Next Generation Earth-System Models: Lessons Learned & Looming Challenges

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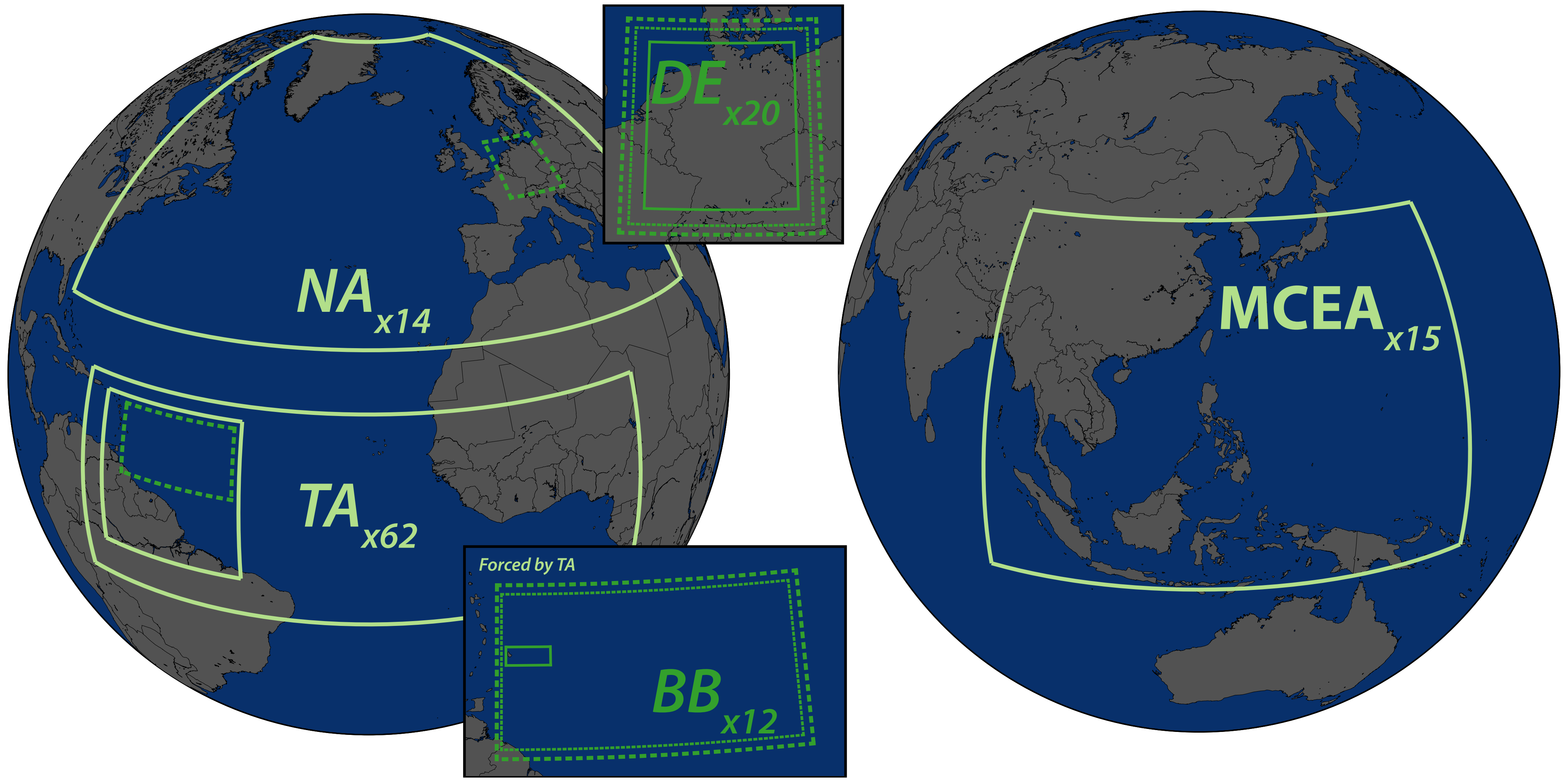
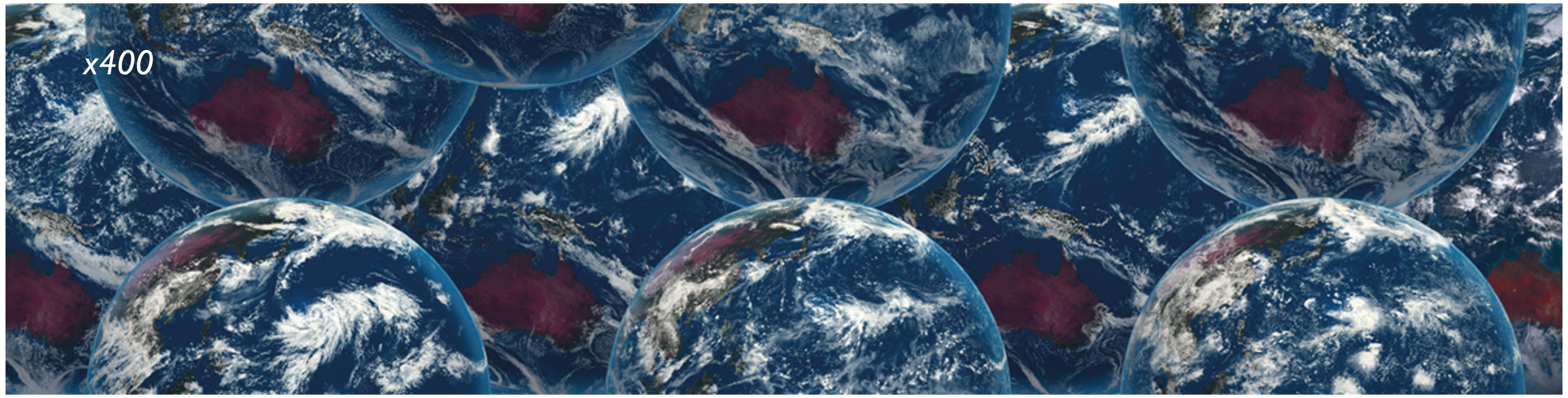
Speaking from Experience



