Frequently used acronyms in this talk:

CESM = Community Earth System Model
CAM = Community Atmosphere Model
WACCM = Whole Atmosphere Community Climate Model

CAM7 overview

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Internal AMWG (Atmospheric Model Working Group) co-chair
National Science Foundation (NSF)'s National Center for Atmospheric Research (NCAR)

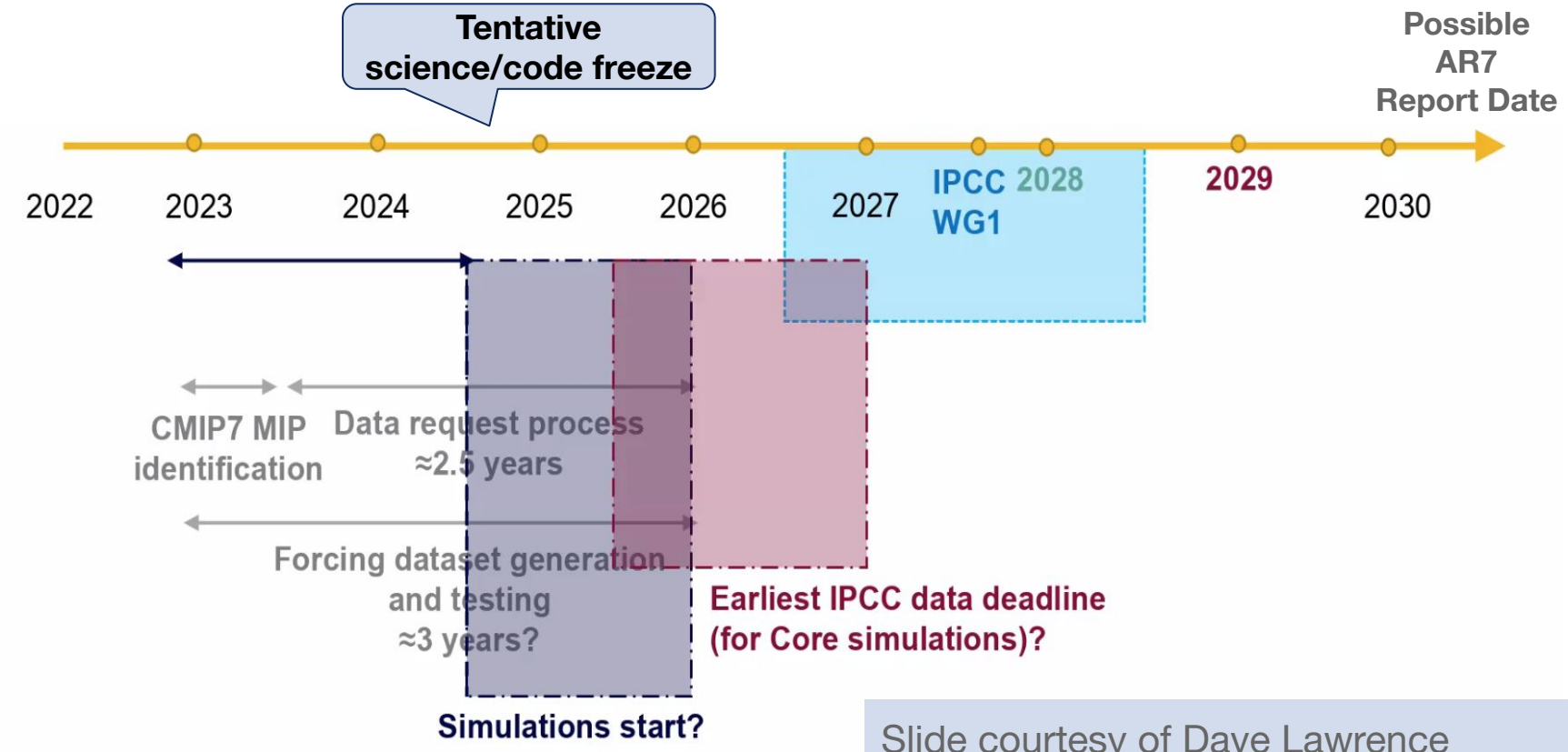
September 12, 2024

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.

Outline

- Where are we in the development cycle?
- What is new in CAM7?
- Main biases we are focusing on in coupled model development

Draft CMIP7 Timeline



Slide courtesy of Dave Lawrence

Outline

- Where are we in the development cycle?
- What is new in CAM7?
- Main biases we are focusing on in coupled model development

From CAM6 towards CAM7

1. Increase vertical resolution (~93 levels; incl. extra layers in boundary layer) and raise model top to ~80km (new COMPSET name FMTHIST, low top version FLTHIST with 58 levels)

Some WACCM settings now default in FMT/FLT: Same simplified chemistry in low and high top (CO2 is advected and radiatively active), unified treatment of gravity waves

2. Zhang and McFarlane (ZM) deep convection scheme modifications for higher boundary layer resolution

3. Physics re-ordering (CLUBB moved to before coupler to alleviate spurious wind oscillations in surface winds)

[won't talk more about this since NorESM (Toniazzo) helped with solution]

From CAM6 towards CAM7

4. Switched from MG to PUMAS microphysics code base (incl. several science changes) and updated CLUBB (e.g., prognostic momentum transport)

5. Convective gustiness parameterization

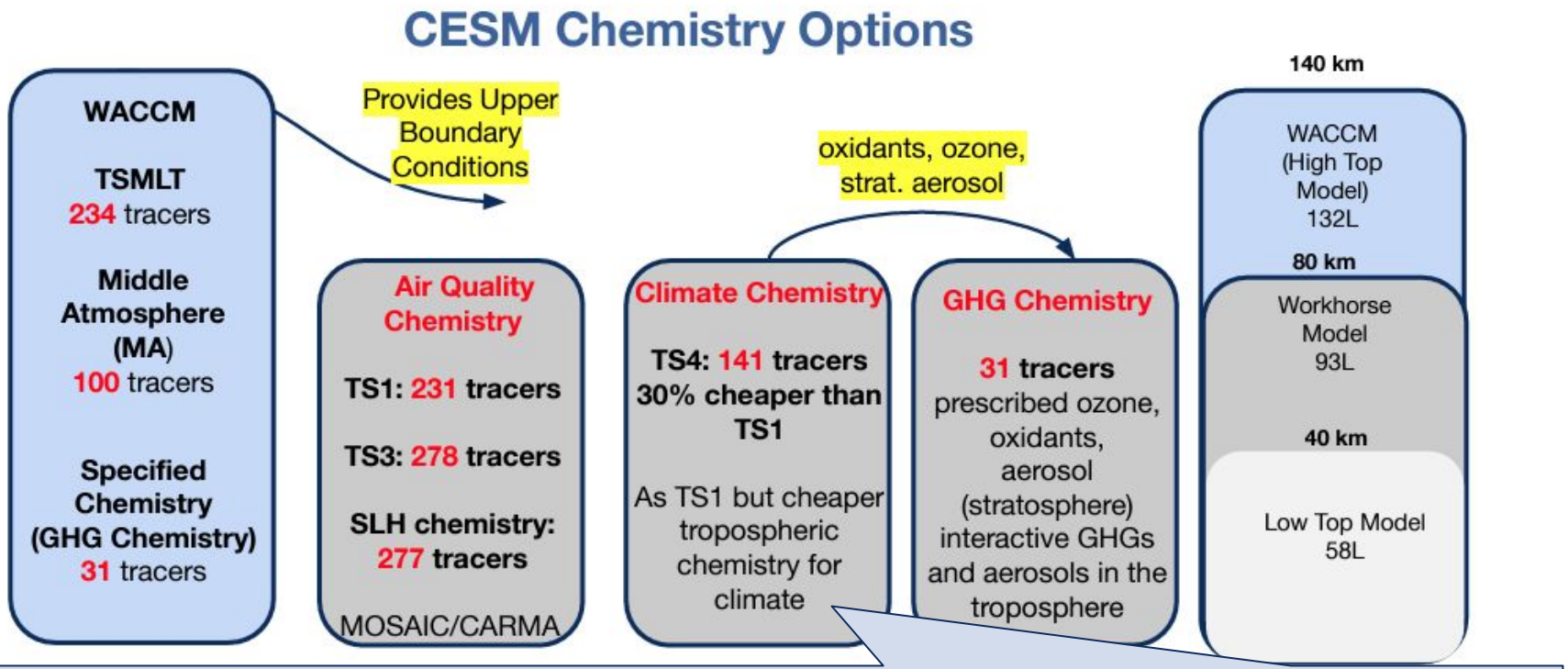
6. New gravity wave drag parameterizations (“moving mountains”)

7. New radiation code base (RRTMG-P): Modernize radiations code (with GPU support) and improve radiation algorithms

8. Changed dynamical core from FV (used for CAM4,5,6) to spectral-elements (SE): lots of changes to the original HOMME dynamical core (dry-mass vertical coordinate, incl. condensates in pressure and energy, reference profiles to alleviate noise of steep orography, physics grid, CSLAM transport scheme, …

From CAM6 towards CAM7: Chemistry

Default Aerosol Model: Modal Aerosol Model (MAM5)

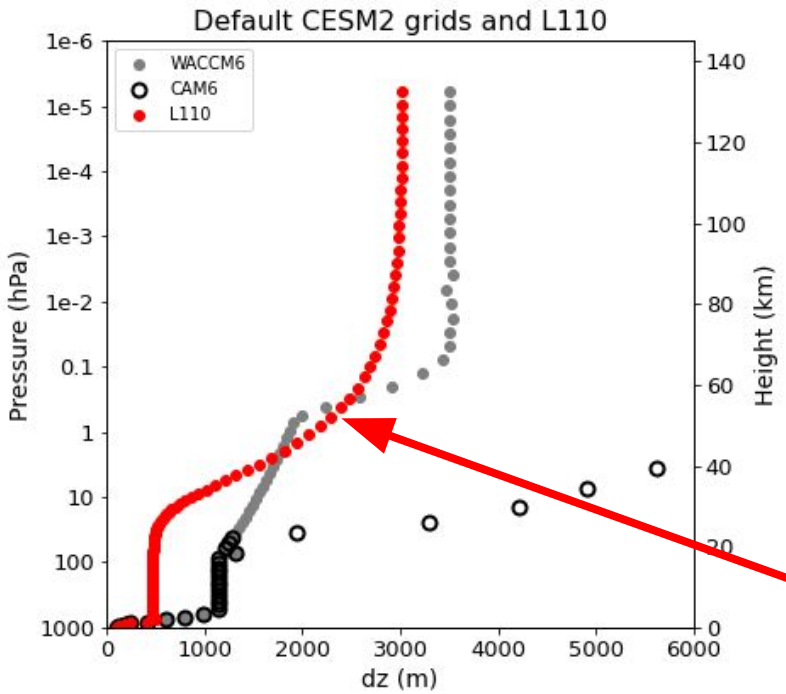


See this presentation by Louisa Emmons for details:
https://www.cesm.ucar.edu/sites/default/files/2024-03/2024-cesm-amwg-lemmons.pdf

Slide courtesy of Simone Tilmes:
https://www.cesm.ucar.edu/sites/default/files/2024-03/2024-cesm-amwg-stilmes.pdf

1

Why are we changing CAM's vertical resolution?



