Some FV3 updates in GEOS:

32-bit Accuracy
Vertical Remapping
Offline Advection

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NOAA – Geophysical Fluid Dynamics Laboratory

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NOAA – Environmental Modeling Center

Finite-Volume Cubed-Sphere Dynamical Core

Finite-Volume transport on a Lat-Lon grid for chemistry transport

Multidimensional Flux-Form Semi-Lagrangian Transport Schemes

Lin and Rood, 1996

Shallow water model development

An Explicit Flux-Form Semi-Lagrangian Shallow Water Model on the Sphere

Lin and Rood, 1997

Full 3-dimensional hydrostatic dynamical core

A finite-volume integration method for computing pressure gradient force in general vertical coordinates

Lin, 1997

Vertically Lagrangian discretization

A "Vertically Lagrangian" Finite-Volume Dynamical Core for Global Models

Lin, 2004

Cubed-Sphere implementation

Finite-volume transport on various cubed-sphere grids

Putman and Lin, 2007

A non-hydrostatic finite-volume algorithm

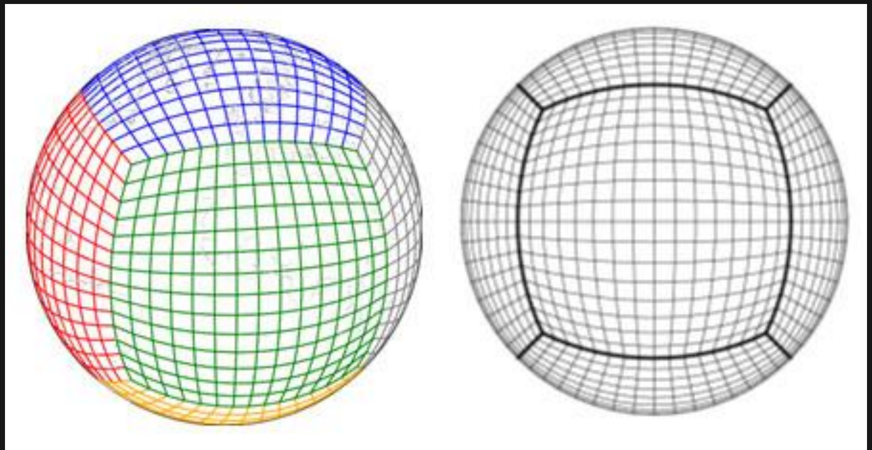
A control volume model of the compressible Euler equations with a vertical Lagrangian Coordinate

