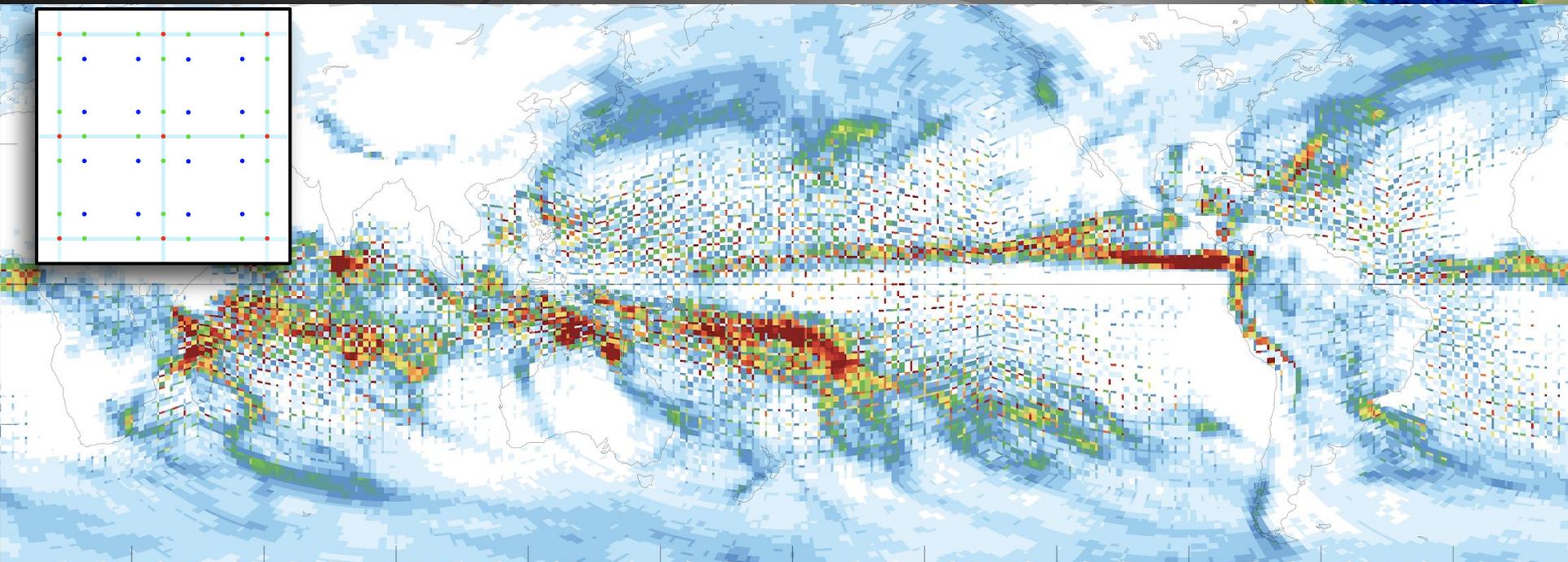
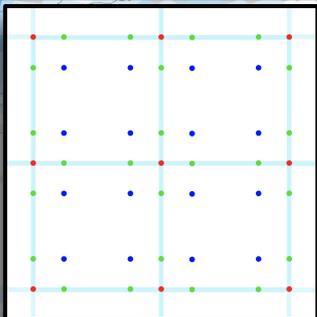


E³SM

Energy Exascale
Earth System Model



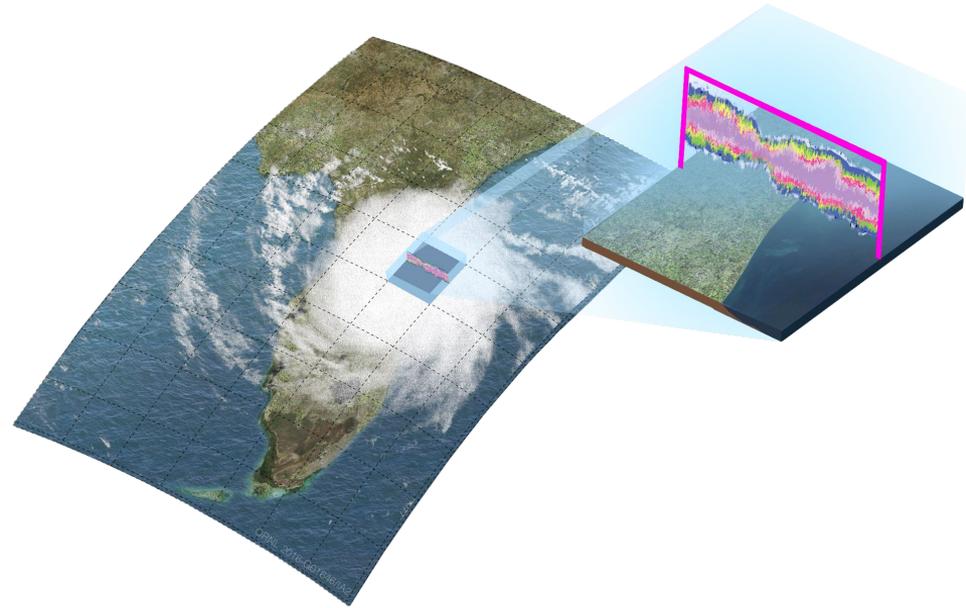


Super-parameterized E3SM (-E3SM)

An embedded cloud resolving model (CRM) is used to override the sub-grid processes:

