Integration of the MPAS Dynamical Core into the CESM

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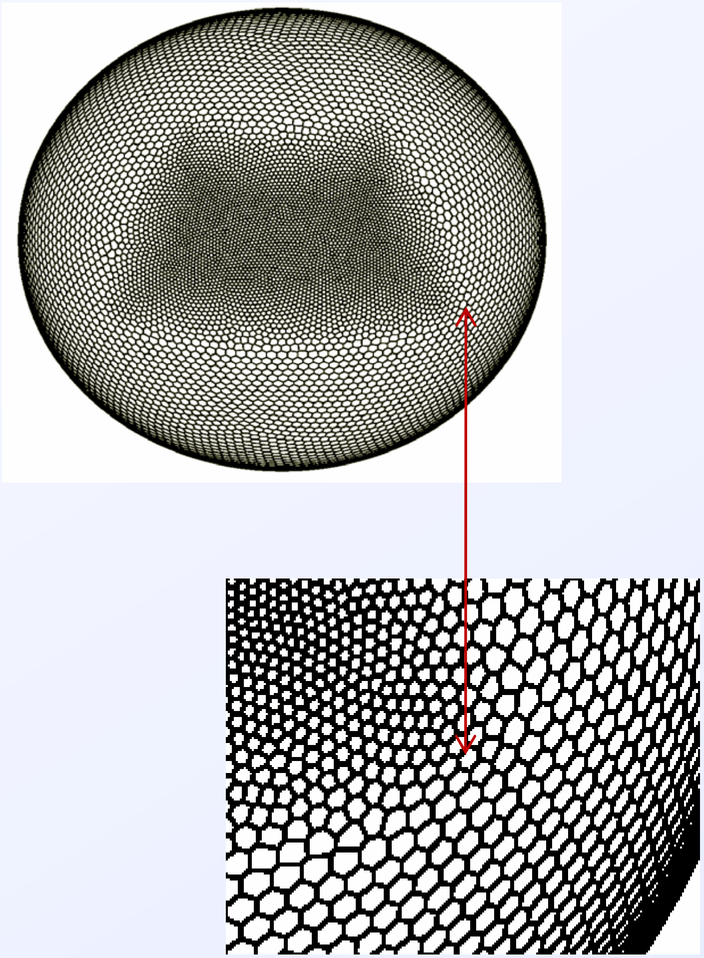
A primary motivator for advanced dycores is to overcome limitations of the latitude-longitude grid

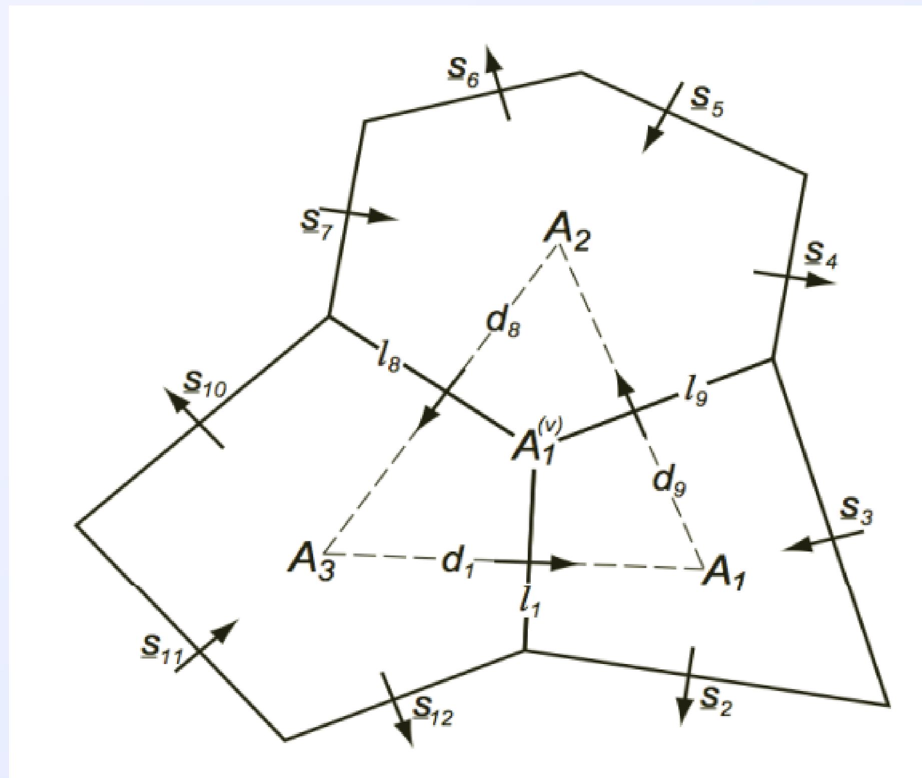
- **Convergence of meridians at poles**
  - **limits time step and provides unnecessarily high resolution in polar regions at expense of other locations throughout globe**
  - **limits scalability by inhibiting effective domain decomposition in longitude**
- **Several new dynamical cores are currently available in versions of CAM**
  - ***Homme* (spectral element, cubed sphere grid, cam trunk)**
  - ***Fvcubed* (finite volume, cubed sphere grid, cam branch)**
  - ***Mpas* [finite volume, icosahedral (hexagonal) grid, cam branch]**

