Computationally efficient modelling of precipitation with ICAR in complex topography

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What are the local effects of a changing global climate

Motivation

Why is this an issue? We have global models after all..

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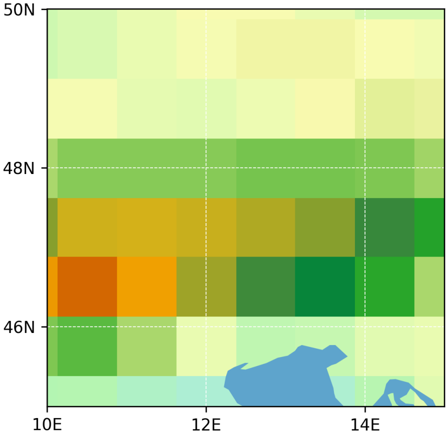

topography of a global model

Motivation

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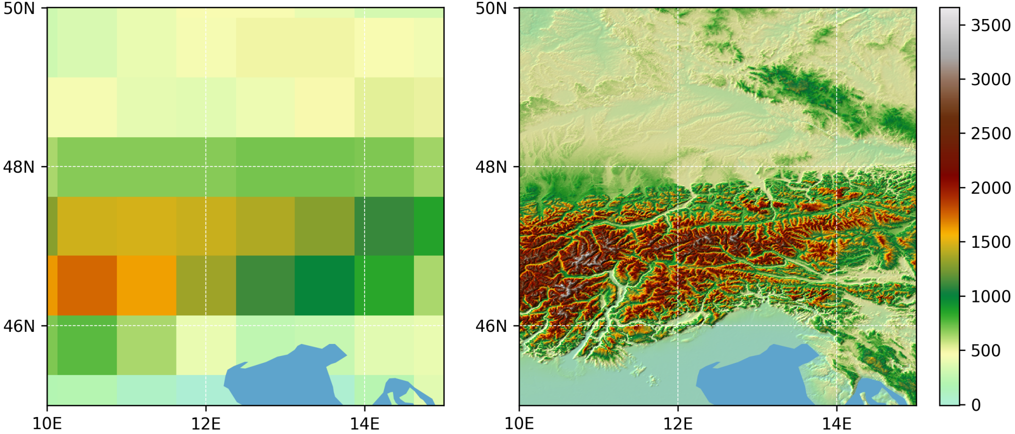

topography of a global model

actual topography

Motivation

Global circulation models (in general):

- spatially coarse
- miss processes characterizing local climate and weather

particularly problematic in complex terrain

$\Rightarrow$ There's a need to bridge the gap between

global scale model and the local scale

So... how to obtain precipitation fields for local impact studies?

$\Rightarrow$ **downscaling**

dynamic downscaling ⟷ statistical downscaling

computationally expensive

physics based

computationally cheap

statistics based

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"intermediate complexity"

Sarker 1966
LOP (Smith & Barstad 2004)
ICAR (Gutmann et al 2016)

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physics based

computationally cheap

statistics based

"intermediate complexity"

Model

Intermediate **C**omplexity **A**tmospheric **R**esearch Model (ICAR; Gutmann et al., 2016)

general features

- quantities stored on 3D grid
- microphysics
- wind field based on linear theory
- numerical advection within wind field

