Analysis of the MPAS hydrostatic dynamical core in aqua-planet mode

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Climate, Ocean and Sea-Ice Modeling Project
http://public.lanl.gov/ringler/ringler.html

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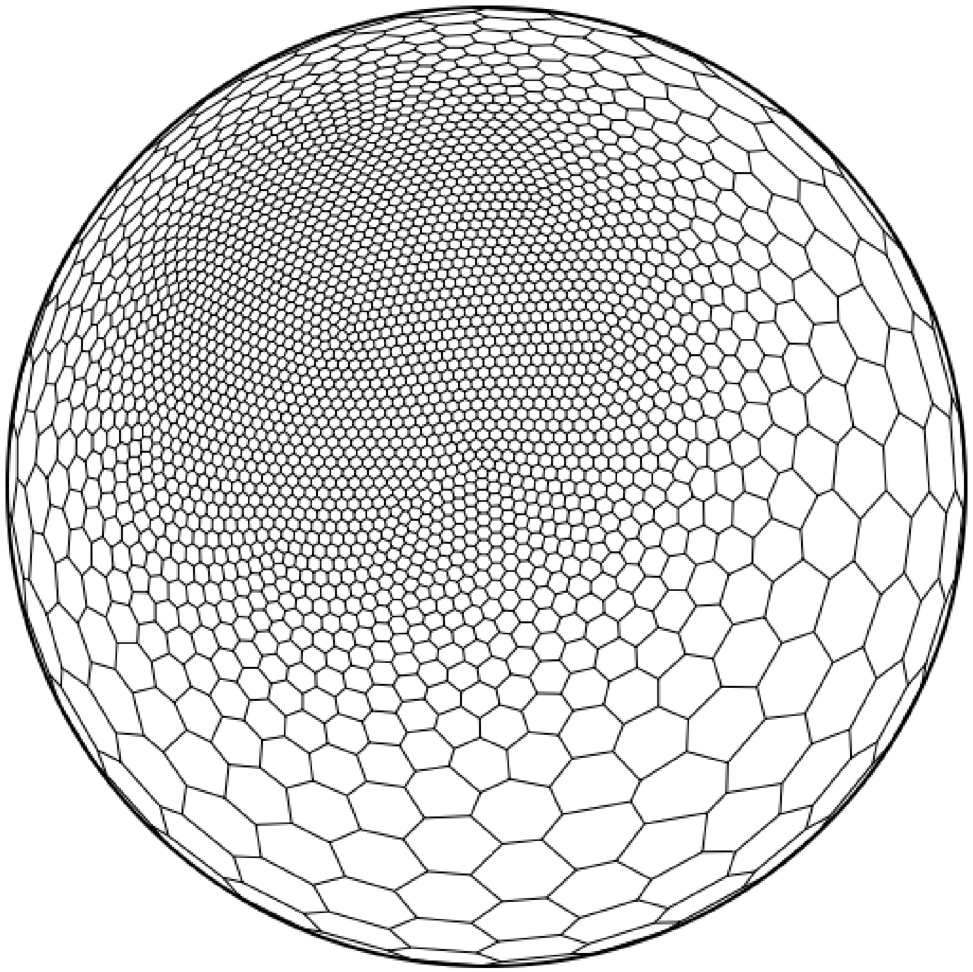
What is MPAS?

1. MPAS is an unstructured-grid approach to climate system modeling.

2. MPAS supports both quasi-uniform and variable resolution meshing of the sphere using quadrilaterals, triangles or Voronoi tessellations.

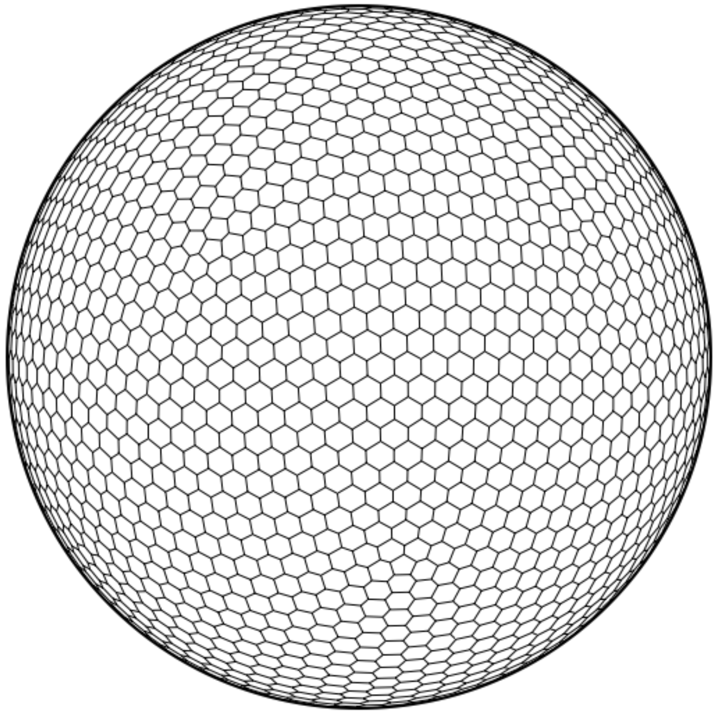
3. MPAS is a software framework for the rapid prototyping of single-components of climate system models (atmosphere, ocean, land ice, etc.)

4. MPAS offers the potential to explore regional-scale climate change within the framework of a global climate system modeling.

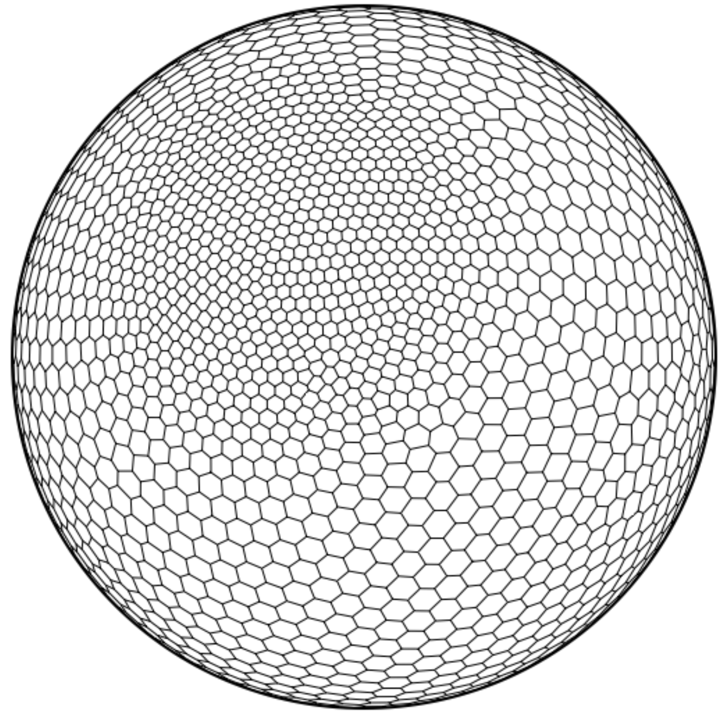


We have started to evaluate the MPAS variable-resolution approach.

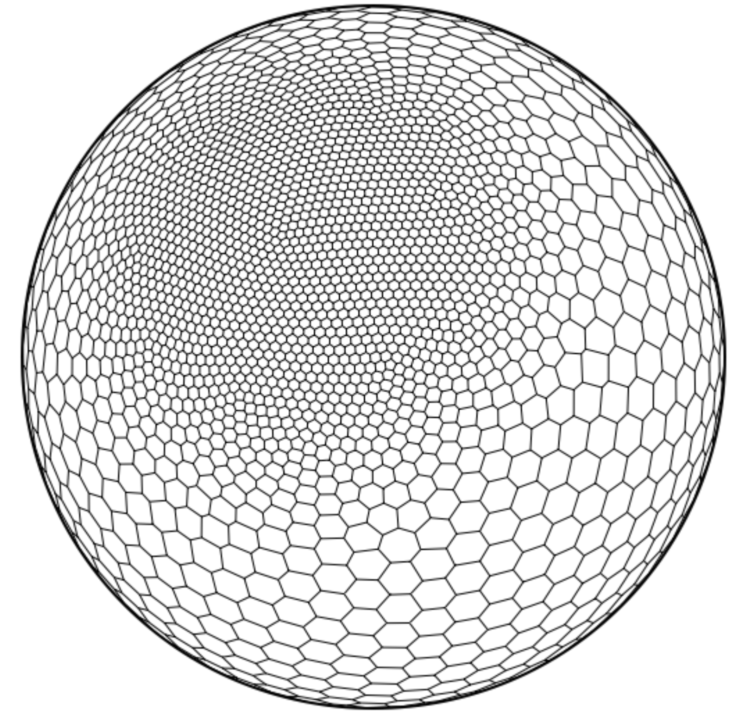
(these are Spherical Centroidal Voronoi Tessellations)



