Frequently used acronyms:

CESM = Community Earth System Model
CAM = Community Atmosphere Model

CCPP and related work in CGD

Peter Hjort Lauritzen
Senior Scientist
Internal AMWG (Atmospheric Model Working Group) co-chair for CAM

Climate and Global Dynamics Laboratory (CGD)
National Science Foundation (NSF) National Center for Atmospheric Research (NCAR)

This material is based upon work supported by the National Center for Atmospheric Research, which is a major facility sponsored by the National Science Foundation under Cooperative Agreement No. 1852977.

One motivation for CAM-SIMA: physics scheme "clarification" and flexibility

CAM4,5,6 and 7 (currently called cam_dev) physics uses the same "driver code":

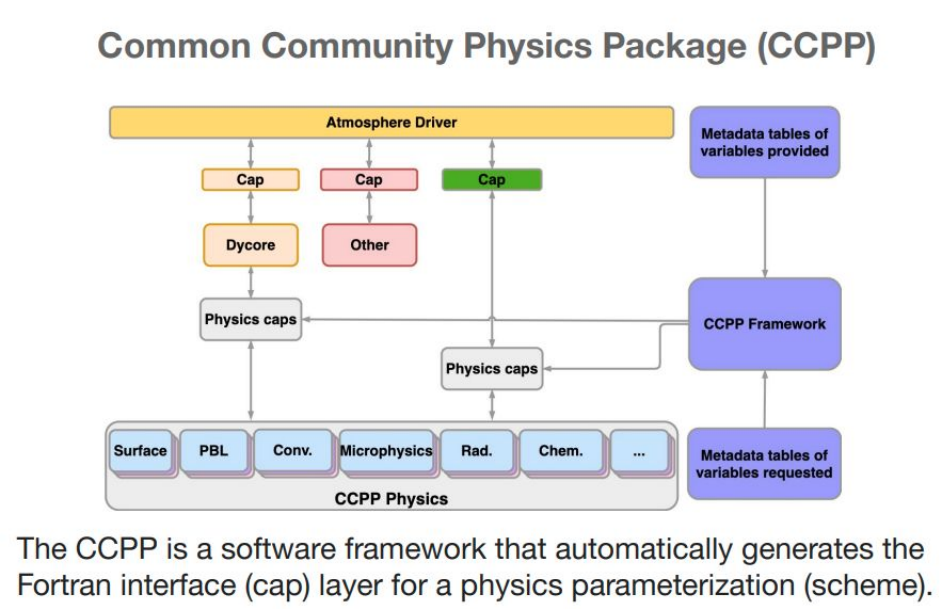
Complicated logic, "hidden" dependencies, hard to change physics scheme ordering (e.g., took months to move CLUBB call from after coupler to before), …

```
if( microp_scheme == 'RK' ) then

   !=================================================
   ! Calculate stratiform tendency (sedimentation, detrain, cloud fraction and microp
   !=================================================
   call t_startf('rk_stratiform_tend')

   call rk_stratiform_tend(state, ptend, pbuf, ztodt, &
        cam_in%icefrac, cam_in%landfrac, cam_in%ocnfrac, &
        cam_in%snowhland, & ! sediment
        dlf, dlf2, & ! detrain
        rliq  , & ! check energy after detrain
        cmfmc,  &
        cam_in%ts,      cam_in%sst,        zdu)

   call physics_update(state, ptend, ztodt, tend)
   call check_energy_chng(state, tend, "cldwat_tend", nstep, ztodt, zero, prec_str, s

   call t_stopf('rk_stratiform_tend')

elseif( microp_scheme == 'MG' ) then
   ! Start co-substepping of macrophysics and microphysics
   cld_macmic_ztodt = ztodt/cld_macmic_num_steps

   ! Clear precip fields that should accumulate.
   prec_sed_macmic = 0._r8
   snow_sed_macmic = 0._r8
   prec_pcw_macmic = 0._r8
   snow_pcw_macmic = 0._r8
```

```
physics/cam/zm_conv_intr.F90:  use phys_control,   only: phys_deepconv_pbl, phys_getopts, cam_physpkg_is
physics/cam/zm_conv_intr.F90:   use phys_control,  only: cam_physpkg_is
physics/cam/zm_conv_intr.F90:  if ( .not. cam_physpkg_is('cam3')) then
physics/cam/zm_conv_intr.F90:  use phys_control,   only: cam_physpkg_is
physics/cam/zm_conv_intr.F90:    else if (nbulk > 0 .and.  cam_physpkg_is('cam4')) then
physics/cam/original1.convect_shallow.F90:  use phys_control,      only : cam_physpkg_is
physics/cam/original1.convect_shallow.F90:      if( cam_physpkg_is('cam3') .or. cam_physpkg_is('cam4') ) then
physics/cam/original1.nucleate_ice_cam.F90:use phys_control,   only: cam_physpkg_is
physics/cam/original1.nucleate_ice_cam.F90:   if (cam_physpkg_is("cam_dev")) then
physics/cam/original1.nucleate_ice_cam.F90:      if (cam_physpkg_is("cam_dev")) then
physics/cam/original1.nucleate_ice_cam.F90:            if (cam_physpkg_is("cam_dev")) then
physics/cam/original1.nucleate_ice_cam.F90:            if (cam_physpkg_is("cam_dev")) then
physics/cam/original1.nucleate_ice_cam.F90:   if (cam_physpkg_is("cam_dev")) then
physics/cam/original1.nucleate_ice_cam.F90:      if (cam_physpkg_is("cam_dev")) then
physics/cam/cospsimulator_intr.F90:  use phys_control,         only: cam_physpkg_is
physics/cam/nucleate_ice_cam.F90:use phys_control,   only: cam_physpkg_is
physics/cam/nucleate_ice_cam.F90:   if (cam_physpkg_is("cam_dev")) then
physics/cam/nucleate_ice_cam.F90:      if (cam_physpkg_is("cam_dev")) then
```

