Frequently used acronyms:

CESM = Community Earth System Model
CAM = Community Atmosphere Model

Center update for NCAR (CMIP centric)

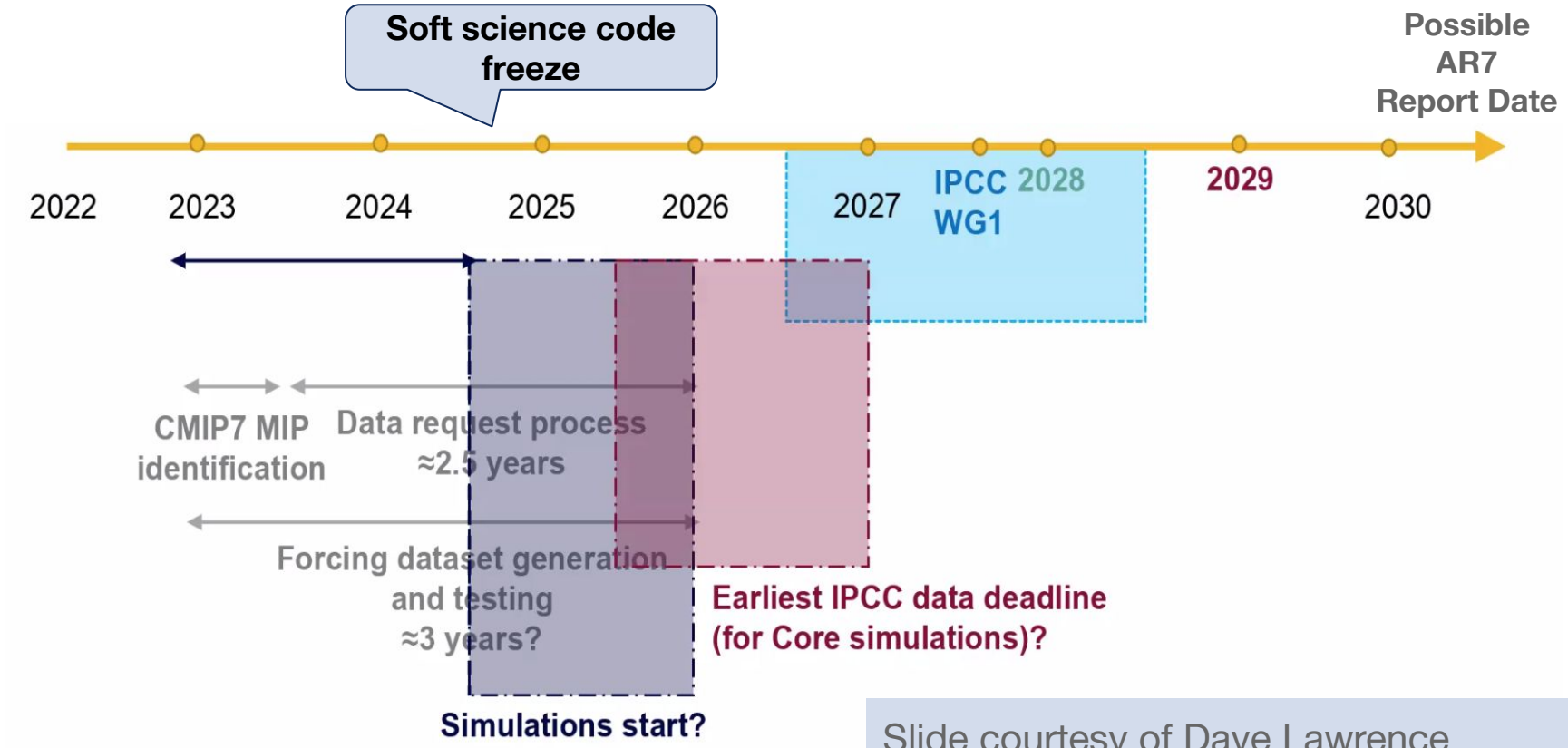
Peter Hjort Lauritzen
Climate and Global Dynamics Laboratory (CGD)
National Science Foundation (NSF) National Center for Atmospheric Research (NCAR), Boulder, Colorado

Working Group on Numerical Experimentation (WGNE) 39, November 4-8, 2024, Toulouse, France

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.

Overview

- What is new in CAM7 (CMIP7 version of atmosphere model)
- Things we are still working on
- Biases we are trying to address
- High resolution CAM7
- Machine learning