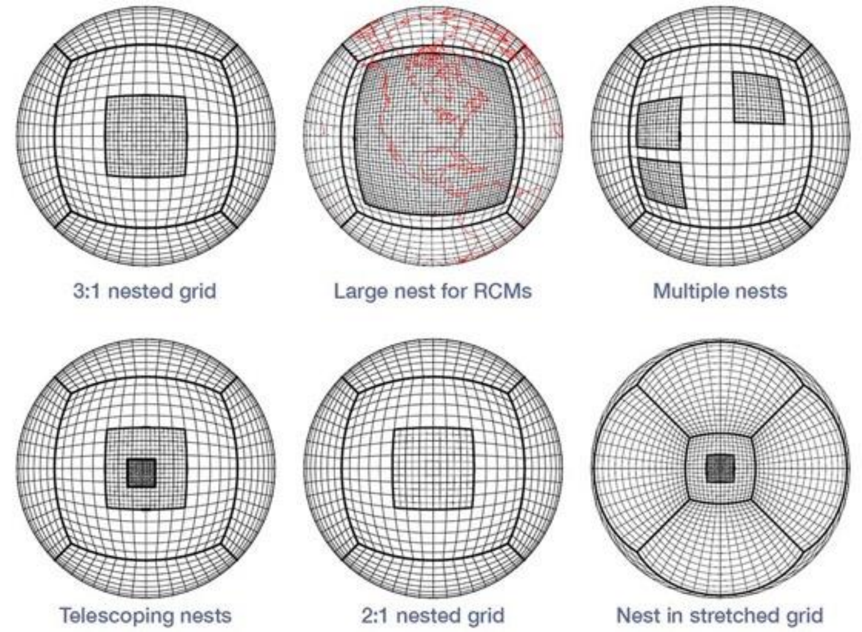
Chen, Lin, and coauthors, 2013

Global to regional nesting

A two-way nested global-regional dynamical core on the cubed-sphere grid

Harris and Lin, 2014





FV3: Interagency Collaboration

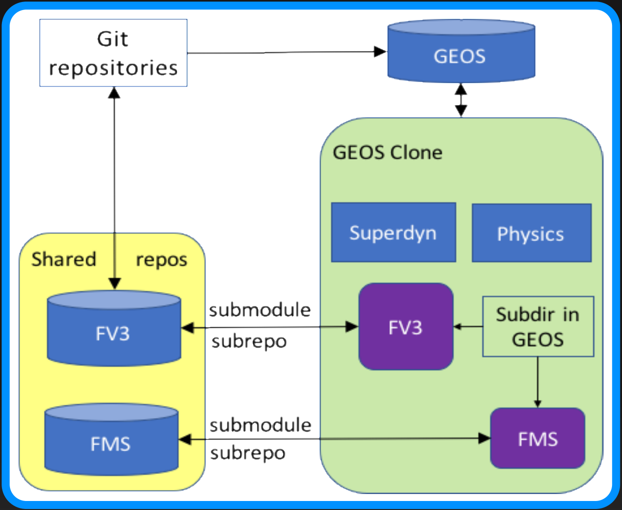
Shared FV3 component lives in separate Git repos

FV3 exists as a normal subdirectory in GCM
- Most users unaware
- Requires some minor refactoring

Two variant Git approaches
- Git **submodule**
  - Lightweight – just links are stored
  - Most users should treat subdir as static
- Git **subrepo**
  - Files stored in both repos
  - Unaware users can modify subdir contents

Hosting shared components
- Ideally via a public site (e.g., GitHub)
- But can use read-only clones at each end

Released versions to NOAA VLab



GMAO
GEOS
- Data Assimilation
- Weather Prediction
- S2S Prediction
- Reanalysis
- Global Mesoscale

GFDL
AM3 CM3 HiRAM
- Climate (IPCC)
- S2S Prediction
- Weather
- High-Resolution

EMC
GFS GEFS SFS
- Operational DA
- Operational NWP
- S2S Prediction
- Reanalysis
- *Future CAM and CAM Ensembles*
- *Hurricanes, Space Weather, WoF …*

GISS
modelE
- Climate (IPCC)
- Exo-planets

Harvard
GEOS-Chem
- Chemical Transport Composition

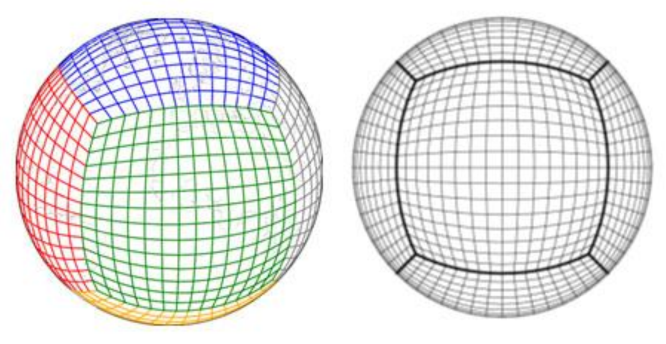
ESRL
NGGPS
- Real-time FV3-GFS
- Advanced Physics

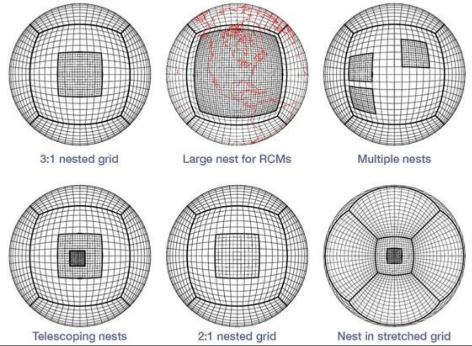
NCAR
CESM
- Climate (IPCC)
- Data Assimilation

