Development of Frameworks for Robust Regional Climate Modeling

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Motivation

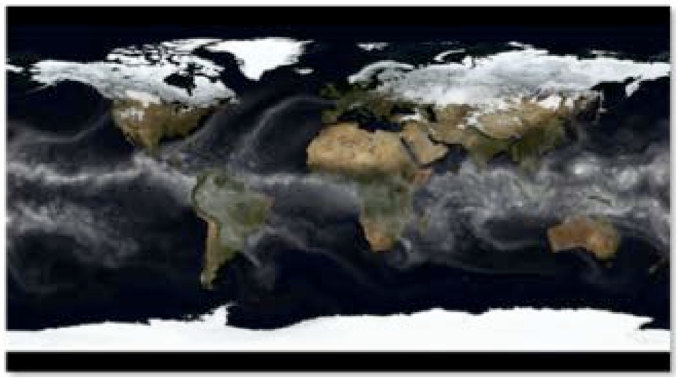
- Predicting the regional hydrologic cycle at time scales from seasons to centuries is important as water supports ecosystems and a wide range of human activities
- Large uncertainties exist in model predictions of the regional hydrologic cycle

Objective

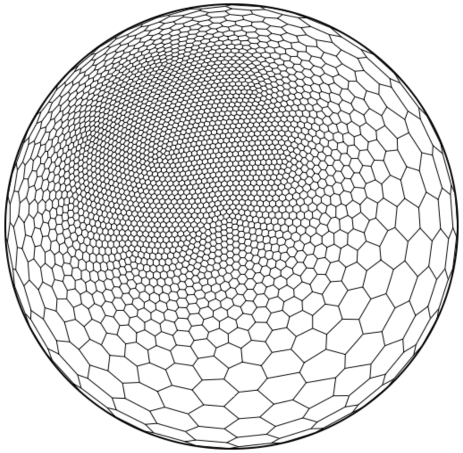
- To reduce uncertainty in regional climate simulations through systematic evaluation and comparison of different modeling approaches to identify and characterize the sources of uncertainty

Overarching hypothesis

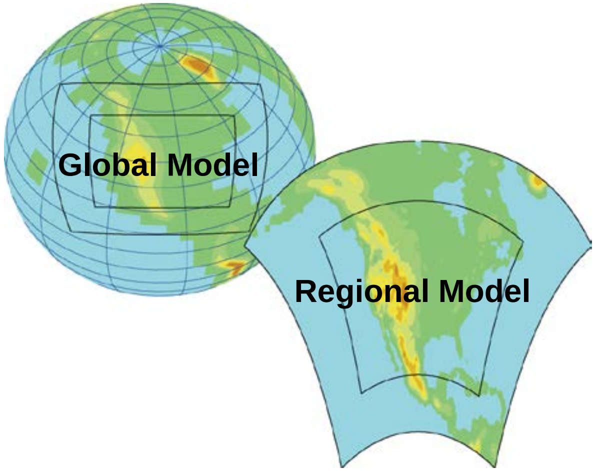
- Different dynamical approaches for modeling climate at regional scales can lead to uncertainties that can be quantified through a hierarchical evaluation framework
  - How important is representing scale interactions?
  - Is coupling of atmosphere/ocean important at regional scales?
  - Is climate feedback sensitive to different approaches and how?



Global high resolution model



Global variable resolution model



Nested regional climate model

A hierarchical evaluation framework

- Evaluate simulations progressing from simple to complex and from idealized to real world
  - Idealized no physics simulations
    - Shallow water test case
  - Idealized full physics simulations
    - Aqua-planet simulation
    - Channel flow simulation
  - Real world single component simulations (N/S America)
    - Real world atmosphere simulations
    - Real world ocean simulations
  - Real world coupled simulations
    - Real world coupled atmosphere-ocean simulations

Global vs regional

- Simulations will be performed with all models sharing the same physics suite:
  - GS-LR:
    - Global Simulations at Low Resolution (T85 or 1º)
  - GS-HR: **Virtual reality / Truth**
    - Global Simulations at High Resolution (T340 or 0.25º)
  - GS-VR:
    - Global Simulations using Variable Resolution (1º/0.25º)
  - RS-HR:
    - Regional Simulations at High Resolution (0.25º) driven by GS-LR

Resolution (GS-LR, GS-HR)

Dynamical approach (GS-LR, GS-HR, GS-VR, RS-HR)

