Framework for quantifying parameterization behavior across scales

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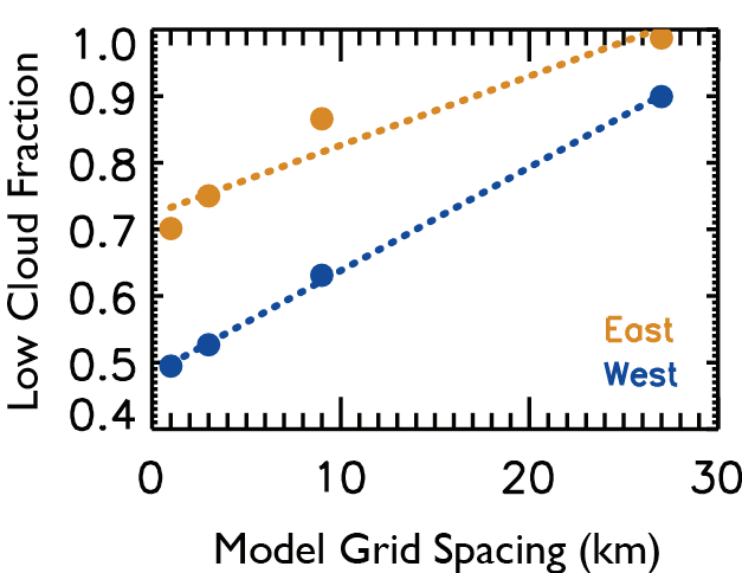
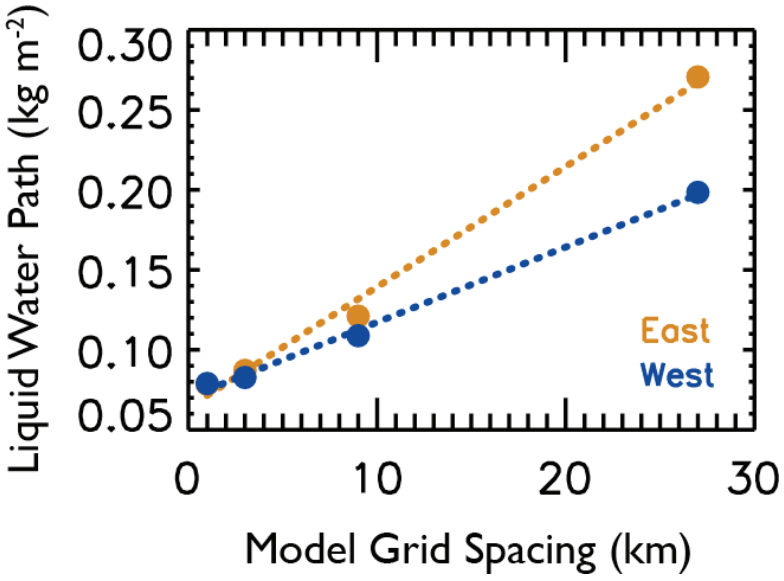
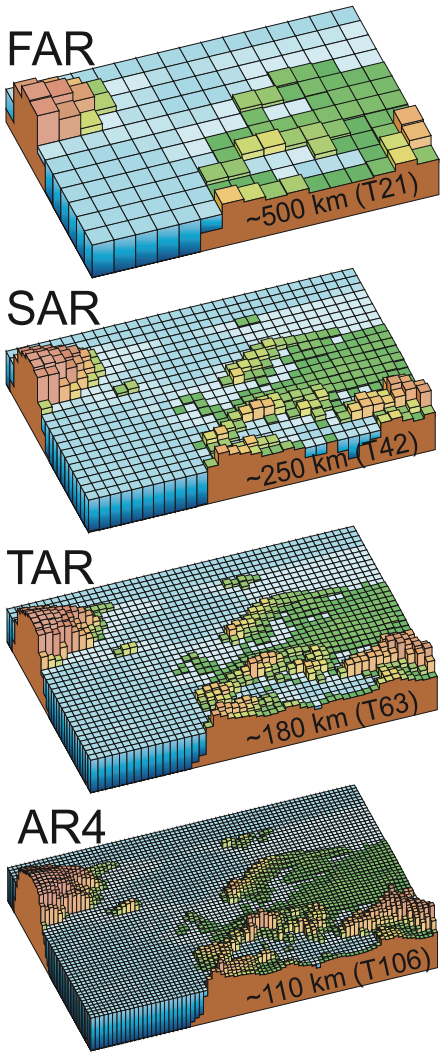
Lack of convergence