(1) It has become well established that the stratosphere has an influence on the troposphere. WACCM6 had a good representation of the stratosphere, but CAM6 is lacking compared to most models nowadays

NEWS & VIEWS

ATMOSPHERIC SCIENCE

Raising the roof

Shaw and Shepherd (2008) Nature Geoscience

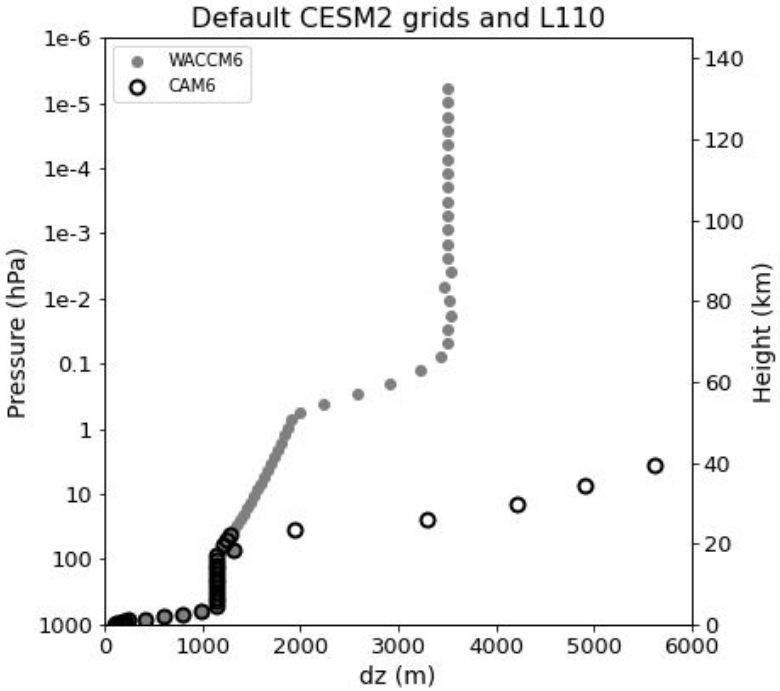
The atmosphere's lowermost 10 km have long been assumed to be almost solely responsible for weather and climate on Earth. Emerging evidence points to the layer above as an important influence on surface winds and temperatures on seasonal to decadal timescales.

(2) Even though WACCM has a well resolved stratosphere, it's still lacking in the resolution required to adequately simulate the QBO (Garcia and Richter, 2019) – a potential source of multi-year predictability

The 110 level configuration of Garcia and Richter (2019) resulted in an improved QBO.

1

Why are we changing CAM's vertical resolution?



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(2) Even though WACCM has a well resolved stratosphere, it's still lacking in the resolution required to adequately simulate the QBO (Garcia and Richter, 2019) – a potential source of multi-year predictability

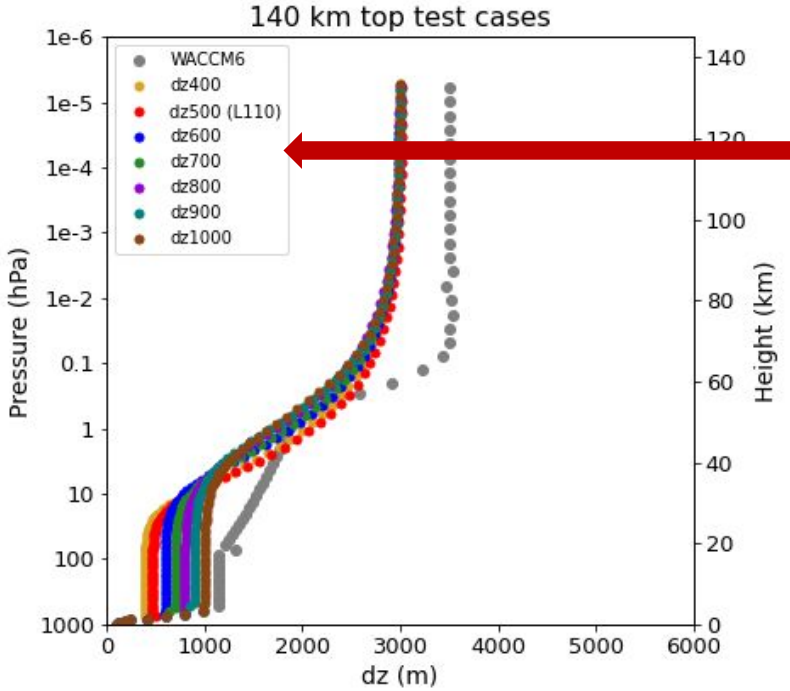
(3) WACCM is difficult to initialize from other reanalyses because its model top is too high.

(4) As we move toward higher horizontal resolution, with regional refinement, or globally, higher vertical resolution is likely beneficial.

(5) We wanted to lower the lowest model level and increase resolution in the boundary layer.

1

The vertical resolution task team work



How much does the vertical grid spacing in the free troposphere and lower stratosphere impact on the QBO and other things?

A series of grids with the spacing (dz) in the free troposphere/lower stratosphere ranging from 1000 m to 400 m

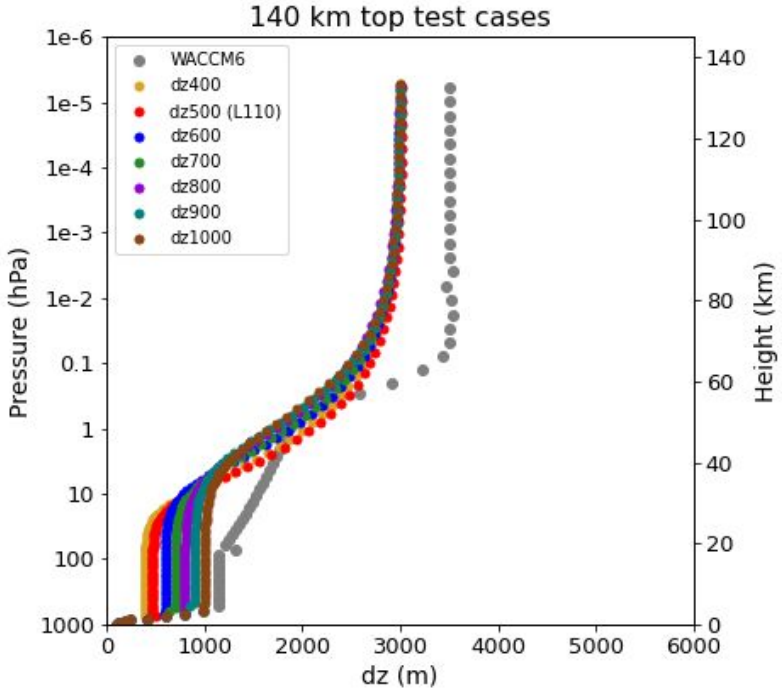
Tapering off following a hyperbolic tangent to 3km grid spacing at the model lid at around 140 km

The dz=500 case is the same as the 110 level model of Garcia and Richter (2019)

F-cases (prescribed SST), ~20 years using **CAM6; FV dycore**

1

The vertical resolution task team work



Conclusions:

- Resolutions lower than dz700 seem to be deficient in the amplitude of the QBO
- As we go to higher resolution, we see more and more of a role for the resolved waves in driving the descending westerly phase of the QBO. Improved representation of Kelvin waves
- Lowering the model top from ~140km to ~80km:

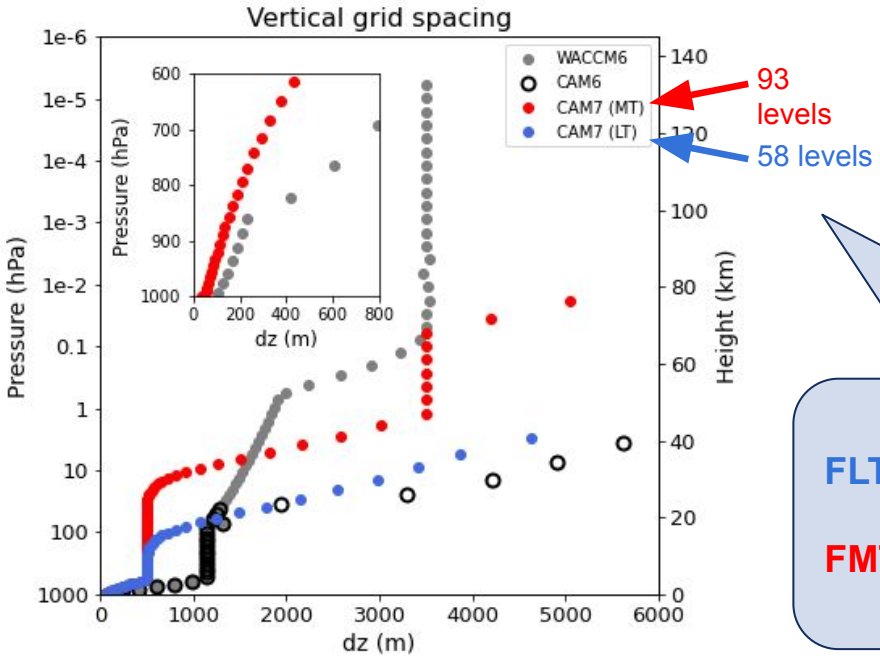
  The QBO still looks good and other things like stratospheric polar vortex variability or tropospheric circulation don't change noticeably

See detailed wave analysis here: https://www.cesm.ucar.edu/sites/default/files/2024-03/2024-cesm-amwg-isimpson.pdf

Slide courtesy of Isla Simpson

Conclusions

- These are the new grids for CAM7



- The mid-top resolution allows us to capture the QBO and associated wave driving processes well
- There are also improvements in various aspects of the tropical waves.
- Despite having a great QBO, we still are not capturing the QBO-MJO connection. But at least we have one of the pieces there.

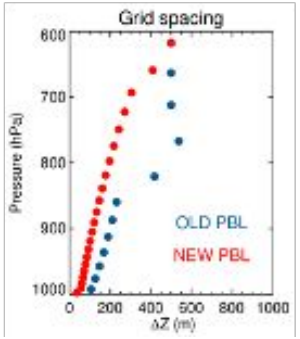
FLT = AMIP COMPSET with 58 level grid

FMT = AMIP COMPSET with 93 level grid

2

ZM2

Increased PBL vertical resolution



- Zhang and McFarlane (ZM) deep convection scheme modifications for higher boundary layer resolution:

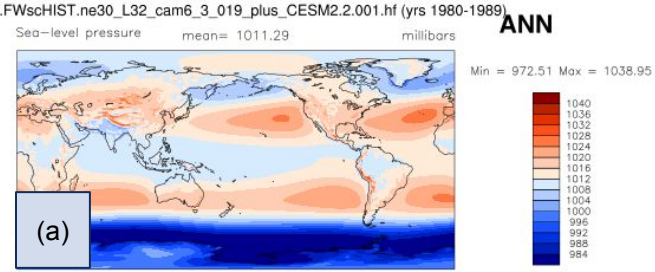
  Modified Launch Parcel Calculation (in particular, no longer launches from lowest model layer):

  - Depends on MSE (Moist Static Energy) and depth of PBL (Planetary Boundary Layer)
  - Introduces vertical length scale
  - 0.5x of PBL depth (‘ZM2’)

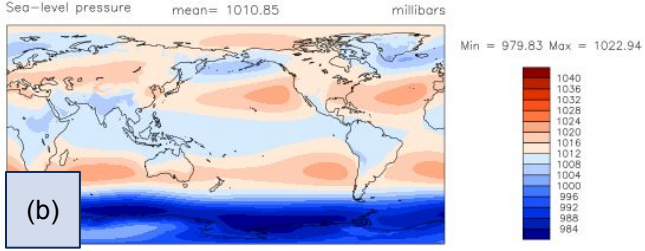
  https://files.cesm.ucar.edu/events/workshops/2022/talks/2022-cesm-workshop-amwg-r.neale.pdf