HD(CP)^2: A (German) national project funded by the Ministry of Education and Research to answer two questions: Can we simulate the climate system at hecto and kilometer scales, and if we do so would doing so break the cloud and precipitation deadlock that renders present climate models unfit for many applications



DYAMOND: an initiative with Masaki Satoh (U. Tokyo) to perform the first ever intercomparison of global storm resolving (kilometer) scale models.

1. Lessons Learned: Technical | Scientific | Sociological

We can do it:
At the beginning of the HD(CP)2 we weren't even sure what model to use. A clear focus on simulation targets helped us concentrate. Likewise when we initiated DYAMOND we thought of involving two models only having groups from around the world eager to join the effort, leading to a 1.5 year project involving 10 models.

We are closer than we think:
For DYAMOND ICON at 2.5 km ran at 6.1 SDPD on 540 nodes. If this could be scaled to Fugaku we could run at 11 SYPD. Kilometer-scale global models with a performance of 1 SYPD are not inconceivable now, also see the IFS experience on Summit.

I/O is manageable, but requires changed expectations:

- output formats and scales
- people don't delete
- more programmable output
- clever analysis methods

Tool Chains:

- CDO with DASK and X-Array
- serverside processing (JUPYTER)
- visualization

1. Lessons Learned: Technical | Scientific | Sociological

Global storm resolving models are not high-resolution GCMs, rather a leap to a new type of model

