Using idealized tests to diagnose the impact of physical parameterizations on atmospheric simulations

Colin M. Zarzycki[1], Christiane Jablonowski[1], Mark A. Taylor[2], and Michael N. Levy[3]
[1]Department of Atmospheric, Oceanic and Space Sciences, University of Michigan, Ann Arbor, MI
[2]Sandia National Laboratories, Department of Energy, Albuquerque, NM
[3]National Center for Atmospheric Research, Boulder, CO
E-mail: zarzycki@umich.edu

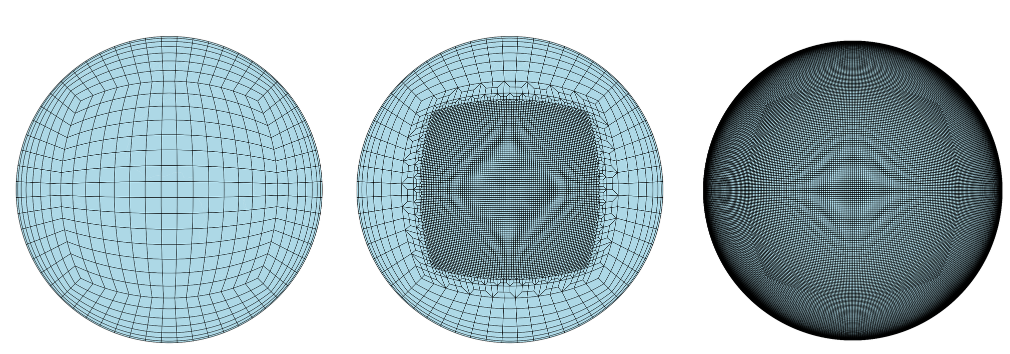
ATMOSPHERIC, OCEANIC AND SPACE SCIENCES
UNIVERSITY OF MICHIGAN

Motivation

- Assessing uncertainty in model processes is important to gaining a more complete understanding of complex climate simulations
- Understanding the effect of these processes such as convection, turbulence, and surface fluxes, on the model solution becomes increasingly crucial as horizontal resolution is increased, allowing the model to more accurately represent previously unresolved phenomena
- Use of idealized simulations such as aquaplanet climate or simplified test runs can help isolate specific parameterizations and their effect on the model solution

Variable-resolution simulations

- Variable-resolution feature implemented in NSF/DoE **C**ommunity **A**tmosphere **M**odel (CAM) **S**pectral **E**lement (SE) dynamical core.
- Six aquaplanet experiments following Neale and Hoskins (2000, ASL) "control" case
  - Three with CAM version 4 physics
  - Three with CAM version 5 physics (bulk aerosols)
- Aquaplanet excellent idealized framework for evaluating variable-resolution simulations
  - Coupled to subgrid parameterizations without topography or other model components (land, ice, etc.)
  - Forcing is zonally symmetric so refinement effects can be isolated by investigating the local departure from zonal mean



Uniform 2° "coarse" | 2° → 0.25° "var-res" | Uniform 0.25° "fine"

Model Settings

Setup	CS res.	Δx (°)	Δx (km)	Cells (#)	dt_{dyn} (s)	K_4 ($m^4\ s^{-1}$)
fine	n_e120	0.25°	28	86,400	50	1.00E+13
coarse	n_e15	2°	222	1,350	600	1.00E+16
var-res	n_e15x8	varies	varies	10,609	50	varies

CS res. is the cubed-sphere resolution, Δx is the grid spacing in degrees and kilometers, Cells is the number of elements tiling the sphere, dt_{dyn} is the dynamics timestep and K_4 is the fourth-order hyper-diffusion coefficient

- Uniform simulations -> 12 months (after spinup)
- Var-res simulations -> 48 months (after spinup)
- Statistics averaged over entire simulation length since model forcings (SSTs, aerosols, etc.) are constant in time

