Next Generation Earth System Models

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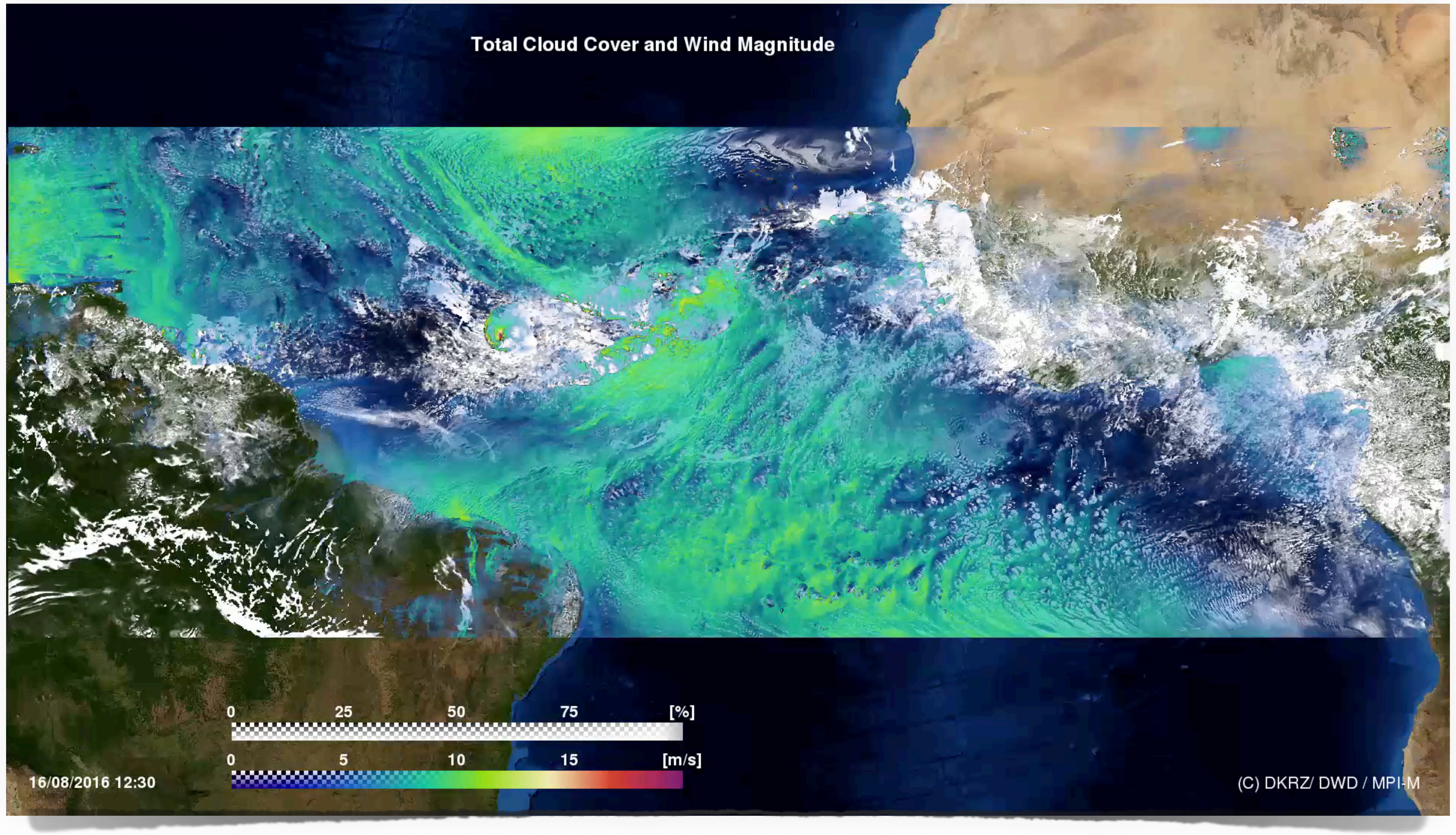
26th May, 2017 — "How Clouds Respond to Global Warming"

Conclusions

- Cloud feedbacks are mostly associated with changes in low clouds
- But how deep convection sets the atmospheric stability plays an important role for both low and high clouds.
- The convection-stability link is responsible for an iris effect whereby high-clouds are reduced with warming, and may portend global scale interactions with low clouds.
- We are however limited because the clouds we represent are all parameterised, break throughs will come from different approaches.



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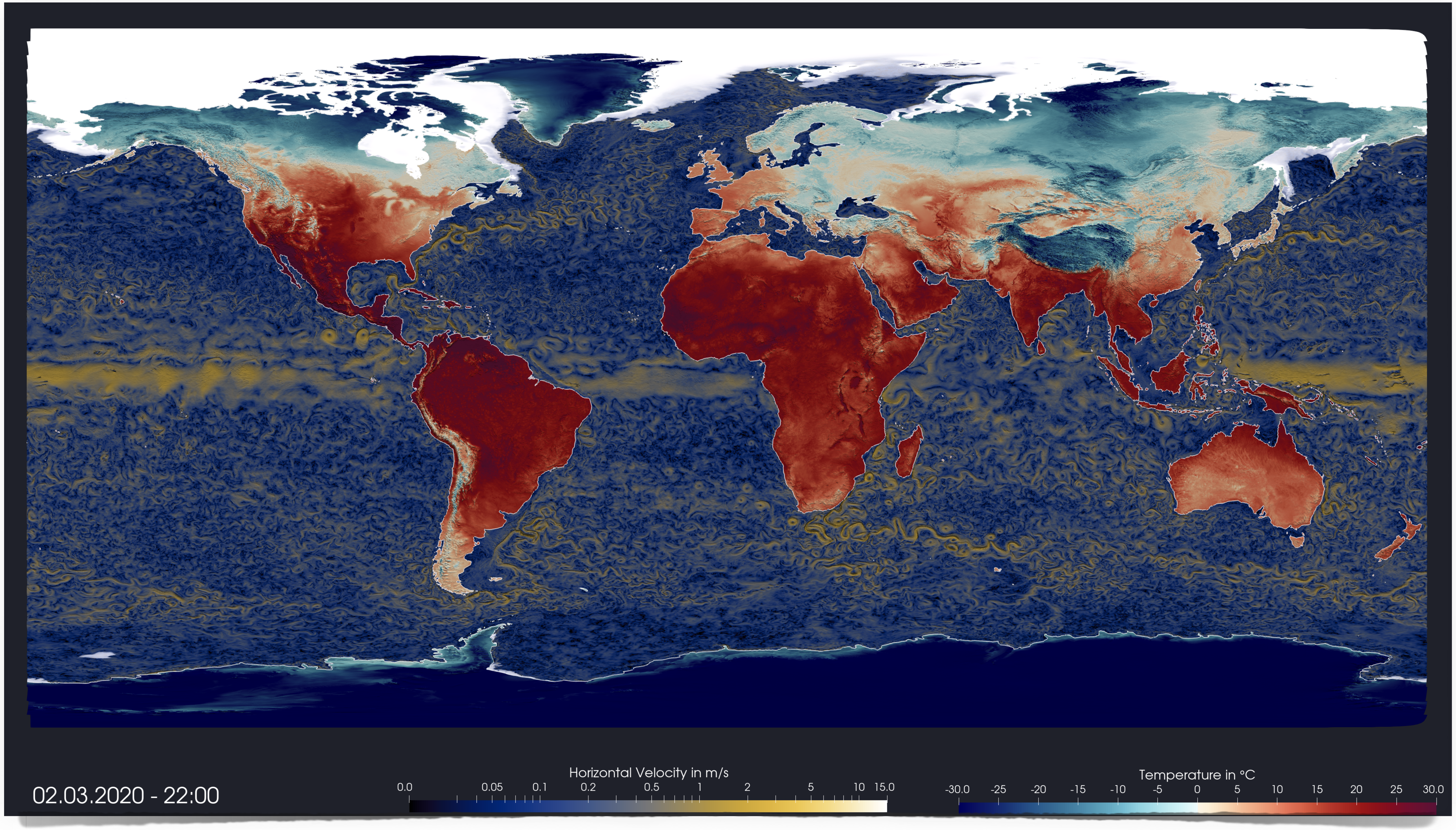
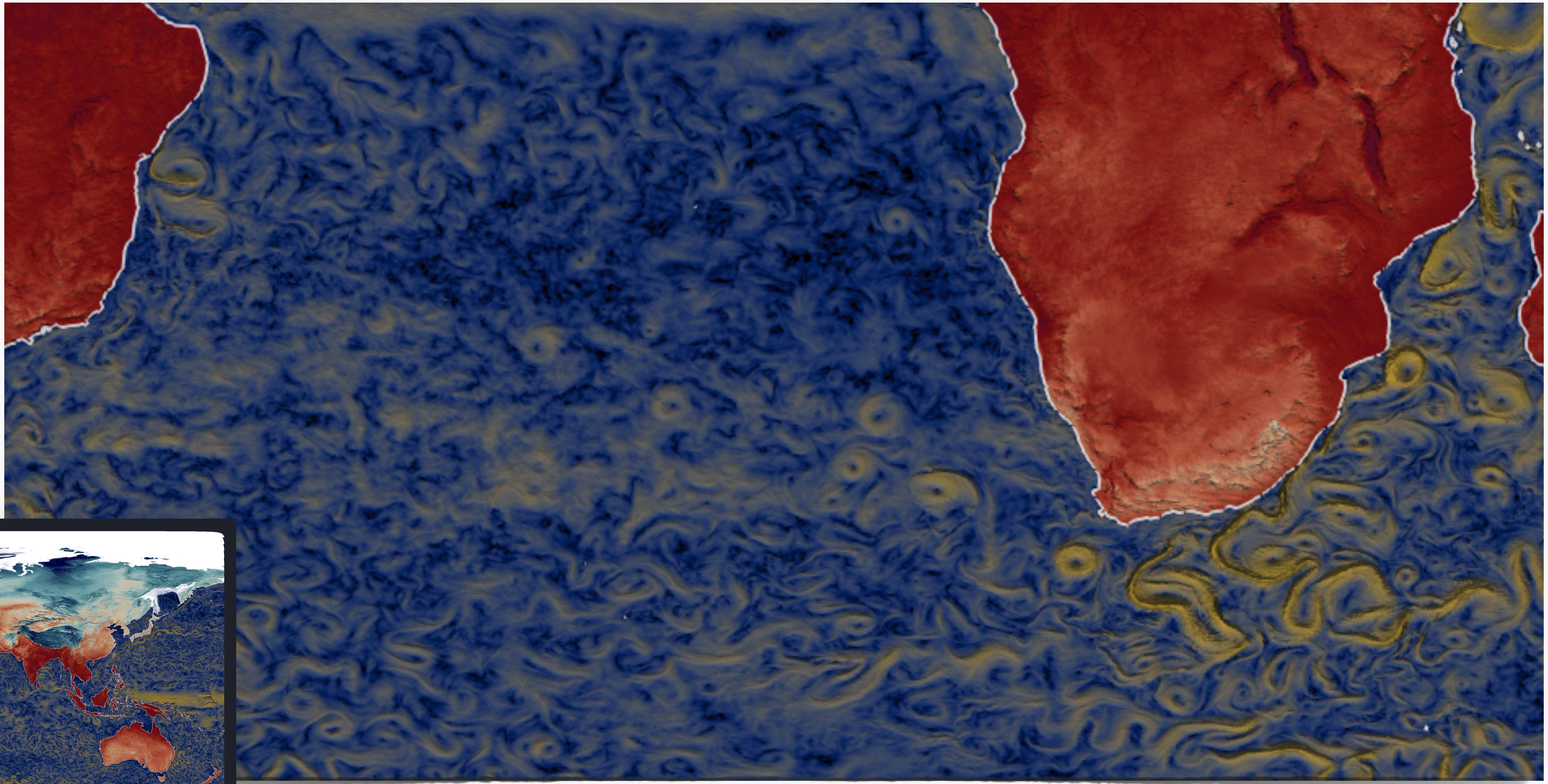
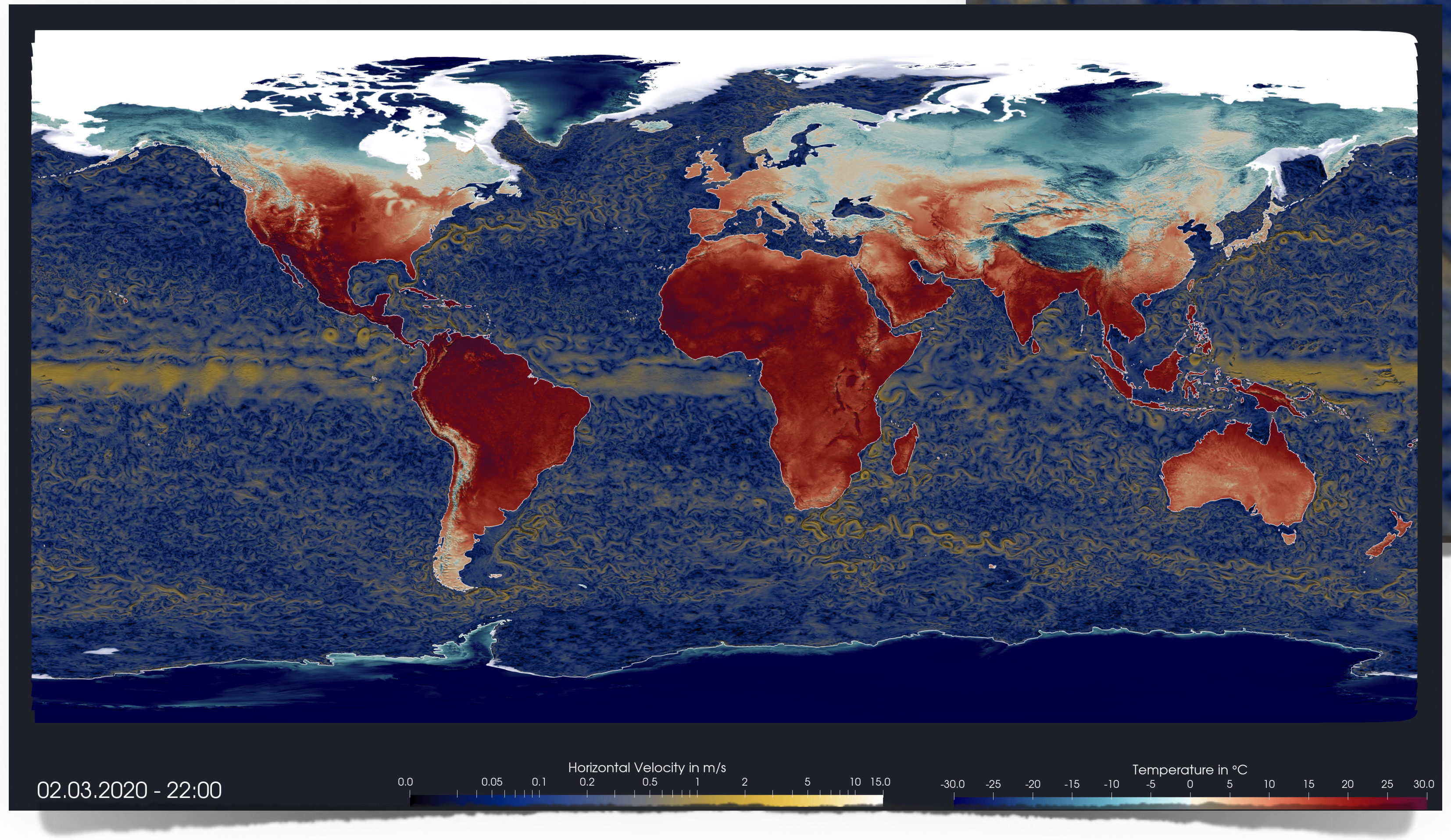
This is coupled to the ocean



