CENTER UPDATE FOR NCAR (“my selection”!)

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37th Session of the Working Group on Numerical Experimentation (WGNE)
November 10, 2022

NCAR

NSF

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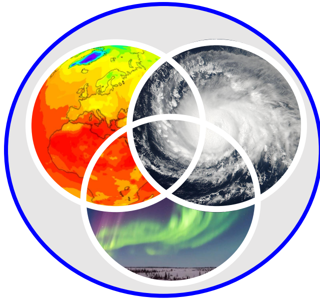
SIMA

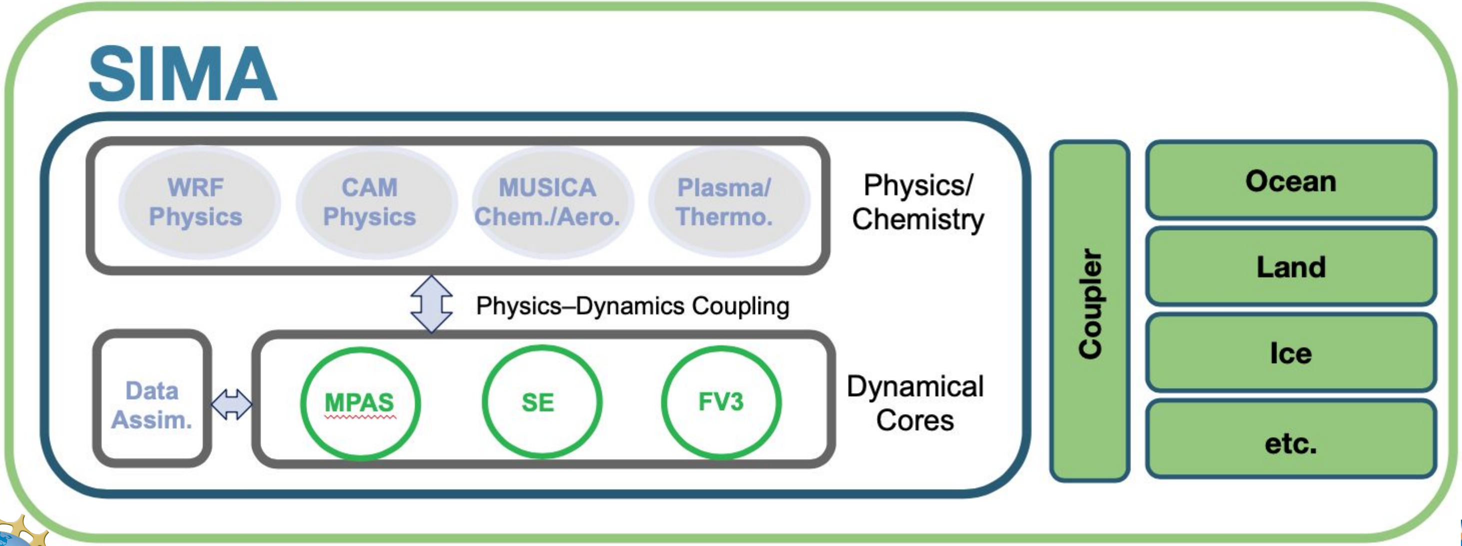
(System for Integrated Modeling of the Atmosphere)



SIMA is an effort to unify **community** atmospheric modeling across weather, climate, chemistry, and geospace

CESM (=Community Earth System Model)

Atmosphere component of CESM is CAM (Community Atmosphere Model)



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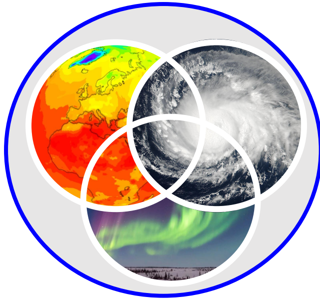