- Convection
- Microphysics
- Turbulent mixing
- Gravity waves*
- Radiation*

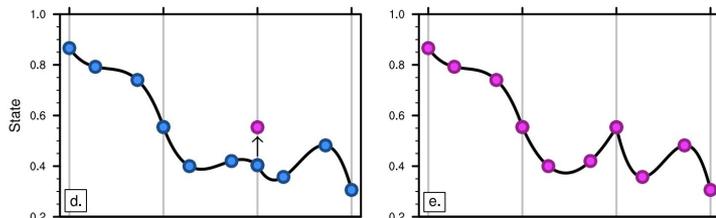
The goal of the Exascale Computing Project (ECP) project is to use GPU acceleration so we can use SP-E3SM for climate length runs with reasonable throughput (>1 sim year per day)



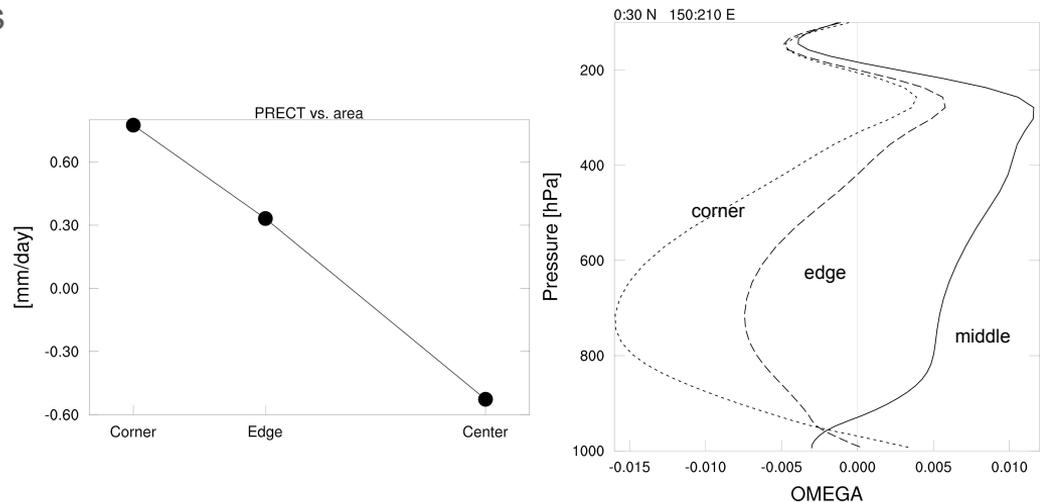
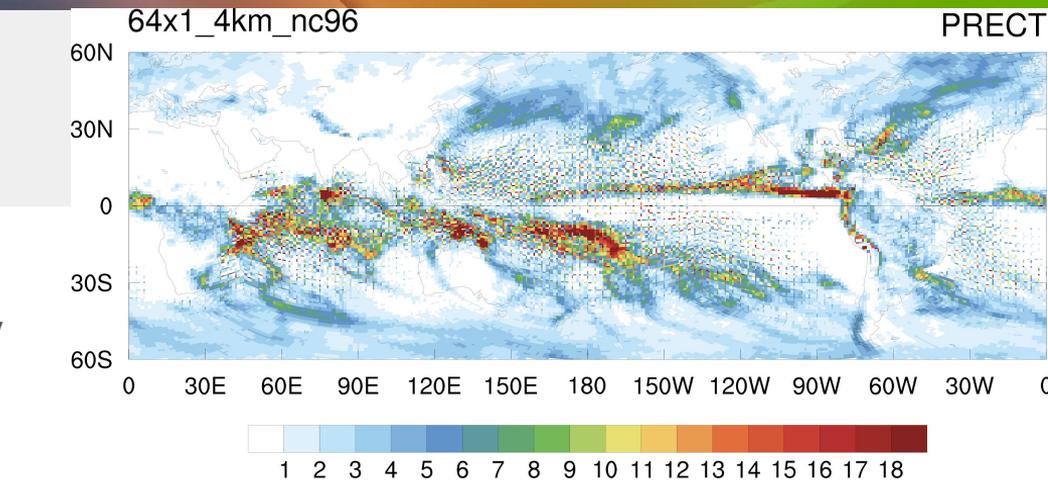
The Problem

The grid imprinting occurs when certain fields have systematic biases depending whether they are on a middle, edge, or corner GLL node.

The root cause is that derivatives are treated differently between these nodes. Element edges are averaged together to obtain a continuous (C0) field, which causes “kinks” in the solution that affect derivative based quantities, such as convergence and omega.



From Herrington et al. 2019

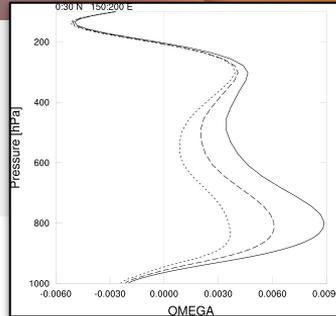


How bad is it?