Slide courtesy of Dave Lawrence

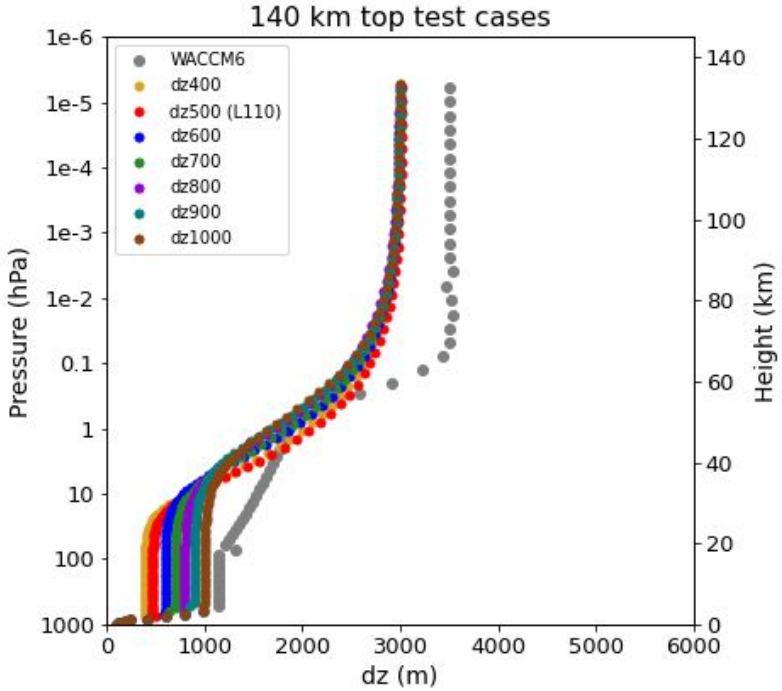
From CAM6 towards CAM7

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

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:

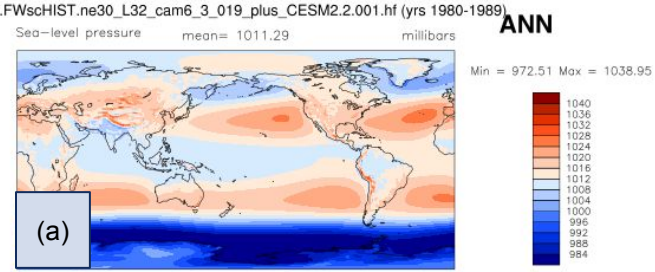
  The QBO still looks good and other things like stratospheric polar vortex variability or tropospheric circulation don't change noticeably

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

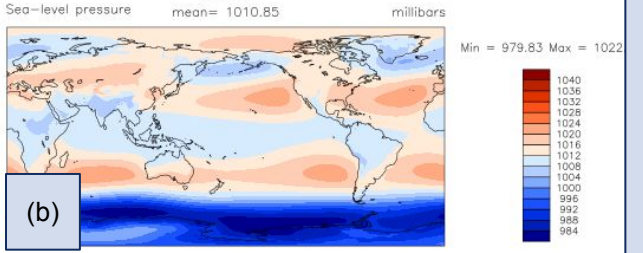
Slide courtesy of Isla Simpson

Increased boundary resolution decreases PSL biases

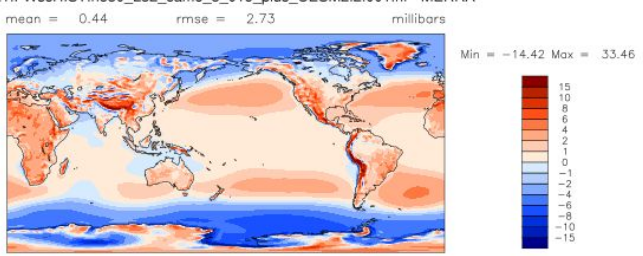
FLT with L32



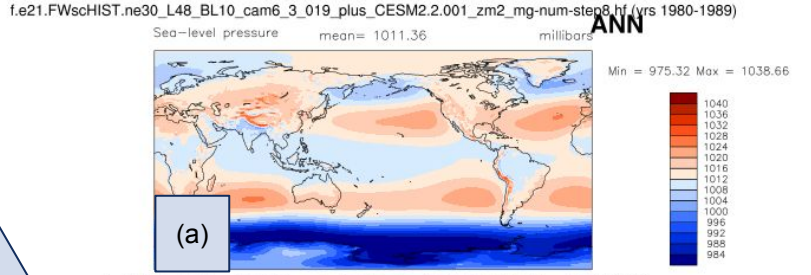
MERRA

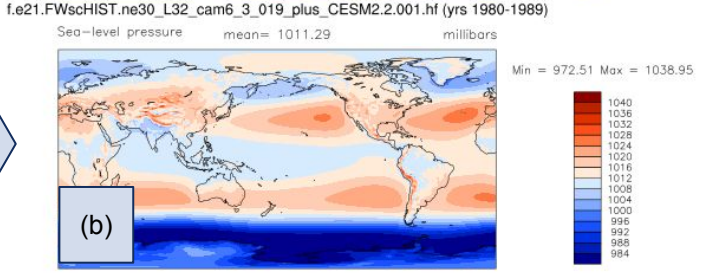


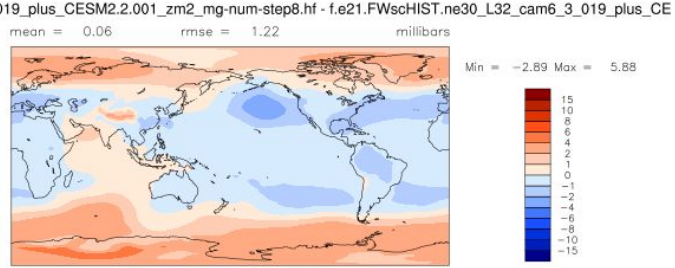
(a)-(b)



low ->higher boundary layer resolution







FLT (L58)

MERRA

(a)-(b)

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)

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)

