Cloud Resolving and General Circulation Model Simulations of an Idealized Walker Circulation

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Background

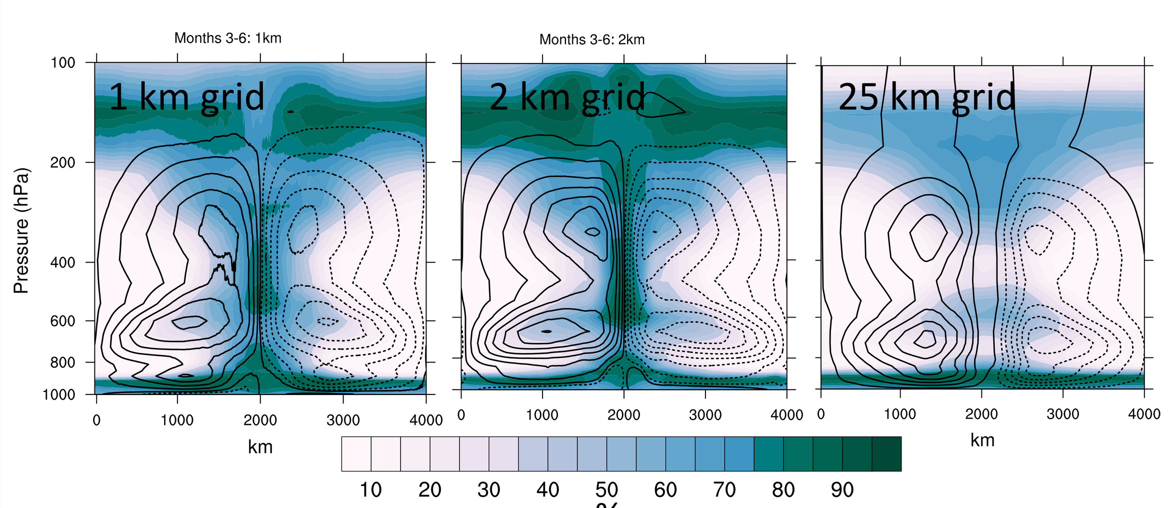
The overturning circulation in the tropical pacific known as the Walker Circulation provides an example of deep convection, shallow convection, and low-level clouds all coupled to the large-scale circulation.

- Computing capabilities allow for higher resolution global models and cloud resolving models on large-domains. What is the best way to transition between these two types of models?

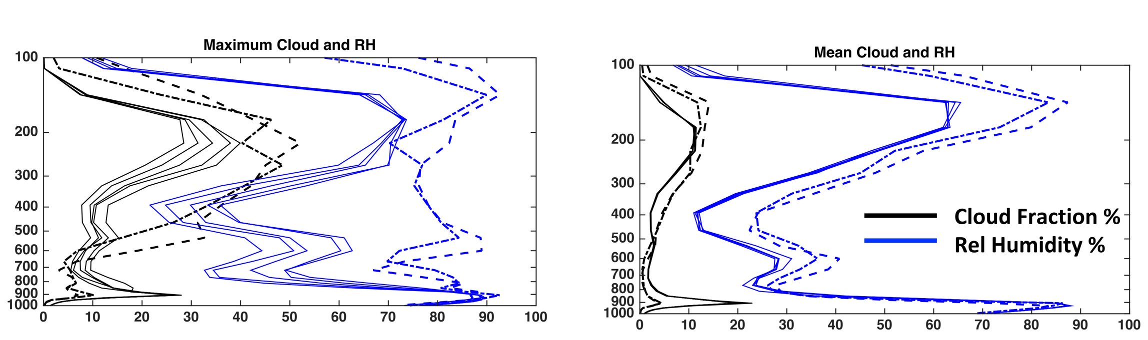
Motivation

- Is there a logical and consistent way to transition from a global model to a cloud-resolving model as grid-spacing decreases? Can a model be 'benchmarked' with itself?
- How do simulations of the Walker Circulation compare between a GCM and a CRM? Can this framework help us better represent low-level clouds in a GCM?
- We Naively assume that the FV3/AM4 model can be used as both a GCM and CRM to benchmark the parameterized clouds in AM4.
- Difficulty in simulating and understanding the impact of clouds on climate derives from their dependence on interactions between radiative energy, circulations, and cloud thermodynamics (Silvers et al., 2016).