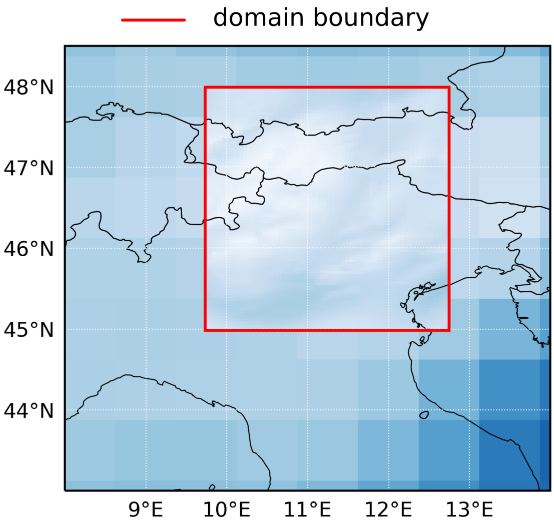
} physics based

wind field

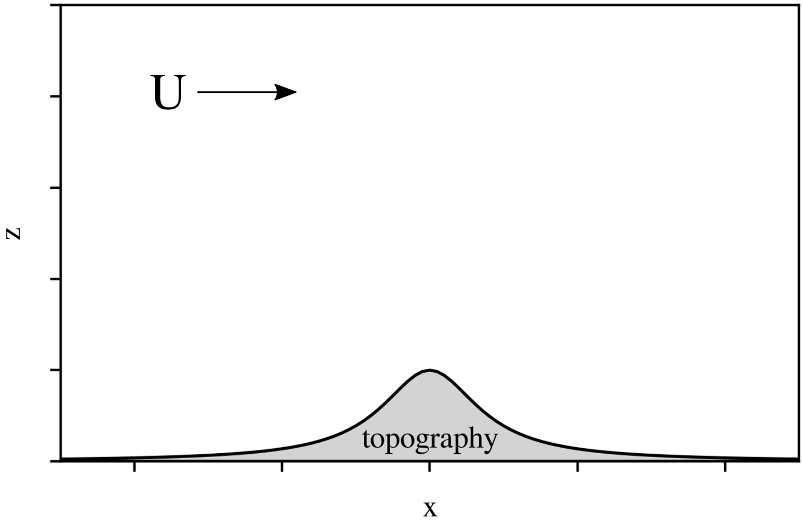
- calculated analytically (instead of numerically)

} computationally efficient!

Model



ICAR - Windfield



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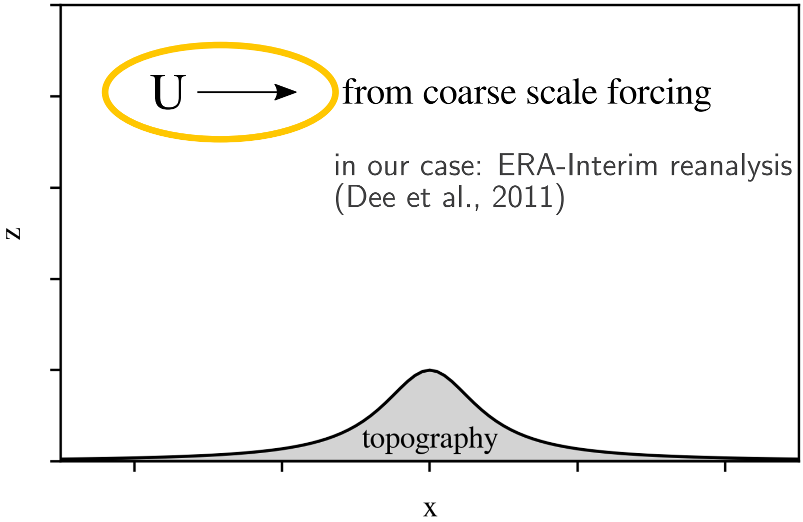

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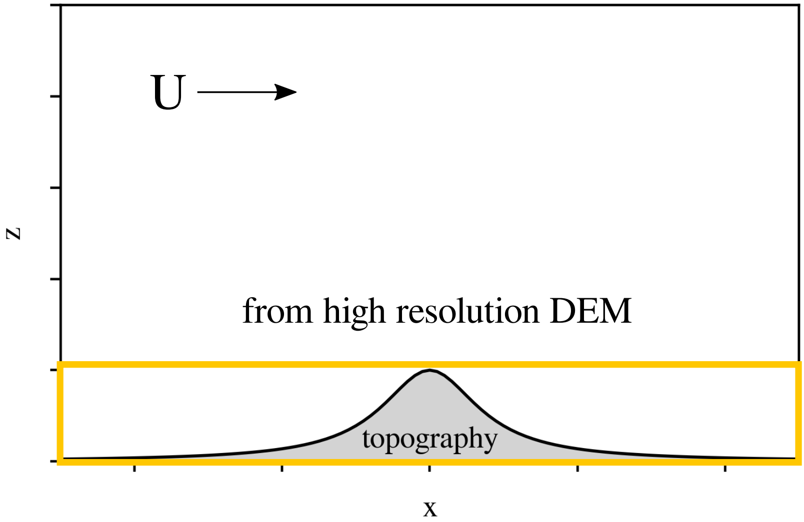