MG -> PUMAS microphysics

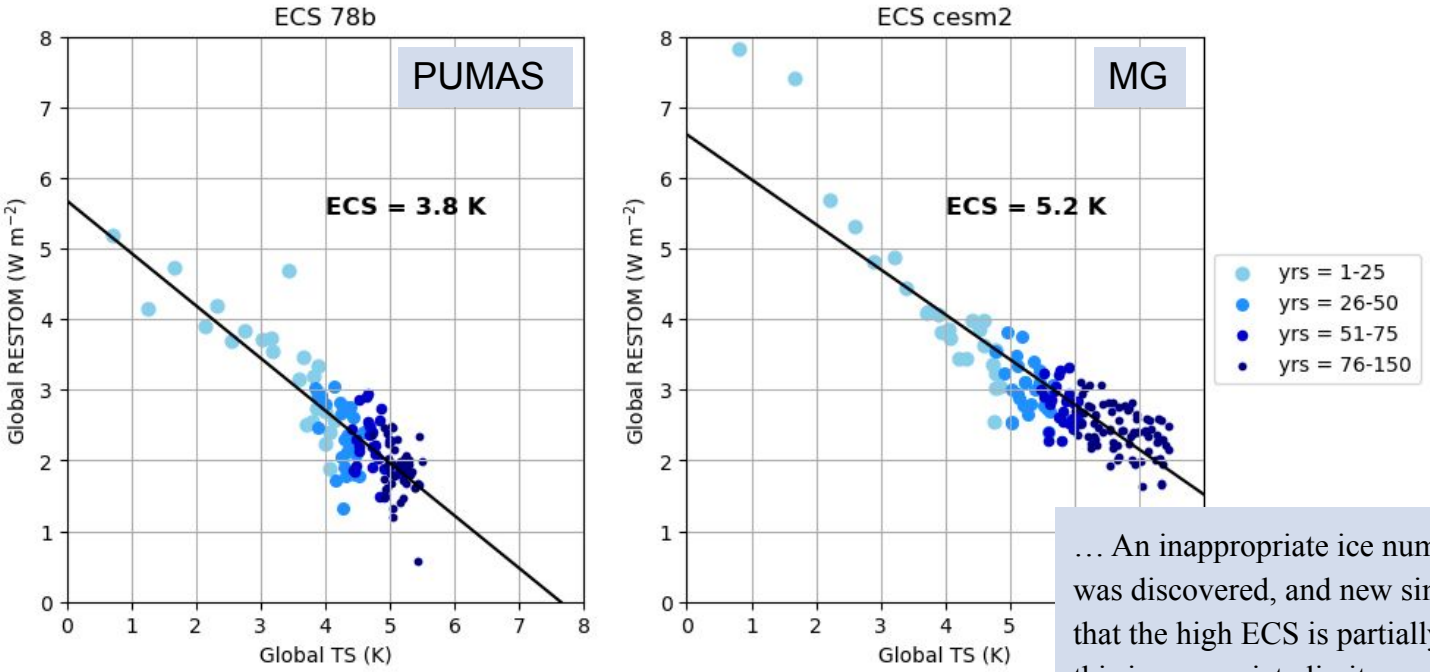
- PUMASv1 (Gettelman et al. 2023)
- New process rate - vapor deposition on snow (new limiter just added)
- Refactor ice limiter, reduce aerosol (dust and bc) seen by ice nucl.
- Numerical dt - impl. sedimentation, tighten autoconv/accr., fall speed corr.

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 …

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

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

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 source for gravity wave drag (“moving mountains”)