Visualization by N. Röber (DKRZ)

This is coupled to the ocean





Visualization by N. Röber (DKRZ)

We call this a Storm-resolving Earth System Model:

- ‘Storm-resolving’ because anything anyone would call a storm is ‘resolved’ by the kilometer scale grid.
- Atmospheric prototypes for this type of model (GSRMs) were pioneered by colleagues in Japan, notably Masaki Satoh (U Tokyo) and Hirofumi Tomita (Riken).
- We (and other groups in Japan and the US) have extended atmospheric GSRMs to represent the coupled system, with similarly resolved oceans, and an interactive land surface.
- Our first simulations a couple of years ago ran the models for periods of forty days, now we are running simulations for multiple years… soon decades.
- This forms the basis for representing the Earth-system, and hence the nomenclature Storm-resolving Earth System Models, or SR-ESMs.

Storm-resolving models are not simply high-resolution climate models

Satoh et al., Global Cloud Resolving Models, *Curr. Clim. Change Rep.* (2019)

Models evolve by qualitative leaps

- EBMs are not spatially resolved; they parameterize all forms of energy exchange based on global mean properties.
- EMICs resolve aspects of spatial structure, but parameterize energy exchanges based on spatially resolved properties.
- CMIP models simulate lateral energy transfer, and gyre-scale ocean circulation, and parameterize the rest.
- SR0ESMs also simulate vertical energy transfer and ocean eddies.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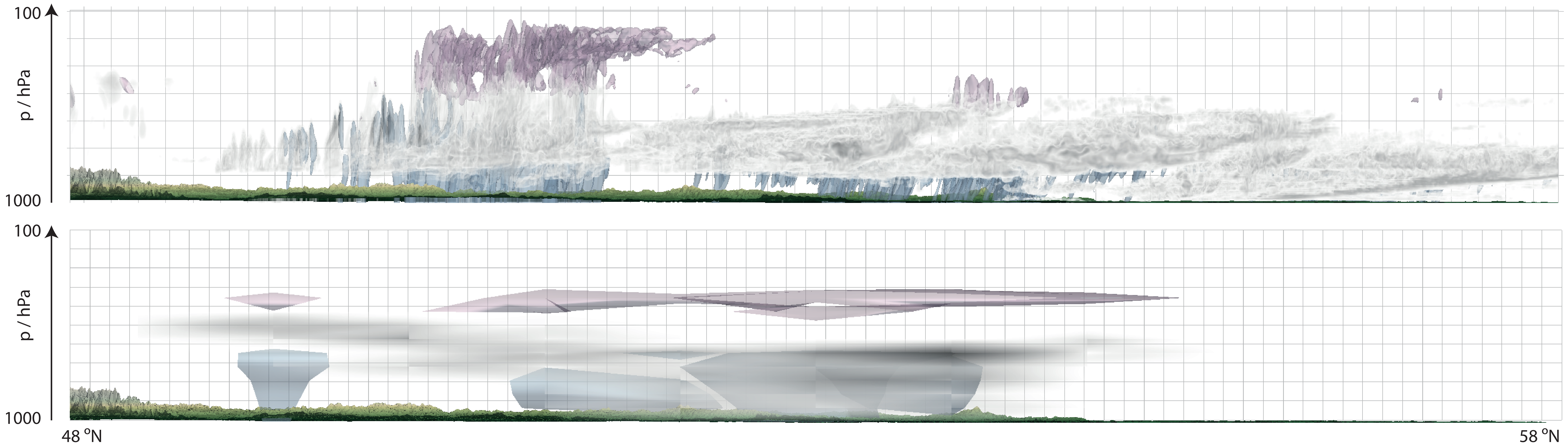
(C) Data: JAMSTEC, Visualization: DKRZ

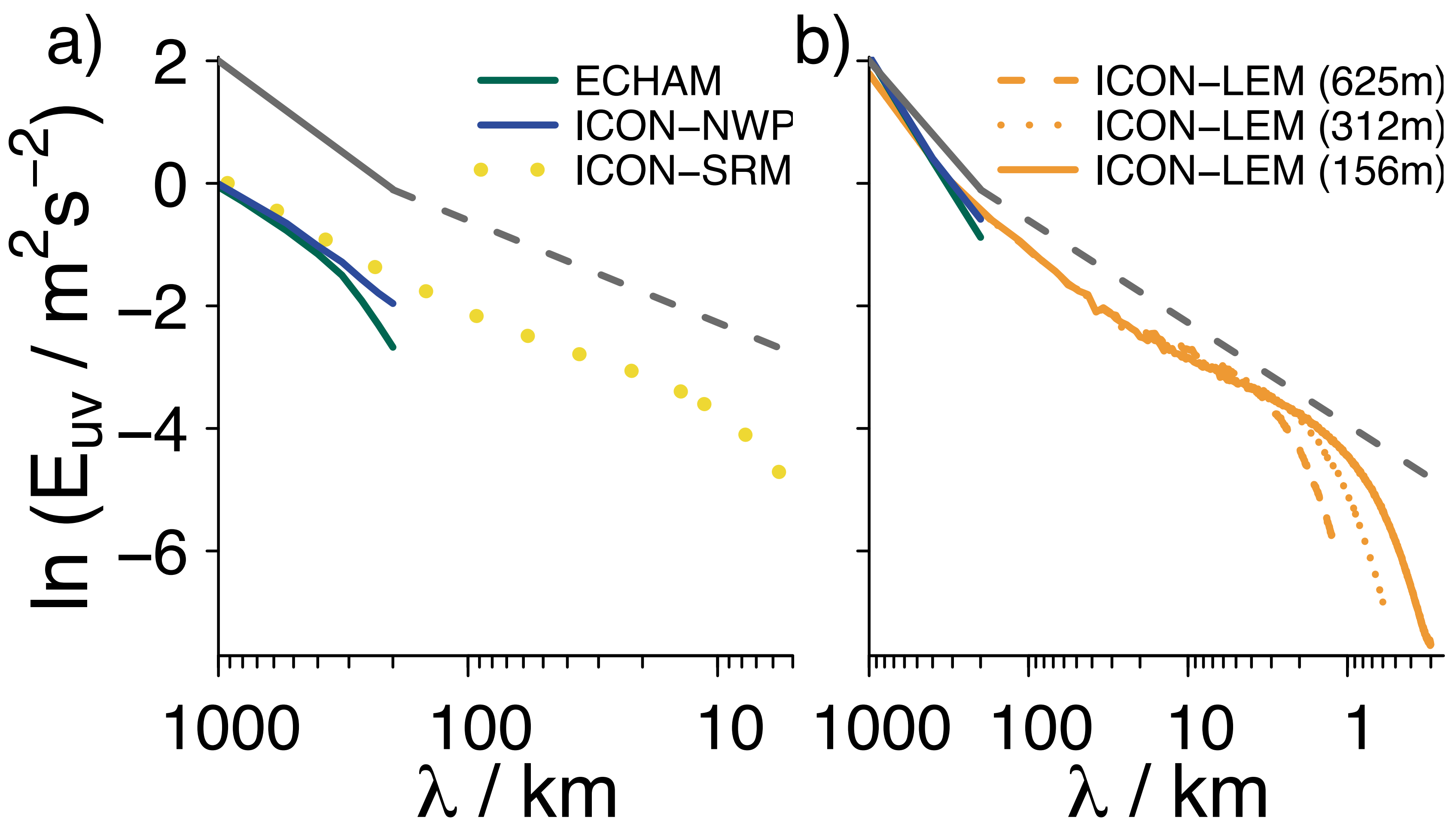
The difference between parameterized and explicit convection

