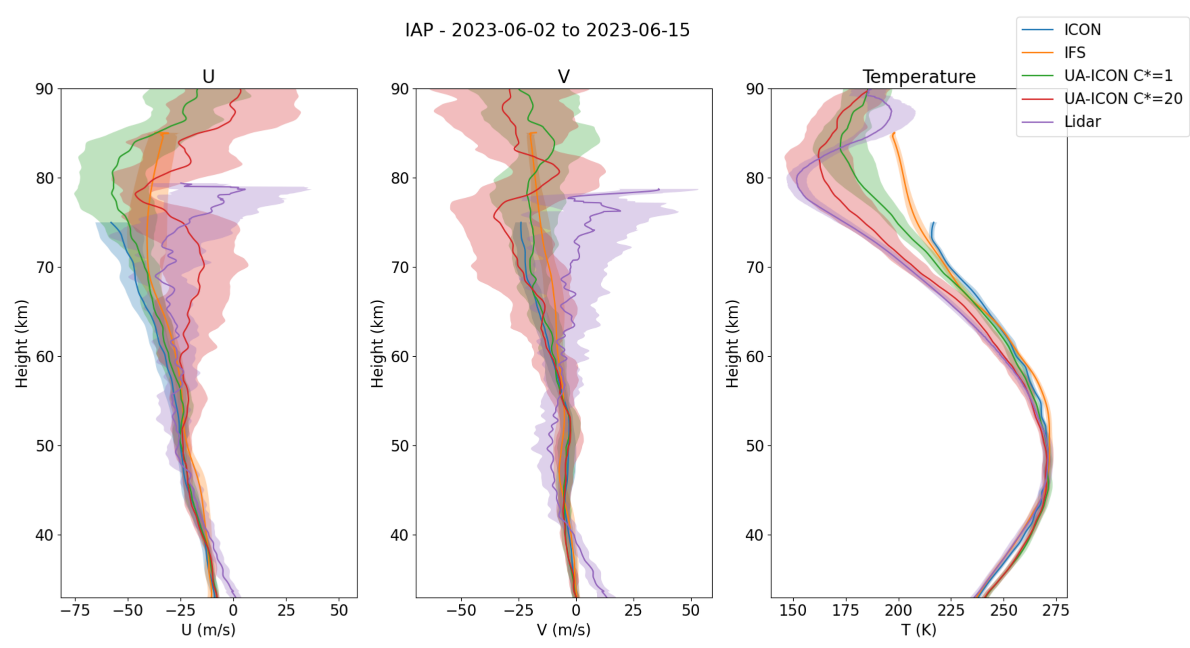


Proposed Lidar sites for model validation

Lidar comparisons

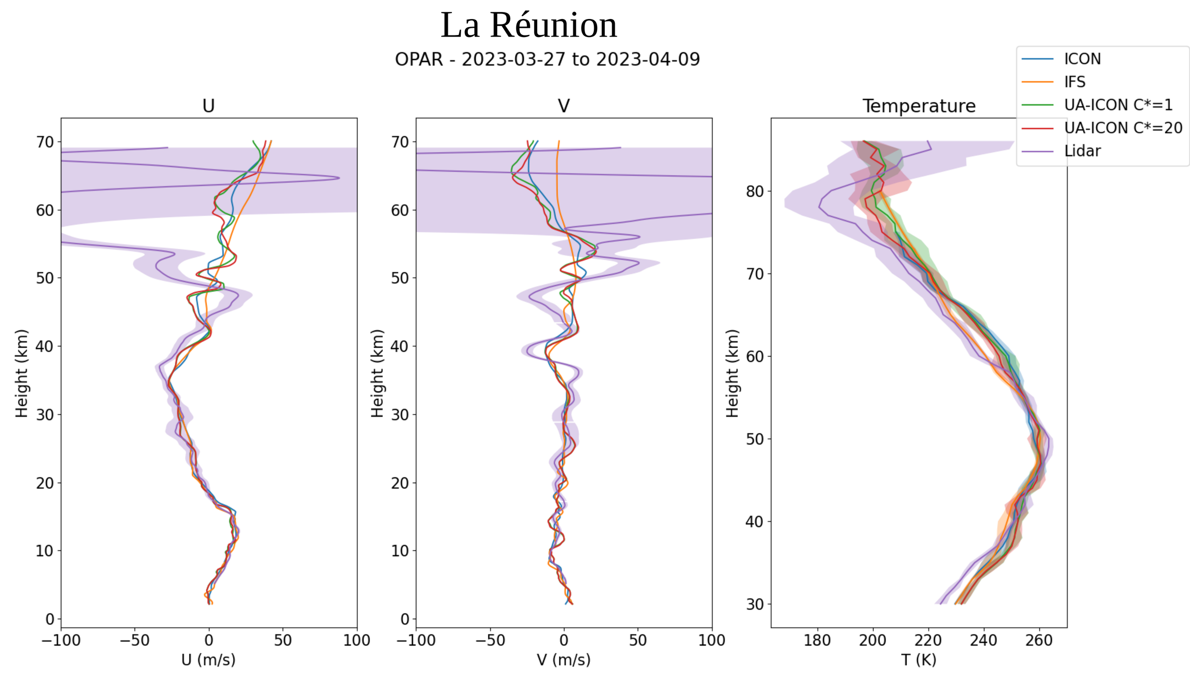
- NWP models and UA-ICON provide similar profiles up to about 50-60 km.
- Notable deviations from temperature are observed using IFS and operational ICON products.
- UA-ICON provides measurements of wind and temperature into the Mesosphere-Lower Thermosphere (MLT)