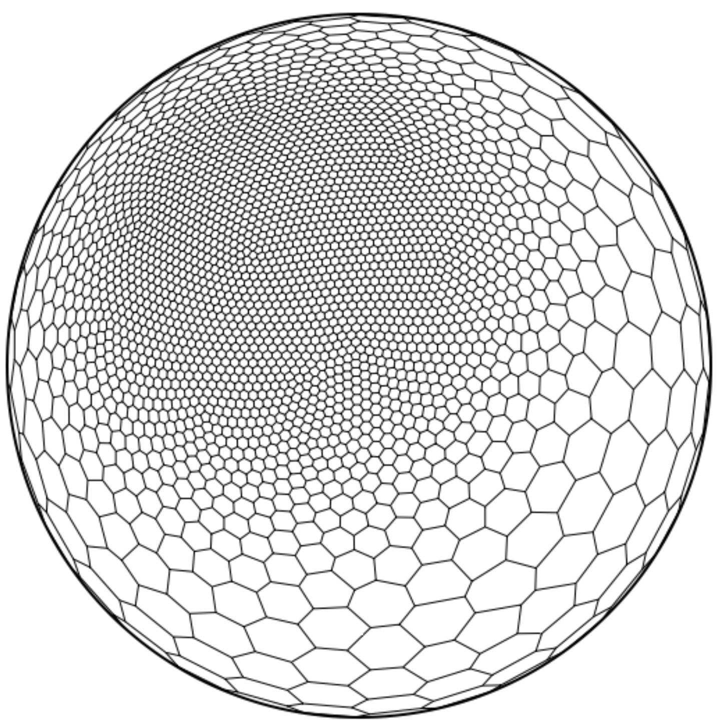
x1



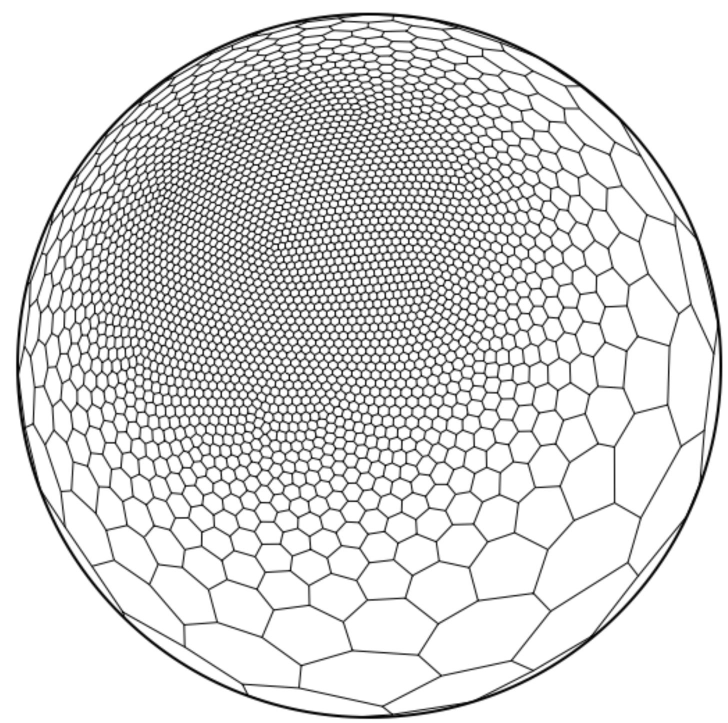
x2



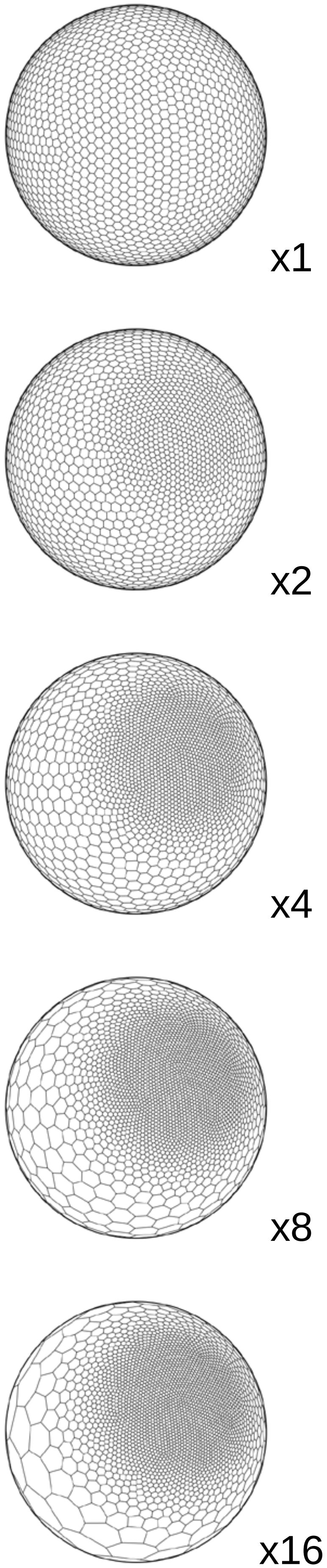
x4



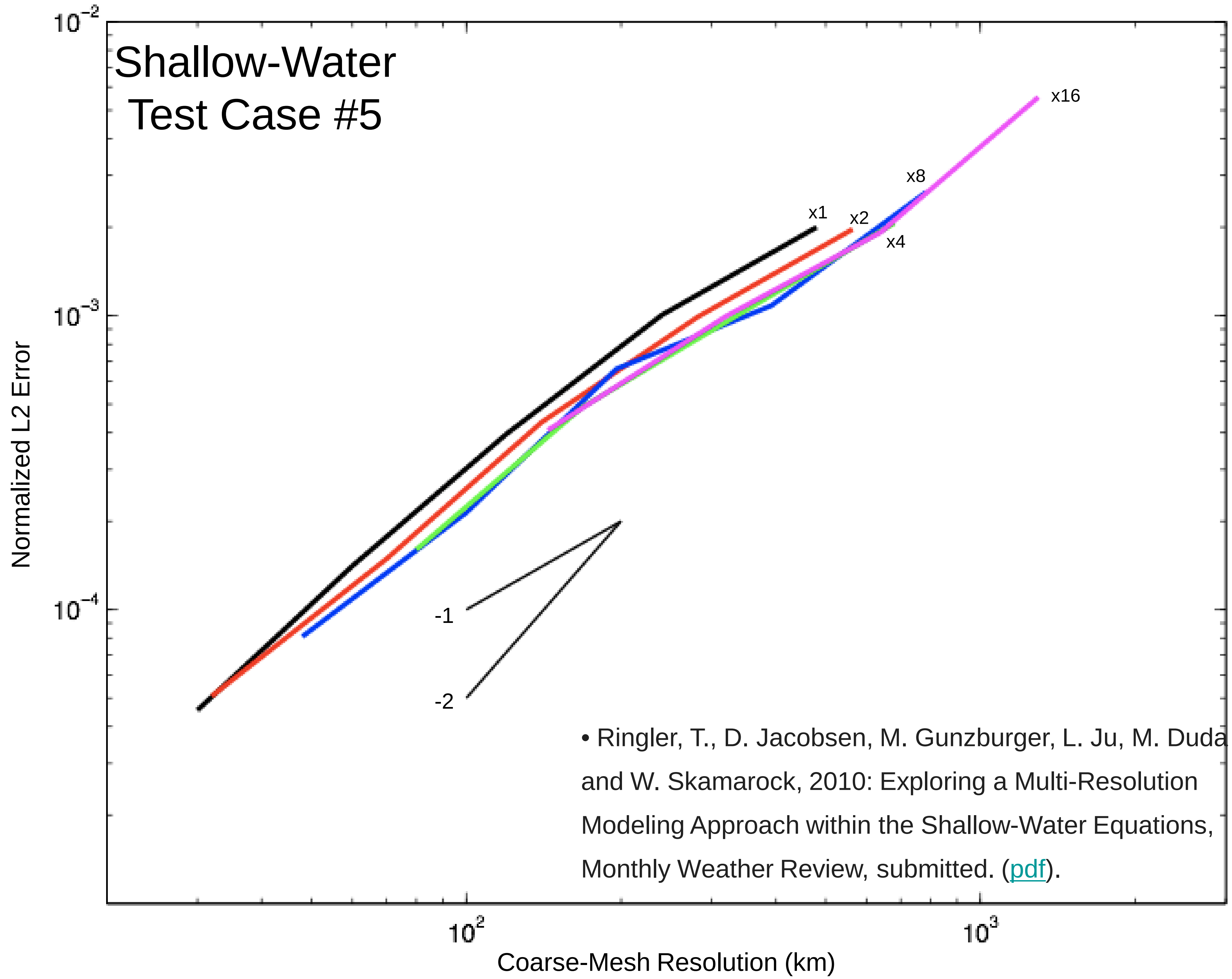
x8



x16



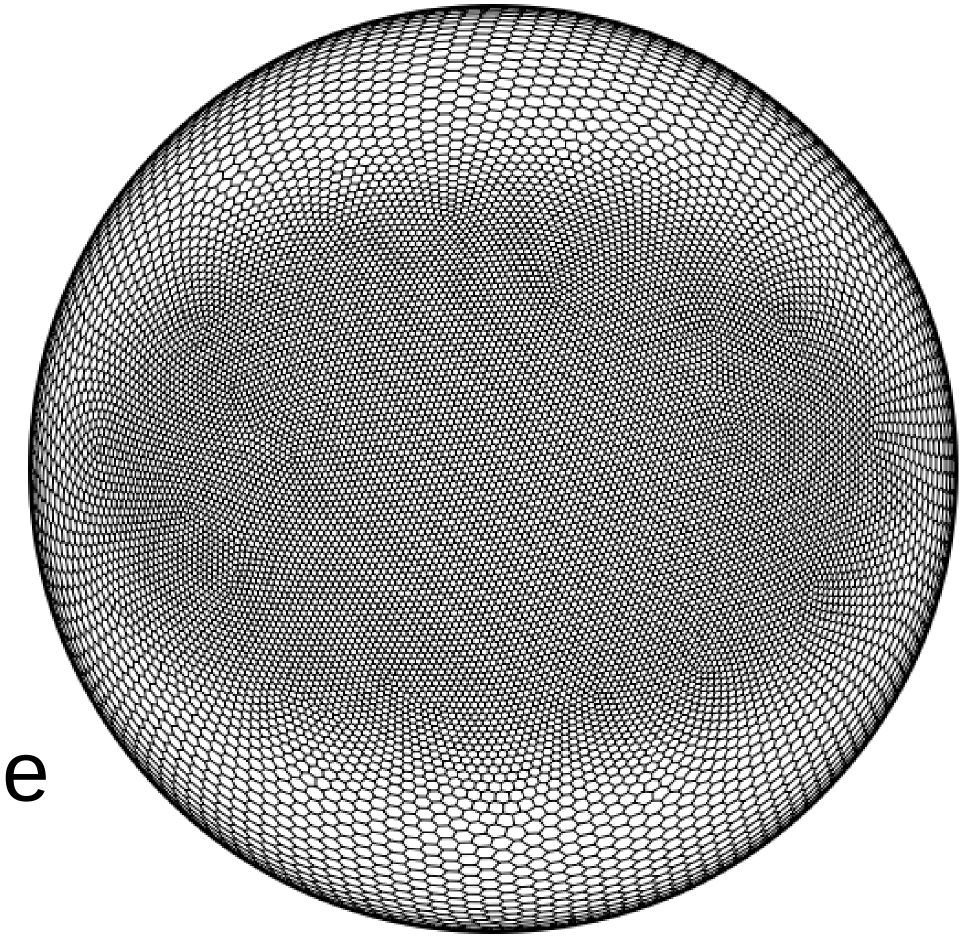
Within the shallow-water system, this evaluation has led us to the following tentative conclusion: We can increase resolution locally without increasing the global solution error.



• Ringler, T., D. Jacobsen, M. Gunzburger, L. Ju, M. Duda and W. Skamarock, 2010: Exploring a Multi-Resolution Modeling Approach within the Shallow-Water Equations, Monthly Weather Review, submitted. (pdf).

