On the integration of the GFDL FV3 dynamical core into NCAR's CESM

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Introduction

The operational FV3 dynamical core* from NOAA's EMC (Environmental Modeling Center) and GFDL (Geophysical Fluid Dynamics Laboratory) has been implemented in NCAR's CESM (Community Earth System Model). The dynamical core has been consistently coupled with the CAM (Community Atmosphere Model) physics parameterization package version 6 (CAM6).

* https://www.gfdl.noaa.gov/fv3/fv3-documentation-and-references/

The goal of this project is to make the FV3 dynamical core available to the community through CESM as well as to perform a basic evaluation of FV3 (initially for standard 1 degree horizontal resolution climate applications).

We compare CAM-FV3 with existing dynamical cores in CESM:

- CAM-SE: Spectral-elements dynamical core
- CAM-SE-CSLAM: CAM-SE with Conservative Semi-LAgrangian Multi-tracer scheme (CSLAM) and separate physics grid
- CAM-FV: Finite-volume dynamical core used for 1 degree CMIP6 simulations.

Scientific validation of implementation in CAM

We make use of total energy and mass diagnostics developed by Lauritzen and Williamson (2019) to monitor that the interface between FV3 and CAM physics operates correctly. In addition, the diagnostics provide a break-down of the total energy budget of CAM-FV3 and a scientific understanding of the total energy errors of FV3 within CAM/CESM.

The TE budget for the dynamical core can be split into 3:

- Top of atmosphere diffusion, i.e. Rayleigh friction applied before the dynamical core time-loop

$$\partial \widehat{E}^{(sponge)}_{dyn} = \frac{\widehat{E}_{dAT} - \widehat{E}_{dBD}}{\Delta t_{phys}} \approx 0.007 W/m^2. \quad (14)$$

  The numerical values are from a 1 year `F2000climo` simulation.

- Floating Lagrangian dynamics (sub-cycled `n_split` times and inside the vertical remapping loop)

$$\partial \widehat{E}^{(2D)}_{dyn} = \frac{\widehat{E}_{dAD} - \widehat{E}_{dAF}}{\Delta t_{phys}/k_{split}} \approx -2.131 W/m^2. \quad (15)$$

  where `k_split` is the number of vertical remappings per physics time step. The diagnostics are outside the `n_split` loop so therefore the tendency is only a function of `k_split` and not `n_split`.

- Vertical remapping

$$\partial \widehat{E}^{(remap)}_{dyn} = \frac{\widehat{E}_{dAR} - \widehat{E}_{dAD}}{\Delta t_{phys}/k_{split}} \approx 1.060 W/m^2. \quad (16)$$

It has been verified that

$$\partial \widehat{E}^{(adiab)}_{dyn} = \partial \widehat{E}^{(sponge)}_{dyn} + \partial \widehat{E}^{(2D)}_{dyn} + \partial \widehat{E}^{(remap)}_{dyn} \approx -1.065 W/m^2, \quad (17)$$

to within $1 \times 10^{-8} W/m^2$. The mapping of physics wind tendencies from the A-grid to the D-grid leads to an TE error of

$$\partial \widehat{E}^{(windAtoD)}_{dyn} = \frac{\widehat{E}_{dBD} - \widehat{E}_{dAP}}{\Delta t_{phys}} \approx 0.015 W/m^2. \quad (18)$$

Axial angular momentum (AAM) conservation

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]:

$$\frac{dM}{dt} = 0. \quad (2)$$

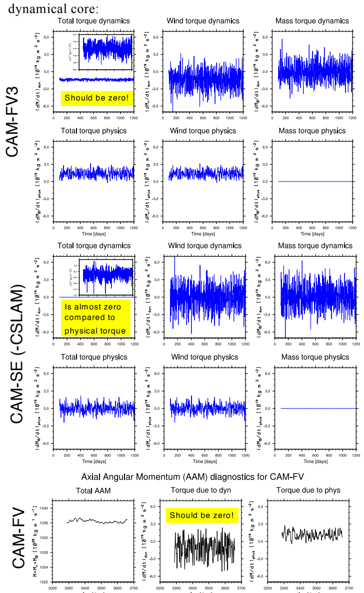
Typically numerical models are divided into a dynamical core (*dyn*) that, roughly speaking, solves the equations of motion on resolved scales and physical parameterizations that approximate sub-grid-scale processes (*phys*). There can therefore be two sources/sinks of AAM:

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

In the absence of mountain torque

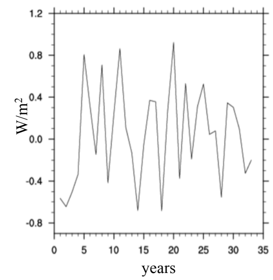
$$0 \sim \left(\frac{dM}{dt}\right)_{dyn} \ll \left(\frac{dM}{dt}\right)_{phys}.$$

We use the Held-Suarez test case (no topography, simple u,v,T parameterization) to assess AAM conservation of the dynamical core:

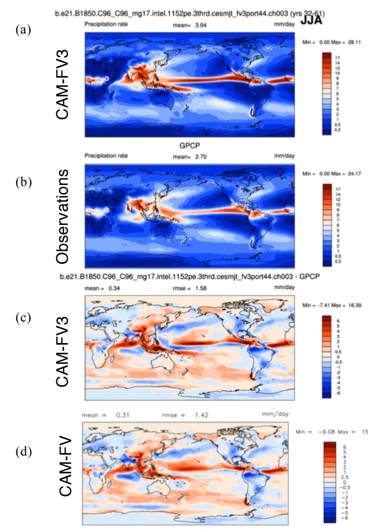


Coupled climate simulation

The coupled CESM-FV3 has been tuned to minimize the global-mean TOA heat flux imbalance (in a pre-industrial run) as shown in Figure below:



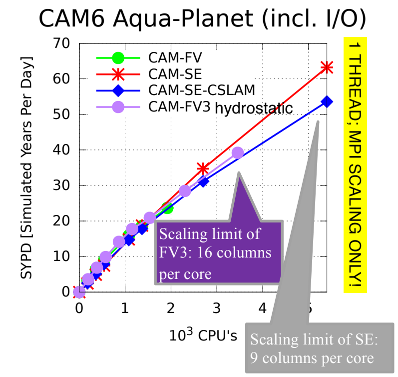
30-year average precipitation rate for JJA for (a) CAM-FV3, (b) GPCP observations, (c) difference and (d) the same as (c) but for CAM-FV:



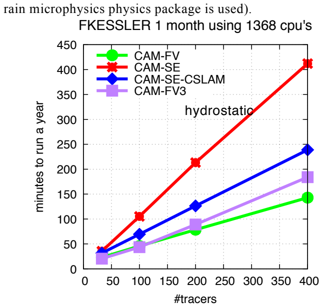
Preliminary performance results

We provide the computational performance in terms of Simulated Years per Day (SYPD) on Cheyenne* for 1° CAM6 aqua-planet configuration using 32 levels and 33 advected tracers. The timings include the default monthly history I/O output as well as the generation of a restart file.

*Cheyenne is an SGI ICE Cluster with 4,032 dual-socket Intel Xeon-based nodes with 36 cores/nodes



Time to solution as a function of the number of tracers (effectively dynamical core timings only since a simple warm rain microphysics physics package is used).



Reference

Lauritzen, P.H. and D. L. Williamson, 2019: A total energy error analysis of dynamical cores and physics-dynamics coupling in the Community Atmosphere Model (CAM): *J. Adv. Model. Earth Syst.*, DOI:10.1029/2018MS001549.

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