The MPAS dycore is designed with local mesh refinement in mind

- **MPAS (Model for Prediction Across Scales) uses unstructured grid based on spherical centroidal Voronoi tessellations and Delaunay triangulation**
  - **most cells are hexagonal**
  - **finite-volume approach using C-grid (normal velocities at cell edges)**
  - **conforming grid (no hanging nodes) is amenable to local mesh refinement (applicable to regional modeling, ice sheets,…)**
  - **grid generator is outgrowth of collaborative effort between LANL and FSU (Gunzburger)**
  - **dycores being developed for atmosphere and ocean**
- ***MPAS has been implemented in CAM and CESM***

MPAS uses conforming, variable resolution grid





MPAS uses vertical coordinate different from those of other CAM dycores

- **MPAS uses an eta-based vertical coordinate, but with dry pressure instead of total pressure**
  - **Pd(x,k) = A(k)*(p0-pt) + B(k)*(psd(x)-pt) + pt**
  - **reduces to same functional form as other dycores if pt=0**
- **Important instances of A(k),B(k) in CAM replaced by pressure state variable or reference pressure**
- **Reference pressure (used for parameterizations) supplied by reference pressure module**
  - **Pref(k) = A(k)*(p0-pt) + B(k)*(p0-pt) + pt**

The MPAS integration into CAM is similar to that of HOMME

- **CAM calls MPAS initialization, time-stepping, and finalization routines**
  - **CAM reads in the initial data and handles restarts**
- **CAM calls MPAS-supplied interface routines to transfer data between CAM and MPAS**
  - **initial data from CAM to MPAS**
  - **dynamics state from MPAS to CAM**
  - **physics tendencies from CAM to MPAS**
  - **restart data in each direction**
- **Physics is evolved on MPAS grid**
  - **all physics load-balance options are supported**
- **Processor decomposition files (computed using *metis* software) for the given grid convey domain decomposition information to CAM (and MPAS)**

MPAS routines are in their own directory

- ***Dynamics/mpas*** **contains control and interface routines**
- ***Dynamics/mpas/external*** **contains precompiled MPAS routines**
  - **a CAM/MPAS precompile script invokes the MPAS precompile procedure (based on registry file) and creates the routines therein**
  - **Precompiled MPAS source has fixed number/type of tracers and MPAS history information (for MPAS output)**
- **A small number of modifications were needed in the *bld*, *bld/namelist_files*, *control*, and *physics/cam* directories**
- **The CAM/MPAS branch is based on cam5_0_15**
  - **to date CAM/MPAS has been run only with CAM4 physics and up to three tracers**

