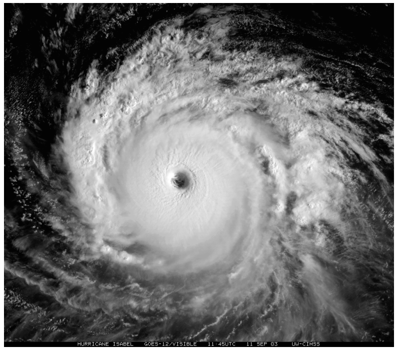
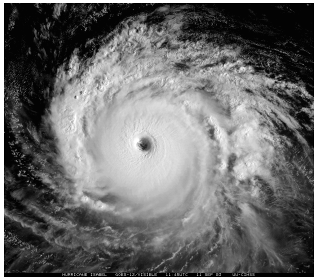


Reduced Complexity Frameworks for Exploring Physics Dynamics Coupling Sensitivities

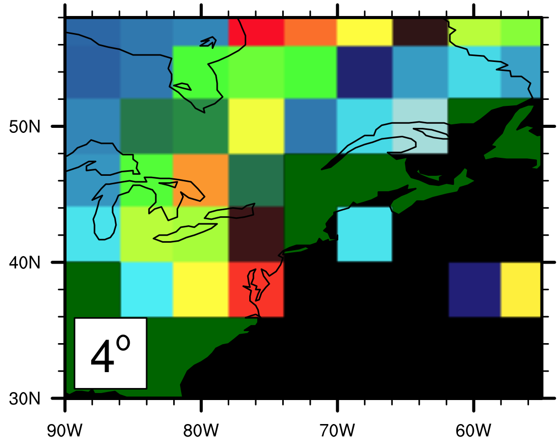
Kevin A. Reed & Adam R. Herrington

School of Marine and Atmospheric Sciences

Stony Brook University, Stony Brook, New York, USA

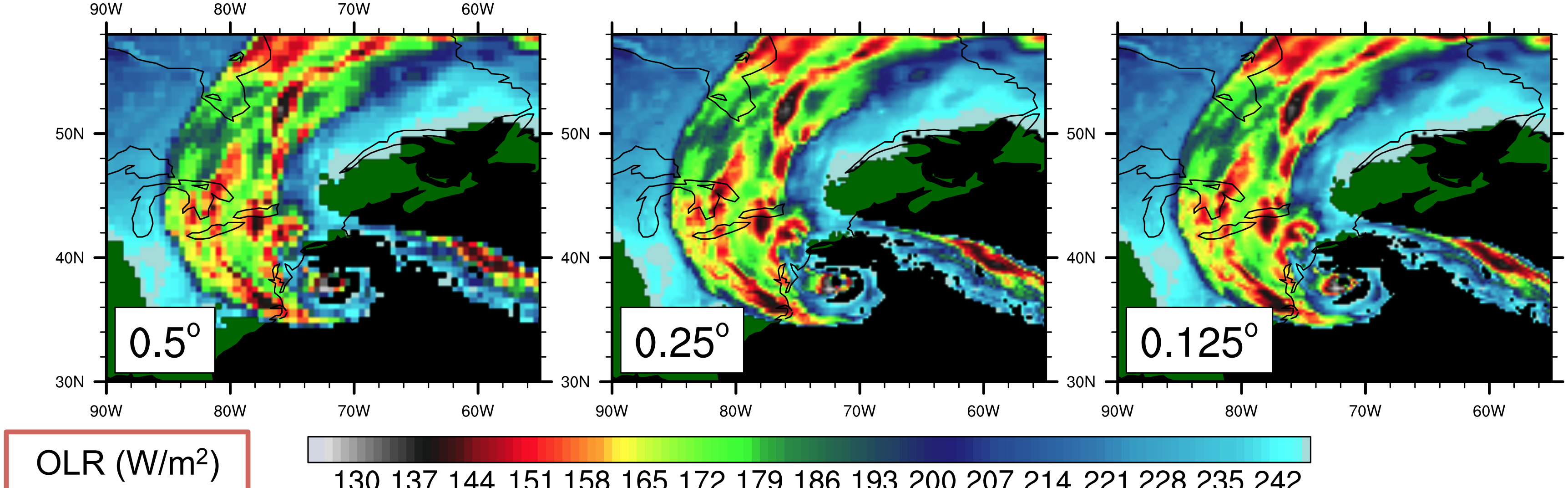


Motivation: Extreme Weather and Climate

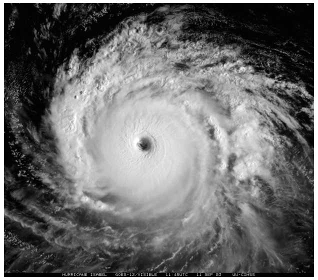


Resolution ↑, better representation of:

- Extreme weather events
- Land-surface processes
- Topography
- Atm/ocn/ice/lnd interfaces
- Chemical emission/transport/reactions/removal



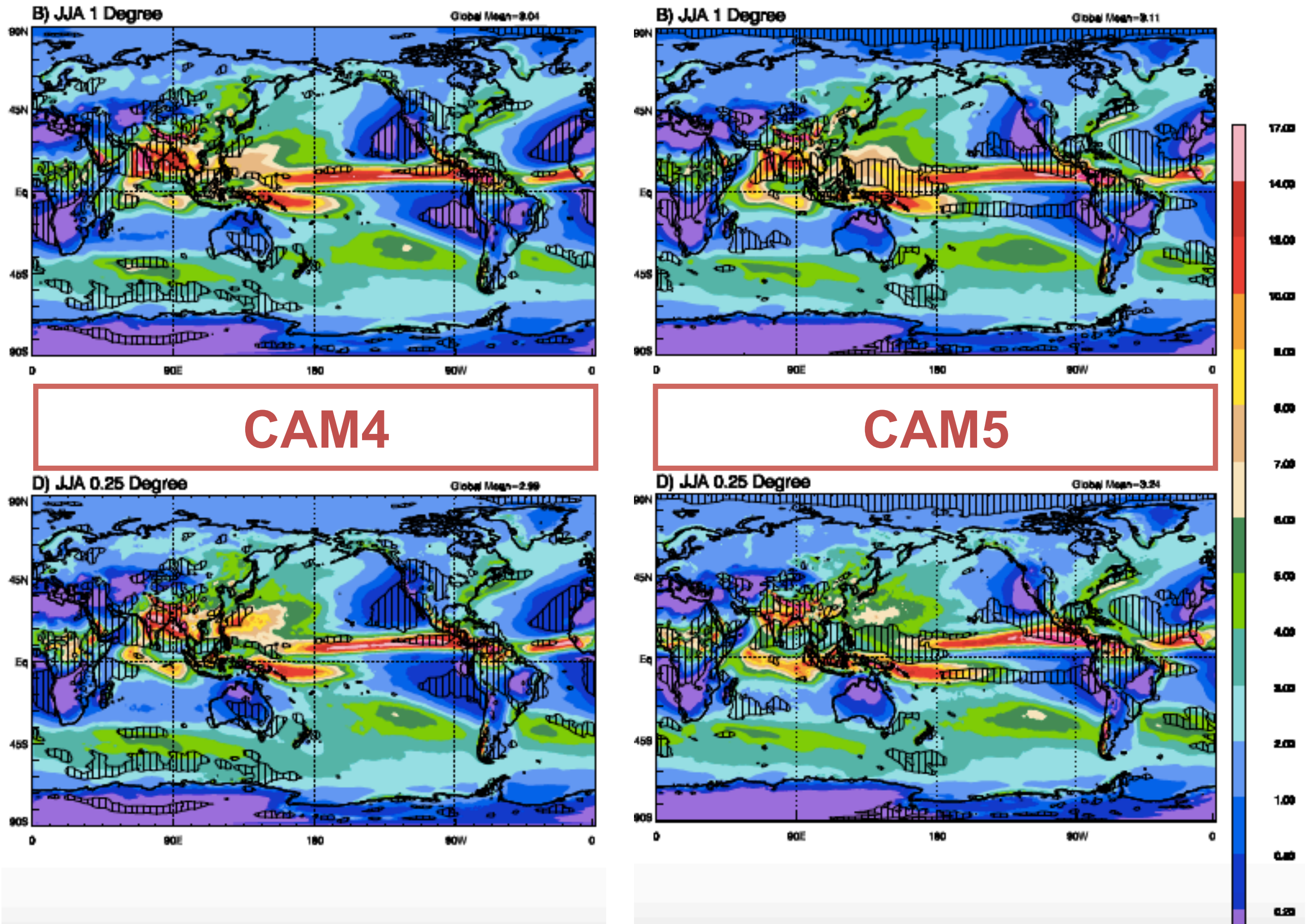
Courtesy of Colin Zarzycki (NCAR)

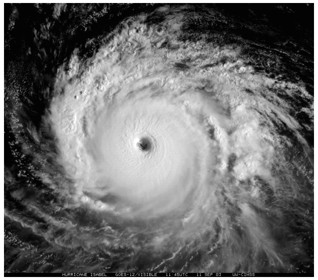


Motivation: Resolution Sensitivity in CAM

1 deg. (100 km)

0.25 deg. (25 km)