Parameterization behavior across scales

CAM4

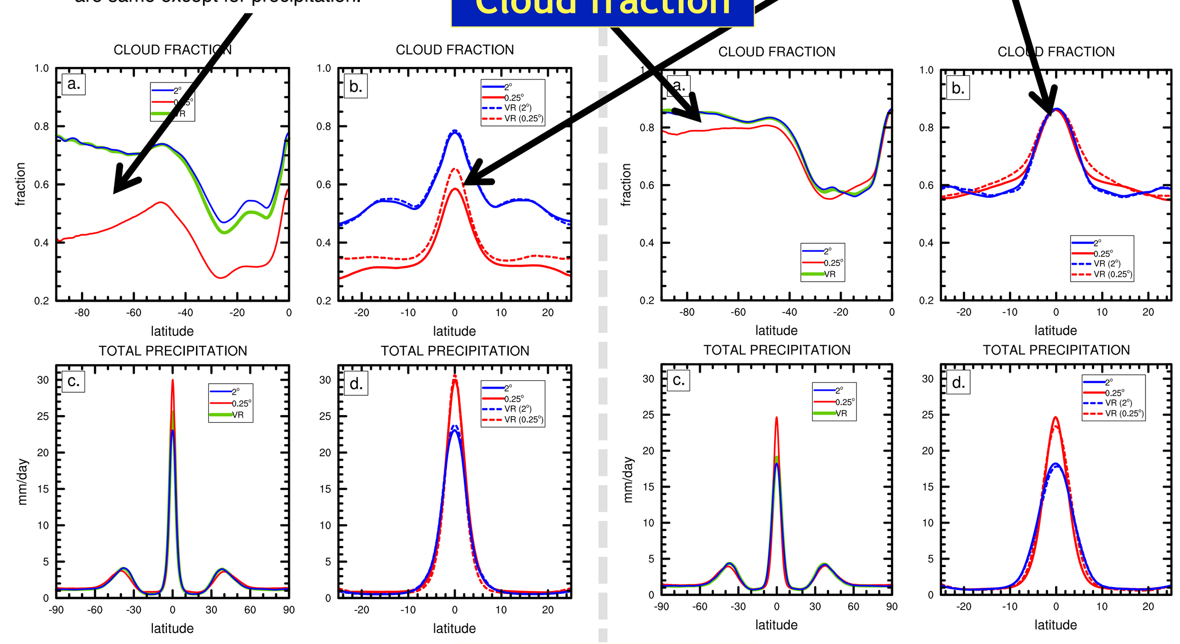
- Extreme scale sensitivity with CAM4 clouds
- CAM5 shows increased cloud fraction at all latitudes, but better behavior at multiple resolutions

CAM5

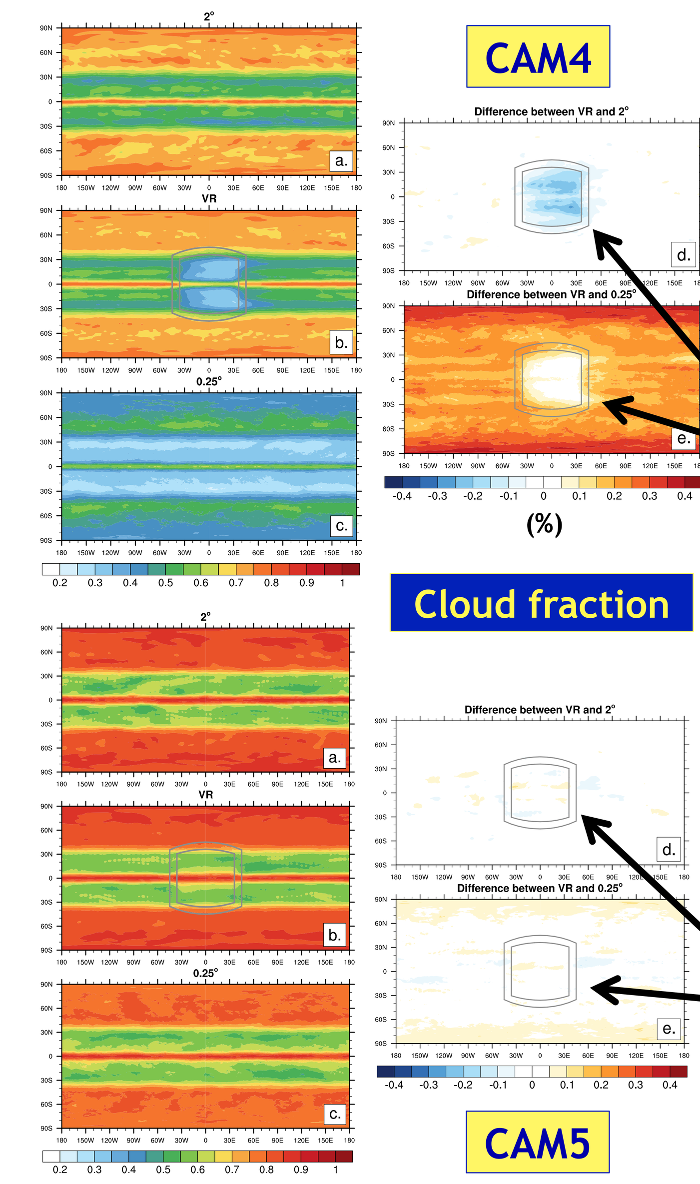
- Fine nest in var-res CAM4 simulation (red dashed) does not match uniform fine simulation (red solid)
  - Indicative of influence from coarse grid
- Behavior improved in CAM5

Zonal mean total cloud fraction and total precipitation rate. (a) Global cloud fraction in all three meshes. (b) Separating fine region and coarse region of var-res mesh near the equator. (c) and (d) are same except for precipitation.

