The future of dynamical cores in CESM
My personal view!

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Outline:

- Why multiple dycores in CESM?
- Current capability
- CESM dynamical core “tasks”
- CESM improving dycores and workflow? (synergy)
- Decommission spectral-transform dynamical core (EUL)
- Looking into the future (non-hydrostatic, GPU’s, etc.)

Why does CESM have multiple atmosphere dynamical cores?

- To assess (structural) uncertainty due to dynamical core one needs more than 1 dynamical core

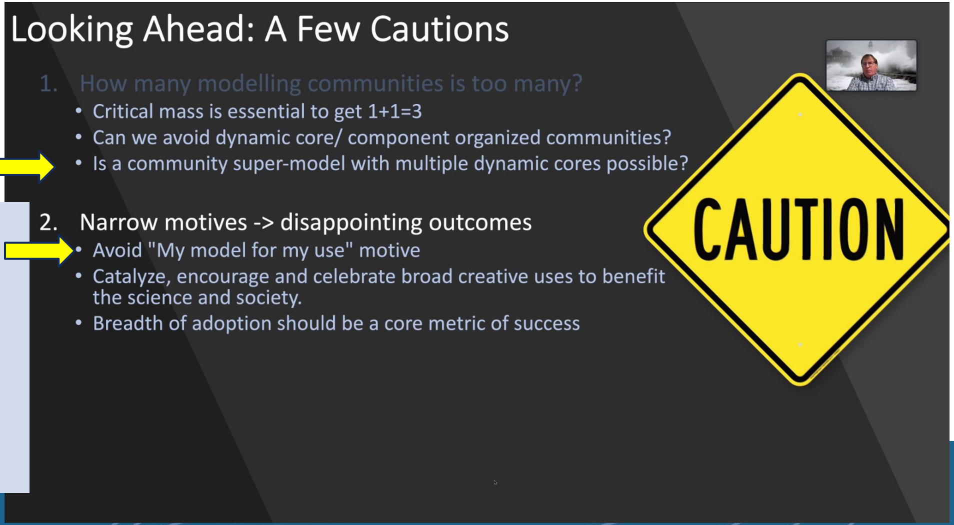
- Dynamical cores are strongly depending on compute platform and programming paradigm (MPI communication, vectorization,…); supercomputing environments are constantly changing!

- Dynamical core science is not settled though many strong opinions in the community

- CESM is unique in that it enables “advanced” dynamical core science in the sense of having idealized to full climate functionality with multiple dynamical cores in one system!

- Used for teaching (e.g. UMICH)

Slide from P. Neilley
(Director of Weather Forecasting Sciences, Technologies and Operations at IBM's Weather Company)
First Symposium on Earth Prediction Innovation and Community Modeling
at AMS, 2022



Dynamical core science "paradise"

Major CESM achievement:

Changing between 5 dynamical cores is a one line change in run-script:

```
se-cslam: /create_newcase -res ne30pg3_ne30pg3_mg17 ...
se      : /create_newcase -res ne30_ne30_mg17 ...
fv3     : /create_newcase -res C96_C96_mg17 ...
fv      : /create_newcase -res f09_f09_mg17 ...
mpas    : /create_newcase -res mpasa120_mpasa120 ...
```

That means diagnostics coded in physics can seamlessly be used with all dynamical cores

For CESM3 we were planning to do a dynamical core comparison involving AMIP and coupled simulations. Internal/external task teams (who were not dycore developers) were assembled, however, we did not get the buy in from all dynamical core developer groups!

“Tasks” for a CESM dynamical core:

- low resolution paleoclimate and WACCM (~200km):
  strong scaling dycore an advantage!

- standard IPCC class: ~80km top, lots of tracers (>200 for full chemistry), (~100km)

- higher top: ~140km (both MPAS and SE needed work for stabilization). (~100-200km)

- geospace: species dependent thermodynamics and horizontal thermal
  conductivity and molecular diffusion operators (~25-200km)
  (wish list: deep atmosphere; ongoing project in SIMA with MPAS)

- variable resolution (e.g. fully coupled dual polar configuration): (~100 -> ~25km/12km or higher)

- functionally for doing only vertical advection for single-column configuration

- ultra high res: non-hydrostatic capability (currently CAM-MPAS)

Red box: Slide from AMWG 2016

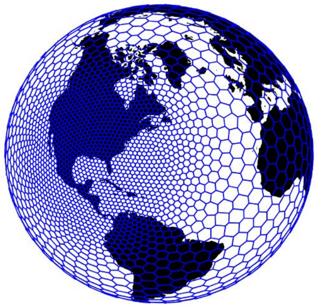
Getting away from CAM-FV ...