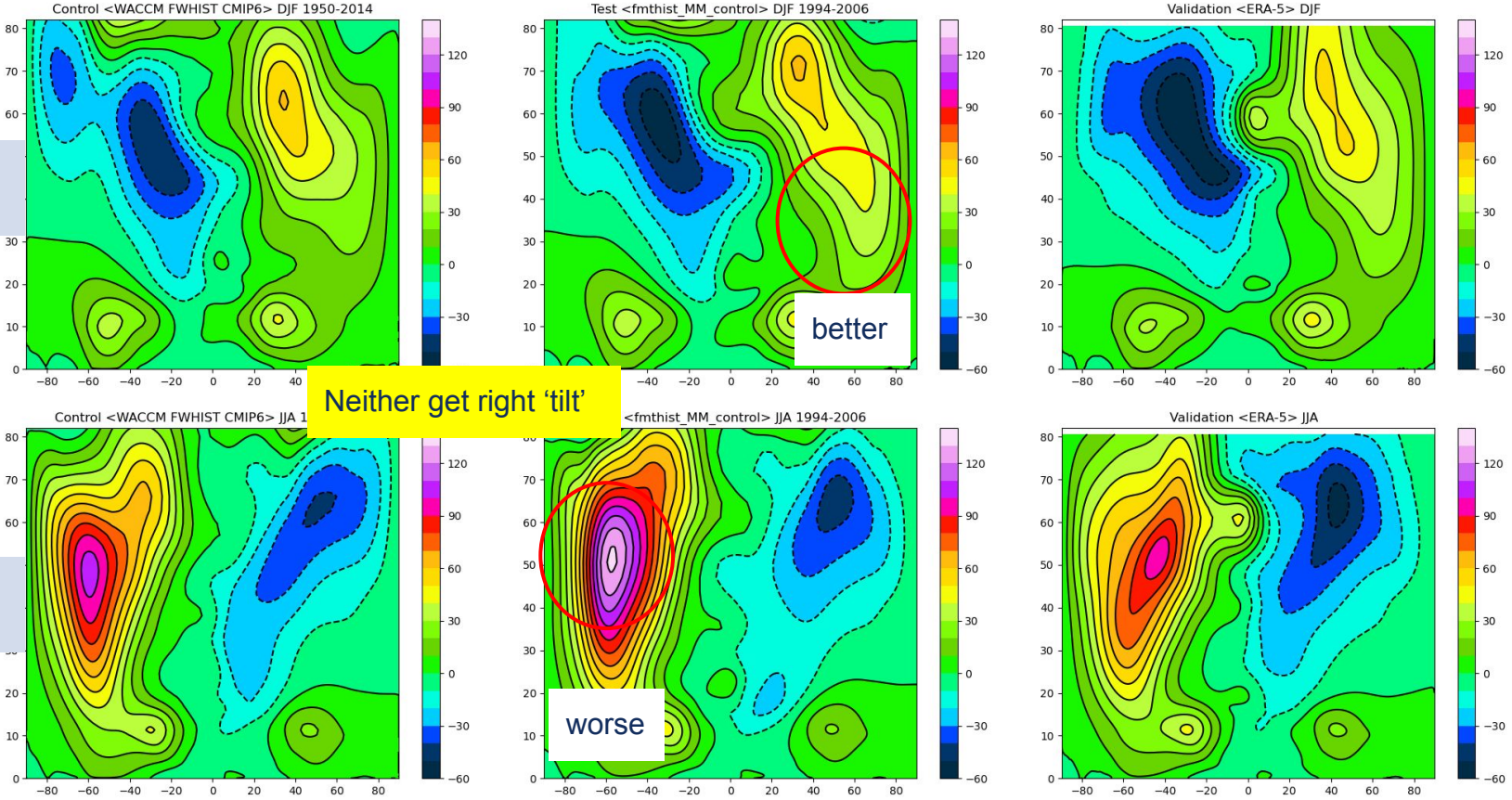
WACCM6 FWHIST L70

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

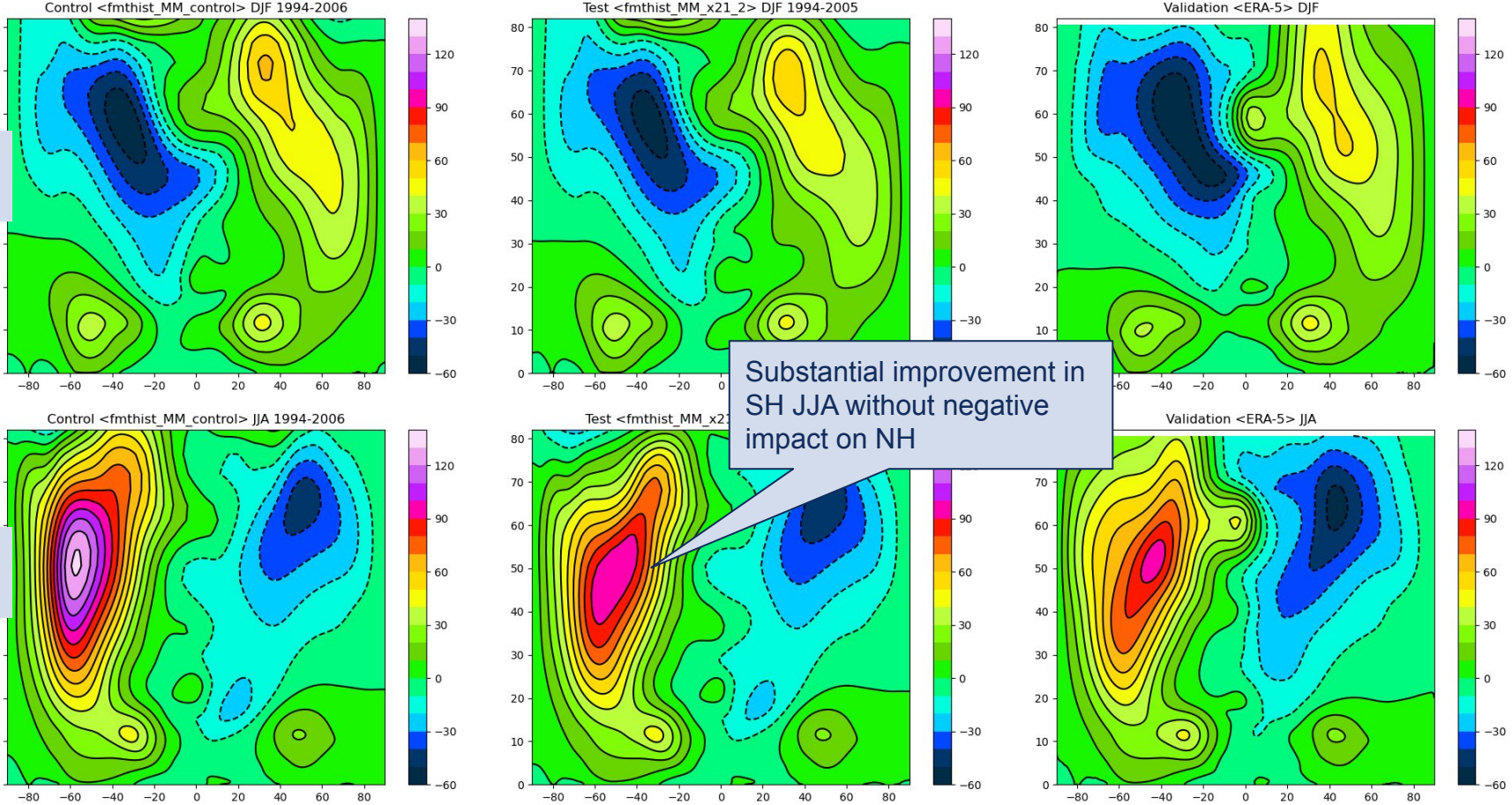
WACCM6 FWHIST L70

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