Although not always evident in precipitation, it is certainly noticeable in subtropical omega profiles

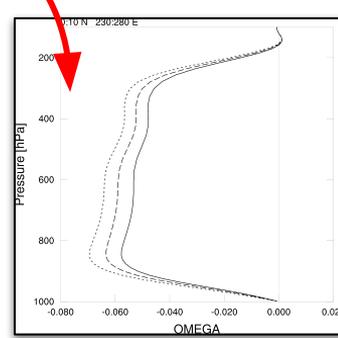
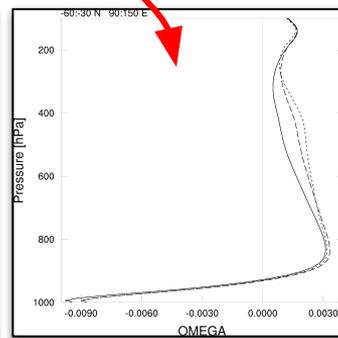
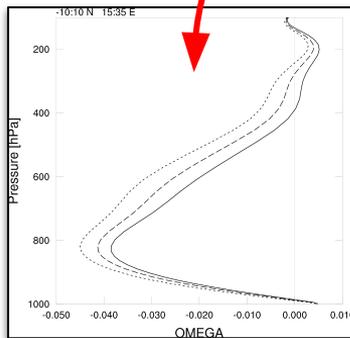
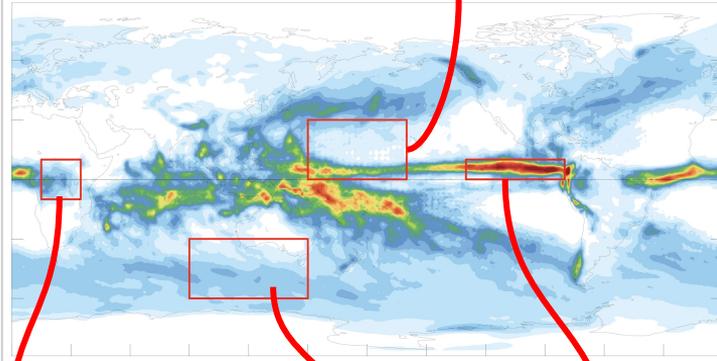
This also occurs in standard E3SM, although it is much smaller. This is likely due to the way ZM allows low entrainment plumes in dry, subsiding environments.

Quantifying the effect of this on the climatology has proven to be difficult



SP-E3SM 64x1km 20-min time step

PRECT

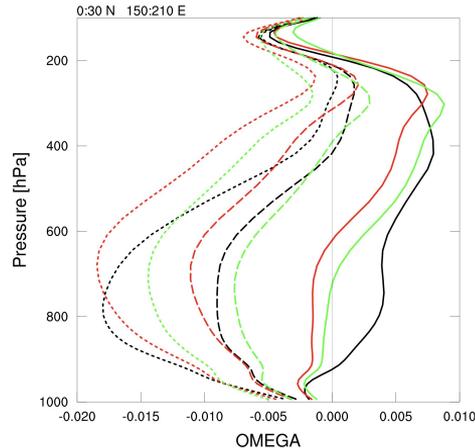




Potential Solution - More Hyperviscosity

Our first attempt to fix this was to add more hyperviscosity to the dynamics or adding a new smoothing operator to the physics

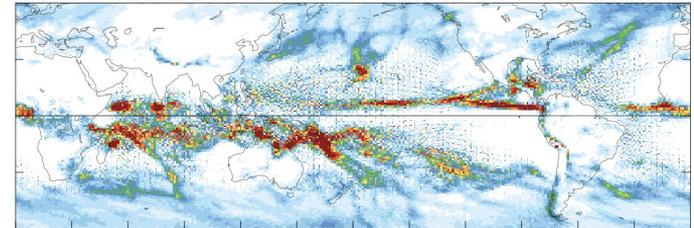
These tests showed degraded climatological features, but little change in the imprinting.



- black** - `hypervis_subcycle = 3`, `nu = 1.0e15`, `nu_div = 2.5e15`, `nu_p = 1.0e15`
- red** - `hypervis_subcycle = 6`, `nu = 2.0e15`, `nu_div = 5.0e15`, `nu_p = 2.0e15`
- green** - `hypervis_subcycle = 9`, `nu = 4.0e15`, `nu_div = 7.5e15`, `nu_p = 4.0e15`

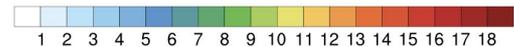
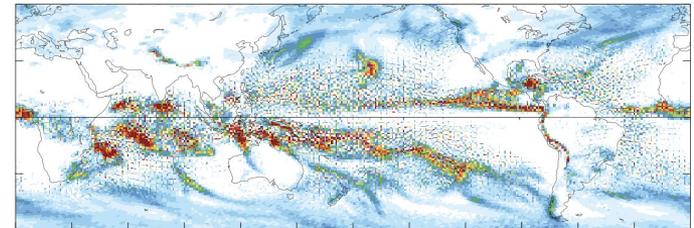
hypervis_subcycle = 3