- A numerical model is said to have "converged" if it gives the same answer using a finer grid spacing as it does at a given coarser spacing.
- Example of grid spacing dependence for marine stratocumulus during VOCALS using WRF:

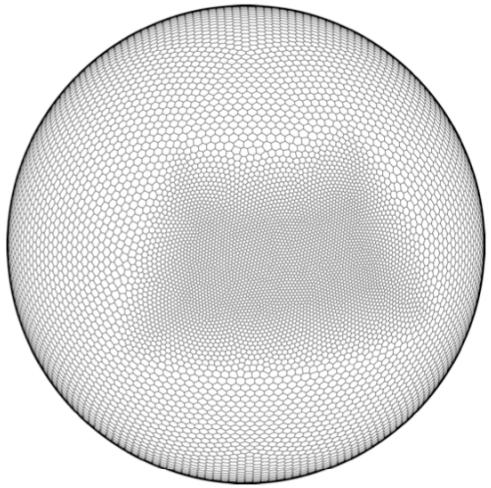


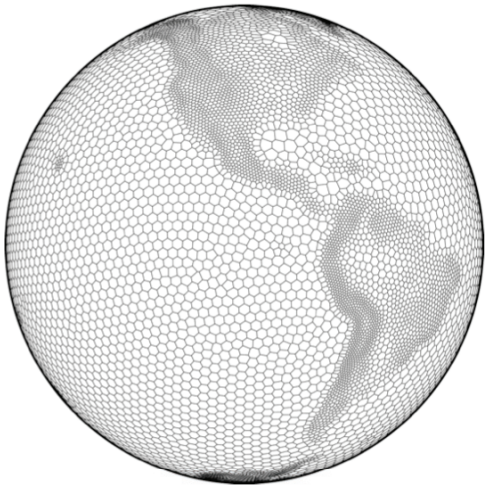


Radical change in next generation models



- Designed with sub-10 km grid spacing in mind
- Proliferation of unstructured grids
- Include options for variables resolution grids





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 Figures from IPCC AR4 & Michael Duda (NCAR)

Looking ahead…

Convergence + New Grids = Road Block

- Multi-resolution grids require scale-aware parameterizations.

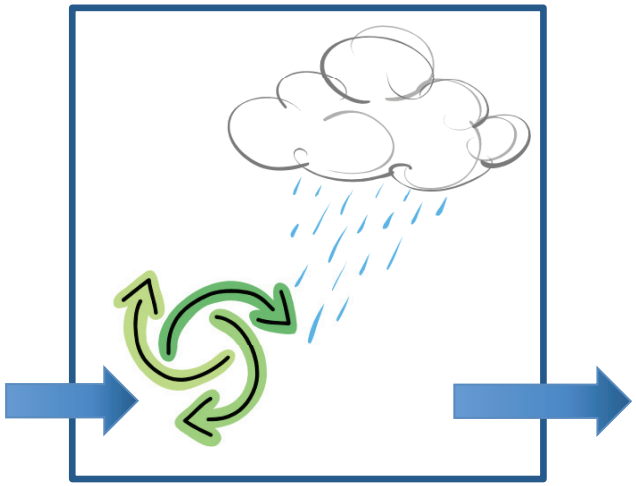
Mathematical basis

- Follows from Jung and Arakawa (JAS, 2004).
- As grid spacing changes, the advective tendency changes in addition to the response of the physics.

$$\frac{\partial \psi}{\partial t} = A_R + P$$

$$A_R = \text{Resolved Advection}$$

$$P = \text{Subgrid Parameterization}$$



- Parameterization includes both physical sources/sinks and subgrid movement, i.e. eddy fluxes and advective tendencies.