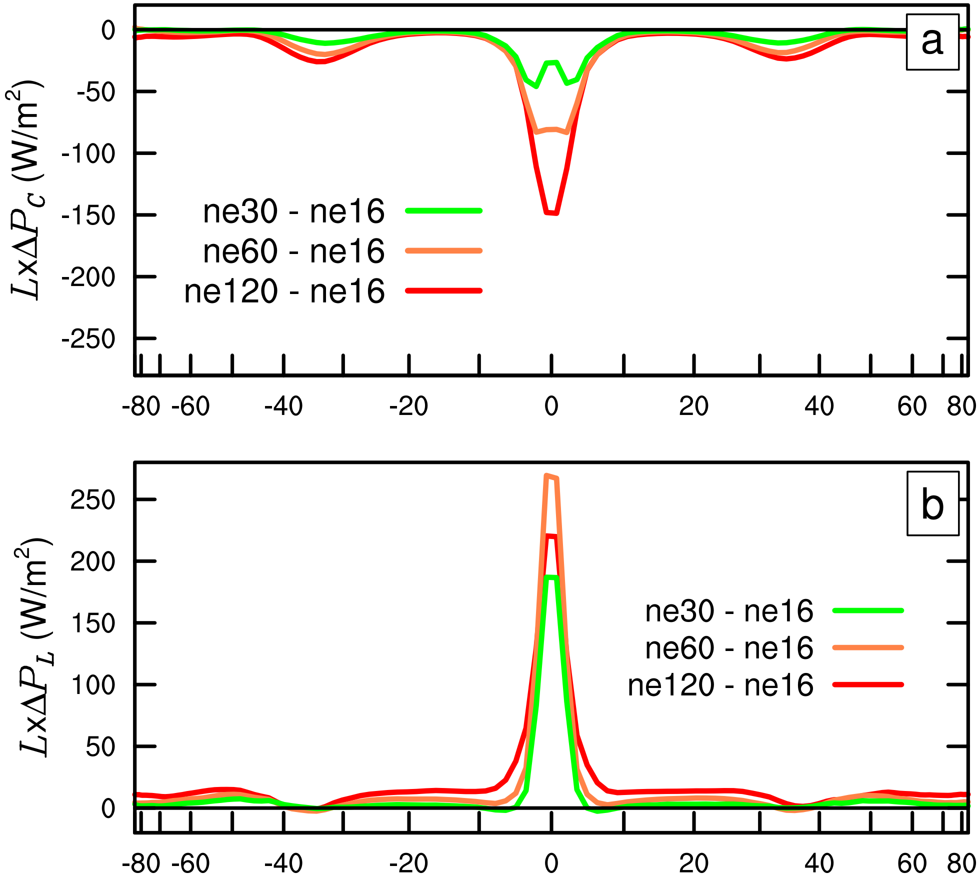




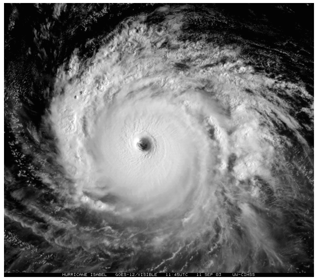
Motivation: Resolution Sensitivity in CAM4

Change in **convective** precipitation

Change in **stratiform** (large-scale) precipitation



[Herrington & Reed 2017, J. Climate]



How are GCMs evaluated? Physics-Dynamics Coupling?

- Utilize a test hierarchy

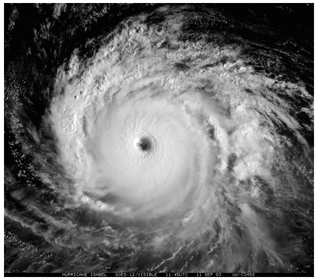
Increasing Complexity →

2D Shallow Water Test Cases → 3D Dry Dynamical Core Test Cases → 3D Aqua-Planet Experiment → 3D AMIP

Deterministic tests

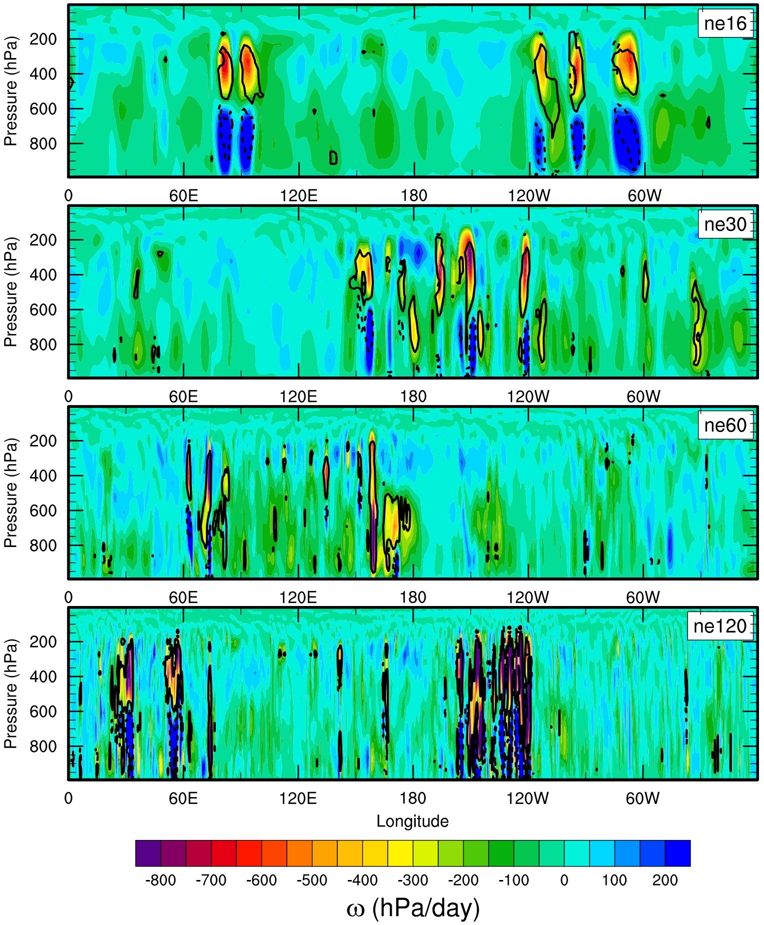
Tests of the **statistical** behavior (model 'climate')

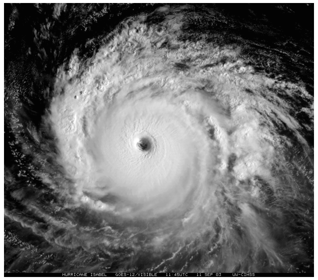
[Reed & Jablonowski 2012, JAMES]



Scale sensitivity in CAM5 Aqua-Planet

- Temperature tendency from the **physical parameterizations** (**black**), vertical pressure velocity from the **dynamical core** (**colors**)
- Magnitude of vertical velocities increase with resolution
- ***Horizontal scale*** of the physics forcing decreases with resolution





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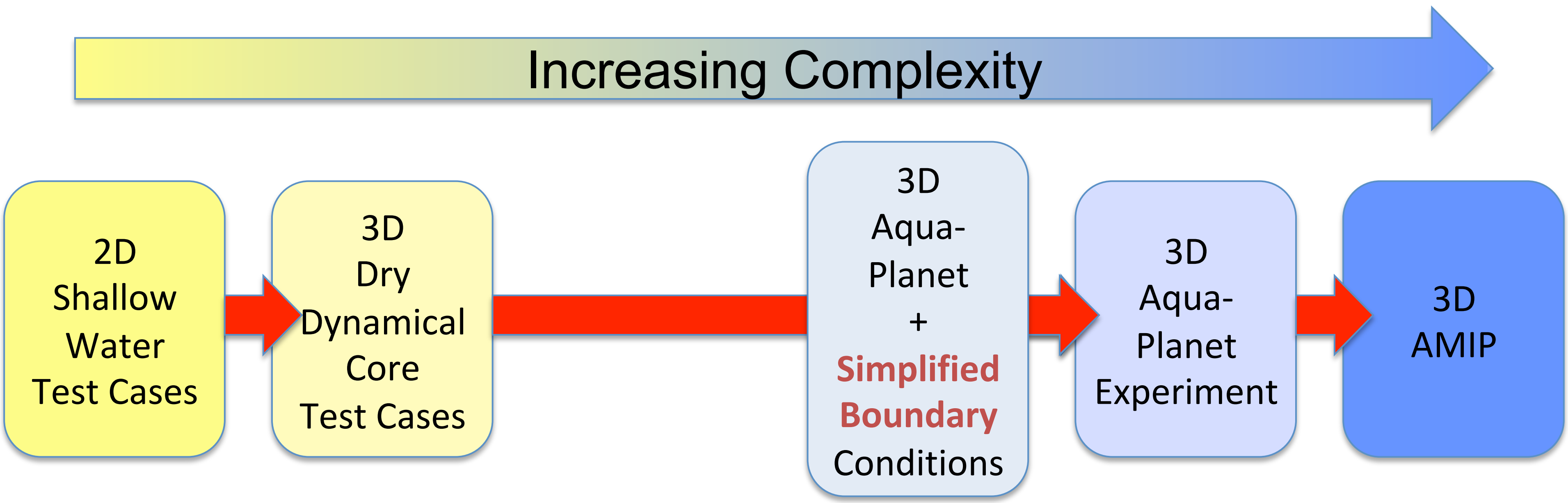
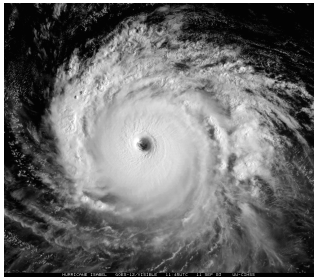


Deterministic Tests

Additional Complexities

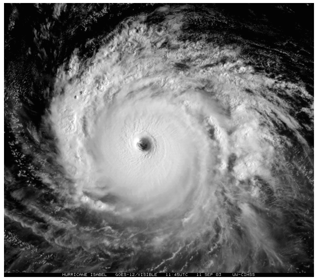
Tests of **Statistical** Behavior

 [*Updated from* Reed & Jablonowski 2012, JAMES]