JCSDA
Joint Center for Satellite Data Assimilation
A multi-agency research center created to improve the use of satellite data for analyzing and predicting the weather, the ocean, the climate and the environment

JEDI
- Data Assimilation


VIRTUAL LAB
FV3GFS
Everything
FV3GFS / Home
FV3GFS Version 0 Release
How to access the FV3GFS Version ...
Announcing the Version 0 Release of the FV3GFS!
NOAA users and external partners with NWS Virtual Lab access can view the release information, as well as other developmental details, in the FV3GFS Community.
NON-NOAA USERS
Users outside of NOAA will need to obtain a VLab External Partner Account. To get an external partner account please fill out the FV3GFS External Partner Request Form.
NOAA USERS AND EXTERNAL PARTNERS
FV3GFS VLab community:





GEOS Architecture Design

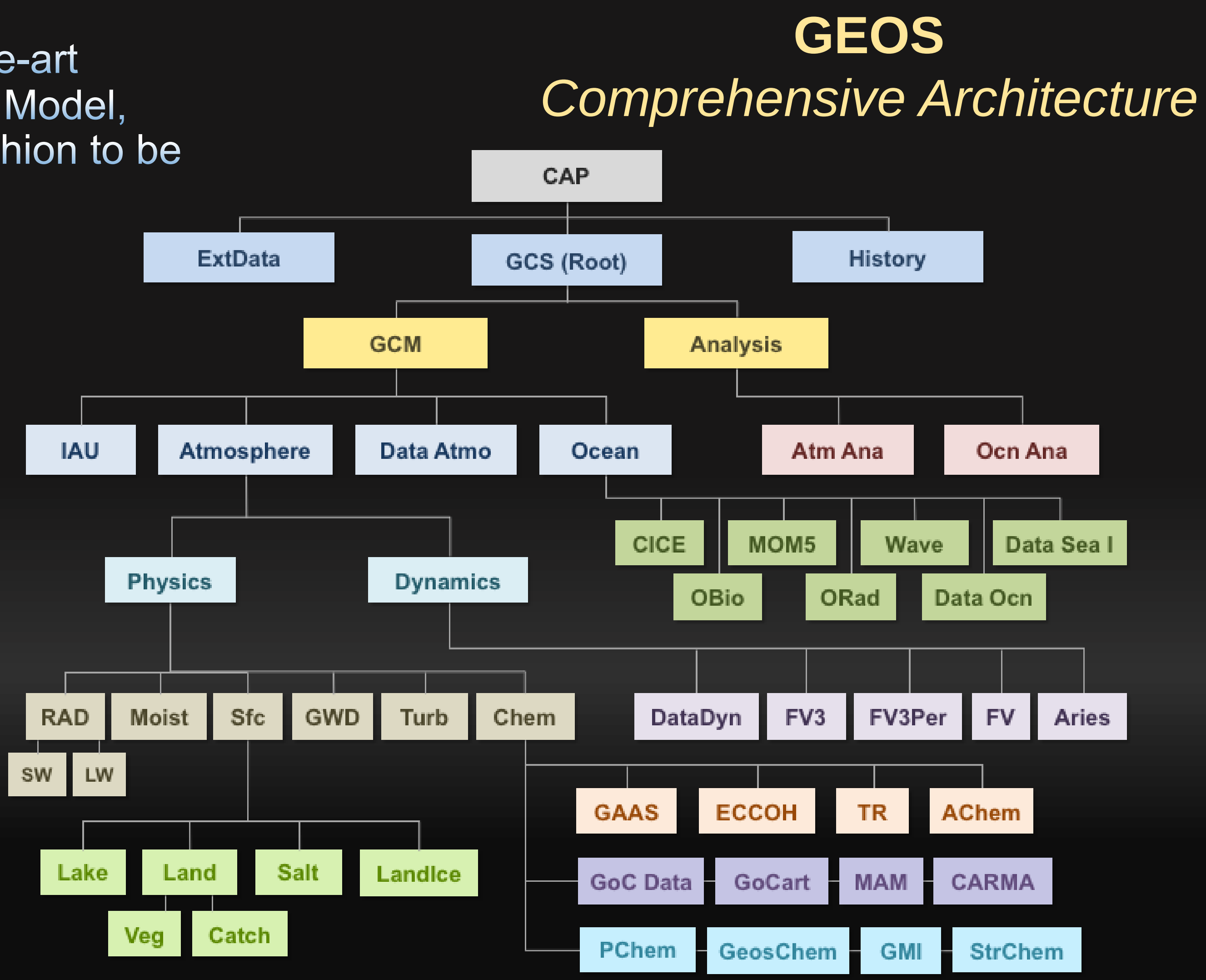
"Since no single organization can maintain state-of-the-art development efforts in all aspects of an Earth System Model, our strategy has been to code GEOS in a modular fashion to be able to import externally-developed components."