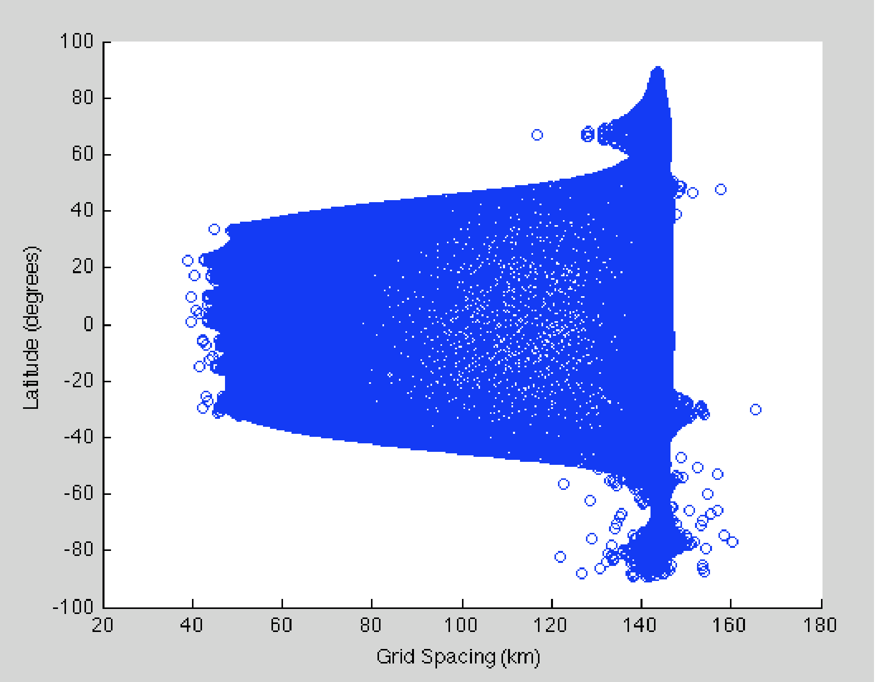
As a proof-of-concept, we pushed on to the MPAS/CAM aqua-planet system.

The mesh has 64258 grid cells with a region of mesh refinement centered on the equator, extending 160 degrees in longitude and 80 degrees in latitude.



The fine mesh region has a resolution of approximately 40 km, while the rest of the mesh has a resolution of approximately 140 km.

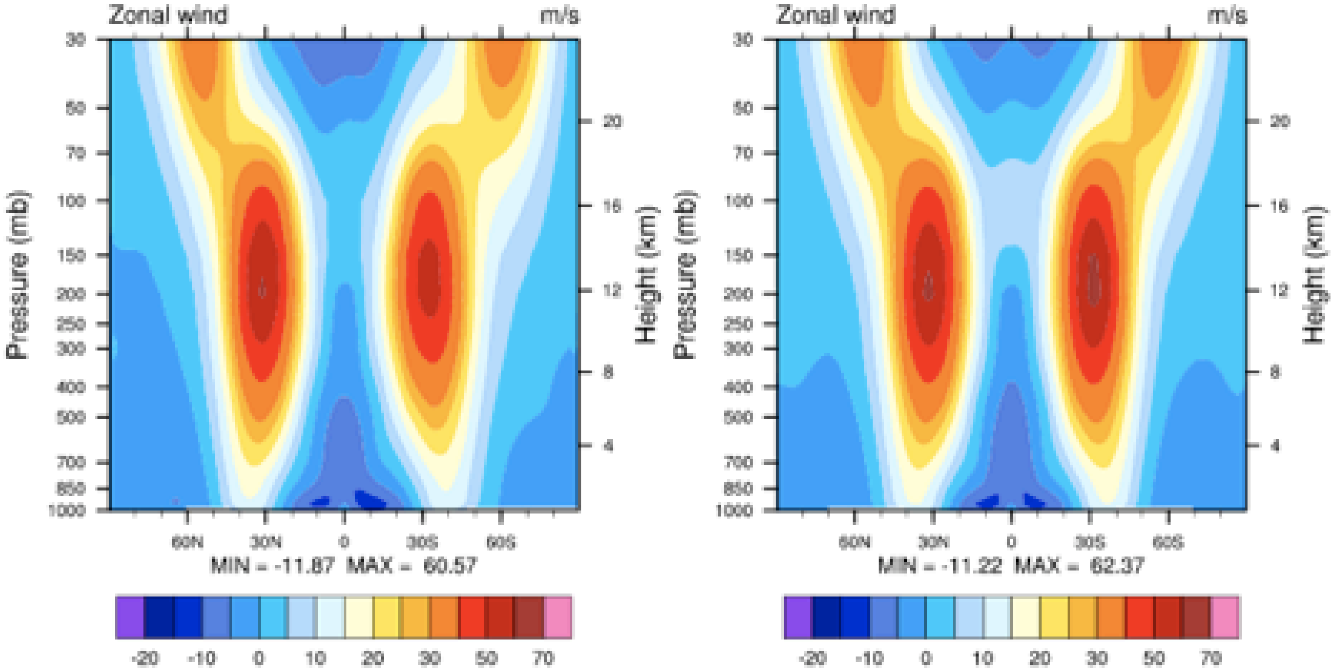
Nominal grid resolution (measured by average distance to neighbors) as a function of latitude.



Comparison of the multi-resolution 40 km - 140 km simulation with a global quasi-uniform 120 km simulation.