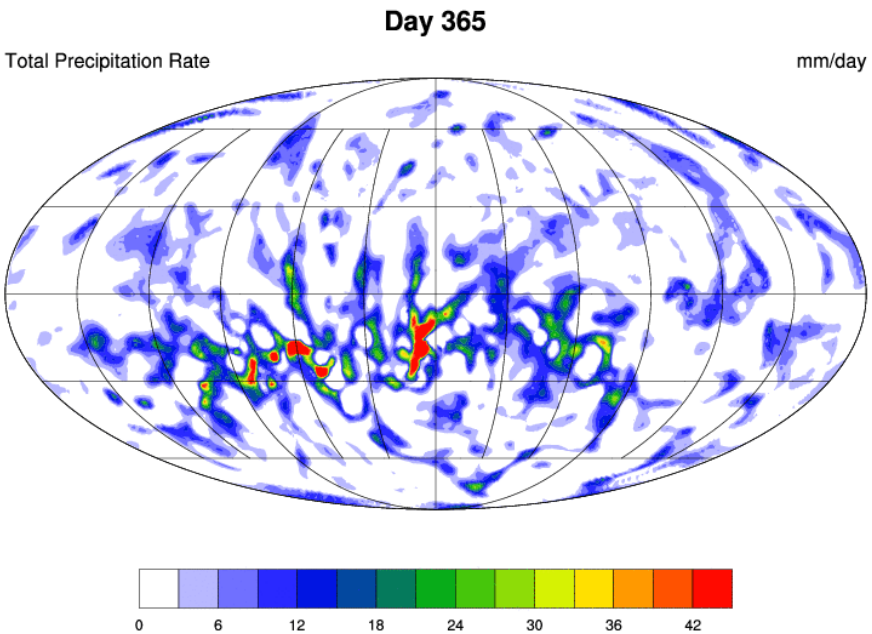
Design of RCE Experiments

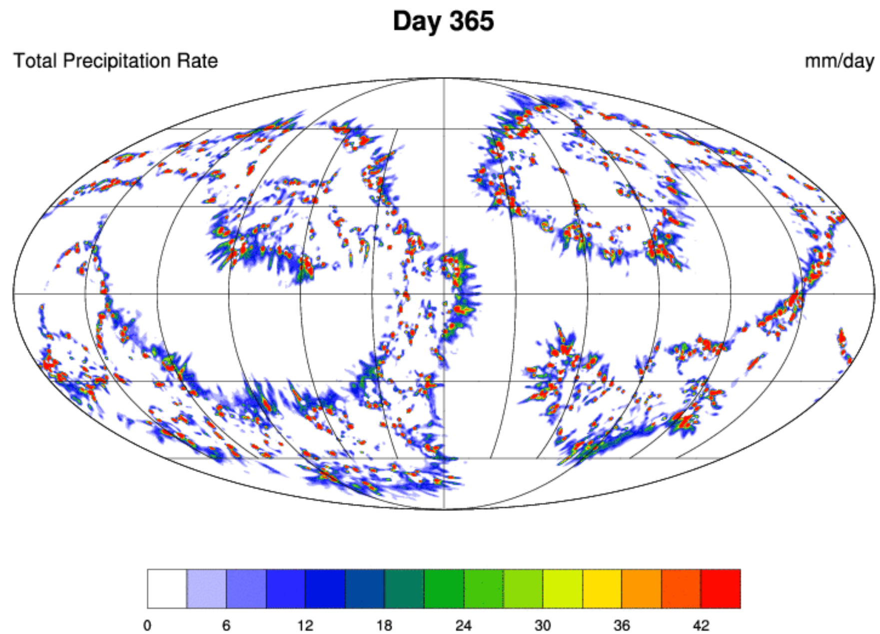
- NCAR's Community Atmosphere Model version 5 (CAM 5).
- The SE dynamical core with 30 vertical levels is used at the horizontal resolutions of:
  - ne=30 (~100 km) **=> with reduced Earth radius**
  - ne=120 (~25 km)
- Full physics in Aquaplanet mode is used, with a simplified ocean covered Earth and constant SST of 29^{o} C.
- No rotation effects (i.e., 10 deg. N).
- Diurnally varying, spatially uniform insolation (~340 W/m^2).
- No direct and indirect effects of aerosols.
- Tuning parameters are set to ne=30 configuration for all simulations.
- Such a setup mimics similar simulations with limited-area or cloud-resolving models, but at a relatively lower resolution.



RCE: Resolution Comparison

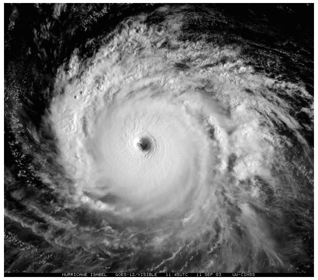
6-hr Avg. Precipitation (mm/day)



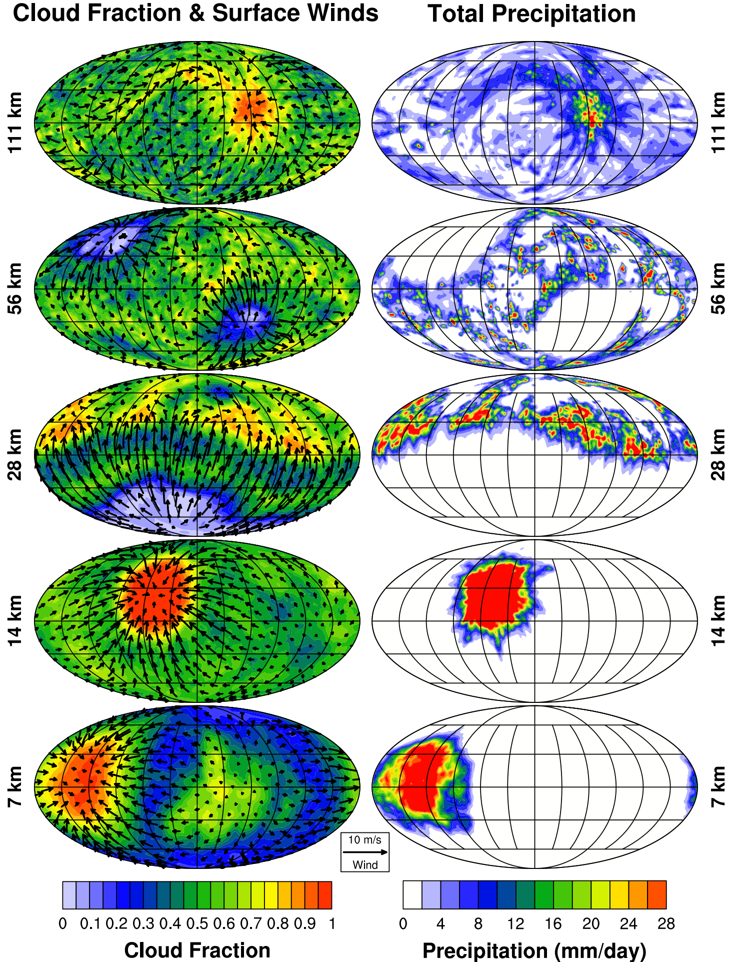


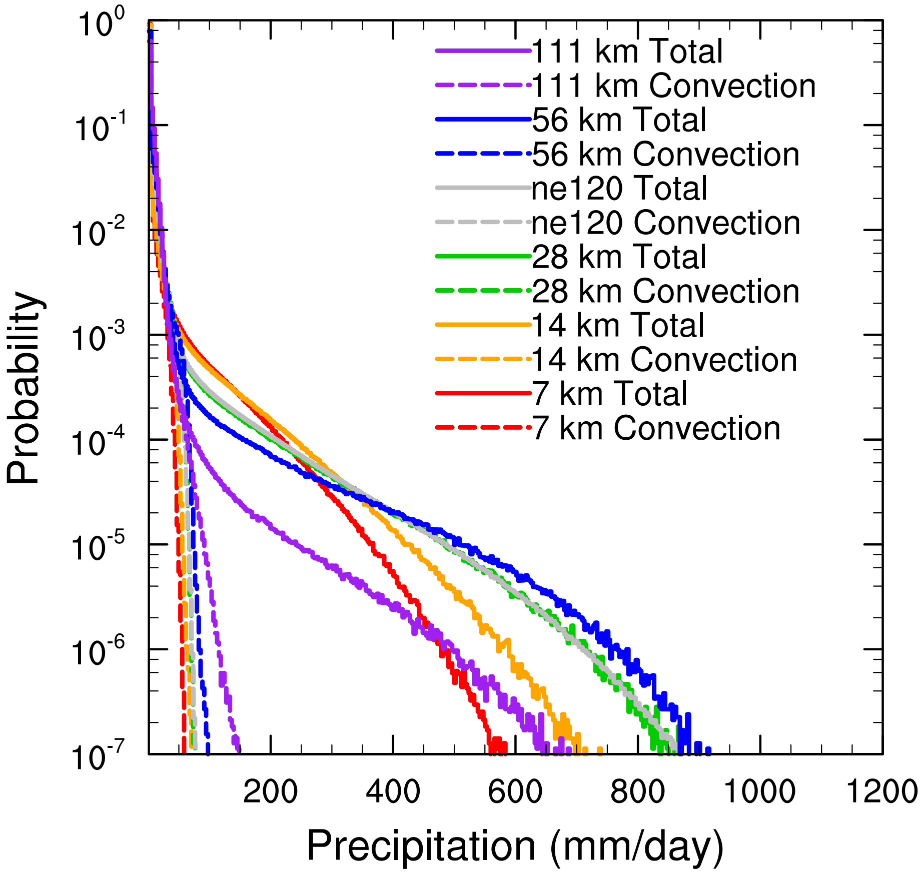
ne30 (~100 km)

ne120 (~25 km)

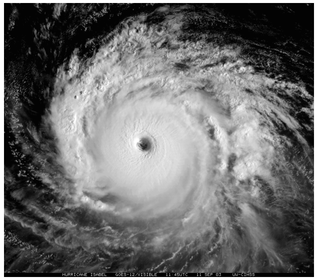


Reduced Planet RCE: Resolution Dependence – Scale Awareness





 [Reed and Medeiros 2016, GRL]



How Do we evaluate GCMs? Physics-Dynamics Coupling?