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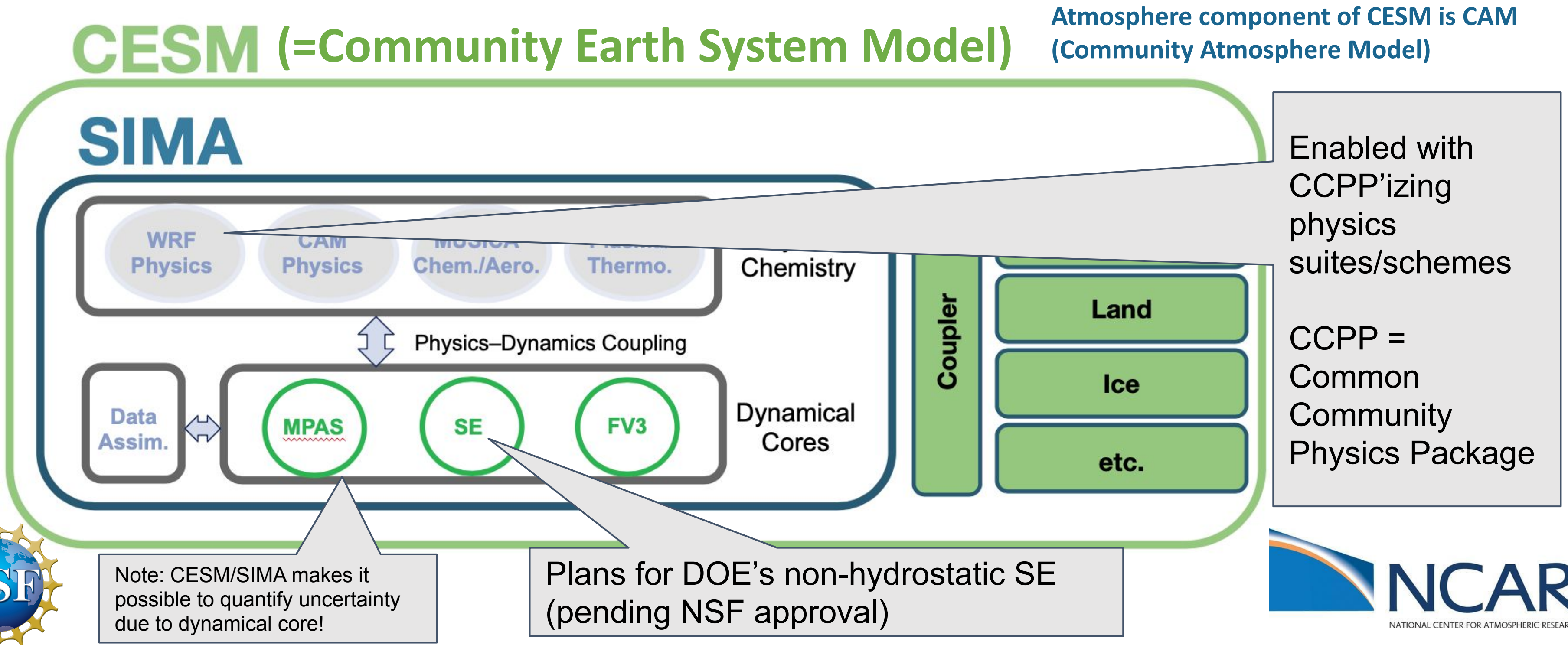