1. Lessons Learned: Technical | Scientific | Sociological

June 2020 P. D. DUEBEN et al. 11

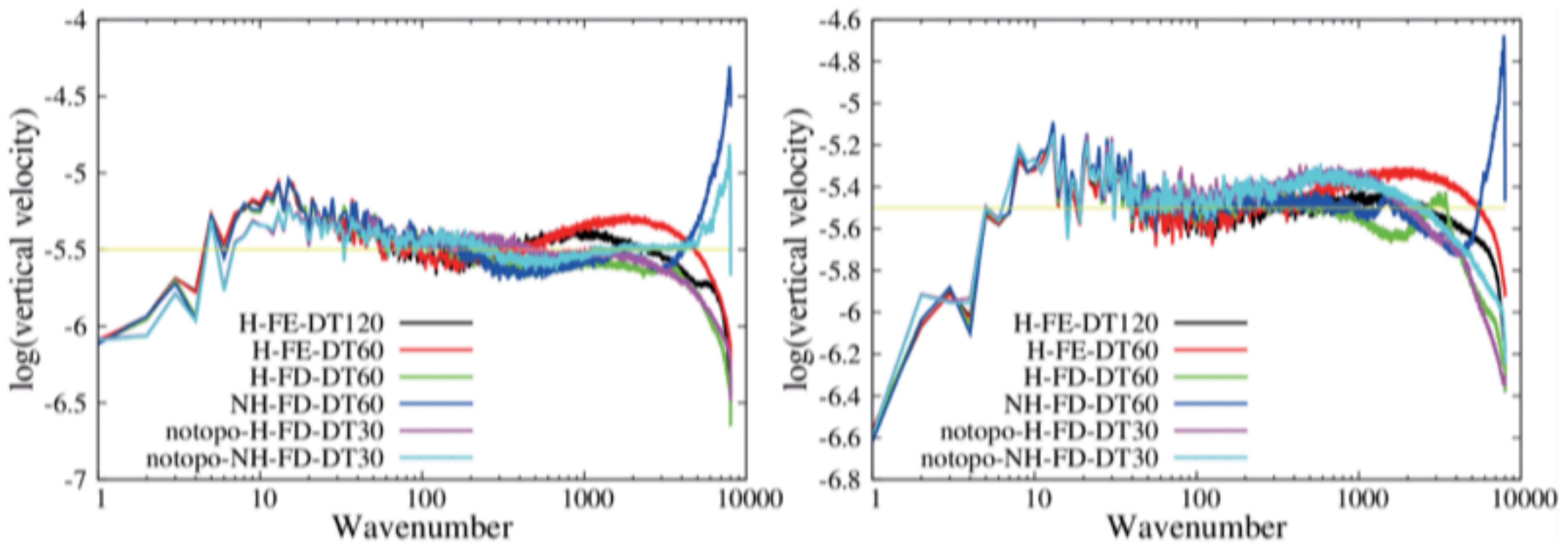
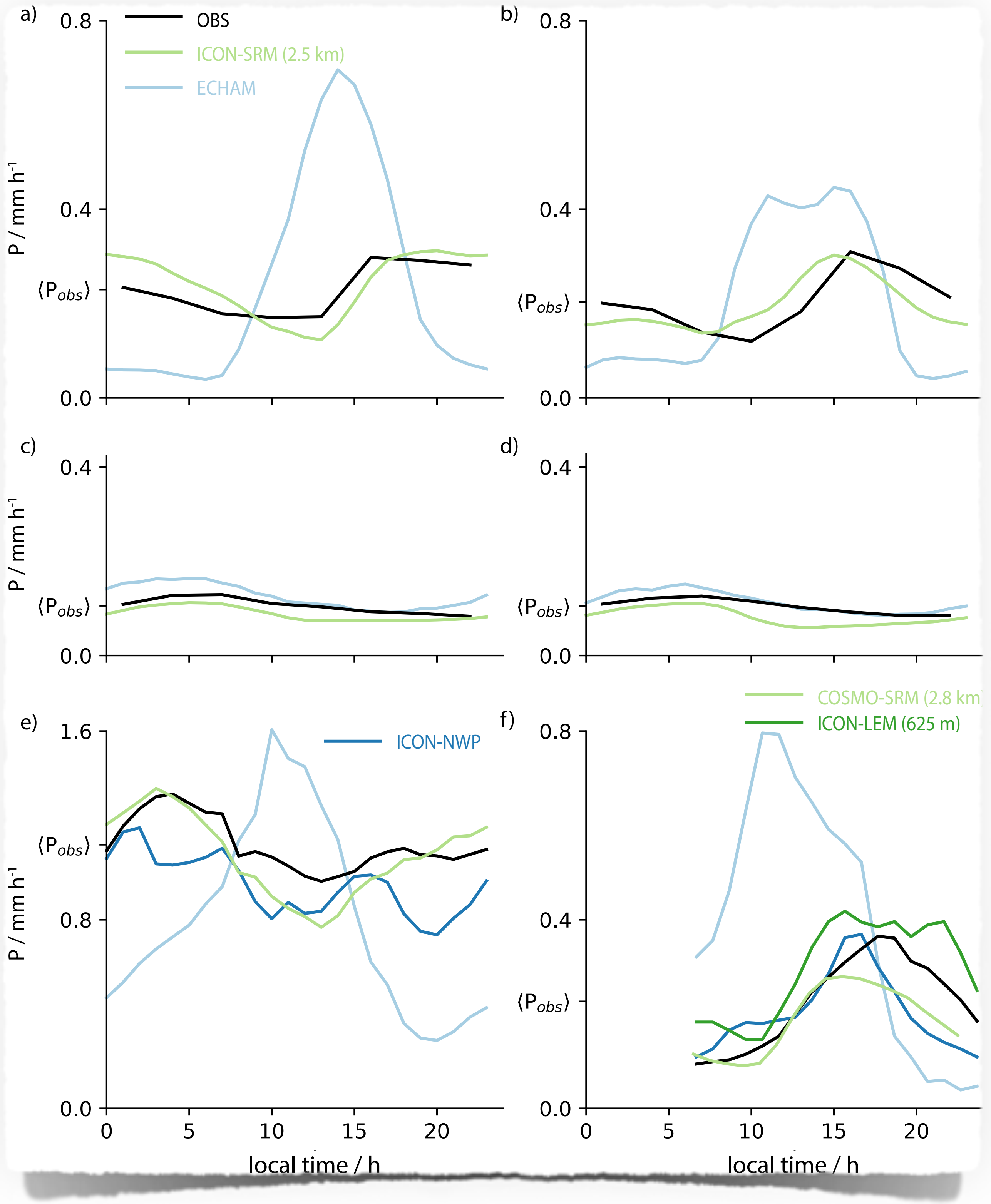