1. GEOS is a hierarchy of ESMF components

- *An infrastructure for building GEOS applications:*
  - Standardized component interfaces
  - Low level data containers for data sharing
  - Grid classes for the physical domain
  - Parallel communication
  - Others: Regridding, Logging, Calendar

2. The MAPL layer interface to ESMF

- *Provides an abstraction of software issues including:*
  - Generic Initialize/Finalize/Run
  - Simplified hierarchy (creation of child components)
  - IO Layers (Asynchronous file server output)
  - Regridding transforms (grids and tiles)
  - Profiling (Performance and Memory)
  - Input (ExtData) / Output (History)



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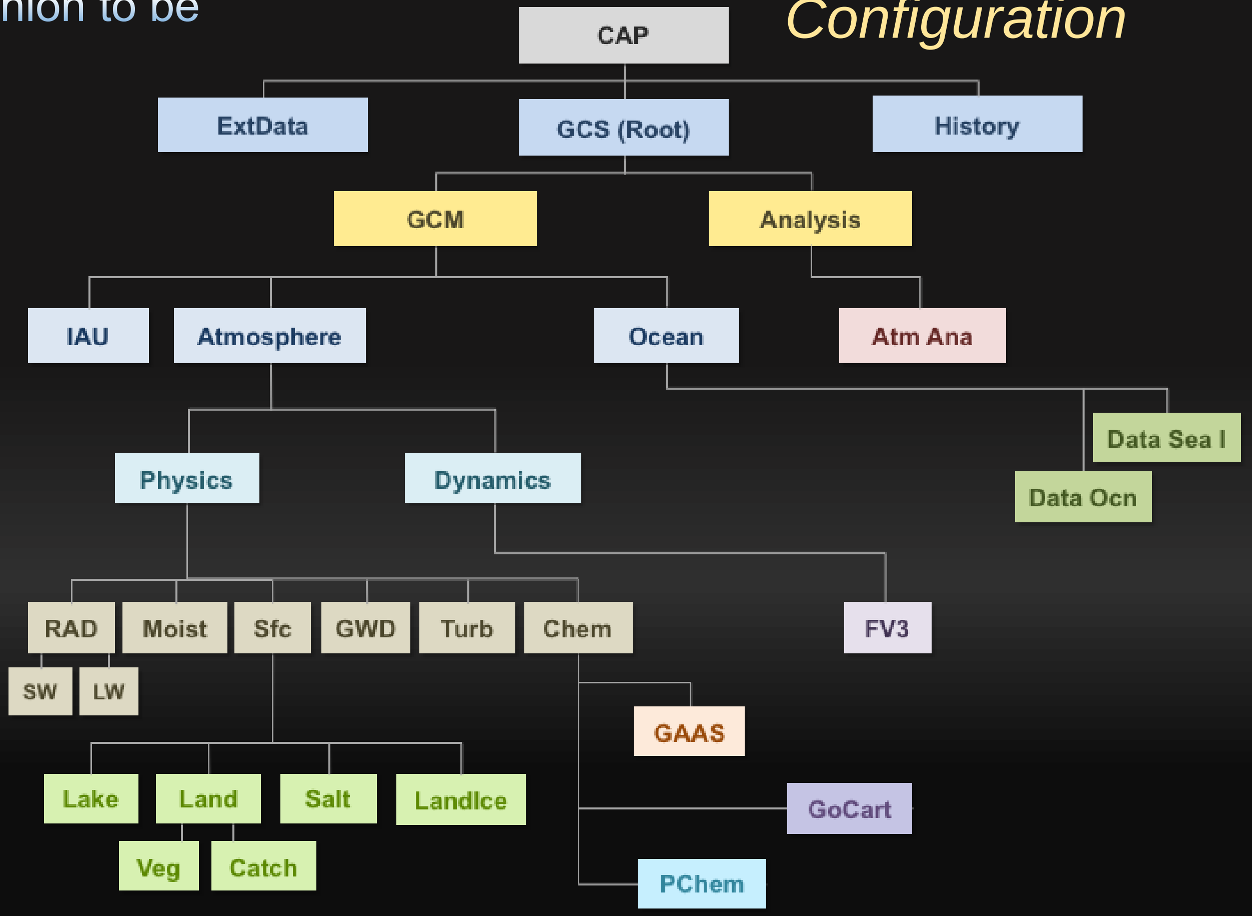
GEOSdas
Numerical Weather Prediction Configuration