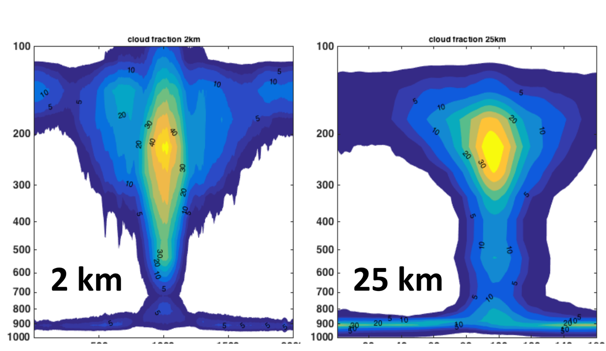
Relative Humidity and Cloud Fraction



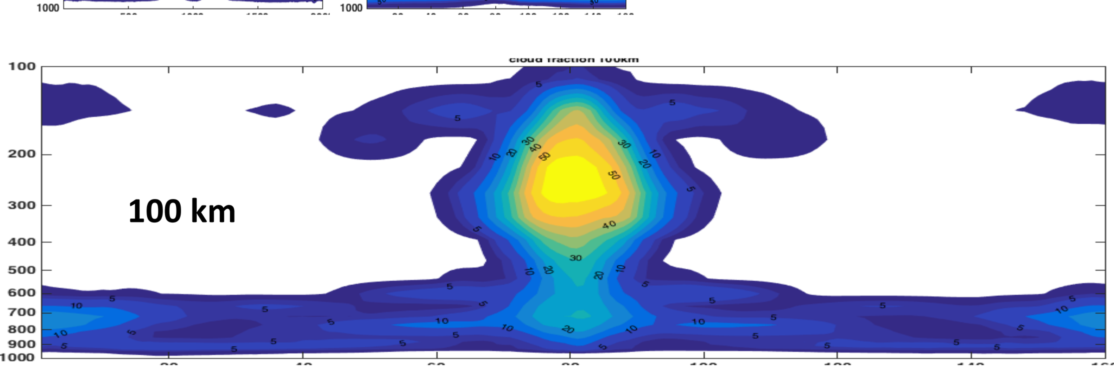
Relative humidity (shading) and mass streamfunction (contours) for 1 km (left), 2km (center), and 25 km (right).



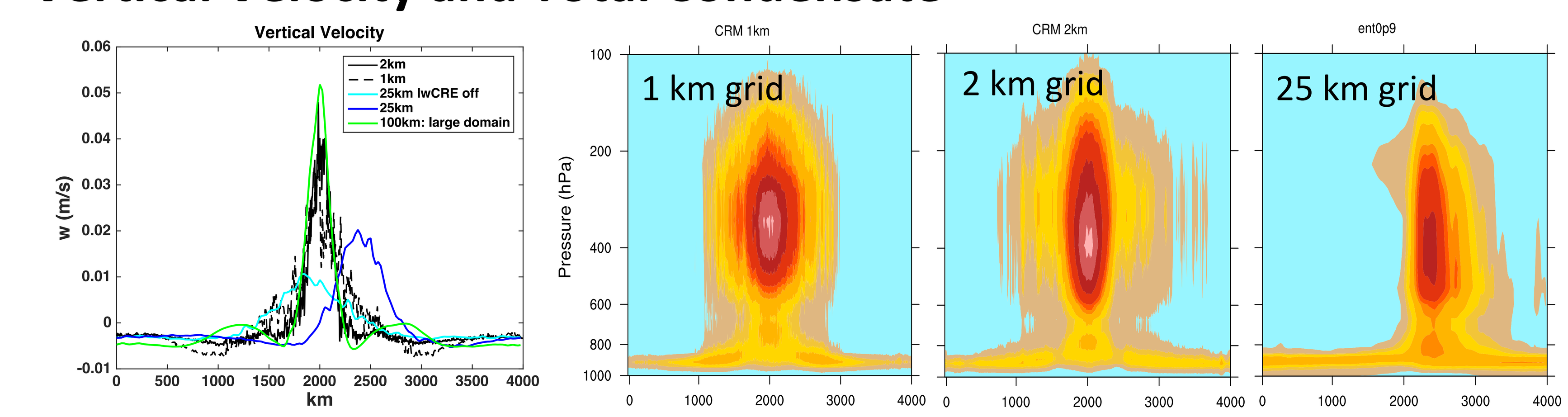
Relative humidity (blue) and cloud fraction (black) for 1 and 2 km experiments (both dashed) and 25 km experiments (solid).