One motivation for CAM-SIMA: physics scheme "clarification" and flexibility

Maintaining code base untenable (with current staffing levels): recommendation from large inter institutional group (NCAR, NOAA, NRL, …) of software engineers was to create CCPP



The CCPP is a software framework that automatically generates the Fortran interface (cap) layer for a physics parameterization (scheme).

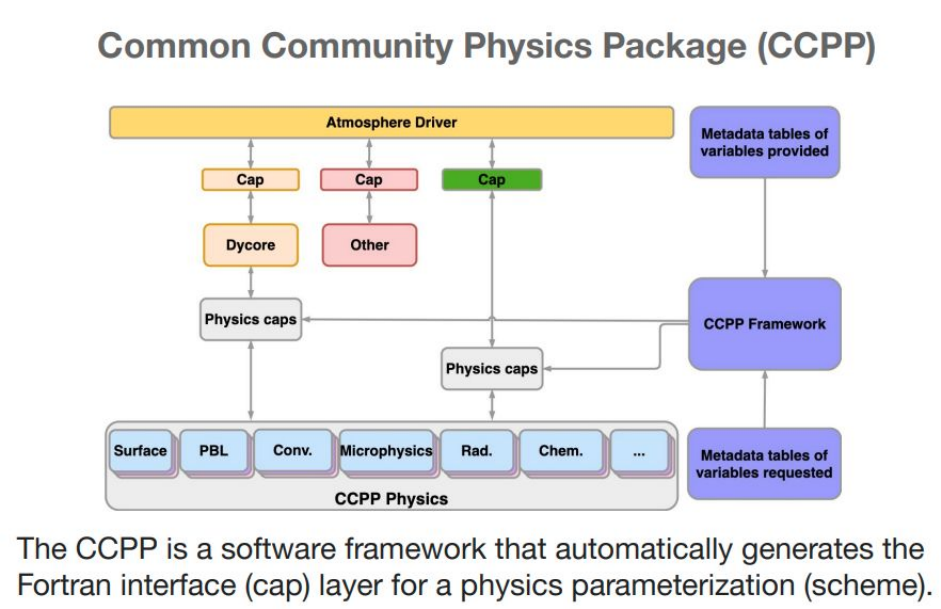
Note:

- The CCPP will always reside in a host model. For example, the host model is responsible for how tendencies from physics are added to the model state (conservation!!!).
- The dycore is not part of the CCPP!
- Once a parameterization is ported we pull it into cam_development (i.e. no duplication of physics schemes in the repositories)

See Jesse Nusbaumer's presentation from last AMWG winter meeting

One motivation for CAM-SIMA: physics scheme "clarification" and flexibility

Maintaining code base untenable (with current staffing levels): recommendation from large inter institutional group (NCAR, NOAA, NRL, …) of software engineers was to create CCPP



The CCPP is a software framework that automatically generates the Fortran interface (cap) layer for a physics parameterization (scheme).

