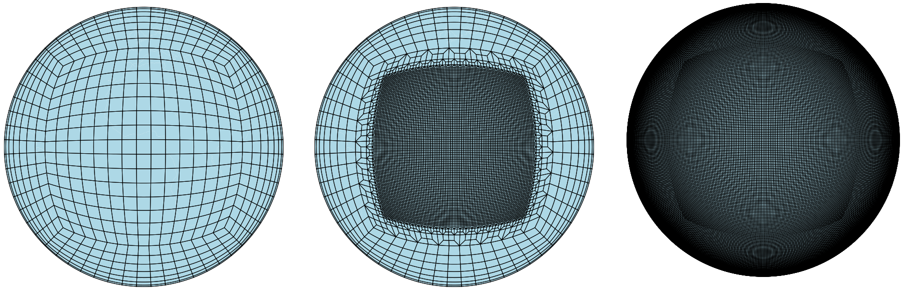
Motivation

Atmospheric, Oceanic and Space Sciences
UNIVERSITY of MICHIGAN

The impact of localized grid refinement on subgrid parameterization in idealized climate simulations

- **For variable-resolution general circulation models to be effective tools for climate assessments they need to be validated in conjunction with subgrid physical parameterization**
- Use DoE/NSF Community Atmosphere Model Spectral Element dynamical core (CAM-SE) to test variable-resolution performance with GCM physics package
- Perform 6 simulations using "control" aquaplanet from Neale and Hoskins (2000, ASL)
  - Three using **CAM4** physics
  - Three using **CAM5** physics
- Assess climatology



"coarse" "var-res" "fine"

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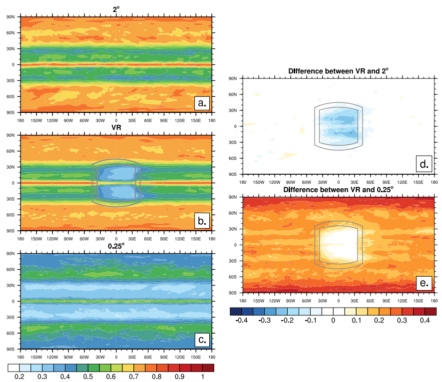
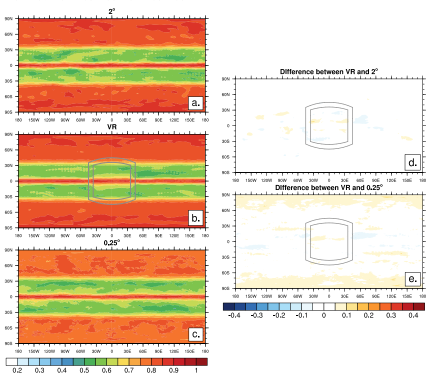
(Some) Results

