Multiskalen-Simulationen mit PMAP und EULAG

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1 Part A: Linear Theories and Nonlinear Numerical Simulations Across the Orographic Gravity Wave Spectrum

This first part of the report summarizes the work by Binder et al. (2026). The manuscript has been submitted to the Journal of the Atmospheric Sciences (American Meteorological Society) and, after the first review round, is now close to acceptance. The study systematically contrasts nonlinear numerical simulations with established linear solutions for the surface gravity wave drag (GWD) across the entire spectrum of mountain wave (MW) regimes. Particular emphasis is placed on sensitivity tests that identify a simulation setup capable of reproducing these linear predictions and thereby provide general guidance for designing similar numerical experiments. The study also compares the results of two different numerical models, the Portable Model for multi-scale Atmospheric Prediction (PMAP) and the predecessor of its dynamical core, the EULerian/semi-LAGrangian flow solver (EULAG). All PMAP simulations ran on Levante's GPU partition, the EULAG simulations on its CPU partition.

Overall, the numerical simulations for twelve mountain half-widths $L = 0.5$–$150\,\mathrm{km}$ reproduce the linear predictions very well, for the meridionally uniform ridge (see last year's report) as well as for axisymmetric mountain geometries (Fig. 1). These results are now complemented by a systematic sensitivity analysis, which demonstrates that this agreement requires a carefully designed simulation setup: adequate resolution, sufficiently large domains and long integration times, open meridional boundaries, and small-amplitude topography. Deviations from this configuration introduce systematic biases, particularly in the inertia-gravity wave regime. Extending the analysis vertically, zonal-mean momentum and energy fluxes in the simulations satisfy the Eliassen–Palm relation for rotating flows and follow established theoretical expectations for the wave-energy partitioning (Eliassen and Palm 1960). The results are robust across numerical models and equation formulations, which indicates that agreement with linear theory depends primarily on an appropriate simulation setup. The surface GWD from PMAP and EULAG differs by only 0.93 % on average and the compressible and anelastic formulations differ by only 0.39 %, compared with the mean deviation of 2.76 % between the ridge simulations and the linear solution of Blumen (1965).

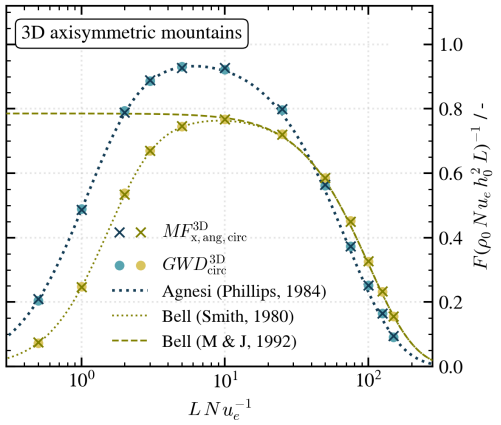


Figure 1: Fig. 7d of Binder et al. (2026): markers represent the area-integrated drag in numerical simulations with the axisymmetric Witch of Agnesi (blue) and the bell-shaped (yellow) mountain. Dashed and dotted lines represent their shape-specific linear solutions (Phillips 1984; Smith 1980; Miranda and James 1992).

2 Part B: Gravity wave breaking and secondary gravity waves above the Southern Andes

This second part of the report summarizes the status of the simulations of the flow across the Southern Andes, the propagation and breaking of mountain waves, and the associated generation of vortex structures and secondary gravity waves. During the first half of the current allocation period, these simulations were transitioned from EULAG to PMAP in order to exploit its GPU capabilities and to further increase the resolution. To this end, PMAP was extended to deep atmospheres up to 130 km altitude, equipped with the relevant subgrid-scale models, and supplemented with an option to output limited-volume data sets at very high temporal resolution.