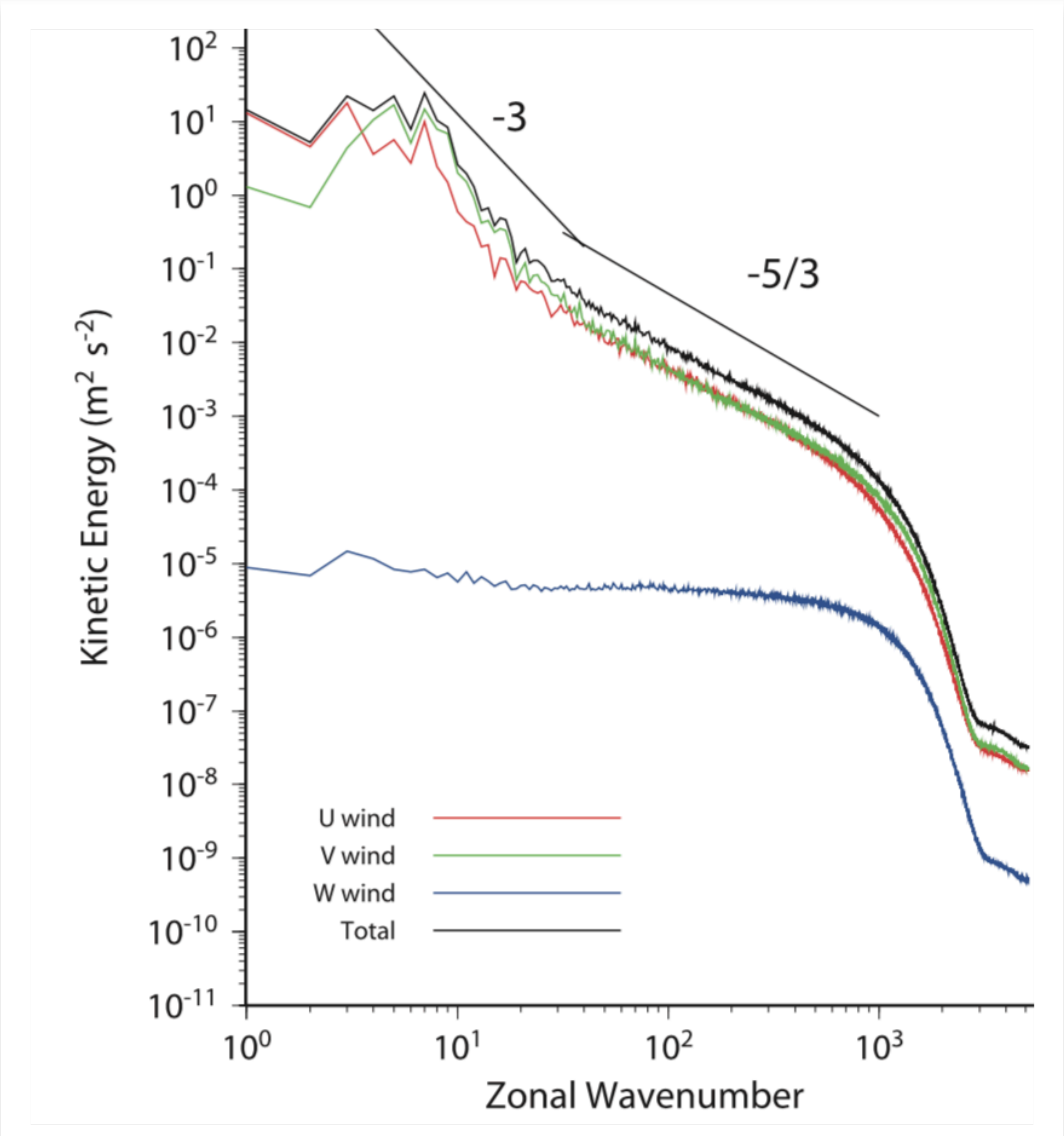


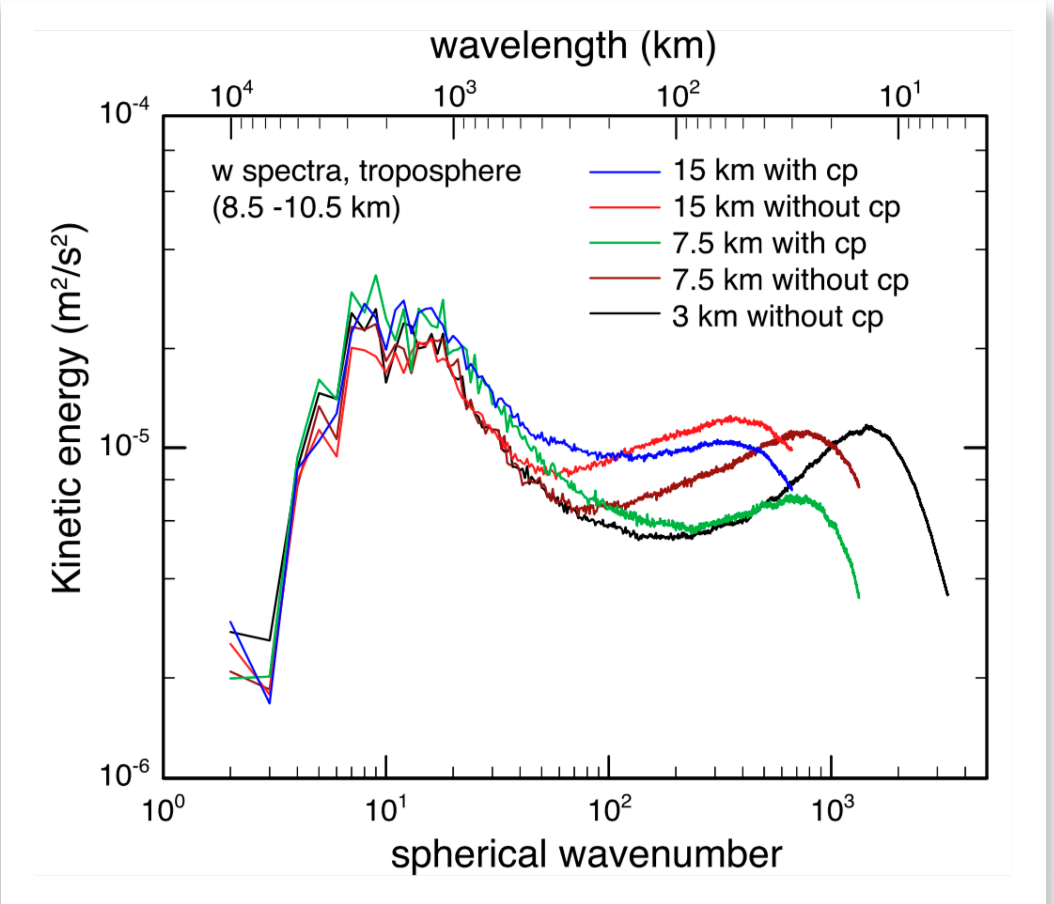
… explicit convection is expressed by the flow; this kinematic coupling of diabatic processes maintains geometric relationships that parameterizations destroy and modelers struggle to recreate.

Stevens et al., *J. Meteorol. Soc. Japan,* (2019, submitted),; cf SuperParameterization