Cloud fraction

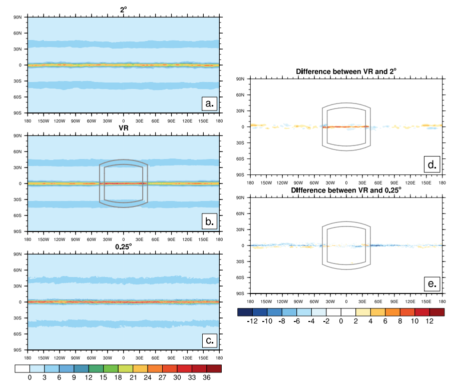
CAM4

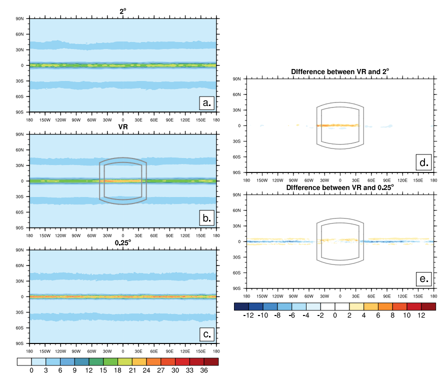


CAM5



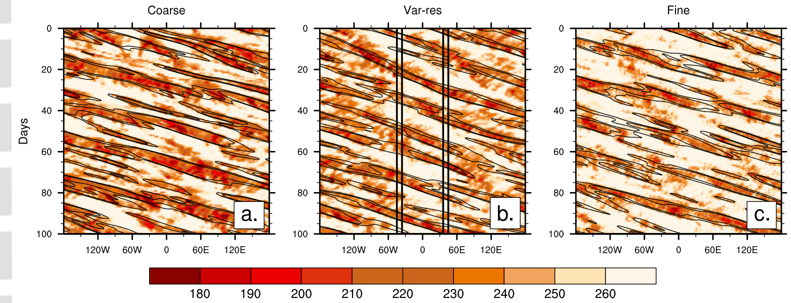
Precipitation



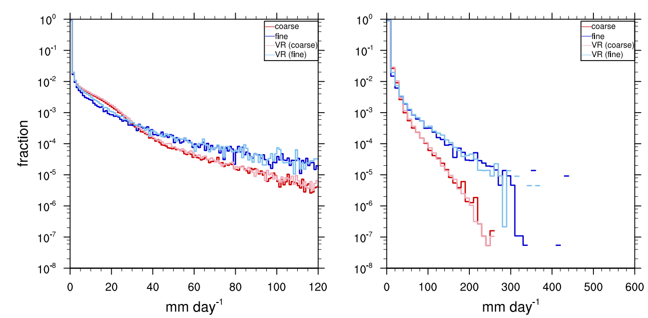


- CAM4 physics shows extreme scale sensitivity to cloud fraction, CAM5 much improved
- Both physics packages increase precipitation with resolution

Kelvin Waves



Precipitation extremes



- CAM-SE allows wave features to pass through transition region satisfactorily
- Climate in nest matches corresponding uniform climate

The impact of localized grid refinement on sub-grid parameterization in idealized climate experiments

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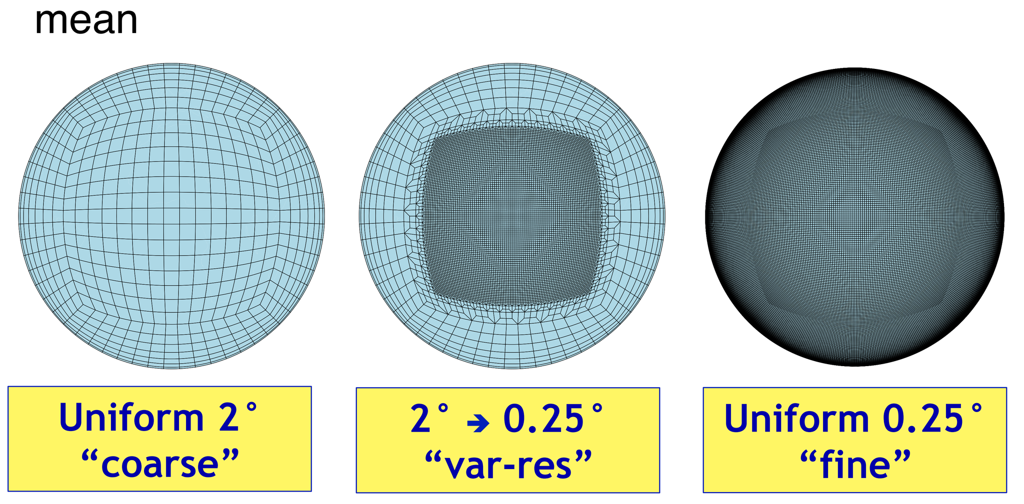
Variable Resolution in CAM-SE

- Variable-resolution feature implemented in NSF/DoE **C**ommunity **A**tmosphere **M**odel (CAM) **S**pectral **E**lement (SE) dynamical core.
- From **H**igher **O**rder **M**ethods **M**odeling **E**nvironment (HOMME)
- Quadrilateral elements on a cubed sphere
  - Arbitrary quadrilateral elements (no rectangular restriction)
  - **Conforming refinement**
    - Every edge shared by only two elements
  - **Unstructured**
    - No need for grtid to be tiled in (i,j) fashion
  - **Static refinement**
    - Grid refined during initialization, does not follow atmospheric features
- Special considerations (relative to uniform grid with CAM-SE)
  - Timestep globally restricted to finest grid scale (CFL)
  - Fourth-order hyper-diffusion based on cell length scale