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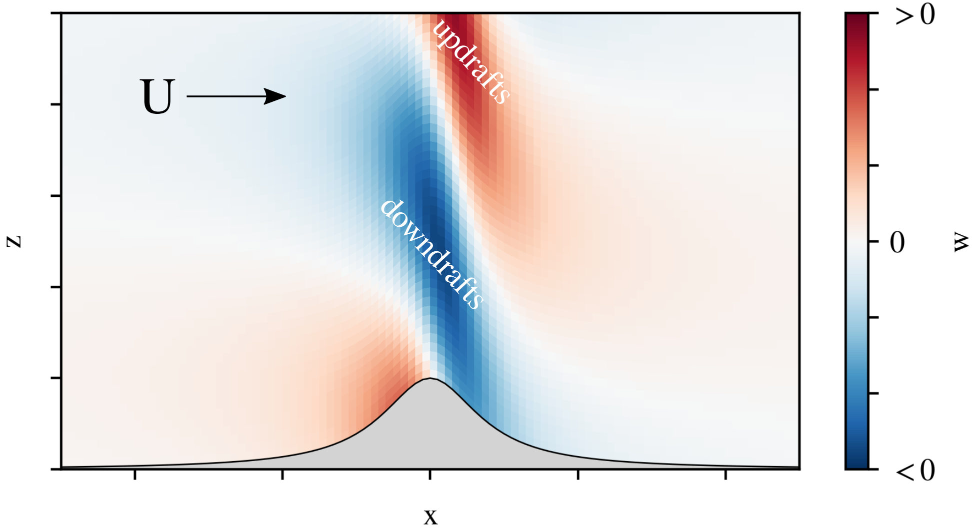
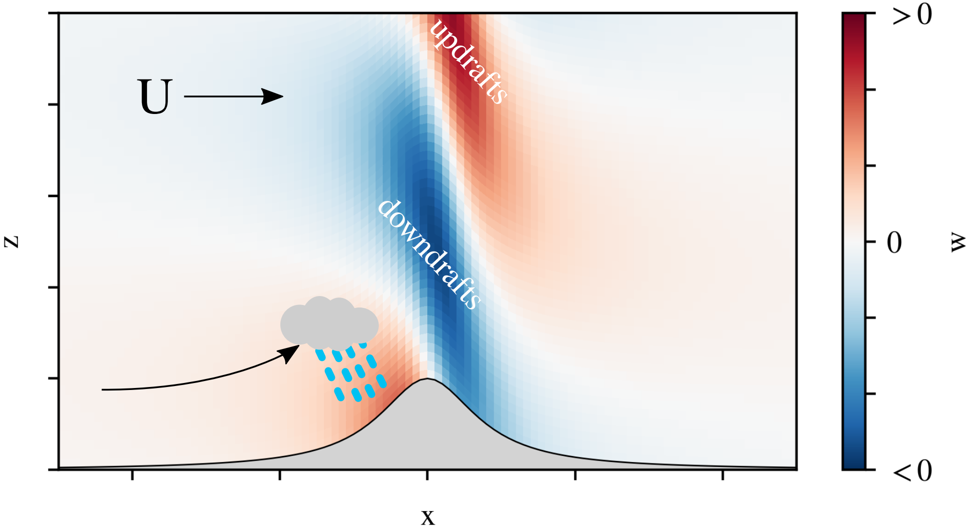


equations: Barstad and Grønås (2006)

ICAR - Windfield



equations: Barstad and Grønås (2006)

Model

- mainly orographic precipitation
- some synoptic precipitation
- **NO** convective precipitation

solution to include convective precipitation:
add ERA-Interim convective precipitation

Model

So... does the model work?

yes, you can produce downscaled atmospheric fields:

publication	domain	grid spacing
Gutmann et al. (2016)	Colorado Rockies, USA	$\Delta x = 4\,\mathrm{km}$
Engelhardt et al. (2017)	Western Himalaya, India	$\Delta x = 5\,\mathrm{km}$
Bernhardt et al. (2018)	Zugspitze, Germany	$\Delta x = 1\,\mathrm{km}$

BUT

- are these fields useful for local impact studies?

e.g. can ICAR simulate the precipitation measured at an alpine weather station?