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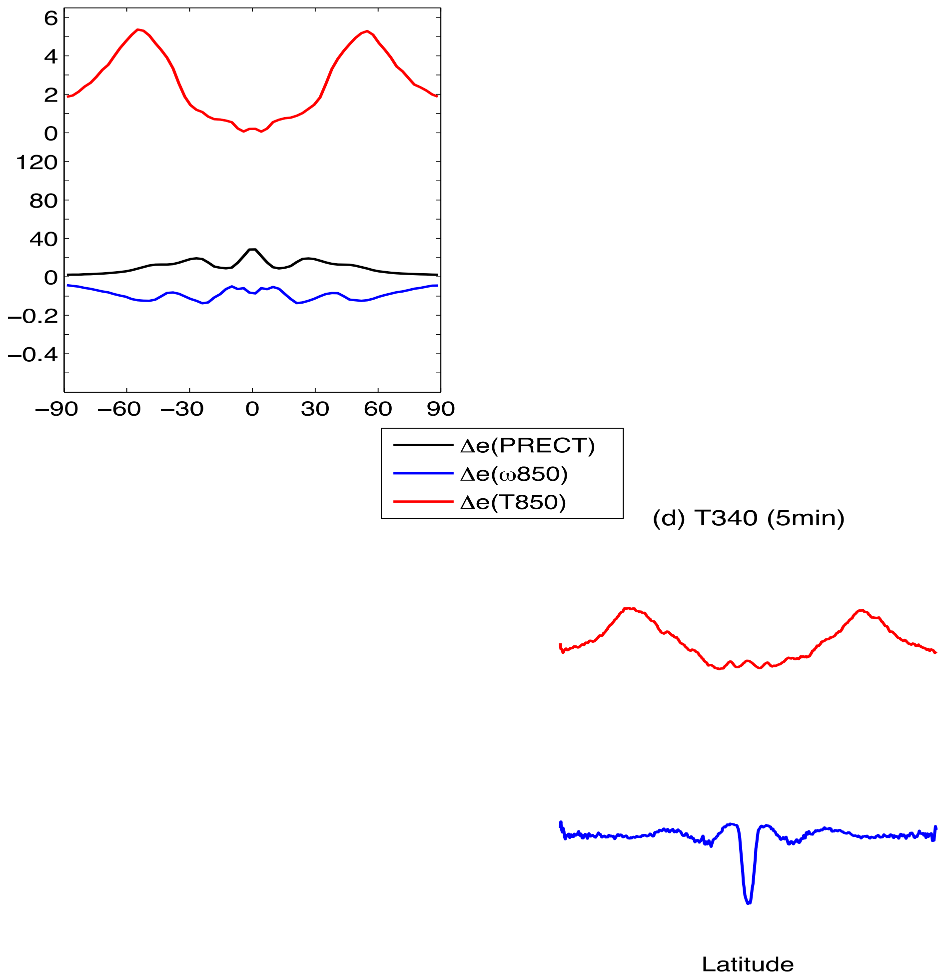
Participating climate models

- Community Climate System Model (CCSM)
  - Atmospheric component
    - CAM-spectral (Eulerian) – LBNL, ORNL
    - CAM-HOMME (spectral finite element) - SNL
    - MPAS-A (variable resolution finite volume) - LANL
  - Ocean component
    - POP (finite difference) - LANL
    - MPAS-O (variable resolution finite volume) - LANL
- Nested regional climate models
  - Weather Research and Forecasting (WRF) Model - PNNL
    - Atmospheric component: WRF driven by CAM-spectral
    - Ocean component: ROMS driven by POP
  - RegCM3 - ORNL
    - Atmosphere only (*different physics) driven by CAM-spectral

Aqua-Planet Experiment (APE)

- CAM-spectral: T42, T85, T170, T340
- CAM-MPAS: 240km, 120km, 60km, 30km, 240km $\longrightarrow$ 30km
- CAM-HOMME: 2°, 1°, 0.5°, 0.25°
- WRF: 1°, 0.25° (1°, 0.2°, 0.04°)

CAM-spectral APE: Impact of horizontal resolution on the simulation and projection of extreme precipitation



Results:

- Precipitation extremes do not converge with climate-model horizontal resolutions, primarily due to the parameterization of prognostic stable precipitation.
- Updraft appears to contribute to the resolution dependency of extreme precipitation and to be the driving physical factor for the extreme events

Anomalies of extreme precipitation (black), ω (blue) and temperature (red) as functions of horizontal resolution

