Better downscaling results for the right reasons - A process based evaluation of the ICAR model

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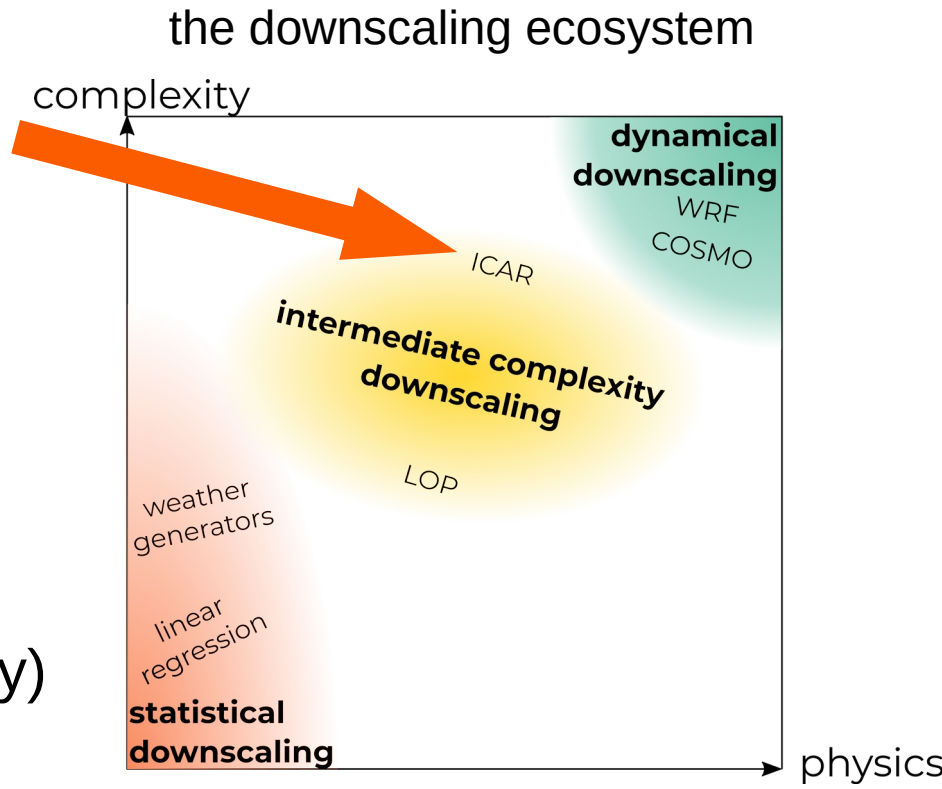
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ICAR