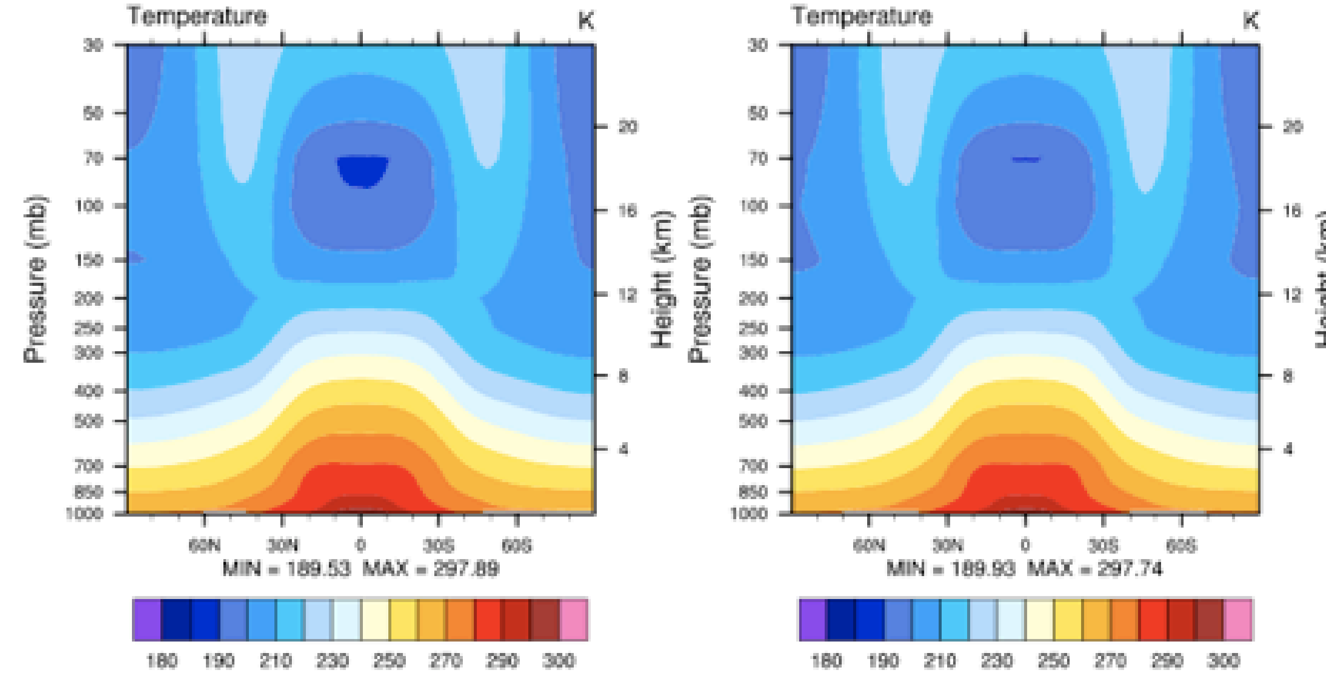
Zonal Mean Zonal Flow

40 km - 140 km | 120 km

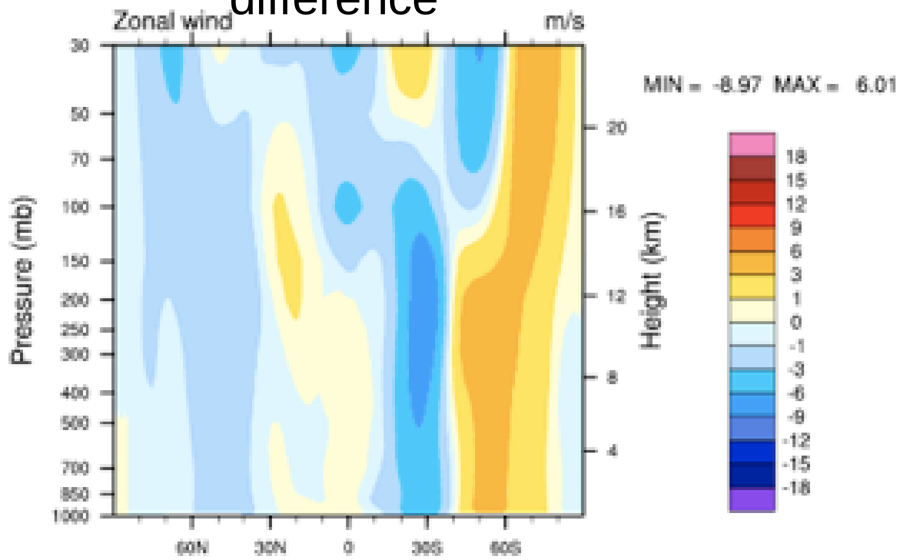


Zonal Mean Temperature

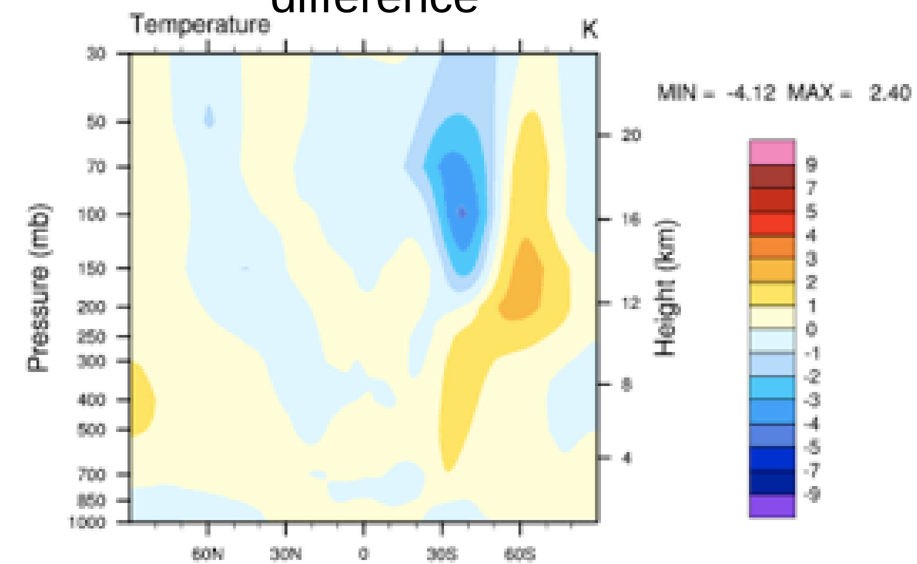
40 km - 140 km | 120 km



difference



difference



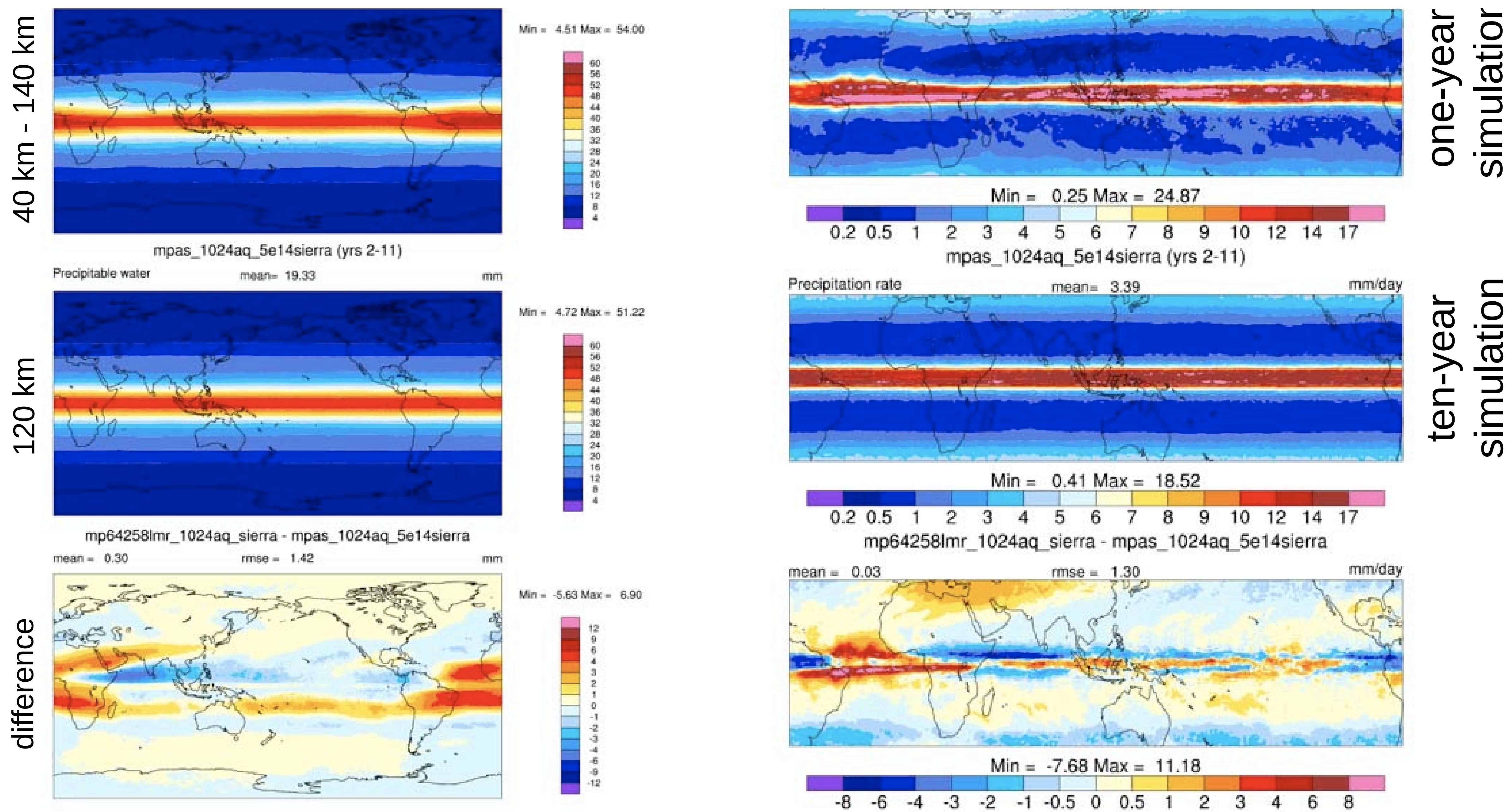
As hoped, the zonal means are essentially the same.