The energy spectrum of the atmosphere



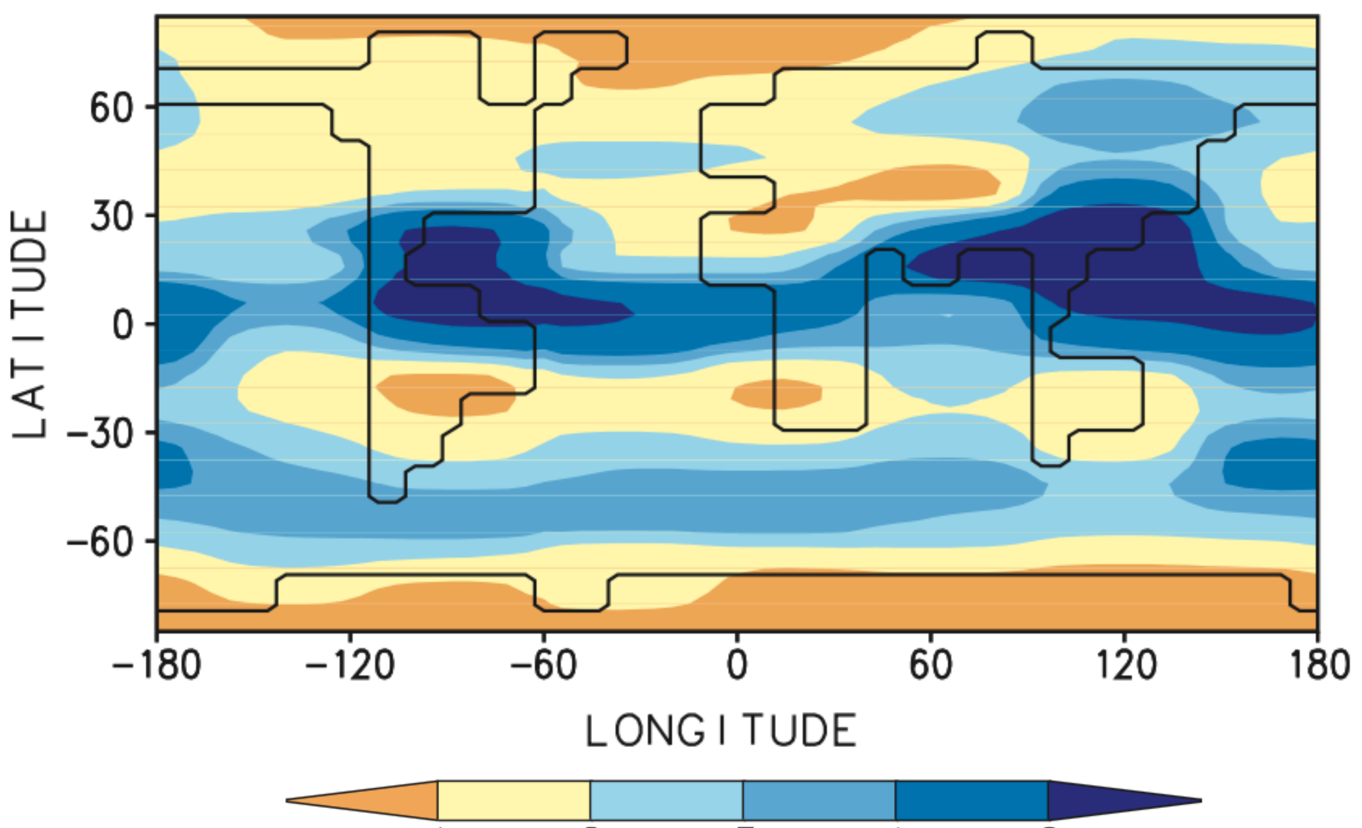




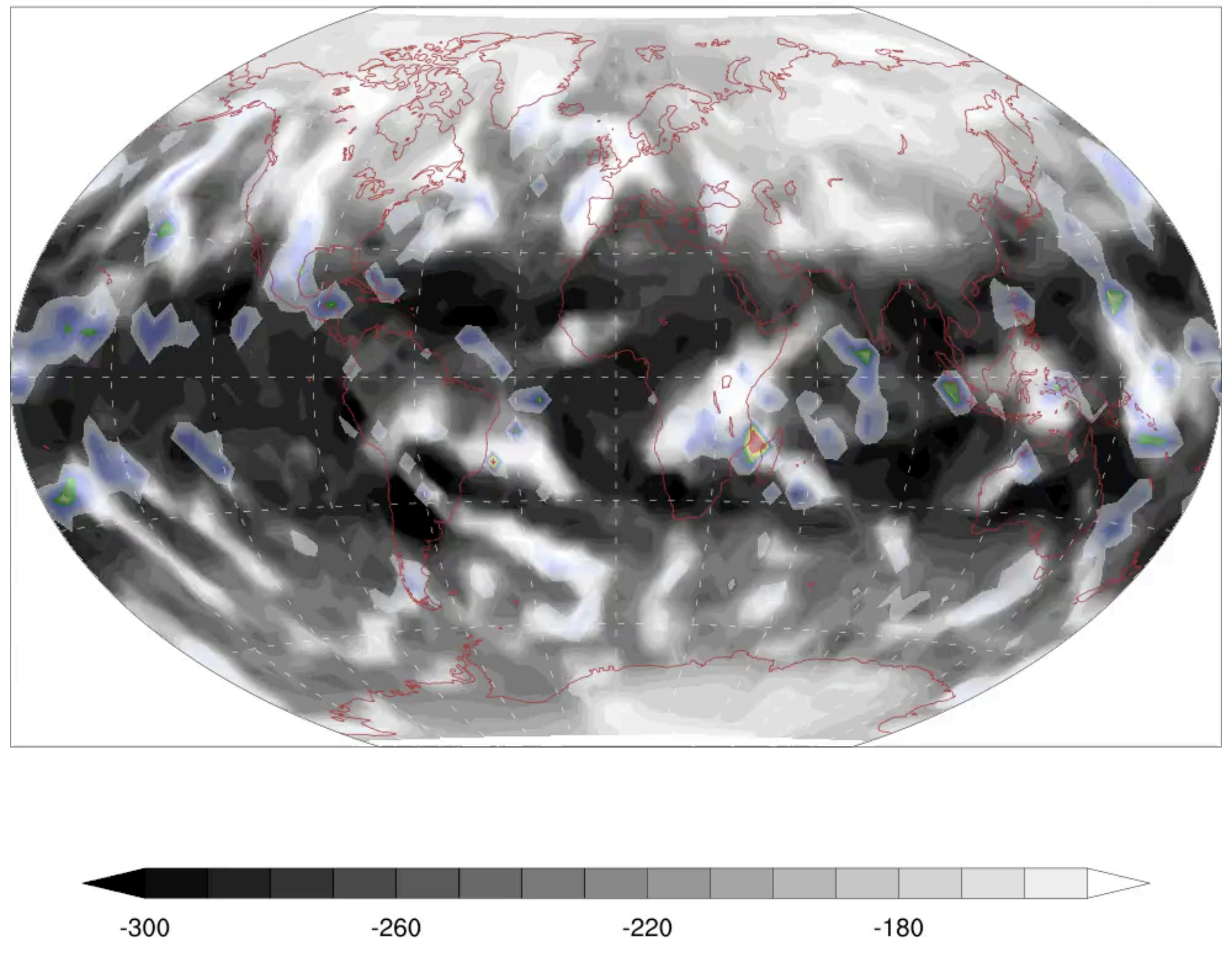
Stevens et al., *J. Meteorol. Soc. Japan,* (2020); Terasaki et al., *SOLA* (2009), Skamarock et al.,*J. Atmos. Sci.,* (2014)

A Gallery of Simulations Across Scales

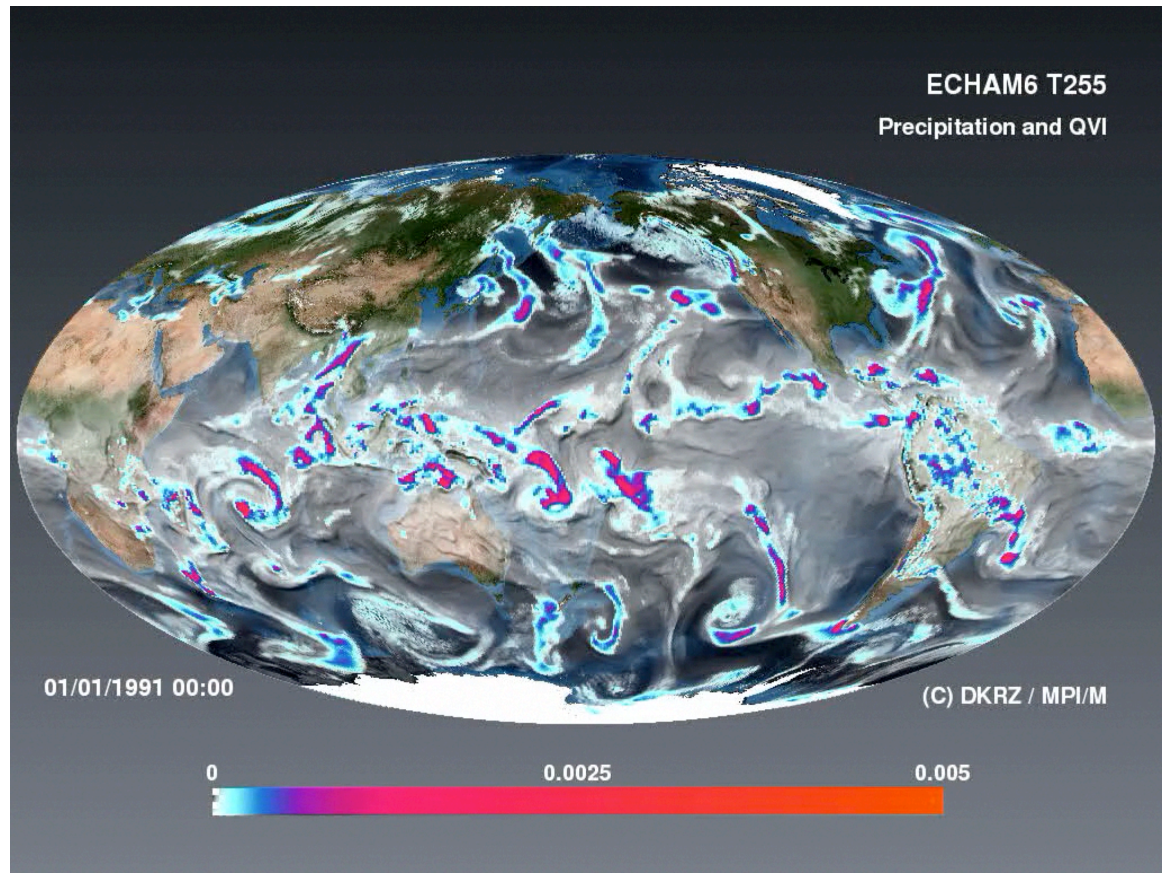
Rain rate (mm day^{-1})