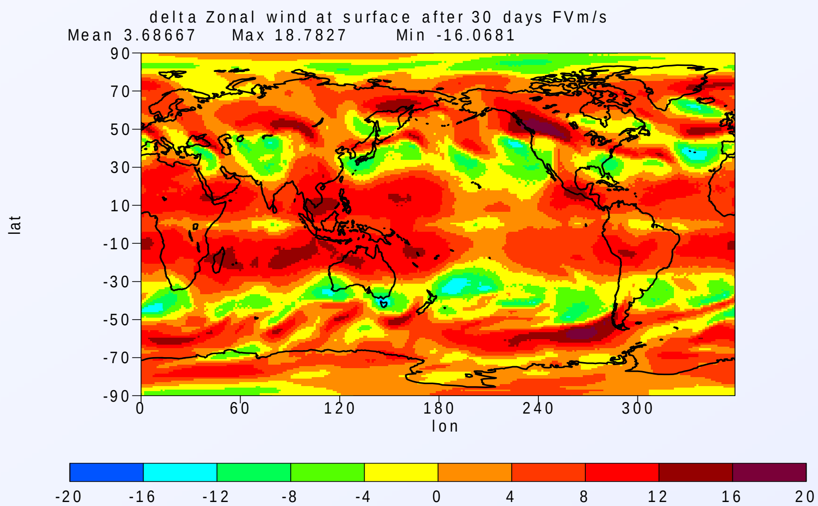
CAM/MPAS has undergone validation

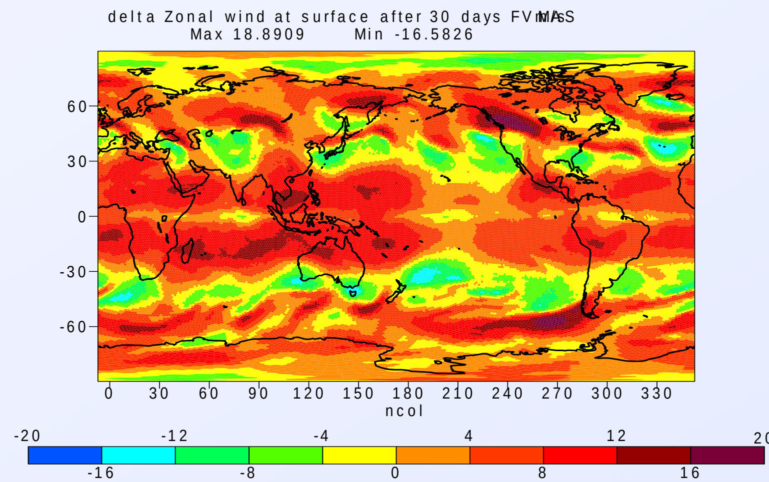
- **Compared physics tendencies on FV grid vs MPAS grid**
- **Compared MPAS driven by CAM (without physics) with MPAS-standalone for baroclinic wave tests, including advection of passive tracers**
- **Code runs on jaguar (ORNL), franklin (NERSC), bluefire (NCAR), and atlas/sierra (LLNL)**
- **Verified that restarts are bit-for-bit**

Zonal velocity change over month (physics tendencies only, no dynamics)