CAM-FV (finite volume)
Lin (2004)

CAM-EUL/SLD

No active development in over a decade

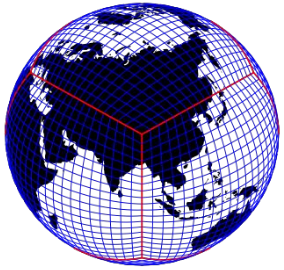
CAM-SE (spectral elements)
Taylor et al., (1997)
Dennis et al., (2012)



CAM-MPAS (Model for Prediction Across Scales)
Skamarock et al., (2012)

Available in CAM since 2021

Available in CAM since 2020:



CAM-FV3
(GFDL/NOAA global dynamical core)

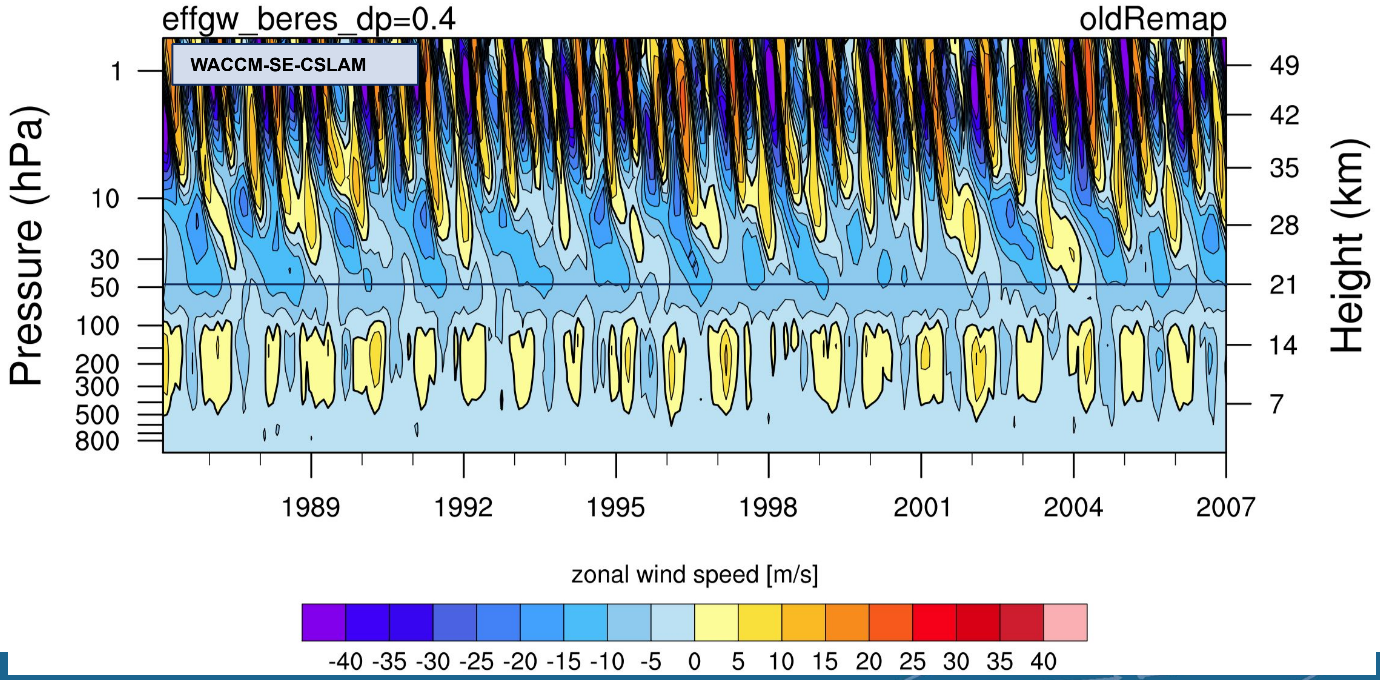
Examples of dycore issues/improvements resulting from being in CESM