PRECT



hypervis_subcycle = 9

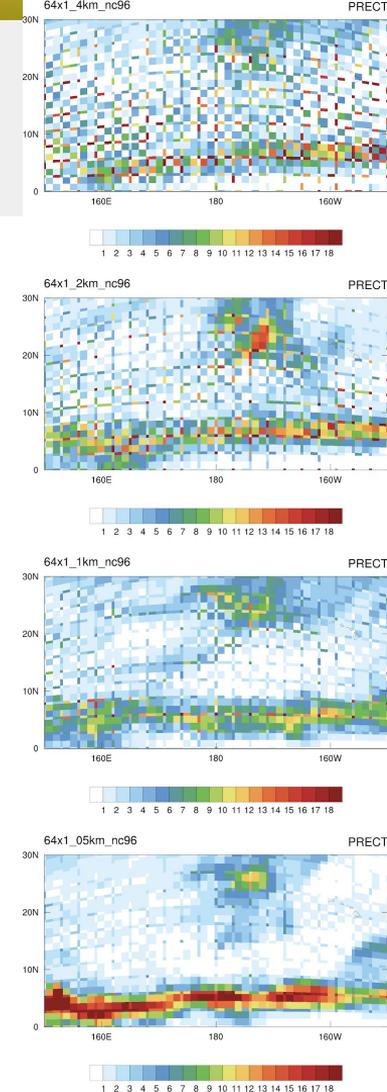
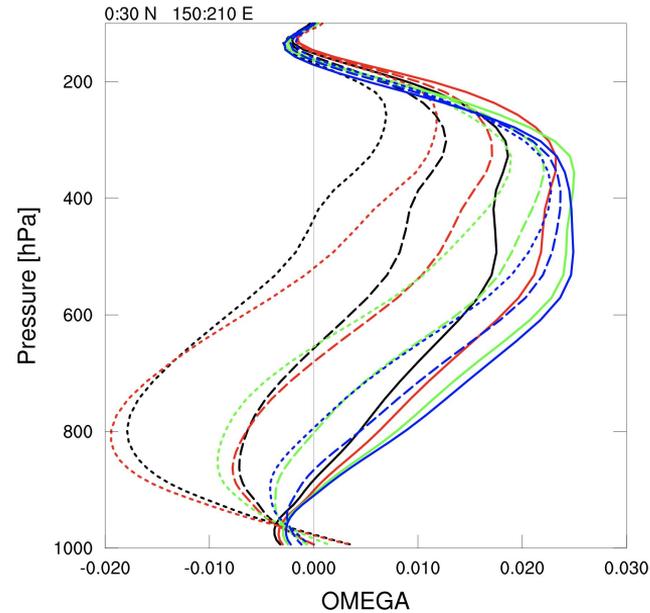
PRECT

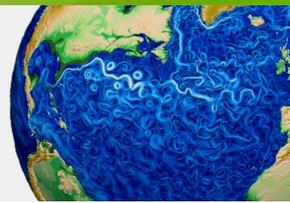


Potential Solution - Can we tune it away?

Sensitivity tests have shown that we can reduce the problem by modifying the CRM parameters.

The major downside of this is that future sensitivity tests are worthless since they will reintroduce the problem





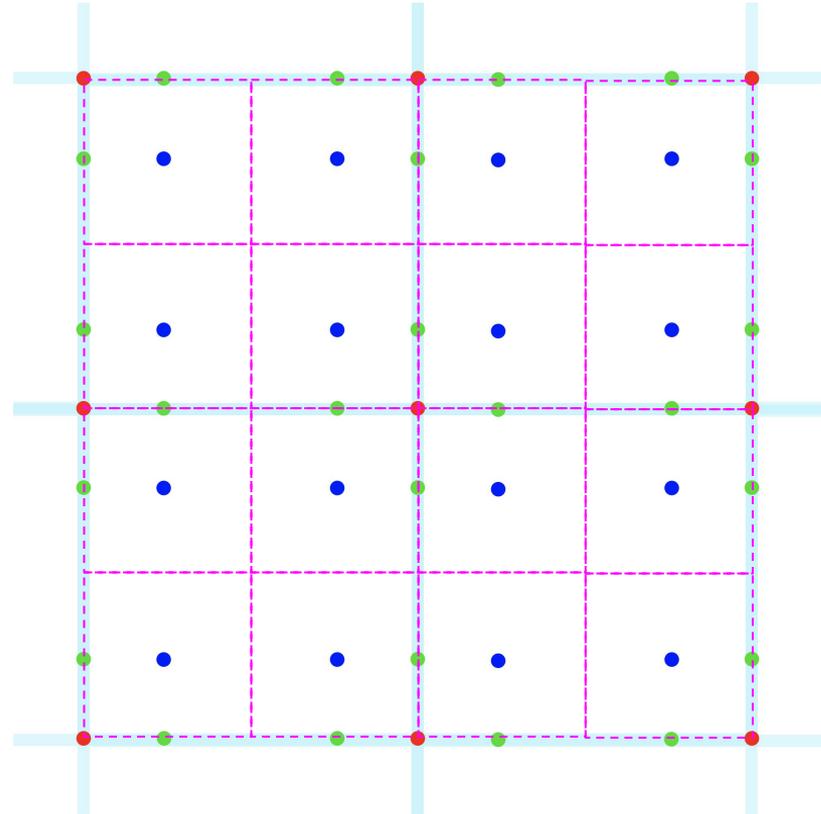
Actual Solution - FV Physics Grid

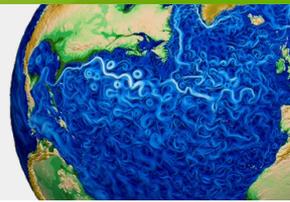
The idea is to put physics columns on a 2x2 FV grid to avoid the heterogeneity of the physics columns.