Experimental Setup

- 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



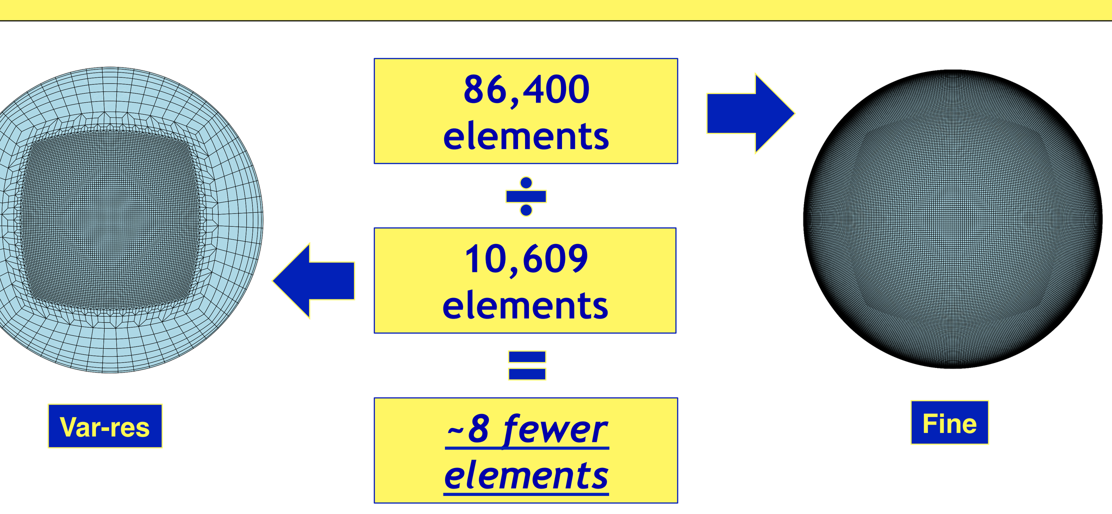
Model Settings

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

Computational Considerations



- Cursory simulations show essentially linear speedup for the atmospheric component
  - Var-res simulation runs 7-9 times faster than uniform fine grid (without controlling for variations due to hardware)

Reference

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 (manuscript available on http://www.colinzarzycki.com until AMS Early Online Release)