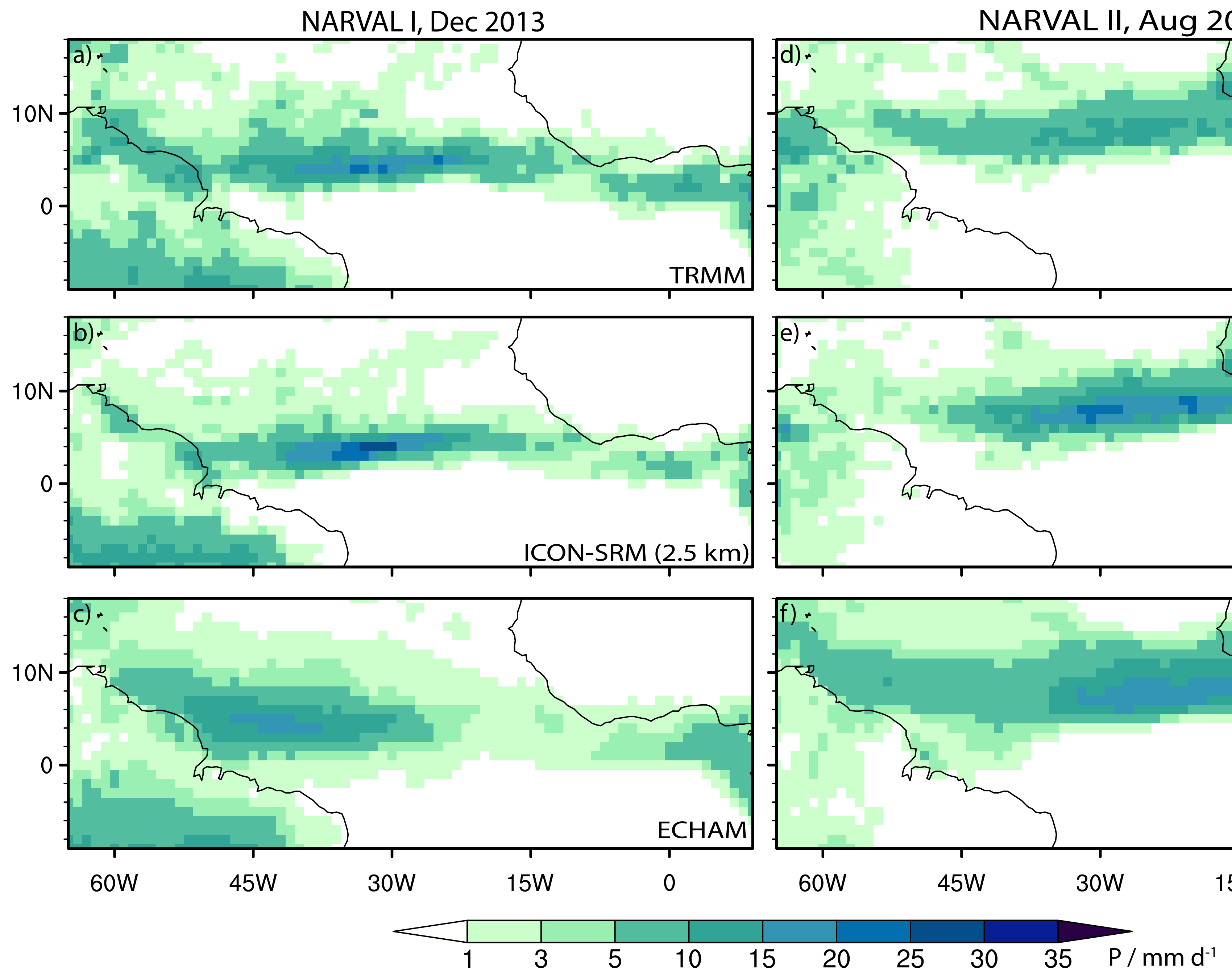
Fig. 6. Spectra of vertical velocity at 250 hPa (left) and 500 hPa (right) 12 h into the forecast.