Status of CCPP'ization of CAM:

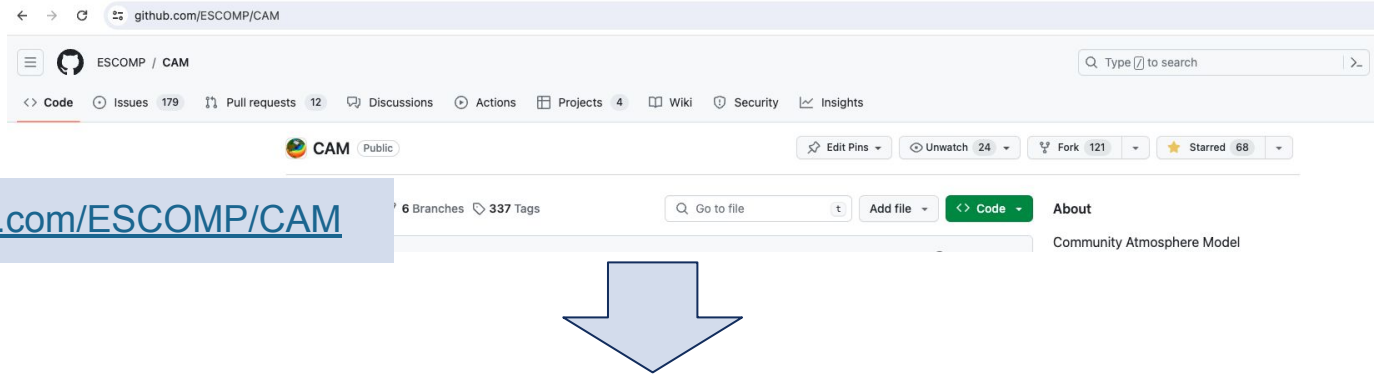
- Close to done with porting CESM simpler models physics to the CCPP
- CAM7 physics to be ported by end of FY25. Full chemistry and aerosols will be ported by end of FY25 or soon afterwards
- Funded NSF CSSI proposal for porting CAM4,5,6ish

See Jesse Nusbaumer's presentation from last AMWG winter meeting

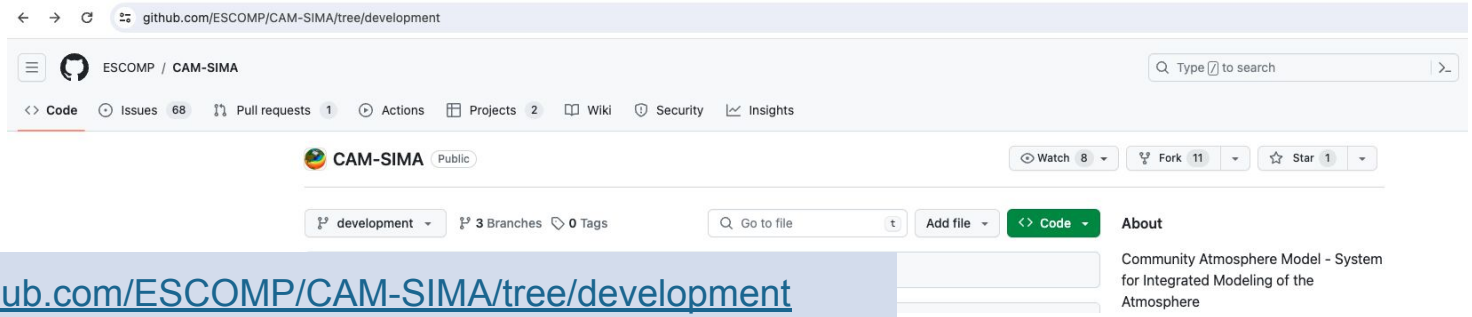
For example, not porting old radiation package (will use RRTMG-P), …