Parameterization Behavior Across Scales

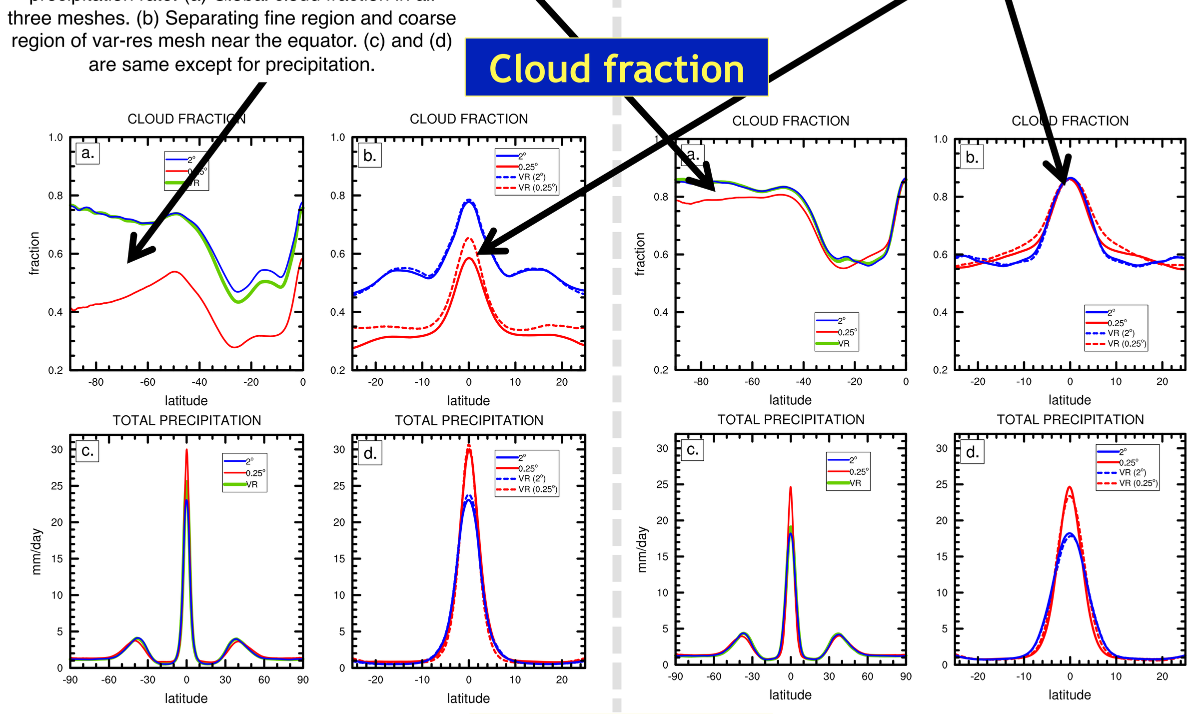
CAM4

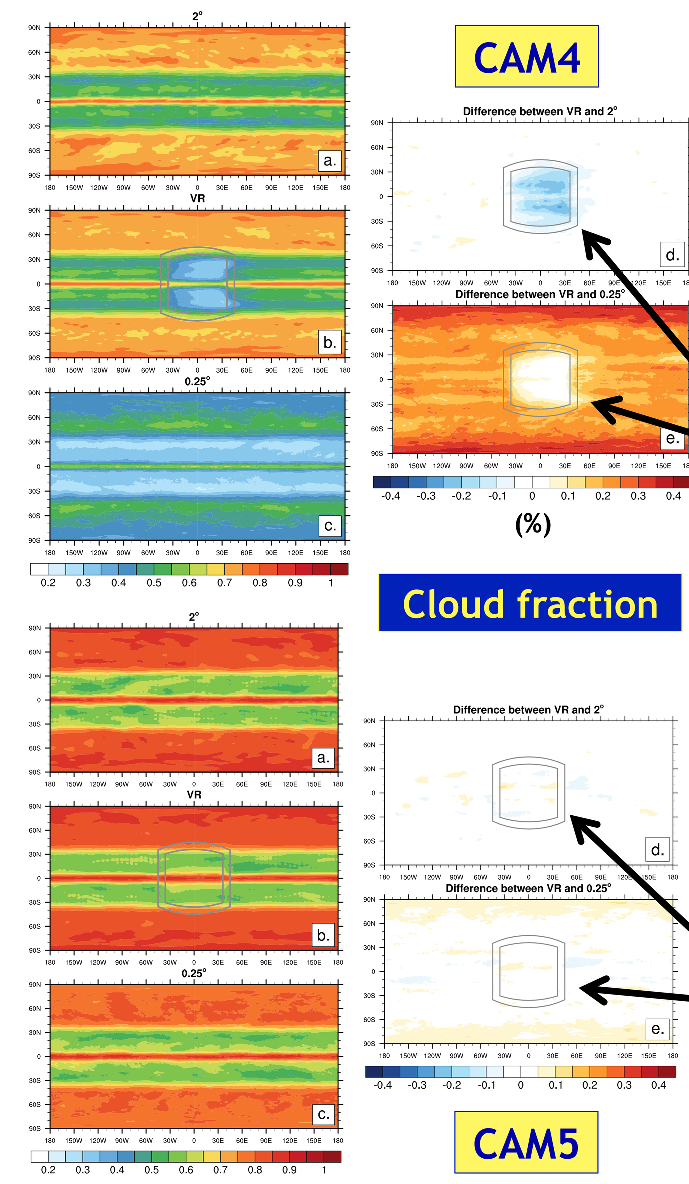
- Extreme scale sensitivity with CAM4 clouds
- CAM5 shows increased cloud fraction at all latitudes, but better behavior at multiple resolutions

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.