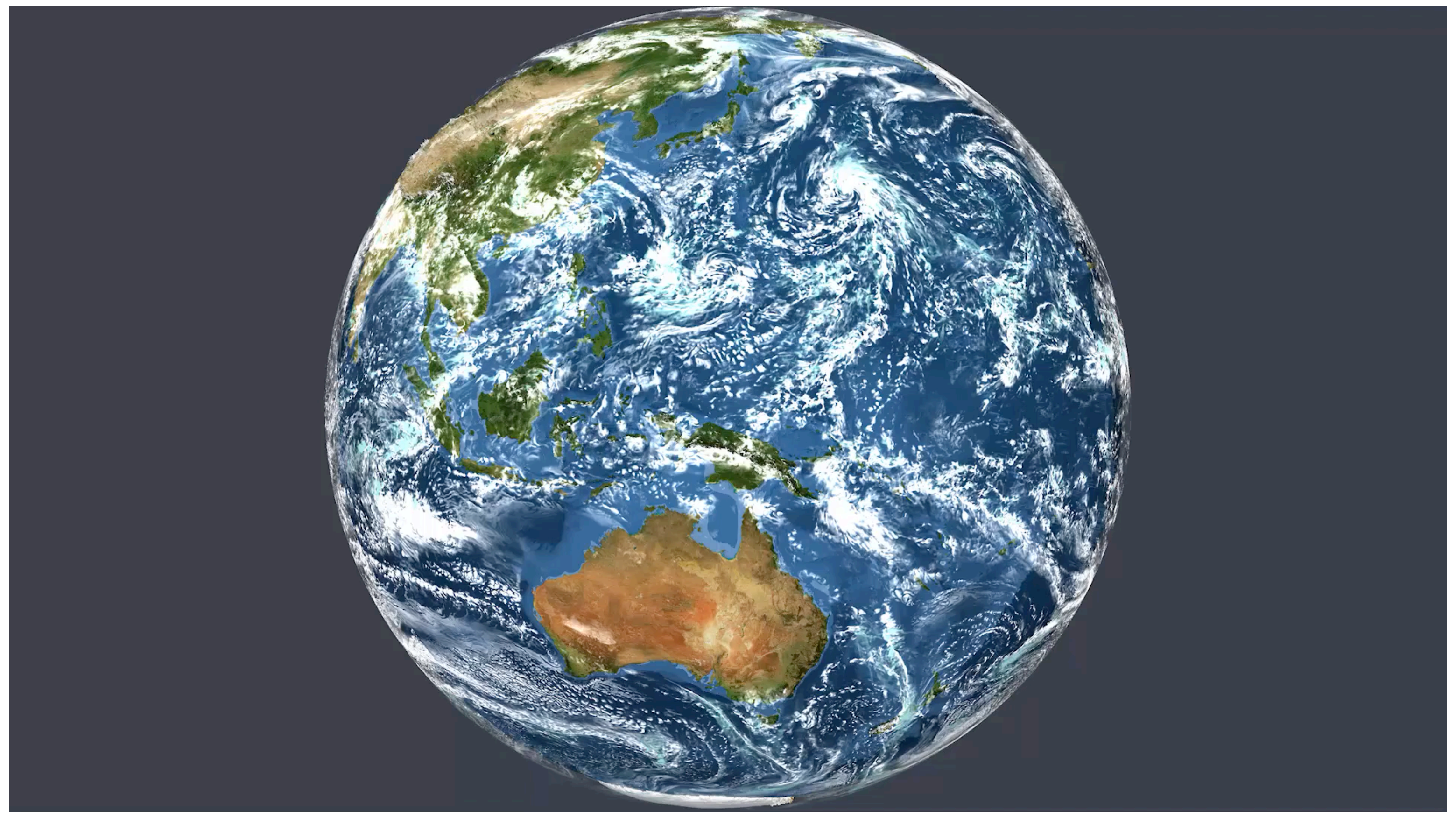


OLR (W m^{-2})



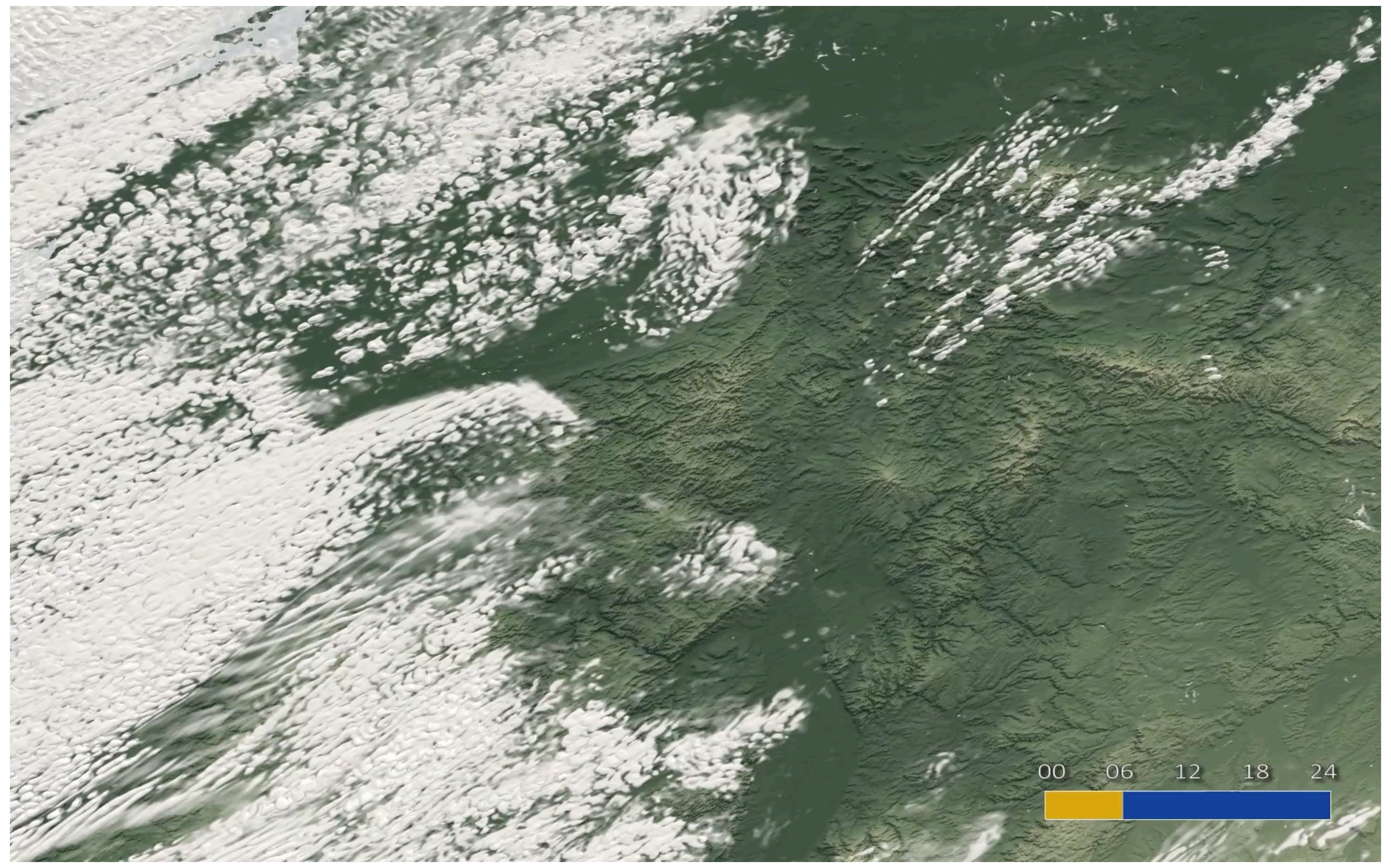
Precipitation & Water Vapor





Global Storm Resolving

SR-ESMs



Toward Global LES

Why did we have to wait so long?

$H/V \sim 2^7$.

In four dimensions, a 2^7 refinement in scale implies 2^{28} more computation.

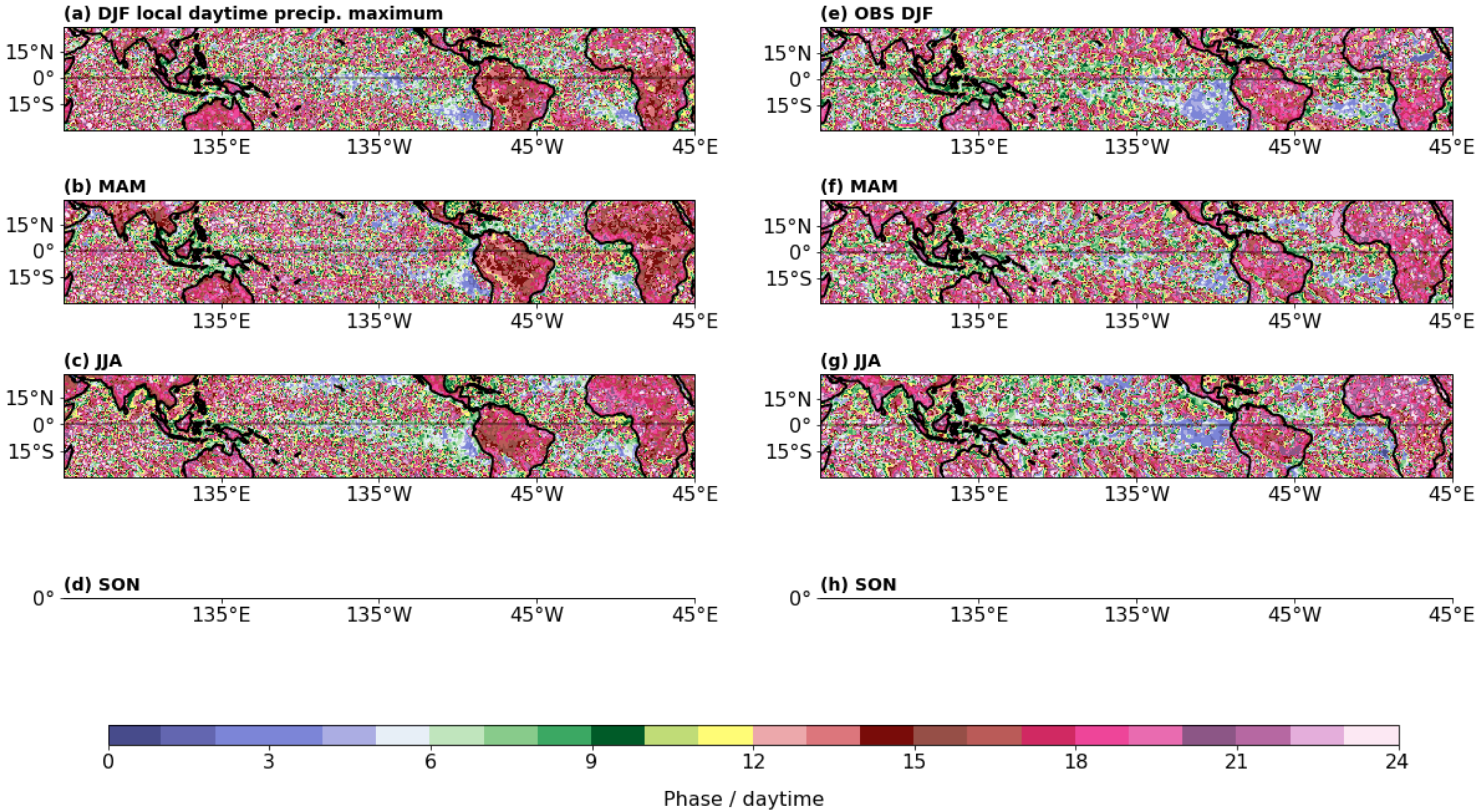
Moore's law dictates a doubling every 1.5 years…. 42 years

Remarks

- We are seeing rapid advances in our simulation capacity; advances that gives one the feeling of a breakthrough.
- This has given a birth to a new type of model, global storm-resolving models
- GSRM simulations of the atmosphere are becoming common place, ECMWF recently simulated a year, globally at 1km.
- A number of groups are beginning to explore coupled storm-resolving simulations — prototype SR-ESMs — multi-annual km scale coupled simulations are possible now.
- At my next seminar (in four years) I will present multi-decadal SR-ESM simulations performed on a new generation of computers now coming on line, i.e., LUMI, JUWELS-Booster.