Increased boundary resolution decreases PSL biases

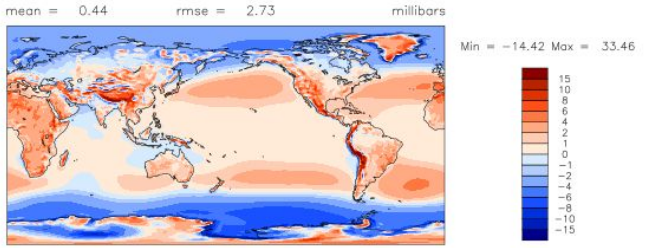
FLT with L32

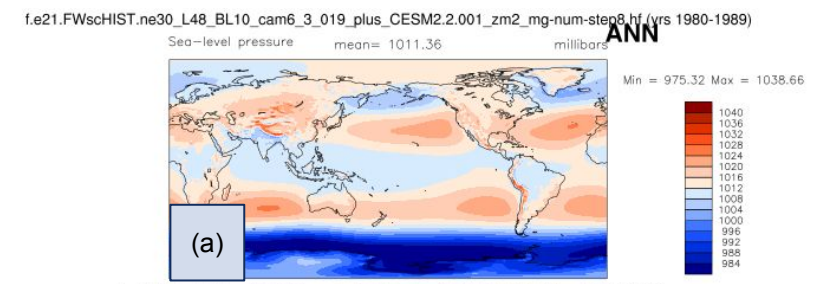


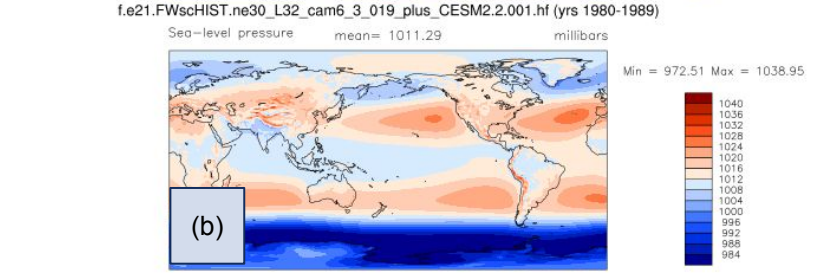
MERRA

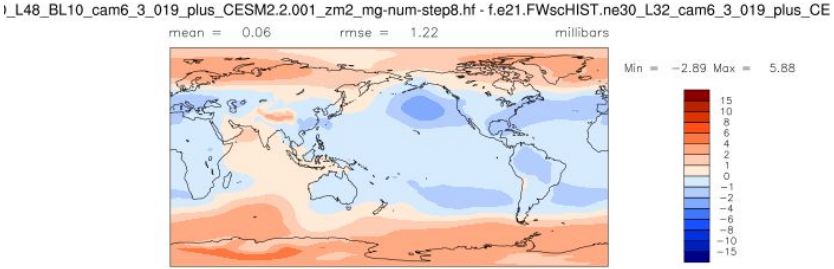


(a)-(b)









FLT (L58)

MERRA

(a)-(b)

MG -> PUMAS microphysics

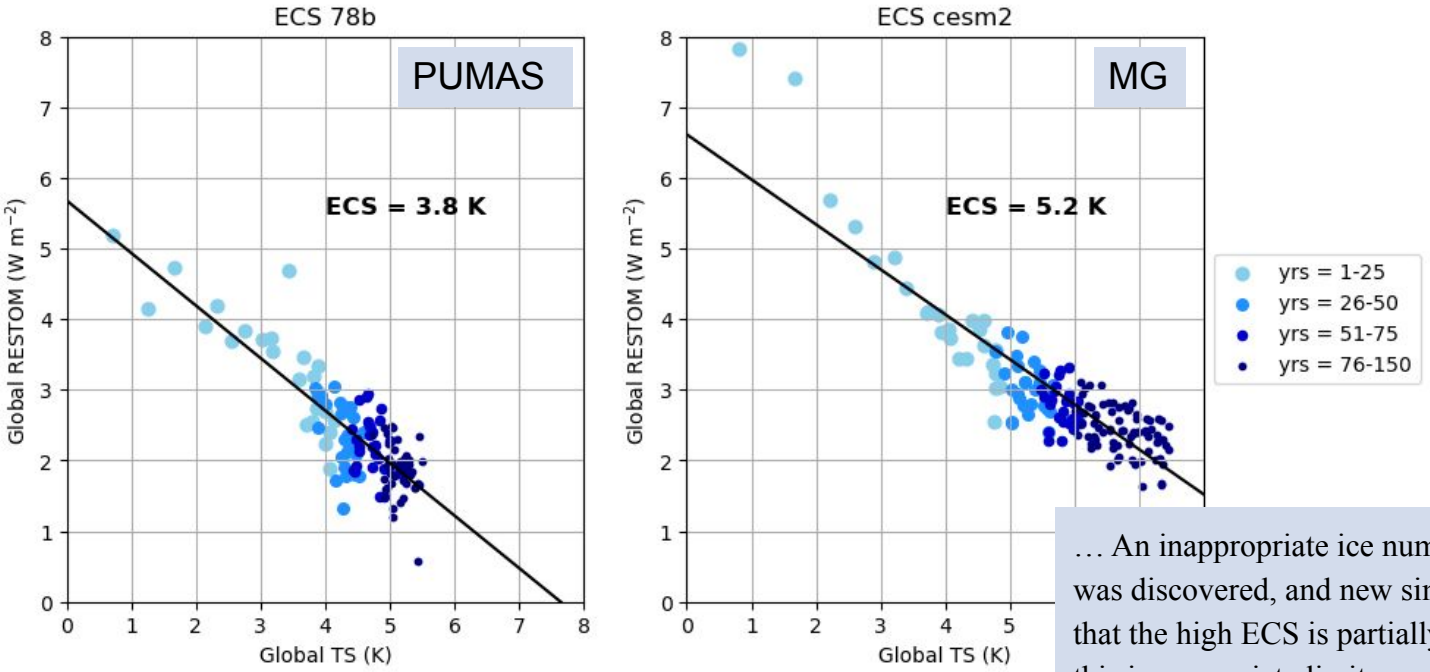
- PUMASv1 (Gettelman et al. 2023)
- New process rate - vapor deposition on snow (new limiter just added)
- Refactor ice limiter, reduce aerosol (dust and bc) seen by ice nucl.
- Numerical dt - impl. sedimentation, tighten autoconv/accr., fall speed corr.

PUMAS is an external code base: https://github.com/ESCOMP/PUMAS

See more details from A. Gettelman's presentation from last AMWG winter meeting
https://www.cesm.ucar.edu/sites/default/files/2023-03/2023-AMWG-A-Gettelman.pdf

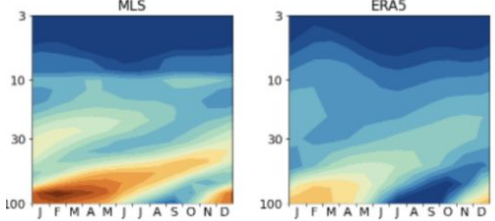
MG -> PUMAS microphysics

Updating to PUMAS reduced ECS (equilibrium climate sensitivity) significantly compared to CESM2 that used MG microphysics



… An inappropriate ice number limiter in MG was discovered, and new simulations indicate that the high ECS is partially attributable to this inappropriate limiter …

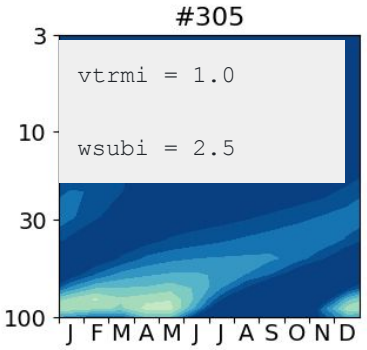
H2O tape recorder and PUMAS

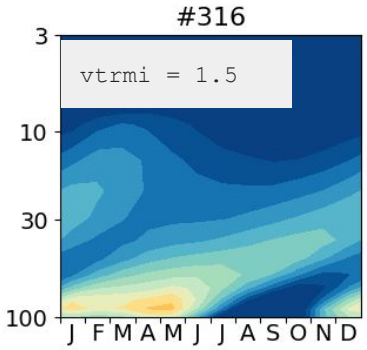


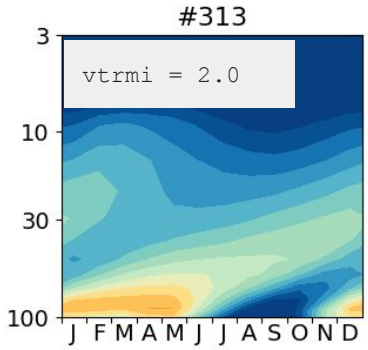
#317: new HB
micro_mg_vtrmi_factor = 0.5->1.5

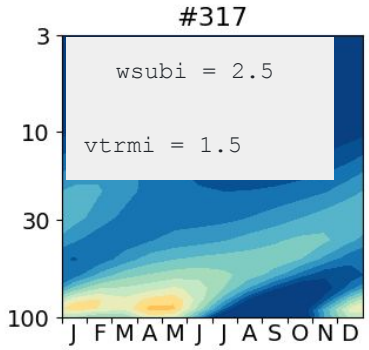
#306: microp_aero_wsubi_scale = 2.5->1.0

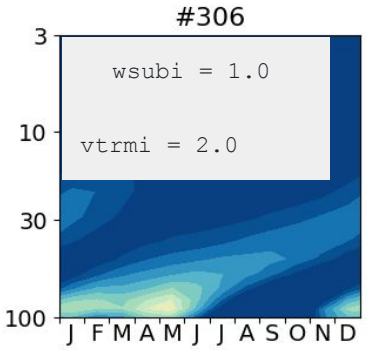
#319: microp_aero_wsubi_scale = 2.5->5.0

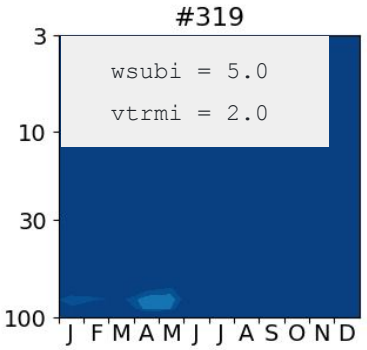


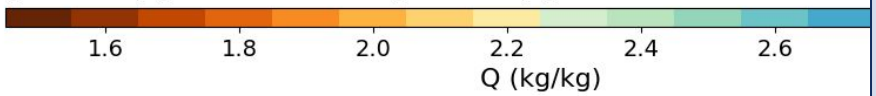












#305: micro_mg_vtrmi_factor = 0.5->1.0

#316: micro_mg_vtrmi_factor = 0.5->1.5

#313: micro_mg_vtrmi_factor = 0.5->2.0

Unitless scaling factor for ice droplet subgrid scale vertical velocity during aerosol activation

CLUBB changes:

- Prognostic momentum fluxes
- Turn-off downgradient diffusion on Theta_l/Qt
- Allow CLUBB to operate in layers above the tropopause

Related:

- Free atmosphere Richardson number based mixing (where CLUBB is not active) has been added to stabilize higher top versions of CAM and we believe there is missing mixing in the free atmosphere

For top-of-atmosphere radiative balance tuning we usually use `clubb_c8`

"CLUBB_C8 is a skewness coefficient associated with the third moment of vertical velocity. Larger CLUBB_C8 values correspond to thicker, more reflective clouds."
https://journals.ametsoc.org/view/journals/clim/37/1/JCLI-D-23-0250.1.xml

Discovered runaway problem in paleo “hot climates” simulations
Solution: remove an unphysical limiter on the vertical extent of CLUBB