CAM-SIMA: New infrastructure to support CCPP and other functionality

A new code repository for CAM (to be released with CESM3.x where x>0):



https://github.com/ESCOMP/CAM



https://github.com/ESCOMP/CAM-SIMA/tree/development

CAM-SIMA: New infrastructure to support CCPP and other functionality

A new code repository for CAM (… release … CESM3.x where x>0):

https://github.com/E…

Very important for developers and users of CAM: What is not ported to CAM-SIMA will not be available and supported long term …

Note that standard configurations of CAM4,5,6,7, CAM-Chem, WACCM, WACCM-x will be supported

https://github.com/ESCOMP/CAM-SIMA/tree/development

Note: Our policy is that we support released code for 5 year:

Hence cam_development (part of CESM3.0 release) will be supported for 5 years after the release date!

https://www.cesm.ucar.edu/about/support

On the factory floor of model development …

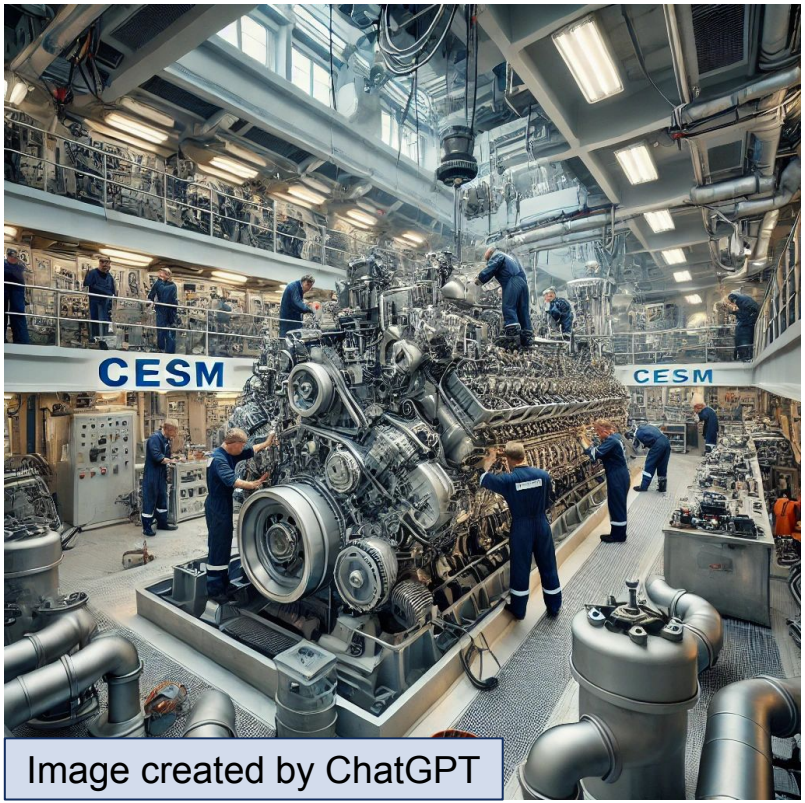
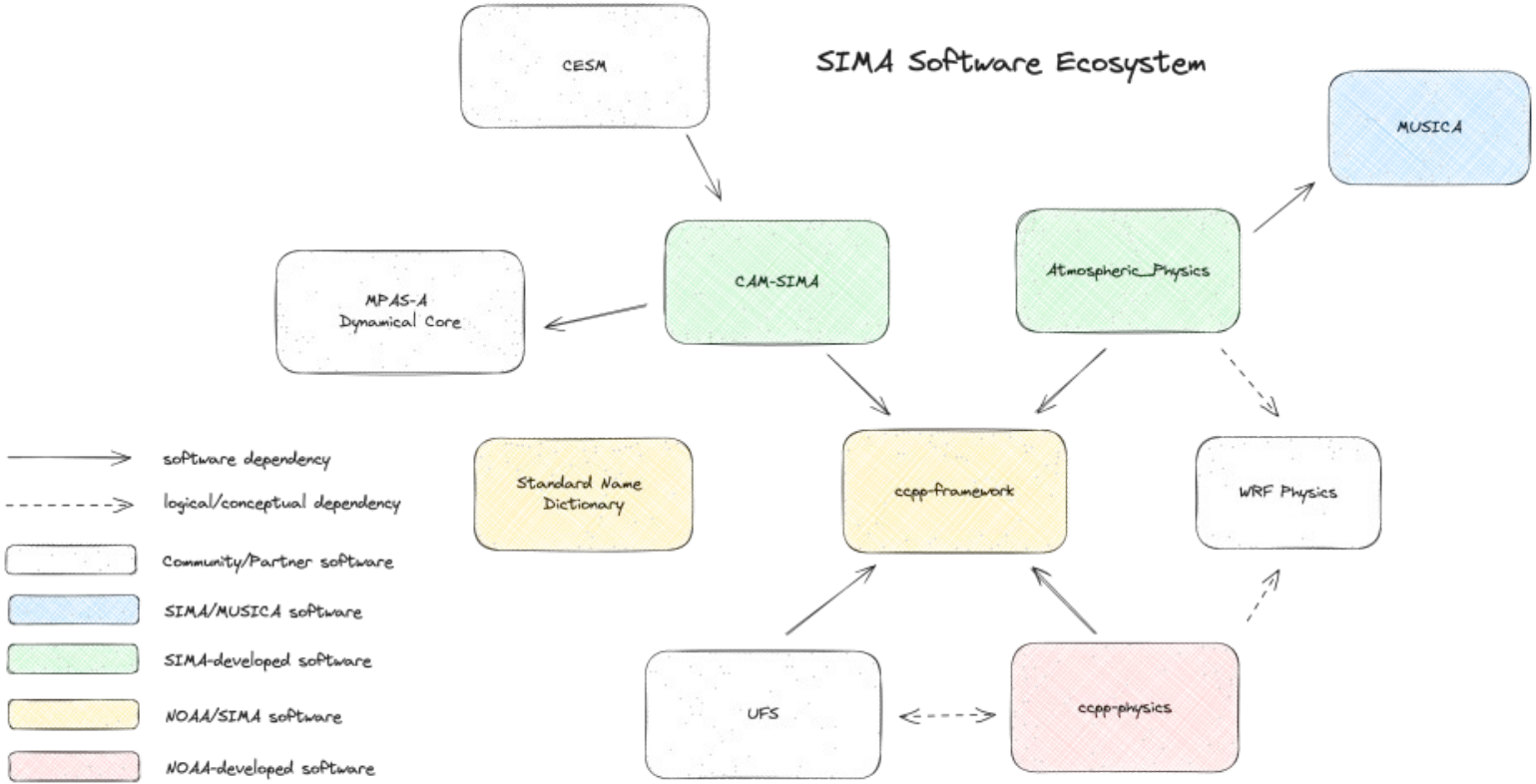