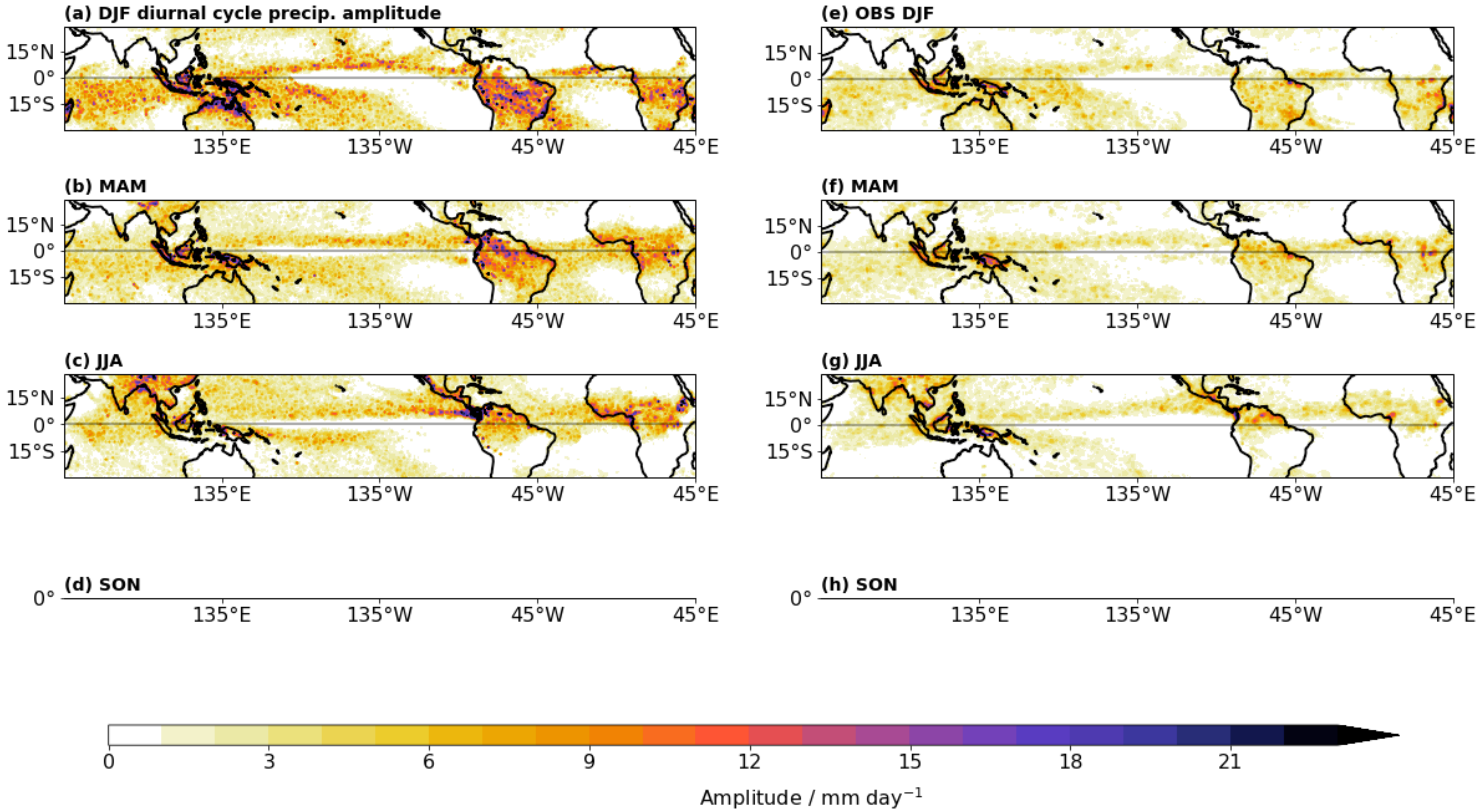
Where does this get us?

What does it get us?



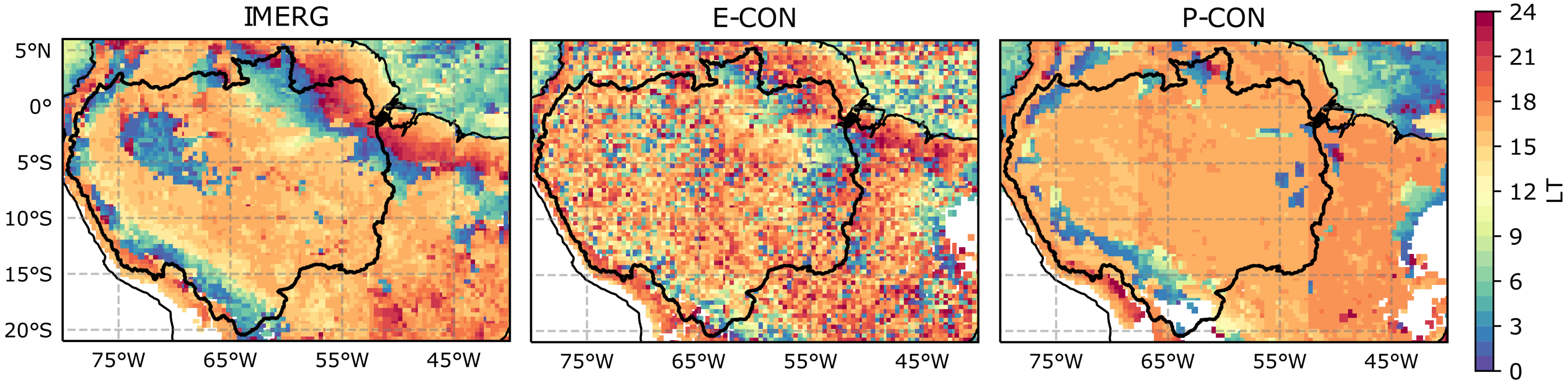
Analysis By C. Wengel, manuscript in preparation

What does it get us?

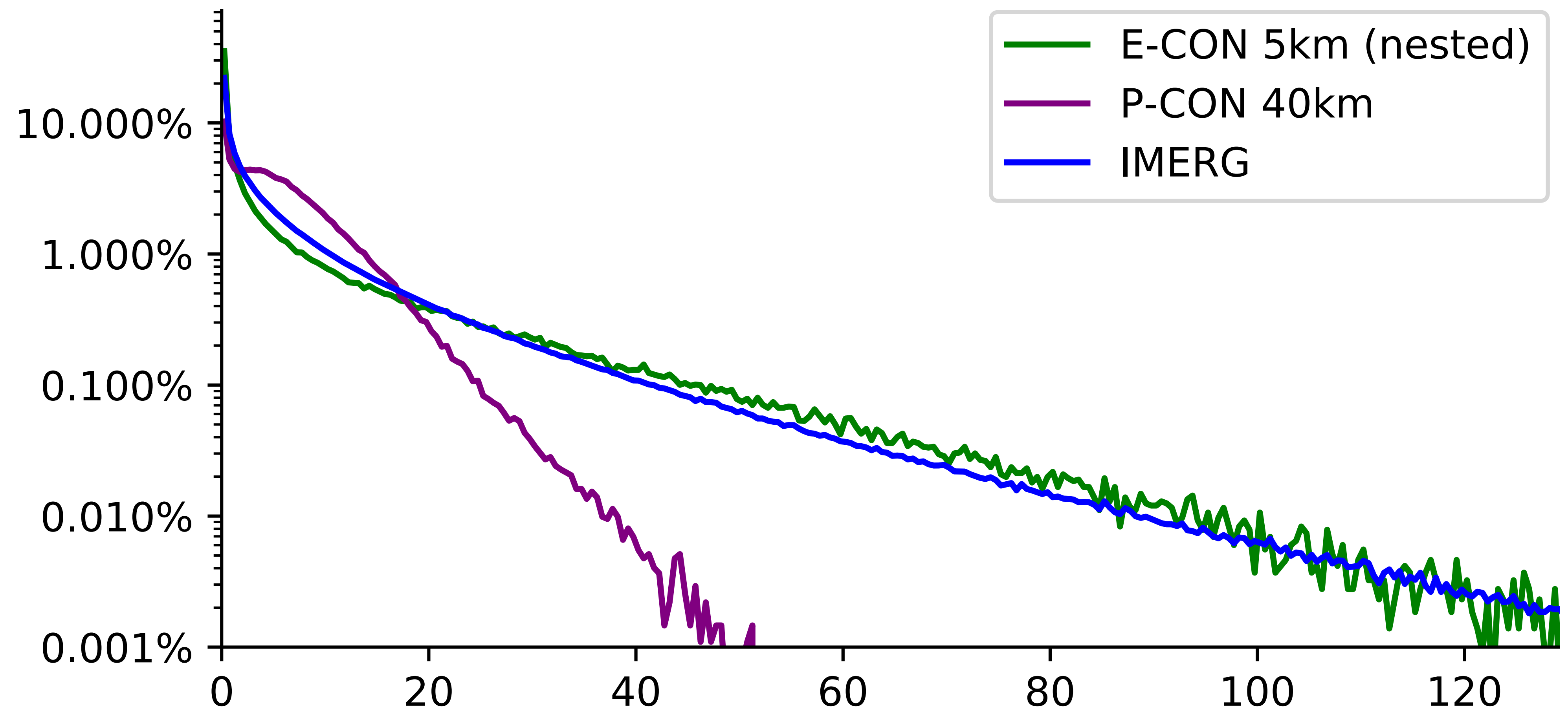


Analysis By C. Wengel, manuscript in preparation

Zoom over the Amazon



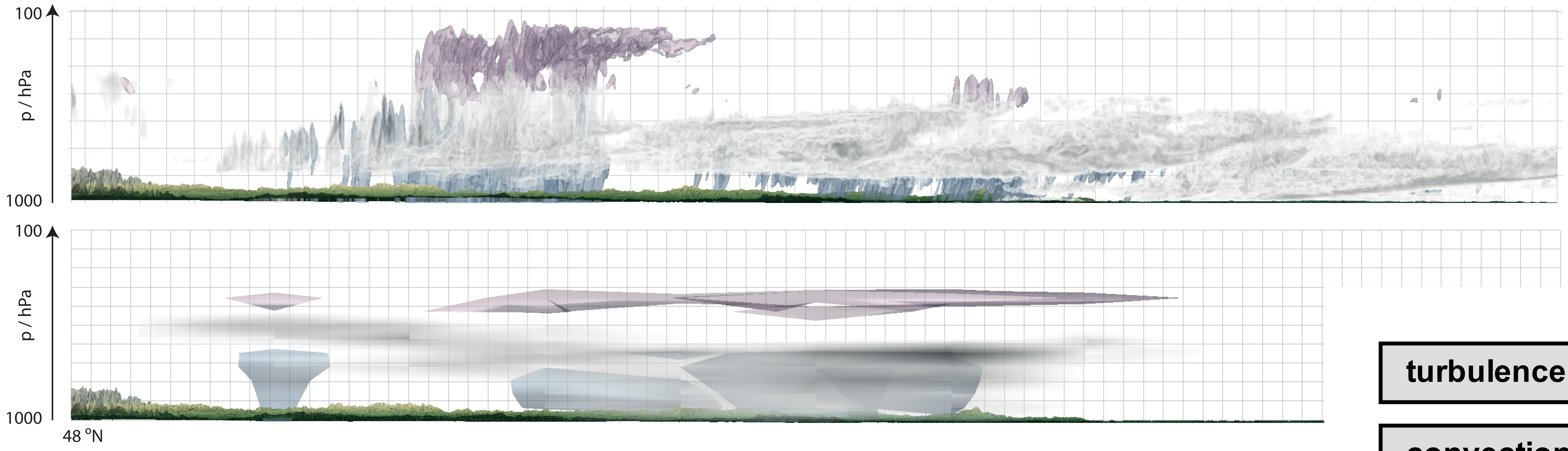
… explicit convection captures the temporal and intensity distribution of precipitation, transforming its interaction with the land surface.