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 source of gravity wave drag (“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, …

8 Separate physics, transport and dynamics grid

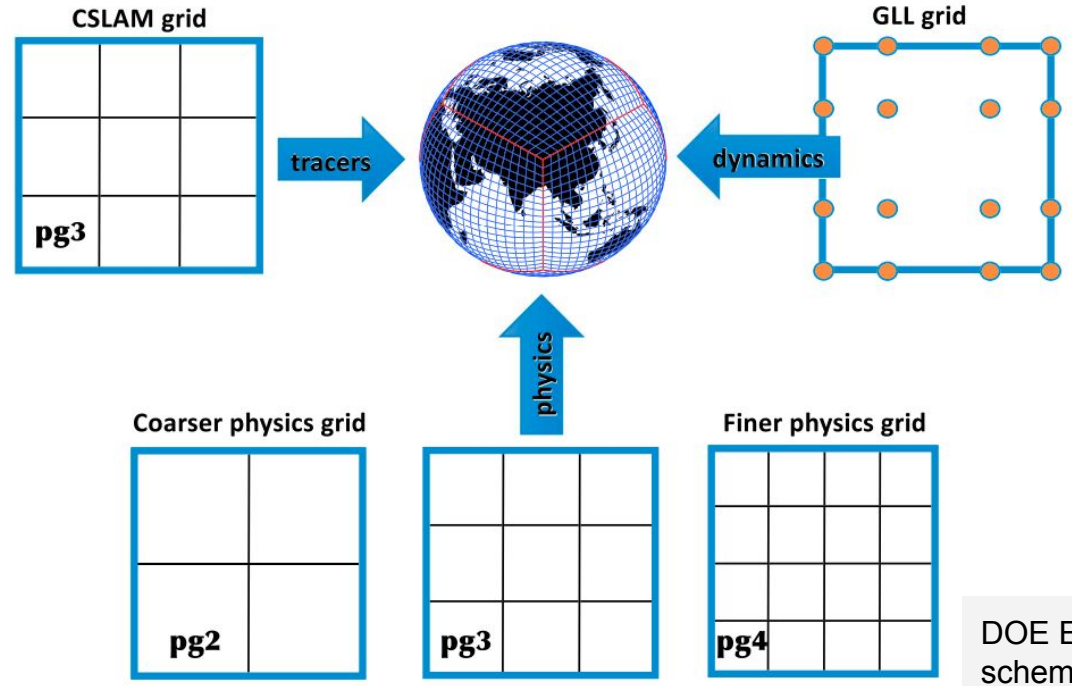


Figure 1. An overview of the different grids in CAM-SE-CSLAM.