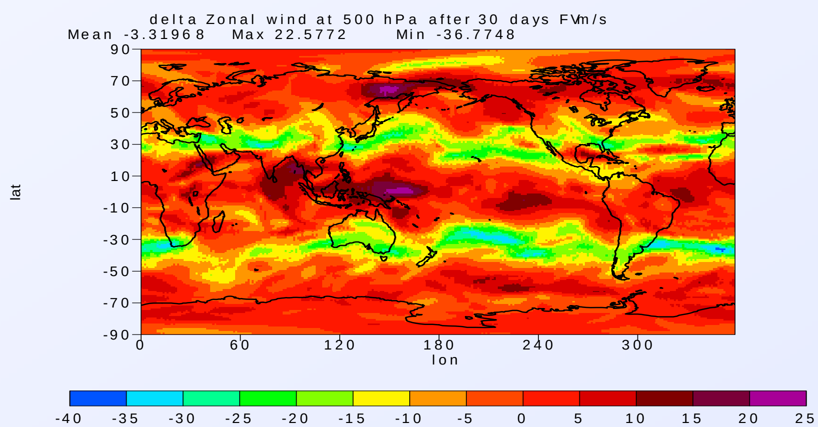
fv | **mpas**

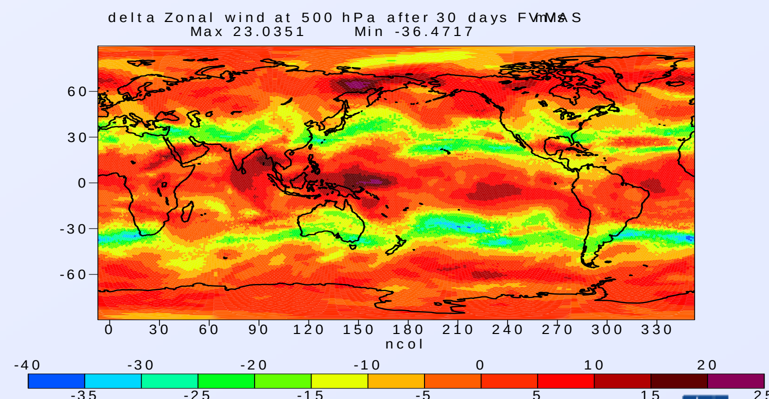
surface





500 hPa

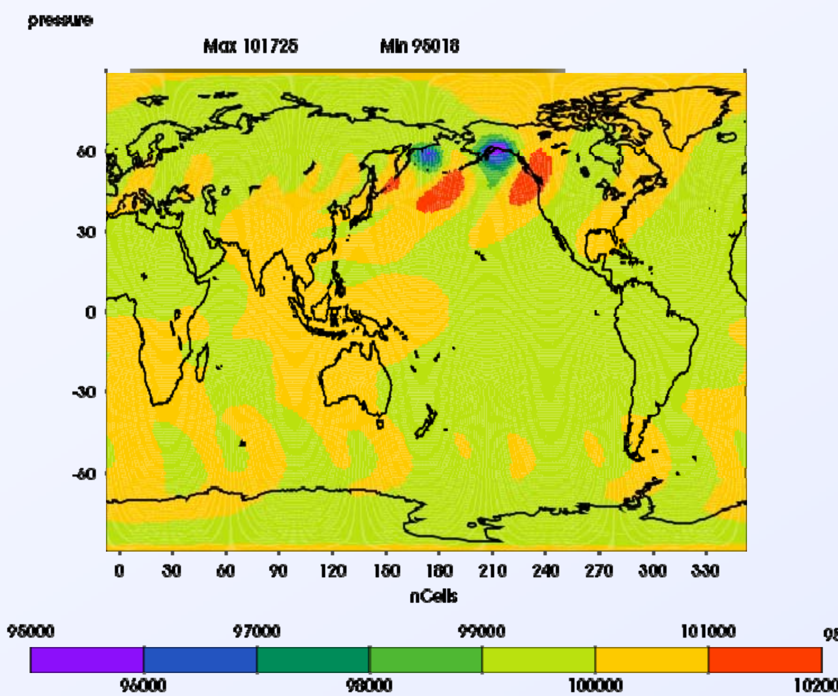




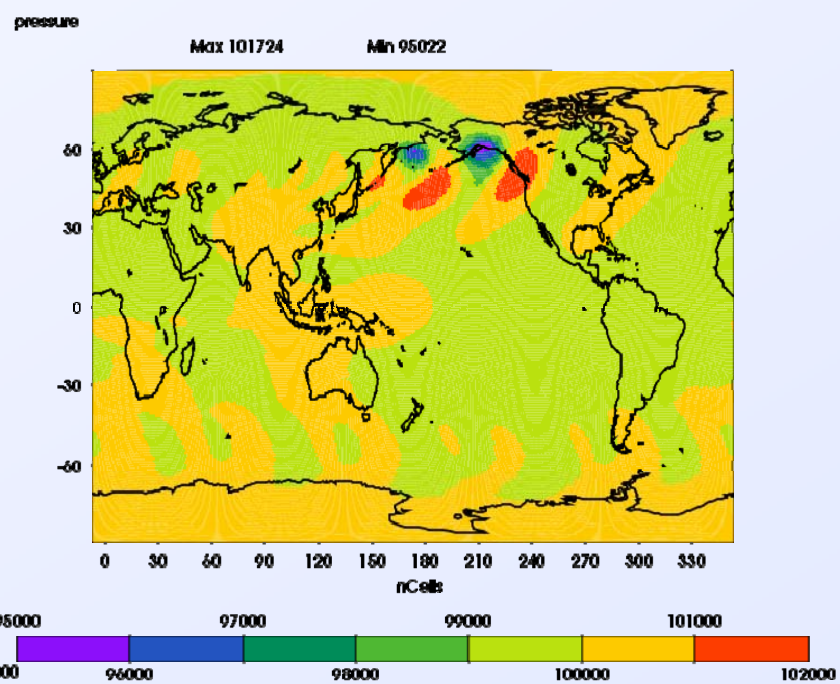
Baroclinic wave test (Jablonowski and Williamson)