Cloud fraction



Precipitation



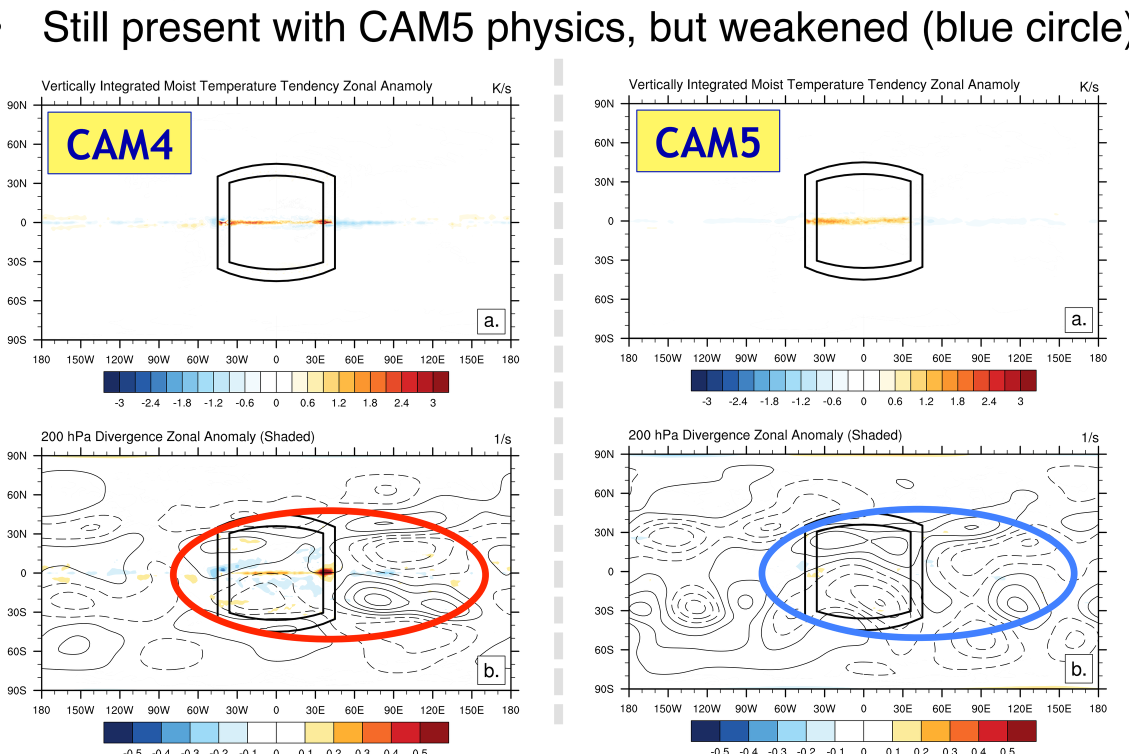
CAM4 | **Cloud fraction** | **CAM5**

- **CAM4**
  - Very scale selective, climate in the coarse (top left) very different from fine (bottom left)
  - Significant grid imprinting induced by the physics in the var-res simulation
- **CAM5**
  - Increase in cloud fraction in all simulations at all latitudes compared to CAM4
  - Much better performance at multiple grid spacings; very weak signature of nest in var-res simulations

CAM4 and CAM5 contour plots of total cloud fraction (%, top) and precipitation (mm/day, bottom) for (a) coarse (b) var-res, and (c) fine runs. The difference between the var-res and coarse simulation is plotted in (d) and the var-res and fine simulation in (e).

