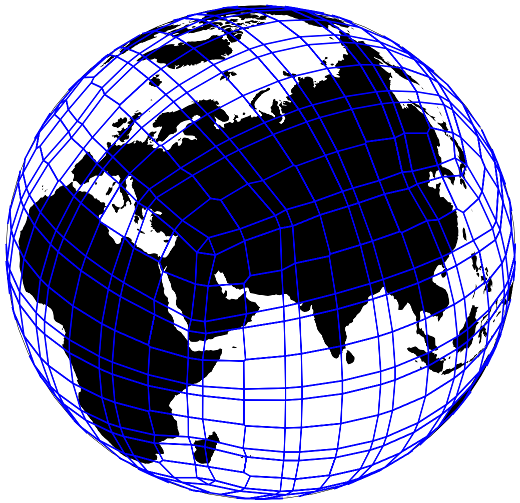
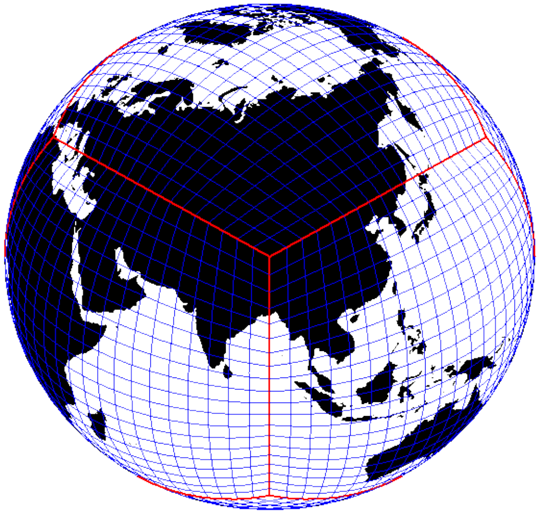
CAM dynamics update

Peter Hjort Lauritzen[§], M.A. Taylor[*], J.-F. Lamarque[§], J. Bacmeister[§],
F. Vitt[§], S. Goldhaber[§], C. Hannay[§],
A. Conley[§], B. Eaton[§], R.B. Neale[§], …





AMWG winter meeting, February 10-12, 2014

[§] NCAR *Sandia National Laboratories

Overview

CAM-SE:

- New default time-stepping
- Axial angular momentum conservation
- Physics-grid and CSLAM transport
- Capability of doing offline simulations driven by meteorological analysis for chemistry applications

Leaving out lots of HOMME development:
non-hydrostatic DG (R.D. Nair & R. Kloefkorn), non-hydrostatic SE (R.D. Nair & D. Hall), implicit time-stepping (K. Evans), …

Other:

- Energy definition in CAM (covered by D.L. Williamson)
- Nudging ("on the physics time-step") – J.T. Bacmeister
- MPAS in CAM

Trunk changes to time-stepping

- tstep_type=5:
  Switched to a 5-stage Runga-Kutta time-stepping;
  based on Kinnmark and Gray (1984) with a modification (Ullrich; unpublished) to make it non-linearly 3rd-order in time (implemented by M.A. Taylor)
- User confusion on CAM namelist:
  (e.g., split namelist variables do not mean the same thing in CAM-SE as CAM-FV)

$$\Delta t_{phys} = dtime,$$

$$\Delta t_{remap} = \frac{\Delta t_{phys}}{se\_nsplit},$$

$$\Delta t_{tracer} = \frac{\Delta t_{remap}}{rsplit},$$

$$\Delta t_{dyn} = \frac{\Delta t_{tracer}}{qsplit},$$

resolution	dtime	se_nsplit	rsplit	hypervis_ subcycle	Δt_{remap}[s]	Δt_{tracer}[s] $= \Delta t_{dyn}$[s]	$\Delta t_{hypervis}$[s]	ν [m^4/s]
ne11np4[a]	1800 (1800)	1 (5)	2 (2)	3 (1)	1800 (360)	900 (180)	300 (180)	2.0×10^{16} (2.0×10^{16})
ne16np4[b]	1800 (1800)	1 (5)	3 (3)	3 (1)	1800 (360)	600 (120)	200 (120)	7.0×10^{15} (7.0×10^{15})
ne30np4	1800 (1800)	2 (10)	3 (3)	3 (1)	900 (180)	300 (60)	100 (60)	1.0×10^{15} (1.0×10^{15})
ne60np4	1800 (1800)	4 (20)	3 (3)	4 (1)	450 (90)	150 (30)	37.5 (30)	1.0×10^{14} (1.0×10^{14})
ne120np4[c]	900 (900)	4 (20)	3 (3)	4 (1)	225 (45)	75 (15)	18.75 (15)	1.0×10^{13} (1.0×10^{13})
ne240np4	600[d] (600)	5 (25)	3 (3)	4 (1)	120 (24)	40 (8)	10 (8)	1.1×10^{12} (1.1×10^{12})

[a] untested
[b] untested
[c] if winds are maximum 600 m/s; for CAM it is 120 m/s
[d] 900 works, however, gravity wave noise!

qsplit=1

http://www.cgd.ucar.edu/cms/pel/software/cam-se-dt-table.pdf

- assuming Lagrangian vertical coordinate

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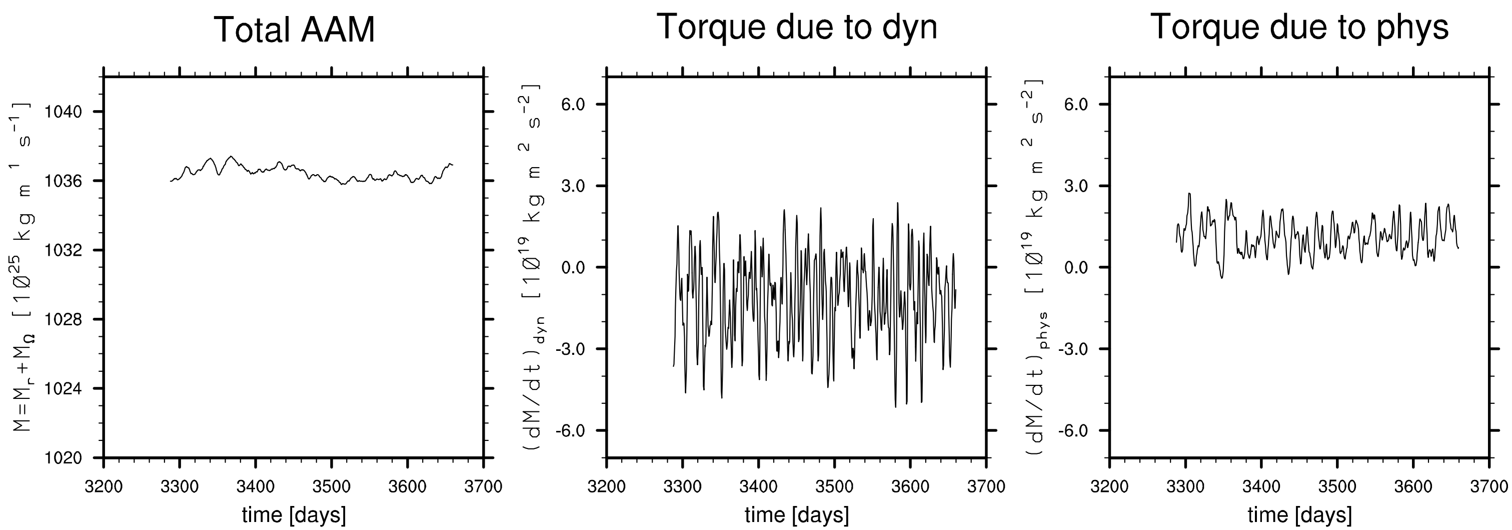
Axial angular momentum analysis

Held-Suarez forcing (flat Earth => no mountain torque)

CAM-FV: finite-volume (Lin, 2004) dynamical core in CAM

Axial Angular Momentum (AAM) diagnostics for CAM-FV



M=global integrated axial angular momentum

$$0 \sim \left(\frac{dM}{dt}\right)_{dyn} \ll \left(\frac{dM}{dt}\right)_{phys}.$$

NOT fulfilled!