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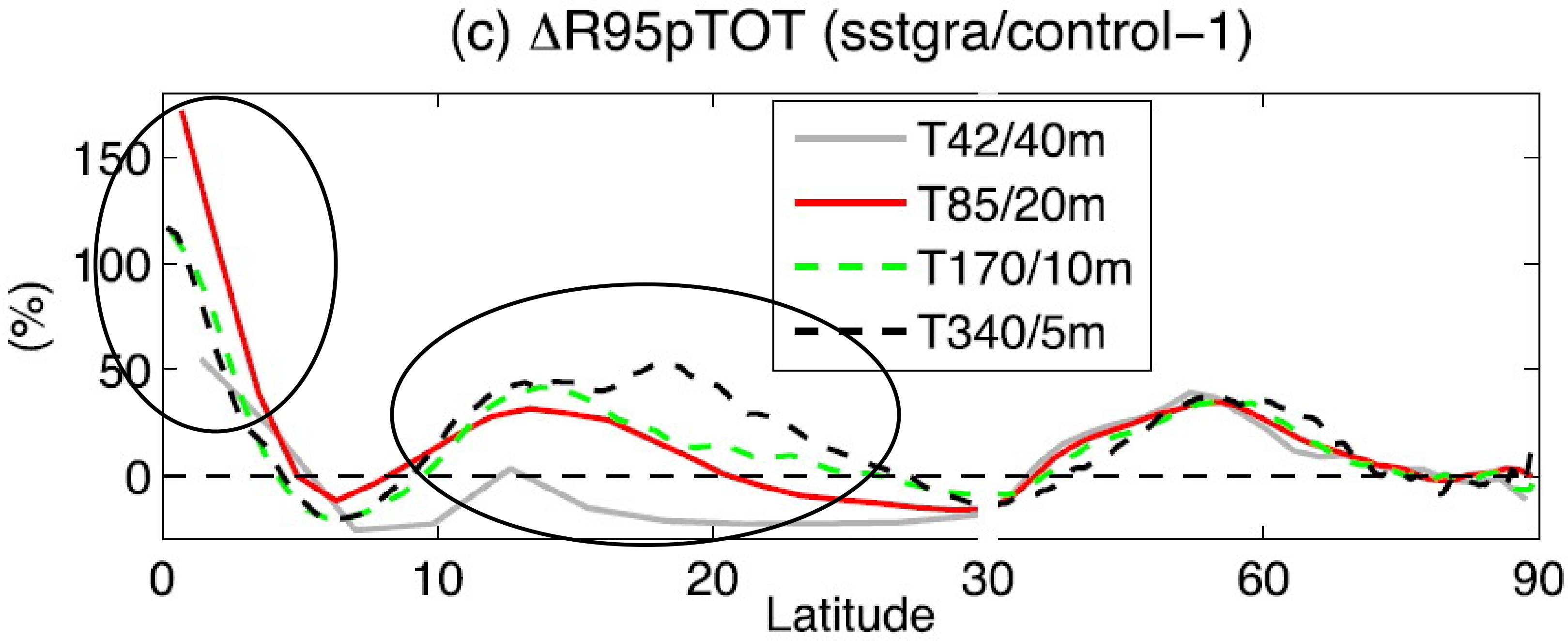
Fractional changes of extreme precipitation (>95th percentile) under global warming

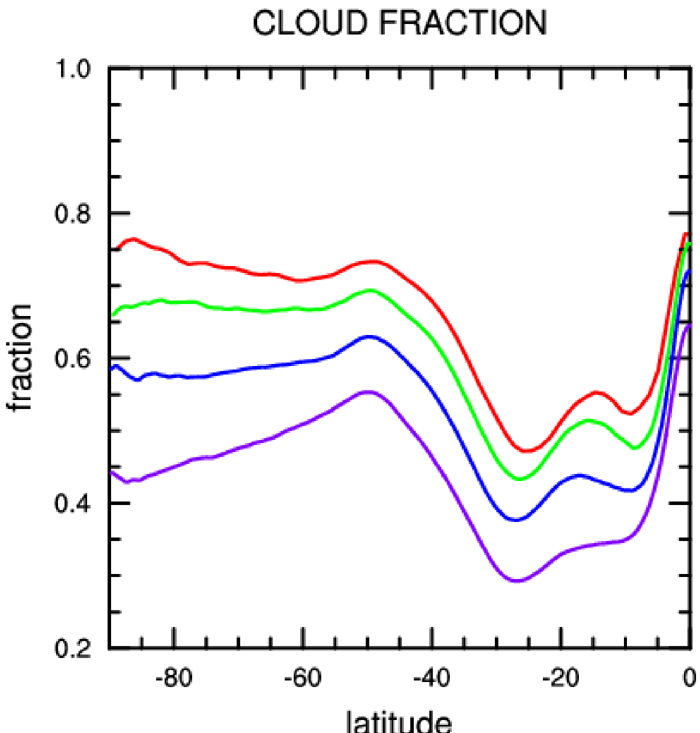


Results:

Horizontal model resolution plays important roles in extreme precipitation projections, strongly affecting the global warming signals in low-mid latitude regions – have to account for the effects of horizontal resolution to develop more robust projections of precipitation extremes.

CAM-HOMME APE

- Completed CAM4 simulations for use in variable resolution dycore studies
  - 5 year simulations at 2.0, 1.0, 0.5 and 0.25º resolutions
- CAM aquaplanet_cam4 produces a climate that is symmetric about the equator and shows a strong signal under mesh refinement, similar to that seen in CAM3.1 (Williamson, Tellus 2007)