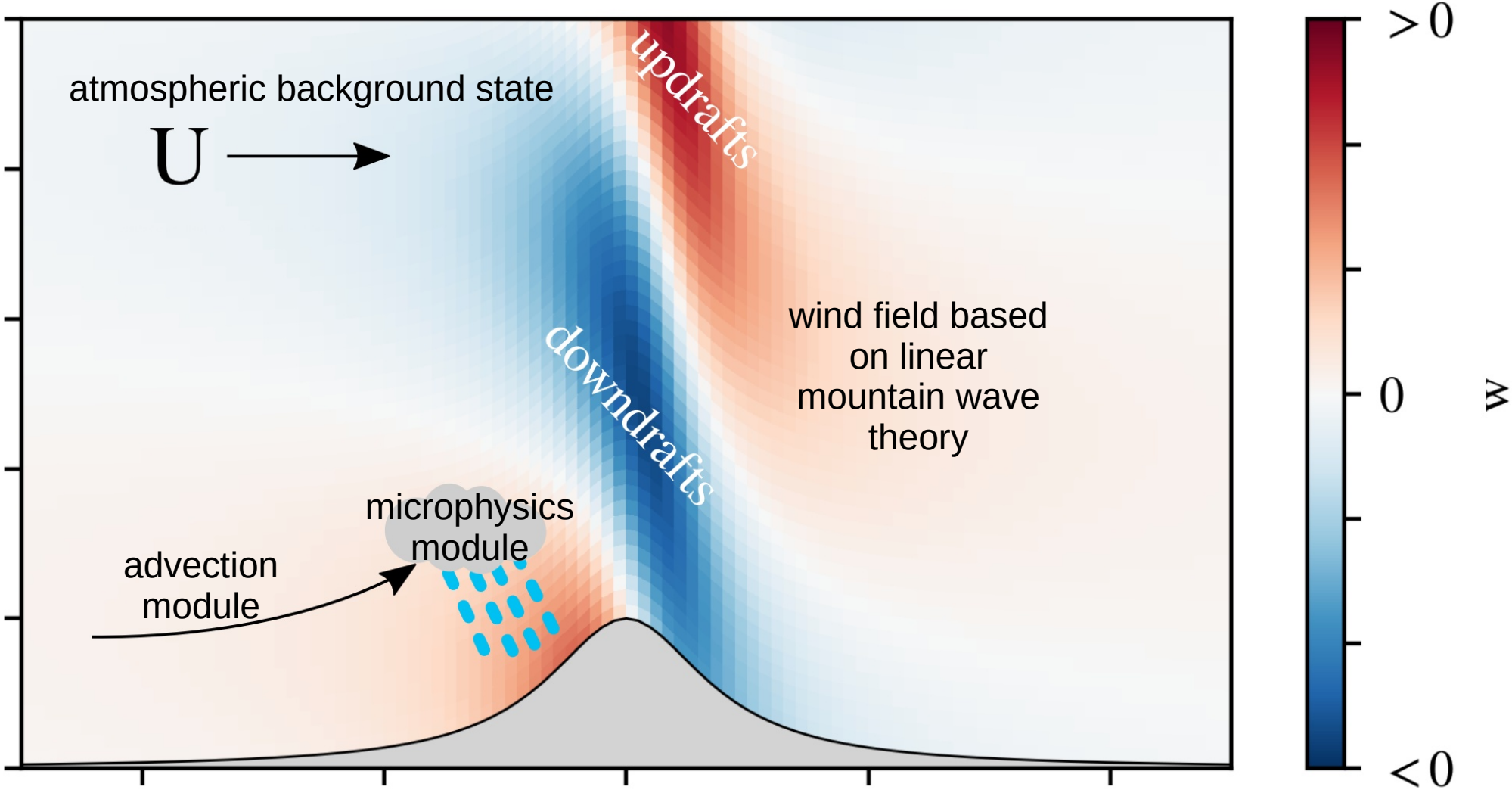
- **I**ntermediate **C**omplexity **A**tmospheric **R**esearch Model

- physics based BUT simplified wind field calculation

  (based on linear mountain wave theory)



ICAR – an atmospheric model with simplified wind field calculations



Model Evaluation

- Compare to measurements! (e.g. precipitation)
  - model results **disagree** with measurements

indicates a potential problem

- model assumptions
- model setup
- numerical issues
- ...



leads to improvements!
(science)

Model Evaluation

- Compare to measurements! (e.g. precipitation)
  - model results **agree** with measurements

⇒ the model works…? not necessarily!

- different processes / indistinguishable results
- numerical artifacts
- …

you want “the right results for the right reasons”

Additional challenges for ICAR

- based in linear mountain wave theory
- not all processes modelled
  - e.g. convection, wave amplification, ...

the model results **could disagree** with observations

BUT the model **physics worked correctly**

wrong result but for the **“right” reason**

Additional challenges for ICAR

Conundrum:

model **agrees** with observation / model **disagrees** with observation

how do we tell whether it performed to the best of its abilities?

Example:

The formation of clouds and precipitation may be correct for a linearized wind field but disagree with measurements due to the occurrence of nonlinear effects.

answer: physical processes need to be investigated!