The transition yielded a substantial gain in resolution. Whereas the original goal with EULAG was an isotropic grid spacing of 400 m, comparable domains are now simulated with 200 m horizontal and 100 m vertical grid spacing, i.e., with 16 times more grid points than originally envisaged. The largest run to date comprises a $4096 \times 3072 \times 731$ grid with 9.2×10^9 grid points covering a domain of $820 \times 615 \times 90\,\mathrm{km}^3$.

Figure 2 illustrates the direction of the ongoing analysis. The three-dimensional vortex structures in the wave-breaking region (Fig. 2a,d,e) are related to what a vertically pointing Rayleigh lidar would observe in the same volume: the time series and the time-height diagram of temperature perturbations of the virtual lidar (Fig. 2b,c) can equally be derived from an actual measurement of the Compact Rayleigh Autonomous Lidar (CORAL; Kaifler and Kaifler 2021). The model can thus be compared directly with the observation and subsequently be used to investigate the physical processes underlying the observed structures. In Fig. 2, the focus lies on the formation of horseshoe-shaped vortices during gravity wave breaking. The simulations are intended to demonstrate that CORAL observed such vortex structures during the night of 18/19 July 2024. This work continues as planned in the 2027 request.

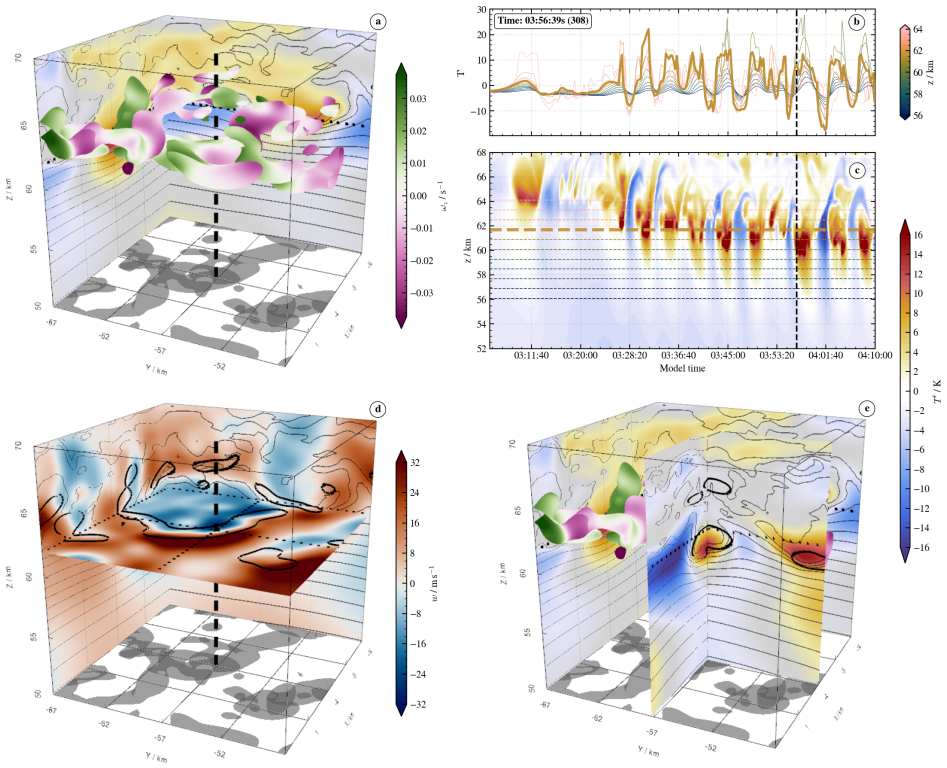


Figure 2: Compilation of 2D and 3D visualisations of an extracted cube from a PMAP simulation for the 18/19 July 2024 CORAL measurement. (a) λ_2 isosurfaces of the vortex structures in the breaking region (50 - 70 km), coloured by vertical vorticity ω_z, with T' on the cube faces. (b) T' time series between 56 and 64 km. (c) time-height curtain of the virtual lidar (dashed column in the 3D cubes). (d) Horizontal cross-section of w at 62 km with λ_2 contours. (e) Quarter-cut view with T' slice planes.

References

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