Methods / Study Domain

South Island of New Zealand evaluated for

- **11 year period** (2007-2017)
- **11 alpine weather stations**

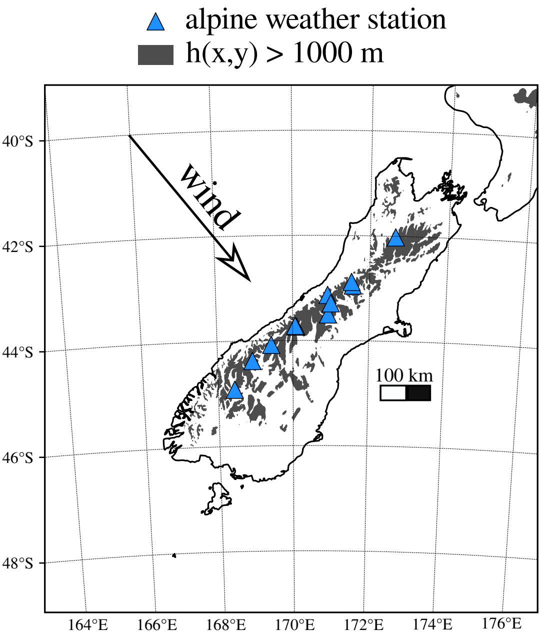
(Horak et al., 2018)

Why here?

- orographic precipitation regime
- predominant wind direction
- surrounded by ocean

Research question:

- improvement over global model?

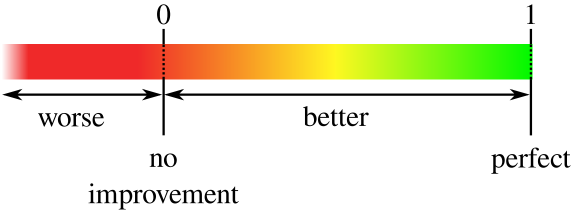


Methods

Better than some other reference model?
$\Rightarrow$ quantifiable with skill scores

e.g. based on the MSE

$$\mathrm{SS}_{\mathrm{MSE}} = 1 - \frac{\mathrm{MSE}_{\mathrm{ICAR}}}{\mathrm{MSE}_{\mathrm{reference}}}$$



Methods

physical factors affecting model performance

- topographic complexity
  - alpine topography
  - coastal topography
- season
- large scale weather patterns
- atmospheric background state

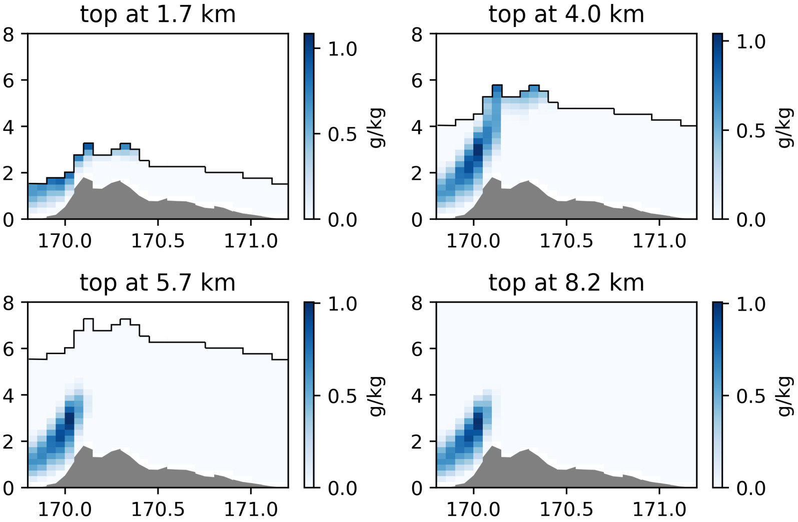
BUT: Preliminary studies revealed:

the **model top setting** is crucial

had not been investigated before!

Results

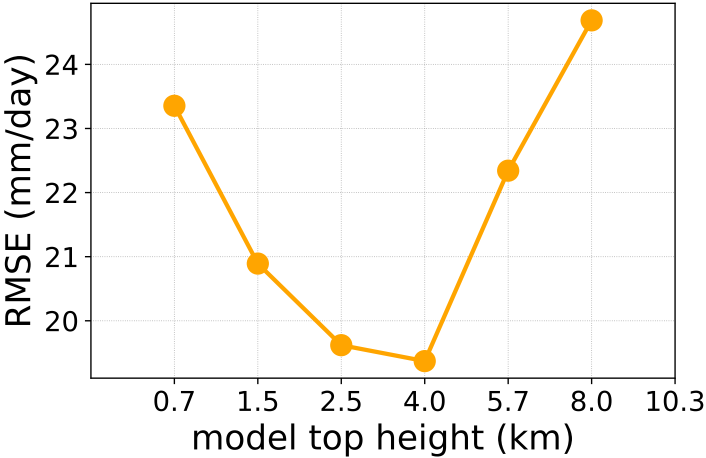
Example - Effect of the model top on cloud water distribution