Influence of the model setup

a related question

how should the model be set up to be able to perform to the best of its abilities?

- model top height as parameter of interest
  - results of previous study indicated this as an avenue of research

Computational Cost and Physical Fidelity

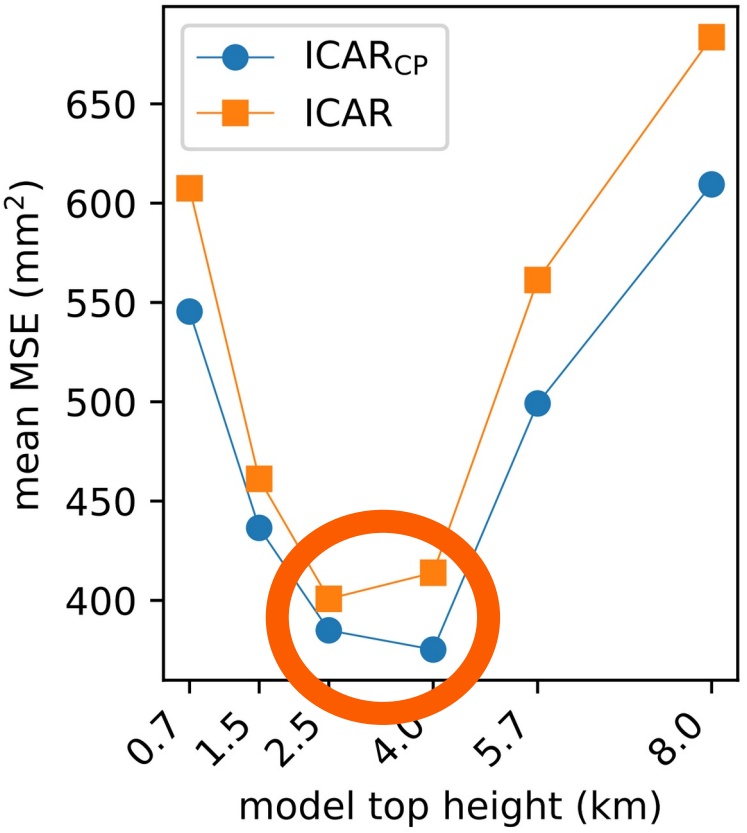
- Keeping the computational cost low

  we don’t want to set the model top height any higher than absolutely necessary.

- No additional compromise on physical fidelity

Overall: We want the best possible result from ICAR for the least amount of computational cost without compromising on the physical fidelity.

ICARs model top height



Comparison to precipitation measurements at weather stations

- lowest mean square errors:
  for model top height at 2.5 km or 4 km

that's low…

Performance according to expectations in all other analyses (Horak et al., 2019)

But this oddity warranted further investigation

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.