Image created by ChatGPT

https://sima.ucar.edu/what-we-do/technical-developments



CAM-SIMA infrastructure

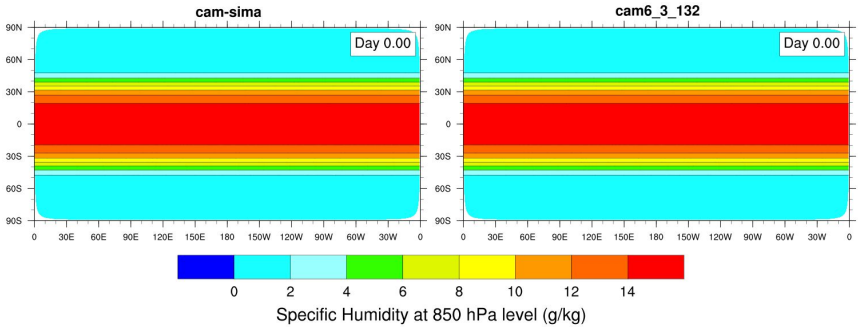
- Modularization of history (started by Steve G.; now Courtney)
- Constituents object (already in core framework; is NOAA using it?)
- Dycore port: dynamic levels and number of tracers (runtime); can also change number of tasks without recompiling

Testing/validation

- Using snapshots of state before and after parameterization from cam_development run and use of validation in CAM-SIMA
- Regression tests in cam_development
- Little regression testing in CAM-SIMA (this is highly needed but postponed due to time constraints from funders); unit testing for helper schemes