- Utilize a test hierarchy

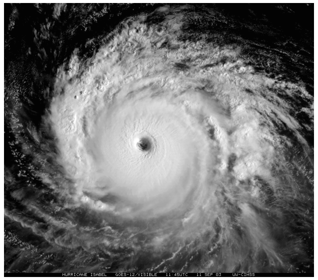
Increasing Complexity →

2D Shallow Water Test Cases → 3D Dry Dynamical Core Test Cases → 3D Dynamical Core + **Moist Simplified-Physics** Test Cases → 3D Aqua-Planet + **Simplified Boundary** Conditions → 3D Aqua-Planet Experiment → 3D AMIP

Deterministic Tests

Additional Complexities

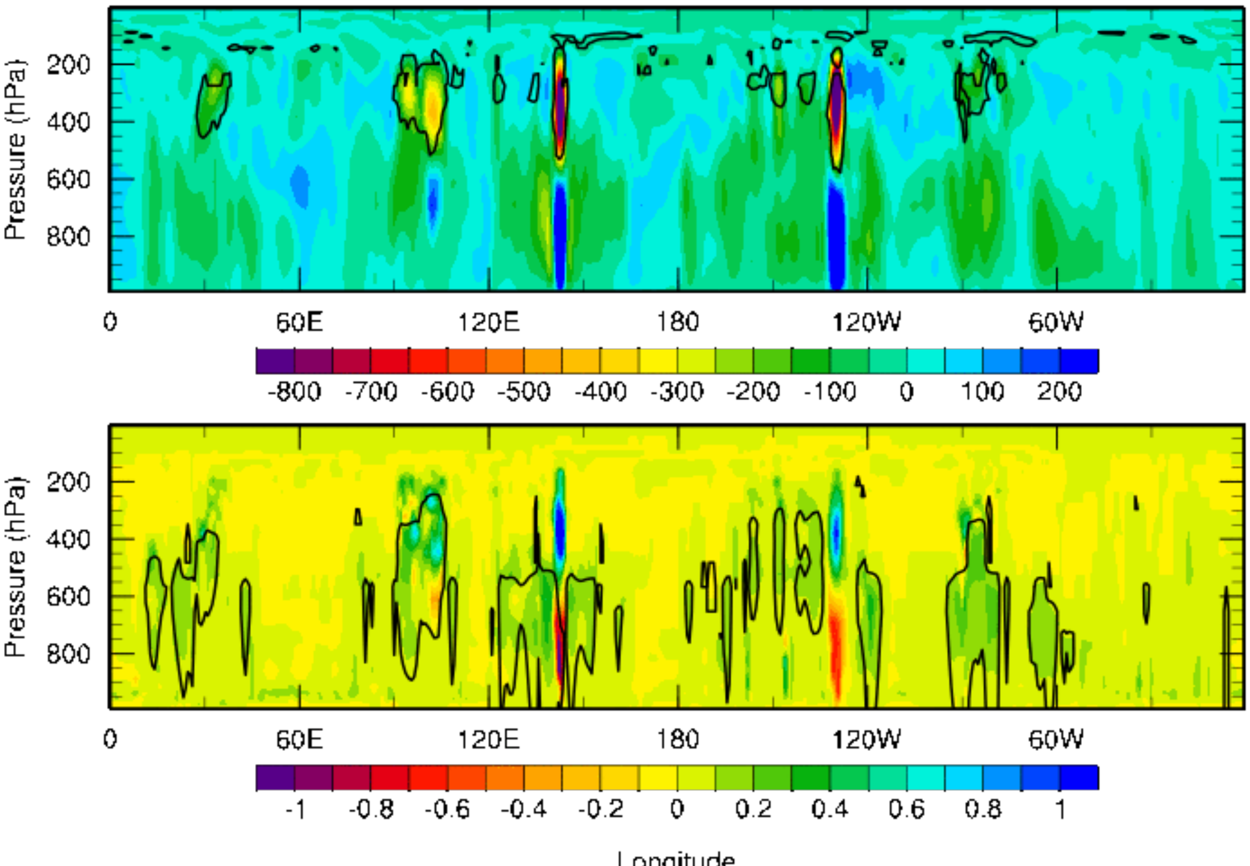
Tests of **Statistical** Behavior

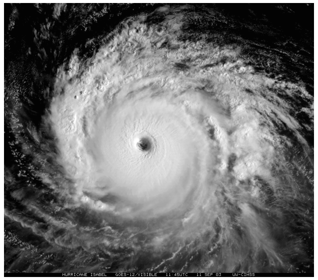


Think Back to the CAM5 Aqua-Planet

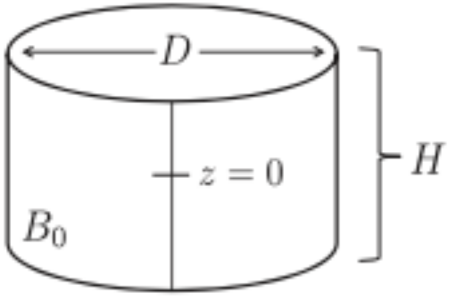
Resolved vertical pressure velocity (colors)

Potential Temperature perturbation from parameterizations (color) with **Deep convective mass fluxes** (black contour)





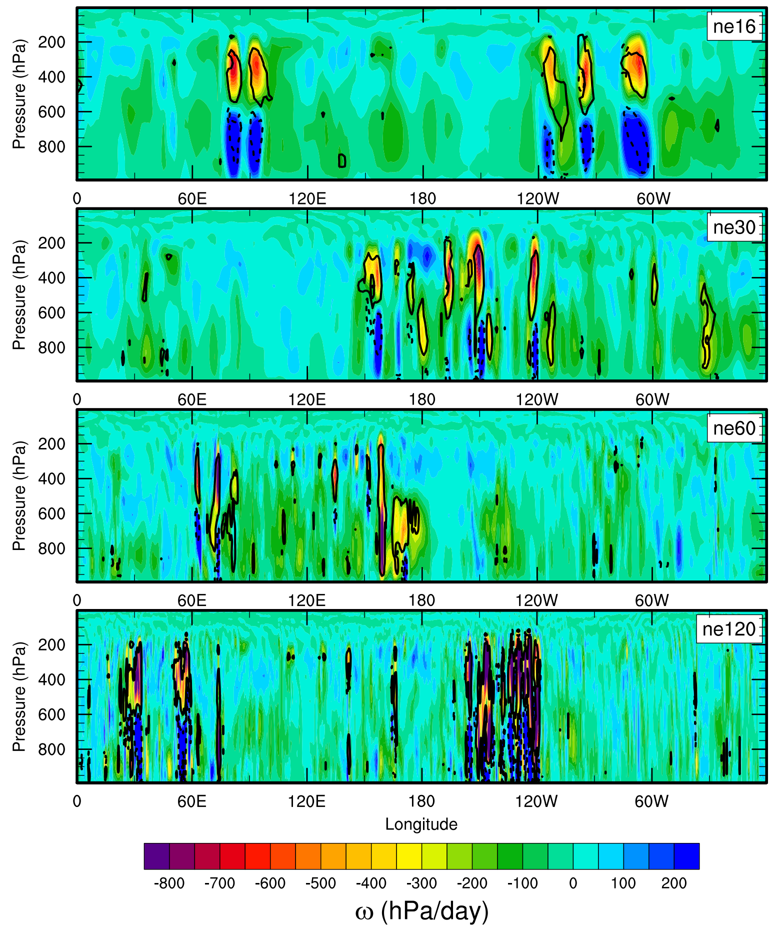
The thought....

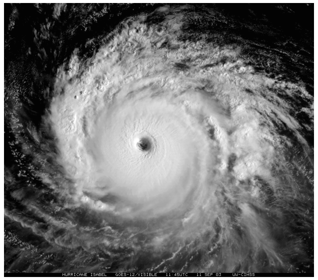


$$W = \sqrt{B_0 H}\; {}^{H}/_{D}$$

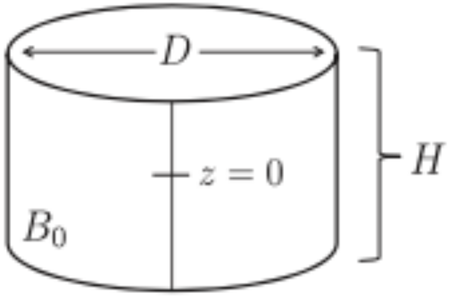
Hypothesize D proportional to Δx in aqua-planets & and that their equilibrated solutions are described by the scaling:

W ~ 1/Δx



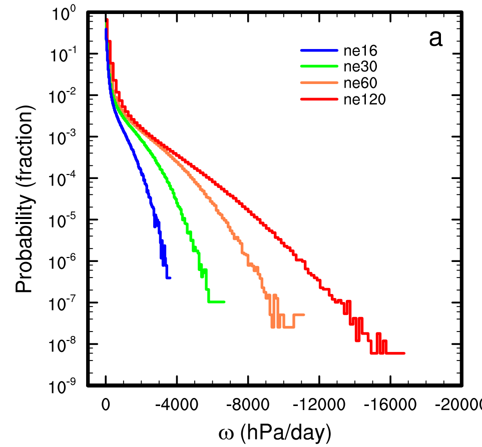


The thought....

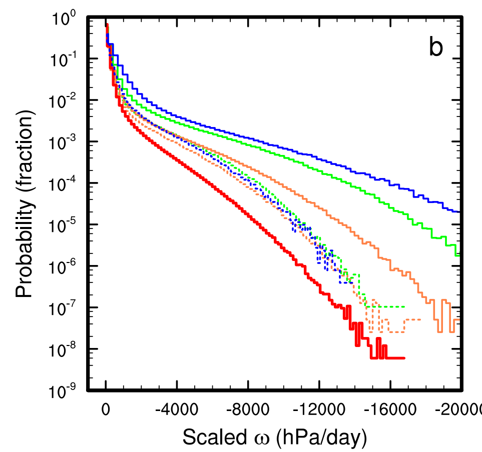


$$W = \sqrt{B_0 H}\, {}^{H}/_{D}$$

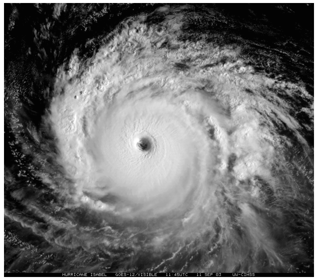
This **scaling over-``predicts”** the vertical velocity response to horizontal resolution on aqua-planets...



