Three recommendations to improve ICAR

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

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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_{top}) and numerical artifacts in the topmost vertical levels, leading to three key questions:

What is the influence of the ...

1) ...Brunt-Väisälä frequency (N) calculation method?
2) ...model top on processes in the domain?
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 agnesi 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 Θ, water vapor q_v, suspended hydrometeors q_{sus} and precipitating hydrometeors q_{prc} and **(iii)** 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.

Theis study then investigated the distribution and total mass of q_v, q_{sus} and q_{prc} in cross sections. Differences in 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 adaptions 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.

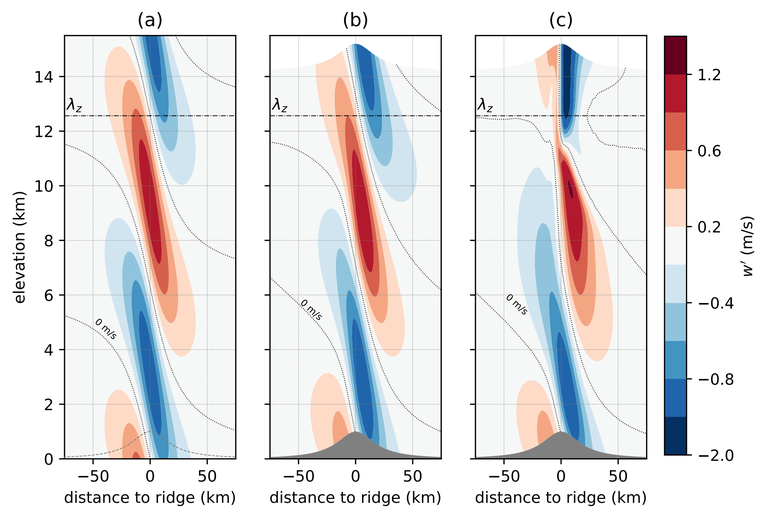

Figure 1 – The vertical wind field calculated **a)** analytically, **b)** by ICAR when calculating N from the forcing data set **c)** by ICAR when calculating N from the perturbed state of the domain.

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

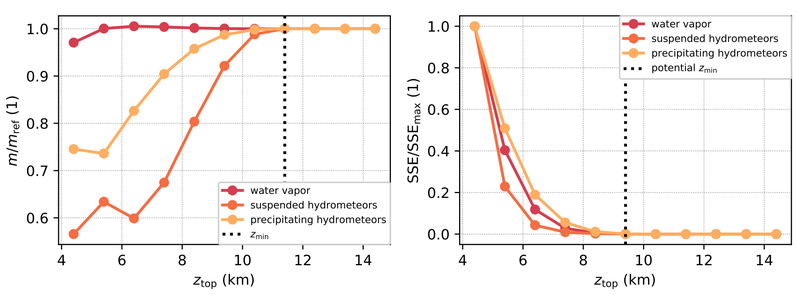

Figure 2 – The 24h mean mass **(left panel)** and SSEs of the 24h mean spatial distribution **(right panel)** of water vapor and hydrometeors in the cross section in dependence of the model top height. The dotted vertical line indicates the minimal necessary model top setting above which only minor improvements are found for the respective fields. Plotted for a ridge of 1 km height and 40 km width and an ICAR simulation employing constant gradient BCs at the upper boundary.

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 neglectable once $z_{top} > z_{th}$. However, the treshold elevation z_{th} was smaller than z_{min} in the investigated parameter space. Nonetheless, the results indicated that z_{th} dependeds on the topography with the clearest dependence found for ridge height, see Figure 3.

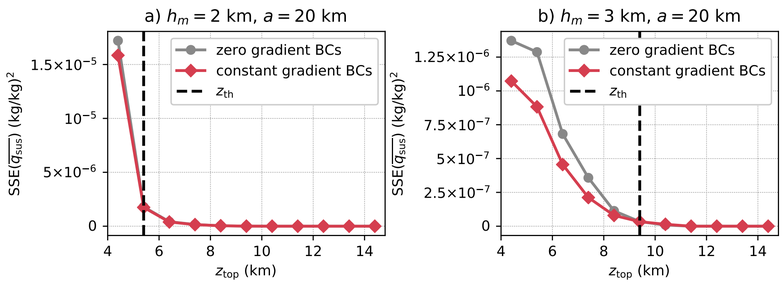

Figure 3 – The SSE of suspended hydrometeors for two ICAR simulations employing either a zero gradient BC (red curve) or a constant gradient BC to all quantities for a 500m high ridge **(left panel)** and a 3km high ridge **(right panel)** of equal width. The vertical dashed curve indicates the model top height threshold above which the choice of BCs does not affect the q_{sus} field anymore.

The results additionally suggested a dependence of z_{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 upwind, predicting the precipitation maximum along the western slopes of the alpine range below 1000m m.s.l. (mean sea level), see Fig. 4.

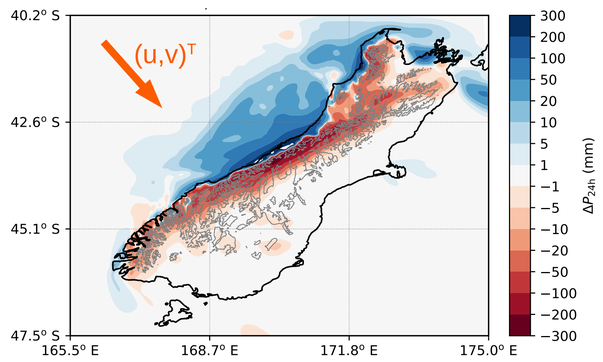

Figure 4 – Difference in 24h accumulated precipitation between an ICAR simulation employing the setup and configuration in Horak et al. (2019) and an ICAR simulation applying the recommendations outlined in the conclusions. The arrow indicates the wind direction throughout most of the troposphere and the gray outline the 1000 m m.s.l. contour line of the topography.

CONCLUSIONS / RECOMMENDATIONS

1) N should be calculated from the forcing data set
2) ICAR requires a minimum model top height zmin which may be determined by simulating a representative portion of a study period for increasing values of z_{top}. Above z_{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...

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Reference
Horak et al., *Assessing the added value of the Intermediate Complexity Atmospheric Research (ICAR) model for precipitation in complex topography*, Hydrol. Earth Syst. Sci., 23, 2715–2734, https://doi.org/10.5194/hess-23-2715-2019, 2019.