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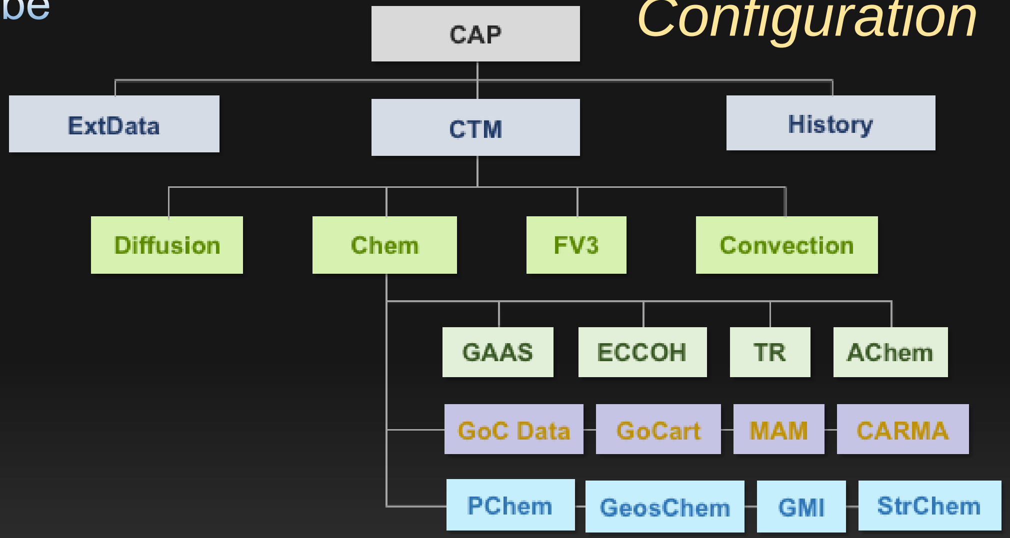
GEOSctm