Results

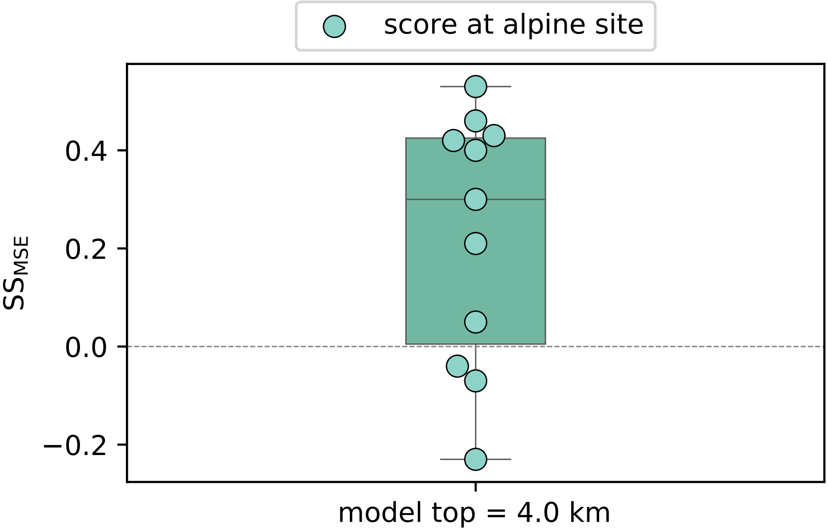
Choosing the optimal model top:

mean RMSE of ICAR at alpine weather stations



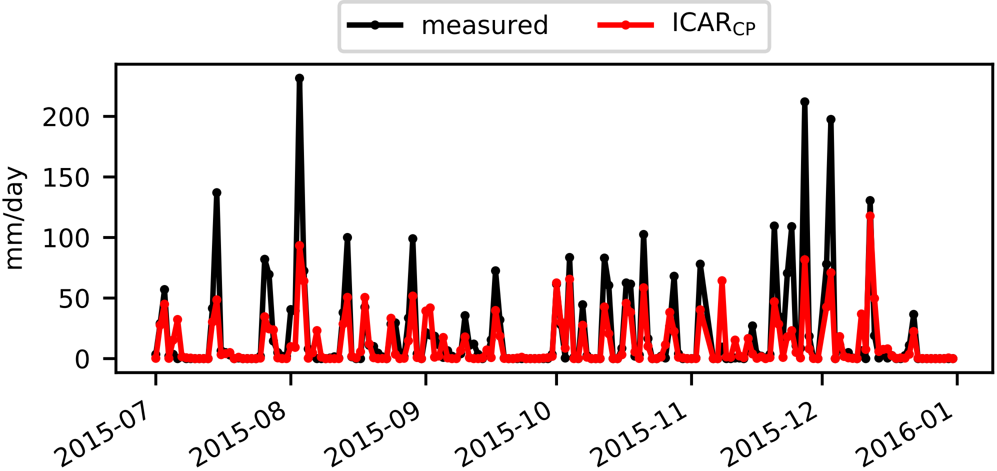
Results

ICAR performs better than ERA-Interim! (mostly)



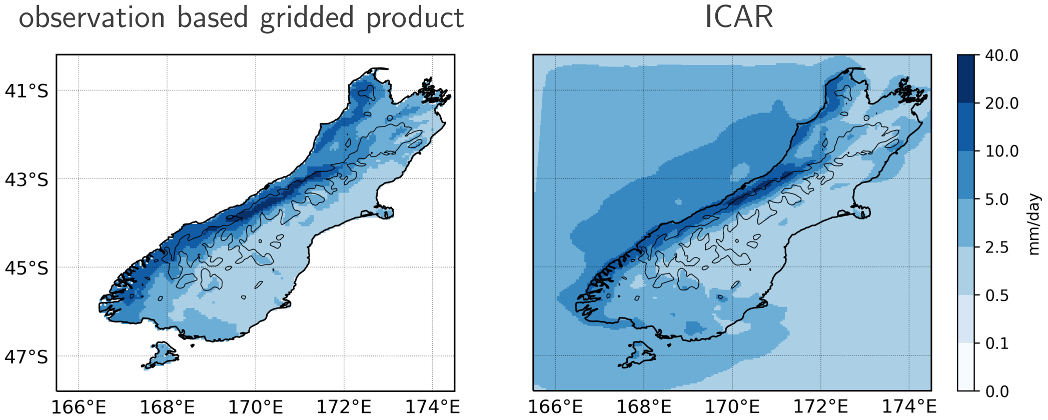
Results

Ivory, $z = 1390\,\text{m}$ MSL, 2 km upwind of alpine crest



Gridded Datasets

mean daily precipitation (2007–2017)