Implication for multi-resolution grids

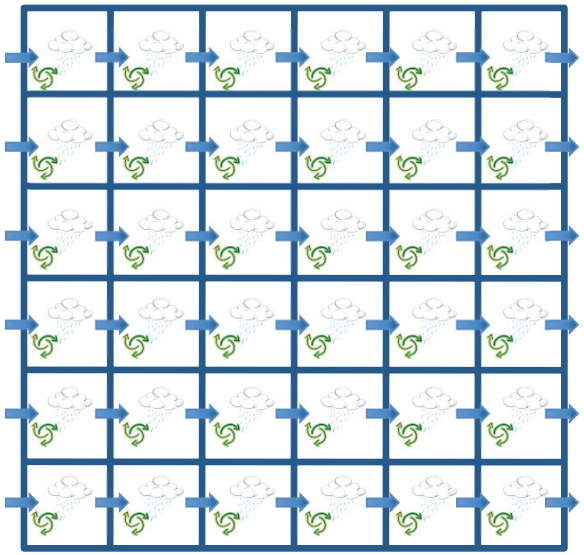
- As grid spacing changes, parameterization must account for…
  - Changing cloud characteristics, e.g. which clouds are resolved
  - AND modified advective tendencies due to eddies that become resolved at higher resolution

$$\frac{\partial \psi}{\partial t} = A_R + A_S + S$$

$$A_R = \text{Resolved Advection}$$

$$A_S = \text{Subgrid Advection}$$

$$S = \text{Source/sink term}$$

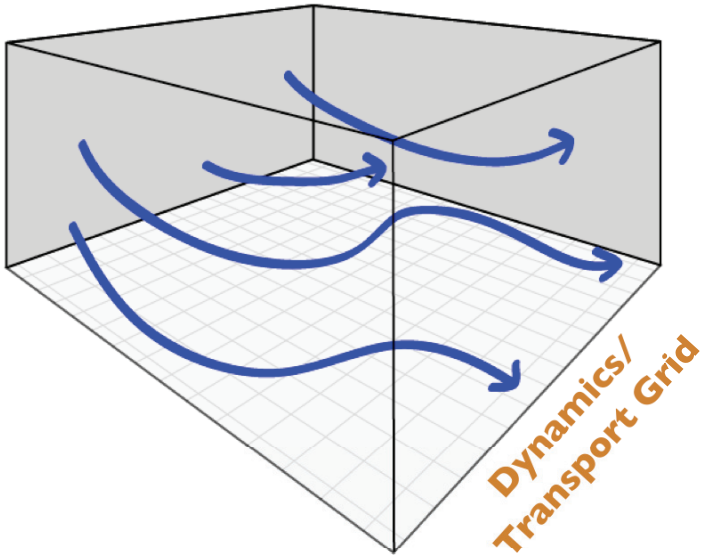


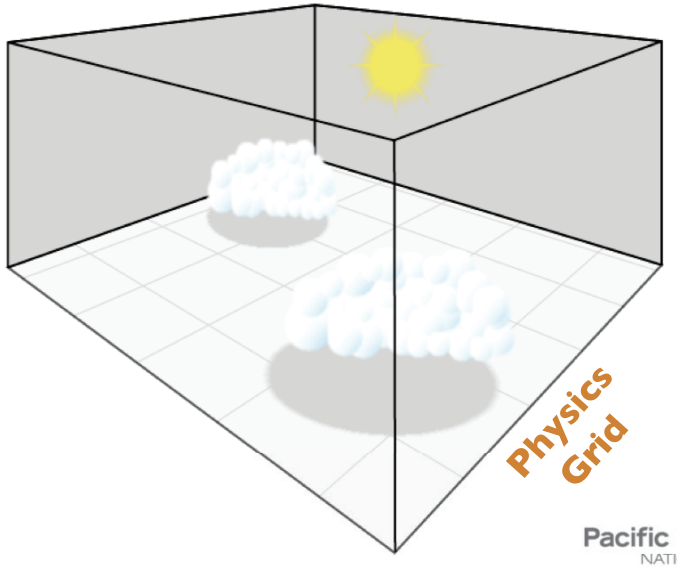
Need a framework for testing scale dependency of parameterizations