IAP



- Operational models overestimate temperature in the mid to high-latitude summer mesosphere
- Increasing C* to 20 provides a much better fit to temperature (low mesopause temperature).
- Zonal wind results are less clear.

La Réunion

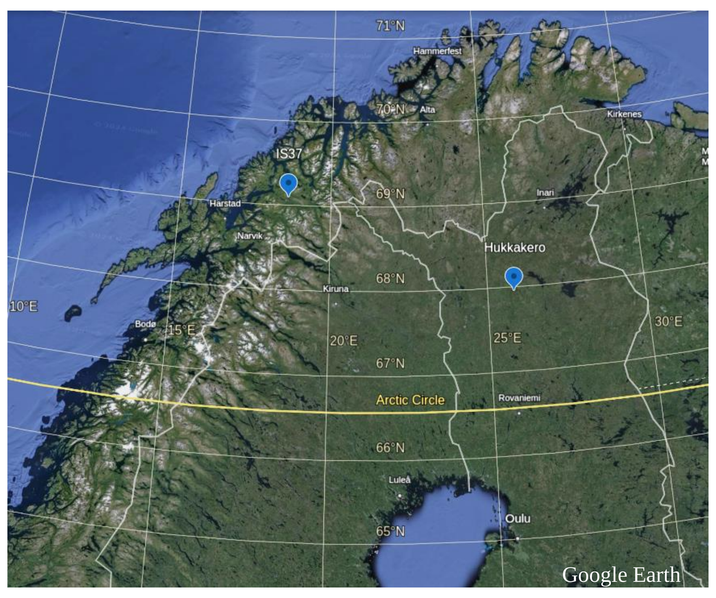


- Fall, low-latitude (La Réunion) show less pronounced temperature over-estimation.
- UA-ICON models are in close agreement with operational ICON.
- ICON shows slight temperature overestimation in the lower mesosphere (~60 km).

4. Infrasound

Hukkakero

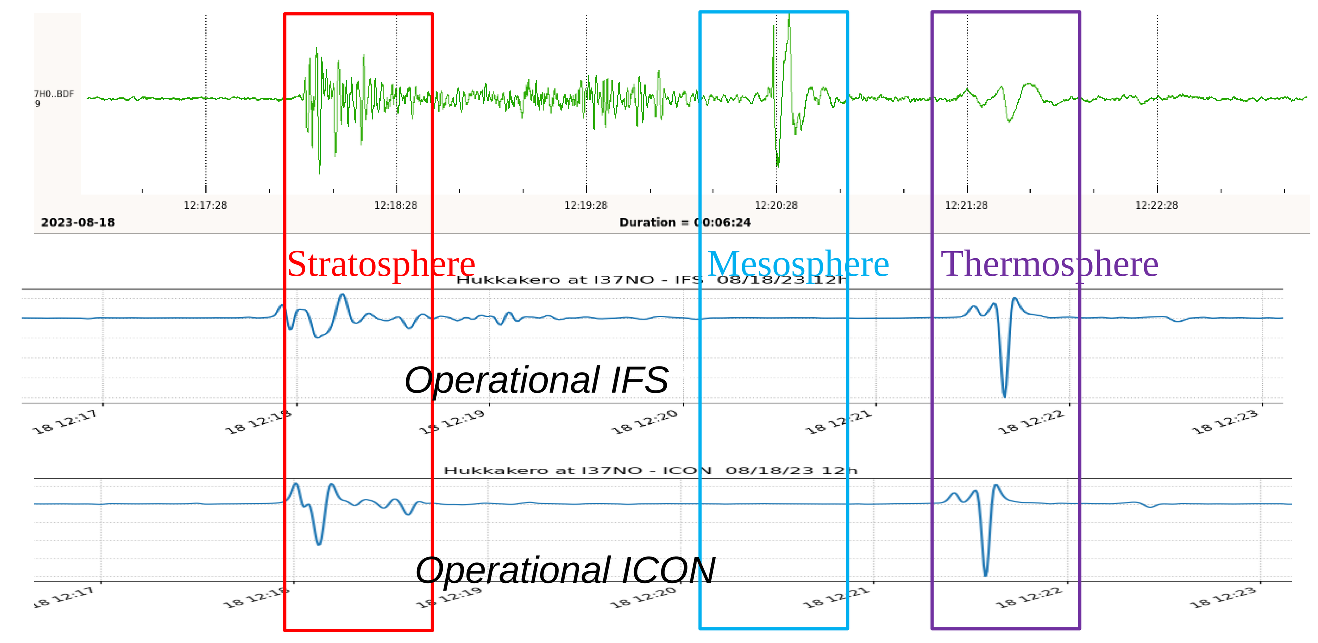
- At Hukkakero Finland munitions are destroyed every August.
- These ground-truth events provide an excellent reference for infrasound calibration.
- IS37 (69.1N 18.6E) is located approximately 320 km from this site.
- Signal and arrival time predictions were made using several different atmospheric model configurations (notably UA-ICON).
- Different C* values were tested to see which provided the closest results to the observations.