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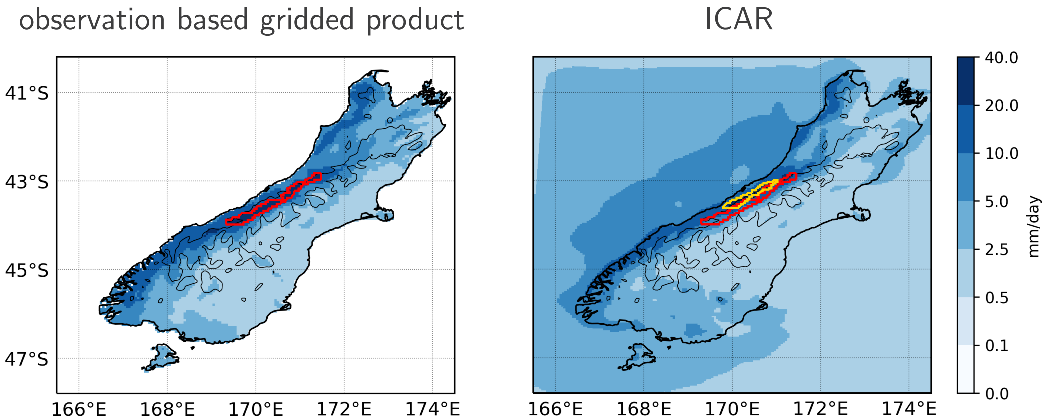

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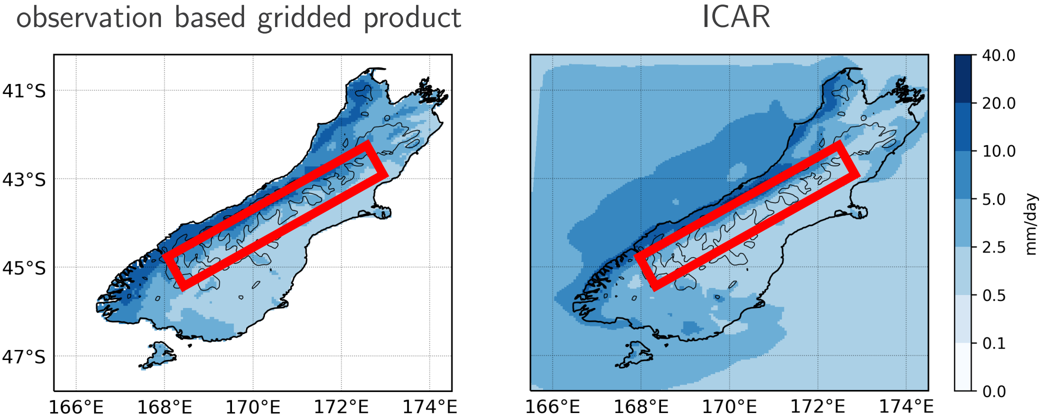

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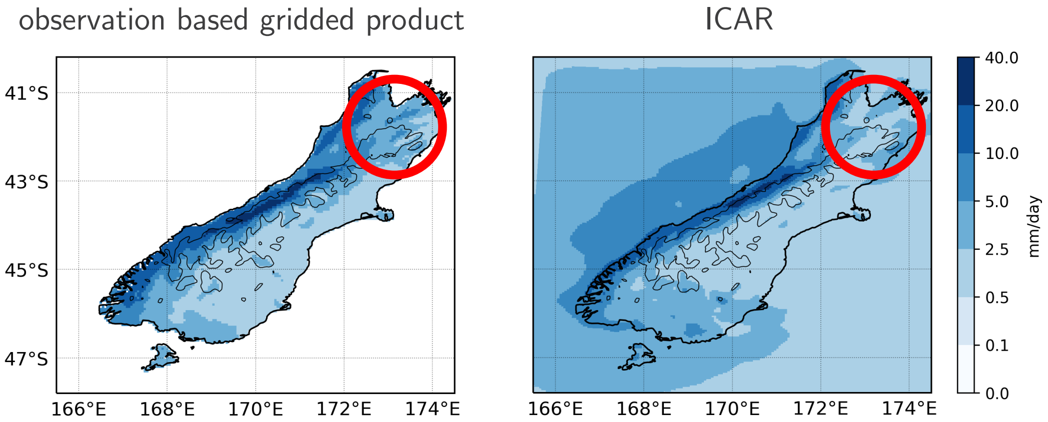