- Requirements:
  - Able to isolate physics from dynamics
  - Capable of testing a range of grid spacings from CRM to GCM
  - Easy to compare against extensive observations
  - Ability to quickly implement new parameterizations for testing

Separate Physics and Dynamics Setup (SPADS)

- Built off of Williamson's (1999) dual-resolution model technique, using a regional scale (WRF).
  - Separate the physics and dynamics so that they operate on independent grids.
  - Keep dynamics grid spacing constant and vary physics resolution for selected parameterizations.
  - Physics tendencies used to update state can come from either grid.

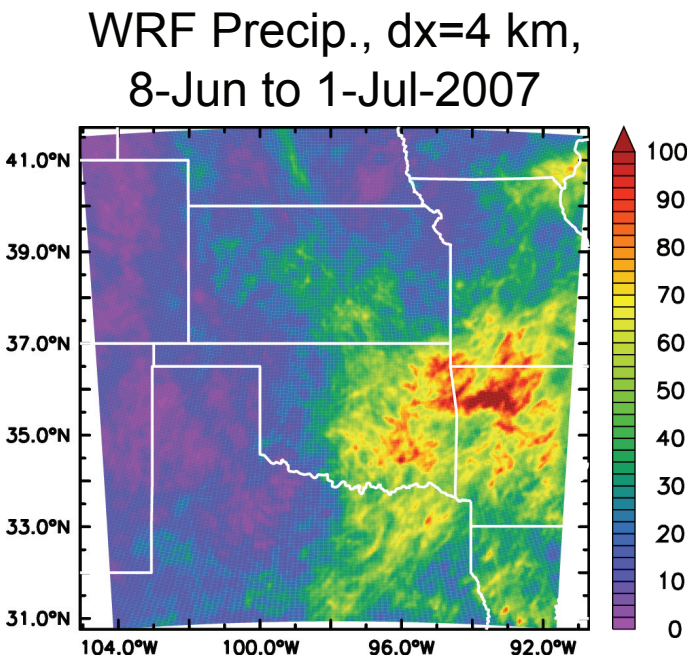




Advantages of SPADS enabled WRF

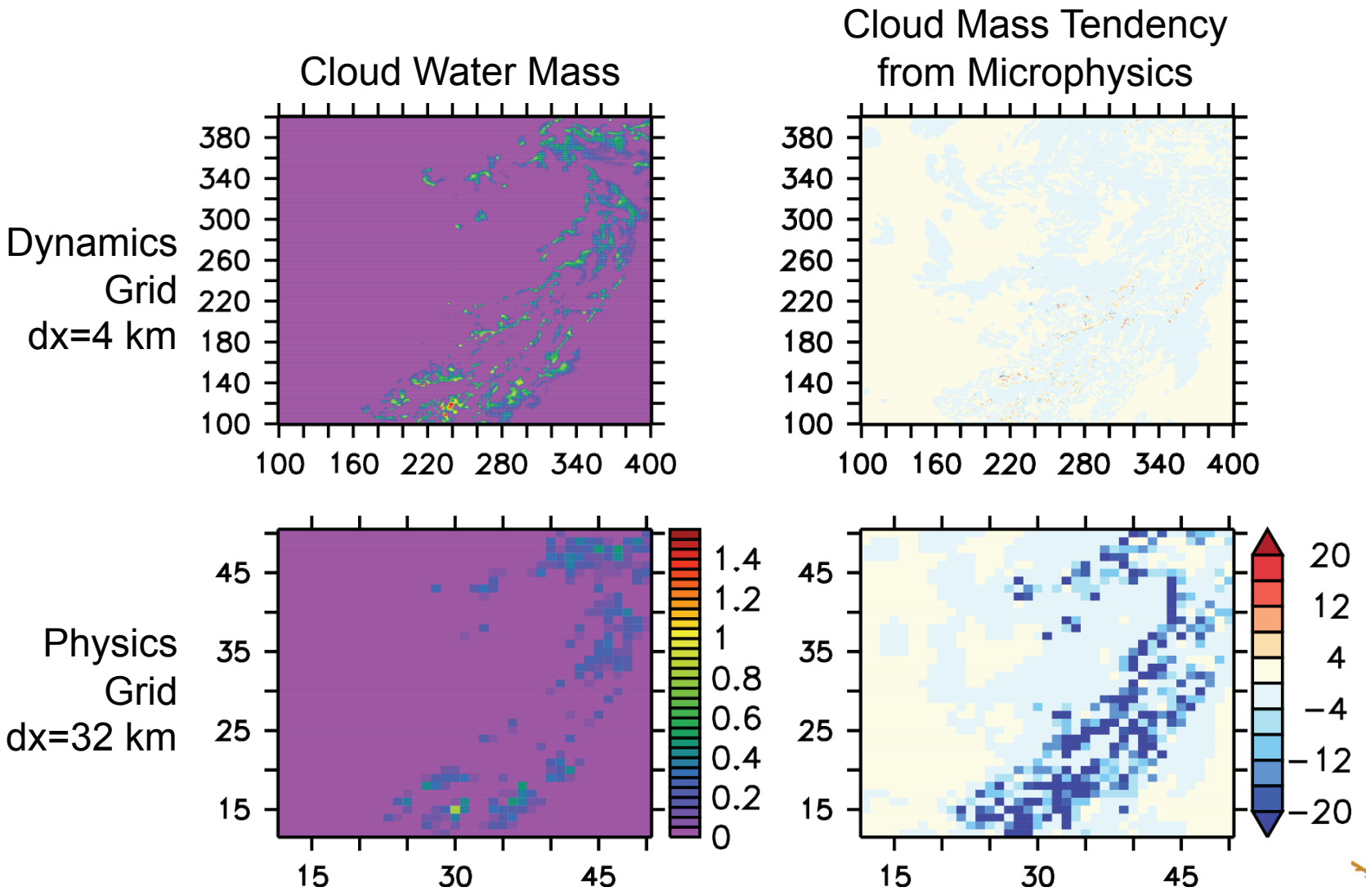
- Separate grids
  - Avoids issue of everything changing at once when changing grid spacing, as happens with traditional models.
- Regional setup much more affordable
  - Able to use "next generation" resolution today
  - Able to easily target data rich locations at high resolution
  - Able to run multi-season to multi-year simulations
- Ease of coding
  - WRF parameterization suite is modular by design
  - Easy to use infrastructure for communication and disk I/O