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

9? Potential additional changes to CAM7

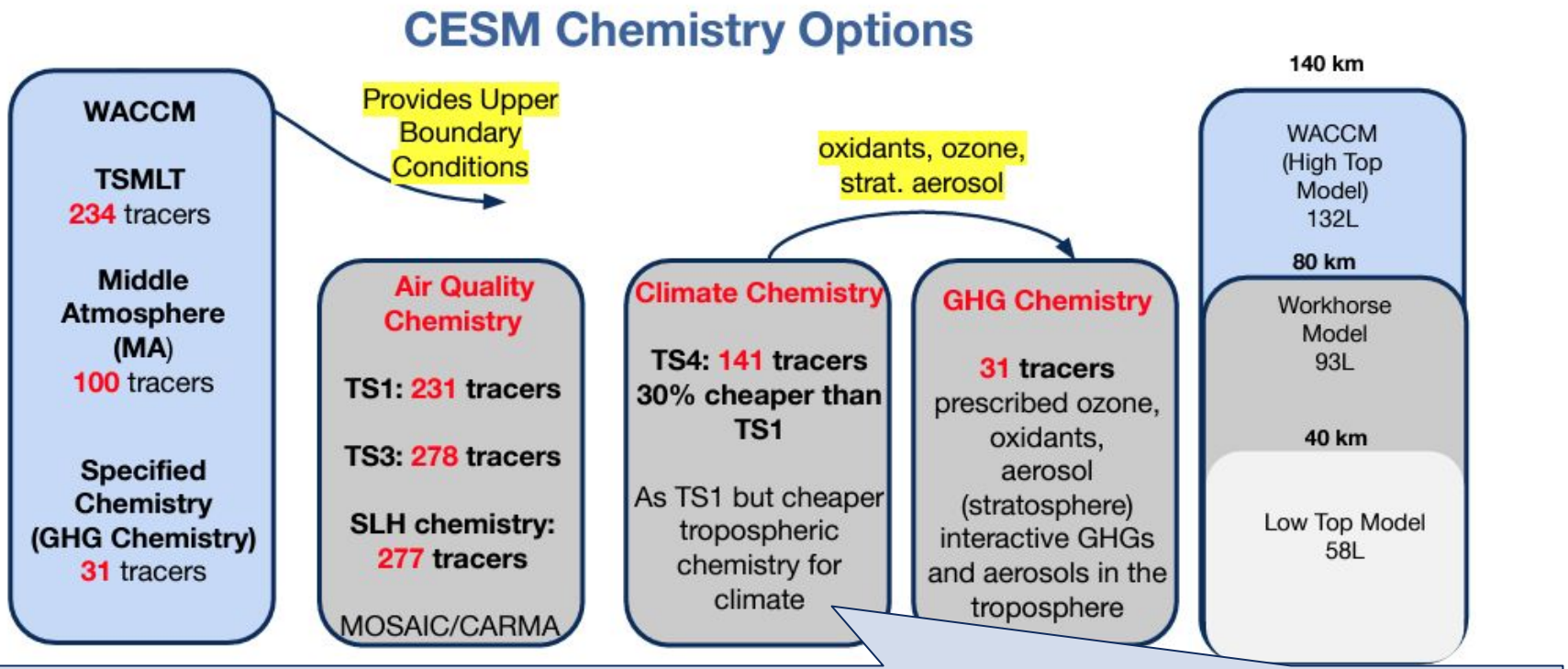
[note: after September 30 any new science in CAM7 will need SSC approval and will have to demonstrate significant bias reduction in CESM3 in order to commit to cam_development]

- 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)

From CAM6 towards CAM7: Chemistry

Default Aerosol Model: Modal Aerosol Model (MAM5)



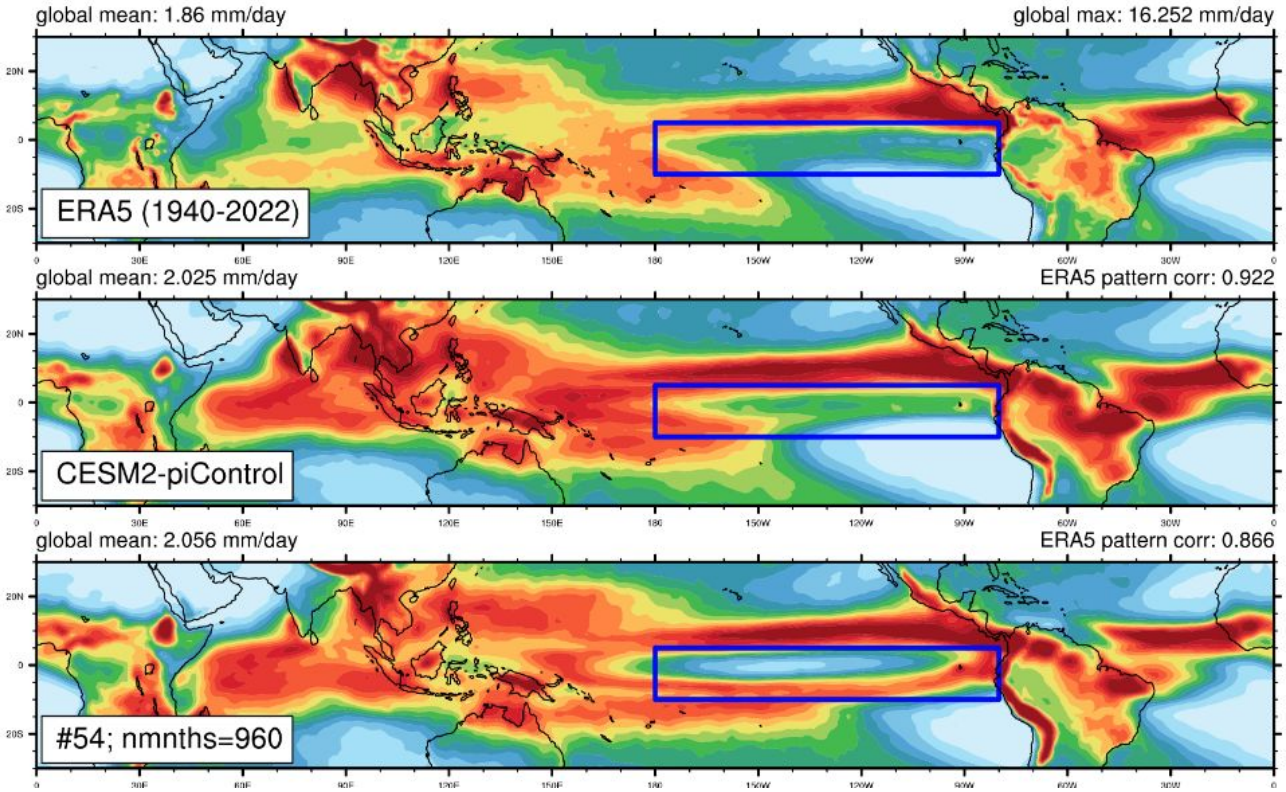
See this presentation by Louisa Emmons for details:
https://www.cesm.ucar.edu/sites/default/files/2024-03/2024-cesm-amwg-lemmons.pdf