Comparison of the multi-resolution 40km-140km simulation with a global quasi-uniform 120 km simulation.

(Region of mesh refinement is centered at 0 degrees longitude.)

Precipitable Water

Tropical Precipitation



As expected, the physical parameterizations are sensitive to mesh resolution.

Our working hypothesis is that a robust regional model must be a robust global model, so ....

We have started the process of evaluating the MPAS hydrostatic model by conducting a suite of global, quasi-uniform aqua-planet simulations.

These simulations were conducted in order to identify glaring deficiencies in model formulation or software construction.

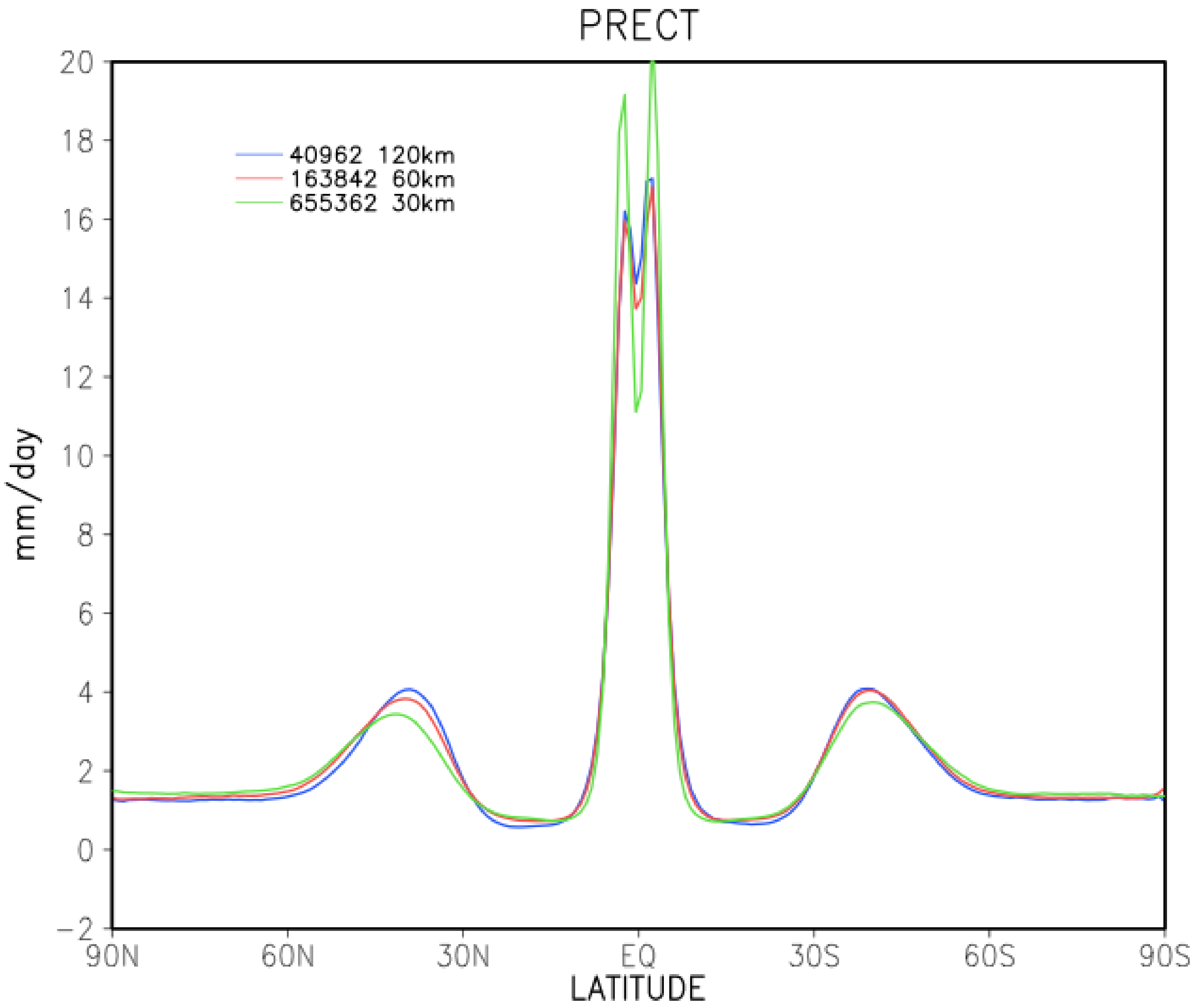
We will be recomputing all of the simulations as part a DOE BER project for the evaluation of regional climate modeling frameworks (includes HOMME and global spectral model).

List of quasi-uniform simulations:

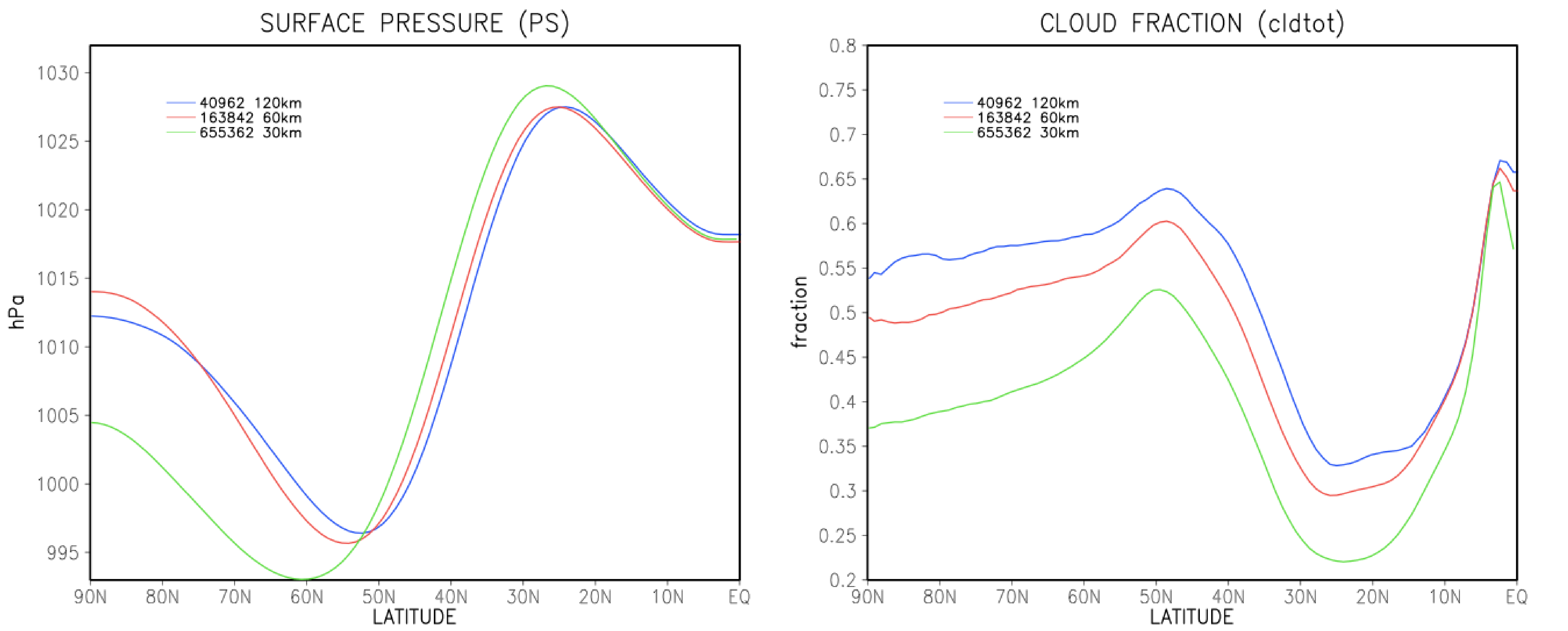
Resolution	hyper-diffusion (m4/s)	Physics time-step (s)	Dynamics time-step (s)	Simulation length (yrs)
40962 cells (120 km)	5.00E+14	900.0	450.0	10.0+0.25 spinup
163842 cells (60 km)	5.00E+13	900.0	225.0	1.0+0.25 spinup
655362 cells (30 km)	5.00E+12	450.0	112.5	1.0+0.25 spinup

All simulations use CAM4 physics.

Total precipitation shows amplifying (double) ITCZ with increased resolution.



Simulations show decreasing polar surface pressure and decreasing total cloud fraction with increasing resolution.