Lebonnois et al., (2012)

Axial angular momentum analysis

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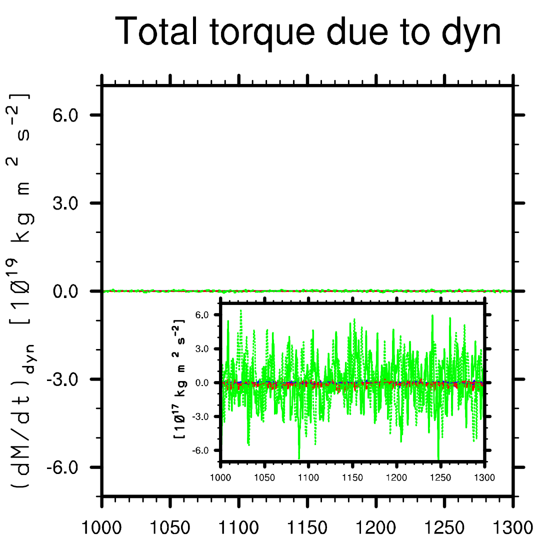
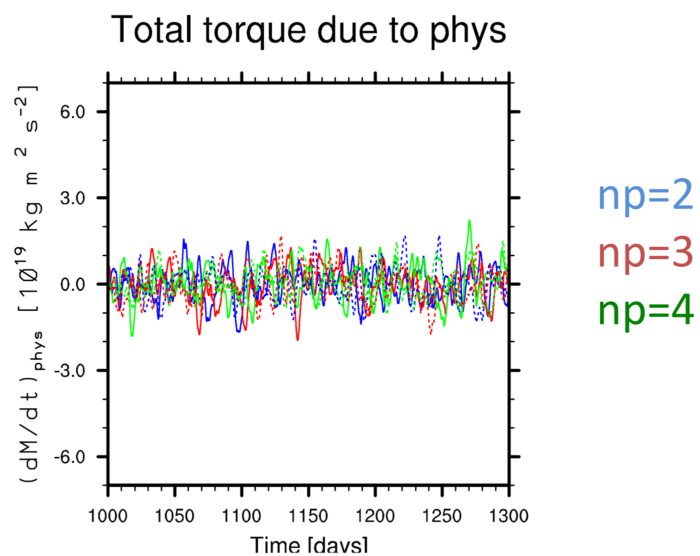
CAM-SE results:



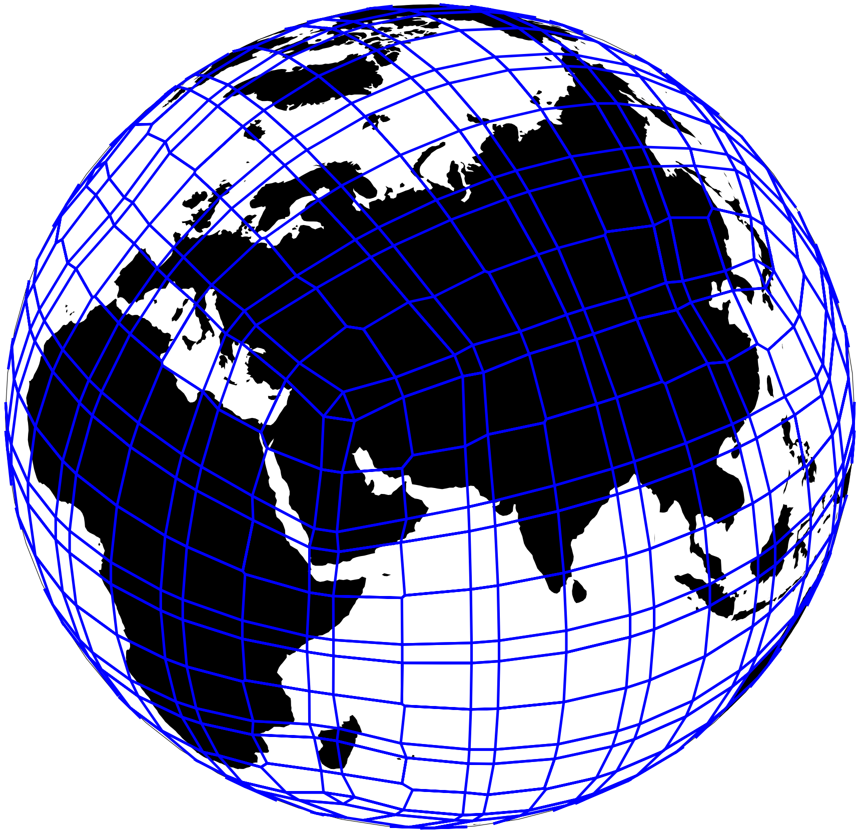


$$0 \sim \left(\frac{dM}{dt}\right)_{dyn} \ll \left(\frac{dM}{dt}\right)_{phys}.$$

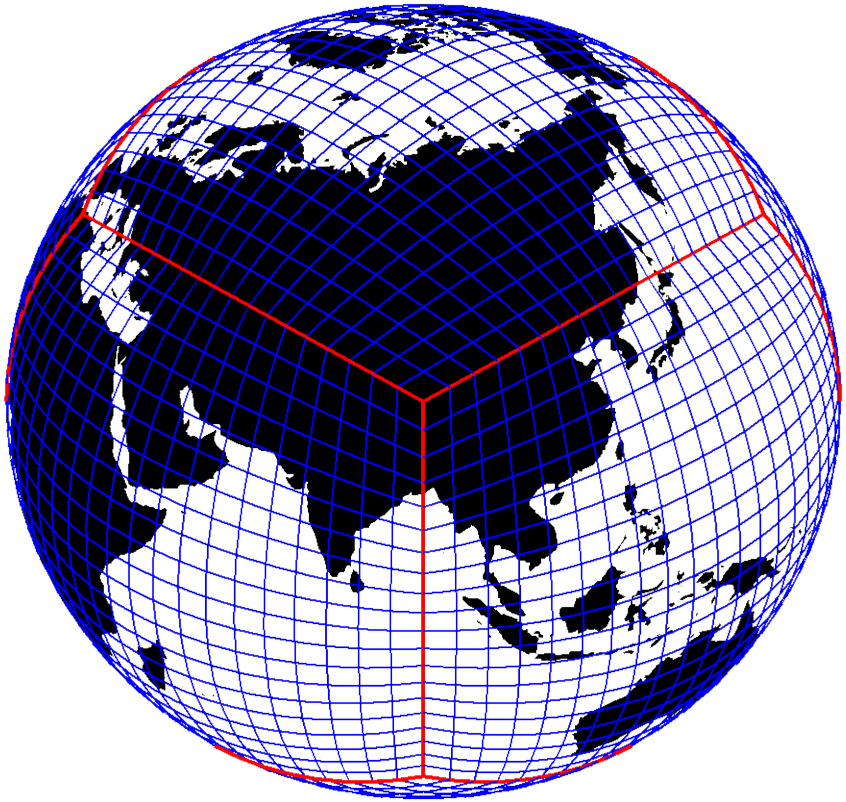
Lauritzen et al. (2014; in press)