- **Initial velocity field is zonally symmetric and contains mid-latitude northern and southern hemisphere jets**
- **Apply zonal wind perturbation**
- **Evaluate using 40962-cell grid (nominally 1-deg)**
- **Compare with literature**
- **Compare CAM/MPAS with MPAS-standalone**

Results of baroclinic wave test (10 days)



CAM/MPAS



MPAS-standalone

Input/Output involves auxiliary scripts and procedures

- **Initial conditions may be created from an existing FV IC file using an IDL script that invokes *interpic***
  - ***make_ic(gridfile,FV_IC_file,template_file,output_file)***
  - **velocities are at their native locations (normal velocity at edge)**
- **Cell boundary information is added to netcdf history files to enable visualization with VCDAT (*meshfill* option)**
- **Scrip conservation remap files are computed to interpolate CAM history files from MPAS grid to standard lat-lon grid**
  - **AMWG diagnostics package can then be invoked**
- **Both CAM and MPAS produce output data**

Several aqua-planet validation cases have been run

- **Aqua-planet cases use quasi-uniform grid unless otherwise stated**
  - **120 km**
  - **60 km**
  - **30 km**
  - **60-120 km locally refined grid**

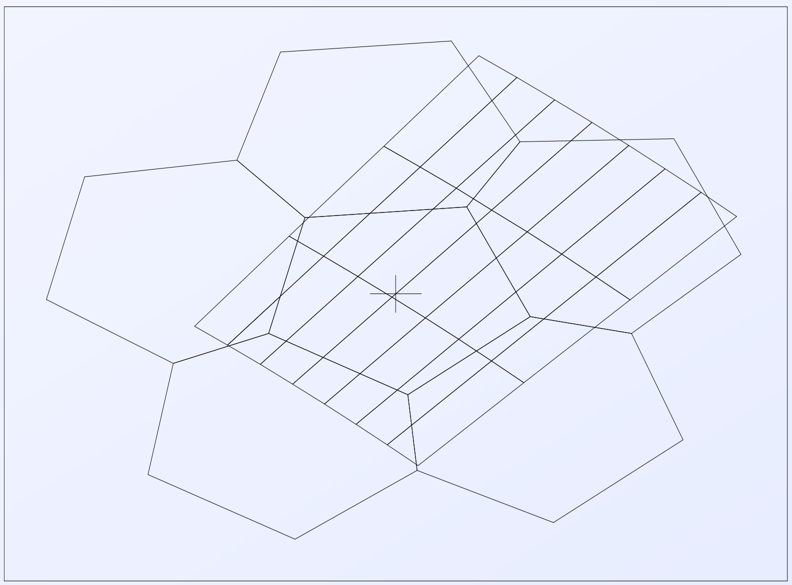
- **See presentation by Ringler, et al.**

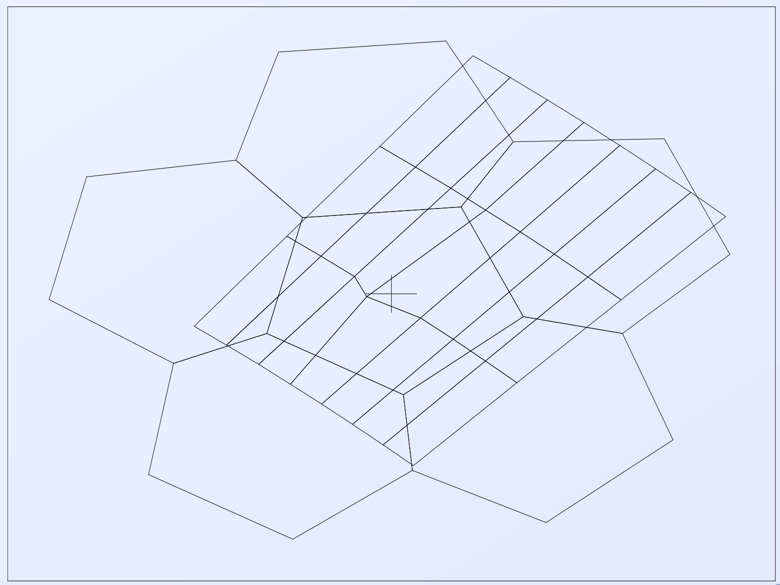
CAM/MPAS has been integrated into CESM

- **The only additional steps, beyond CAM/MPAS, were to modify a few files in the *scripts* directory**
- **The code integration is based on cesm1_0_beta07**
- **Scrip was used to compute conservation remap files between the MPAS (1-deg; 40962 points) grid and both the land (0.9x1.25) and ocean (gx1v6) grids**
- **We carried out one-year CESM/MPAS demonstration case using the F-configuration (active land, prescribed sea-ice, data ocean)**