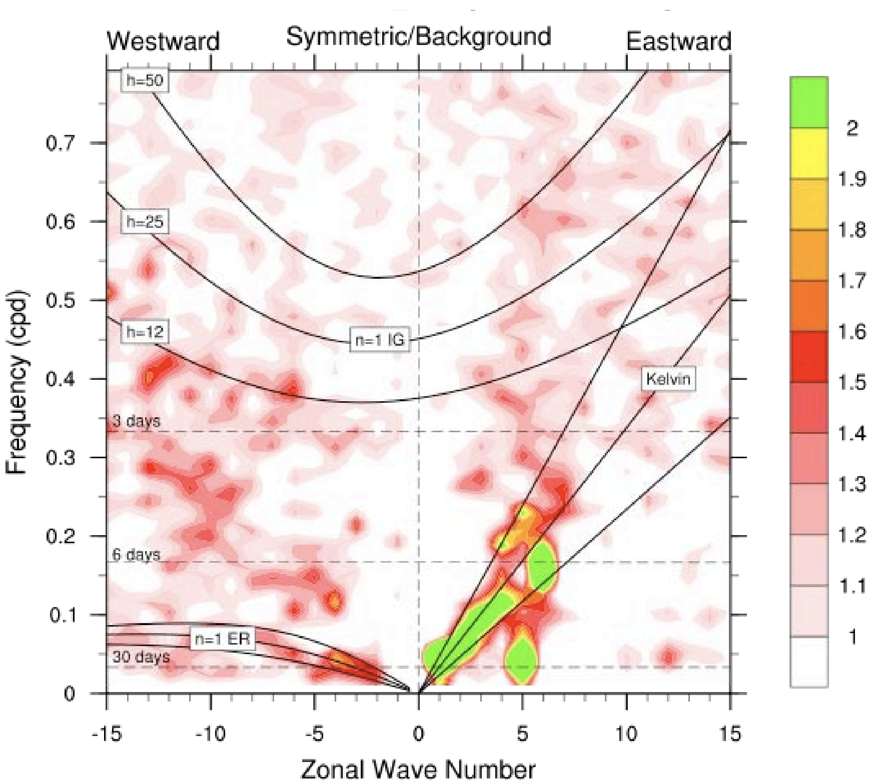


This tend is consistent with Williamson (2008).

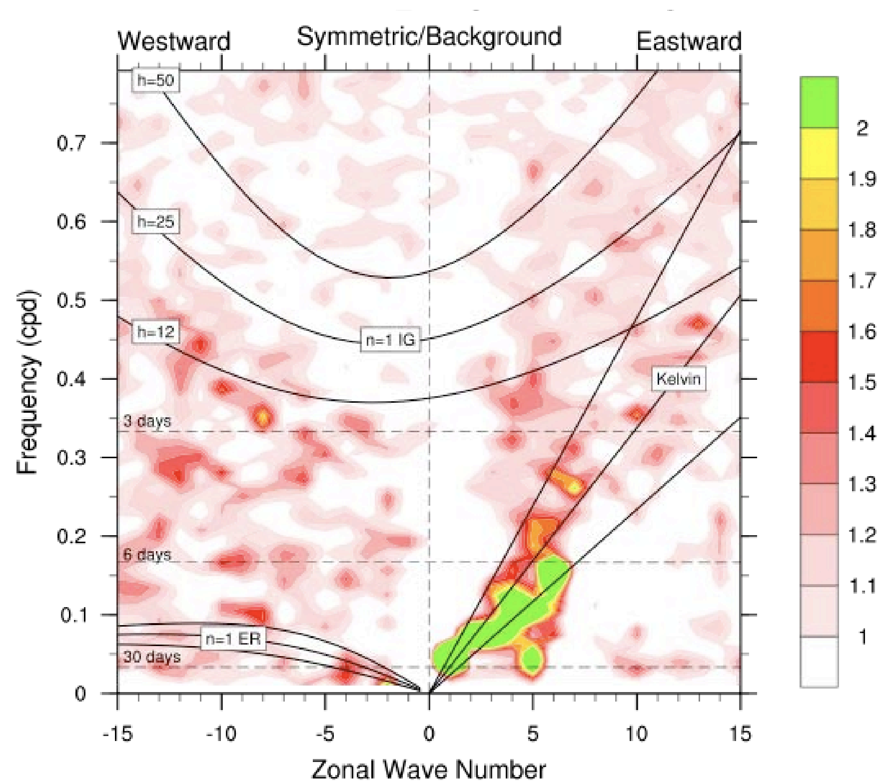
Williamson, D., 2008: Convergence of aqua-planet simulations with increasing
resolution in the Community Atmospheric Model, Version 3, Tellus, 60A, 848–862

The tropical wave analysis is consistent with other recent results, e.g. Mishra et al. 2010.

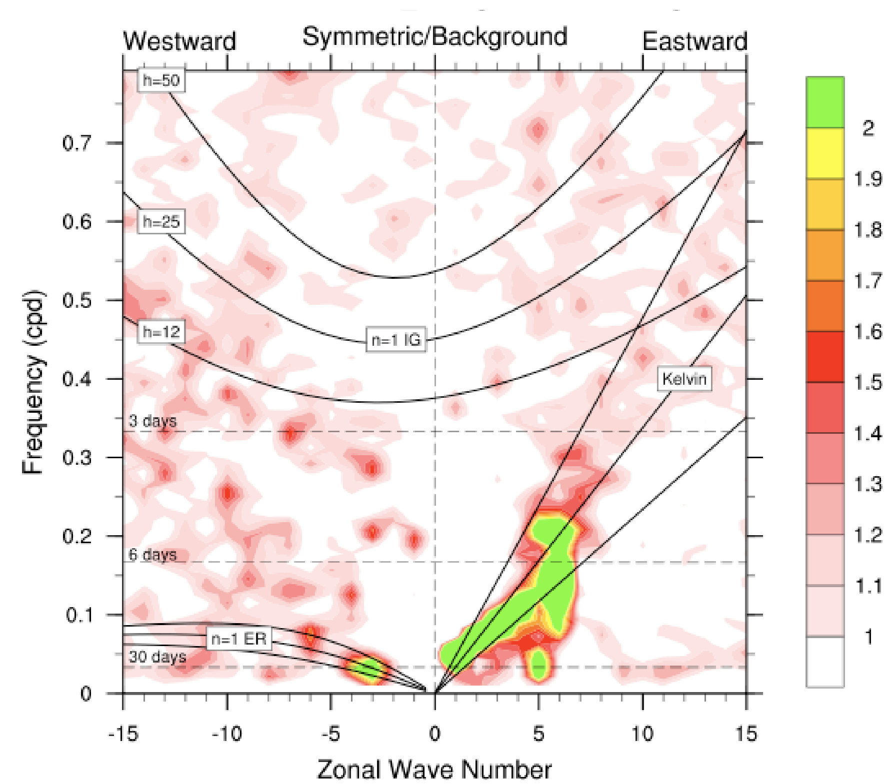
120 km



60 km



30 km

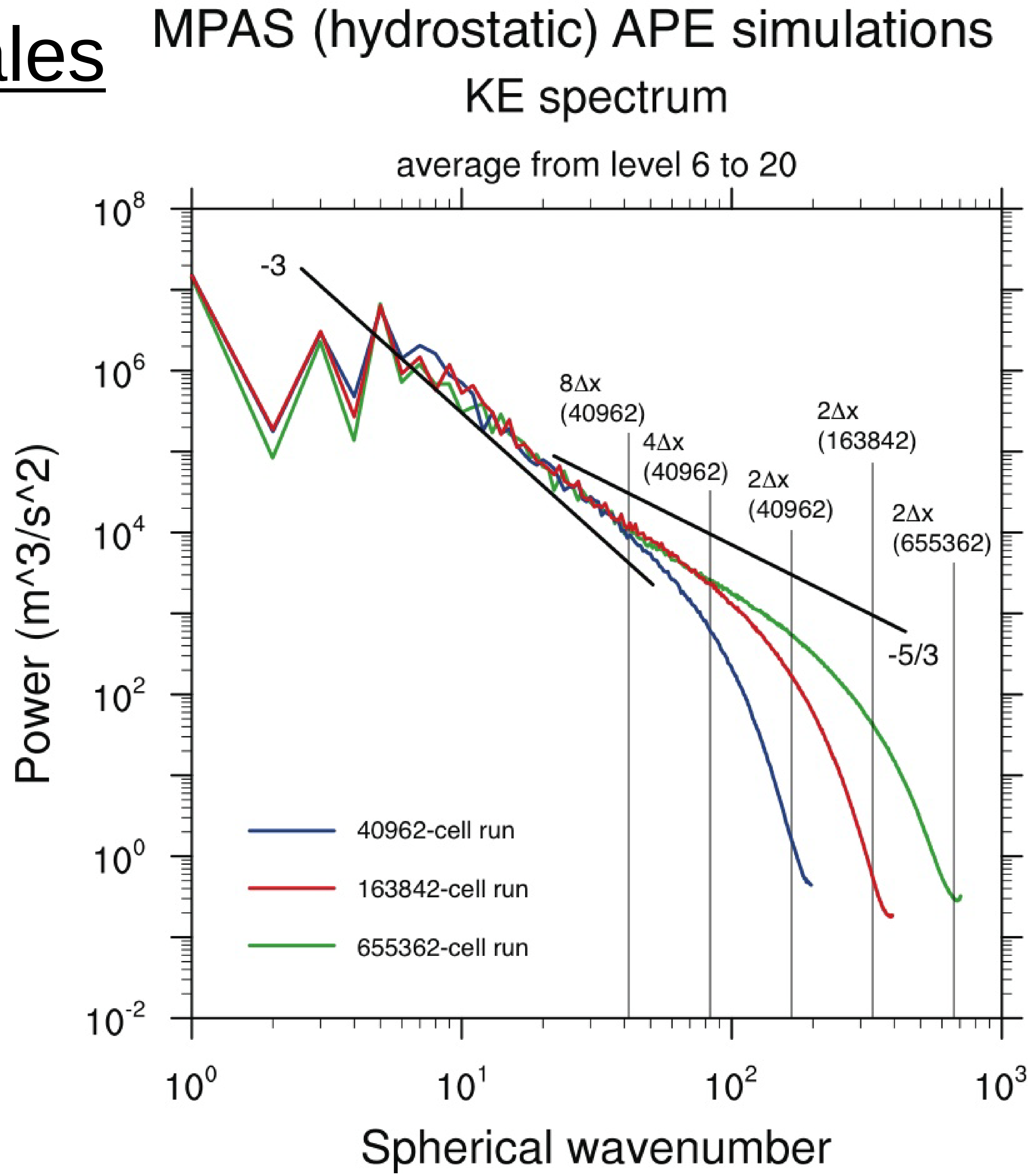


In addition to the commonly found Kelvin waves, we find strong westward propagating Rossby waves.