Separating physics and dynamics grids

Current physics/"coupler" grid



Finite-volume equi-angular gnomonic grid



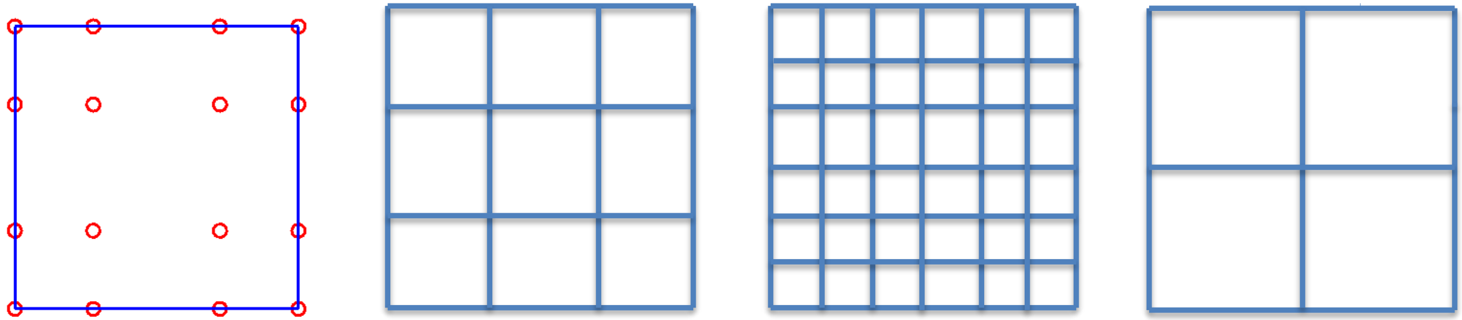
Separating physics and dynamics grids

6 month+ of re-engineering of CAM history output …. (S. Goldhaber)

Main tasks:

- enable output on an arbitrary physics grid (different from dynamics grid)
- remove assumptions in physics assuming dynamics-physics points co-located
- interface code for SE stored entire grid on every MPI task – fixed! (should help scalability on small memory massively parallel machines)
- dp_coupling is now able to support physics grid
- tools to create IC files with different grids in one file

Current physics grid is equal-area finite-volume-type grid in each element (support coarser, finer, or similar resolution within each element)



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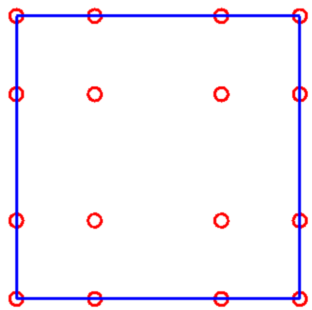
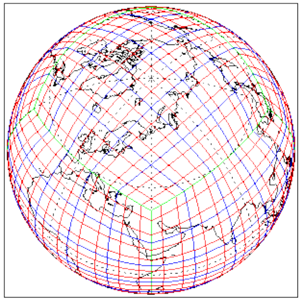
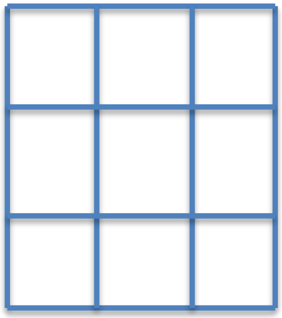
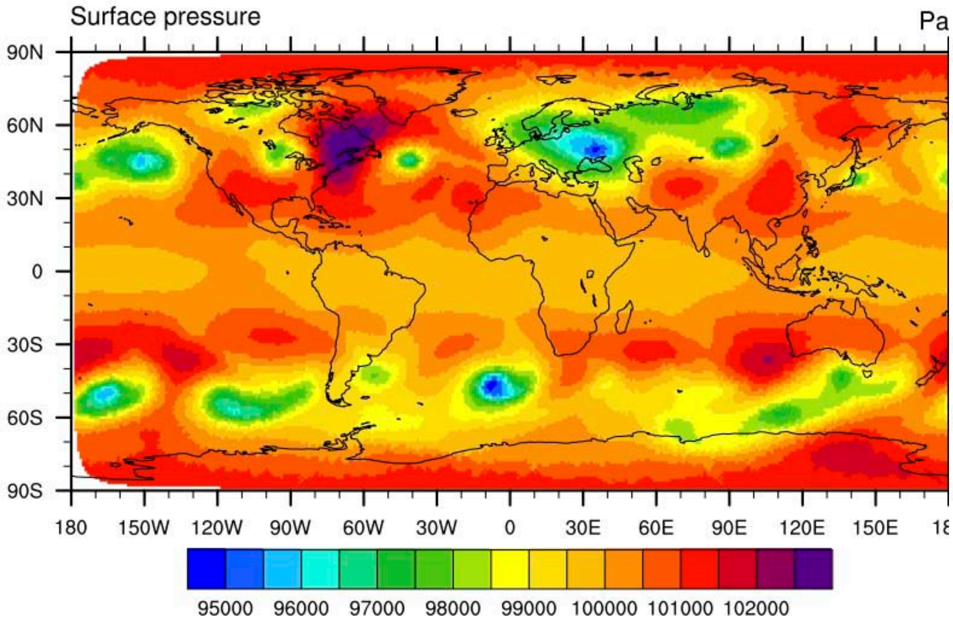
Held-Suarez runs with physics grid