Reassessing the clubbtop limiter #134

adamrher started this conversation in **X: General**

adamrher on Jun 17, 2022 Collaborator edited

A limiter on the vertical extent that clubb can provide tendencies to CAM was introduced a number of years ago by **@bogensch**. The limiter impacts CLUBB's tendencies of vapor, liquid and temperature, but interestingly it does not touch diffusion of tracers and ice. The reason it was implemented is because clubb creates spurious drying tendencies above the tropopause, which have an outsize influence on the moisture due to the lack of any other competing physical process up there. Therefore, this clubbtop limiter was developed to eliminate the spurious drying. This clubbtop limiter currently operates by:

1. call clubb
2. find chemical tropopause (note that poleward of 50˚, it returns a tropopause no larger than 300 hPa)
3. scan downward from tropopause and set clubbtop to the first occurrence of rcm /= 0 AND rtp2 > small number
4. accumulate tendencies above clubbtop and distribute into this newly defined active region (from the surface to clubbtop)

More details: https://docs.google.com/presentation/u/0/d/1WCuWT-0SgAYj_JnS0W0A0jQ4YnEly9mX/edit?fromCopy=true&ct=2

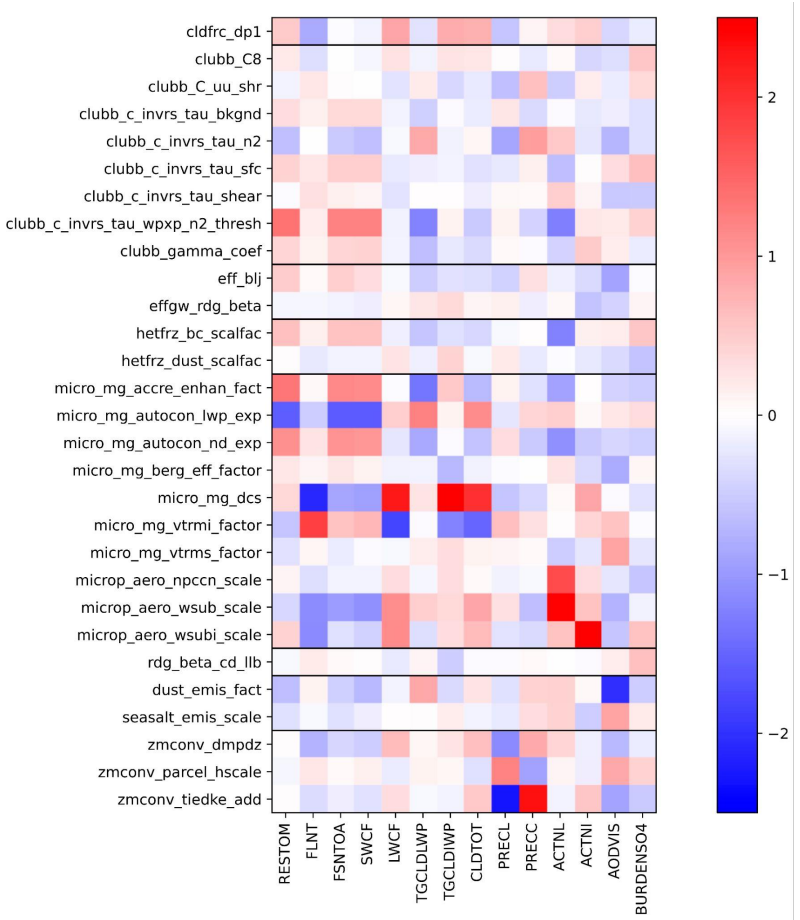
Systematic parameter tuning

CESM2.2-CAM6 Perturbed Parameter Ensemble (PPE)

https://egusphere.copernicus.org/preprints/2024/egusphere-2023-2165/

CAM7 (early version) PPE results on Figure on the right!

Projects under LEAP



Convective gustiness parameterization

- New parameterization to enhance surface fluxes from the ocean as a result of convective gustiness.

Indian Ocean biases have largely improved

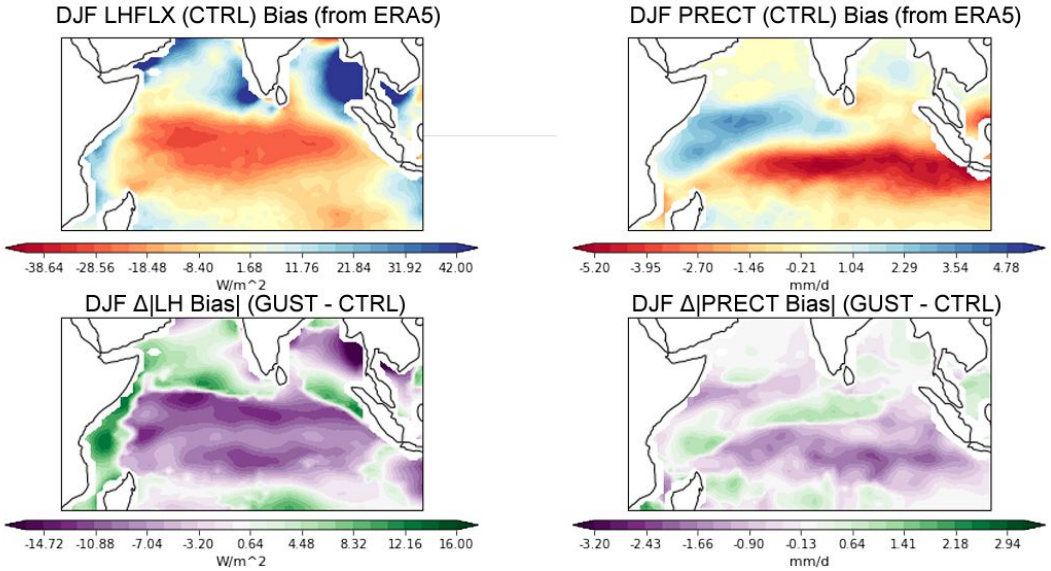
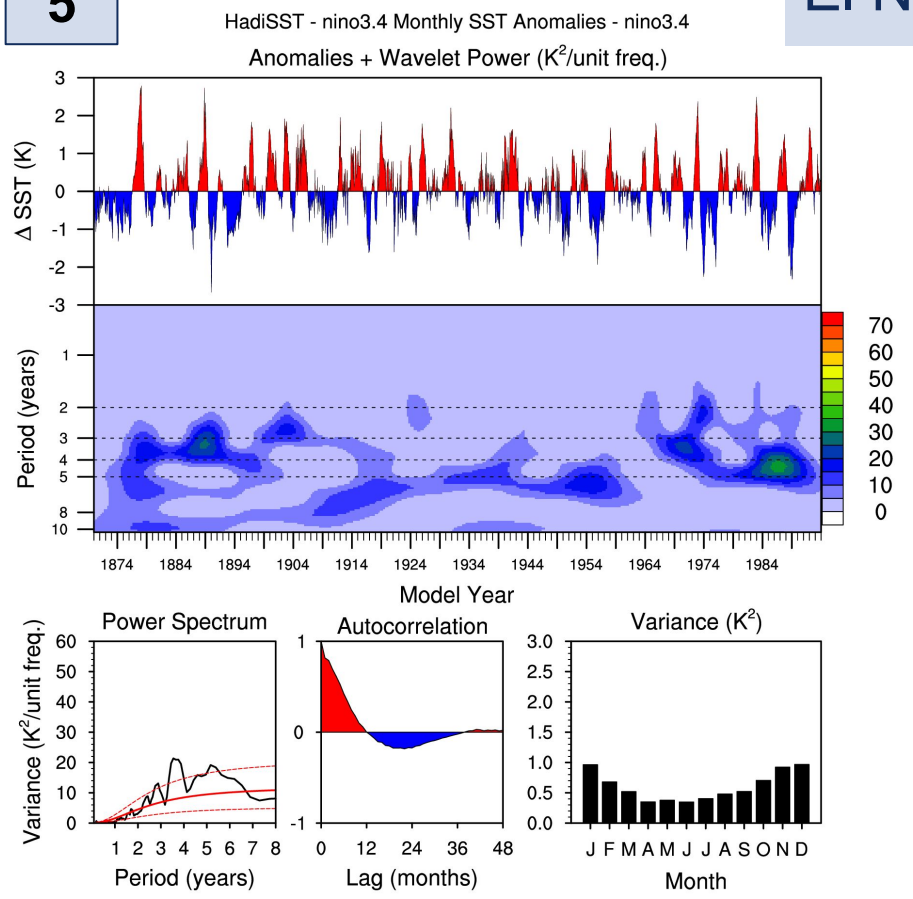


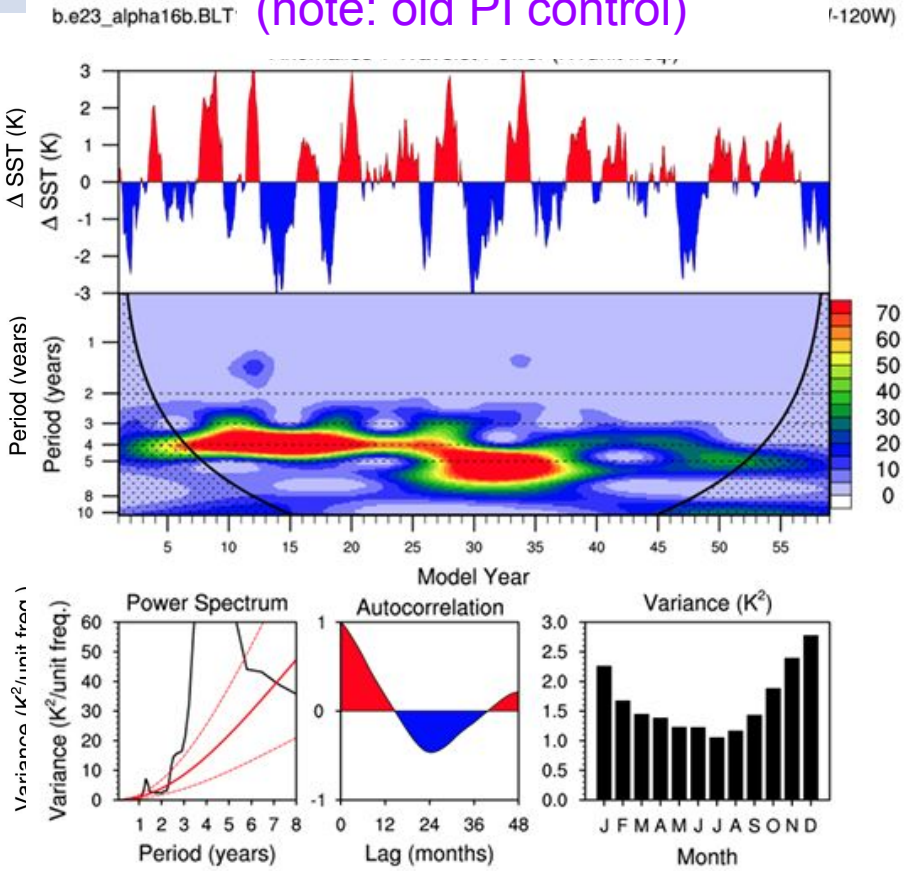
Figure courtesy of Meg Fowler

El Nino

HadiSST (Obs.)