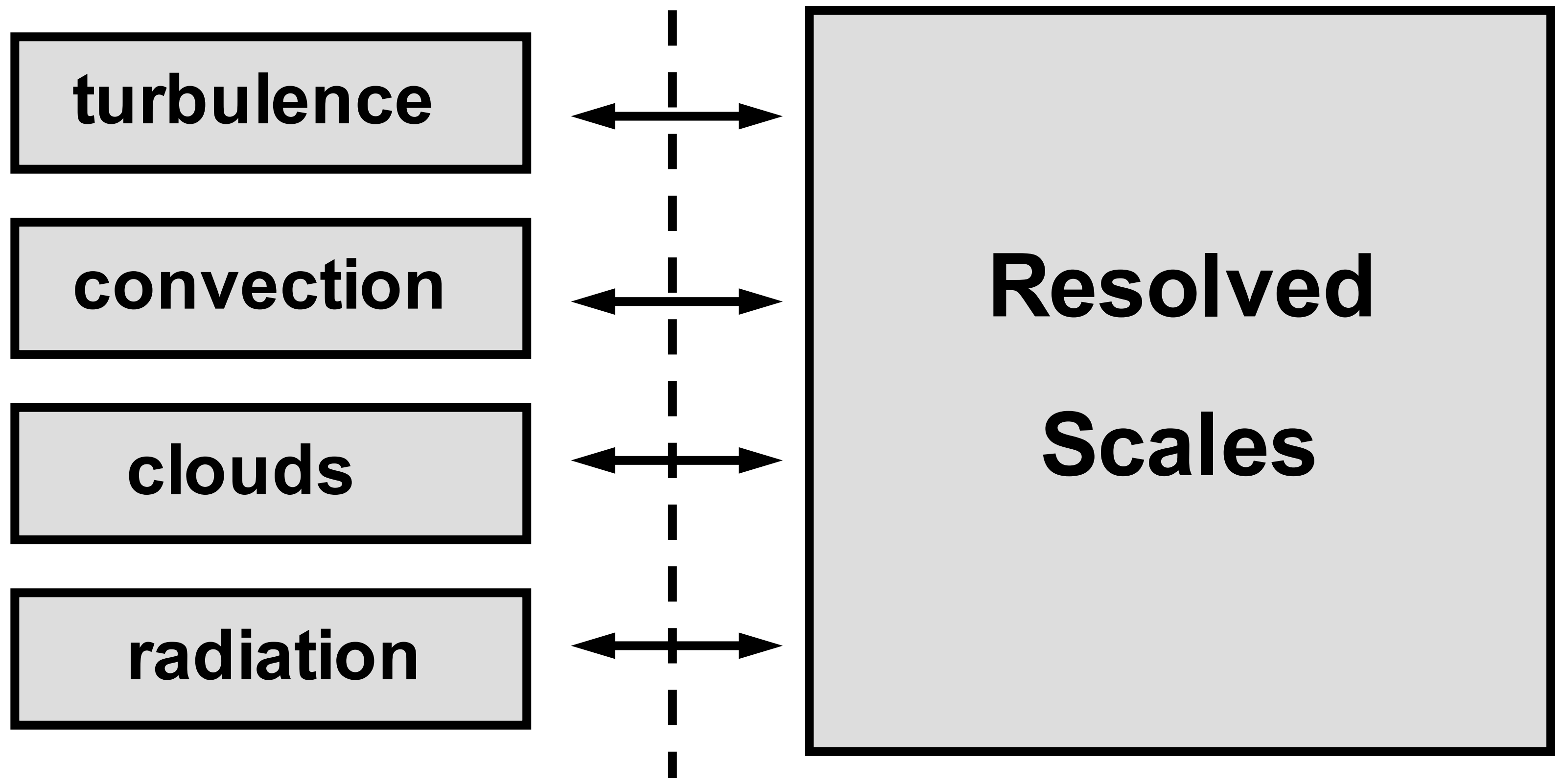


Laura Paccini (in preparation, 2021)

Changing how we work

SR-ESMs define new classes of problems

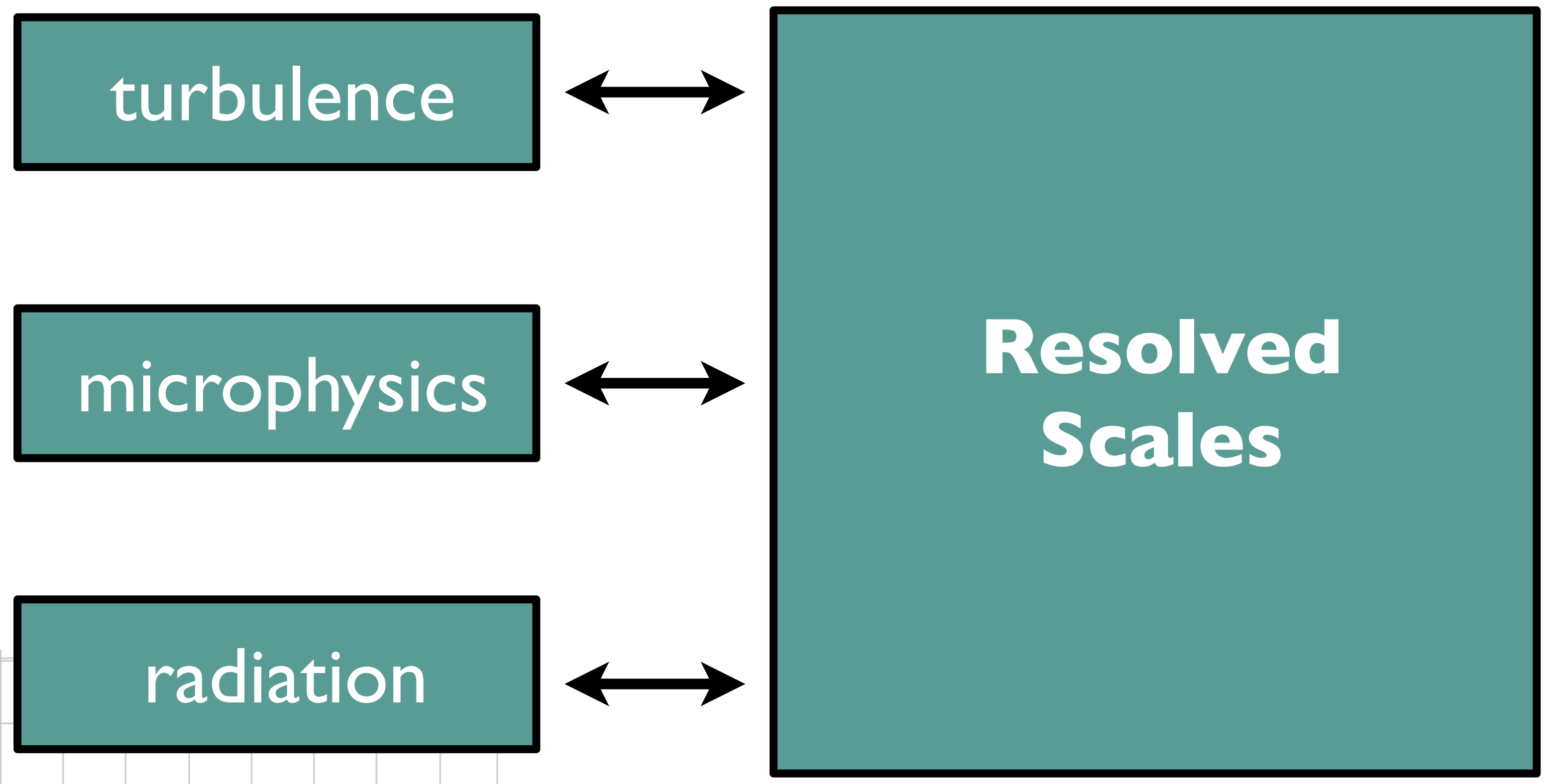


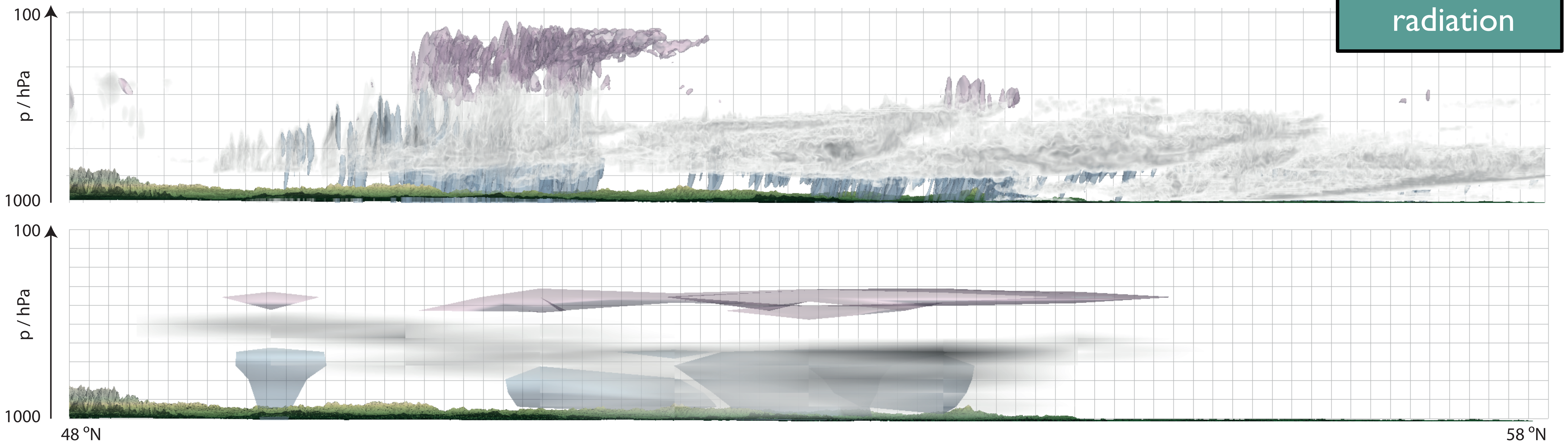


… highly parameterized models create unphysical distortions.