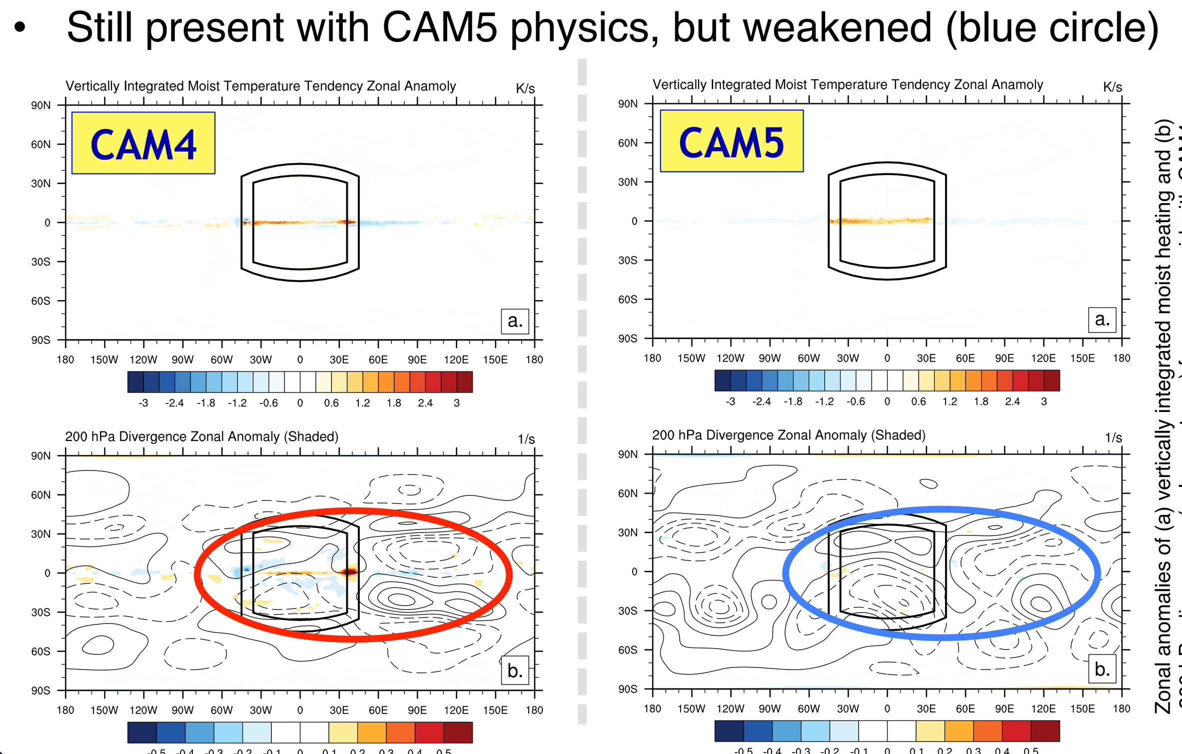


- **CAM4**
  - Very scale selective, climate in the coarse (top left) very different from fine (bottom left)
  - Significant grid imprinting induced by the physics in the var-res simulation
- **CAM5**
  - Increase in cloud fraction in all simulations at all latitudes compared to CAM4
  - Much better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