Aqua-planet solutions

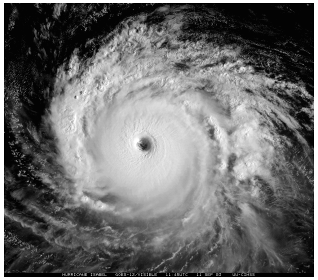


Scaled to high-res

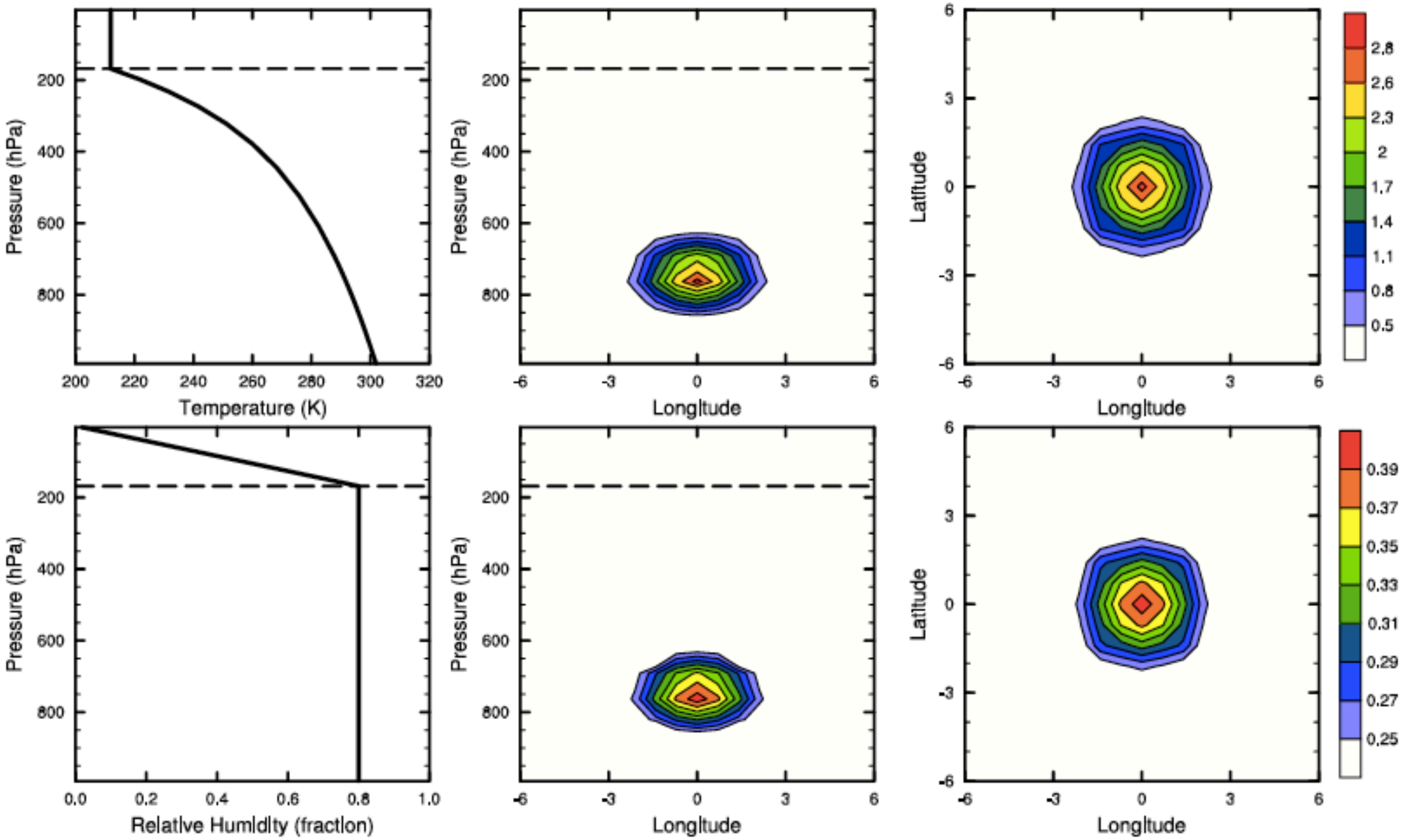


Design of Idealized Bubble Experiments

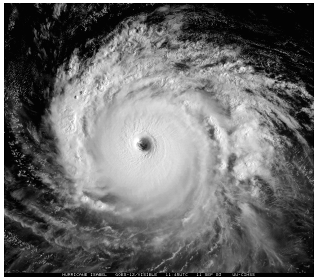
- NCAR's Community Atmosphere Model version 5 (CAM 5).
- The SE dynamical core with 30 vertical levels is used at the horizontal resolution of ne=30 (~100 km).
- The radius of the Earth is then decreased to **mimic increase resolution**.
- Select physics (i.e., none (dry), simple condensation, or stratiform precip only) in is used, with a simplified ocean covered Earth and constant SST of 29^{o} C.
- No rotation effects.
- Any tuning parameters are set to ne=30 configuration for all simulations.
- Such a setup mimics similar to previous work with bubble experiments, but to include moisture!



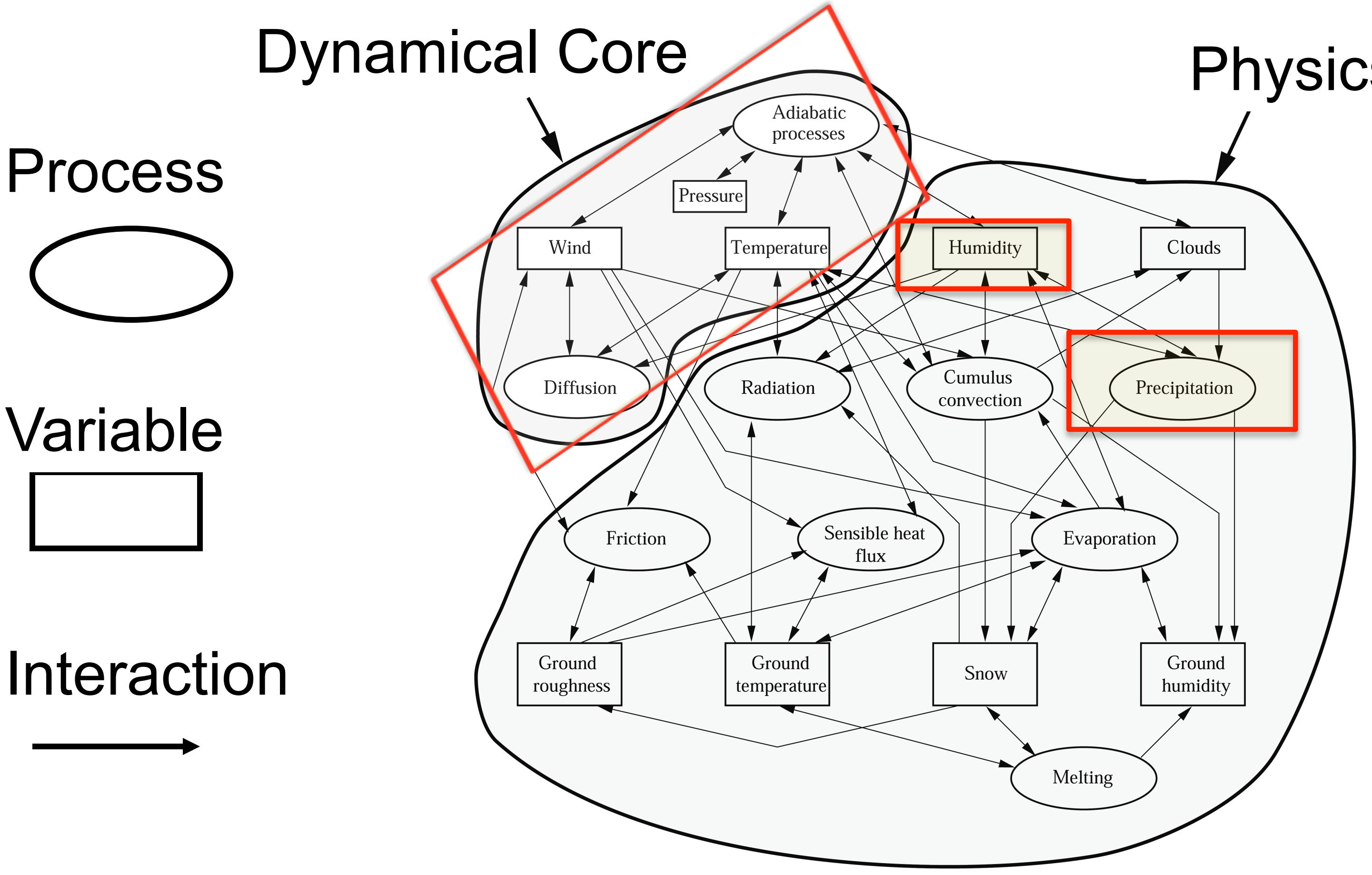
Design of Idealized Bubble Experiments

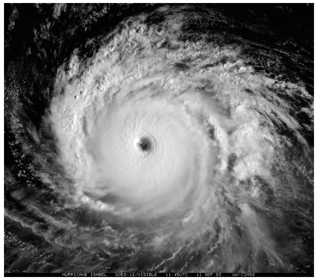


[Herrington & Reed 2018, JAMES]



Reduced Complexity



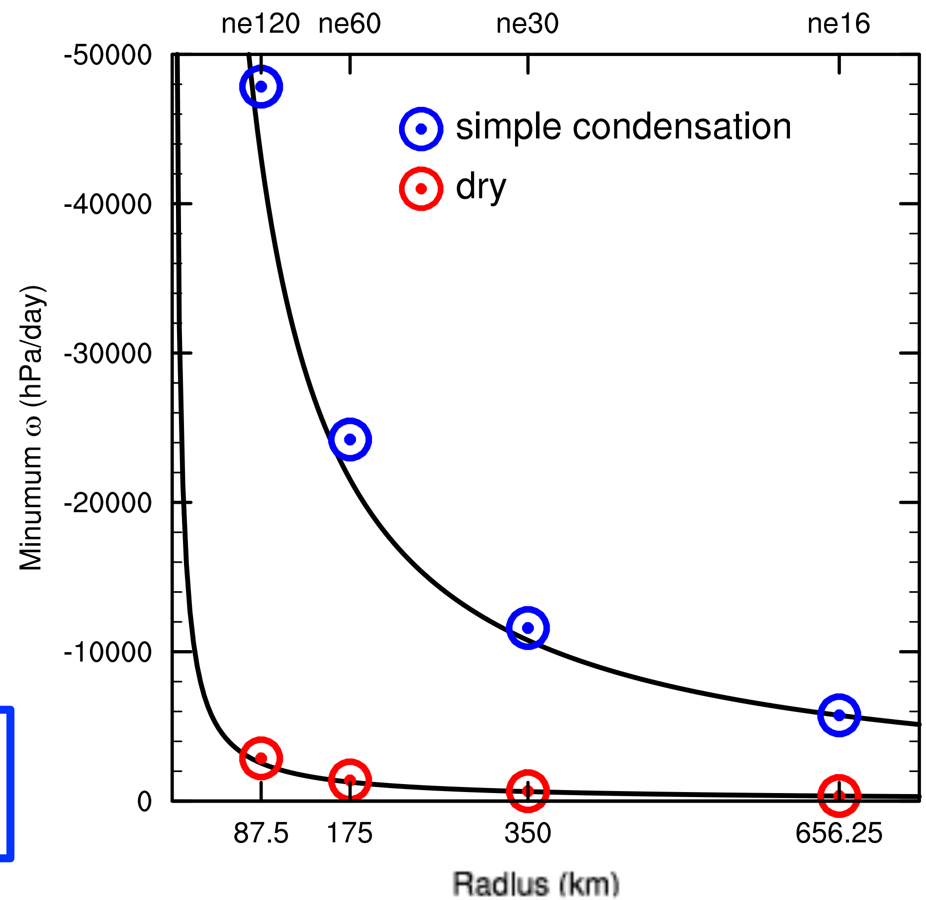


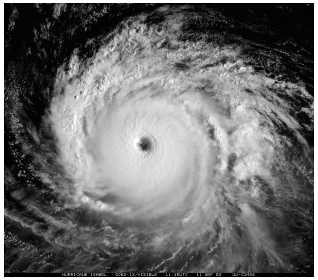
Scaling with Bubble Test: Dry and Simple Physics

- **RED:** Consider the dry SE dynamical core only
- **BLUE:** Couple with a large-scale condensation routine from Reed and Jablonowski 2011.