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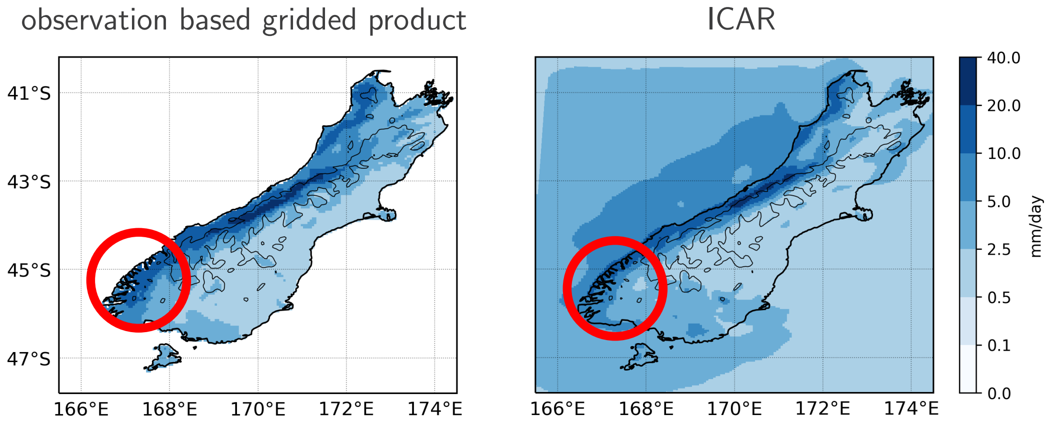
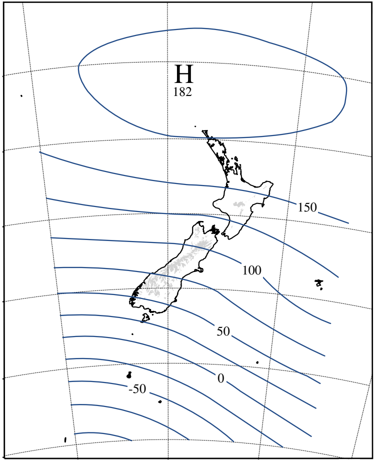


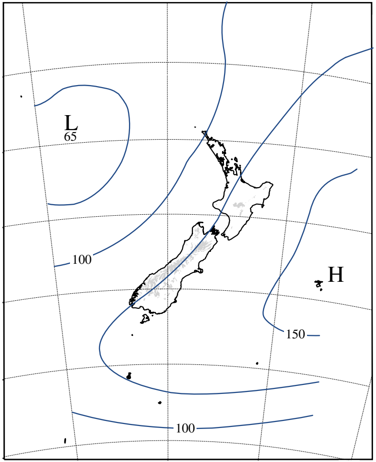
Results

influence of synoptic weather patterns (contours show geopotential height at 1000 hPa)



cross alpine flow

⇒ highest scores



flow parallel to alps

⇒ lowest scores

Results

influence of flow properties

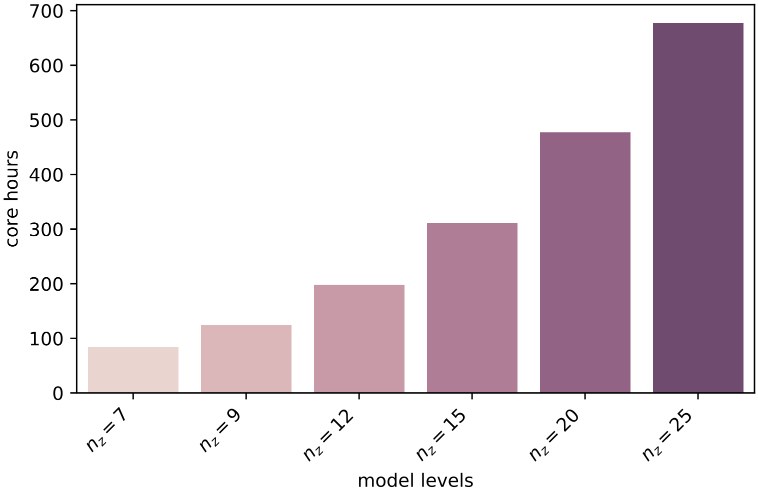
idea: linear theory valid for linear flows - does ICAR work better for those?

yes!