Stevens et al., *J. Meteorol. Soc. Japan,* (2020); see also SuperParameterization

SR-ESMs define new classes of problems

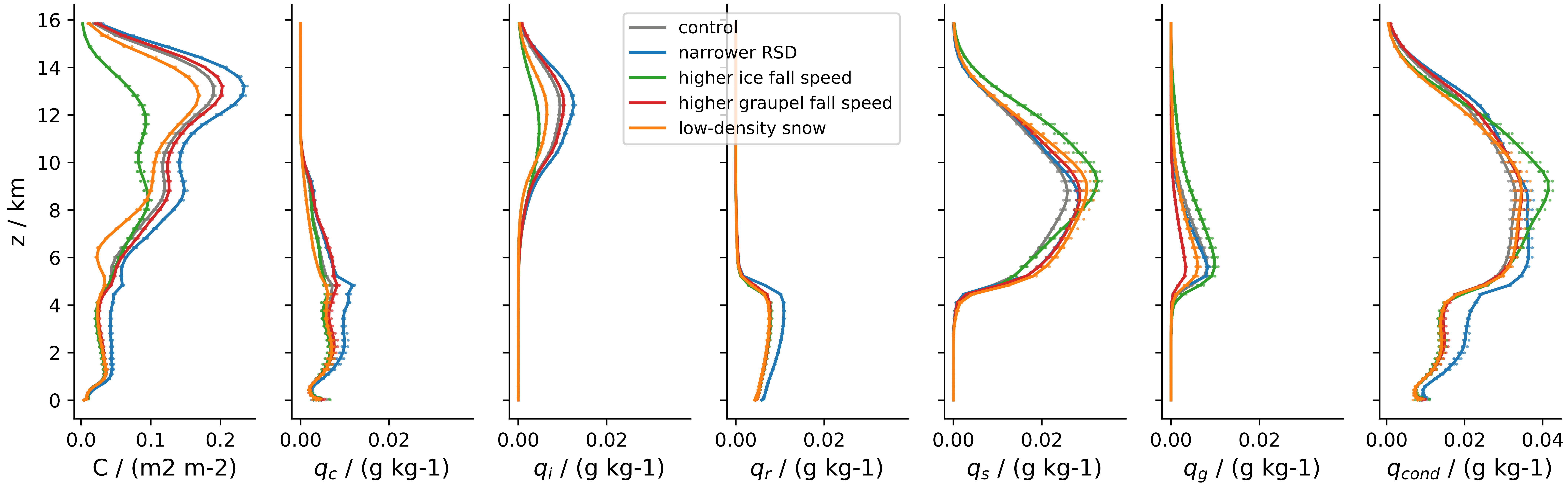




… SR-ESMs pose well founded parameterization problems, and make the link between small scale atmospheric processes, and the climate tractable.

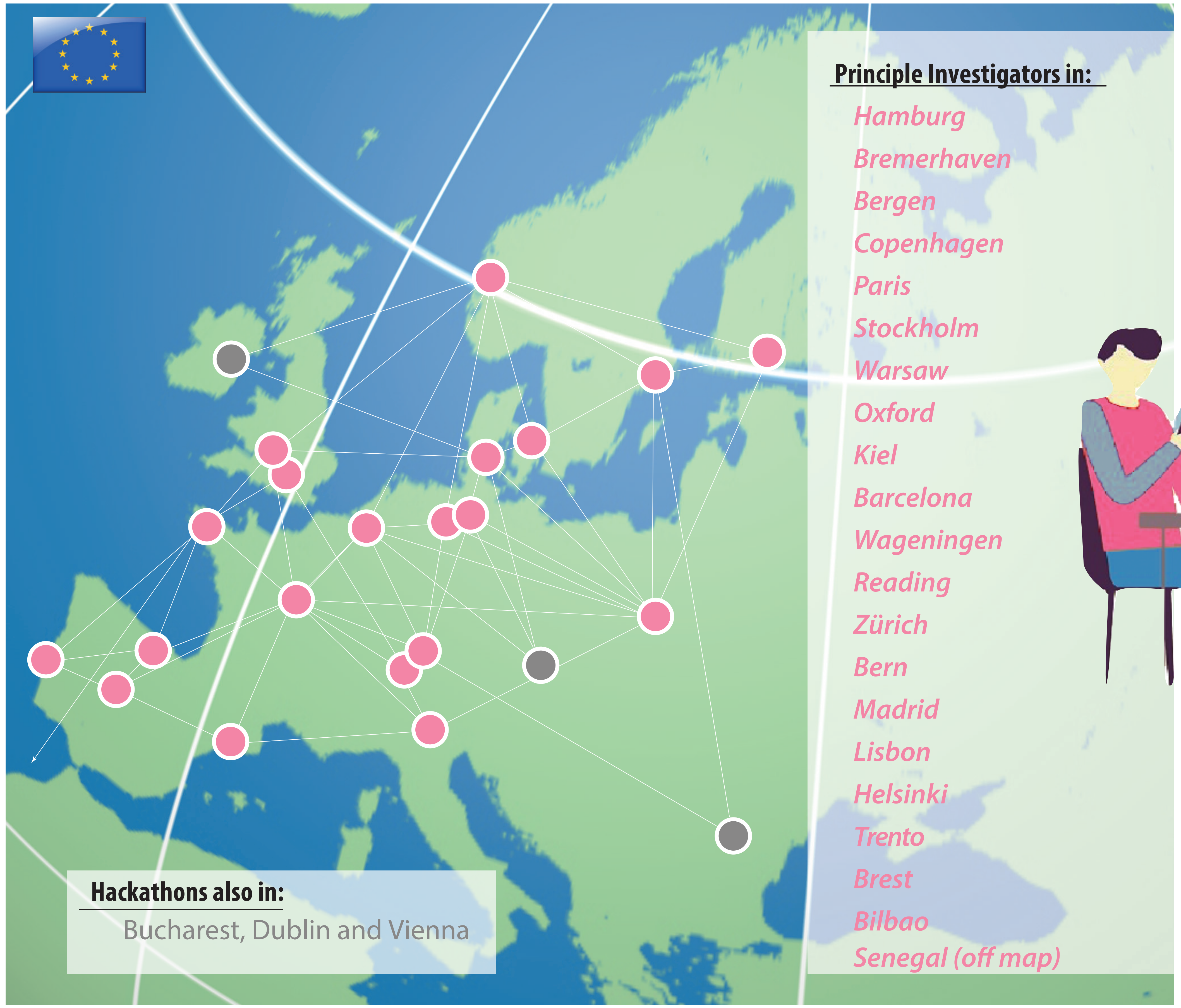
Stevens et al., *J. Meteorol. Soc. Japan,* (2020); see also SuperParameterization

Cloud microphysical effects on climate



AK Naumann, in preparation (2021)

SR-ESMs change how work with each other and with machines



… because we no longer need to work at the machines, and and because SR-ESMs better separate concerns, our efforts become more scalable. This should open opportunities for smaller groups.

SR-ESMs don't solve every problem

- Sensitivity to microphysics, and turbulent mixing.
- First coupled simulations show persistence of overly pronounced cold tongue.
- Low cloud fields are distorted, and in some respect simulations are too cloudy.
- Emergence of un-observed phenomena, for instance in the tropical oceans.

… this makes them interesting.

SR-ESMs work in terms of observables

- The scales resolved are commensurate with scales we observe.
- The scales resolved are commensurate with the scales of impacts.

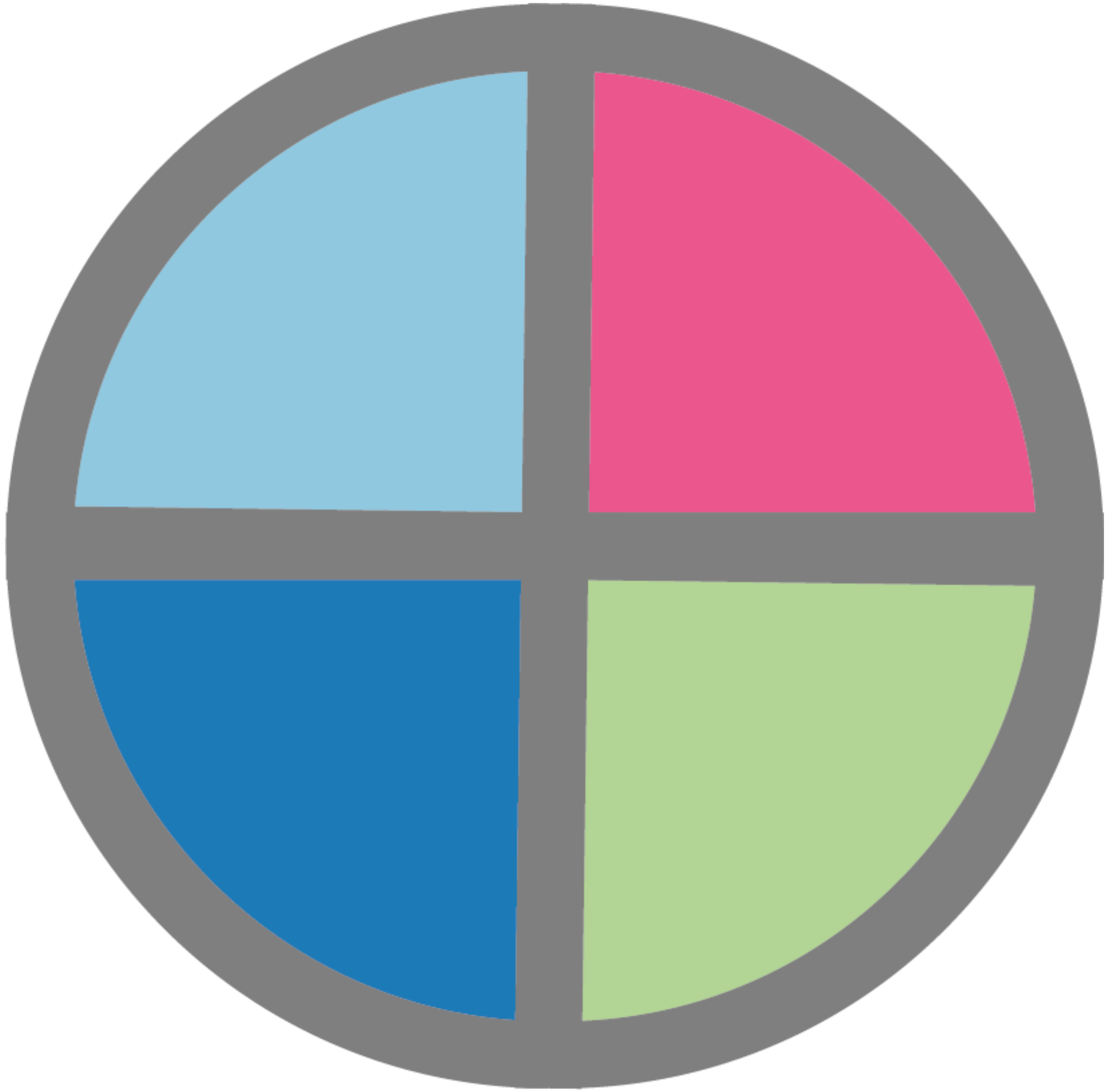
… this makes them effective.

Conclusions

- SR-ESMs are a new type of climate model.
- Their emergence is expanding our scientific frontiers and changing how we work.
- SR-ESMs provide the foundation for planetary scale information systems (Digital Twins).
- A number of very exciting new initiatives are developing that endeavor to understand and exploit their capabilities.

Bauer et al., *N. Climate Change* (2021)

One of these Projects is called NextGEMS



And the University of Warsaw is one of its main partners