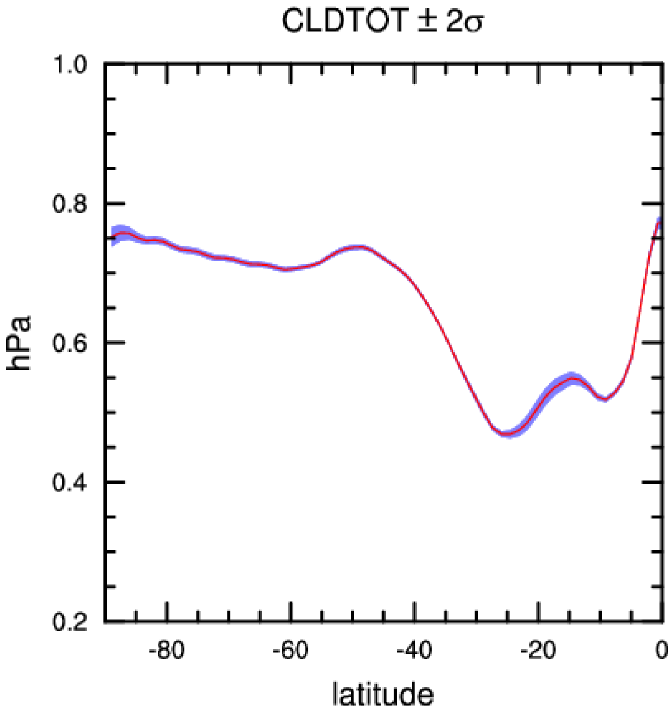
Cloud fraction shows expected strong resolution sensitivity.

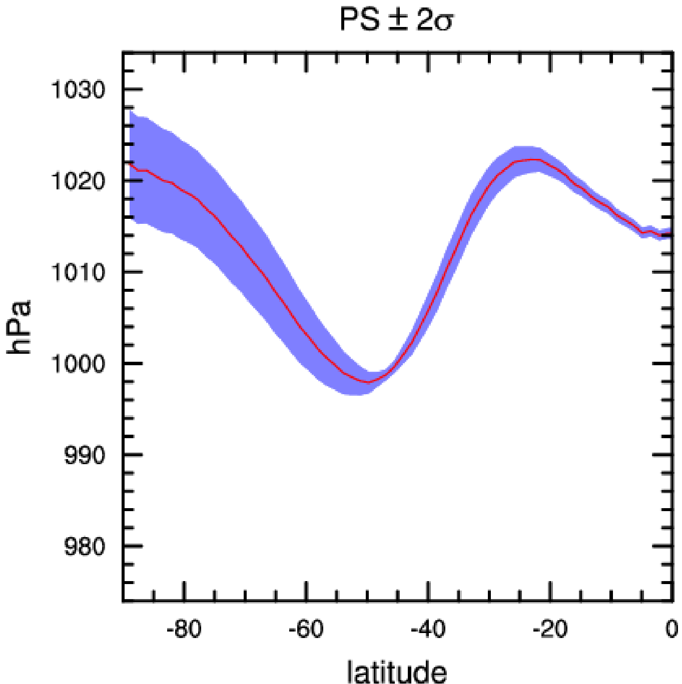
2	red
1	green
0.5	blue
0.25	purple

CAM-HOMME APE

- Zonal means are well converged when averaged over 1 year, except surface pressure (PS)
  - PS variability above 50N (or below 50S) is as large as the changes with respect to resolution, thus significantly longer simulations are needed if PS is to be included in a resolution study

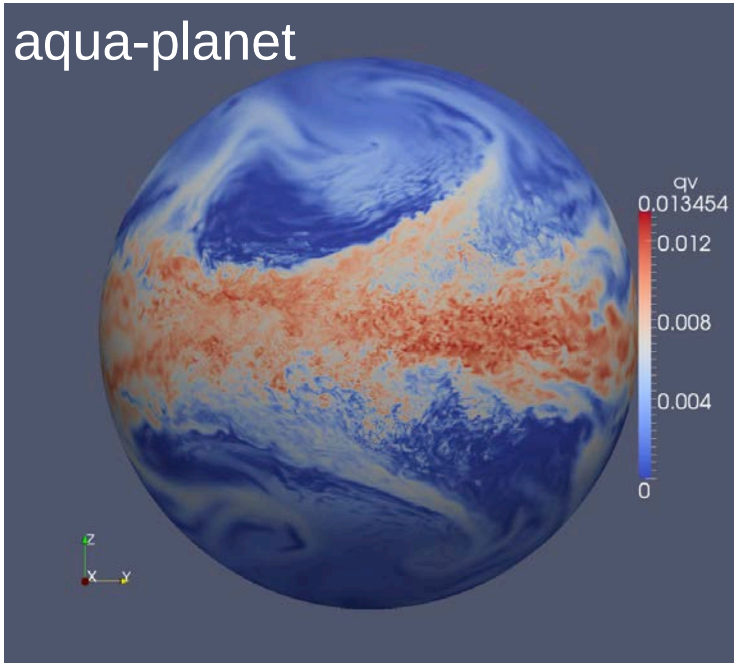
20 year average (red) and s.d. (purple) of zonal mean cloud fraction and PS