Chemistry Transport Configuration



GEOS: Timeline of Development

7km-G5NR Production

1.5km GEOS Simulation

12km MERRA-2 Downscaling

G5NR-Chem Production

1.5km GEOS Simulation

DYAMOND
3km Convection Allowing Inter-comparison

2013	2014	2015	2016	2017	2018	2019

MERRA-2 Production

FP Update
Surface Drag

FP Update
13km Resolution
RAS + 1-Moment Updates

FP Update
GMTED Topography
GWD Tuning

FP Update
VLAB FV3
1-Moment liq/ice radii
RRTMG-LW

FP Update
GF Convection
UW Shallow
Turbulence Tuning
RRTMG-SW

FP Update
132-Levels
2-Moment

FV3 VLAB updates for GEOS

- **32-bit precision changes**
  - Order of operations in continuity equation
  - Surface pressure accumulation
- **Updated vertical remapping options**
  - Maintain total-energy remapping (with GMAO cubic option)
  - Simplify the options
    - REMAP_T in Log(P)
    - REMAP_PT in P
    - REMAP_TE in Log(P)
- **n_sponge in addition to n_zfilter**
  - n_zfilter input option is used in fv_subgrid_z
  - n_sponge input option adds layers to the sponge layer damping
- **Offline advection for CTM**
  - Updated interface in fv_tracer2d
  - Accumulated mass fluxes in 64-bit precision
  - New routine to drive offline advection from mass flux and courant numbers

FV3 namelist configurations

	NASA (GEOS)		NCEP (GFS)	
Horizontal Resolution	c720 (13 km)	c180 (50 km)	c769 (13 km)	c384 (25 km)
Vertical Resolution	72 (0.01 mb)	72 (0.01 mb)	64 (0.28 mb)	64 (0.28 mb)
DT (s)	225	450	225	300
hydrostatic	T	T	F	F
k_split (vertical remapping steps)	2	1	2	1
n_split (acoustic time steps)	6	6	6	12
CORES (computer)	5400	864	1536	576
n_sponge (sponge layer & dz-filter)	25	25	10	10
fv_sg_adj (remove 2-dz instability)	450	900	450	450
kord_mt/wz/tr (vertical remap)	9/9/9	9/9/9	9/9/9	9/9/9
hord_mt/vt/t/p/tr (horiz advection)	5/6/6/-6/8	10/10/10/10/8	6/6/6/-6/8	6/6/6/-6/8
do_vort_damp (vorticity damping)	T	F	T	T

32-bit (R4) FV3 Dry Mass Conservation

Original code for pressure update in d_sw:

```
delp(i,j) = delp(i,j) +                          &
            (fx(i,j)-fx(i+1,j)+fy(i,j)-fy(i,j+1))*rarea(i,j)
```

Updated code for pressure update in d_sw:

```
delp(i,j) = delp(i,j) +                          &
            ((fx(i,j)-fx(i+1,j))+(fy(i,j)-fy(i,j+1)))*rarea(i,j)
```

Save original surface pressure in fv_dynamics before k_split loop:

```
psx(i,j) = pe(i,npz+1,j)
```

Zero out 64-bit storage for mass update (dpx) in sw_core:

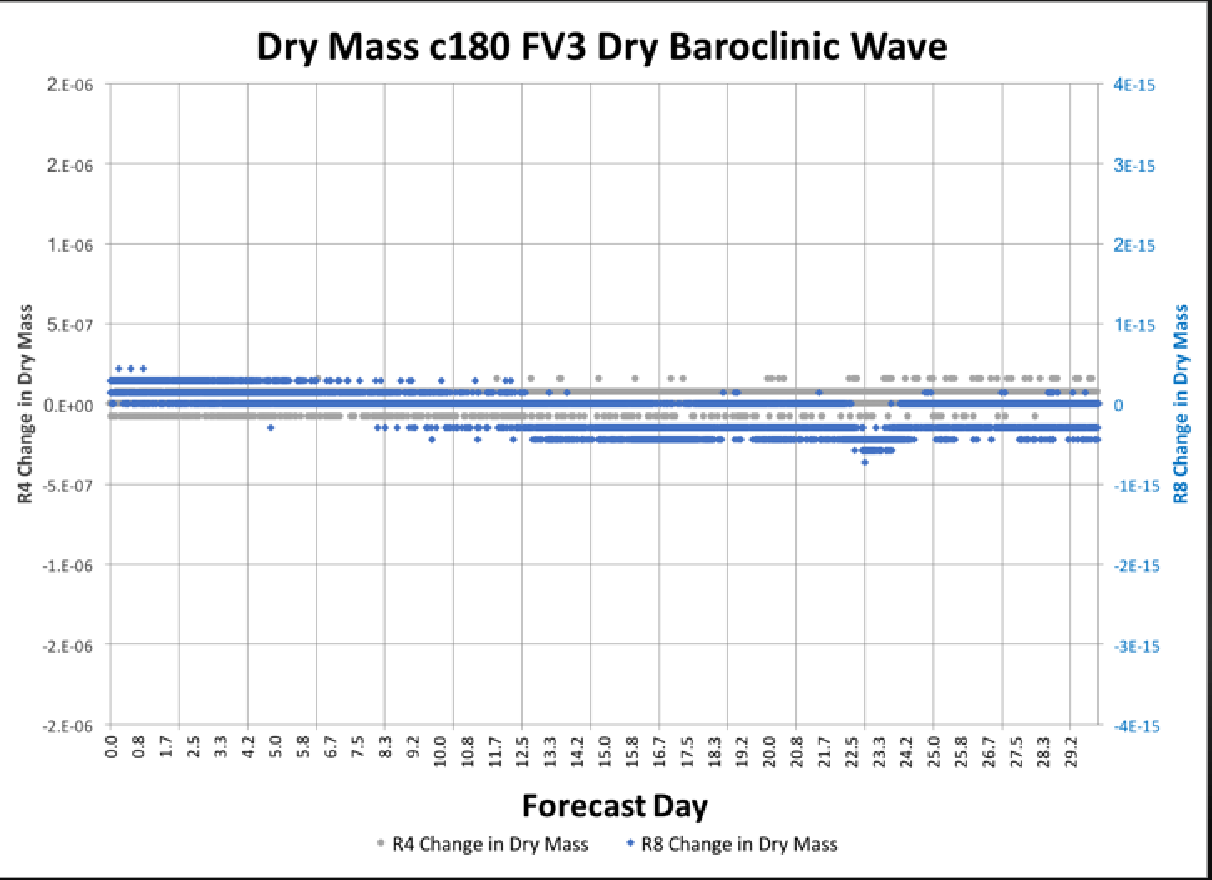
```
dpx(i,j) = 0.0
```

Accumulate mass update in 64-bit (dpx) inside d_sw:

```
dpx(i,j) = dpx(i,j) + ( (fx(i,j)-fx(i+1,j)) + (fy(i,j)-fy(i,j+1)) )*rarea(i,j)
```

Remove roundoff error by replacing PS with R8 accumulated mass update before going into remap:

```
if (last_step) then
   psx(i,j) = psx(i,j) + dpx(i,j)
   pe(i,npz+1,j) = psx(i,j)
endif
```



Advanced Vectorization Optimizations in FV3 (GEOS)

Compiler Optimization	Floating Point Optimization	Precision	FV3 (s)
Intel 18 -O3	-fpe0 -fp-model source -ftz -align all -fno-alias	**64-Bit**	**1574**
Intel 18 -O3 -xCORE-AVX2	-fpe3 -fp-model consistent -ftz -align all -fno-alias -fma	**64-Bit**	**1214**
Intel 18 -O3 -xCORE-AVX2	-fpe3 -fp-model consistent -ftz -align all -fno-alias -fma	**32-Bit**	**859**
Intel 18 -O3 -xCORE-AVX2	-fpe3 -fp-model fast=2 –no-prec-div -ftz -align all -fno-alias -fma	**64-Bit**	**1184**
Intel 18 -O3 -xCORE-AVX2	-fpe3 -fp-model fast=2 –no-prec-div -ftz -align all -fno-alias -fma	**32-Bit**	**800**