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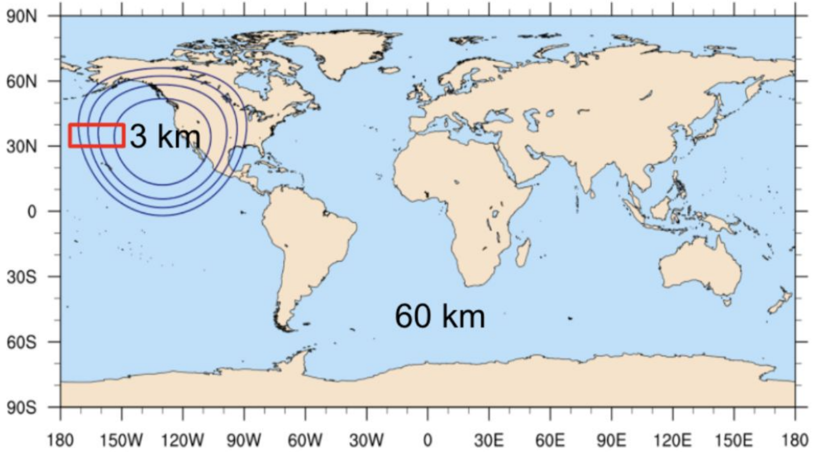
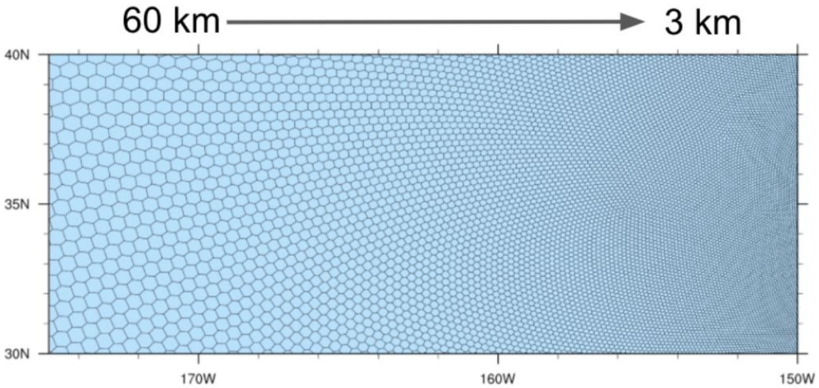
“Weather resolution” in CESM/CAM

MPAS (Model for Prediction Across Scales) non-hydrostatic dynamical core coupled with the CAM (Community Atmosphere Model) physics package (SIMA-MPAS)



A) Grid mesh configuration in 60-3km experiments



B) Unstructured spherical centroidal Voronoi mesh with a smooth transition mesh densities