CAM-SIMA: idealized physics mostly done

- Baroclinic wave with simple warm rain microphysics (Kessler)
- Held-Suarez physics
- Moist Held-Suarez (TJ16) physics
- …



Animation courtesy of Adam Herrington

CAM-SIMA: planned work for CAM7 (and older CAM versions)

Scheme	Status	Assignee	Estimate (FTE months)
clubb_tend_cam	Not Started	Adam	9
PUMAS (microp_driver_tend)	Not Started	Jesse	9
hack (convect_shallow)	In Progress	Haipeng	4
rk_stratiform_tend	Not Started	Haipeng	4
HB PBL	Not Started	Haipeng	4
cam_thermo_water_update	In Progress	Haipeng	3
RRTMGP (radiation_tend)	Not Started	Courtney	3
qneg4	Not Started		2
ZM (convect_deep & convect_deep_tend_2)	In Progress	Cheryl	1.5
flux_avg_run	Not Started		1
check_energy_chng	In Progress	Haipeng	1
vertical_diffusion_tend	In Progress	Michael W	1
rayleigh_friction_tend	Not Started	Kate	1
gw_tend	In Progress	John T	1
physics_dme_adjust	In Progress	Brian D	1
tropopause_output	Done	Haipeng	1
state & tendency diagnostics	In Progress	Courtney	0.5
set_dry_to_wet	Done	Steve	0
qneg3	Done	Courtney / Steve	0
dadadj_tend	Done	John T	0
		Total FTE months	**47**

Time sinks and lessons learned

- PR's to two repos
- CCPP standard naming (biweekly meeting software engineers <-> scientists)
  - almost done for CAM
- Debugging constituents (in particular SE dycore)
- **Restructure code for CCPP'ization (legacy code; decades old)**
  - **probably biggest time sink**
- cam_development keeps evolving (we are in rapid model development phase for CESM3)
- Quick back and forth between software engineers and scientists very important!
  - need very close collaboration (we do 1.5-3hours hackathons every week)