c720 72 Level 1-Day GEOS Benchmark on 1536 Cores

FV3 GMAO Cubic TE Remapping

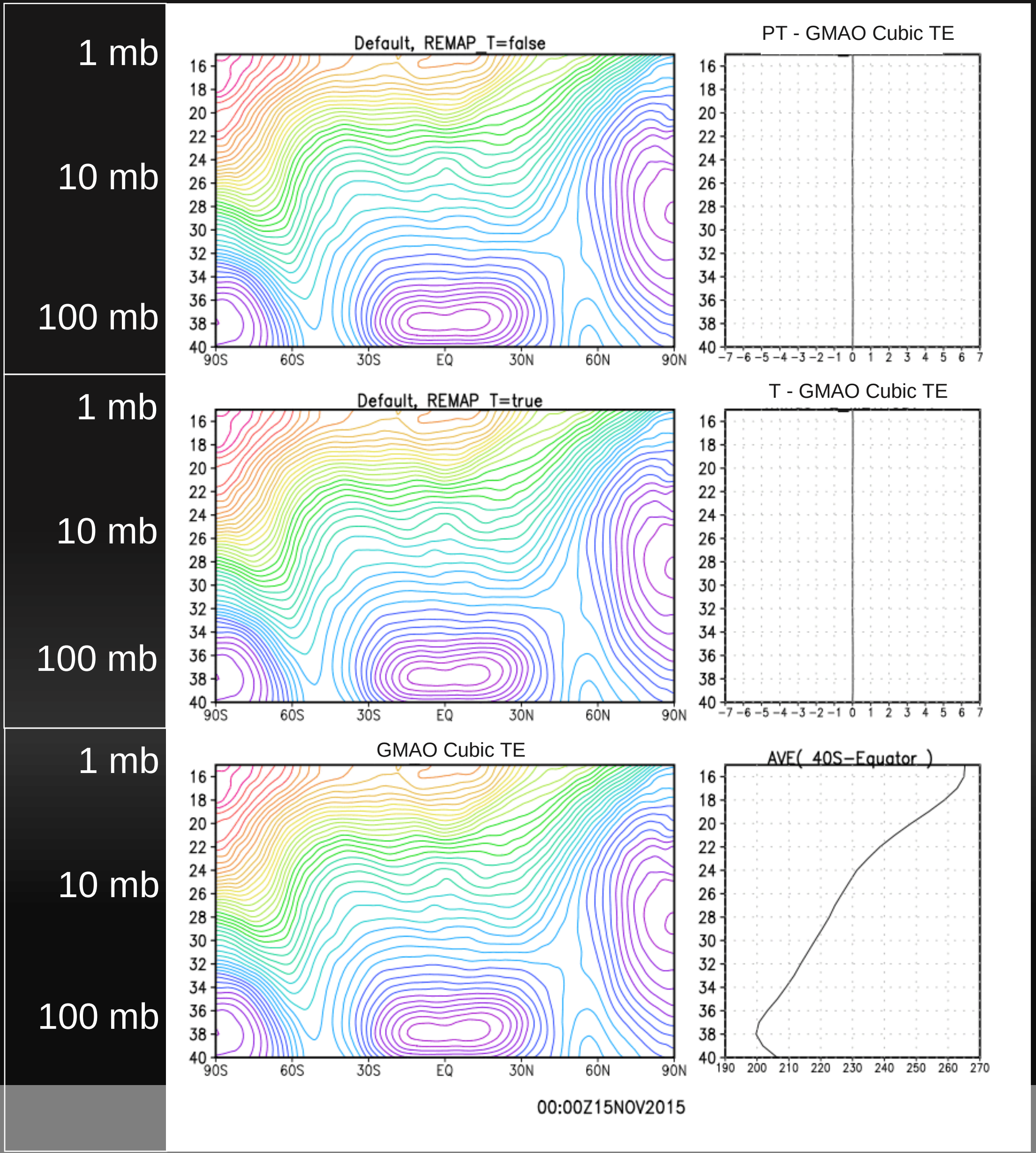
These results are based on FV3 remapping code prior to VLAB releases.

In the latest FV3 the fv_subgrid_z implementation sufficiently resolves these issues.

FV3 Cubic PT Remap
DZ noise

FV3 Cubic T Remap
DZ noise

GMAO Cubic TE Remap
No DZ noise



FV3 in GEOS Code Walkthrough

https://github.com/GoddardESM/FVdycoreCubed_GridComp