(Model the environment/ bubble after aqua-planets)

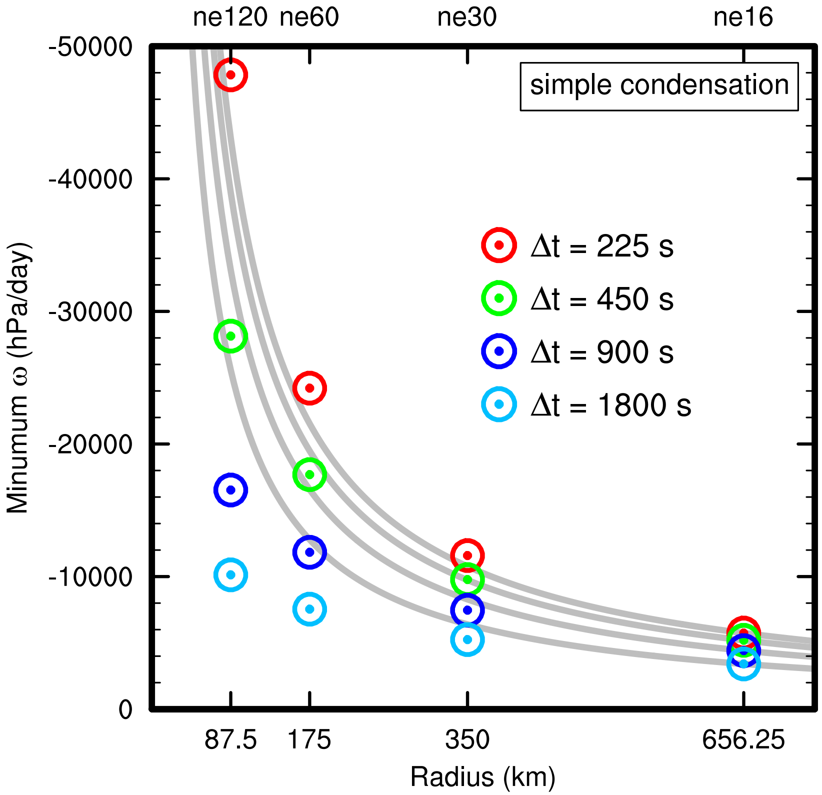
The $w = \sqrt{B_0 H}\,{}^{H}/_{D}$ scaling works, even with moisture!!

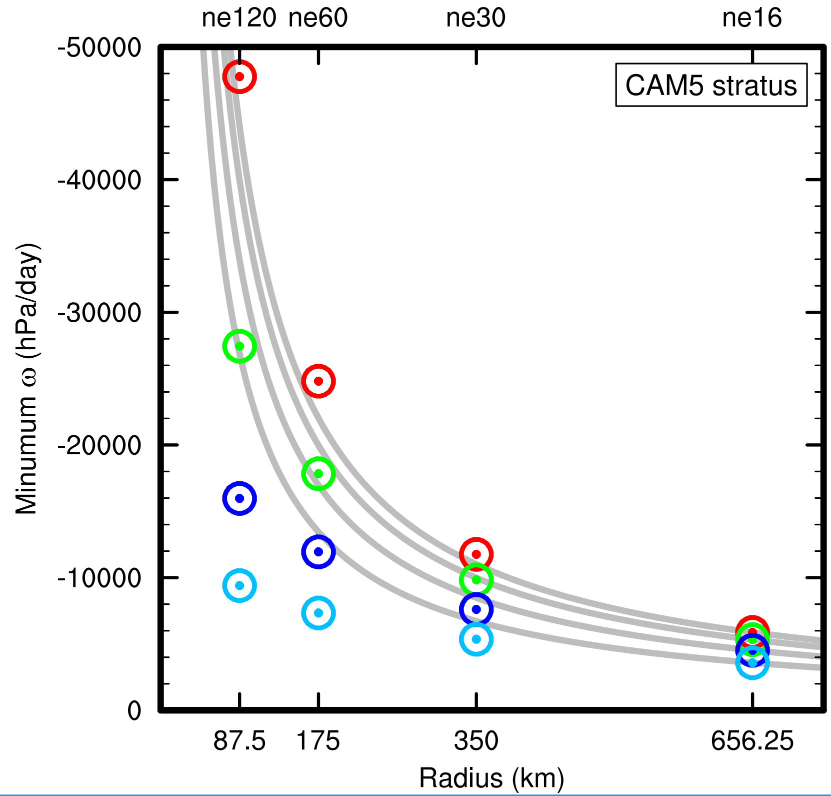


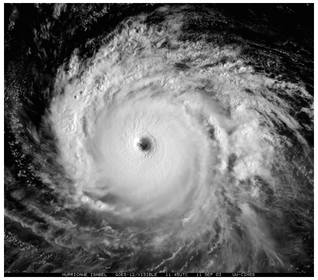


Test the Scaling: Choice of Physics Time-Step

- Conventionally, physics packages only update the state periodically
- **Incrementally increase the physics time-step** (dycore Δt = 75 s)

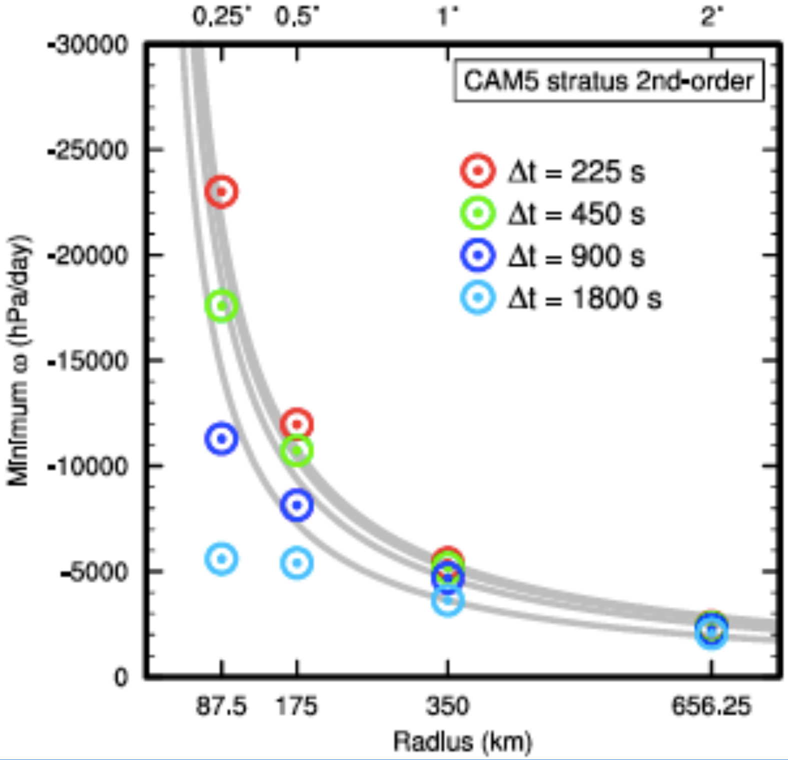


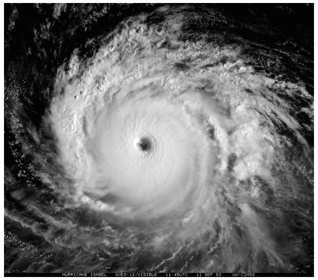




Test the Scaling: Choice of Dynamical Core

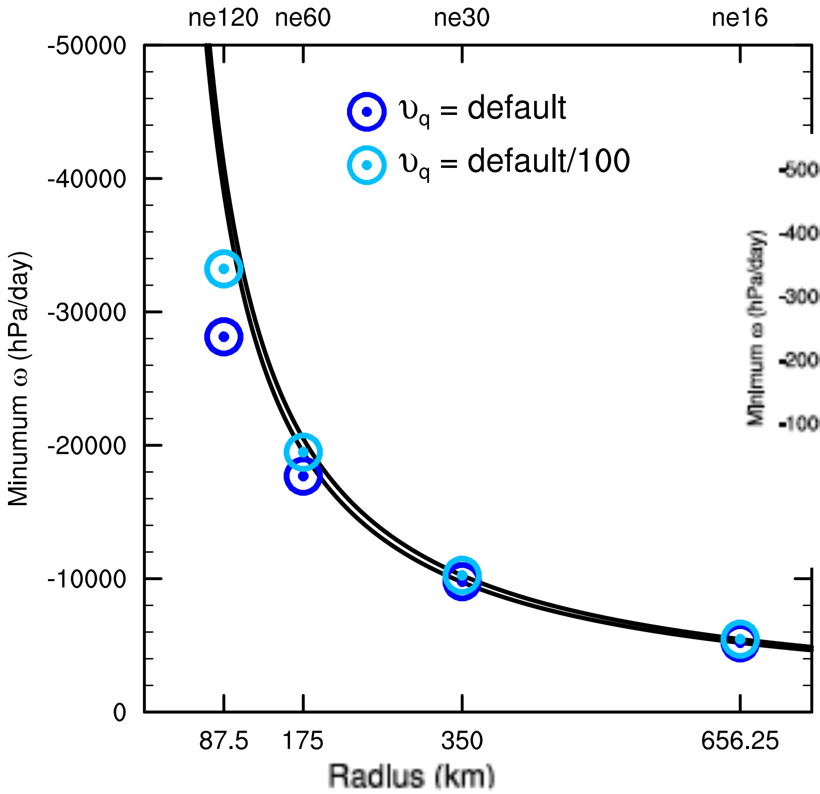
- Is this sensitive to the choice of dynamical core and therefore potentially physics-dynamics coupling decisions?
- **Results are similar with CAM-FV core!**