Huang et al. (2022) https://gmd.copernicus.org/preprints/gmd-2022-111/

“Weather resolution” in CESM/CAM

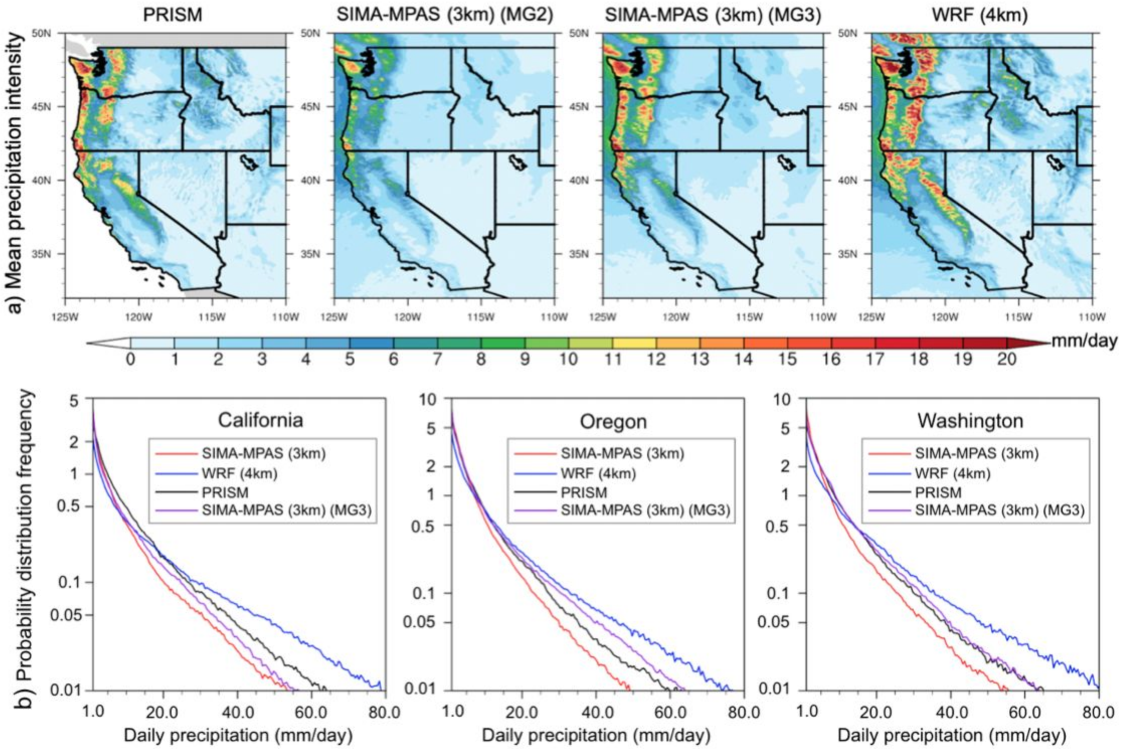


Figure 6: MG2 vs. MG3 microphysics used in SIMA-MPAS for the wet-season (Nov-March) precipitation over western US (1999-2000). a) mean precipitation intensity; b) Probability distribution of daily precipitation frequency, like Figure 5 but for only one wet season with SIMA-MPAS (MG3) added in purple lines.

Huang et al. (2022) https://gmd.copernicus.org/preprints/gmd-2022-111/

“Weather resolution” in CESM

Challenges:

- Memory bottlenecks when ingesting meshes from files (ESMF).
- New entirely parallel surface dataset generation in land model (CLM) was created that permitted very high resolution raw datasets to be read in parallel and mapped in parallel to the target model resolution grid. Without this new capability it would have been impossible to actually generate a 3.75 km CLM surface dataset with the older surface dataset generation utility. With the new utility, a 7.5 km surface dataset was generated in 10 minutes whereas previously it had taken 2 days.
- Still I/O bottlenecks in CAM history and restarts at 3.75km uniform resolution
- Physics-dynamics coupling: Coupling a pressure-based physics package with a height-based dynamical core while preserving energy and thermodynamic consistency

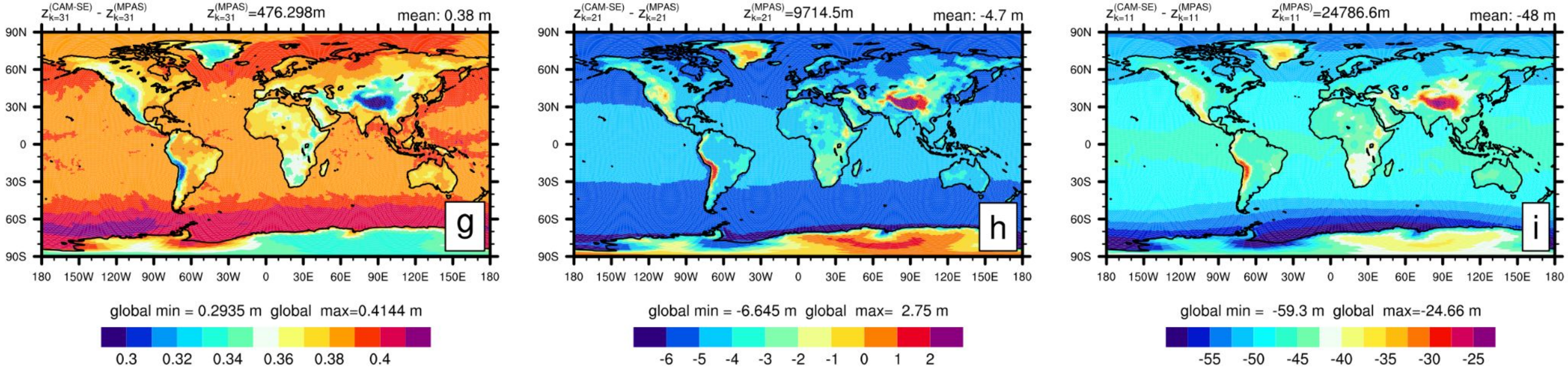
Discretization issue

Prognostic and diagnostics variables

Discrete representation of state in physics and dynamics may differ (both in terms of prognostic variables and staggering) which can lead to inconsistencies. Example:

$$\left(\theta_k^{(m)}, \vec{v}_k^{\perp}, \rho_k^{(d)}, z_{k+1/2}^{(MPAS)}, m_k^{(\ell)}\right) \qquad \left(T_k, \vec{v}_k, p_{k+1/2}, q_k^{(\ell)}, m_k^{(\ell)}\right)$$

Problem: z is fixed in MPAS whereas z is diagnosed (from hydrostatic balance) in CAM physics! If not careful in physics dynamics coupling -> z discrepancies. Example below:



See Lauritzen, Skamarock, ... et al. (in prep) for details

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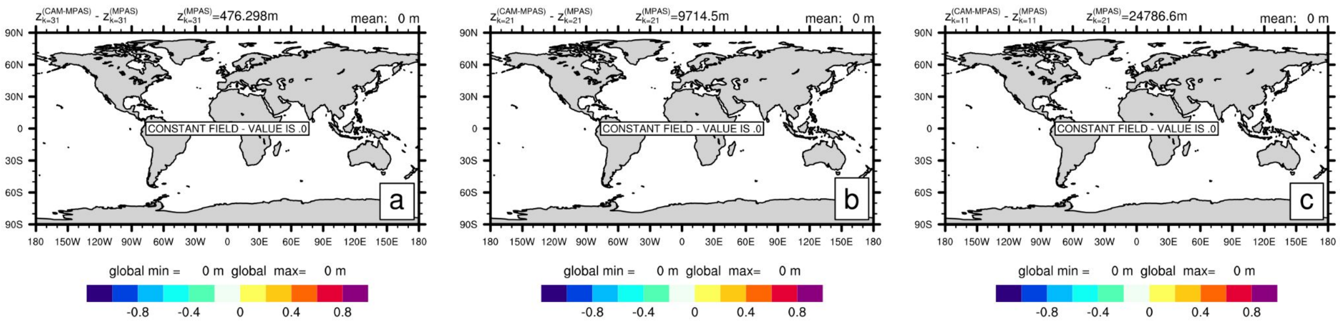
CAM-MPAS physics dynamics coupling

(addresses some consistency issues but not all)

See Lauritzen, Skamarock, … et al. (in prep) for details

- Preserving hydrostatic relations (heights diagnosed in physics consistent with MPAS dycore by cleverly choosing how the mid-level hydrostatic pressure is computed from MPAS state)



- Energy increments in physics (under constant pressure assumption) matching energy increment in hydrostatic MPAS (by scaling temperature increment and careful conversion from temperature tendency to modified potential temperature tendency used in MPAS)

- Making sure CAM physics energy fixer uses total energy formula consistent with hydrostatic MPAS

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JAMES Journal of Advances in Modeling Earth Systems

Reconciling and Improving Formulations for Thermodynamics and Conservation Principles in Earth System Models (ESMs)

P. H. Lauritzen[1], N. K.-R. Kevlahan[2], T. Toniazzo[3,4], C. Eldred[5], T. Dubos[6], A. Gassmann[7], V. E. Larson[8,9], C. Jablonowski[10], O. Guba[5], B. Shipway[11], B. E. Harrop[9], F. Lemarié[12], R. Tailleux[13], A. R. Herrington[1], W. Large[1], P. J. Rasch[9], A. S. Donahue[14], H. Wan[9], A. Conley[1], and J. T. Bacmeister[1]

Physics-dynamics coupling is often overlooked; this paper is an attempt to draw more attention to this “complex” topic!