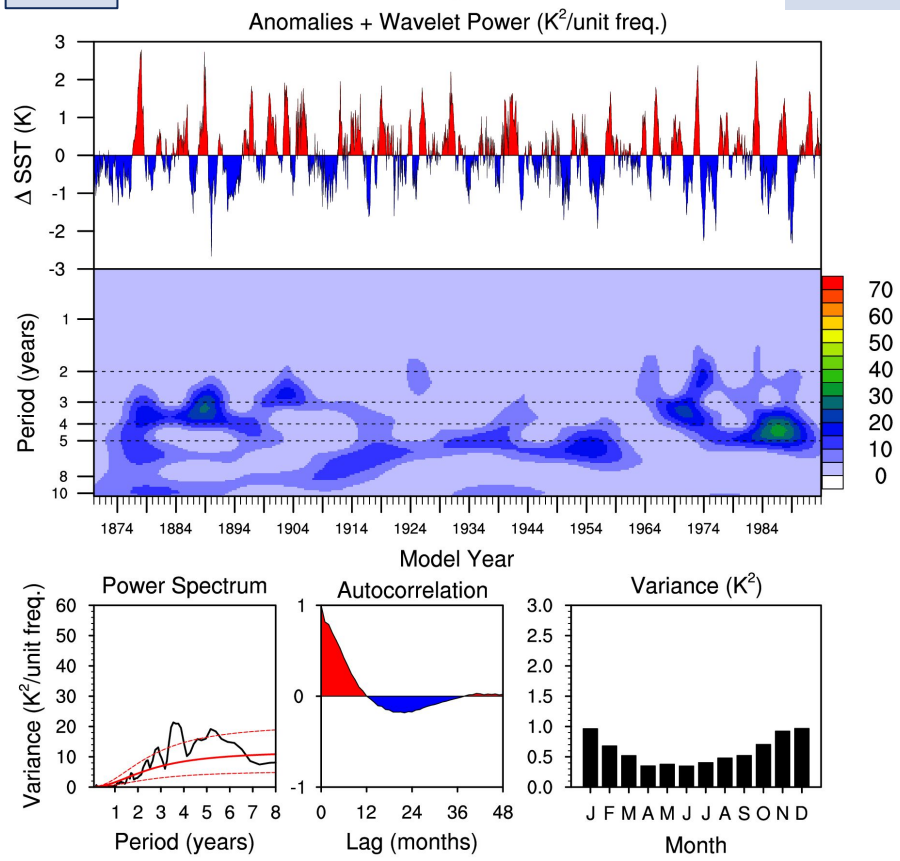


BLTHIST no gustiness (note: old PI control)

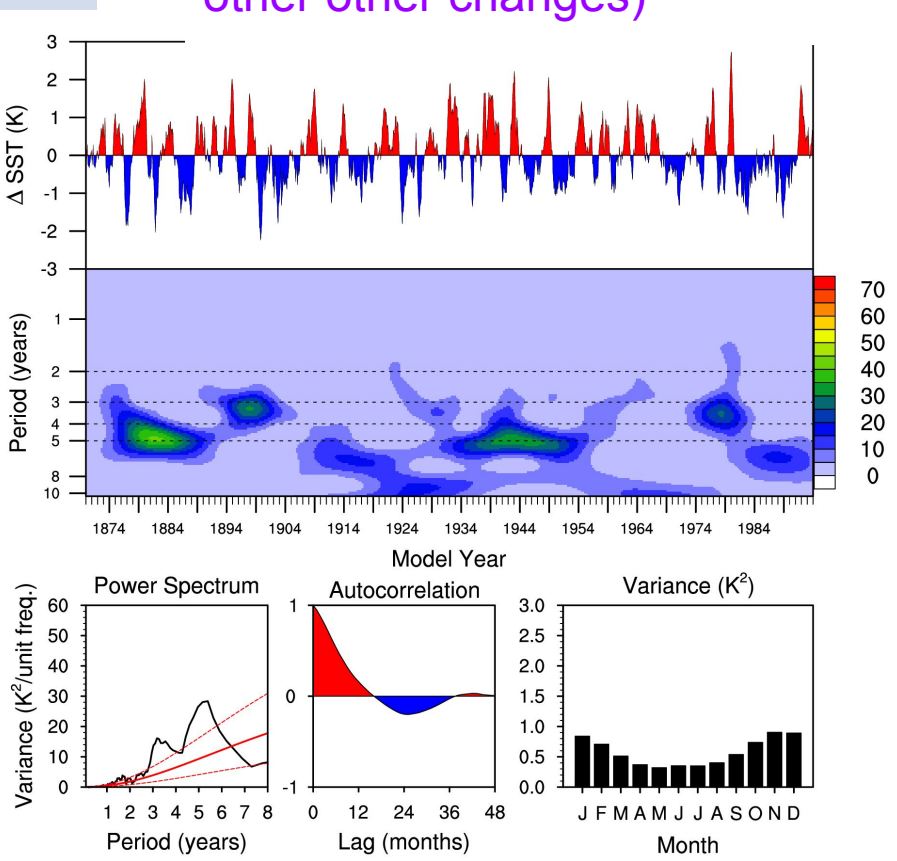


El Nino

HadiSST (Obs.)



BLTHIST (with gustiness and other other changes)



“moving mountains” drag parameterization

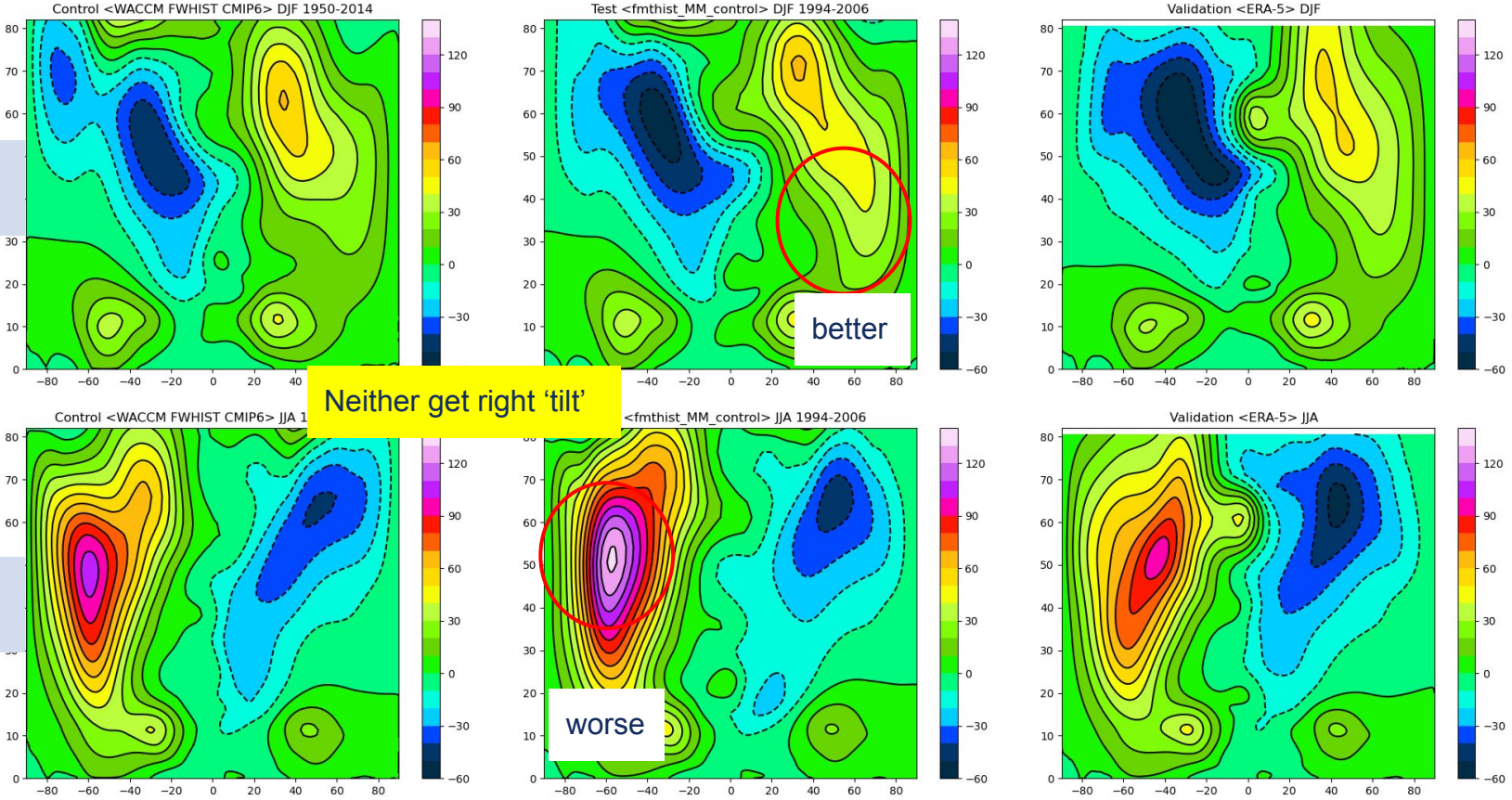
WACCM6 FWHIST L70

FMTHIST L93

ERA5

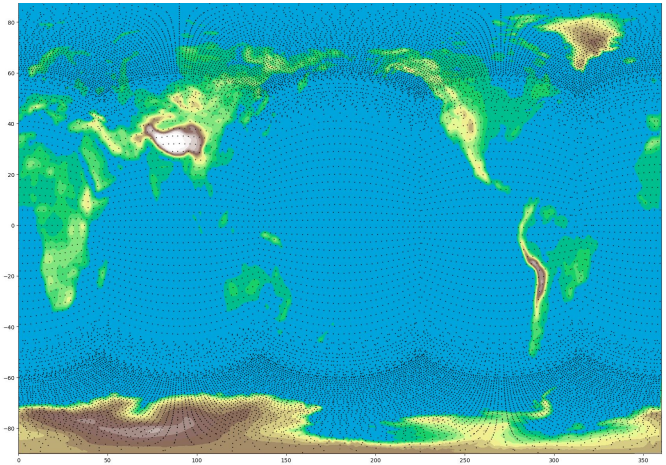
DJA

JJA



Slide modified from Julio Bacmeister's AMWG talk:
https://www.cesm.ucar.edu/sites/default/files/2024-03/2024-cesm-amwg-jbachmeister.pdf

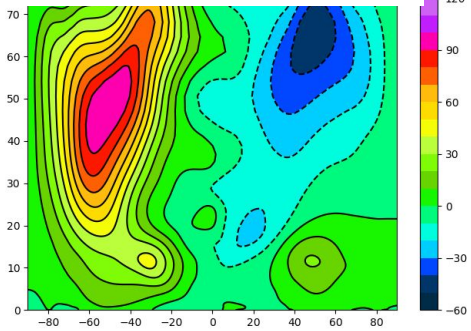
Dual Polar grid (A. Herrington, R. Wijngaard) 100km global ⇒25km polar



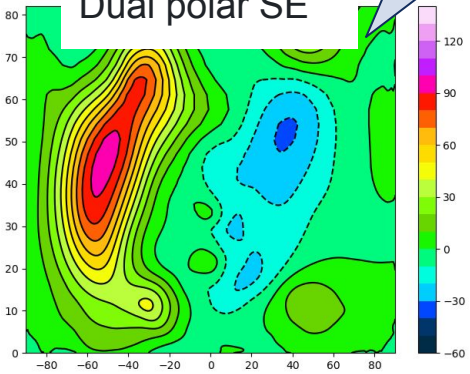
Increased polar resolution improves Southern hemisphere wind biases compared to 1 degree spectral-elements significantly indicating that reduced polar resolution through using quasi-uniform grids (like cubed-sphere) plays a role

Note: 1 degree SE with rougher topography did not improve wind biases significantly …

