Final report for Project: **1371**

Project title: **Nested high-resolution UA-ICON simulations for NASA VortEx sounding rockets campaign at ALOMAR**

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Report period: **2023-07-01 to 2025-06-30**

Activity 2023/2025

During the last reporting period (2024/2025), we used 7,133 node-hours (∼92%) of the allocated resources for simulations with the upper-atmospheric version of the ICON model (UA-ICON) (Borchert et al., 2019). These resources supported a series of experiments assessing the impact of resolved versus parameterized gravity waves (GWs). High-resolution nested simulations were conducted over Andøya, Norway (ALOMAR), to compare with mesospheric observations from the NASA "Vorticity Experiment" (VortEx) in March 2023. Observations include temperature and wind profiles up to ∼80 km from the Rayleigh-Mie-Raman (RMR) lidar, as well as wind fields from the MF Saura and SIMONe radar systems. Building on the previous period's comparison (2023/2024), we also included winds from a NASA sounding rocket above ∼90 km and temperature fields from the Advanced Mesospheric Temperature Mapper (AMTM).

UA-ICON was configured with 180 vertical levels and the model top at 150 km, using a global grid at R2B7 (∼20 km). One-way nesting was applied down to R2B11 (∼1.25 km) through intermediate domains R2B8 (∼10 km), R2B9 (∼5 km), and R2B10 (∼2.5 km), as shown in Fig. 1. The large-scale dynamics were specified by nudging the global domain to ECMWF operational analyses up to an altitude of 50 km. Nudging was applied only to the global domain to constrain large-scale structure while allowing small-scale dynamics to evolve freely within the nested domains. To isolate the impact of explicitly resolved waves, we ran experiments progressively turning off non-orographic GW and convective parameterizations, starting from domain R2B9.

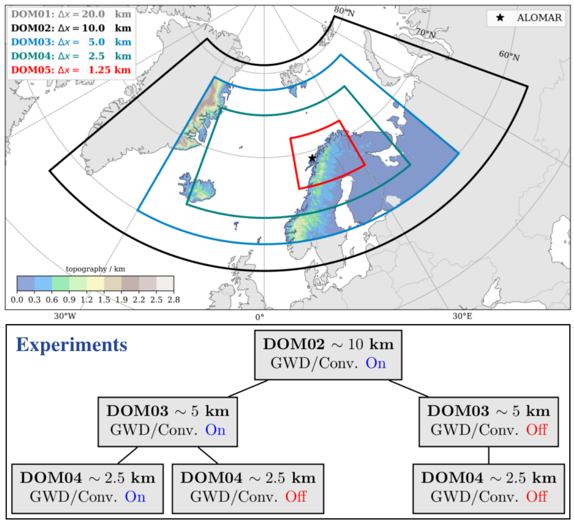

Fig. 1: Experiments and domain configuration.

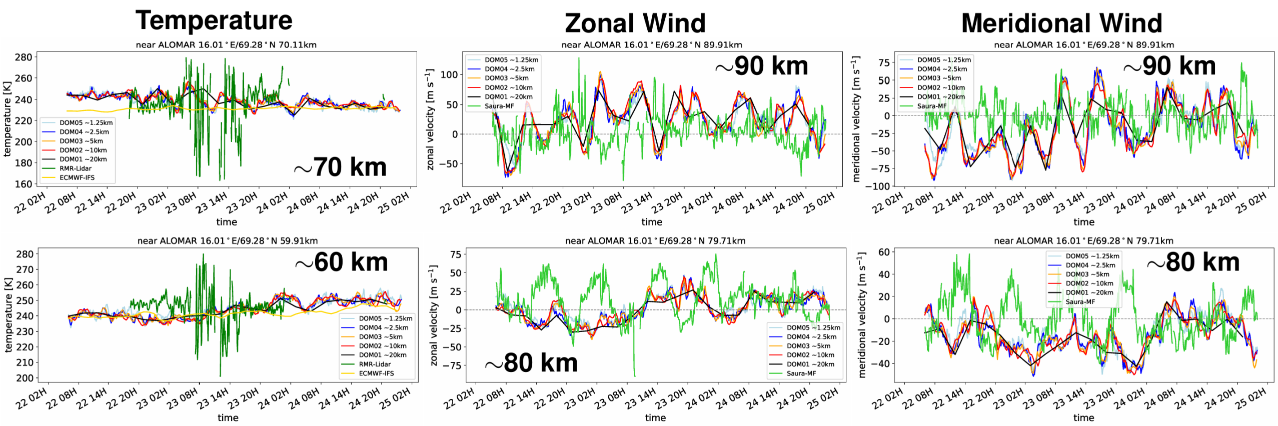

Fig. 2: Time-series of temperature (left), zonal wind (middle), and meridional wind (right) from MF Saura and UA-ICON at selected height levels as indicated.