Basic idea of the study

idealized setting – reduce complexity

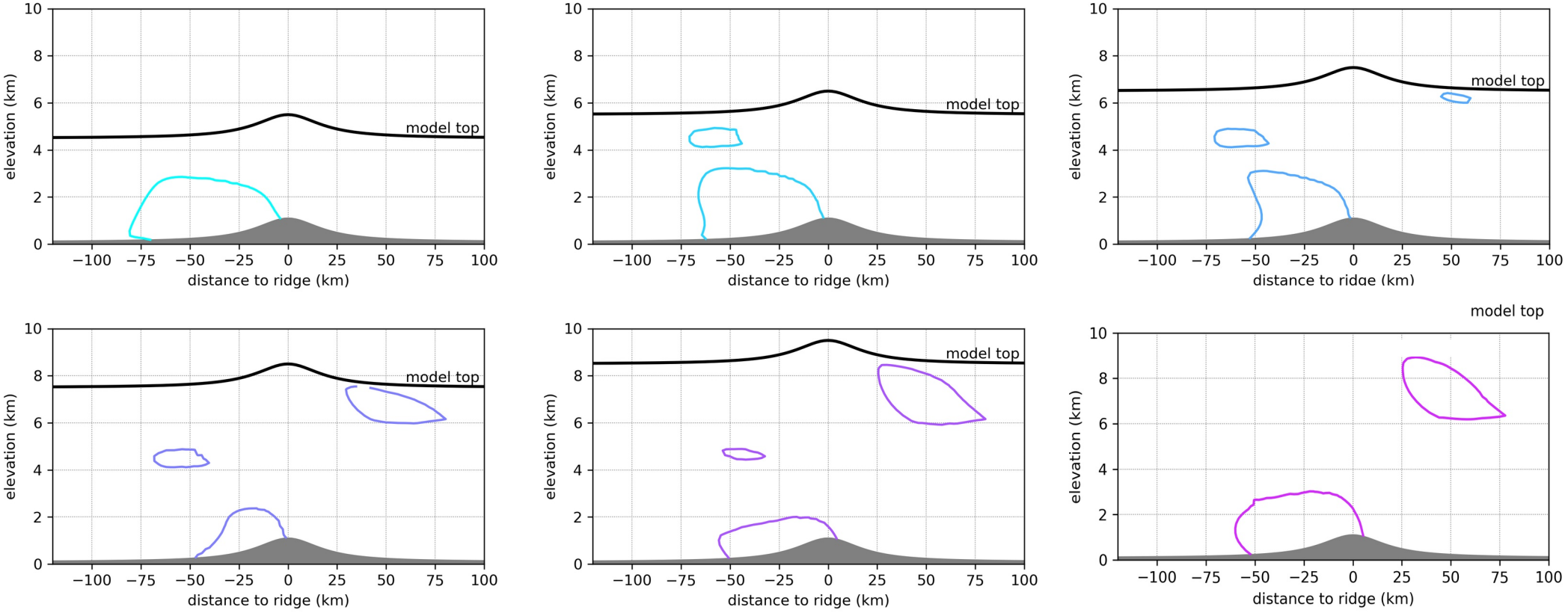
- 2d ridge, uniform background state, U=20ms^{-1}, N=0.01 s^{-1}, saturated conditions

vary model top height

what happens to, e.g. the cloud boundary?

- use it as one indicator for whether physical processes in the domain are influenced by some parameter (like the model top height)

cloud boundary in six simulations after 30 hours of simulation time (steady state reached) in dependence of the model top height chosen for each simulation.



the model physics are clearly influenced by the top boundary!

what is the correct boundary?

- from a **reference simulation** where the model top does not influence the results anymore.
- sum of squared errors (SSE) allows to quantify the error relative to the reference simulation for all other simulations for, e.g. water vapor field, cloud water field, ...

Note: SSE chosen over MSE since the latter depends on the size of the domain and favors larger domains. While the SSE favors smaller ones a smaller SSE for large domains (higher model tops) in comparison to small domains (lower model tops) then indicates that increasing the model top height successfully reduces errors