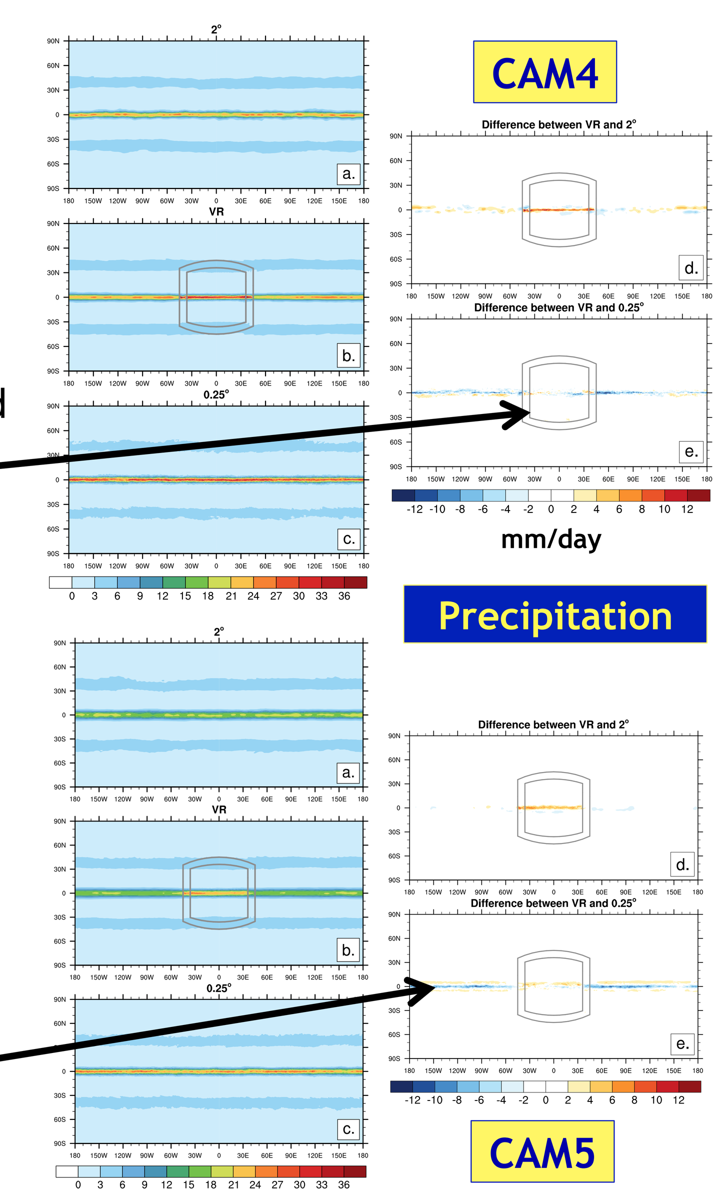
- Precipitation increases at equator with increasing resolution for both CAM4 and CAM5
- Adjusts more "instantaneously" to resolution than cloud fraction

- Gill circulation can be induced by variations in precipitation along equator
- Anomalous diabatic heating in fine nest leads to divergence and circulation in CAM4 (same as Rauscher *et al.* (2013, J. Clim.) (red circle)
- Still present with CAM5 physics, but weakened (blue circle)



Zonal anomalies of (a) vertically integrated moist heating and (b) 200 hPa divergence (color contours) for var-res grid with CAM4 (left) and CAM5 (right) physics. In (b) the 200 hPa eddy streamfunction is contoured by $10^6\ m^2/s$. Negative contours are dashed

- **CAM4**
  - Robust increase in equatorial precipitation maximum at increased resolution
  - Signature of refined nest in var-res simulation matches fine grid
- **CAM5**
  - Equatorial maximum broader and weaker than CAM4 at all simulations
  - Difference plots show narrowing of equatorial max, response to increased Hadley strength?