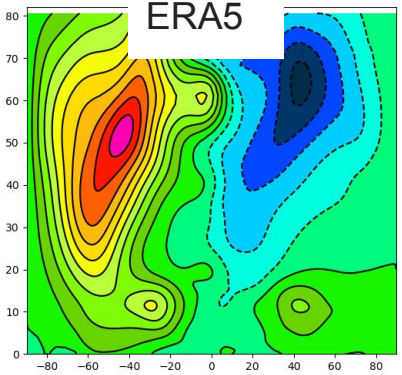
CESM2 FV WACCM



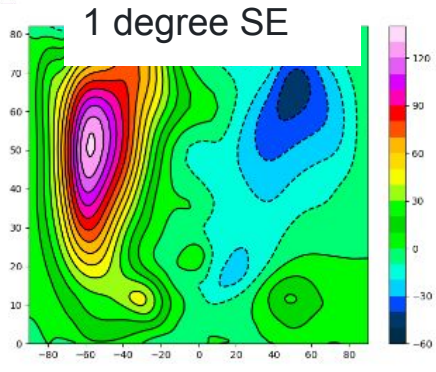
Dual polar SE



ERA5



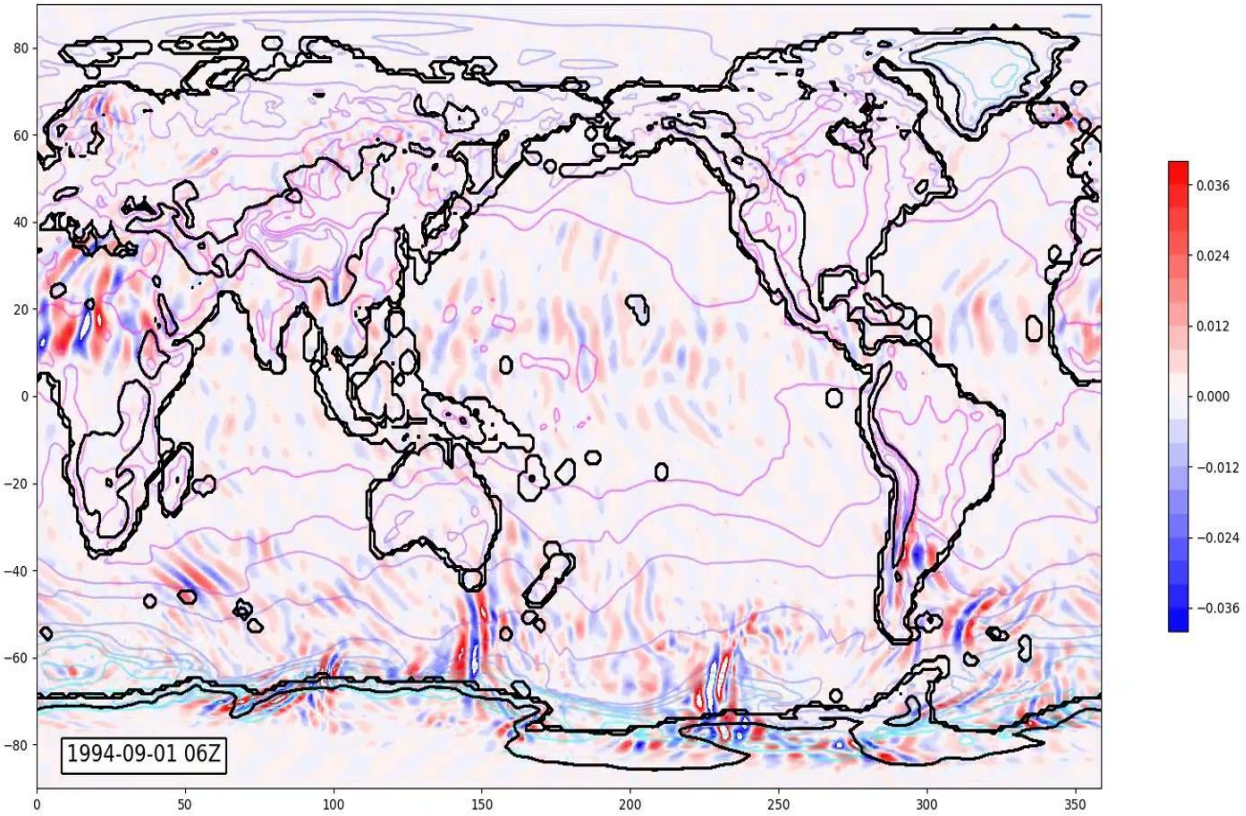
1 degree SE



Slide modified from Julio Bacmeister's AMWG talk: https://www.cesm.ucar.edu/sites/default/files/2024-03/2024-cesm-amwg-jbachmeister.pdf

Missing gravity waves source? See M. Bramberger's presentation

https://www.cesm.ucar.edu/sites/default/files/2024-03/2024-cesm-amwg-mbramberger.pdf



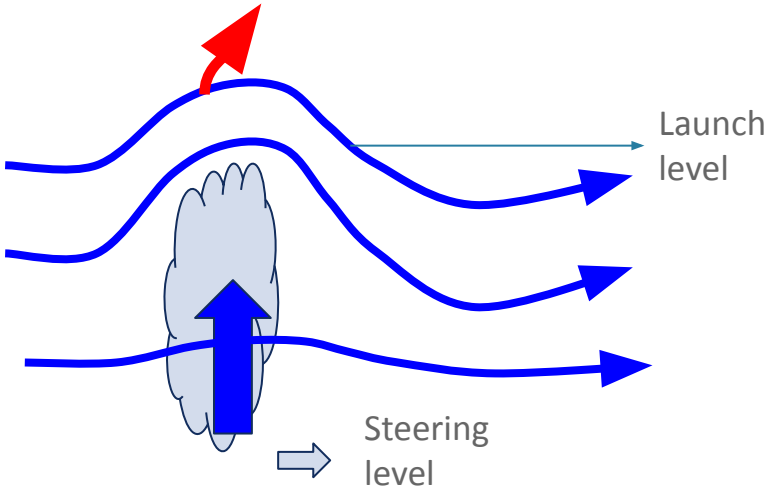
mation courtesy of Julio Bacmeister

Initial tests - Moving mountains from PBL
work with Martina Bramberger, Joan Alexander (CoRA)

Missing GW source?

- Moving Mountains: Low but non-zero phase speeds

Launch level momentum flux *(currently estimated from CLUBB momentum fluxes)*



Test #1:

- Steering level fixed to ~40m
- Launch level fixed to ~750m
- Source momentum flux:
  - 0.01 x average CLUBB momentum flux 0-750m

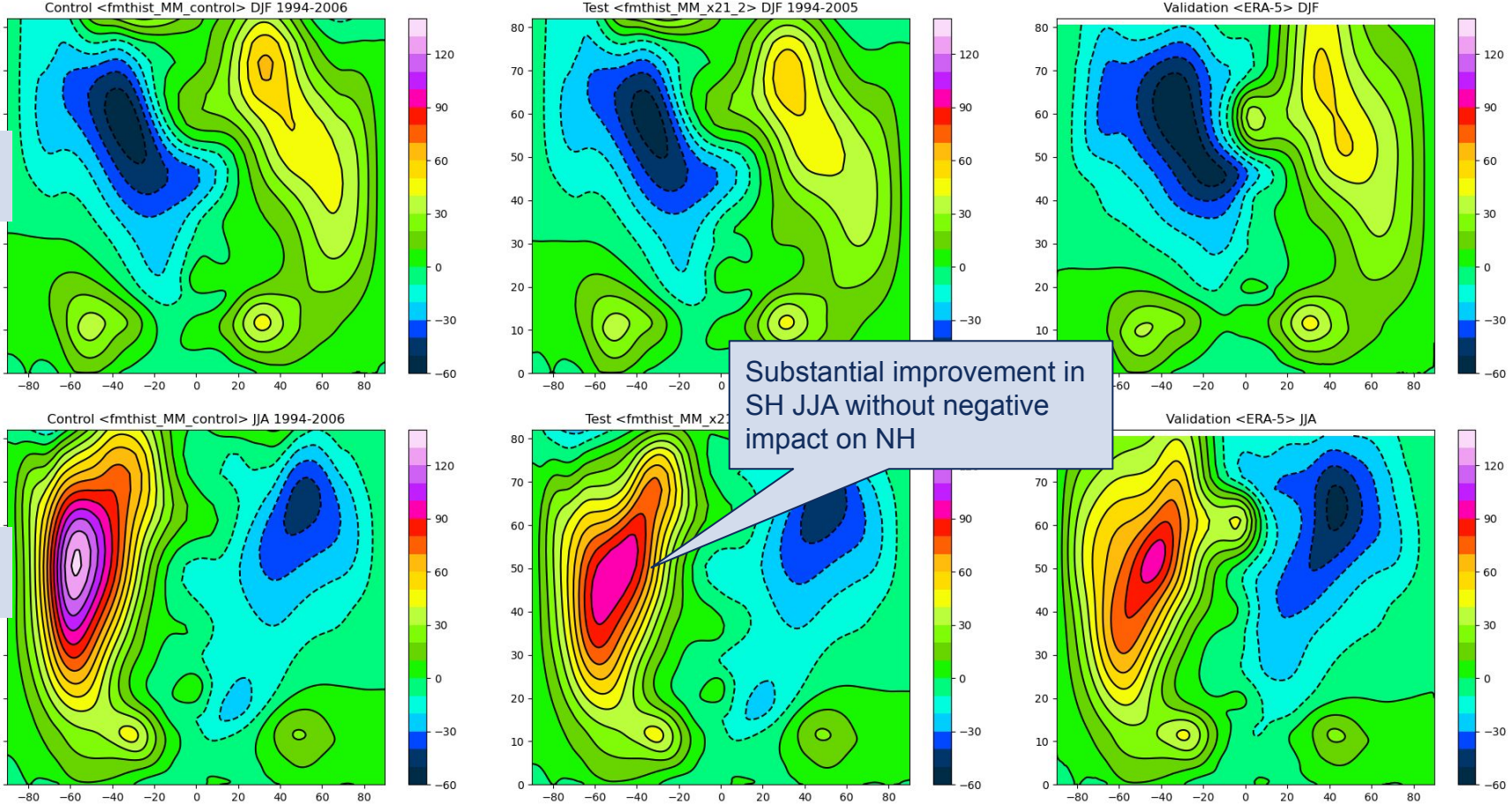
WACCM6 FWHIST L70

FMTHIST L93+"moving mountains"

ERA5

DJA

JJA



Substantial improvement in SH JJA without negative impact on NH

Slide modified from Julio Bacmeister's AMWG talk: https://www.cesm.ucar.edu/sites/default/files/2024-03/2024-cesm-amwg-jbachmeister.pdf

New radiation code base (RRTMG-P)

- Some modifications needed in CAM to make RRTMG-P operate properly for ~80km top model

  https://github.com/ESCOMP/CAM/issues/1063

FYI: modifications to RRTMG-P needed for the new CMIP7 solar forcing

Spectral-element dynamical core

Getting away from CAM-FV …

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

CAM-FV **(finite volume)**
Lin (2004)
CAM-EUL/SLD

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

Note:

New dynamical cores have mesh-refinement capability!