Featured as Editor’s Highlight in Eos:
https://eos.org/editor-highlights/consistently-closing-the-energy-budget-in-earth-system-models

Paper link: https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2022MS003117
(warning: 83 pages)

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- Derivation of energy equations and discussion of assumptions and missing processes:

  - e.g. single temperature assumption, single velocity assumption, variable versus constant latent heats, energetics of falling precipitation and evaporation, frictional heating, thermodynamic consistency issues, …

- Specific analysis of CAM's energy budget (possibly applies to other modeling systems)

- Next a couple of slides from the WCRP km-scale climate modeling workshop giving some examples from paper …

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E. Issues from 1st principles

Important missing term in total energy equation

Lauritzen et al. (2022)

Modified CAM total energy equation incl. missing flux terms

$$\frac{\partial}{\partial t}\int \overline{\rho}^{(d)}\left\{\left(1+\overline{m}^{(H_2O)}\right)\left[\overline{K}+\overline{\Phi}_s+c_p^{(d)}\left(\overline{T}-T_{00}\right)\right]+\overline{m}^{(wv)}L_{s,00}+\overline{m}^{(liq)}L_{f,00}\right\}dz$$

$$-\Delta\widehat{\mathcal{I}}_{\partial m^{(H_2O)}/\partial t}-\Delta\mathcal{I}_{m_{tn}^{(H_2O)}} = \overline{F}_{net}^{(H_2O)}\left[c_p^{(d)}\left(\widetilde{\overline{T}}_s-T_{00}\right)+\widetilde{\overline{K}}_s+\overline{\Phi}_s\right]+\overline{F}_{net}^{(wv)}L_{s,00}+\overline{F}_{net}^{(liq)}L_{f,00}+\overline{F}_{net}^{(turb,rad)}$$

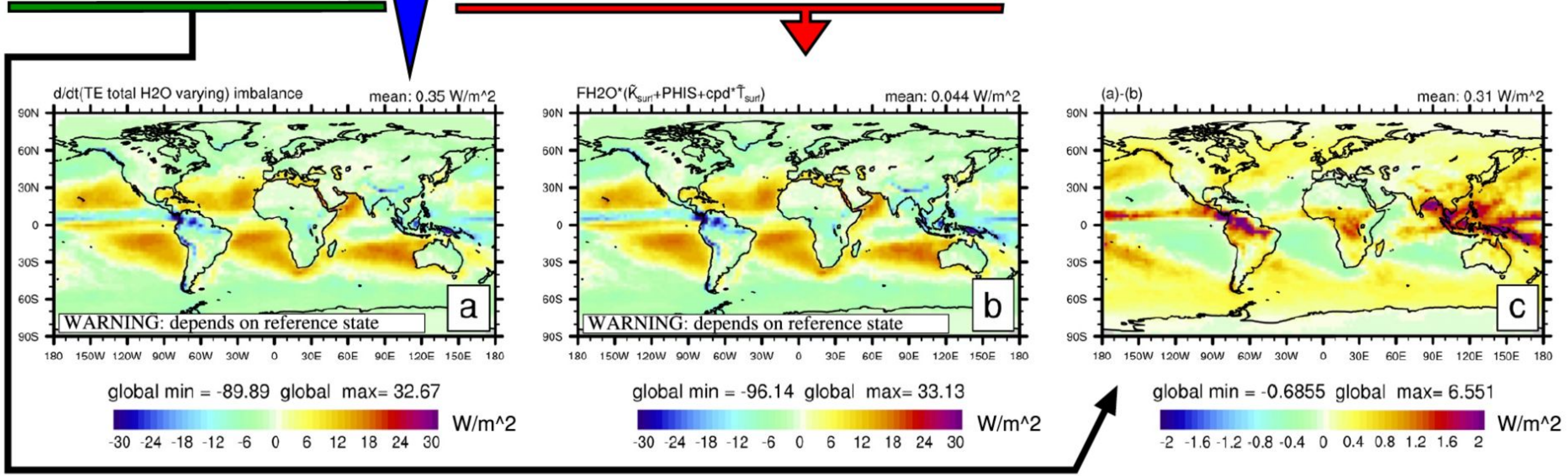
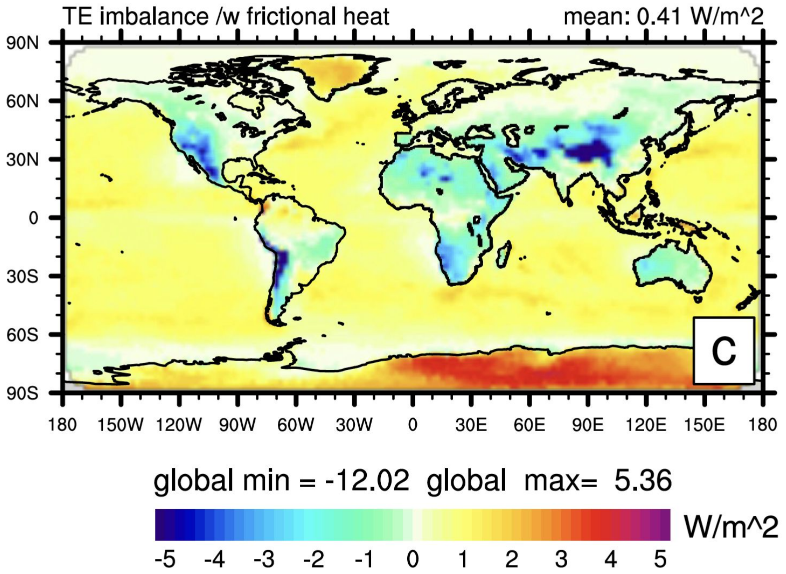