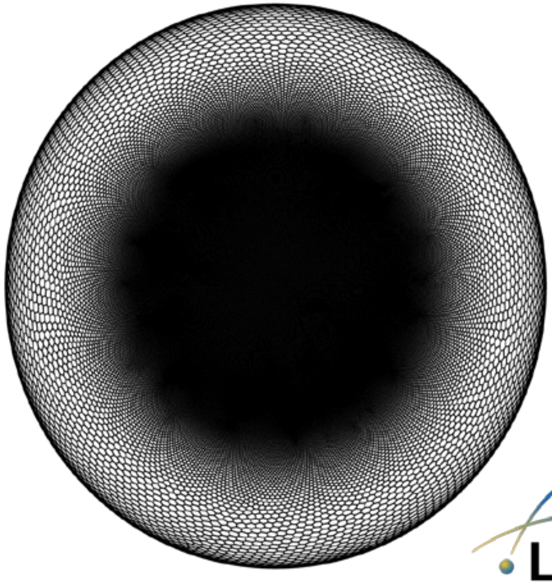
CAM-MPAS (Model for Prediction Across Scales) APE

- MPAS is a global-to-regional climate modeling approach that permits an arbitrary number of user- specified regions of mesh refinement
- The LANL/NCAR team is evaluating this approach in the context of the shallow-water system, 3D atmosphere hydrostatic/non-hydrostatic systems and 3D ocean hydrostatic system



Snapshot of water vapor (kg/kg) at 450 hPa.
Figure centered on high resolution region.

240km→30km ~ 1/10 number of grid points of a global, quasi-uniform mesh of 30 km



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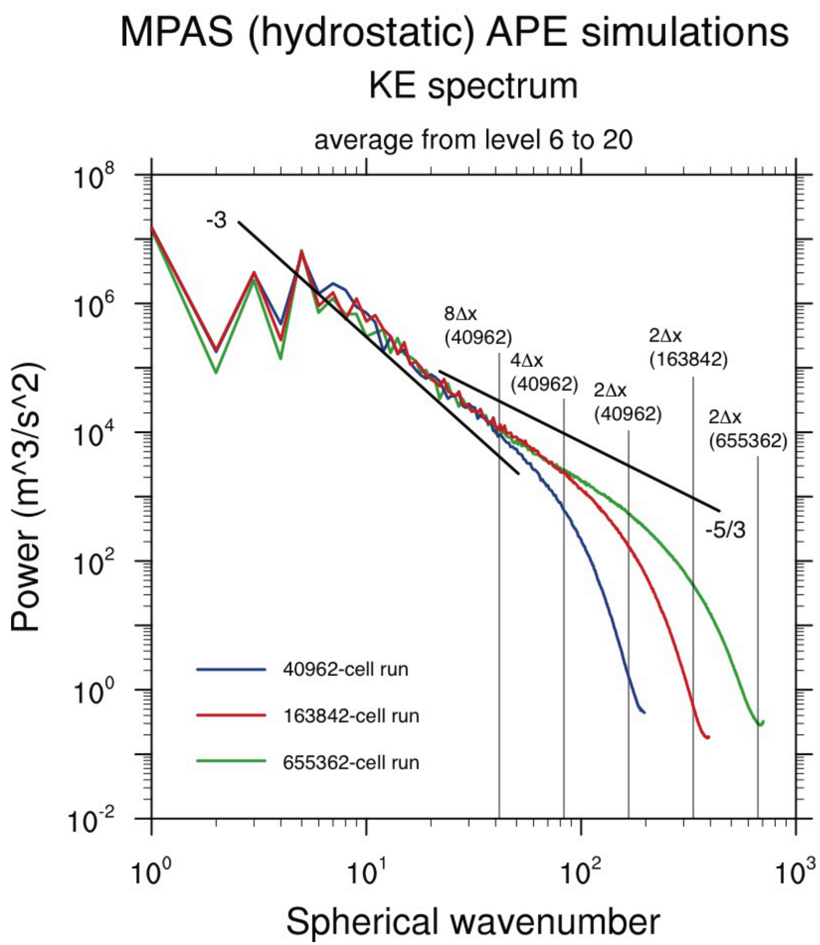
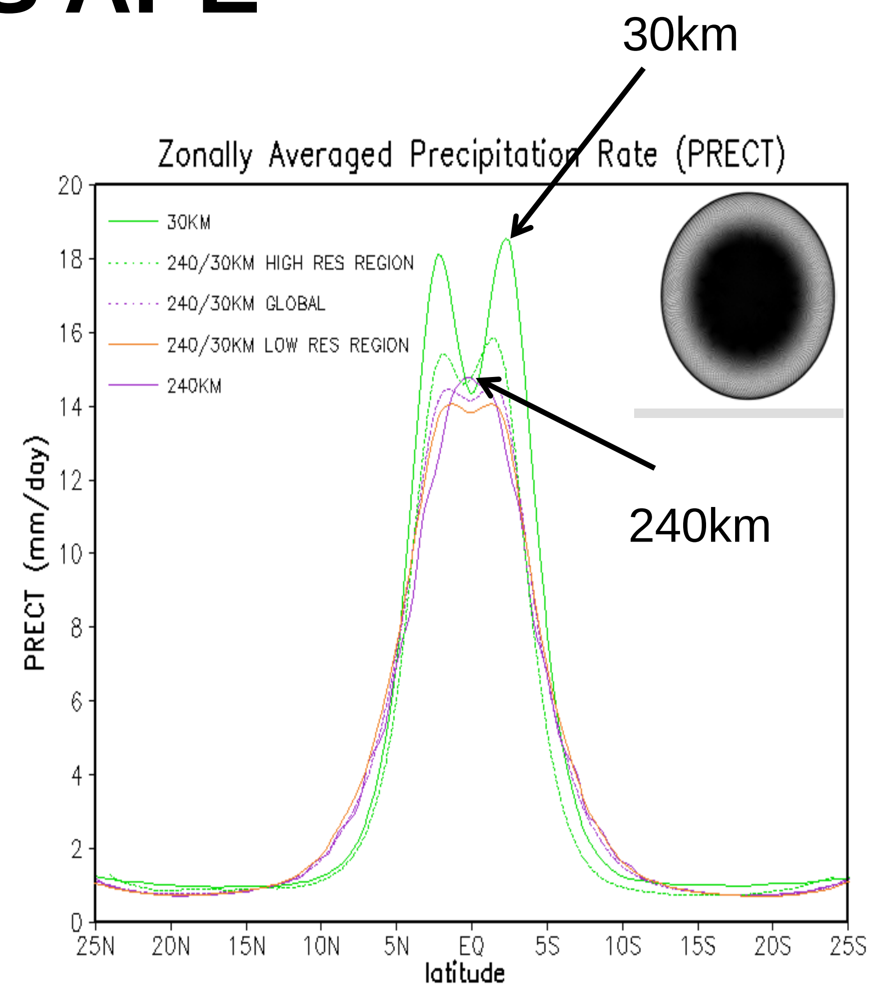
CAM-MPAS APE