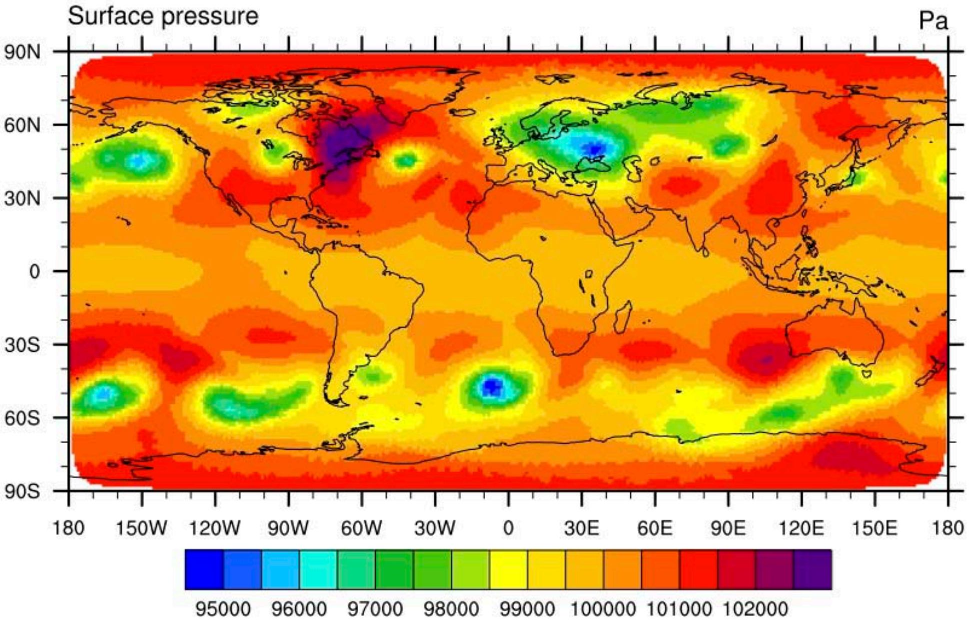




Control, day 9

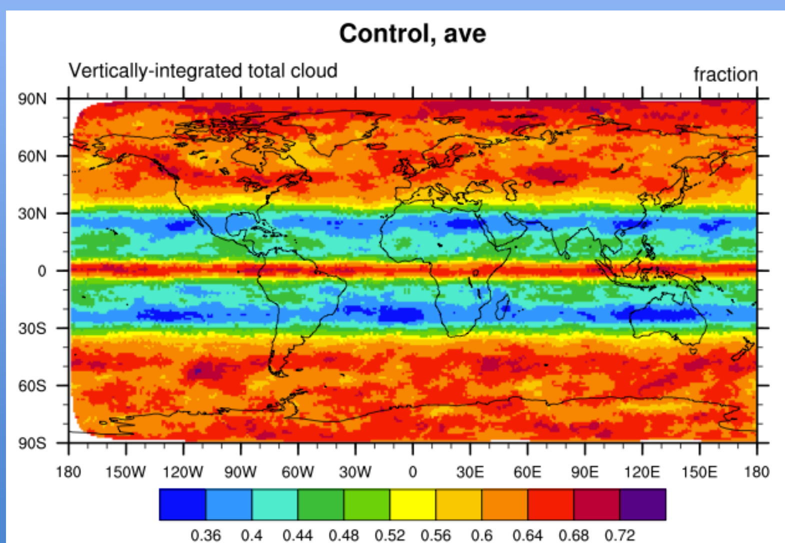


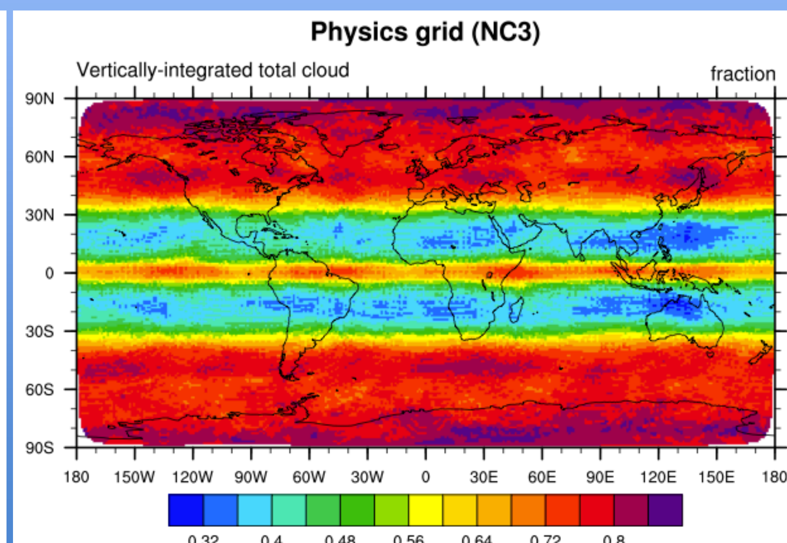
Physics grid (NC3), day 9



Held-Suarez runs with physics grid

Currently debugging the Aqua-planet run





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Current physics grid is equal-area finite-volume-type grid in each element

Todo:
- flush out bugs …
- longer term: generalize mapping to support arbitrary physics grids (for example, this will support mesh-refinement in the dynamical core and run physics on a uniform resolution grid)
- enforce total energy conservation in mapping process

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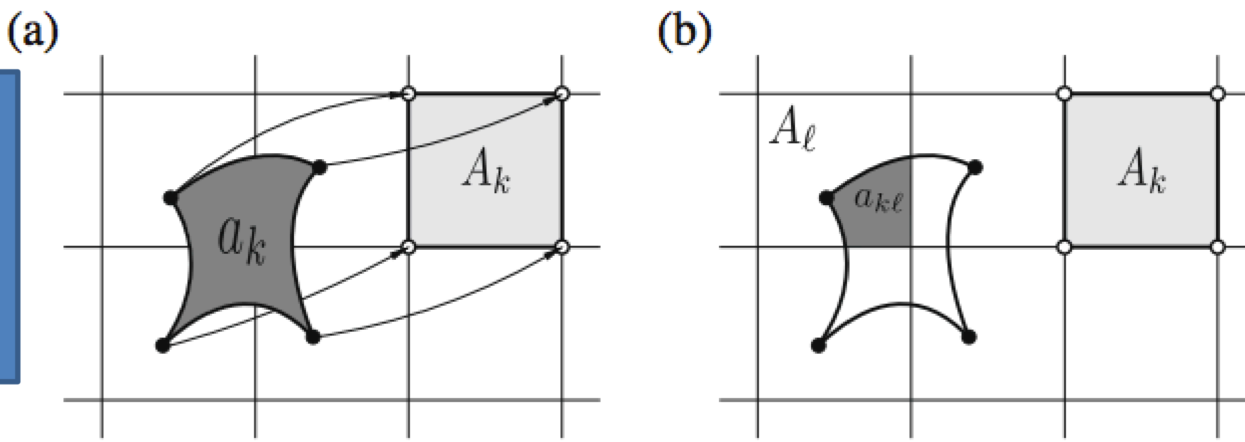
Multi-tracer transport (CSLAM) in CAM-SE

- Stand-alone Lagrangian CSLAM scheme has been in HOMME for a while (Erath et al. 2012); also other option: SPELT (Erath and Nair, 2014)

Allows for long time-steps

=> less MPI communication



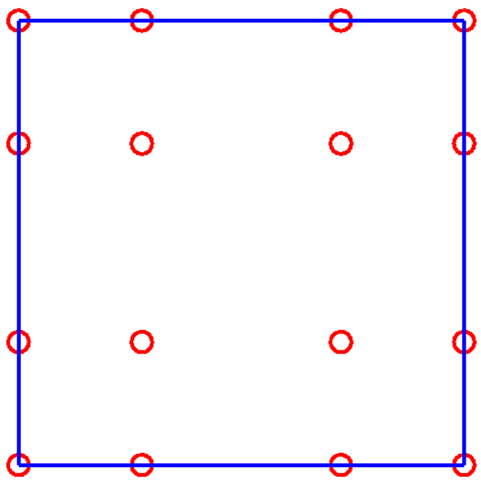
Computing overlap areas is expensive but weights can be re-used for each additional tracer

Fig. 1. A schematic illustration of concepts used in the semi-Lagrangian finite-volume scheme. (a) The deformed departure cell a_k (dark shaded area) ends up, after being transported by the flow for one time-step, at the regular arrival cell A_k (light shaded area). The trajectories for the cell vertices are shown with arrows, and the departure and arrival cell vertices are marked with filled and open circles, respectively. (b) Illustrates the overlap region between the grid cell A_ℓ and the departure cell a_k referred to as $a_{k\ell}$ used for the upstream integral computation given in Eq. (4).

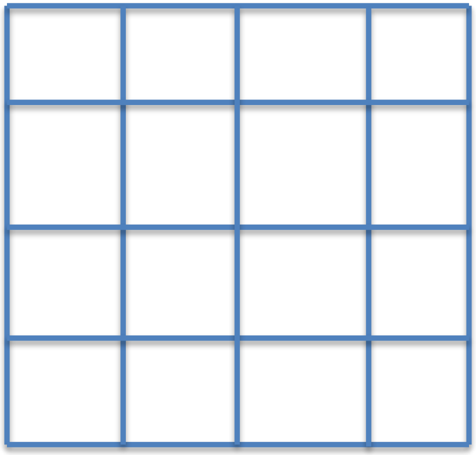
Multi-tracer transport (CSLAM) in CAM-SE

Now that physics grid infrastructure is maturing we can start focusing on CSLAM transport (CSLAM scheme is using a finite-volume (quasi equal-area) grid and needs new physics grid infrastructure in CAM)

SE (np=4)



CSLAM (nc=4)



Multi-tracer transport (CSLAM) in CAM-SE

Now that physics grid infrastructure is maturing we can start focusing on CSLAM transport (CSLAM scheme is using a finite-volume (quasi equal-area) grid and needs new physics grid infrastructure in CAM)

- Stand-alone Lagrangian CSLAM scheme has been in HOMME for a while (Erath et al. 2012). **However, Erath et al. (2012) did not consider coupling with CAM-SE air density**

- To couple CSLAM scheme with CAM-SE we are using a conventional flux-form methodology (used in, for example, CAM-FV):