The power in the vertical mode of motion is equipartitioned across scales

Düben, Wedi, Saarinen and Zeman, *JMSJ* (2020)

1. Lessons Learned: Technical | Scientific | Sociological

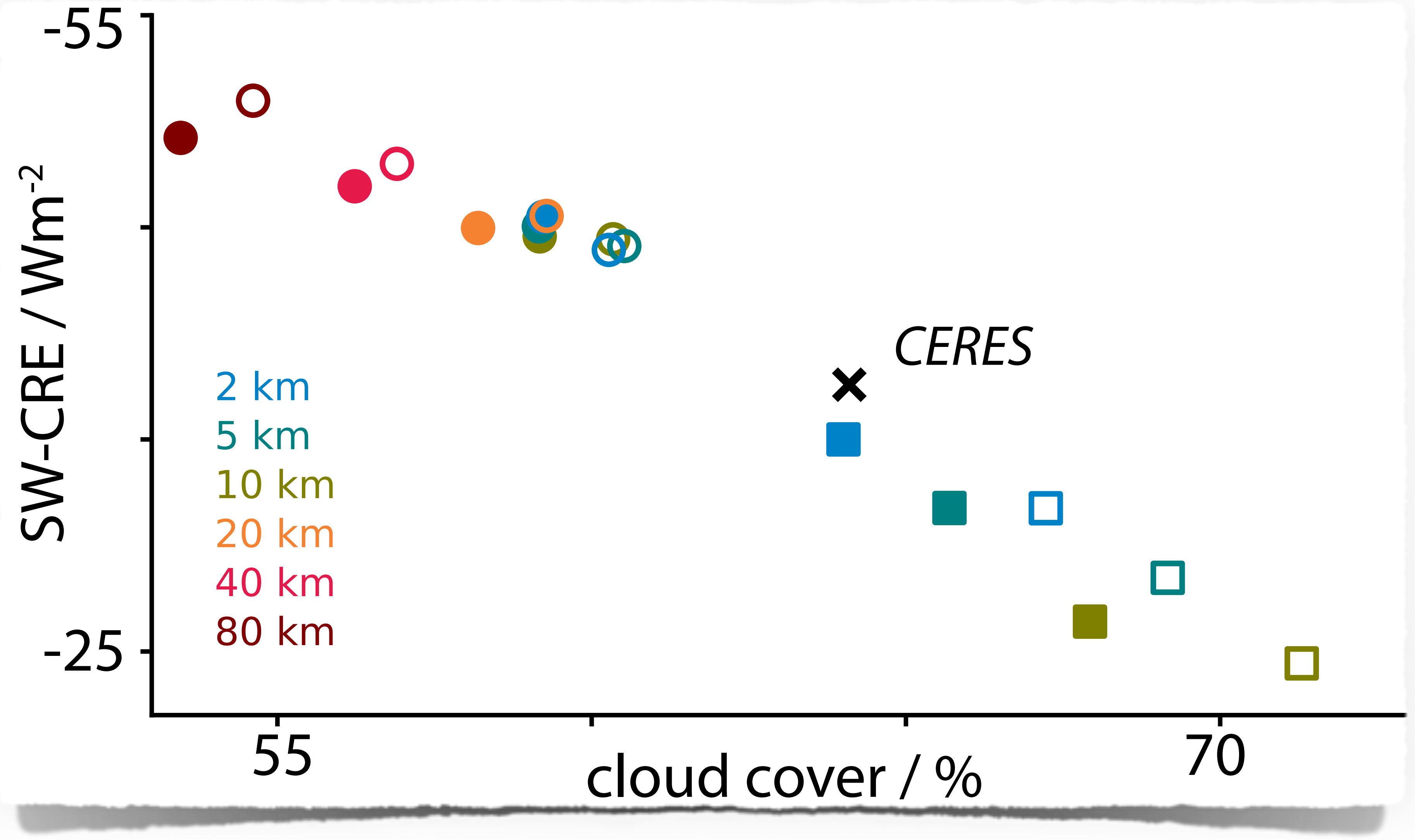




Precipitation comes for free, with most of the gain already evident at kilometer scales

Stevens et al., *JMSJ* (2020)