- QBO
- CAM physics being generalized (see Monday's SE-CSLAM talk) to support constant height and pressure dynamical cores
- Coupling with MOM6: variable latent heats formulation (see Monday's SE-CSLAM talk)
- Finding bugs when run in diverse CESM applications: N2O issue with variable resolution spectral-elements
- Workflow (e.g. topography generation software)

QBO with CAM-SE-CSLAM

Initial simulations with WACCM-SE-CSLAM showed almost no QBO signal compared to WACCM-FV

- Did not appear to be “tunable” with effgw_beres parameter



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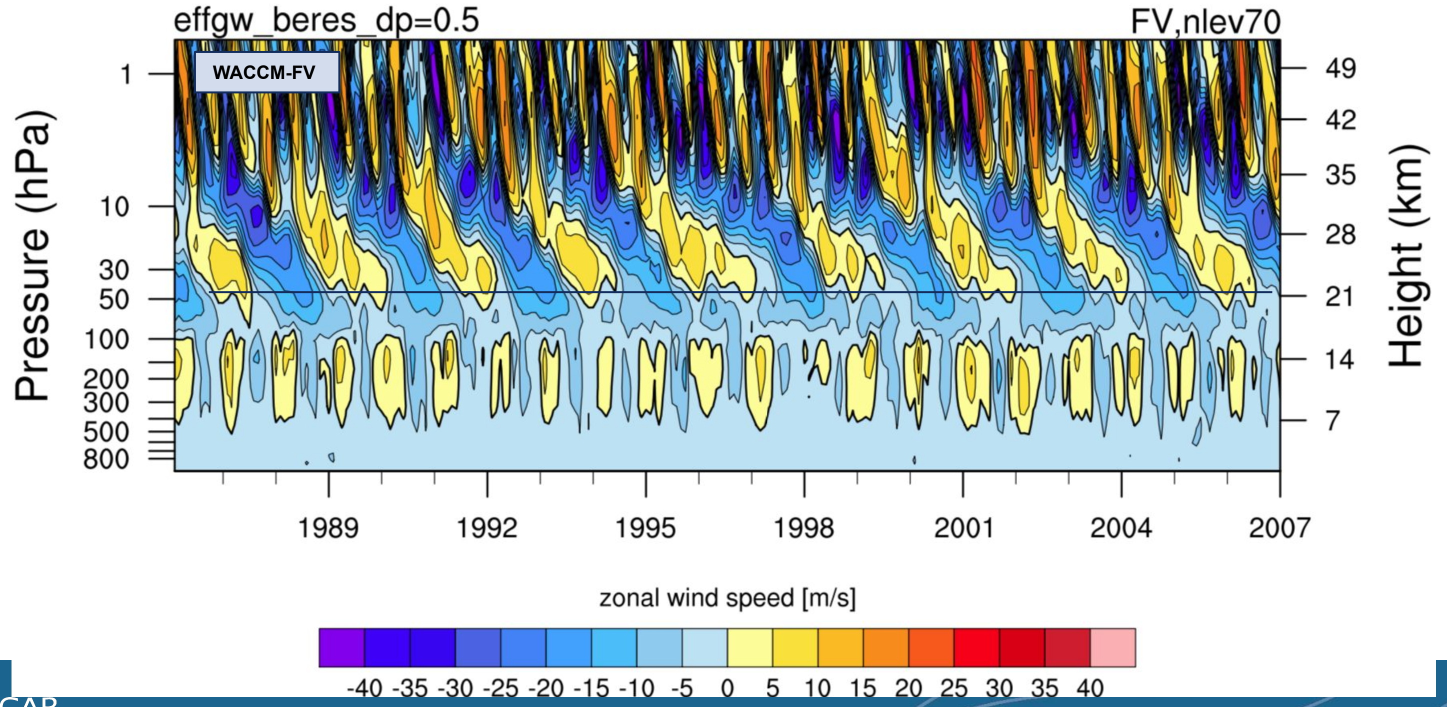