MPAS:

non-hydrostatic

8 Separate physics, transport and dynamics grid

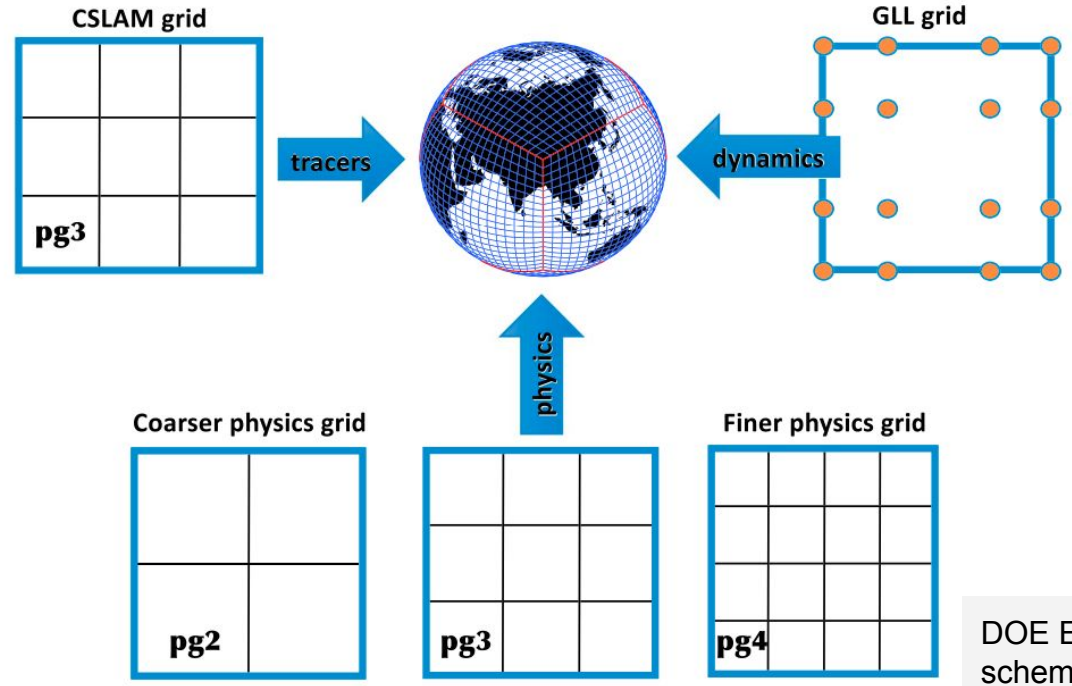


Figure 1. An overview of the different grids in CAM-SE-CSLAM.

For CESM3 we use pg3 grid for CAM physics!

Separating grids is not trivial - mapping between grids must be done carefully!
https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2019ms001684

Transport scheme:
Conservative Semi-LAgrangian Multi-tracer scheme
(consistent coupling with spectral-elements dycore described here https://journals.ametsoc.org/view/journals/mwre/145/3/mwr-d-16-0258.1.xml)

Note: Dry-mass vertical coordinate makes CSLAM-SE dycore coupling more consistent!

DOE E3SM is using similar approach (but transport scheme faster and supports variable resolution grids)

UK Met Office is exploring separation of grids as well

From HOMME* to CAM-SE-CSLAM

- Dry-mass vertical coordinate
- Separate physics grid and tracer transport grid/scheme
- Condensates incl. in pressure; variable latent heats / coupling with MOM6
- Reference profiles for hyperviscosity
- High top stability
- Computational speed-up

Changes energy equation!

*High-Order Method Modeling Environment

9? Potential additional changes to CAM7

[note: after September 30 any new science in CAM7 will need SSC approval and will have to demonstrate significant bias reduction in CESM3 in order to be put in cam_development]

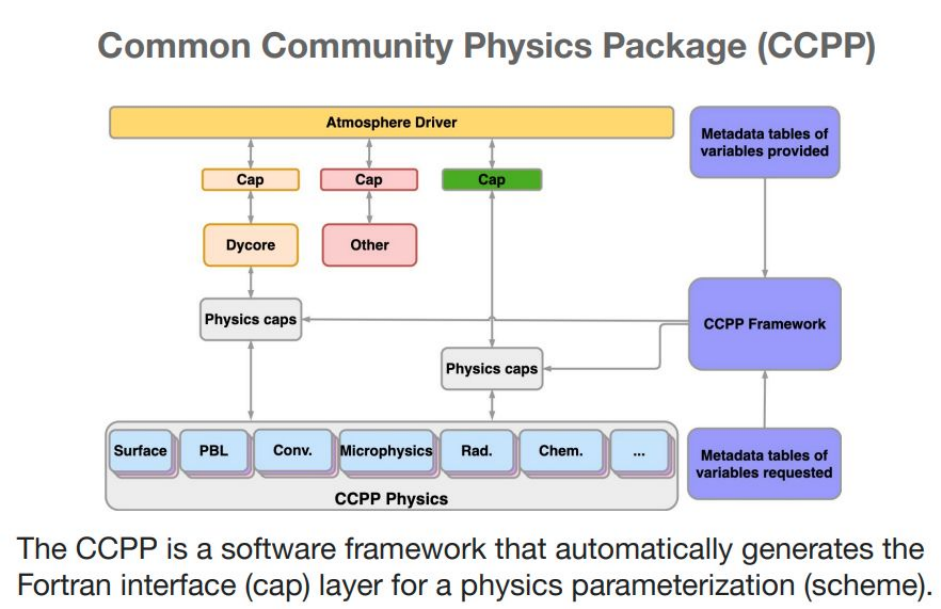
- Improvement to “moving mountains” trigger function.
- Explicit enthalpy flux exchange between CAM and MOM6 ocean model (collaboration with NorESM; T. Toniazzo)
- Possible ZM modifications for, e.g., better QBO simulations in WACCM.

Developers: please be aware that a new code base for CAM is in the works (called CAM-SIMA where SIMA=System for Integrated Modeling of the Atmosphere)

Steve Goldhaber heavily involved!

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:

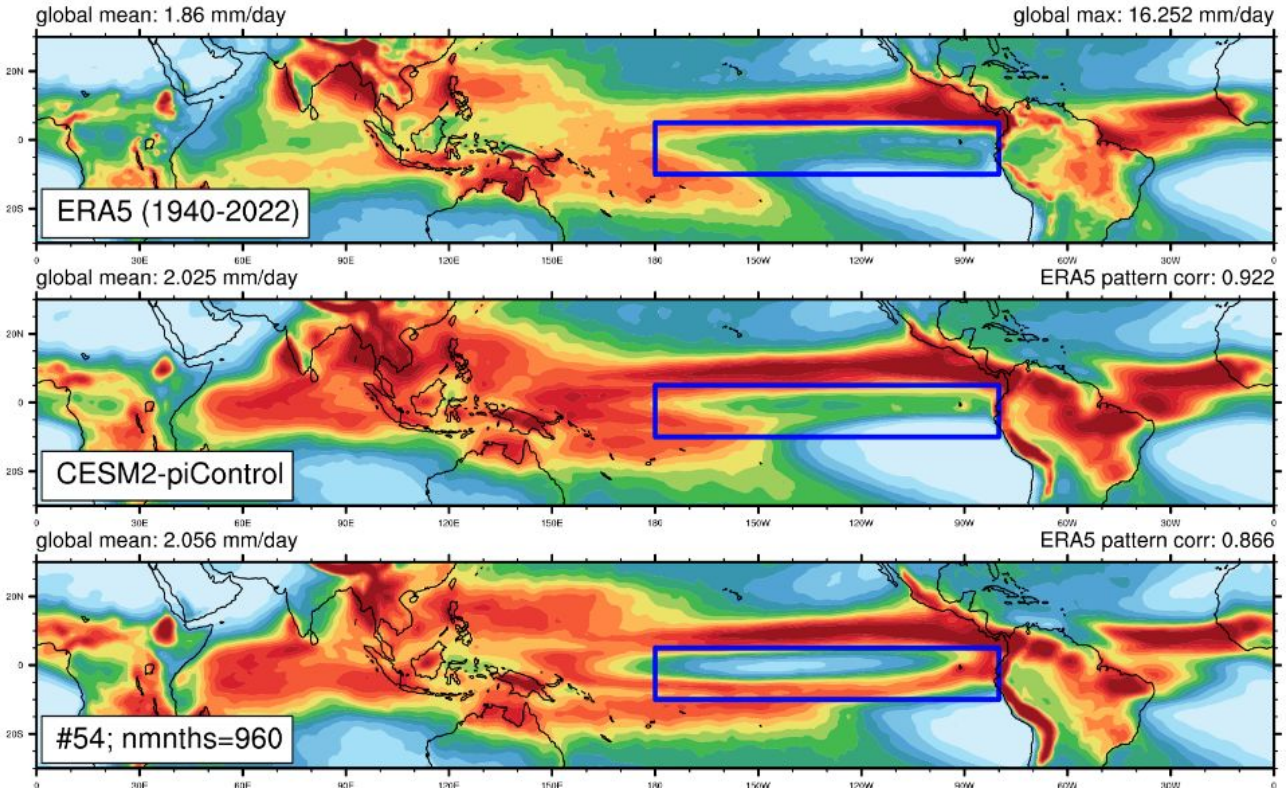
- The CCPP will always reside in a host model. For example, the host model is responsible for how tendencies from physics are added to the model state (conservation!!!).
- The dycore is not part of the CCPP!
- Once a parameterization is ported we pull it into cam_development (i.e. no duplication of physics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

See Jesse Nusbaumer's presentation from last AMWG winter meeting

Outline

- Where are we in the development cycle?
- What is new in CAM7?
- Main biases we are focusing on in coupled model development

Warm SST bias in MOM6 and Pacific precipitation



New vertical mixing scheme (called FPMIX) in MOM6 has shown promise in cooling the Pacific SST's and improving precipitation biases …

Figure courtesy of Adam Herrington

Coupled development model issues:

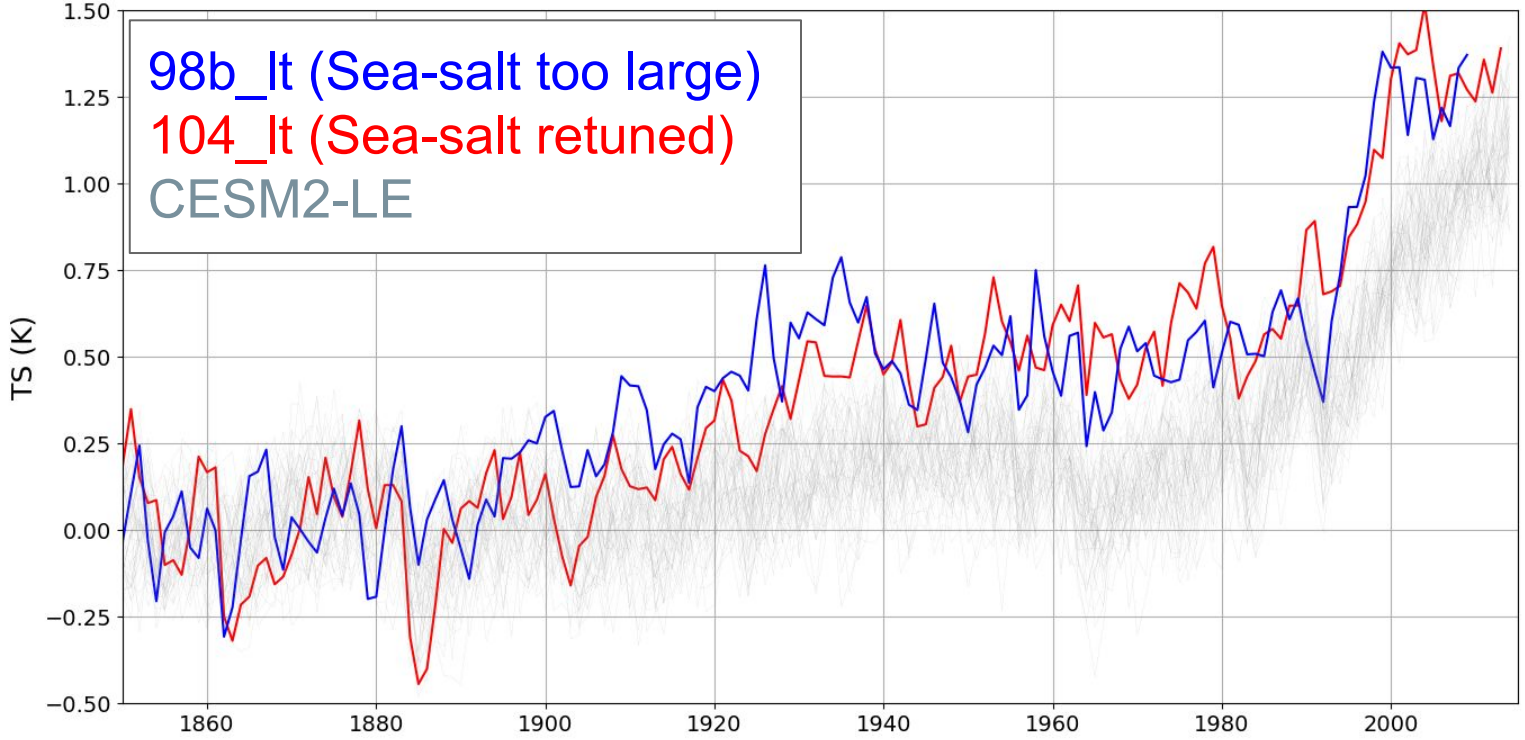
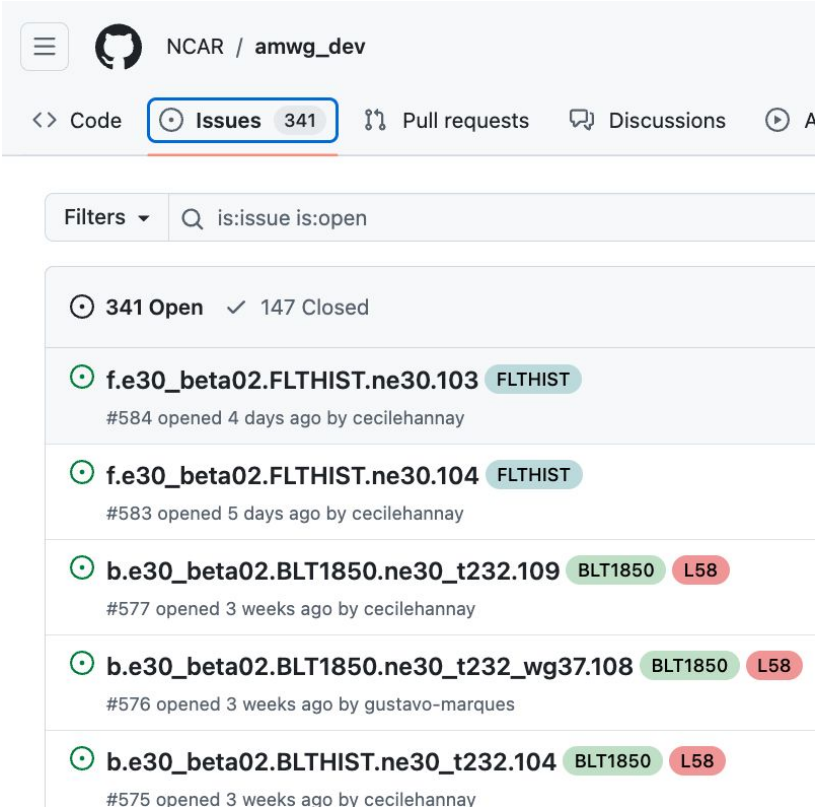
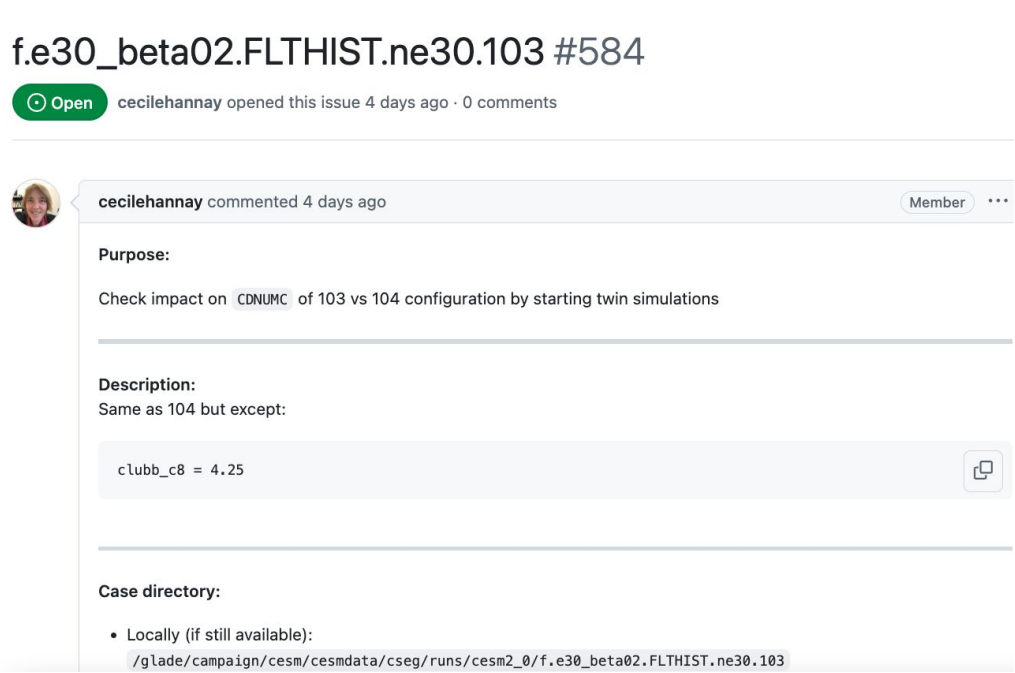


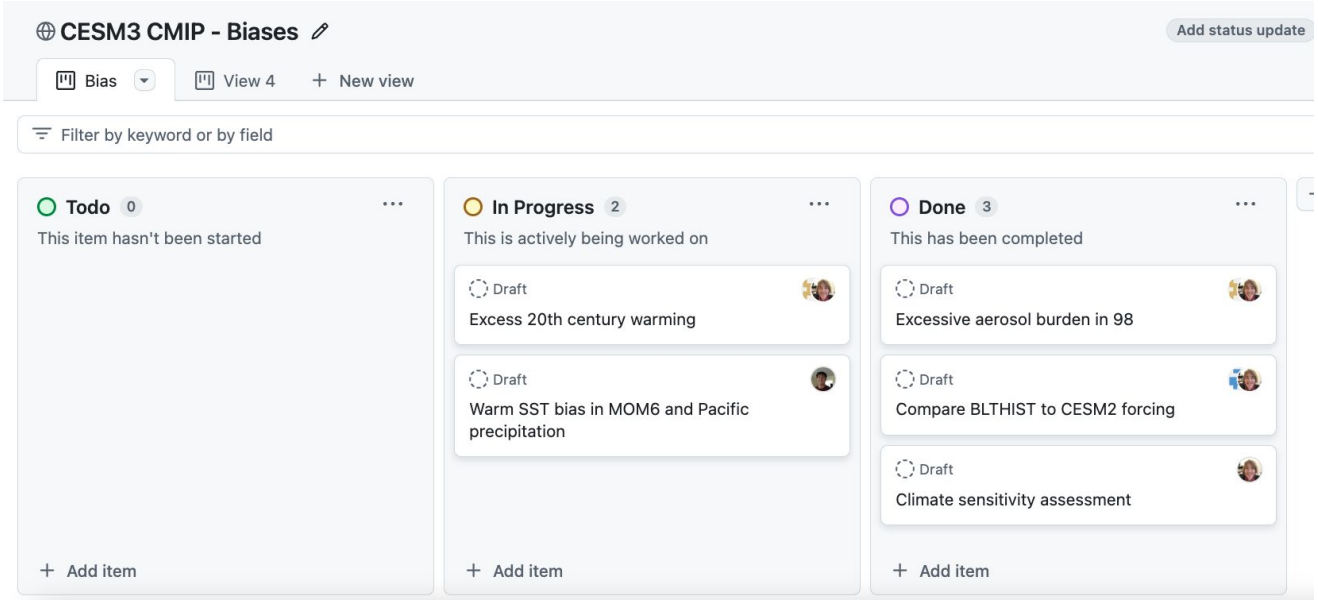
Figure courtesy of Cecile Hannay

Follow our development: https://github.com/NCAR/amwg_dev/





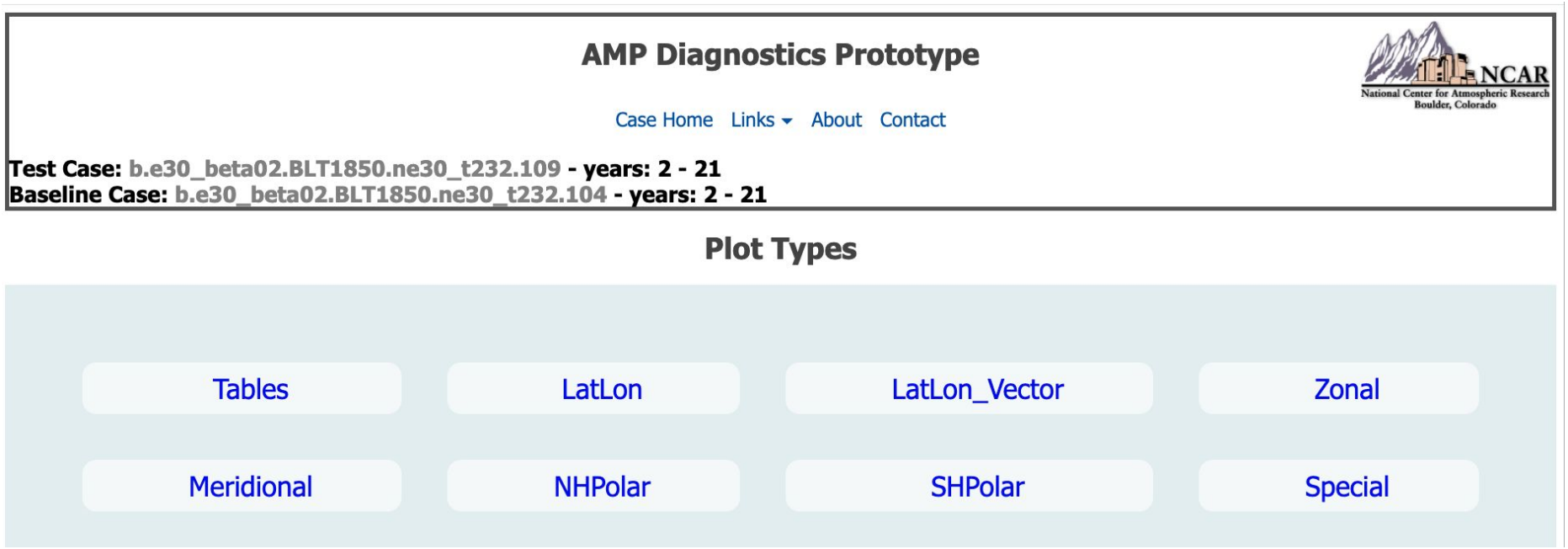
Follow our development: https://github.com/NCAR/cesm_dev



We just started this page where CESM3 development runs will be posted, including associated discussions about the simulations.

Also,
"Projects page" for an overview of what biases we are working on …

Python-based diagnostics package: https://github.com/NCAR/ADF



Python-based diagnostics package: https://github.com/NCAR/ADF

CAM Diagnostics

Case Home Plots Links About Contact

Test Case: b.e30_beta02.BMT1850.ne30_t232.104 **- years: 2 - 21**
Baseline Case: b.e30_beta02.BLT1850.ne30_t232.104 **- years: 2 - 21**

Special - QBO

TimeSeries Amplitude

Back to Special Back to Plot Types