CAM4 | mm/day | **Precipitation** | **CAM5**

Sensitivity of ITCZ to convection and diffusion

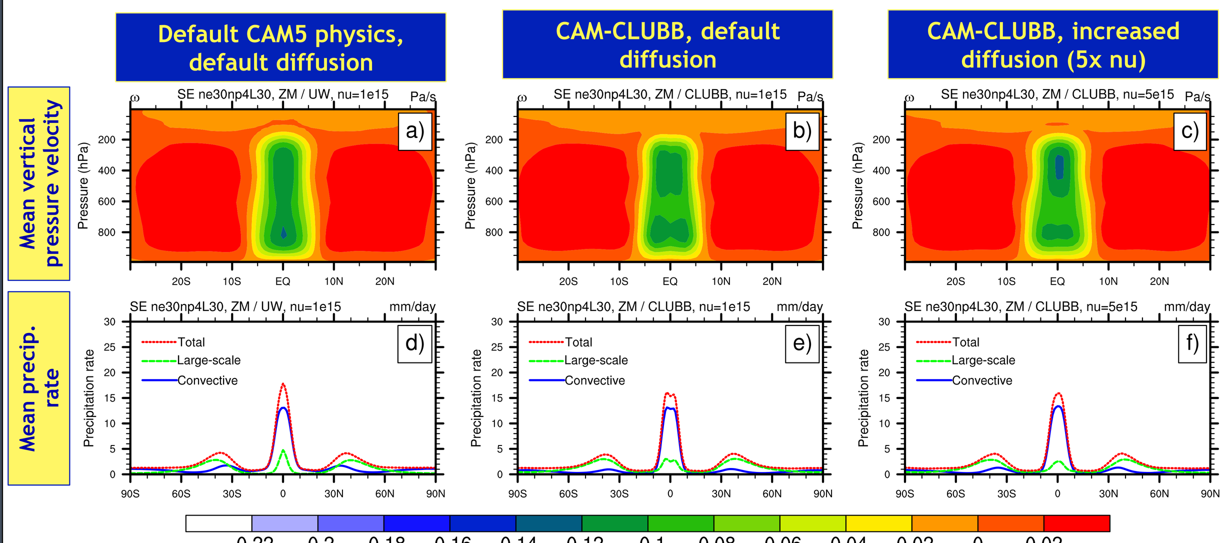
- Intertropical convergence zone (ITCZ) location and intensity varies widely between model configurations
- Goal: isolate specific mechanisms in parameterization of precipitation, vertical mixing, and diffusion which play role in sensitivity

Model configuration:
- CAM-SE
- 1° (~110 km) grid spacing
- Δt = 1800 sec
- "Control" aquaplanet case from Neale and Hoskins (2000, ASL)
- 3-year averages

CAM-SE aqua-planet simulations. (a-c) show the tropical time-mean zonal-mean vertical pressure velocity, (d-f) shows the corresponding total, large-scale and convective precipitation rate.

Default CAM5 physics, default diffusion | CAM-CLUBB, default diffusion | CAM-CLUBB, increased diffusion (5x nu)

Mean vertical pressure velocity | Mean precip. rate



- Using Cloud Layers Unified by Binormals (CAM-CLUBB) in lieu of existing (University of Washington, UW) planetary boundary layer and shallow convection schemes produces double weak double ITCZ (b,e) with default diffusion settings for CAM-SE
- Increasing 4[th]-order hyper-diffusion coefficient by 5x eliminates double-peak signal (c,f)
- Similar behavior to results of Williamson and Olson (2003, QJRMS) using CAM-Eulerian dynamical core