  - convert Lagrangian CSLAM to flux-form (90% done in HOMME; Lauritzen)
  - compute finite-volume type fluxes from CAM-SE (method derived by Taylor and Ullrich)

  NCAR-Sandia is working on uniform resolution implementation (Lauritzen-Taylor)
  Argone-Sandia are working on variable resolution implementation (PI: F. Hoffman)

Capability for doing offline simulations driven by (GEOS5) meteorological analysis in CAM-SE

focus: chemistry applications

J.-F. Lamarque (PI), F. Vitt, A. Conley, P.H. Lauritzen

Current method in CAM-FV (CAM-Chem): Overwrite u,v,T,PS at every physics time-step and apply mass-fixer (directionally biased) to enforce consistency between internal mass-fluxes and driving data

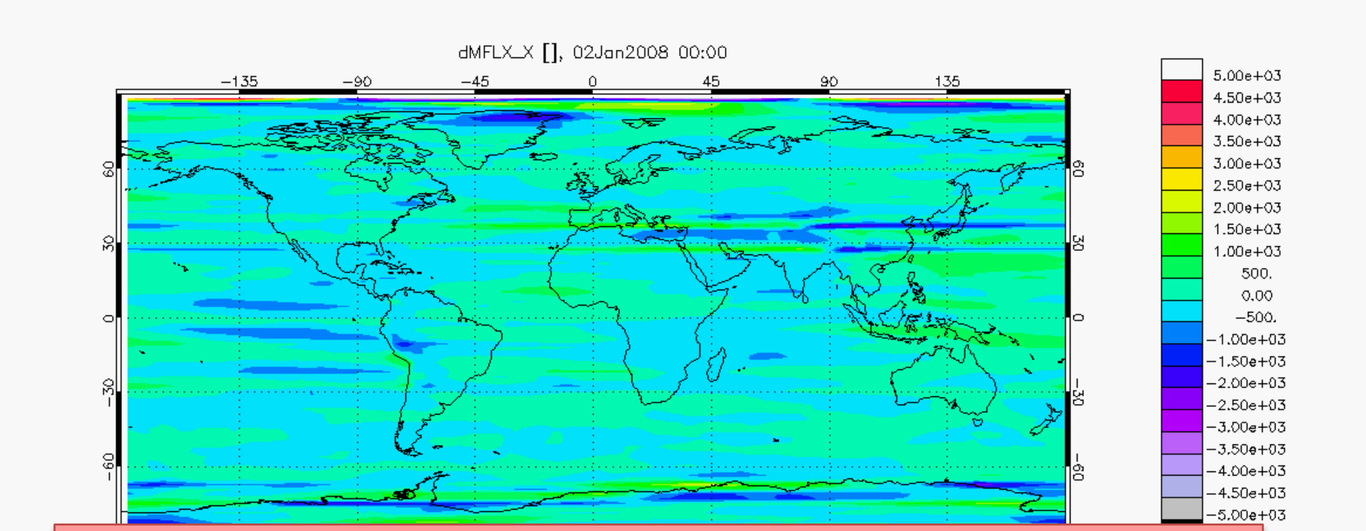


Figure: mass flux adjustment coming from pressure fixer

Capability for doing offline simulations driven by (GEOS5) meteorological analysis in CAM-SE

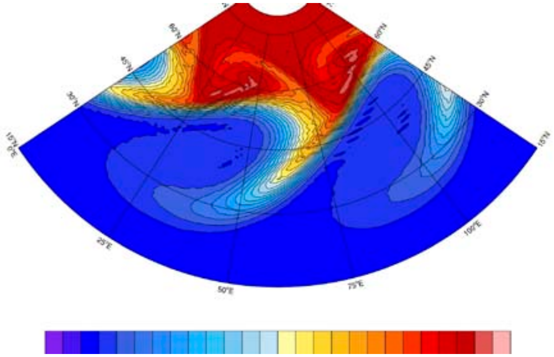
focus: chemistry applications

J.-F. Lamarque (PI), F. Vitt, A. Conley, P.H. Lauritzen

Method implemented in CAM-SE:

- Apply nudging to u,v, T (not PS)
- The nudging is implemented as a forcing term inside the dynamical core
  (at every Runga-Kutta step the dynamical core "feels" the nudging)

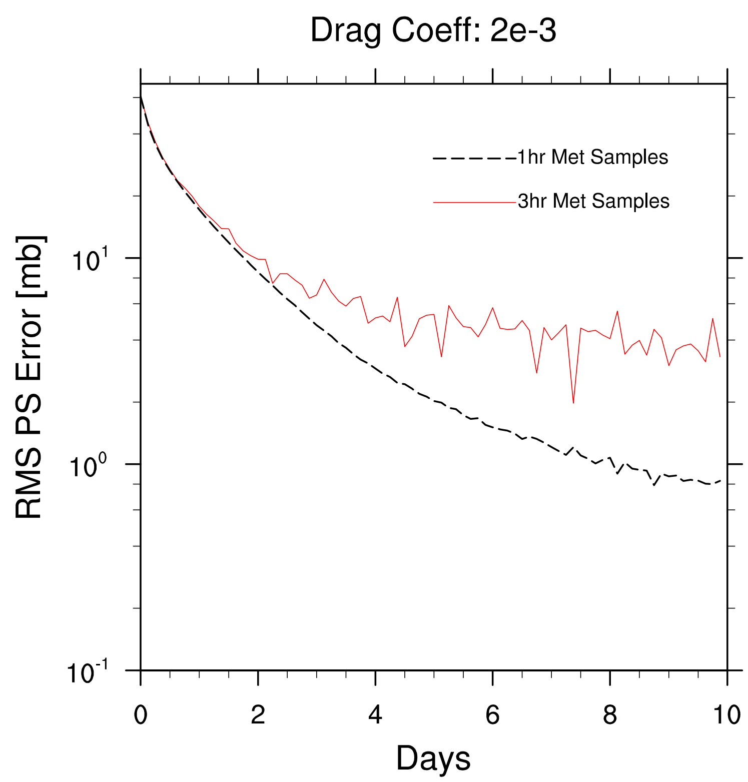
Does it work? Is PS nudged towards offline PS?

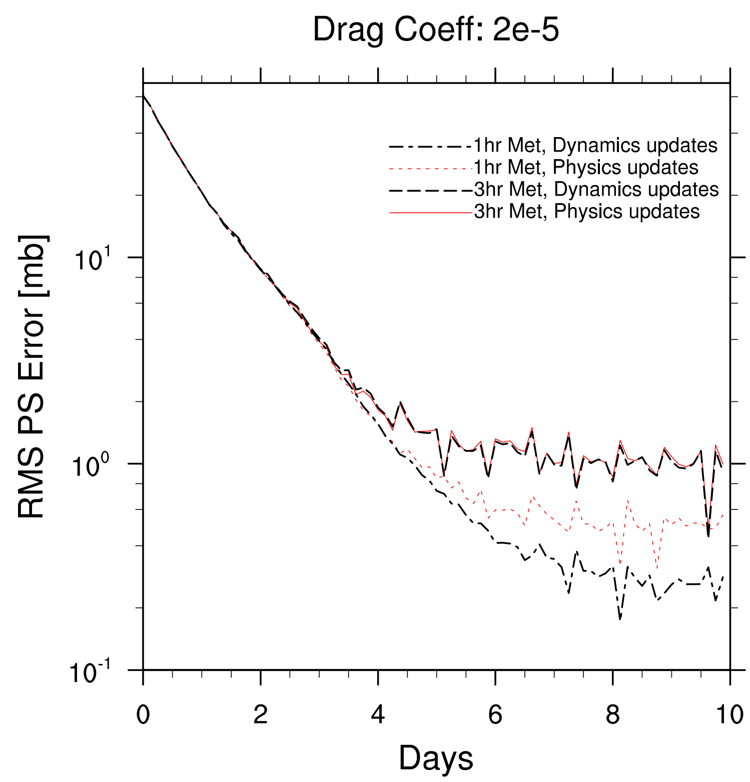


Idealized test:

Initial condition: Polvani baroclinic wave at time T=10 days
Force it to time-evolving solution starting from day 0

- Temporal resolution of meteorology is the largest error
- If you nudge weaker you get better results (time evolution is not linear).
- Updating nudging term every dynamics time-step (linear temporal interpolation between met field updates) only improves results if met fields are updated hourly





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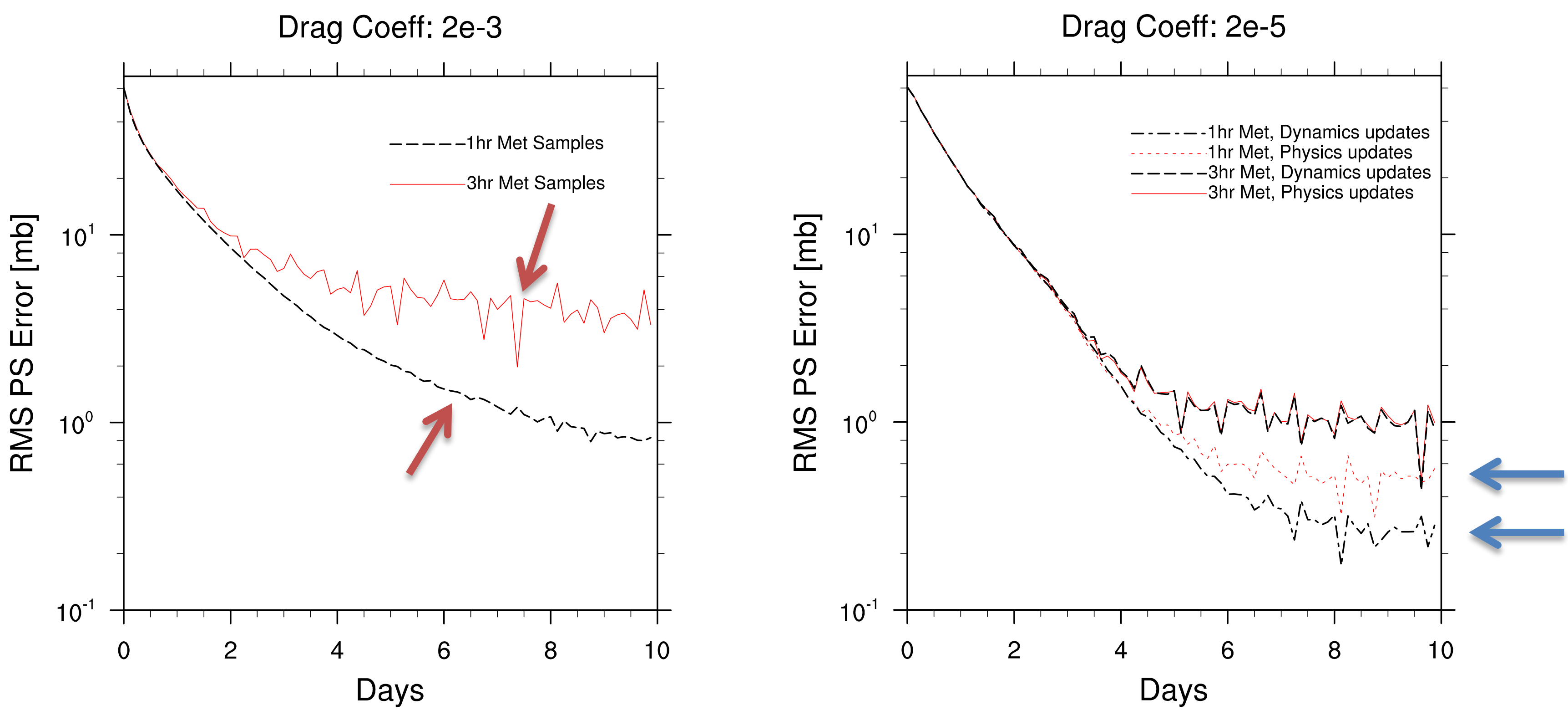
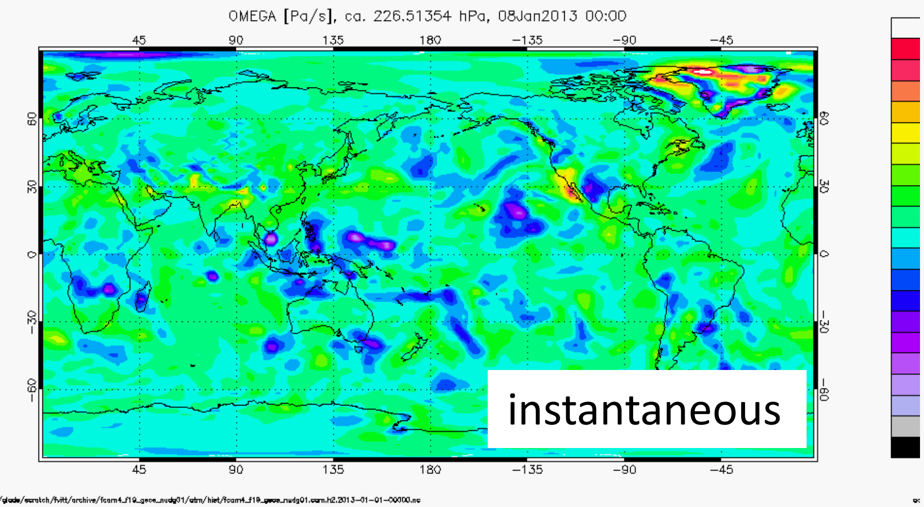
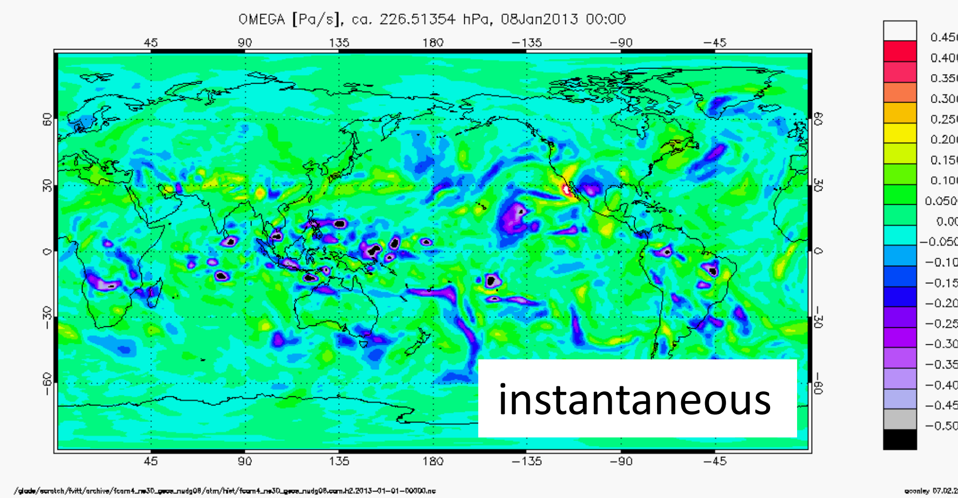