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

Overview

- What is new in CAM7 (CMIP7 version of atmosphere model)
- Things we are still working on
- Biases we are trying to address 
- High resolution CAM7
- Machine learning

Warm SST bias in MOM6 and Pacific precipitation



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

Figure courtesy of Adam Herrington

Coupled development model issues:

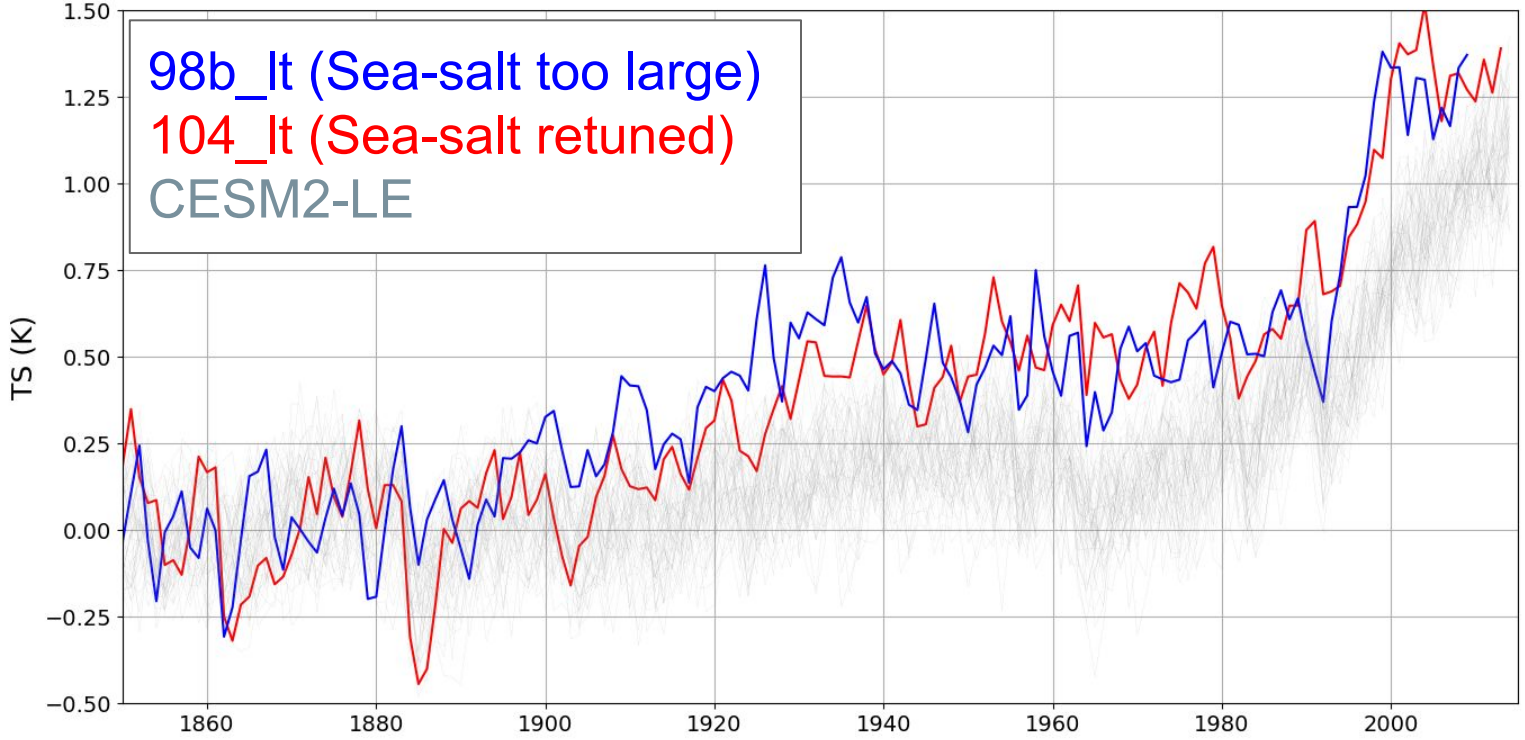


Figure courtesy of Cecile Hannay

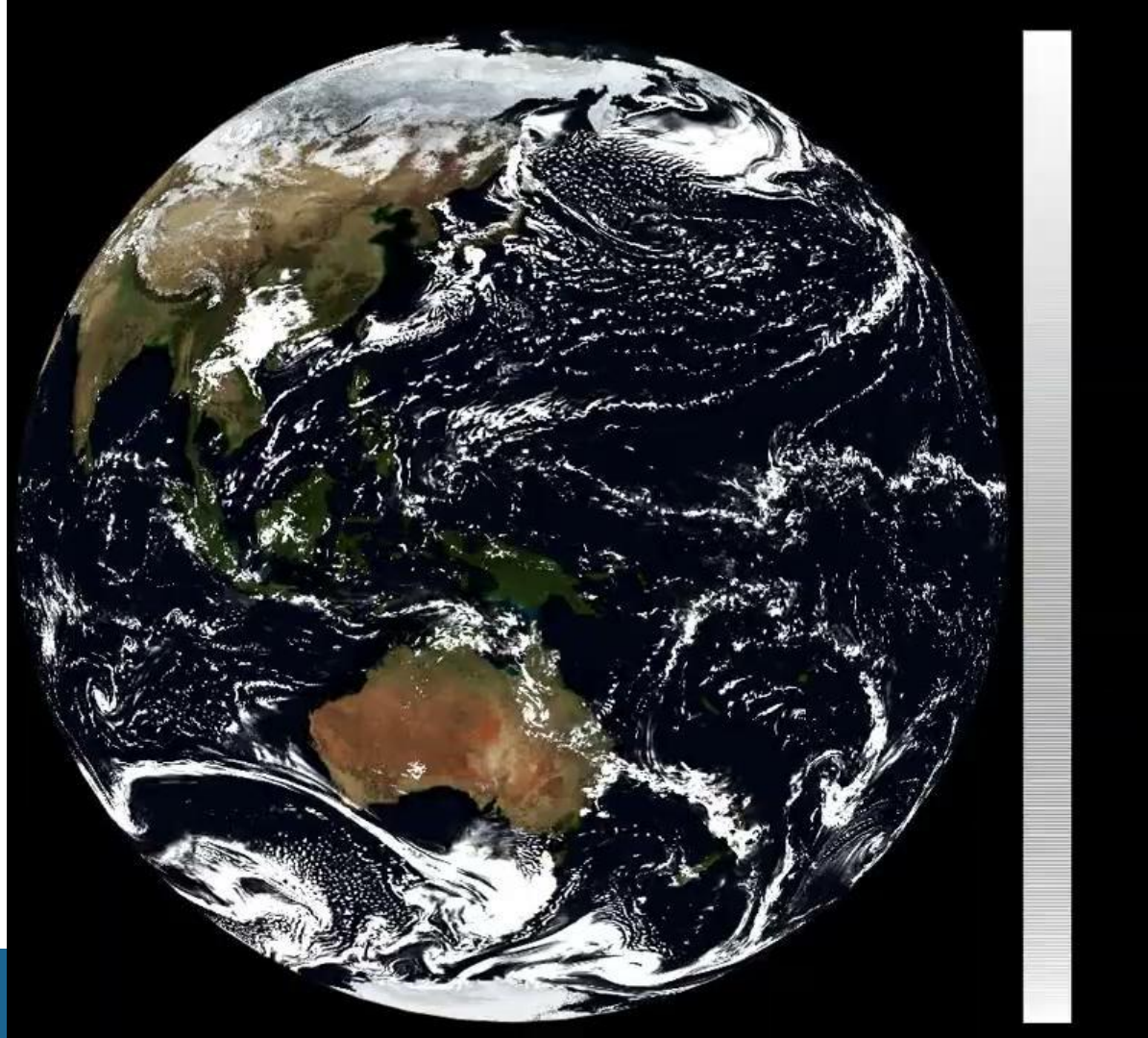