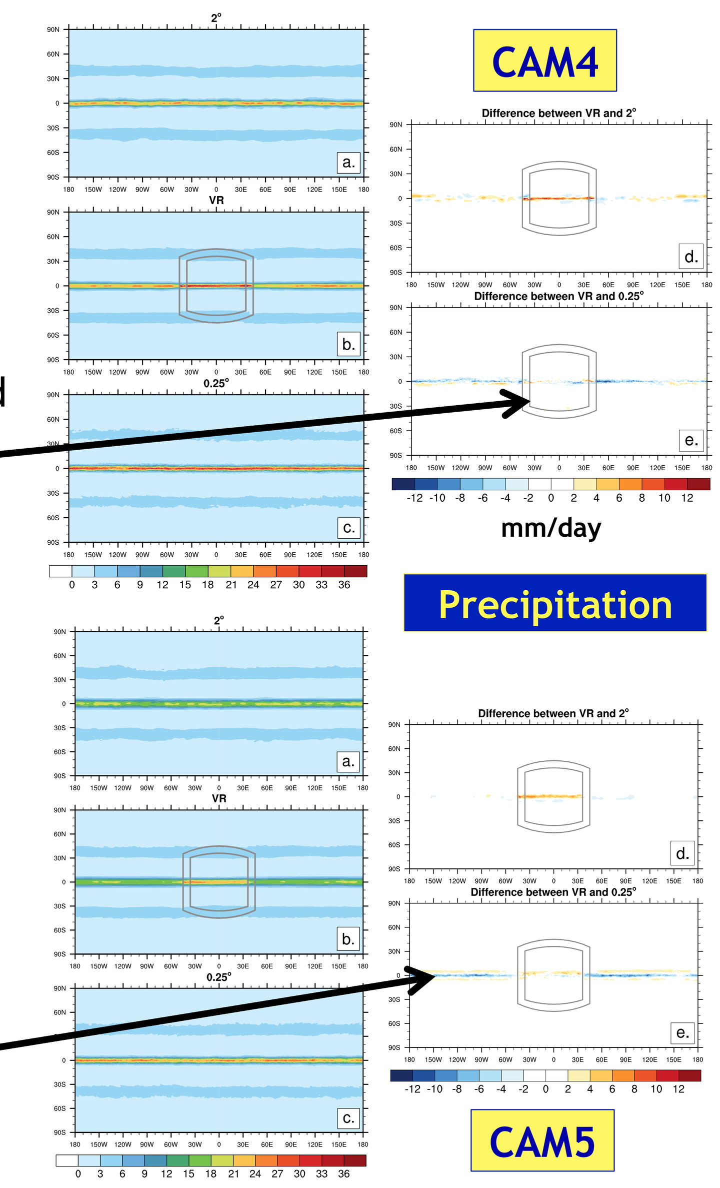
- Precipitation increases at equator with increasing resolution for both CAM4 and CAM5
- Adjusts more "instantaneously" to resolution than cloud fraction

- 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, Jclim) (red circle)
- Still present with CAM5 physics, but weakened (blue circle)



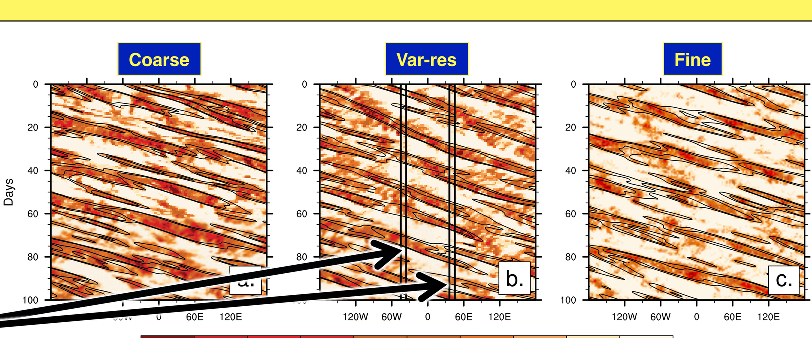
Zonal anomalies of (a) vertically integrated moist heating and (b) 200 hPa divergence (color contours) for var-res grid with CAM4 (left) and CAM5 (right) physics. In (b) the 200 hPa eddy streamfunction is contoured by 10^6 m^2/s. Negative contours are dashed

- **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?