Figure 2 shows the time series of the data shown in Fig. 1 for selected height levels between 60 and 90 km. The temperature fluctuations of the RMR-Lidar, given at a 5-minutes time resolution, are during daylight much larger than UA-ICON DOM05 output at a time interval of 3 minutes. During the night, the variability of both is in better agreement. The Saura MF zonal and meridional wind data show a tidal signature at 80 km, which is also visible in the UA-ICON data approximately 10 km higher at 90 km. The results reported here were presented at the 2024 EGU General Assembly (Kunze et al., 2024).

Figure 3 shows temperature profiles from the model, LIDAR, sounding rocket, and AMTM, averaged between 21:00–22:00 UTC. UA-ICON shows close agreement with the RMR Lidar in the stratosphere, as expected since the large scales are nudged to reanalysis.
Simulations with explicitly resolved GWs show better agreement with AMTM and rocket measurements compared to the experiment with parameterized GWs (dashed line in Fig. 3).Resolving GWs explicitly seems to improve the temperature structure in the mesosphere. Overall, the simulations show reasonable agreement with observations, demonstrating UA-ICON's capability to capture key features of the MLT region. The results reported here were presented at the 2024 AGU General Assembly (Morfa et al., 2024).

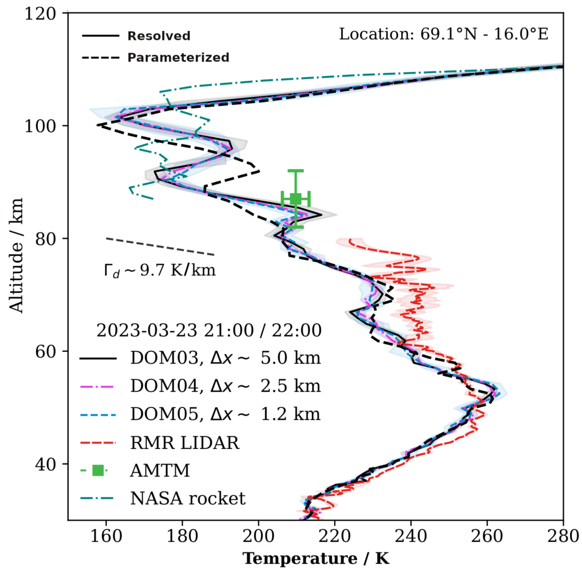

Fig. 3: Temperature profiles from UA-ICON, LIDAR (red), sounding rocket (light green), and AMTM (green) within ±4 K and ±5 km uncertainty at 87 km.