I. Lessons Learned: Technical | *Scientific* | Sociological



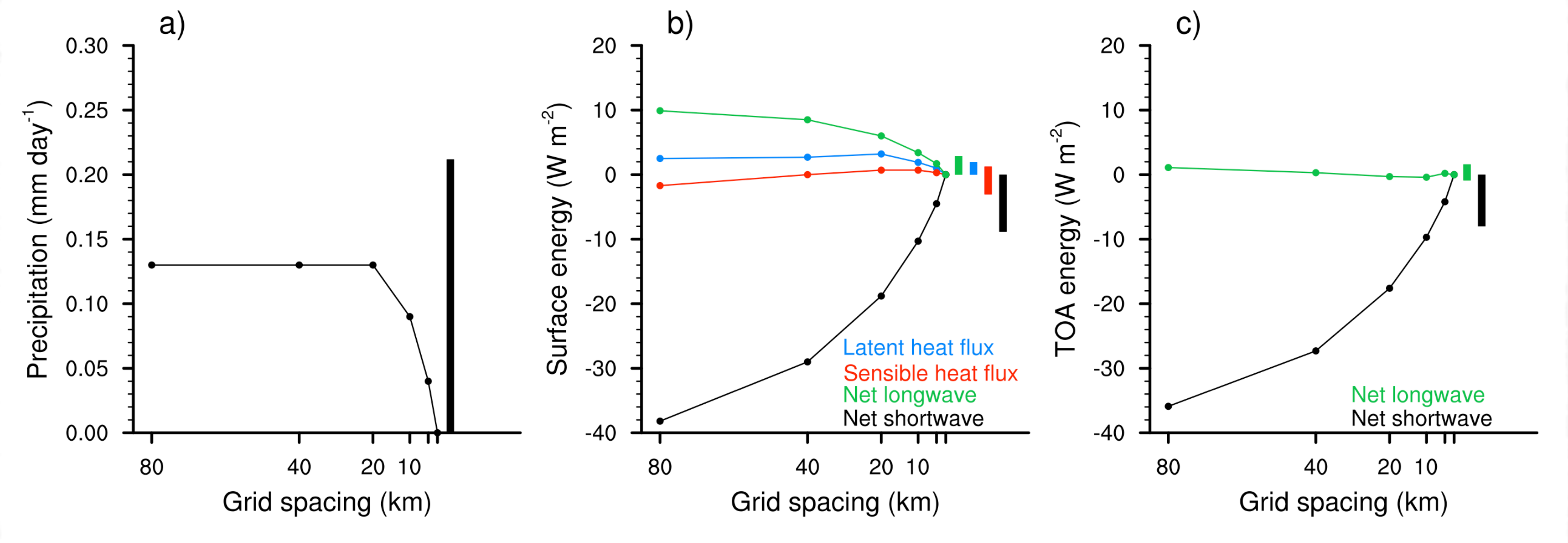


Fig. 1. Global statistics from the ICON simulations, with a grid spacing of 80 km (on the left of the x-axis) down to 2.5 km (on the right of the x-axis), averaged over the 40-day period and expressed as the difference to the 2.5-km simulation: (a) precipitation, (b) surface components of the energy budget, and (c) top-of-the-atmosphere (TOA) components of the energy budget. The vertical bars show one standard deviation of the corresponding quantities in the DYAMOND ensemble. Downward energy fluxes are taken as positive except for sensible and latent heat fluxes, which are taken as positive when directed into the atmosphere. For precipitation, the GEOS model was not included in the computation of the DYAMOND spread as there were errors in the precipitation diagnostics.

Convergence becomes informative, in a way better justifying coarsened ensembles

Analysis in left figure by A. Voigt in Stevens et al., *JMSJ* (2020); Hohenegger et al., *JMSJ* (2019)

1. Lessons Learned: Technical | Scientific | Sociological

It’s fun:
Maybe because it is new, or maybe because it is integrative, but also because one interacts with phenomena from a world that is familiar, so working with such simulations feels even more like exploring the real world.

It’s new:
Many people become involved in science to expand new horizons. Almost anything anyone does with a global storm resolving model is new, thus it captures much of the excitement of how I imagined the early days of GCM development.

It’s integrative:
- better link to observations and observational communities
- stronger link to impacts and applications and their associated communities.

It’s challenging:
Working with the simulations is technically challenging, but this exposes people to new tools, new ways of thinking, and so the novelty of the technical side of working with GSRMs rivals their physical novelty.