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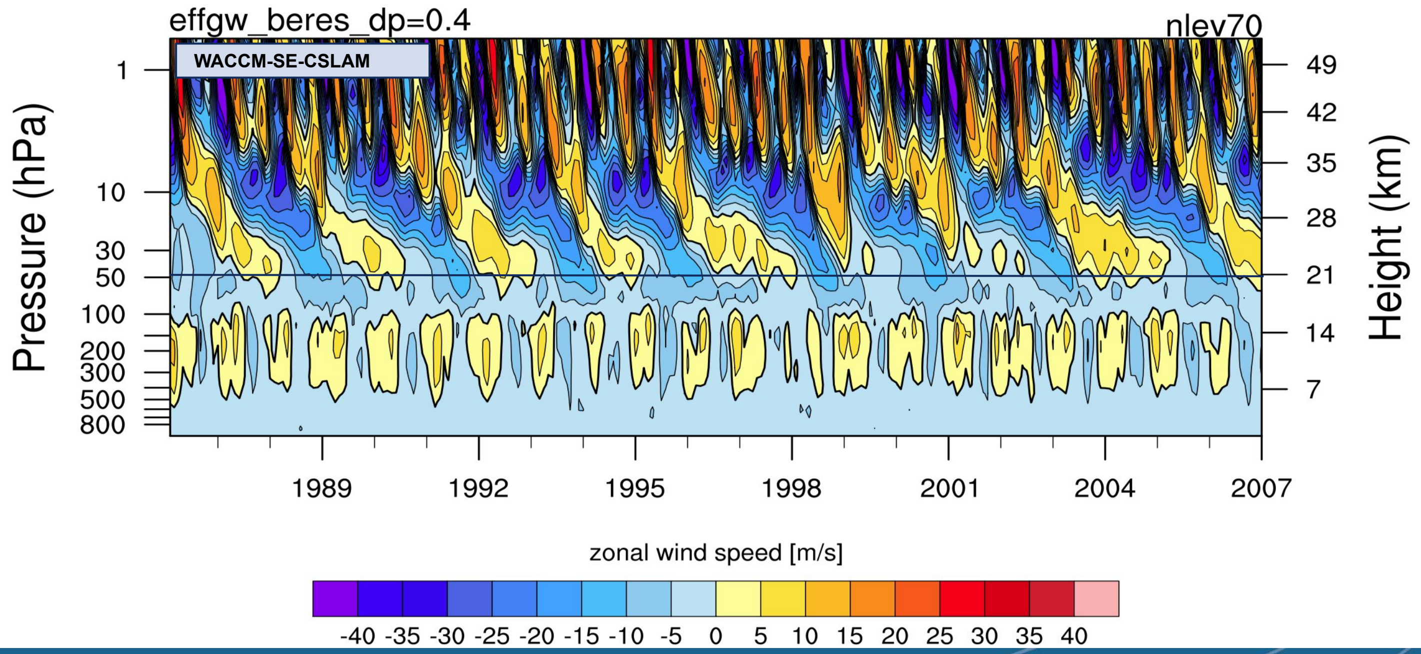
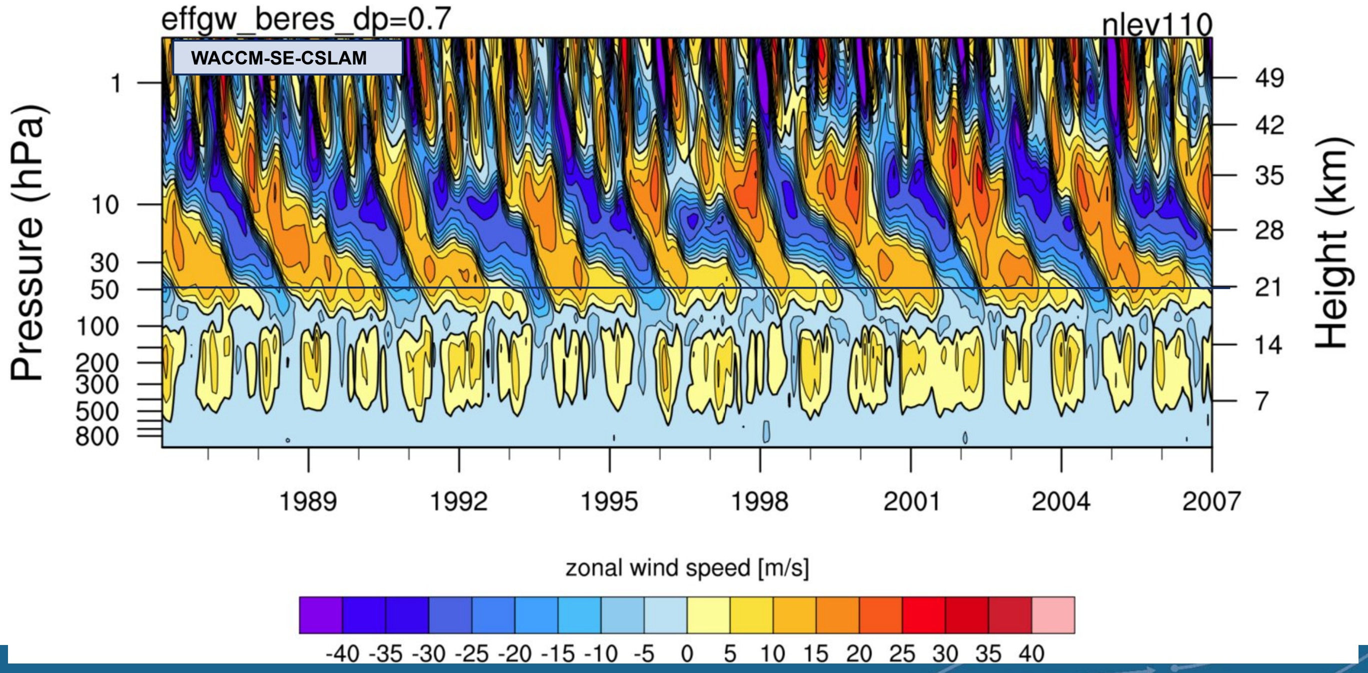
QBO with CAM-SE-CSLAM