This is similar to a method developed at NCAR, which is complicated due to several factors:

- Lagrangian tracer transport scheme (CSLAM)
- cubic spline interpolation
- halo points outside of the element
- Interpolating past the cube face

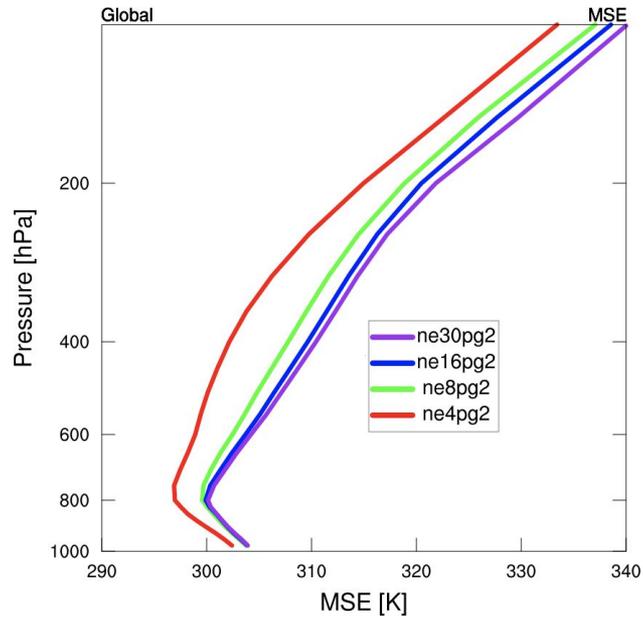
Our approach is much simpler because we will only support 2x2 and we use a localized piece-wise constant approach, so we can directly copy to the GLL nodes in each quadrant.