2. *Looming Challenges: Technical* | *Scientific* | *Sociological*

rich.loft[‘quote’].sqrt() ‘Every factor of ~~ten~~ three is a whole new world’

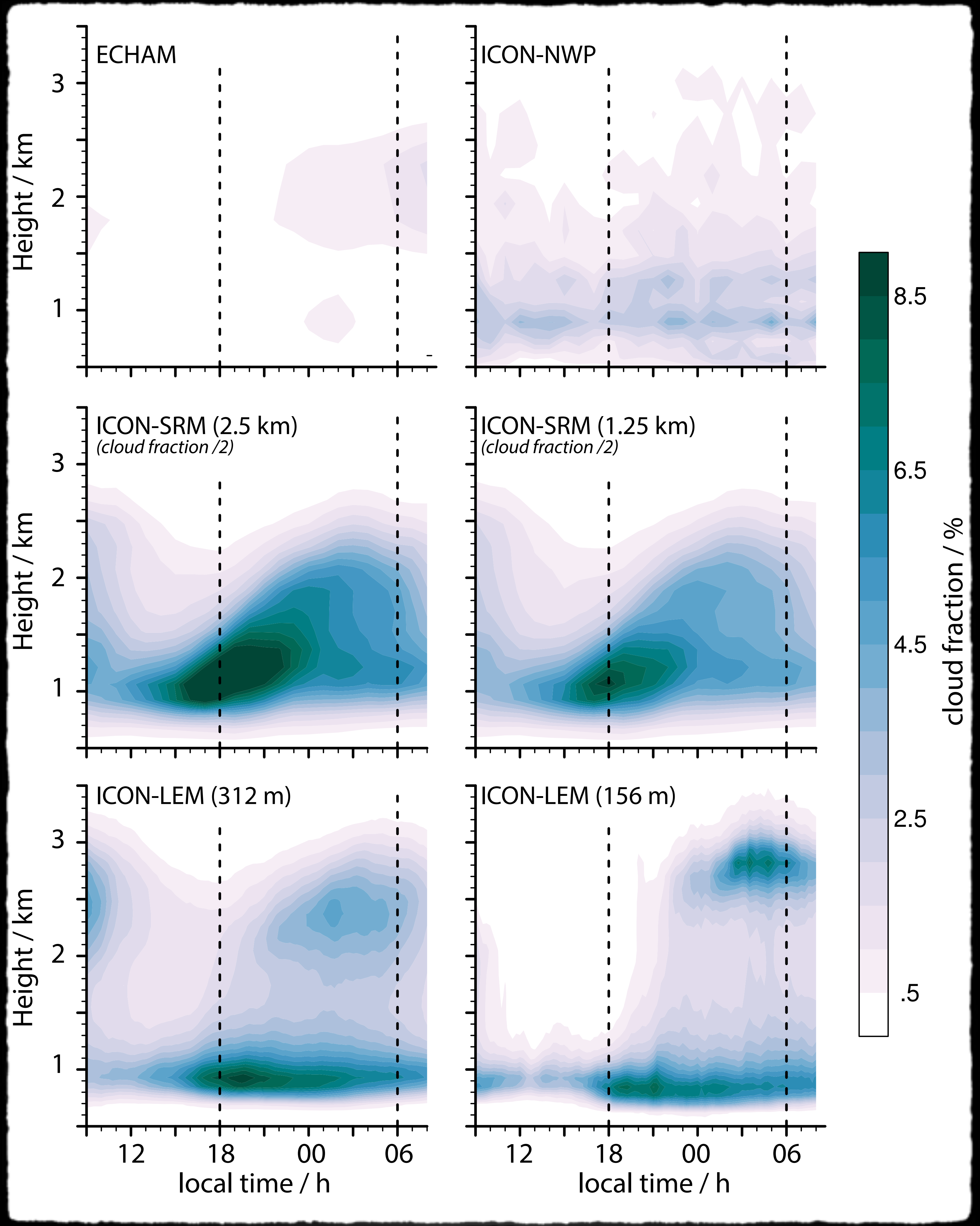
α/ω (analysis and output):

