Three recommendations to improve simulations with the Intermediate Complexity Atmospheric Research (ICAR) model

Johannes Horak, Marlis Hofer and Alexander Gohm

INTRO
The Intermediate Complexity Atmospheric Research (ICAR) model is a simplified 3D atmospheric model (based in linear mountain-wave theory), employing a detailed vertical structure of the atmosphere, that advects atmospheric quantities (e.g. temperature and moisture) and runs microphysics (e.g. Thompson MP).

While evaluating ICAR, Horak et al. (2019) found a strong dependence of ICAR performance on the model top height ($z_{\text{top}}$) and numerical artifacts in the topmost vertical levels, leading to three key questions:

1) What is the influence of the...
2) ...Brunt-Väisälä frequency ($N$) calculation method?
3) ...boundary conditions imposed at the upper boundary on processes in the domain?

METHODS
A sensitivity study with almost 650 idealized ICAR simulations was conducted covering the parameter space spanned by (i) six topographies given by witch of agensi ridges (heights from 0.5 km to 3 km at 40 km width, and widths of 20 km to 80 km at 1 km height), (ii) nine combinations of boundary conditions (BCs) imposed at the model top on potential temperature $\Theta$, water vapor $q_v$, suspended hydrometeors $q_{\text{sus}}$, and precipitating hydrometeors $q_{\text{prec}}$, and (iii) three model top heights between 4.4 km and 14.4 km (plus a 20.4 km reference run).

Sounding: $U = 20$ m/s, $N = 0.01$ s$^{-1}$, $\Theta(z=0) = 270$ K, RH = 100 % and $P(z=0) = 1013$ hPa.

These simulations were conducted with the Italian model with a resolution of equal width. The difference between the spatial distributions to a reference run were quantified with the sum of squared errors (SSE). Total mass and SSE were used as a proxy to determine the influence of the model top and the boundary conditions on the physical processes within the domain.

The effect of the suggested adaptations on 24h accumulated precipitation was demonstrated with a case study conducted for the South Island of New Zealand during strong north-westerlies throughout the troposphere.

RESULTS
1) A comparison of the ICAR wind field to the analytically calculated wind field (Fig 1a) showed that $N$ should be, as stated by linear theory, calculated from the forcing data set (Fig 1b) instead of the state of the perturbed domain in ICAR (Fig 1c) to achieve the most faithful representation of the wind field.

2) For the idealized simulations ICAR was found to require a minimum model top height $z_{\text{min}}$ to allow for sufficient decoupling of processes within the domain from the model top (Figure 2). Further increases of $z_{\text{top}}$ above $z_{\text{min}}$ only resulted in minimal changes of the total masses and distributions of the investigated quantities. The procedure to estimate $z_{\text{min}}$ was extended to a real world application of ICAR.

3) While, in the idealized simulations, a constant gradient BC performed best when applied to all quantities, the influence of the BCs on processes within the domain was found to be negligible once $z_{\text{top}} > z_{\text{th}}$. However, the threshold elevation $z_{\text{th}}$ was smaller than $z_{\text{min}}$ in the investigated parameter space.

Nonetheless, the results indicated that $z_{\text{th}}$ depends on the topography with the clearest dependence found for ridge height, see Figure 3.

The results additionally suggested a dependence of $z_{\text{th}}$ on the atmospheric background state, since convergent downdrafts in the topmost model levels increase the importance of the BCs (not shown).

The case study conducted for the South Island of New Zealand revealed that, compared to the ICAR configuration and setup in Horak et al. (2019), the precipitation pattern shifted upward, predicting the precipitation maximum along the western slopes of the alpine range below 1000 m m.s.l. (mean sea level), see Fig. 4.

CONCLUSIONS / RECOMMENDATIONS
3) $N$ should be calculated from the forcing data set
2) ICAR requires a minimum model top height $z_{\text{min}}$ which may be determined by simulating a representative portion of a study period for increasing values of $z_{\text{top}}$. Above $z_{\text{min}}$, the masses and SSEs of water vapor and hydrometeor fields only show marginal improvements.
3) Imposing constant gradient BCs on water vapor and hydrometeors may potentially avoid the introduction of errors into these fields.

Paper with all details is in preparation...

Reference