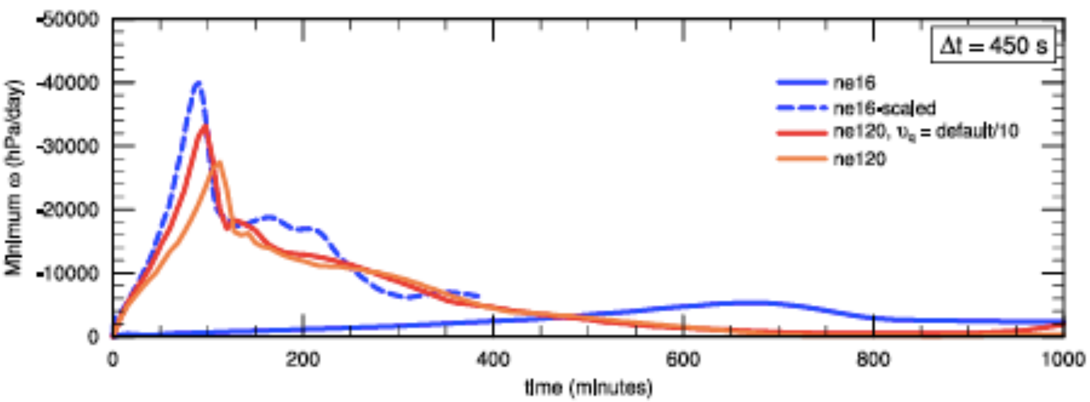


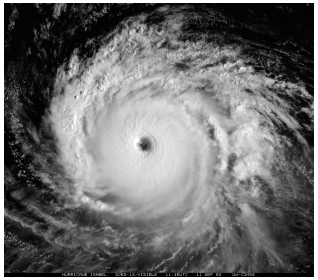


Test the Scaling: Choice of Hyperviscosity Coeficient

- Recover the scaling by reducing the horizontal hyper-viscosity coefficients (for specific humidity, only).

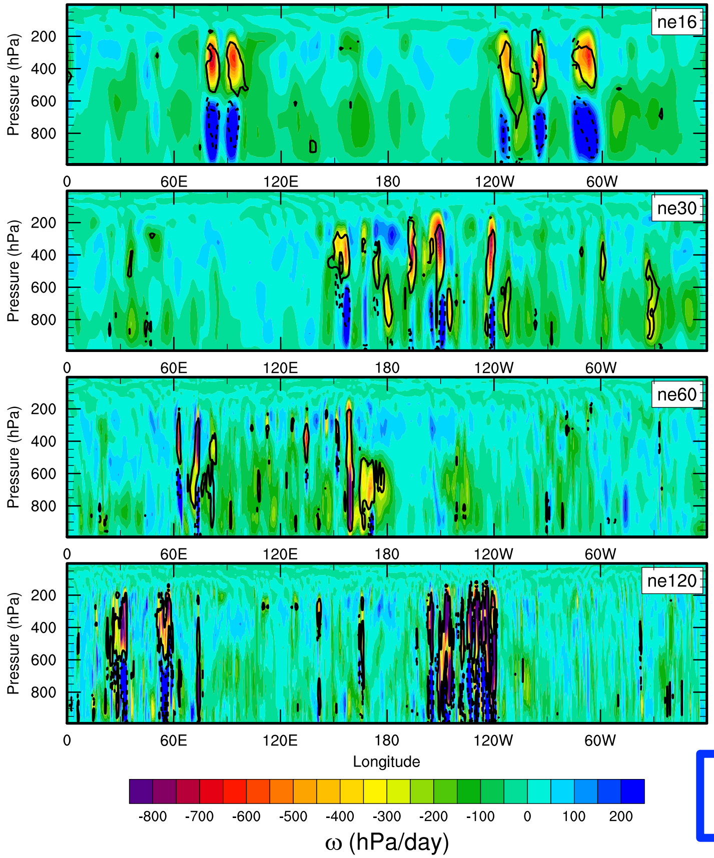


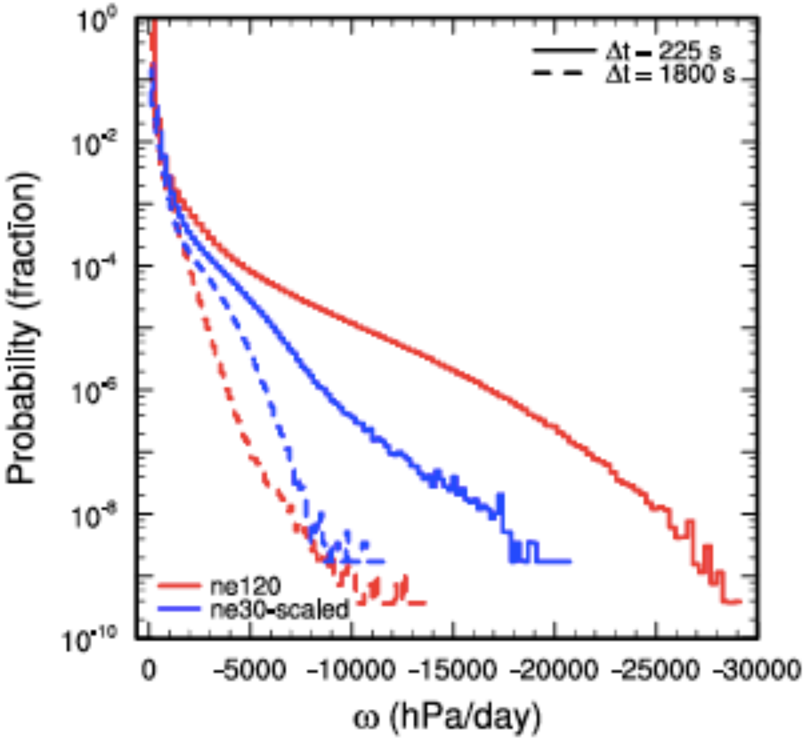




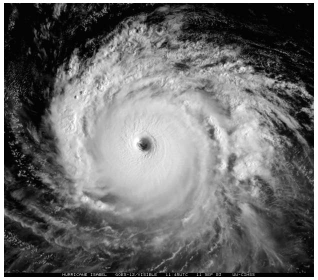
Relate back to Aqua-planet?

- What if we rescale the more complex Aqua-planet simulations?





Need to build up additional complexity!