Preliminary results



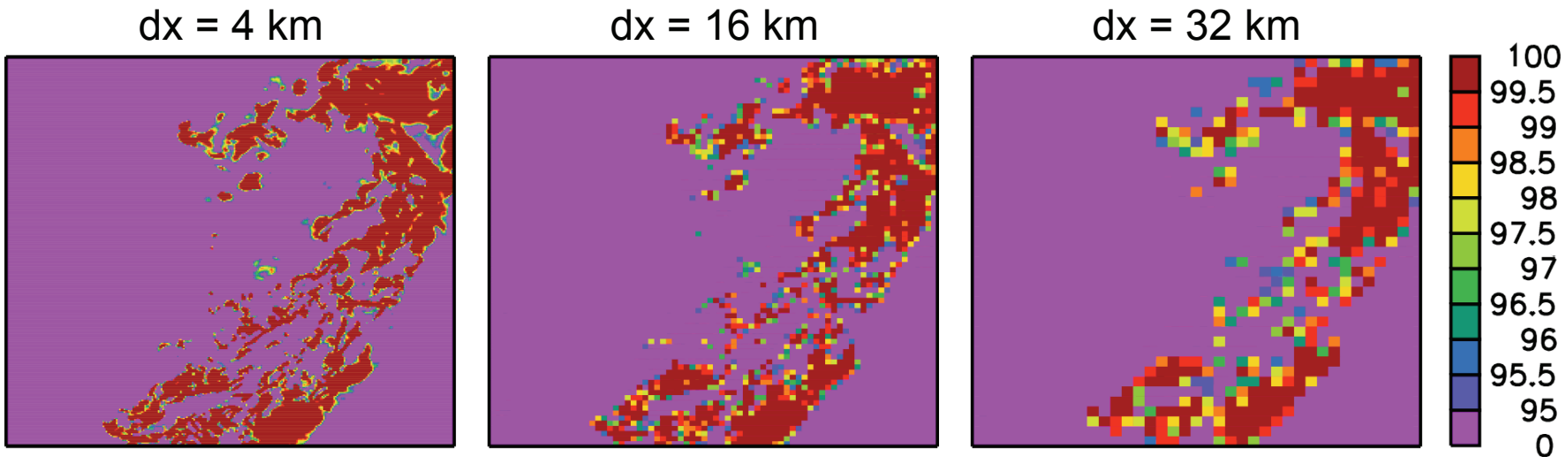
- First look, subject to revision…
- Study designed to look at behavior of cloud parameterization in the "gray zone"
- SPADS configuration
  - Dynamics grid: dx=4 km
  - Physics grid used for updating state: dx=4 km
  - Additional cloud physics tendencies for dx=4, 16, 24, & 32 km
- Using CHAPS field campaign period, June 2007, over DOE SGP site in Oklahoma

Scale induced cloud imbalance



Instantaneous output at 27-Jun-2007 12 UTC, model level 15 (~600 hPa)