Changing to FV3 vertical remapping for u,v,T,and water species improved QBO simulation significantly!



QBO with CAM-SE-CSLAM

Still we needed higher vertical resolution for a good simulation of the QBO



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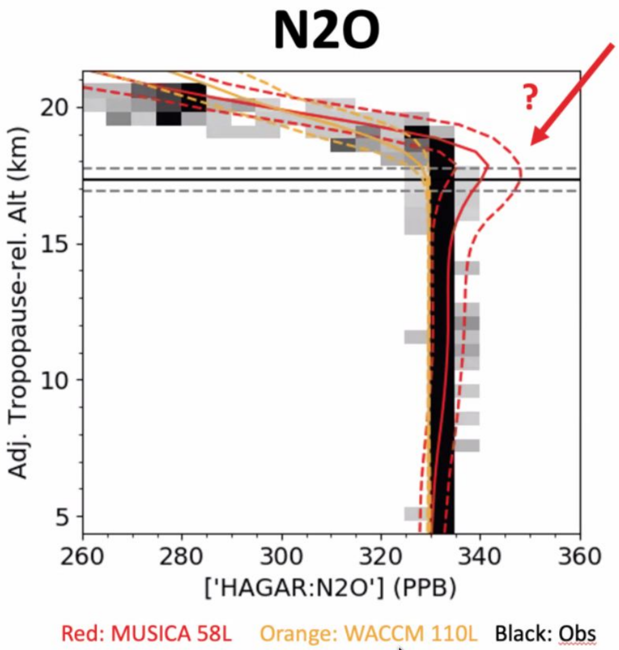
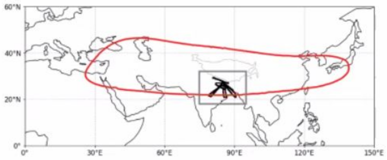
N2O issue: hyperviscosity reference profiles not subtracted from spectral-element advection



We wish to use N2O as a vertical coordinate for “chemical depth in the stratosphere”