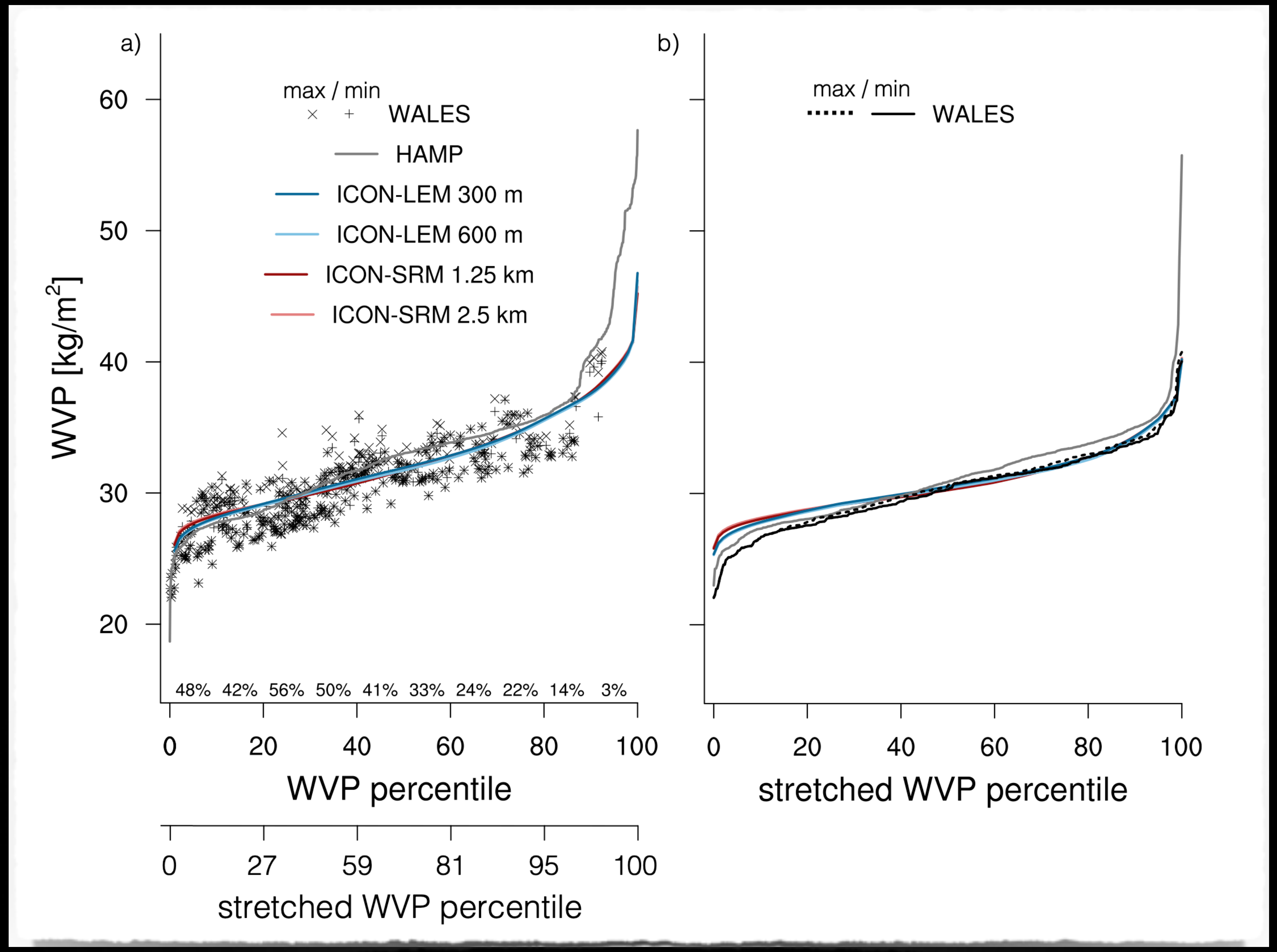
- analyzing the simulation, not its output — ‘programming the model’
- grids & graphing
- storage hierarchies
- AI (also for output)

Repurposing development efforts:
Large efforts are being spent to enhance performance portability, with emphasis mostly placed on the dynamical core. This part of the code determines the geometry of the problem, but is a very small code base and as compared to the rest of the model also the most static. This makes me wonder if the problem is being approached in the right way.

Finding the sweet spots for Machine Learning

2. Looming Challenges: Technical | Scientific | Sociological





1. Low-clouds remain poorly represented at kilometric scales, and this makes it difficult to represent the surface heat budget correctly, which in turn is making efforts to couple these models to a dynamic ocean a challenge that must be surmounted.
2. Designing experiments and analysis methods that allow us to learn from limited output and from simulations of limited duration.

Naumann and Kiemle, *ACP* (2020)

2. Looming Challenges: Technical | Scientific | Sociological

To think of simulations as experiments.

Being able to conceptualize and articulate the benefits of a collective effort.

If we hope to solve big problems we cannot artificially constrain our efforts to fit within individual labs, but rather need a shared infrastructure.

My lessons learned?

It is not possible to reconcile a conviction that climate change is an important societal issue with our current piecemeal, substandard, self-circumscribed, approach to the science. We need a ***European Center for Earth System Science***.

This will:

- advance our capacity to best constrain the behavior of the climate system by our understanding of the physics,
- allow the field to develop the technical capacity (guide developments, set standards) to do its everyday work better,
- increase bandwidth with application communities,
- better advance scientific opportunities for those not working at the lab level,
- use resources more responsibly.

All of this is necessary if we really hope to best inform society of the expected effects of the slow virus we call climate change.