Cloud fraction for 2 km, 25 km and 100 km experiments. Note that the 1 km and 25 km experiments both have 4000 km domains widths while the 100 km experiment has a domain width of 16000 km.



Vertical Velocity and Total Condensate



Above: Meridional mean vertical velocity (m/s) at approximately 500 hPa level. Right: liquid plus ice condensate (g/kg).

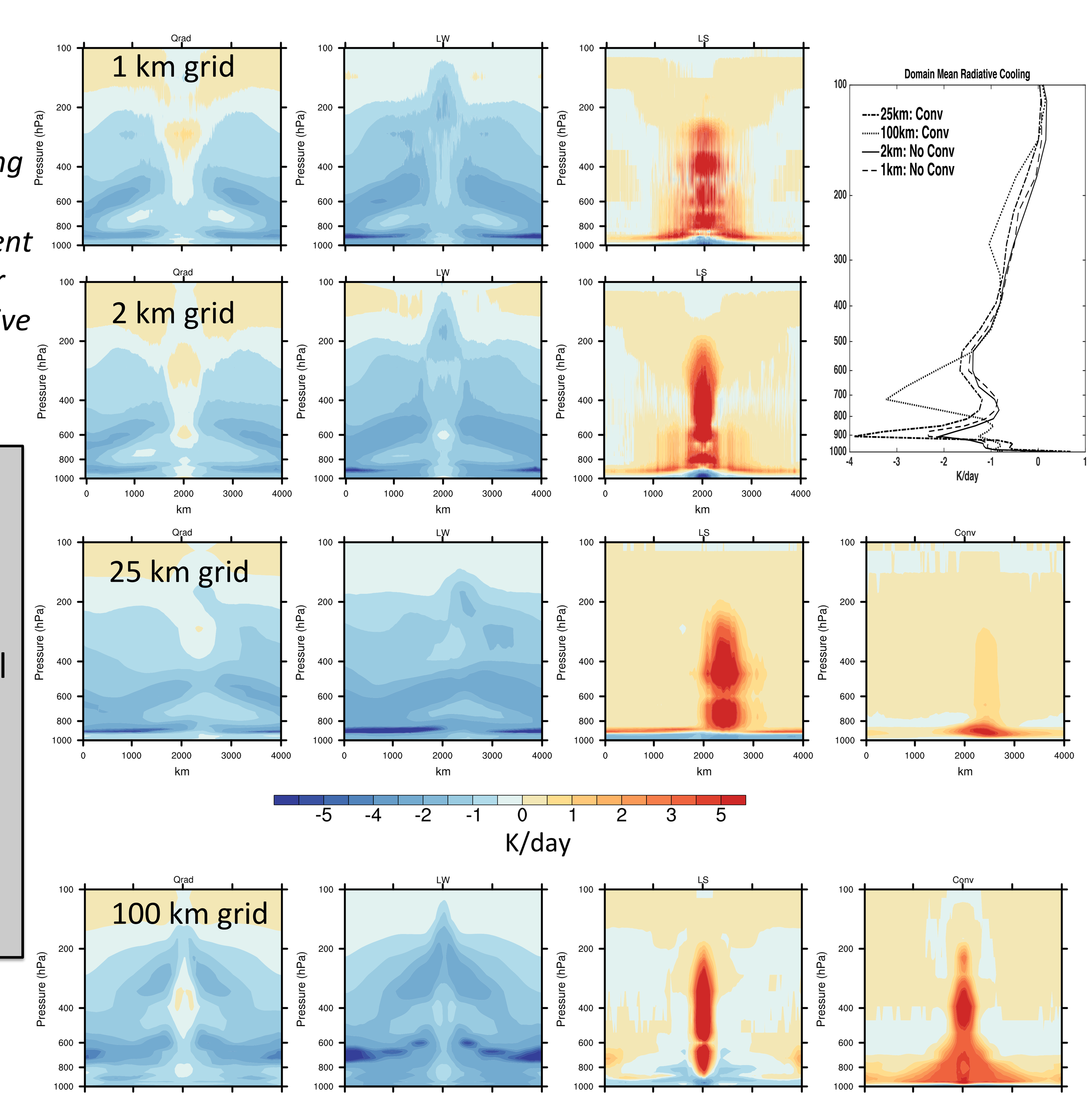
Experimental Configuration

- **Think of RCE with an overturning large-scale circulation** caused by a prescribed 4K warm patch in the center of a doubly periodic domain.
- We use a nonhydrostatic general circulation model to simulate an idealized Walker Circulation with gcm-like grid spacing (25km & 100km; fully parameterized) and cloud-resolving-model-like grid spacing (1km & 2km; no parameterized convection). Model is derived from the AM4.0 physics (Zhao et al., 2018), and the nonhydrostatic FV^3 dynamical core (Harris and Lin, 2013) developed at GFDL.
- All experiments include interactive radiation, the default AM4.0 boundary layer scheme, single-moment microphysics and a large-scale prognostic cloud scheme based on Tiedtke, 1993.
- Convection in experiments with grid-spacing of 1km and 2km is explicit, with no parameterization, the relative humidity threshold for cloud formation is set to 1.

Grid Spacing	# of GP's	Time Step	Domain (km^2)	Convection	Duration
100 km	1280	600 s	800 x 16000	parameterized	5 years
25 km	1280	600 s	200 x 4000	parameterized	5 years
25 km	1280	20 s	200 x 4000	parameterized	1 year
2 km	200,000	20 s	200 x 4000	explicit	6 months
2 km	100,000	20 s	100 x 4000	explicit	6 months
2 km	100,000	5 s	100 x 4000	explicit	6 months
1 km	40,000	5 s	10 x 4000	explicit	6 months

Radiative and Convective Heating Rates

Net radiative heating (left), longwave radiative cooling (center left), large-scale latent heating (center right), convective latent heating (right).