However, the models do not have a consensus on its profile



Gray box = model domain, Red = anticyclone, Black = StratoClim

Figure from D. Kinnison

Examples of dycore issues/improvements resulting from being in CESM

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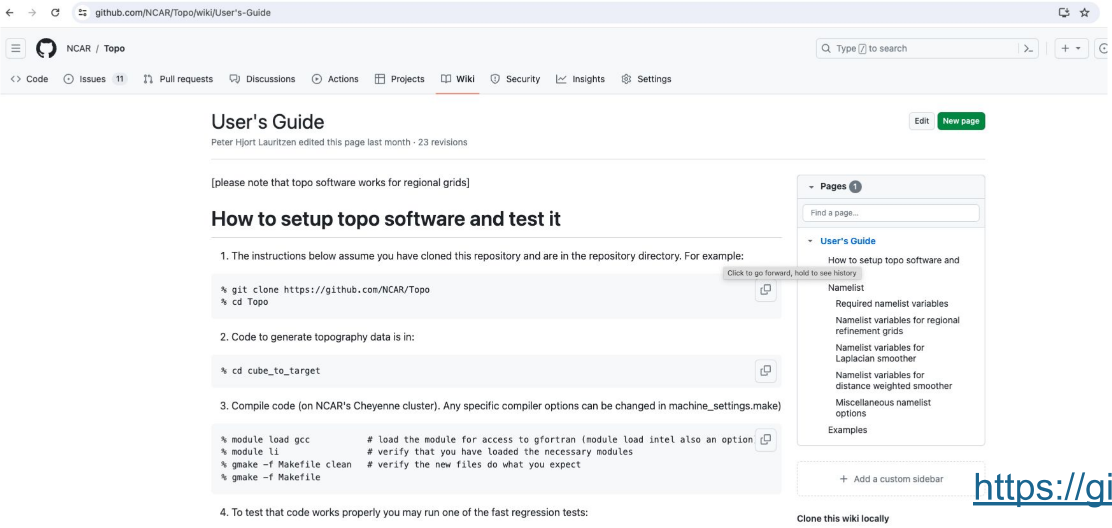
Dycore agnostic topography generation software



github.com/NCAR/Topo/wiki/User's-Guide

NCAR / Topo

Code | Issues 11 | Pull requests | Discussions | Actions | Projects | Wiki | Security | Insights | Settings

User's Guide

Peter Hjort Lauritzen edited this page last month · 23 revisions

Edit | New page

[please note that topo software works for regional grids]

How to setup topo software and test it

1. The instructions below assume you have cloned this repository and are in the repository directory. For example:

```
% git clone https://github.com/NCAR/Topo
% cd Topo
```

2. Code to generate topography data is in:

```
% cd cube_to_target
```

3. Compile code (on NCAR's Cheyenne cluster). Any specific compiler options can be changed in machine_settings.make)

```
% module load gcc           # load the module for access to gfortran (module load intel also an option
% module li                 # verify that you have loaded the necessary modules
% gmake -f Makefile clean   # verify the new files do what you expect
% gmake -f Makefile
```

4. To test that code works properly you may run one of the fast regression tests:

Pages 1

Find a page...

- User's Guide
  - How to setup topo software and
  - Namelist
    - Required namelist variables
    - Namelist variables for regional refinement grids
    - Namelist variables for Laplacian smoother
    - Namelist variables for distance weighted smoother
    - Miscellaneous namelist options
  - Examples

+ Add a custom sidebar

Clone this wiki locally

https://github.com/NCAR/Topo/wiki/User's-Guide

Same smoothing algorithm for all dycores

All sub-grid-scale fields for drag parameterizations computed the same way

Inspired by MPAS-A dycore we modified smoothing algorithm to not smooth over ocean!

Default dynamical core(s) for climate applications as a function of CAM version

CAM3: Eulerian dynamical core (spectral transform)

CAM4: Finite-volume dynamics core (from NASA)
Eulerian dynamical core for single-column

CAM5: Finite-volume dynamics core (from NASA)
Eulerian dynamical core for single-column

CAM6: Finite-volume dynamics core (from NASA)
Eulerian dynamical core for single-column
Spectral-elements dynamical core for high and variable resolution

CAM7: Spectral-elements dynamical core
Spectral-elements dynamical core for single-column
Spectral-elements dynamical core for variable resolution

Up until now we have needed the Eulerian dynamical core for single-column configurations … and through the years it has been a popular dynamical core for CESM Simpler Models.

Given Eulerian is our oldest dynamical core and that spectral-elements can now support these applications, we would like to decommission it!