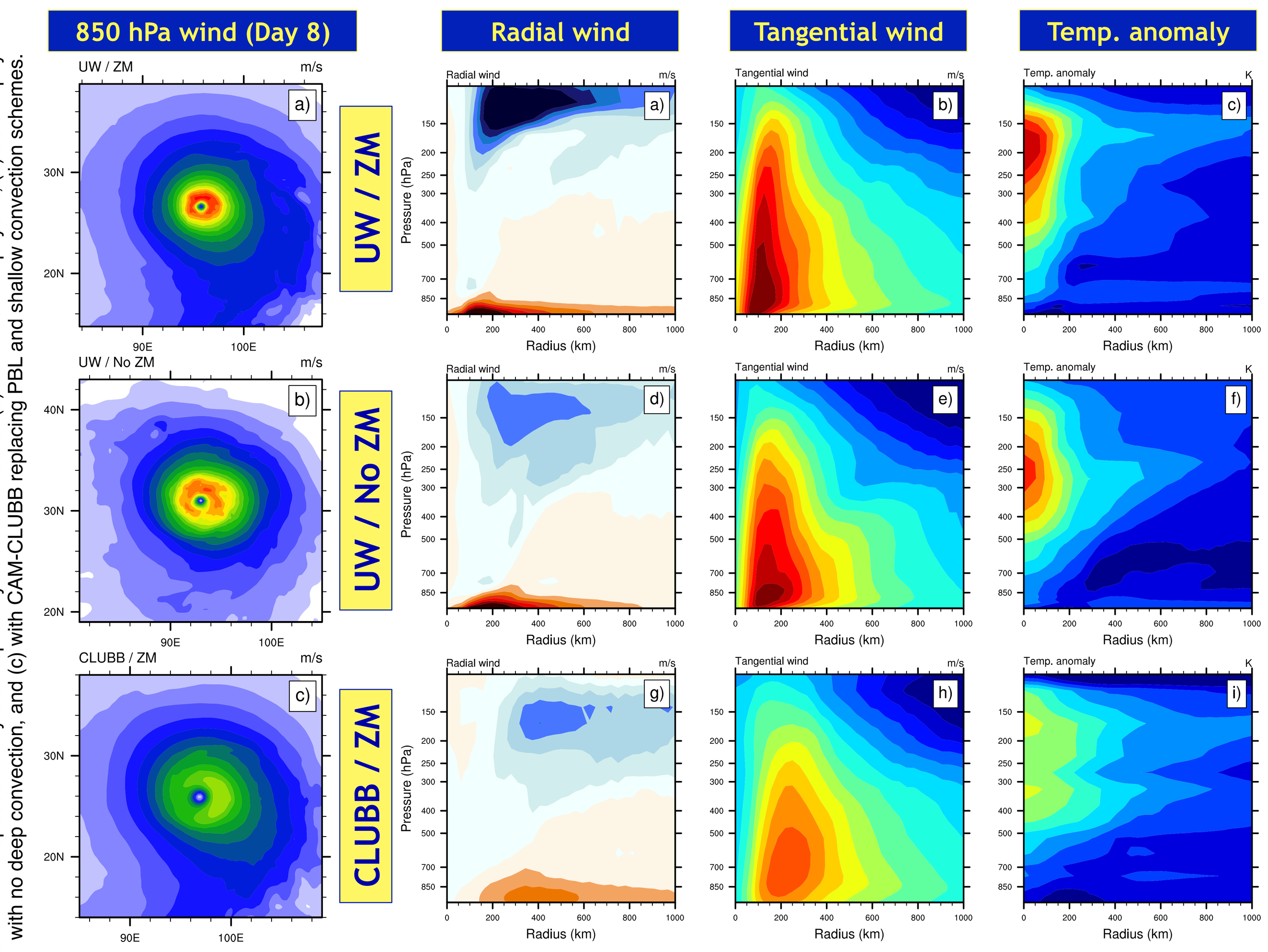
Convective parameterization & tropical cyclone intensity

- Recent AMIP-type climate simulations with CAM-SE at ~14 and ~28 km resolution (Zarzycki and Jablonowski, *in prep.*) imply tropical cyclone strength overpredicted using default physics.
- Simulations using idealized TC vortex test case (Reed and Jablonowski, 2011, MWR) at a horizontal resolution of ~28 km on an aquaplanet imply convective parameterizations play important role in storm intensity modulation
- Intensity of the storm is decreased compared to control (TOP, panels a,b,c) with default physics for simulations without a deep convective (Zhang-McFarlane, ZM) parameterization (MIDDLE, d,e,f) and with CAM-CLUBB (BOTTOM, g,h,i)

Model configuration:
- CAM-SE
- 0.25° (~28 km) grid spacing
- Δt = 1800 sec
- SST = 29° C
- Cyclone initialized at 10° N
- Tropical vertical temperature/ moisture profiles
- No background flow

850 hPa wind (Day 8) | Radial wind | Tangential wind | Temp. anomaly

UW / ZM | UW / No ZM | CLUBB / ZM



850 hPa wind speeds at Day 8 of tropical cyclone test case for (a) default CAM5 physics, (b) default physics with no deep convection, and (c) with CAM-CLUBB replacing PBL and shallow convection schemes.

Radial averages of radial (inflow/outflow) wind (left), tangential wind (center), and temperature anomaly (right) at Day 8 of tropical cyclone test case. Storm center is defined by location of minimum surface pressure.

Conclusions

- **CAM4** physics exhibits strong sensitivity to resolution; poor choice for variable-resolution simulations
- **CAM5** simulations show significantly more promise in facilitating variable-resolution in coupled climate applications
- Climatology in refined meshes in var-res CAM-SE match globally-uniform simulations (for better or for worse!)

C. M. Zarzycki, M. N. Levy, C. Jablonowski, M. A. Taylor, J. Overfelt, and P. A. Ullrich, "**Aqua Planet Experiments Using CAM's Variable-Resolution Dynamical Core.**" *J. Clim.* http://dx.doi.org/10.1175/JCLI-D-14-00004.1

- ITCZ location and intensity can be significantly influenced by choice of convective parameterization as well as model diffusion within the dynamical core
- Similarly, tropical cyclone structure & intensity at high CAM resolutions highly modulated by choice of parameterizations
  - Potentially significant impact on cyclone assessments