We encountered difficulties remapping to gx1v6 grid

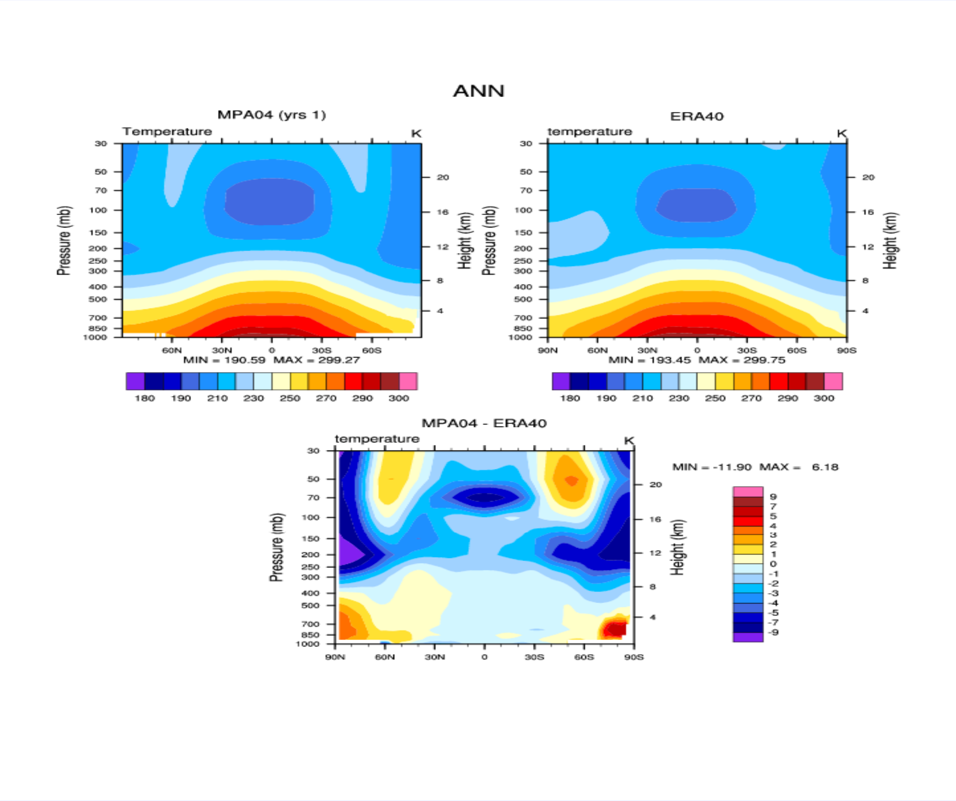
- The ocean grid box boundary lies extremely close to north pole
- SCRIP has difficulty handling the polar singularity
- We moved a single ocean grid point towards a neighboring point to eliminate negative weights





Accomplished CESM/MPAS tri-grid demonstration calculation

- **We carried out one-year CESM/MPAS demonstration case at 1-deg resolution using the F-configuration (active land, prescribed sea-ice, data ocean)**
  - **atmosphere – 40962 points**
  - **land – 0.9x1.25**
  - **ocean – gx1v6**
- **Post-processed with AMWG diagnostics package**



Potential future activities (integration effort)

- **Carry out CAM/MPAS validation cases with CAM5 physics and non-trivial chemistry/aerosol scenarios (e.g., mam3, mozart)**
- **Integrate MPAS onto CAM trunk**
  - **requires integrated make and build-namelist procedure**
- **Carry out full-component CESM/MPAS calculation**
- **Improve performance and scalability of MPAS**
  - **address OpenMP, indirect indexing**
  - **additional processes for physics, concurrent tracer advection**