Looking into the future

Dycores in CESM with active development

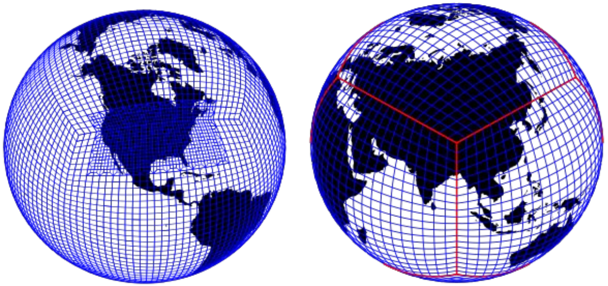
- **SE-CSLAM: Default dycore for CESM3 IPCC class simulations and WACCM-x**
  (FYI: NOAA seed project for developing SE for Mars funded - *CESM Alternative Earths effort*)

- **MPAS**: Extensively used in in SIMA applications and EarthWorks

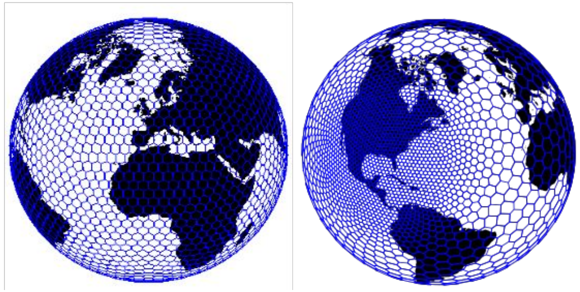
- **FV3**: **Relatively little usage in CESM (as far as I can tell) and no funded efforts for expanding capability (non-hydrostatic, regional refinement, …)**

- **SE-NH: new NSF project**

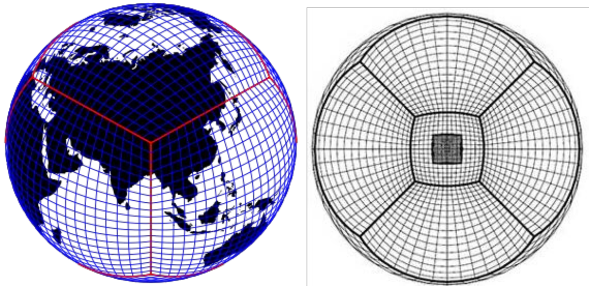
CAM-SE(CSLAM)



CAM-MPAS



CAM-FV3



Dycores in CESM with active development

- **SE-CSLAM: Default**
  (FYI: NOAA seed project for developing S for Mars funded - *CESM Alternative Earths effort*)

Currently no plans for further development after CESM3

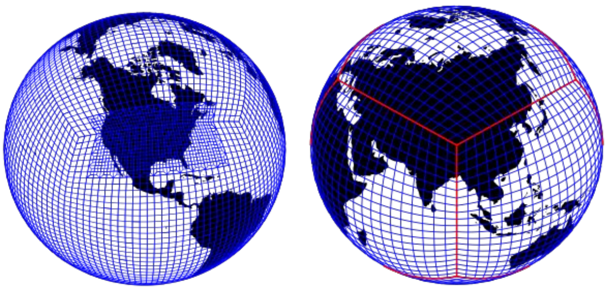
- **MPAS**

Non-hydrostatic; Actively being developed at NCAR (e.g. geospace); a version GPU enabled (Fortran OpenACC)

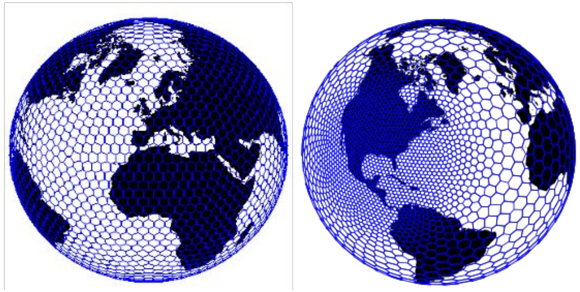
- **FV3: Relatively little usage in CESM (as far as I can tell) and no funded efforts for expanding capability (non-hydrostatic, regional refinement, …)**
- **SE-NH: ne**

Non-hydrostatic; Actively being developed by DOE; GPU enabled (KOKKOS C++)

CAM-SE(CSLAM)



CAM-MPAS



CAM-FV3