- linear flow ⇒ highest scores
- flow of lower linearity ⇒ lower scores
  e.g. turbulences, flow splitting, orographic blocking, wave breaking, ...
- unstable atmospheric conditions ⇒ lower scores

Results

core hours required for the simulation of one year



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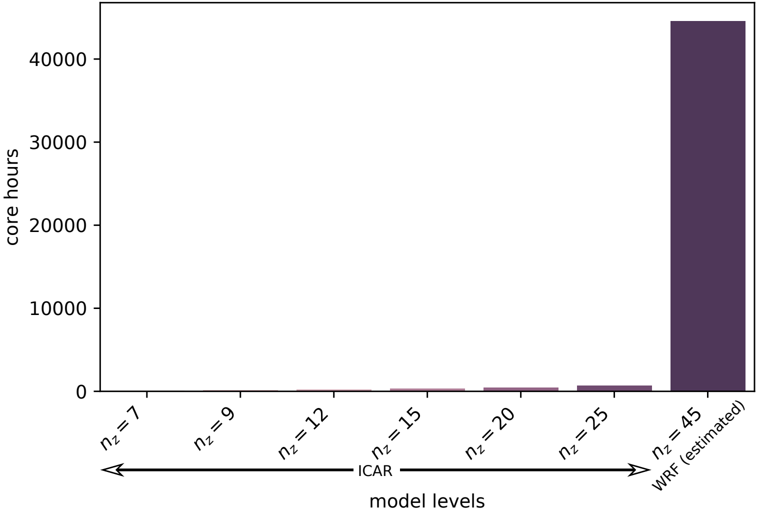

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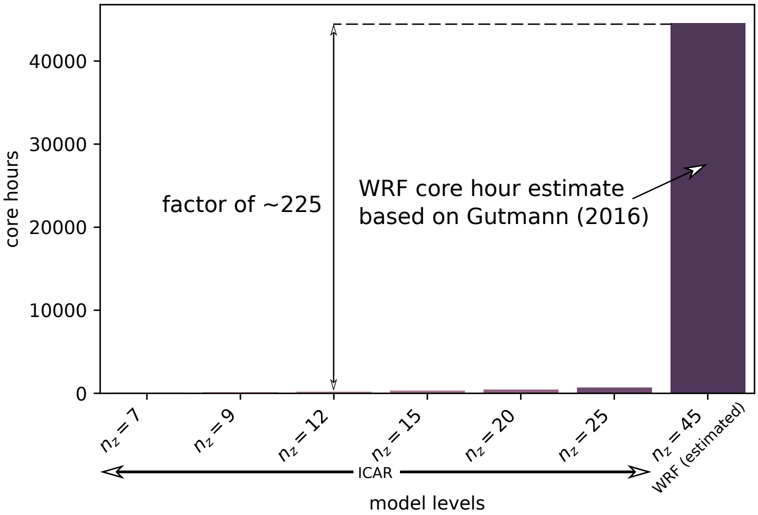

Conclusions

- local precipitation well reproduced at 8 alpine sites
- model underestimates precipitation! $\Rightarrow$ correction necessary
- precipitation patterns well captured at windward slopes of alpine range
- less so farther to the lee
- cross alpine flow leads to better performance than parallel flow
- model top choice critical!
- efficiency: $\approx$ 225 times faster than WRF (Gutmann et al., 2016)

Outlook

Lots of open questions...

- why is the model top so influencial?
- why less accuracy with more z-levels?
- why do we underestimate so much?
- what about other domains?
  - Peruvian Andes
  - European Alps

  we expect difficulties due to
  - less orographic influence
  - higher orographic complexity
  - synoptic situation more complex
  - ...

Thank you!

more details:

Horak, J., Hofer, M., Maussion, F., Gutmann, E., Gohm, A., and Rotach, M. W.: Assessing the Added Value of the Intermediate Complexity Atmospheric Research Model (ICAR) for Precipitation in Complex Topography, Hydrol. Earth Syst. Sci. Discuss., **https://doi.org/10.5194/hess-2018-612**, in review, 2018.

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