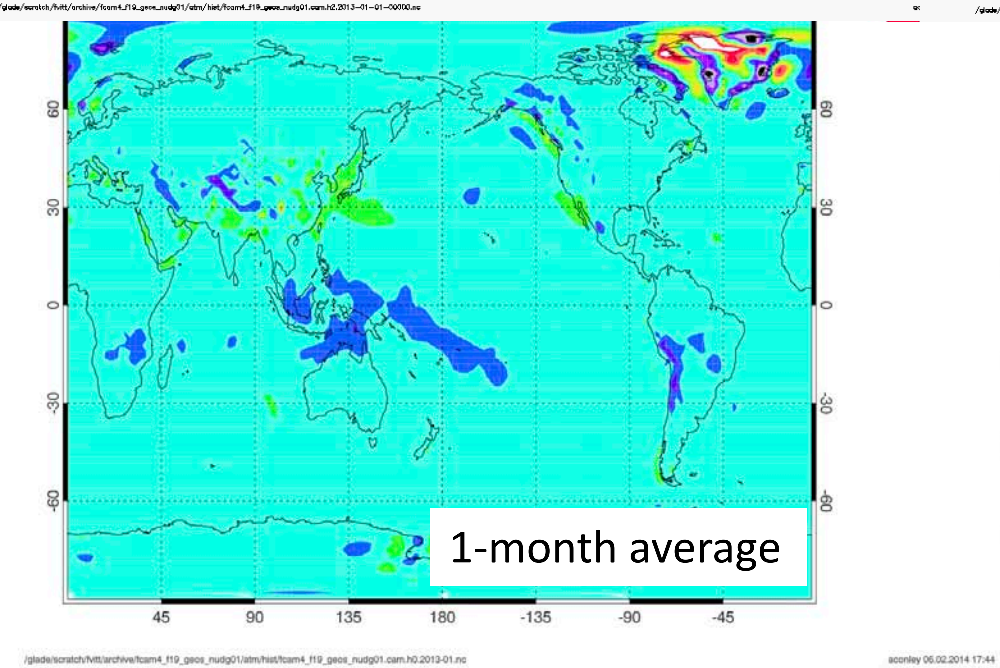
FV:1.9x2.5

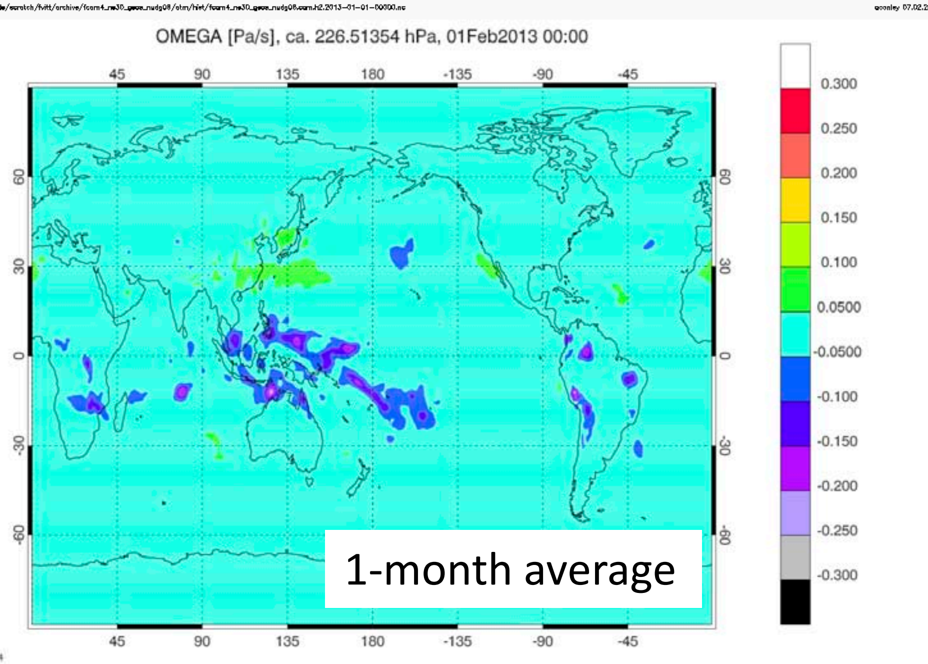
“Full” model results

SE: NE30

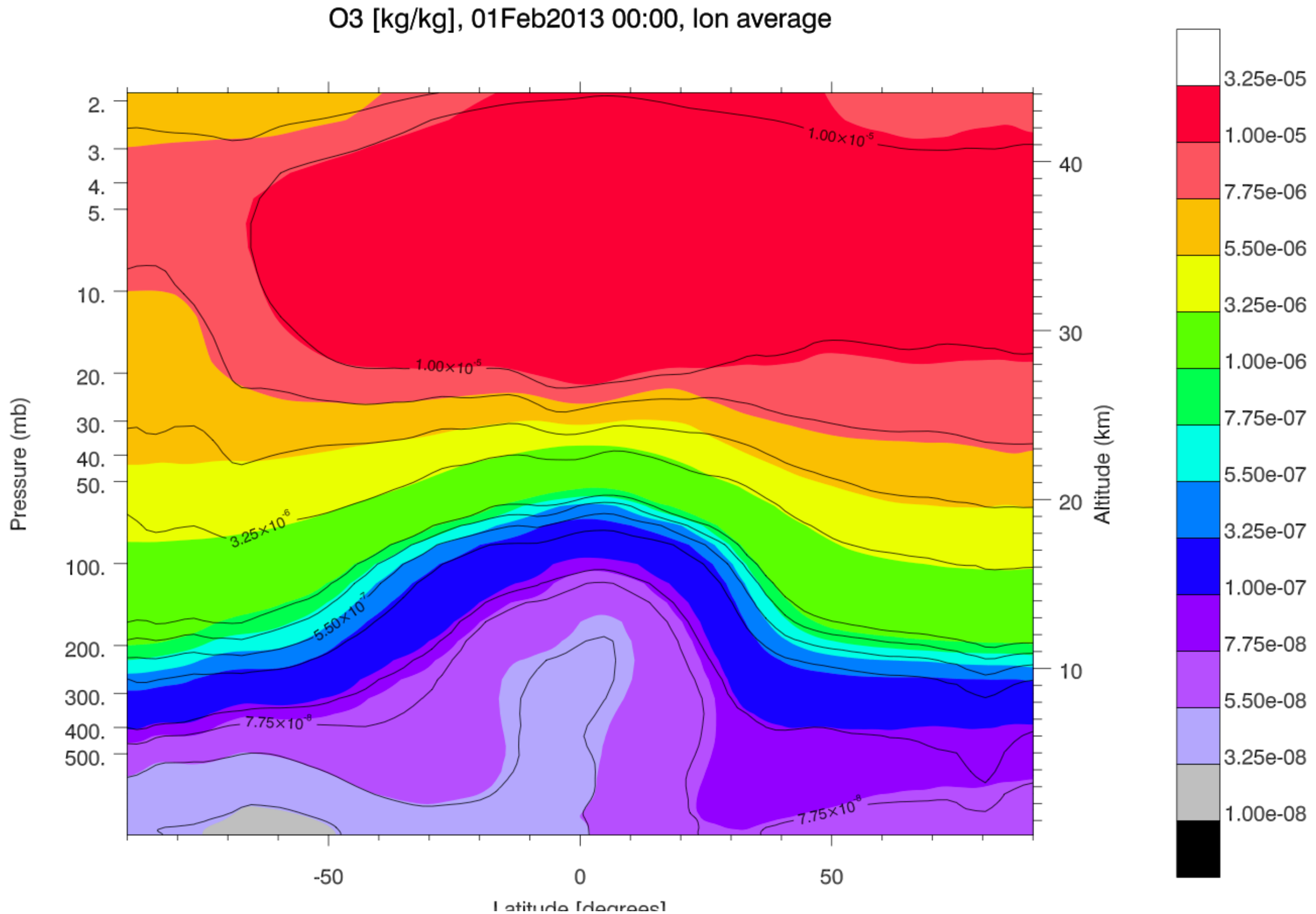








Filled contours: CAM-SE
Black contours: CAM-FV



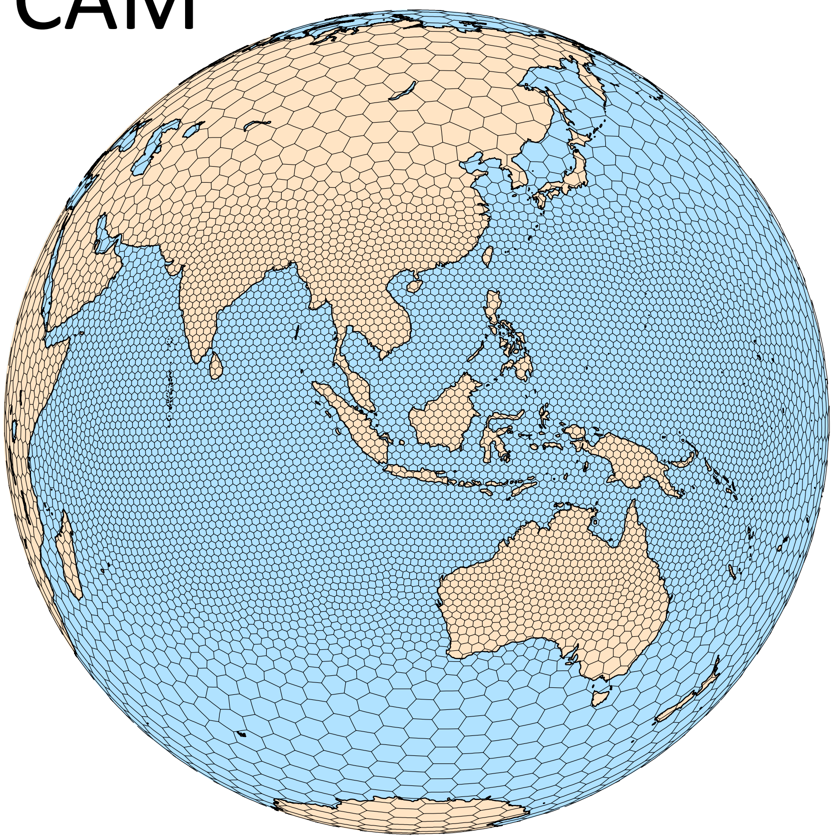
Logarithmic contour scale: factor of 3 too much mixing over Greenland/Equator

Slide from W.C. Skamarock

Nonhydrostatic MPAS-Atmosphere dynamical core port to CAM

- Software engineering of port is complete; uses CAM5 physics.
- Held-Suarez and APE testing is underway.
- AMIP testing this spring.
- NWP testing in hydrostatic regime later this winter.

Major concern: Scale-aware physics, physics (deep convection, microphysics) for nonhydrostatic resolutions in CAM



Variable-resolution MPAS mesh, refinement over the Maritime Continent region

W.C. Skamarock, S.-H. Park, P.H. Lauritzen

MPAS Model for Prediction Across Scales

Los Alamos NATIONAL LABORATORY EST. 1943

U.S. DEPARTMENT OF ENERGY | Office of Science

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NESL

Axial angular momentum

In the absence of any surface torque and zonal mechanical forcing, the hydrostatic primitive equations conserve the globally integrated AAM when assuming a constant pressure upper boundary [see, e.g., *Staniforth and Wood*, 2003]:

$$\frac{dM}{dt} = 0. \tag{2}$$

Typically numerical models are divided into a dynamical core (dyn) that, roughly speaking, solves the equations of motion on resolved scales and physical parameterizations that approximate sub-grid-scale processes ($phys$). There can therefore be two sources/sinks of AAM:

$$\frac{dM}{dt} = \left(\frac{dM}{dt}\right)_{dyn} + \left(\frac{dM}{dt}\right)_{phys}. \tag{3}$$

In the absence of mountain torque: $0 \sim \left(\frac{dM}{dt}\right)_{dyn} \ll \left(\frac{dM}{dt}\right)_{phys}.$

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A simple way to assess axial angular momentum conservation

Held-Suarez forcing: flat-Earth (no mountain torque), physics replaced by simple boundary layer friction and relaxation of temperature toward reference profile

$$\frac{\partial v}{\partial t} = \cdots - k_v(\sigma)v$$

$$\frac{\partial T}{\partial t} = \cdots - k_T(\phi,\sigma)\left[T - T_{eq}(\phi,p)\right]$$

$$T_{eq} = \max\left\{200\mathrm{K}, \left[315\mathrm{K} - (\Delta T)_y \sin^2\phi - (\Delta\theta)_z \log\left(\frac{p}{p_0}\right)\cos^2\phi\right]\left(\frac{p}{p_0}\right)^{\kappa}\right\}$$

$$k_T = k_a + (k_s - k_a)\max\left(0, \frac{\sigma - \sigma_b}{1 - \sigma_b}\right)\cos^4\phi$$

$$k_v = k_f \max\left(0, \frac{\sigma - \sigma_b}{1 - \sigma_b}\right)$$

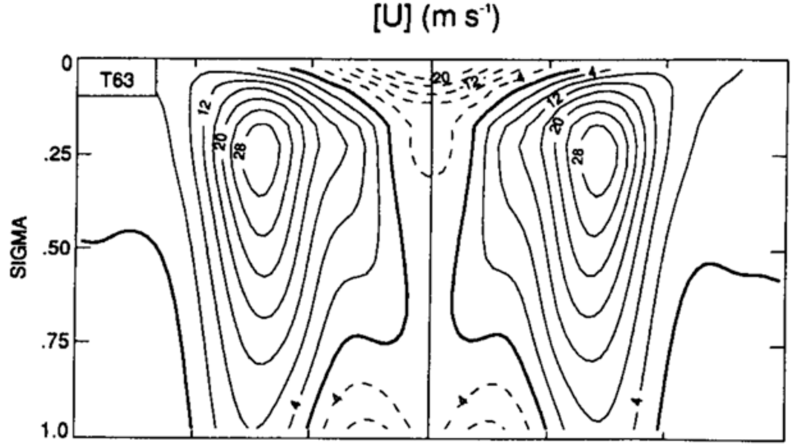
$\sigma_b = 0.7$ $\quad k_f = 1\ \mathrm{day}^{-1}$,

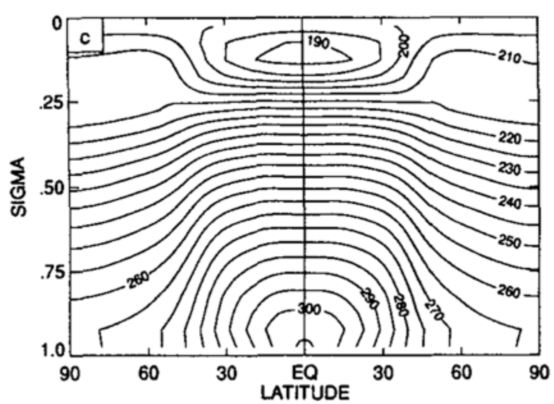
$k_a = 1/40\ \mathrm{day}^{-1}$ $\quad k_s = 1/4\ \mathrm{day}^{-1}$

$(\Delta T)_y = 60\mathrm{K}$ $\quad (\Delta\theta)_z = 10\mathrm{K}$

$p_0 = 1000$ mb $\quad \kappa = \frac{R}{c_p} = \frac{2}{7}$ $\quad c_p = 1004\ \mathrm{J\ kg^{-1}\ K^{-1}}$

$\Omega = 7.292 \times 10^{-5}\ \mathrm{s}^{-1}$ $\quad g = 9.8\ \mathrm{m\ s^{-2}}$ $\quad a_e = 6.371 \times 10^6$ m.





Zonally and time averaged T