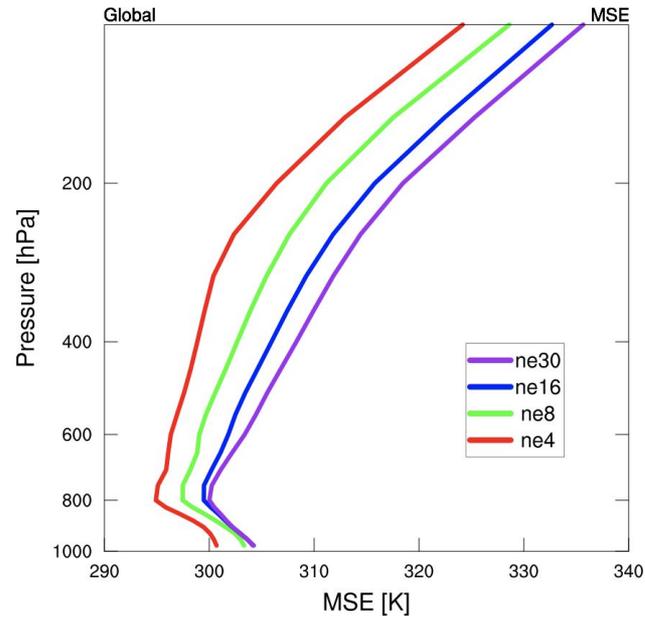


Preliminary Aquaplanet Results

np4



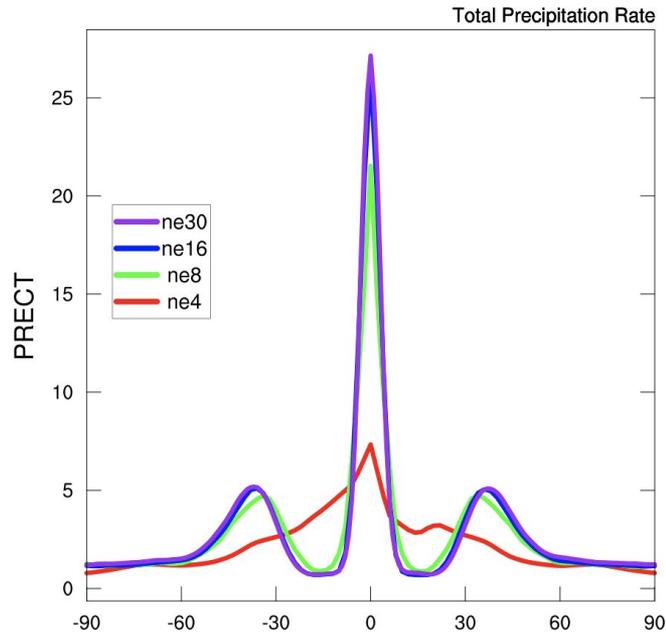
pg2



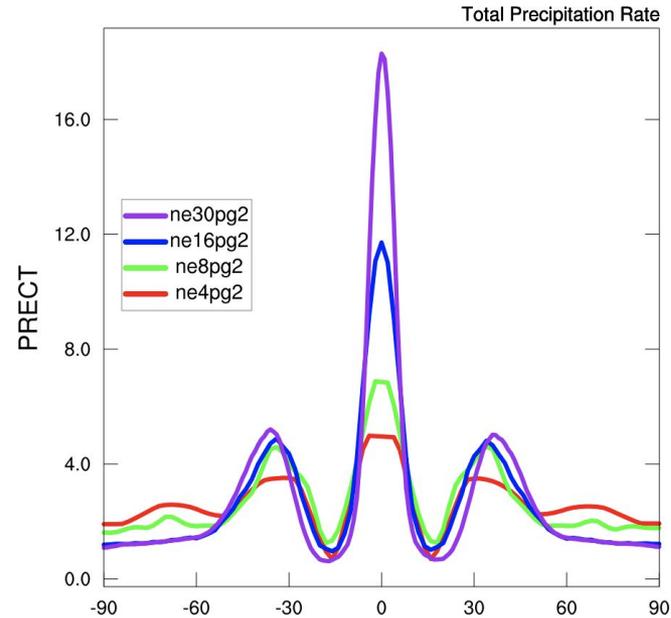


Preliminary Aquaplanet Results

np4

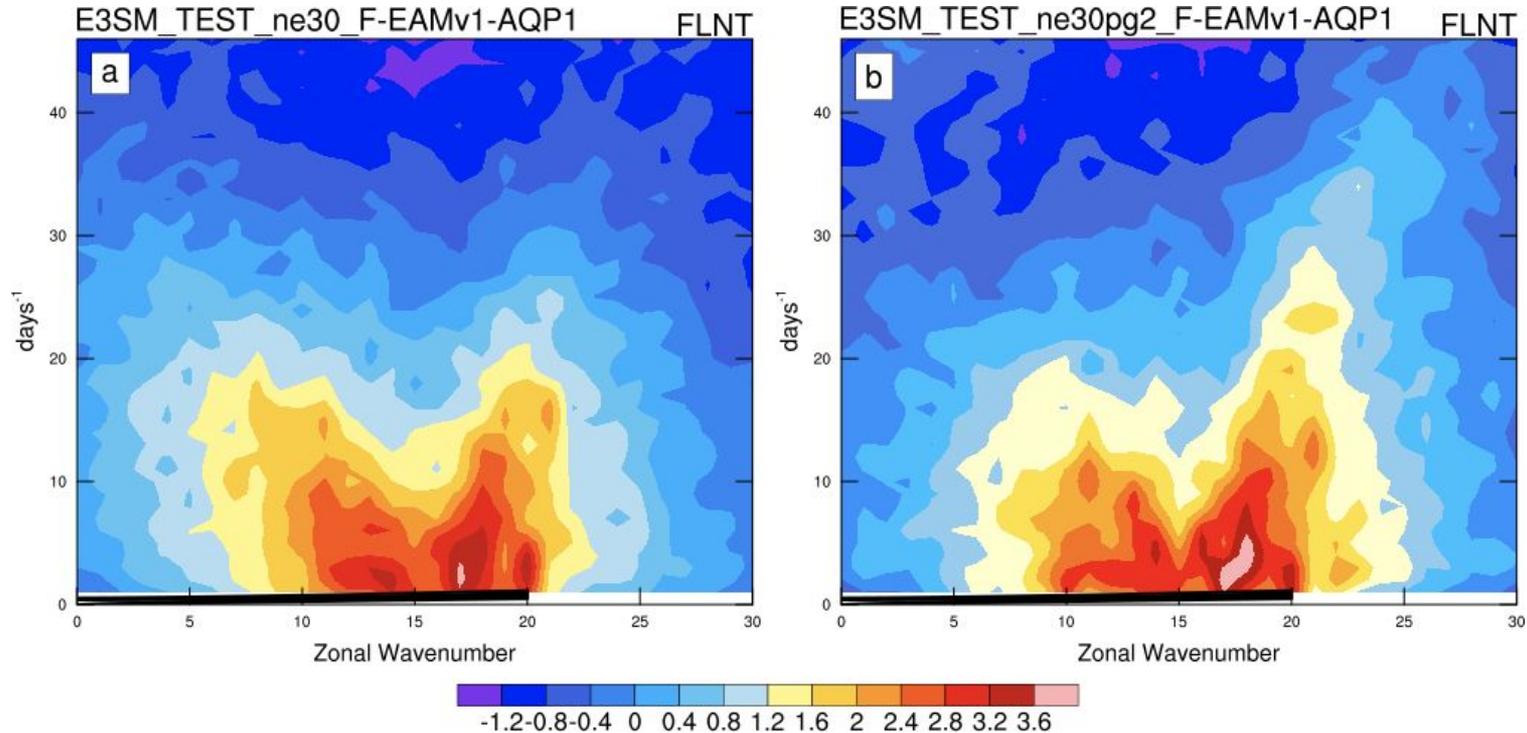


Pg2

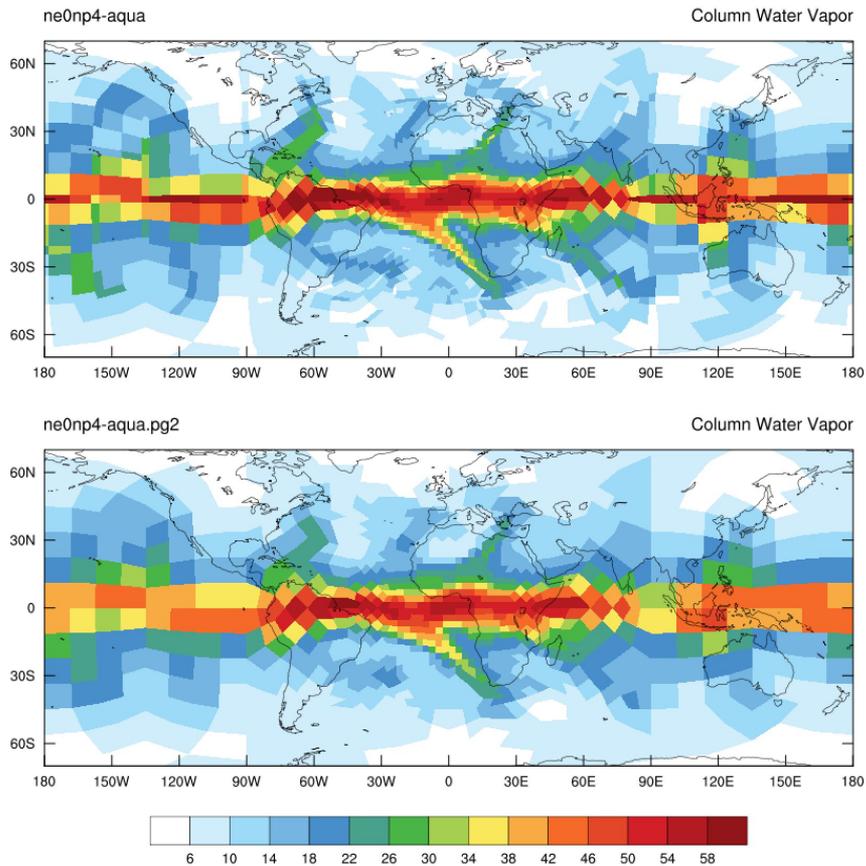




Preliminary Aquaplanet Results



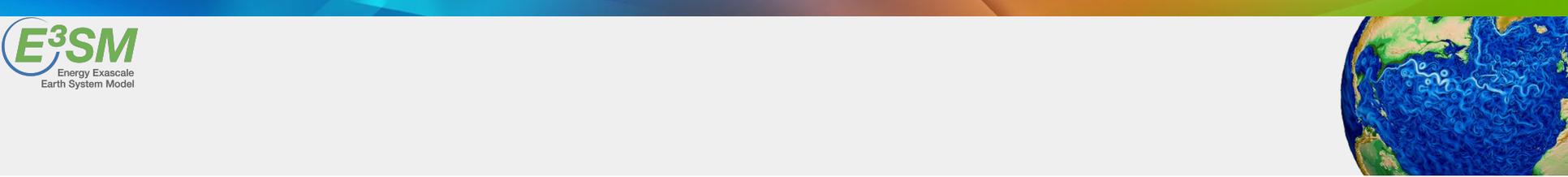
Regional Refinement





Conclusions

- **The 2x2 FV physics grid has significant benefits**