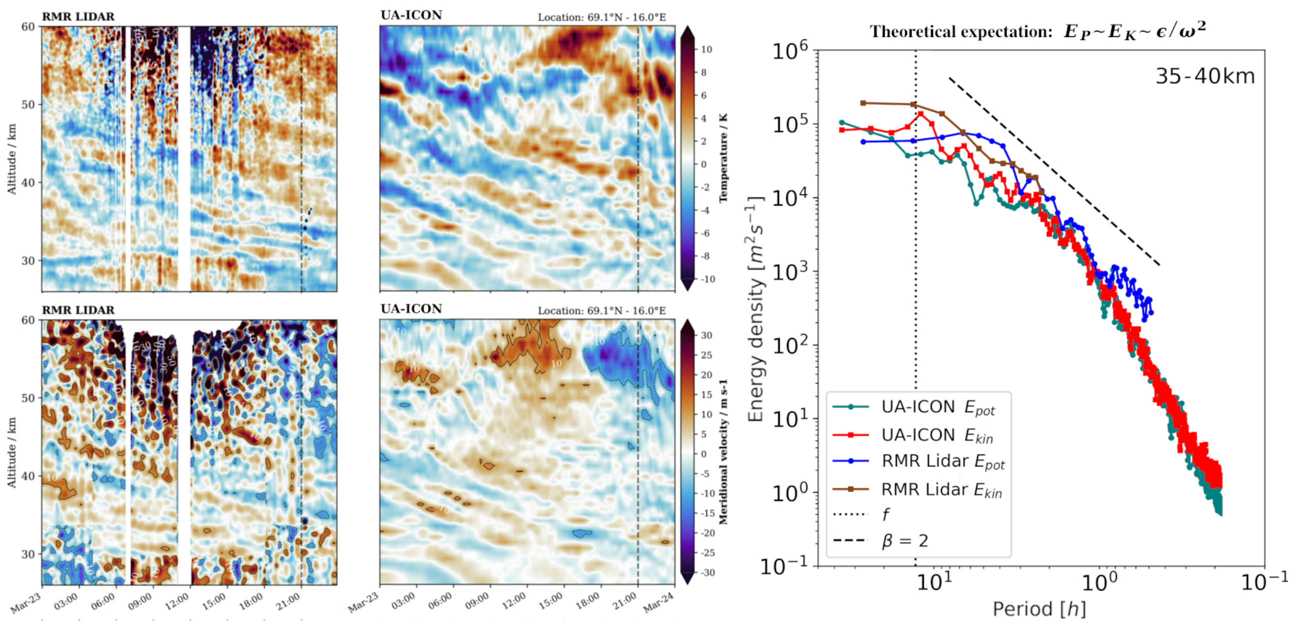

Fig. 4: Left: Meridional wind (top) and temperature (bottom) perturbations from RMR Lidar (left) and DOM05 (right) as a function of time and altitude. Right: Frequency spectra of kinetic (E_{kin}) and potential (E_{pot}) energy averaged between 35–40 km altitude. Reference slope for ω^{-2} is shown in dashed lines.

At resolutions finer than ∼5 km, UA-ICON resolves a broad gravity wave spectrum in the stratosphere. Fig. 4 shows good agreement between simulated and observed wave fluctuations, with energy spectra following the expected ω^{-2} power law (Podglajen et al., 2020).

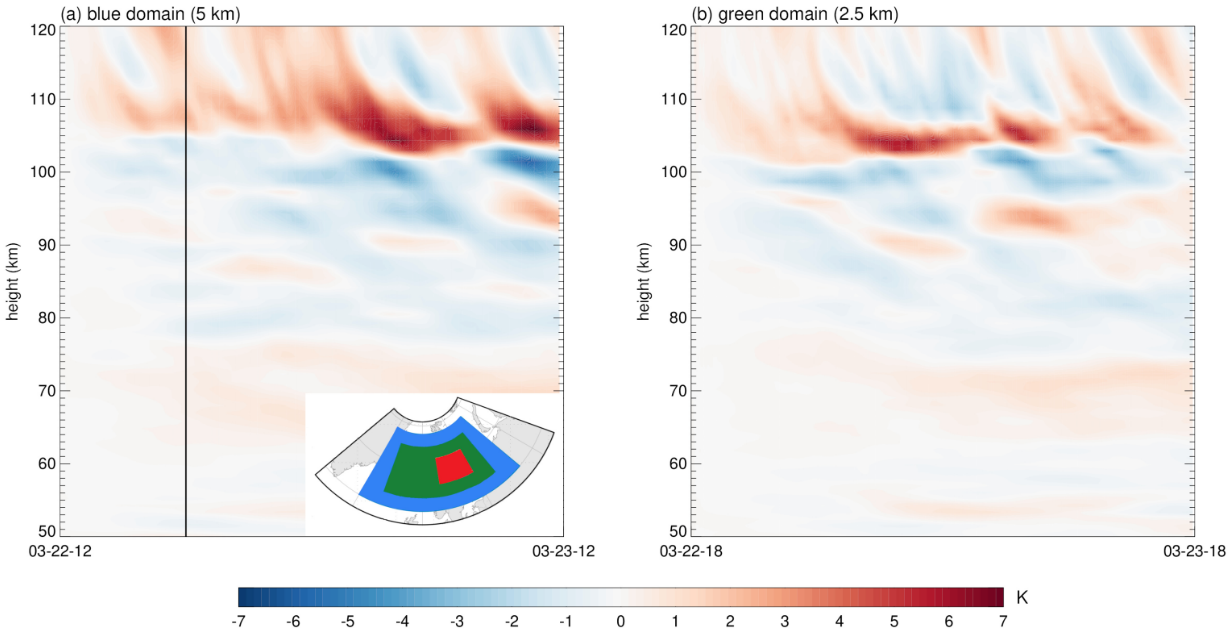

Fig. 5: Temporal evolution of domain-mean temperature differences for the (a) 5 km domain (blue domain in the inlet) and (b) the 2.5 km domain (green domain in the inlet). The blue domain is initialized on March 22, 2023 at 12:00 UTC. The green domain is initialized on March 22, 2023 at 18:00 UTC (marked by the vertical line in panel (a)). For each domain one simulation is performed with parametrizations of orographic gravity wave drag, non-orographic gravity wave drag and convection turned on, and a second simulation is performed with the parametrizations turned off. The panels show the difference (on minus off).

ICON's regional refinement offers a computationally efficient alternative to globally uniform high-resolution simulations. However, in whole-atmosphere models, these must be applied with caution, as GWs become increasingly important with altitude. As shown in Fig. 5, domain-mean temperatures in the 5-km domain diverge significantly, up to ±5 K near the mesopause, within the first day after initialization, when parameterizations are enabled (orographic and non-orographic gravity wave drag, and convection).

References

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