Relative humidity nonlinearities

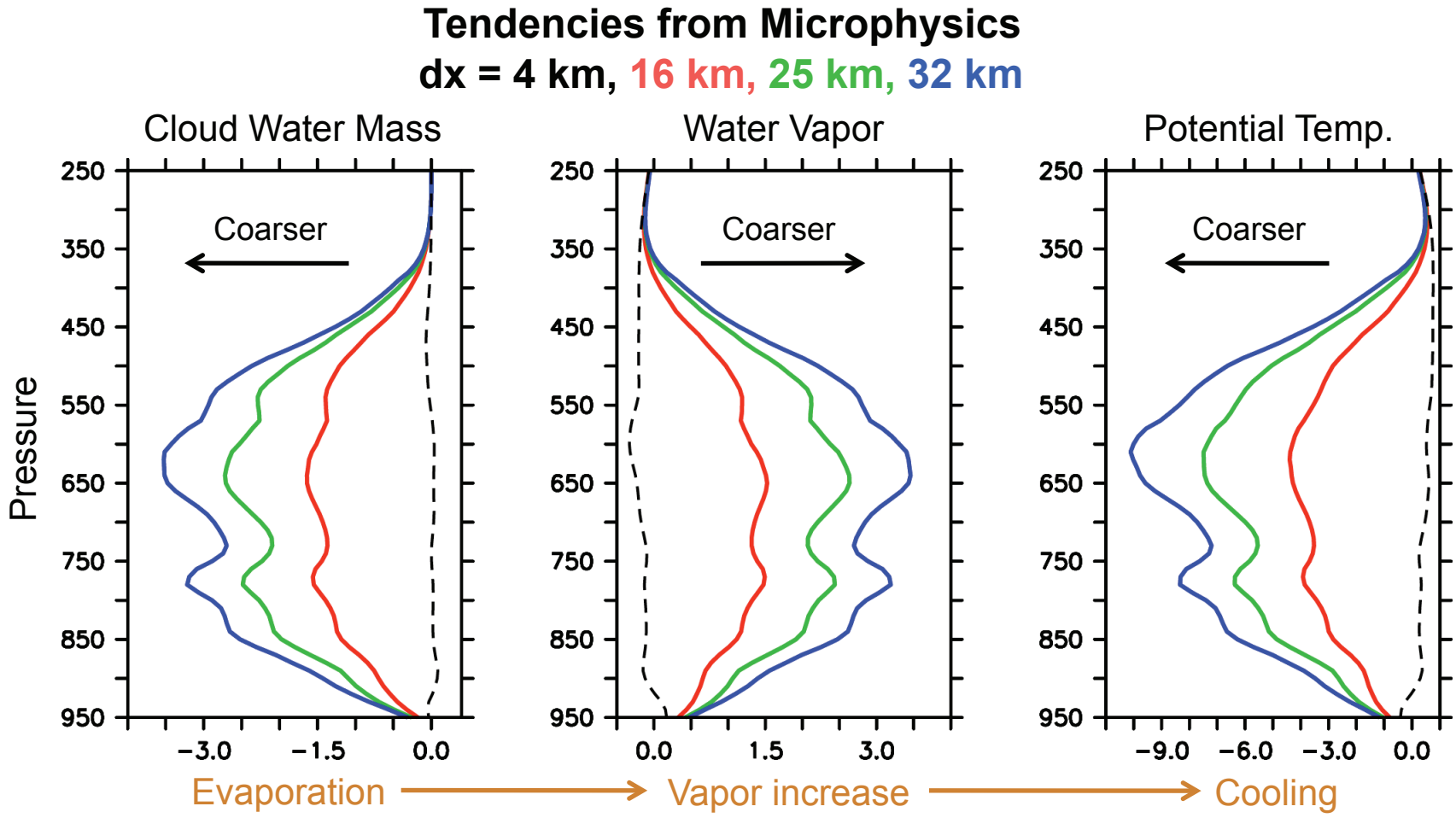


- RH dependencies (temperature, pressure, and water vapor) get smoothed onto coarser grid.
- Nonlinearities in RH calculation, combined with smoothing, result in fewer cloud-friendly grid cells.
- Drop in RH is particularly problematic around cloud filaments.

Instantaneous output at 27-Jun-2007 12 UTC, model level 15 (~600 hPa)

Scale dependency and cloud state

- Scale dependency of microphysics would result in very different cloud state if allowed to feed back to model state.



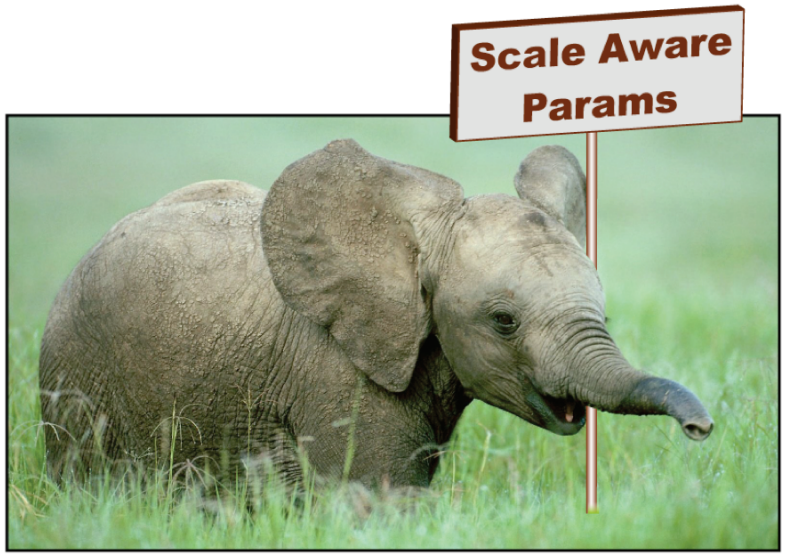
Instantaneous output at 27-Jun-2007 12 UTC

Take home message

- The SPADS enabled WRF is a powerful tool for evaluating scale dependency across a range of scales, conditions, locations, etc.
- The community needs more physics developers addressing scale dependency to enable use of multi-resolution GCMs.
- Current climate model parameterizations are clearly scale dependent—and to a very large degree.

Acknowledgements

- I'm looking for a post-doc interested in this project. Contact William.Gustafson@pnnl.gov for details.



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