A transition from -3 to -5/3 slope at a horizontal scale of approximately 400 km (Nastrom and Gage 1985)



ITCZ has strong resolution dependence

see Petersen talk in Global Ocean breakout
see Ringler talk in High Resolution breakout

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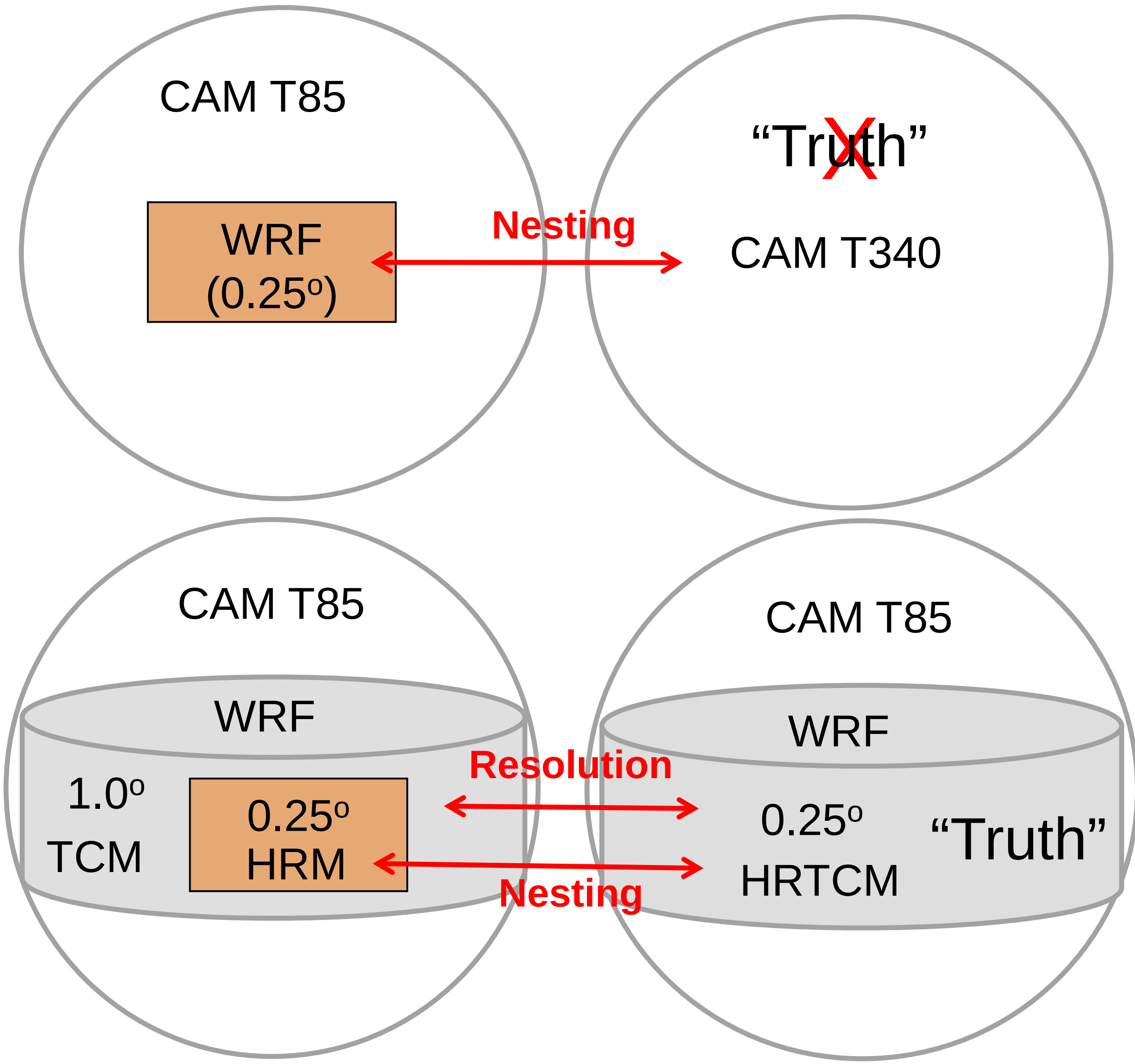
WRF APE experimental design