Figure 6. Modified (consistent) CAM total energy equation terms in W/m²: (a) Imbalance introduced by "dry-mass adjustment" using all forms of water in the kinetic, geopotential and enthalpy terms, (b) missing flux terms, and (c) is the difference between (a and b). Note that the imbalance is locally much reduced when using the modified total energy equation. Also, the imbalance does not depend on the reference state (as should always be the case).

F. Issues from 1st principles

Thermodynamic inconsistency within physics

CAM physics conserves enthalpy (CAM's thermodynamic potential) which under constant pressure assumption leads to total energy conservation (in pressure coordinates). Parameterizations may conserve another thermodynamic variable (such as moist potential temperature; e.g. CLUBB = Cloud Layers Unified By Binormals does that) which is not consistent with the CAM physics total energy equation. This leads to discrepancies:



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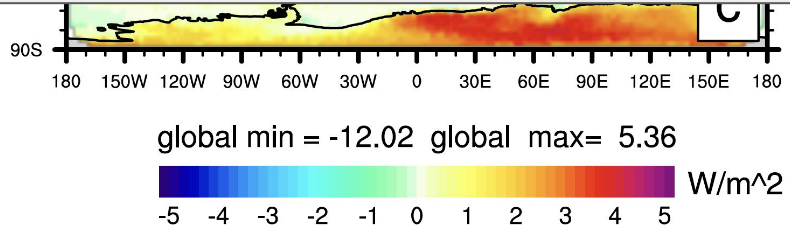
WARNING to CCPP:

CCPP will enable "mix and match" parameterizations … can be dangerous from consistency/conservation perspective (for example, if you use temperature tendencies as the thermodynamic increment variable you have no idea if the heating was applied under constant pressure or volume, what latent heats were used, etc.)

Lauritzen et al. (2022)



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Physics-dynamics coupling and WGNE

Lots of dynamical core developments have been funded the last couple of decades; lots of new parameterization schemes developed … coupling them has received less attention (sometimes viewed as a detail or a software engineering exercise; the details are often not published).

What can we do from the WGNE side?