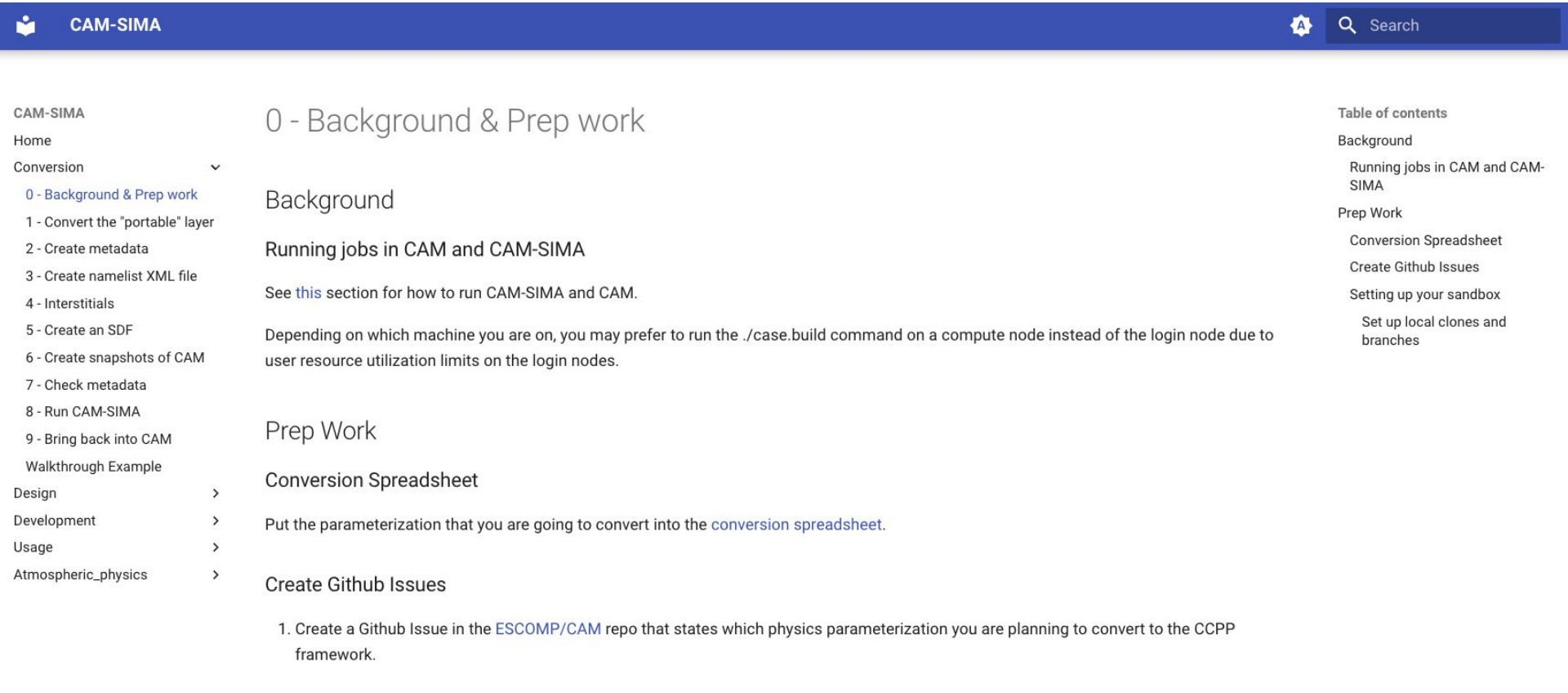
Time sinks and lessons learned

- PR's to two repos
- CCPP standard naming (biweekly meeting software engineers <-> scientists)
  - almost done for CAM
- Debugging constituents (in particular SE dycore)
- **Restructure code for CCPP'ization (legacy code; decades old)**
  - **probably biggest time sink**
- cam_development keeps ...ment phase for CESM3)

Adam Herrington (CGD) will be our first scientist paid for CCPP work (focus on CLUBB)

- Quick back and forth between software engineers and scientists very important!
  - need very close collaboration (we do 1.5-3hours hackathons every week)

https://escomp.github.io/CAM-SIMA-docs/



Some personal ideas on future developments with the CCPP!

National Center for Atmospheric Research is a major facility sponsored by the NSF under Cooperative Agreement No. 1852977

Generalized thermodynamic infrastructure moving forward?

This is likely more involved than defining common functions to compute Exner pressure, potential temperature, etc.

- Parameterizations should be told how to change temperature due to heating

  dQ = rho*cp(d)*dT (some models use generalized cp, some use cv)

- Phase changes: host model should tell the parameterization how to compute heating due to phase changes (to support variable latent heats)

- Isotopes: needs to know details of phase transitions and mixing

  CSSI proposal being prepared to explore this (isotope focus though!)

WGNE Questionnaire on physics-dynamics coupling and energy budgets in Earth System Models

Peter Lauritzen (CGD/NCAR) and Romain Roehrig (Meteo France)

Effort started in 2023

National Center for Atmospheric Research is a major facility sponsored by the NSF under Cooperative Agreement No. 1852977

Why this effort on physics-dynamics coupling and energy budgets?

No coordinated effort to discuss/evaluate how/if Earth System Models close total energy budgets (yet climate change is an energy imbalance!)

It is a very technical subject and model development is not always published

Why WGNE? The Working Group on Numerical Experimentation (WGNE) has responsibility for the development of Earth system models for use in weather, climate, water and environmental prediction on all time scales, and diagnosing and resolving shortcomings.

National Center for Atmospheric Research is a major facility sponsored by the NSF under Cooperative Agreement No. 1852977

Toward Consistent Diagnostics of the Coupled Atmosphere and Ocean Energy Budgets

MICHAEL MAYER AND LEOPOLD HAIMBERGER

Department of Meteorology and Geophysics, University of Vienna, Vienna, Austria

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 or regarded as a technical detail; 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)

Paper earned the 2023 UCAR/NCAR outstanding publication award

Modeling groups who responded
(received many in-depth responses)

- NCEP GFS/UFS (USA)
- GFDL (USA)
- NASA GISS (USA)
- CNRM-CM (France)
- CMC (Canada)
- ECMWF IFS (Europe)
- DOE E3SM (USA)
- NCAR CESM3/CAM7 (USA)