Mishra et al., 2010, Performance of the HOMME Dynamical Core in the Aqua-Planet Configuration of NCAR CAM4: Equatorial Waves, revised for GRL.

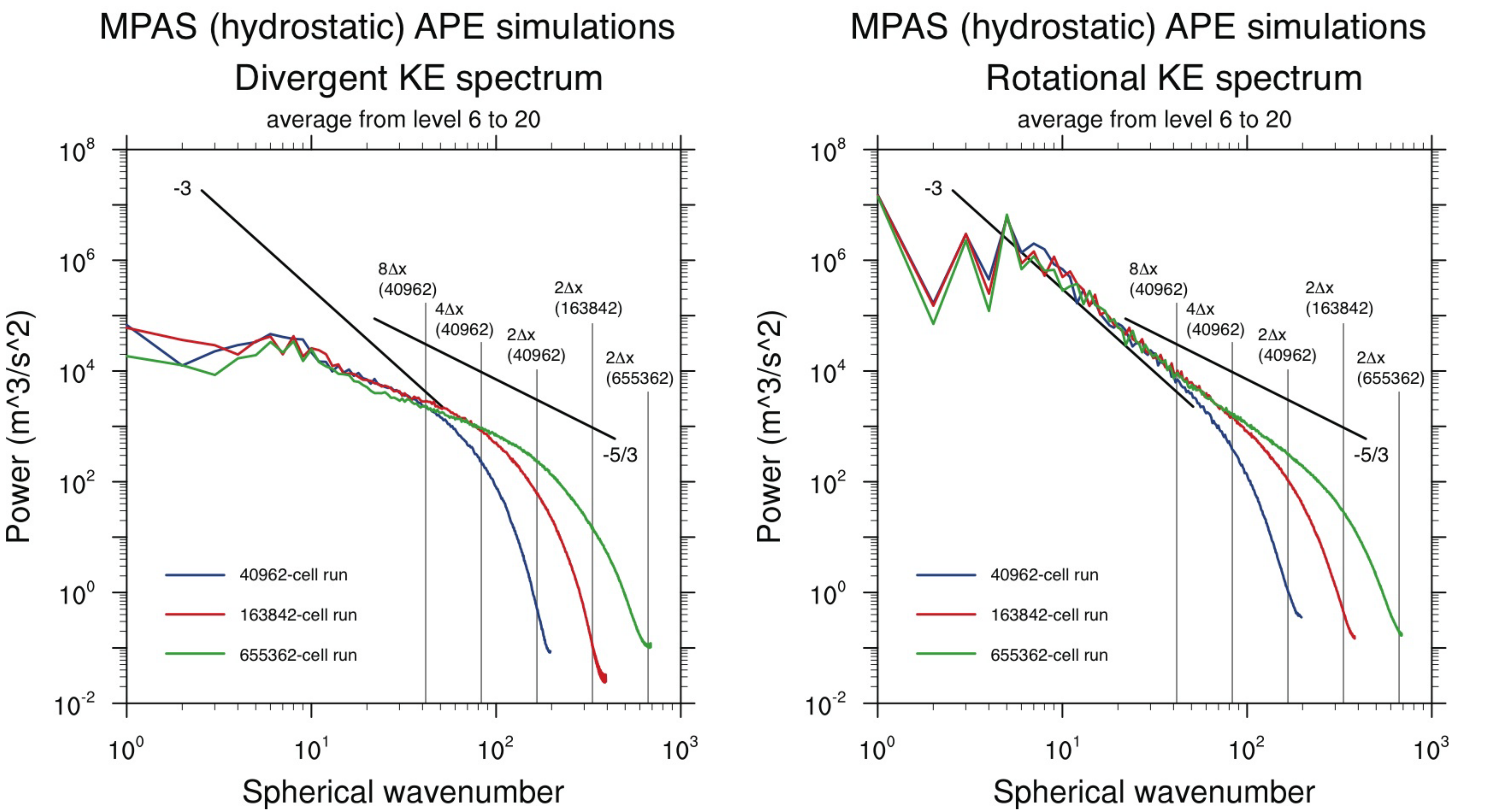
Transition at Mesoscales

Consistent with Nastrom and Gage (1985) we see a transition from -3 to -5/3 slope at a horizontal scale of approximately 400 km. (Note, 480 km is about 4 dx on the 40962 mesh.



Nastrom and Gage (1985): A climatology of atmospheric wavenumber spectra of wind and temperature observed by commercial aircraft, Journal of the Atmospheric Sciences, vol. 42 (9) pp. 950–960

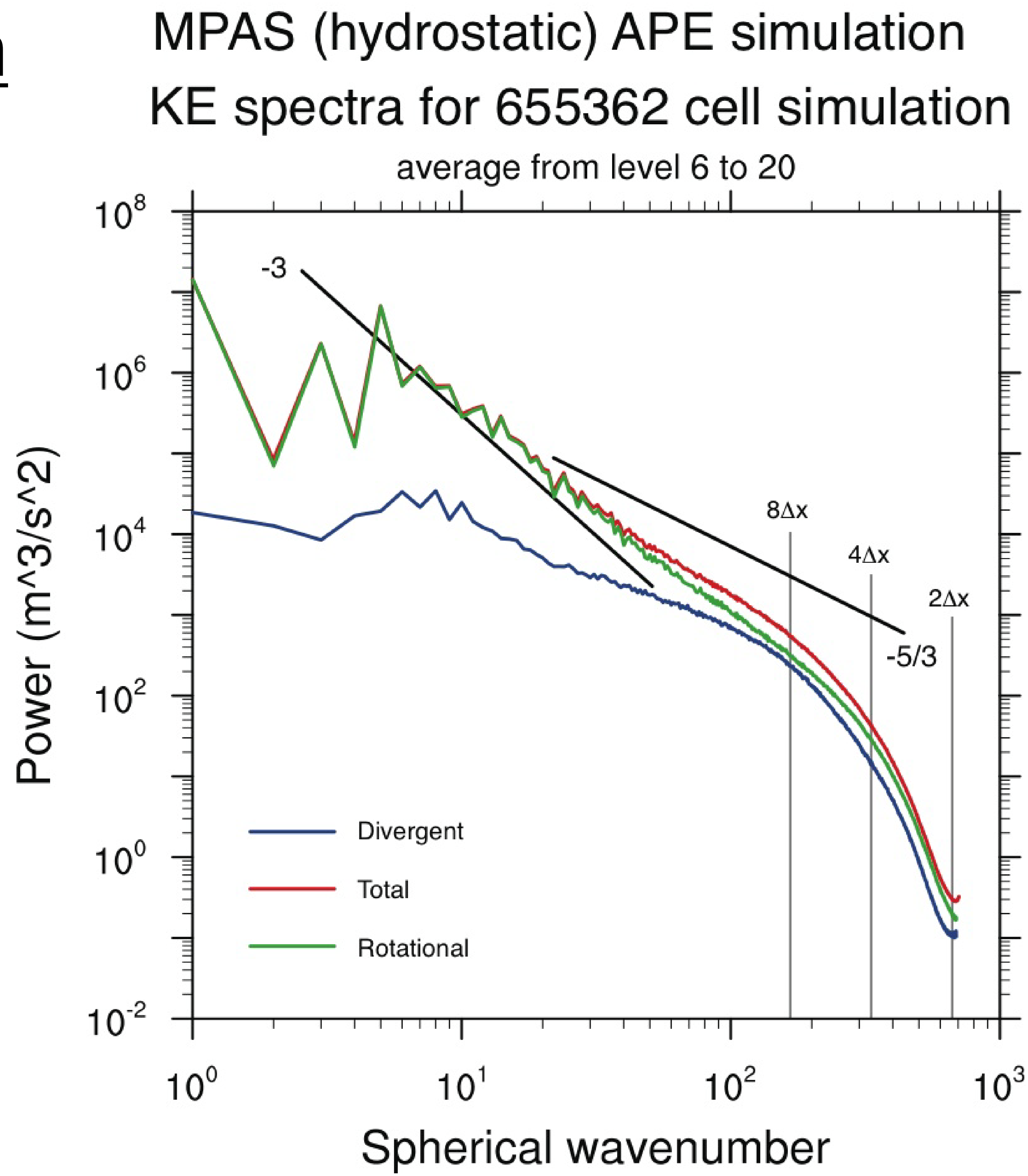
We find an approximate equal partitioning of power between the vertical vorticity and divergence modes in the mesoscale.