 - Solves grid imprinting problem
 - Simplifies process of running on new grids
- Aquaplanet results are very promising
- Tests with realistic land and topography will be conducted soon but will require generating new land surface data and some further modification to how the model is initialized

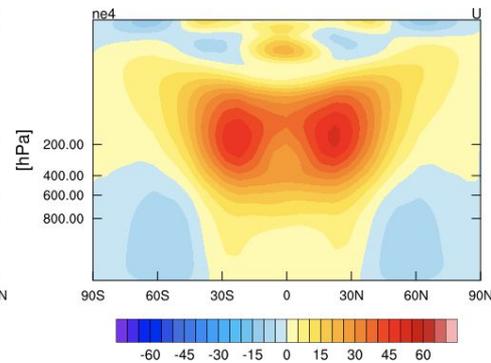
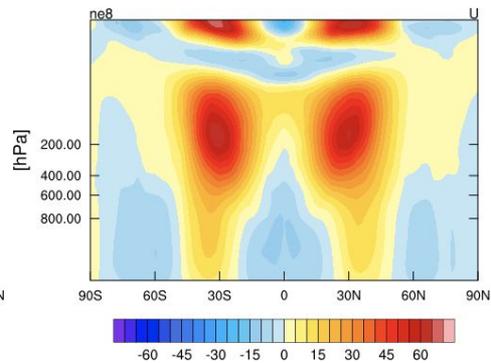
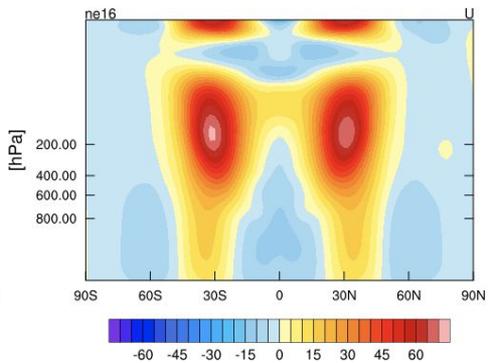
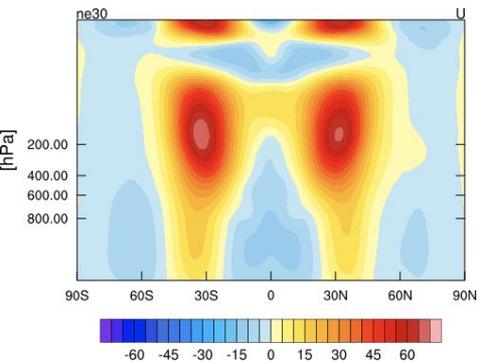