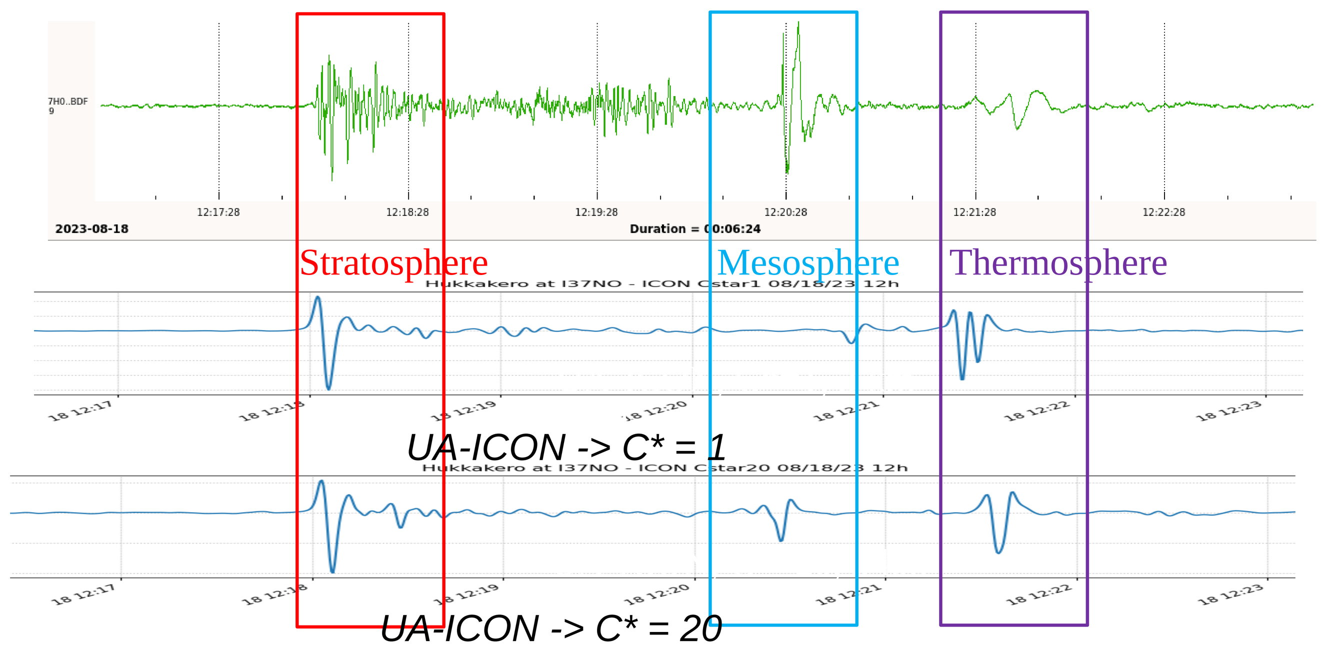


Map of IS37 and Hukkakero site

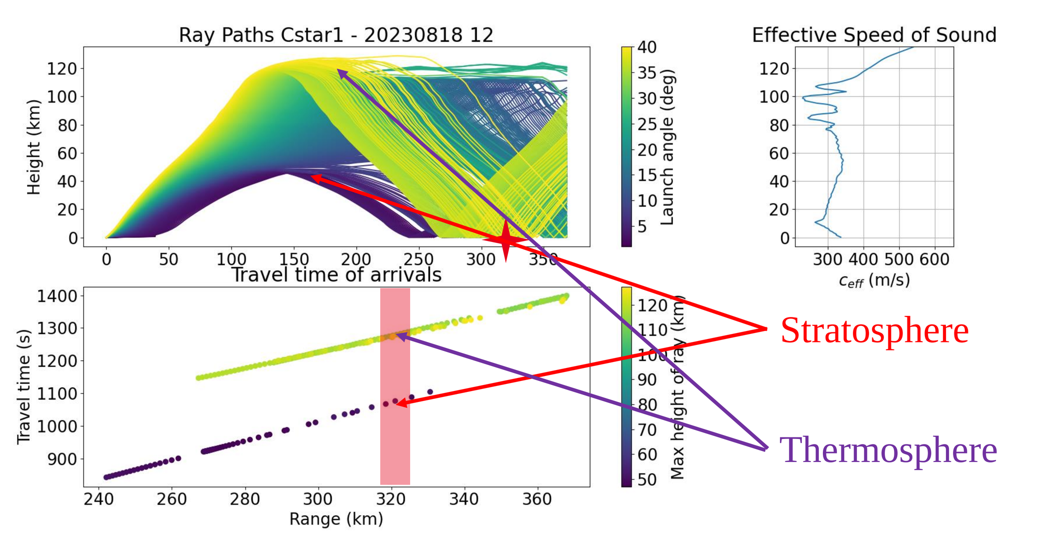
Infrasound Results

- The operational models provide good estimates of the stratospheric phase of the waveform, with the climatology providing the thermospheric phase.
- UA ICON (13 km resolution) with C*=20 provides a good reproduction of the mesospheric phase of the waveform, in addition to the stratospheric and thermospheric phases.

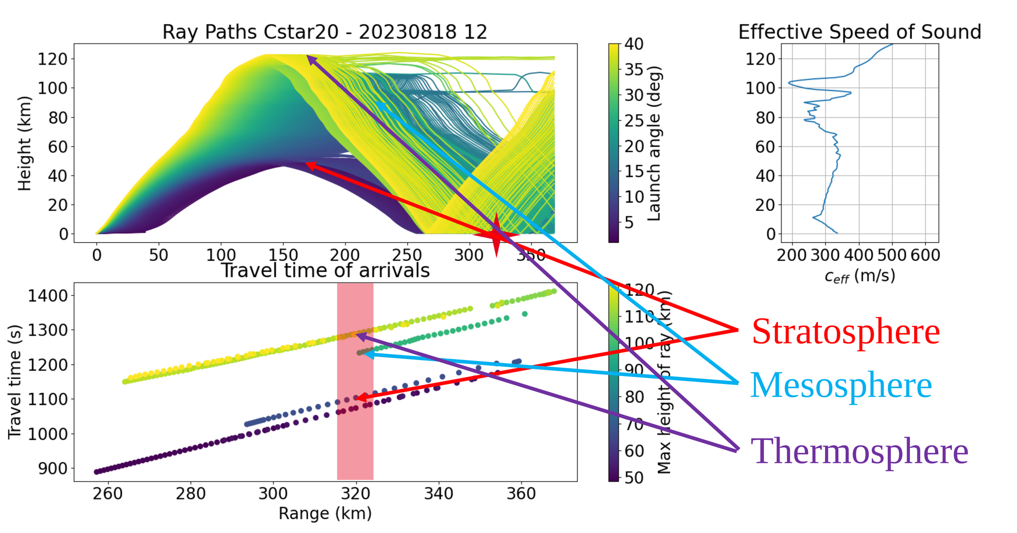




UA-ICON -> C = 1, 3 km horizontal resolution*



UA-ICON -> C = 20, 3 km horizontal resolution*



Range-dependent ray tracing simulation demonstrating the prediction of additional geometric waveguide with UA-ICON, in agreement with observations.

The best performing UA-ICON simulations use a horizontal resolution of 3 km (nesting) and C*=20.

The results improve by both increasing C* to 20 and increasing the resolution to 3 km. At 13 km resolution, the mesospheric return is not observed.

5. Conclusion

- Infrasound propagation is highly dependent on atmospheric conditions (temperature, wind etc.) in the middle atmosphere that are above the operational model (IFS and ICON) tops, but are provided by UA-ICON
- Current GW parameterisations (e.g. C*) do not properly estimate MLT winds and temperatures.
- Lidar comparisons during the summer of 2023 show good agreement with UA-ICON – C*=20
- The Hukkakero reference event further demonstrates the importance of correct MLT model predictions, with C*=20 again providing the best results, especially at very high (3 km) horizontal resolution.
- Further Lidar comparisons are necessary to better tune GW parameterisations
- Study of other IS events (Hukkakero etc.) will provide additional model validation.