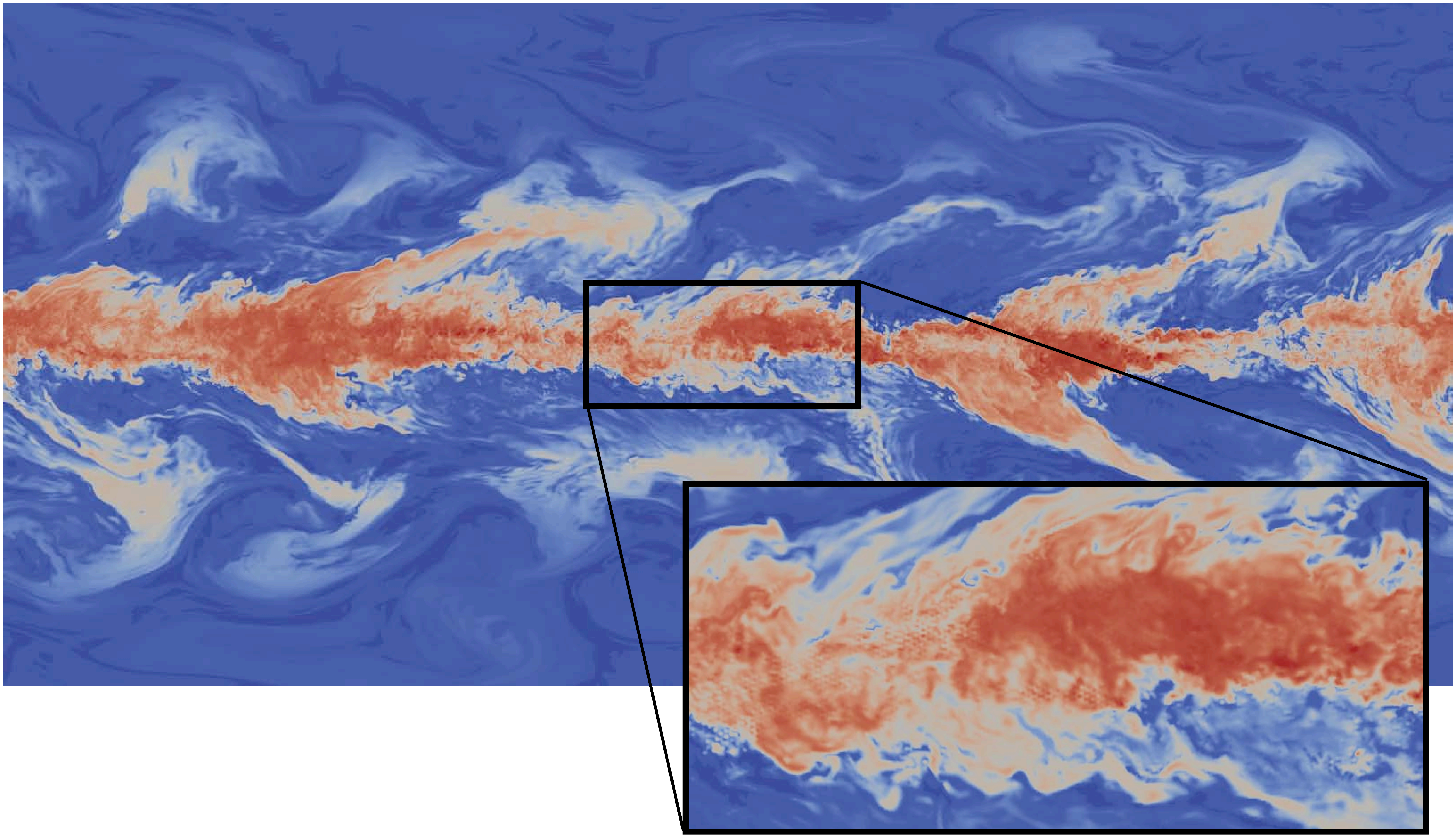
Effective Resolution

We find that the spectrum begins to dip below the -5/3 slopes at approximately 8*dx; we regard this to be the effective resolution.

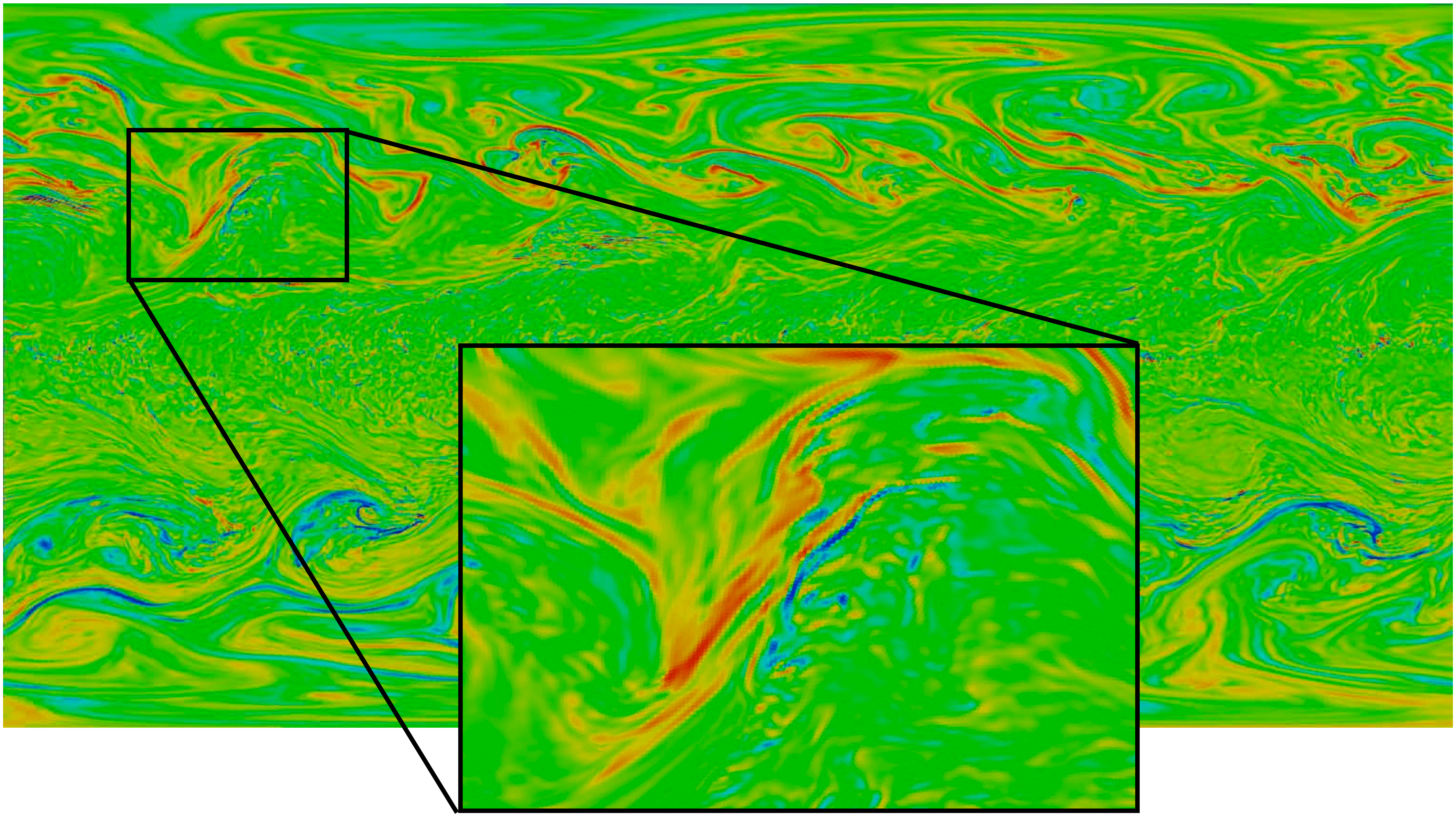
By tuning the hyper-diffusion and/or exploring other closures, we hope to push the
effectively resolution out to approximately 6*dx.



APE, 30 km: Snapshot of water vapor @ 450 hPa.



APE, 30 km: Snapshot of relative vorticity @ 450 hPa.



Conclusions

1. We have designed a numerical method where the multi-resolution mesh does not adversely impact the **dynamics** (i.e. we maintain all conservation properties, do not require ad hoc stabilization methods and do not degrade accuracy when using a multi-resolution mesh.)

2. The same does not hold true for the **physics**. The physical parameterizations (e.g. cumulus convection) certainly feel and respond to the multiply resolutions associated with the mesh. This is both a challenge and an opportunity.

3. In the short term we anticipate that using multi-resolution meshes with standard coarse and fine mesh resolutions (e.g. 120 km / 25 km) along with the commensurate parameter settings in each region will allow us to obtain scientifically useful results regarding regional climate processes.

Thanks!