Extra Slides

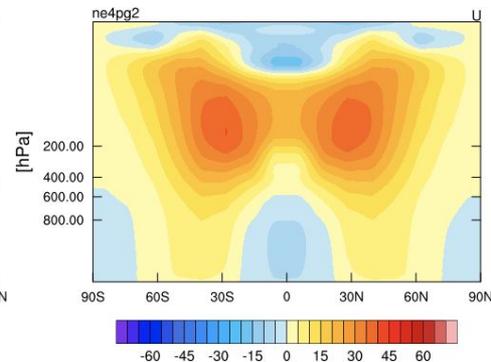
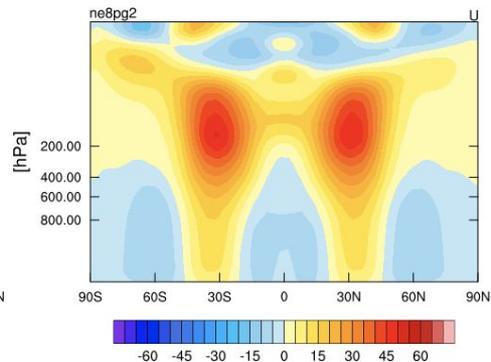
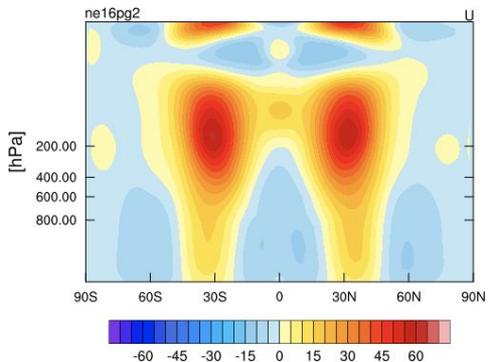
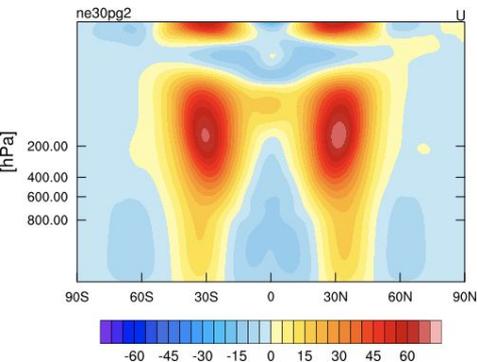


Preliminary Aquaplanet Results

np4



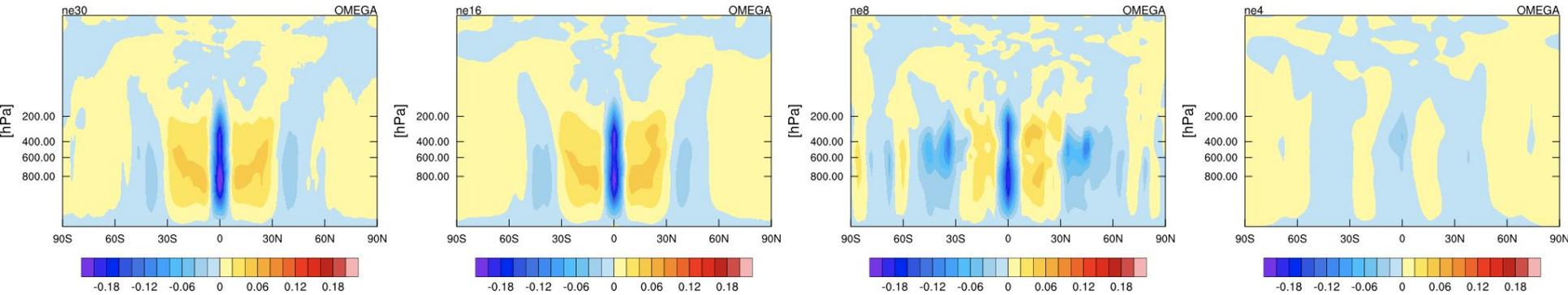
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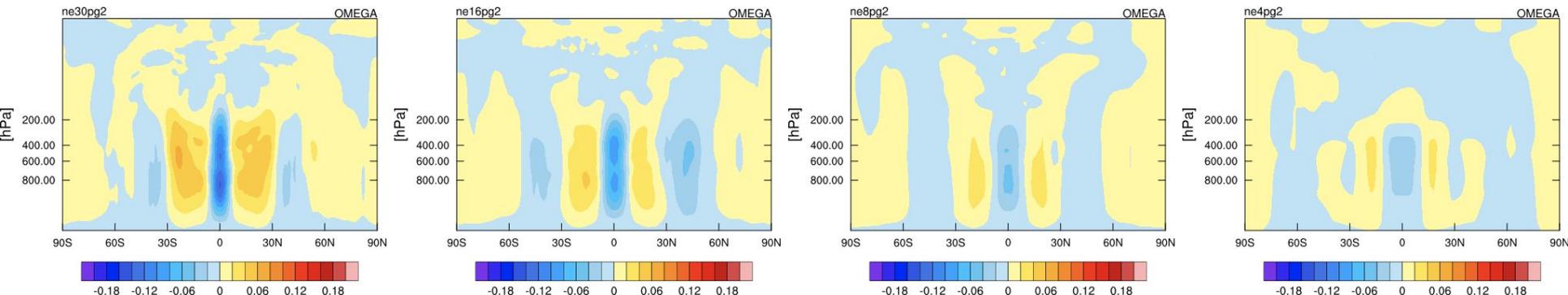


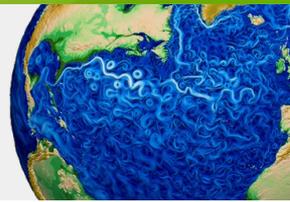
Preliminary Aquaplanet Results

np4



pg2





NCAR's New Physics Grid

- E3SM vertical coordinate is based on moist pressure whereas CESM switched to dry pressure
 - Vertical levels based on moist pressure are effectively moved by any moisture tendency. This dramatically complicates how we would interpolate between the GL grid and a decoupled phys grid. Switching to a dry pressure vertical coordinate is doable, but would be a big effort.
 - There are also issue with tracer transport that I don't fully understand, but Peter Lauritzen is adamant that C-SLAM would be required to use a 3x3 grid.
- Even without the vertical coordinate problem, I think there is a potential for the GCM and CRM to drift apart due to the use of different halos for each interpolation step
- There's also a semi-political argument for forging our own path instead of taking stuff from CESM