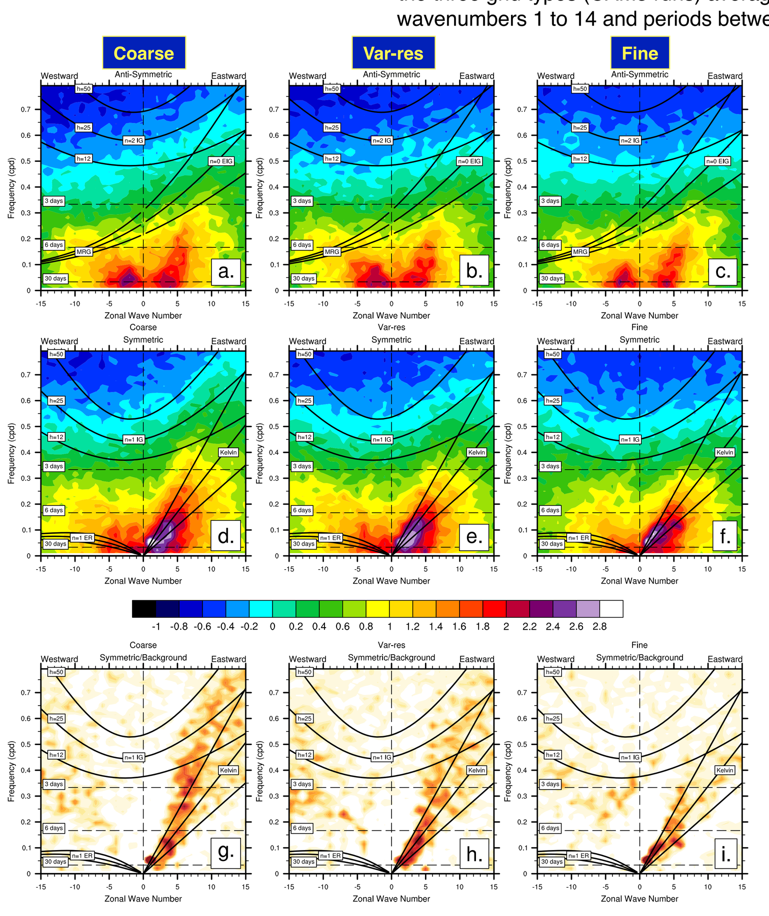


Equatorial Waves (CAM5)

- Kelvin waves transit through discontinuity
- No wave reflection at grid boundary regions



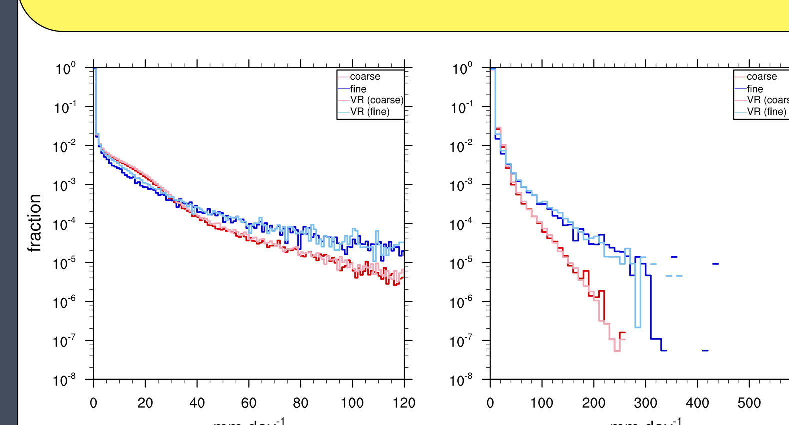
Time-longitude diagram of 100 days of outgoing longwave radiation (W/m²) for each of the three grid types (CAM5 runs) averaged between 10° N/S. A band-pass filter of wavenumbers 1 to 14 and periods between 2.5 and 20 days is contoured in black.



- Top two rows -> unnormalized power spectra based on Williamson (2008a, Tellus)
- No anomalous power spikes
- Var-res runs show "transition" between uniform/ coarse resolutions
- Normalized spectra (bottom row) show robust Kelvin waves, similar results

Wavenumber-frequency diagrams of outgoing longwave radiation averaged between 10° N/S for CAM5 runs. Unnormalized anti-symmetric (a-c), unnormalized symmetric (d-f), and normalized symmetric (g-i) components of the log of the power are shown for the coarse (a,d,g), var-res (b,e,h), and fine (c,f,i) simulations

Precipitation Extremes (CAM5)



Precipitation histogram of fraction (log scale) of instances where 6-hourly precipitation rates were in specific intensity bins (CAM5 runs). Statistics averaged between 10° N/S. Var-res simulation is broken into component resolutions (pastel colors). Data is same in both panels; bin size and horizontal axis are modified.

- High-resolution grid spacing provides better representation of precipitation extremes
- Nest components match grid spacing of same uniform grid

Conclusions

- Refined CAM-SE grids coupled to subgrid physical parameterizations in idealized settings show promising results
  - No spurious grid imprinting or wave reflection at boundaries, even with addition of parameterizations which update dynamical state variables
  - Climate in refined nest matches climatology from a uniform high-resolution simulations of equivalent resolution (clouds, precipitation averages and extremes)
- **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