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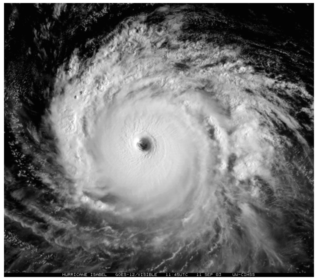
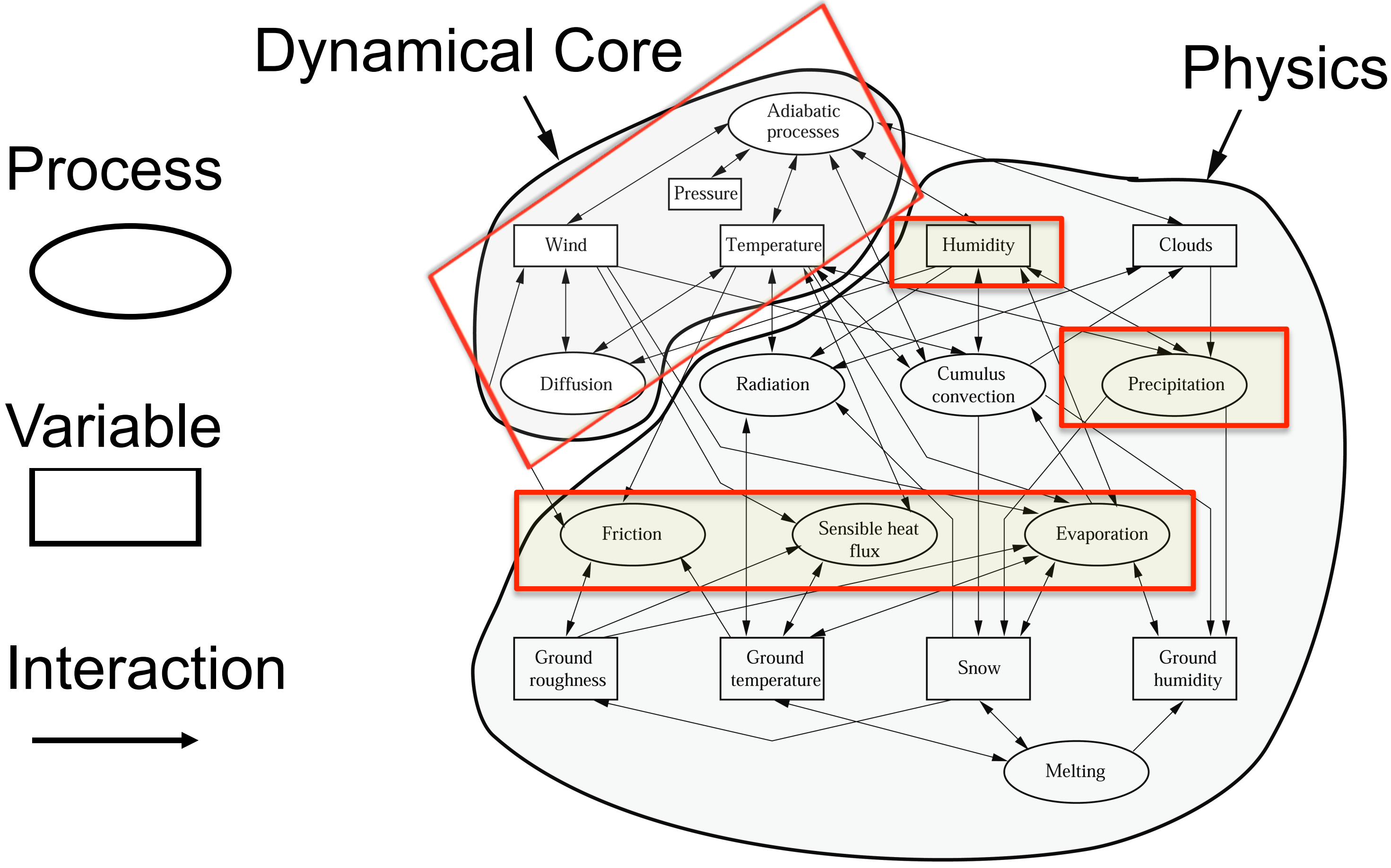
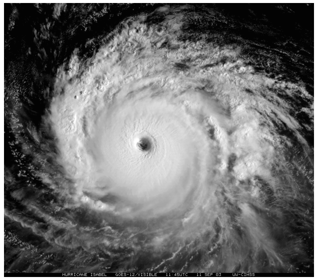
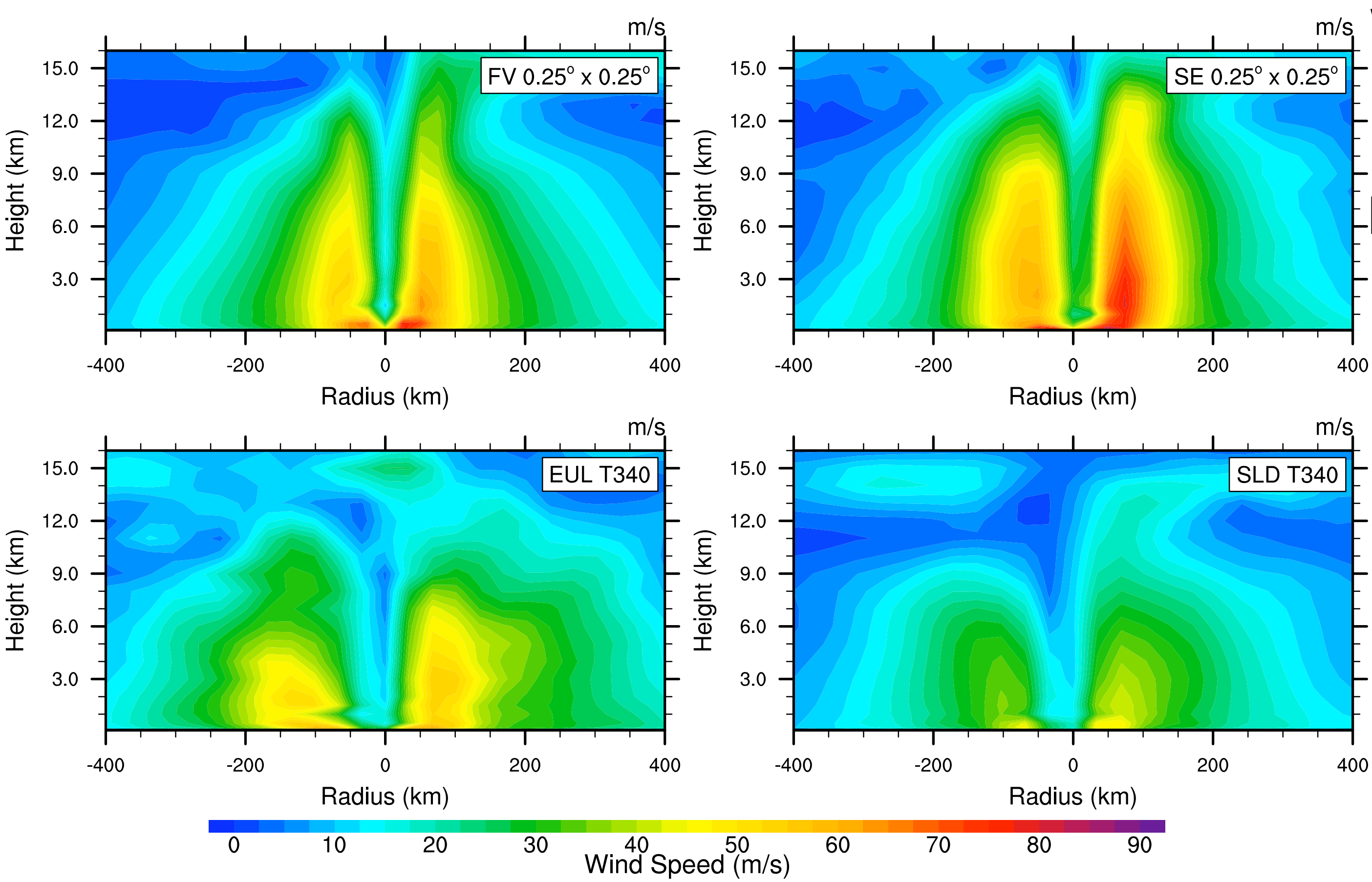


Simple-Physics





Simple-Physics Dynamical Core Comparison – Coupling Role?



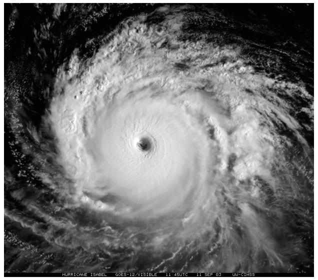
Wind Speed (m/s)
At Day 10

Differing strengths and shapes:

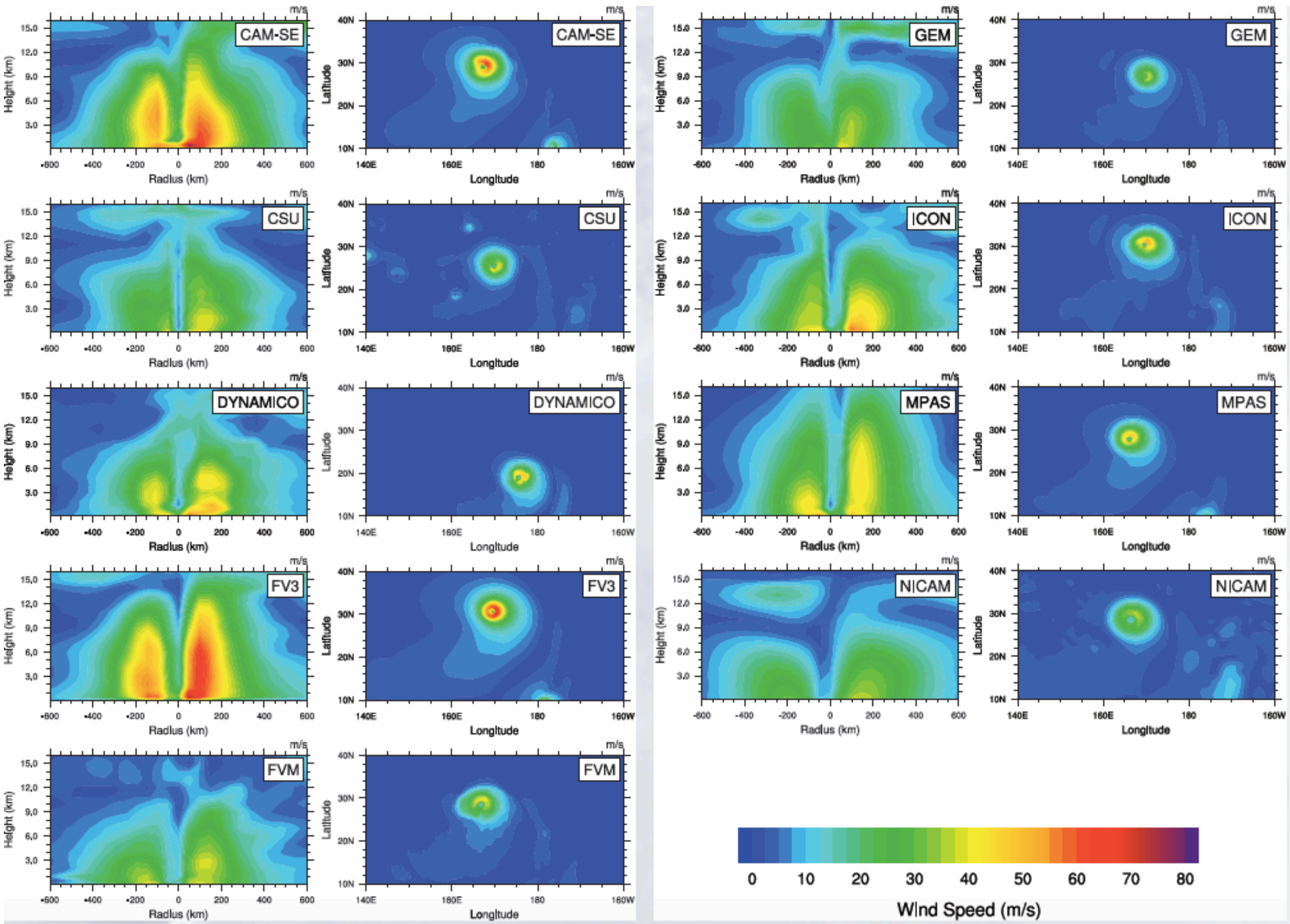
FV & SE
at 0.25°
(≈ 28 km)

EUL & SLD
at T340
(≈ 39 km)

[Reed & Jablonowski 2012, JAMES]



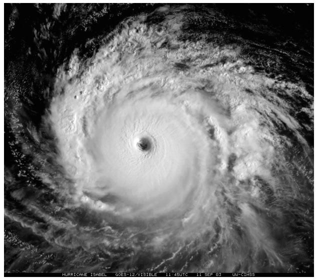
DCMIP-2016: Dynamical Core Intercomparison Project



Wind Speed (m/s)
At Day 10

Differing strengths and shapes:

Various Models from around the world at 0.5^{o} (≈ 56 km)



Final Thoughts

- Standard and reduced complexity CAM simulations show a **sensitivity to horizontal resolution**. The magnitude of this sensitivity is not expected from *simple scaling arguments*
- Isolating interactions between a dynamical core and moisture processes using **simplified physics packages** can reveal aspects of the physics-dynamics coupling that impact this resolution sensitivity (i.e., **coupling frequency!**).
- **Reduced complexity testbeds** are a useful tool (with quick turn around times) to test/understand **physics-dynamics coupling**, since they can be analyzed more easily than traditional climate modeling approaches.

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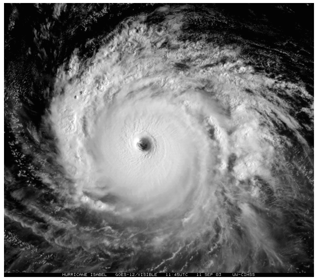

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Radiative–convective equilibrium model intercomparison project

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[4]Max Planck Institute for Meteorology, Hamburg, Germany
[5]Laboratoire de Météo
[6]Japan Agency for Ma