- The CAM4 physics package is used in both CAM and WRF simulations
- Even with the same physics, differences between CAM and WRF dynamical cores and how physics are implemented matter – CAM T340 cannot be treated as the "truth" for evaluating WRF
- WRF is configured as TCM and run at 1° with a nested domain at 0.25° for comparison with the TCM at 0.25°

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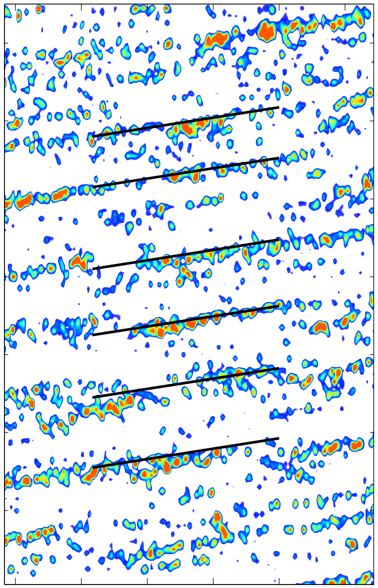
Propagating features and phase speed

TCM **HRM1WAY** **HRM2WAY** **HRTCM**



Raw precipitation averaged between 10S and 10N in mm/day – the black lines mark the propagation speed of about 23 m/s

- The precipitation signal is dominated by 20-day Kelvin waves that maintain their amplitude and phase as they propagate through the boundaries of the regional domain

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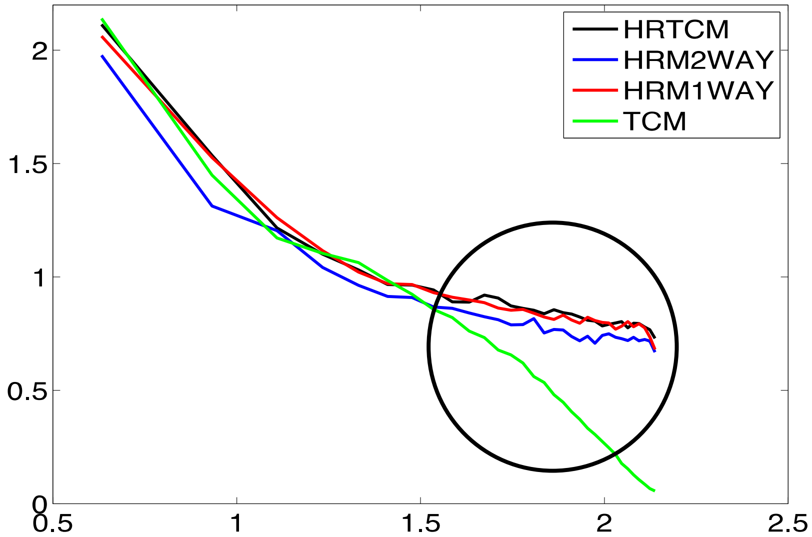
Precipitation spectra