Solution

- the physical fidelity of a simulation S1 is acceptable if

  a simulation S1 with model top height z_1

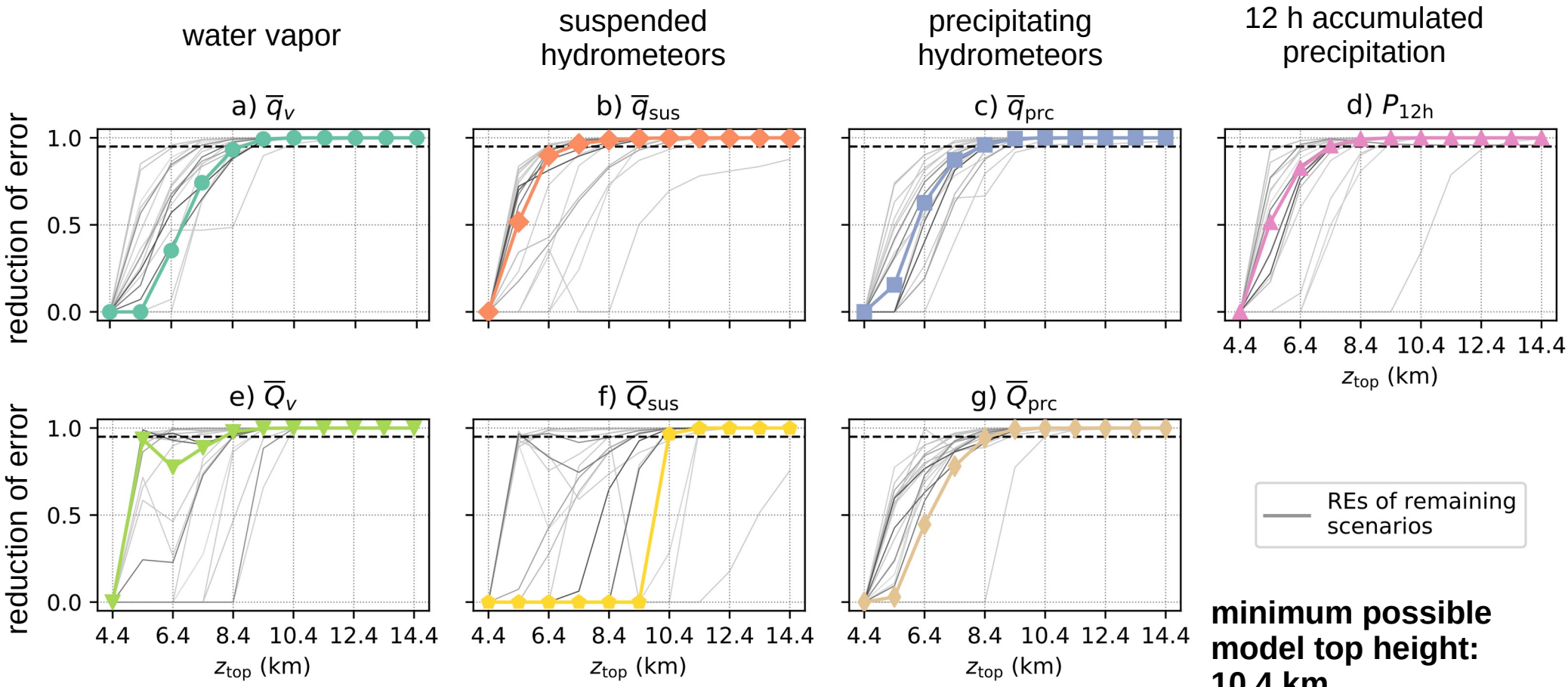
  reduces 95 % of the errors found in a

  simulation S2 with a very low model top height z_2

  for all investigated quantities.

- For our study the 95% threshold yielded optimal results. Higher model tops resulted in smaller improvements.

Example



top row: distribution of the quantity, **bottom row**: total mass in domain. Highlighted curve corresponds to default scenario, gray curves indicates results for all other scenarios.
the dashed line indicates the 95 % threshold

minimum possible model top height: 10.4 km
(for the default scenario)

Conclusion

- the presented method ensures that the model is set up to perform to the best of its abilities – may be extended to other parameters or real cases
- maximizes physical fidelity while retaining maximum amount of computational frugality compatible with that goal

- evaluating models extends beyond their agreement with measurements
- there's a potential pitfall if the ability of the model to represent cloud and precipitation processes is judged only from surface measurements
- model and process understanding is key!

- more information in our peer reviewed study:

  Horak, J., Hofer, M., Gutmann, E., Gohm, A., and Rotach, M. W.: **A process-based evaluation of the Intermediate Complexity Atmospheric Research Model (ICAR) 1.0.1**, Geosci. Model Dev., 14, 1657–1680, https://doi.org/10.5194/gmd-14-1657-2021, 2021.