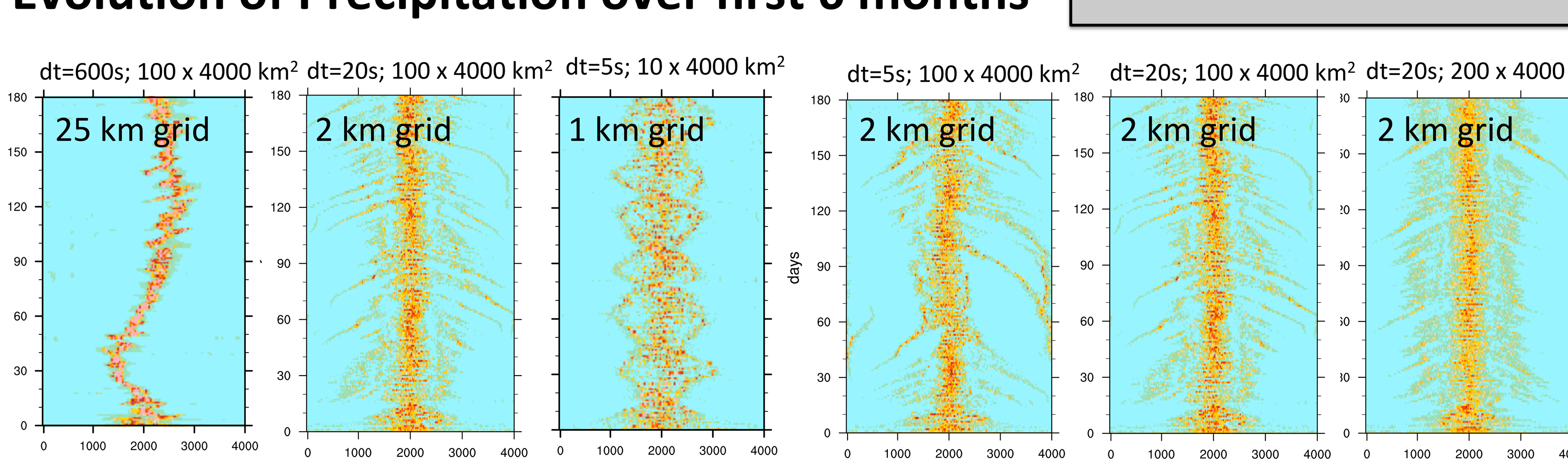


Conclusions

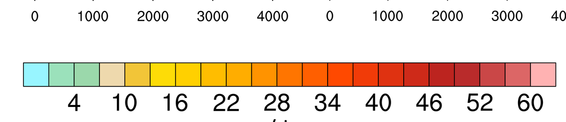
- Why don't the explicit convection models produce more low-level clouds? Details of the large-scale cloud scheme matter.
- High resolution models have stronger vertical velocity over the warm pool, larger amounts of condensate and RH aloft.
- GCM like models have more low-level cloud with strong low-level radiative cooling.

What is the 'right' answer??

Evolution of Precipitation over first 6 months

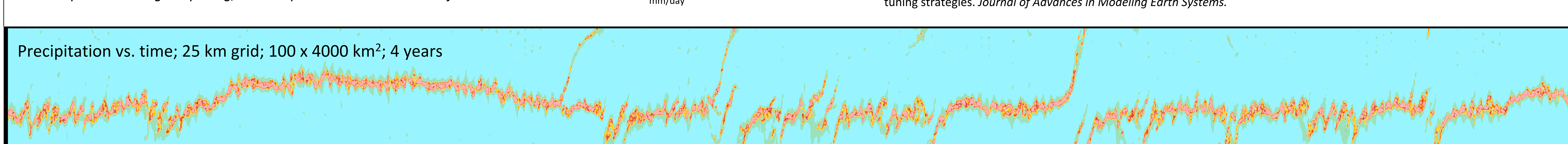


Total precipitation evolution over 6 months, averaged over meridional dimension. Shows dependence on grid-spacing, time-step and meridional width of the domain



References:

- Harris & Lin, 2013: A two-way nested global-regional dynamical core on the cubed-sphere grid. *Monthly Weather Review.*
- Silvers, Stevens, Mauritsen, & Giorgetta, 2016: Radiative convective equilibrium as a framework for studying the interaction between convection and its large-scale environment. *Journal of Advances in Modeling Earth Systems.*
- Tiedtke, 1993: Representation of Clouds in Large-Scale Models. *Monthly Weather Review.*
- Zhao et al. 2018: The GFDL global atmosphere and land model AM4.0/LM4.0: 2. Model description, densitivity studies, and tuning strategies. *Journal of Advances in Modeling Earth Systems.*



Precipitation vs. time; 25 km grid; 100 x 4000 km^2; 4 years