Total precipitation

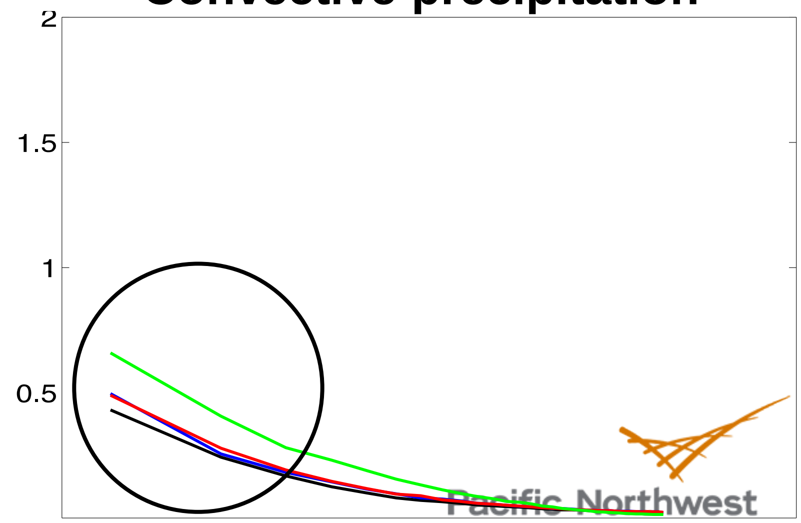


Non-convective precipitation

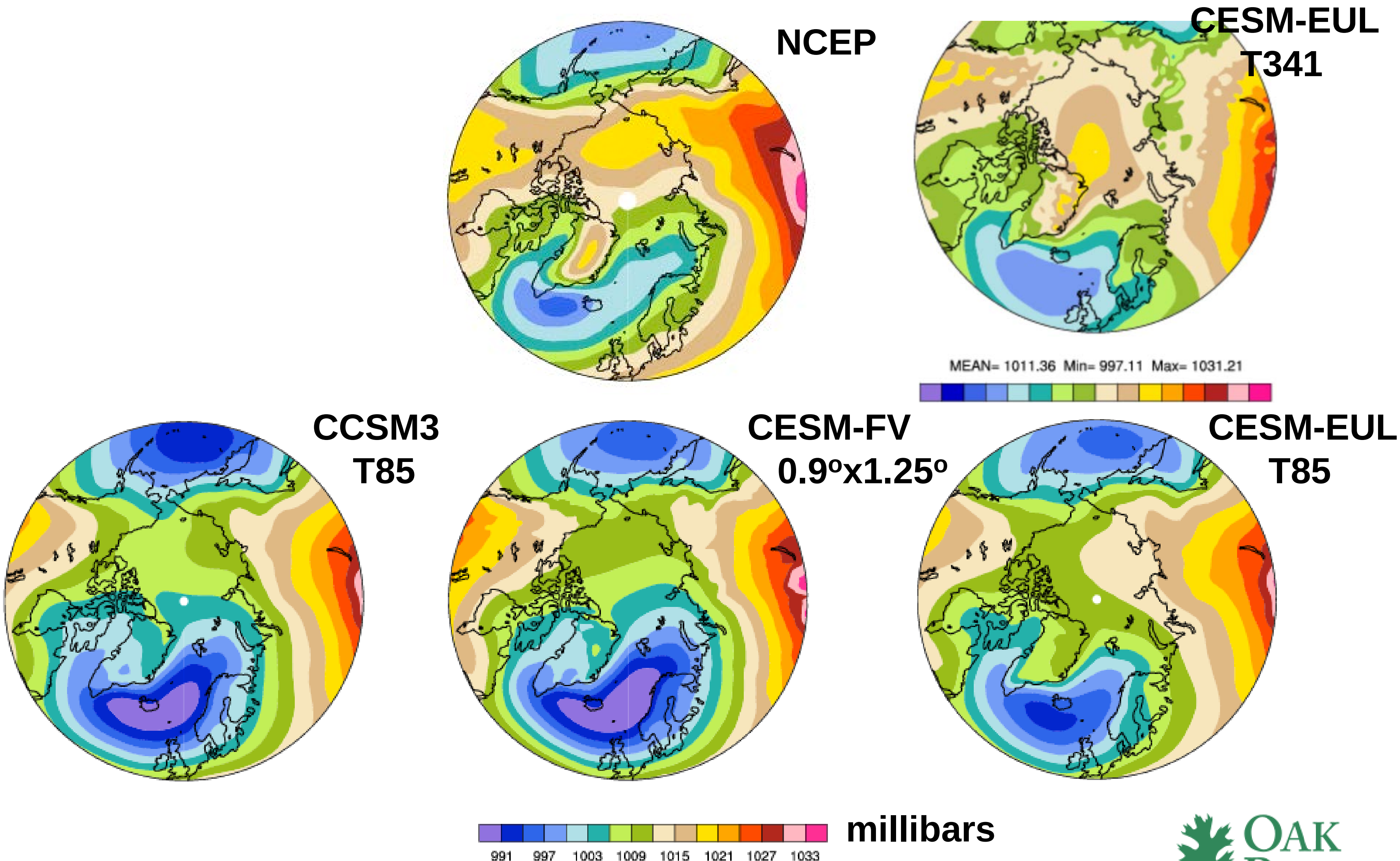
- More eddies of scale < 1000 km are resolved by HRM and HRTCM

- At higher resolution, convective precipitation is reduced but compensated by the resolved precipitation at finer scales

Convective precipitation



CAM-spectral real world simulations: DJF Sea Level Pressure – Northern Hemisphere



Summary

- A hierarchical evaluation framework is used to quantify the effects of dynamical approaches and resolution on climate simulations at regional scales
- Aqua-planet simulations are being performed using three different CAM dynamical cores and a nested regional model (WRF)
- Analyses of APEs have focused on the hydrological cycle in the tropics – some indications that:
  - The variable resolution and nesting approaches can reproduce important features of the global high resolution "truth"
  - Resolution (between 1^{o} to 0.25^{o}) has larger effects on the simulation than dynamical approaches
  - Even larger effects are from 0.25^{o} to cloud permitting scales
- Some efforts on real world simulations have begun, and will be a focus of the next phase