Overview

- What is new in CAM7 (CMIP7 version of atmosphere model)
- Things we are still working on
- Biases we are trying to address
- High resolution CAM7

- Machine learning

High res CAM-MPAS

7.5km FLTHIST run

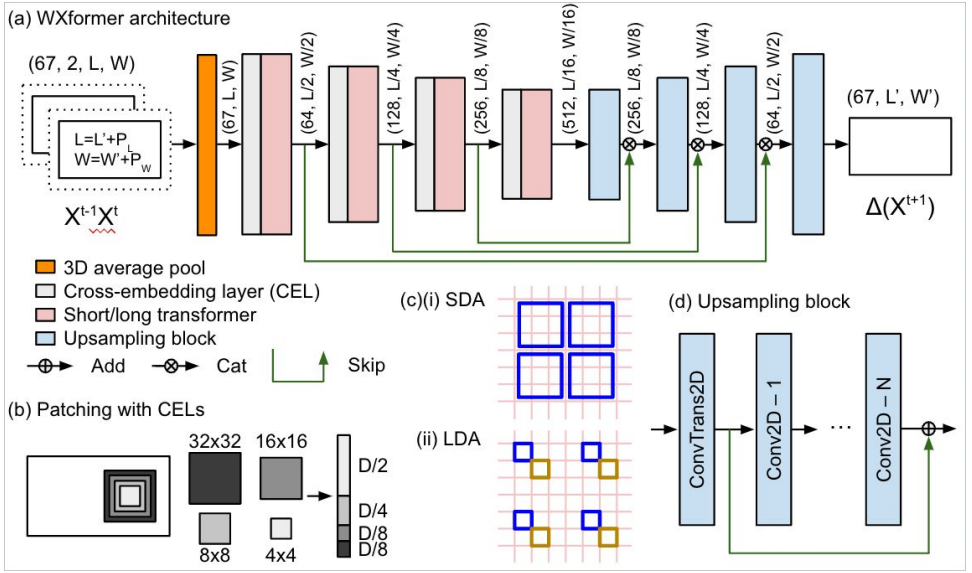


Overview

- What is new in CAM7 (CMIP7 version of atmosphere model)
- Things we are still working on
- Biases we are trying to address
- High resolution CAM7
- Machine learning

NSF NCAR Community Research Earth Digital Intelligence Twin (CREDIT)

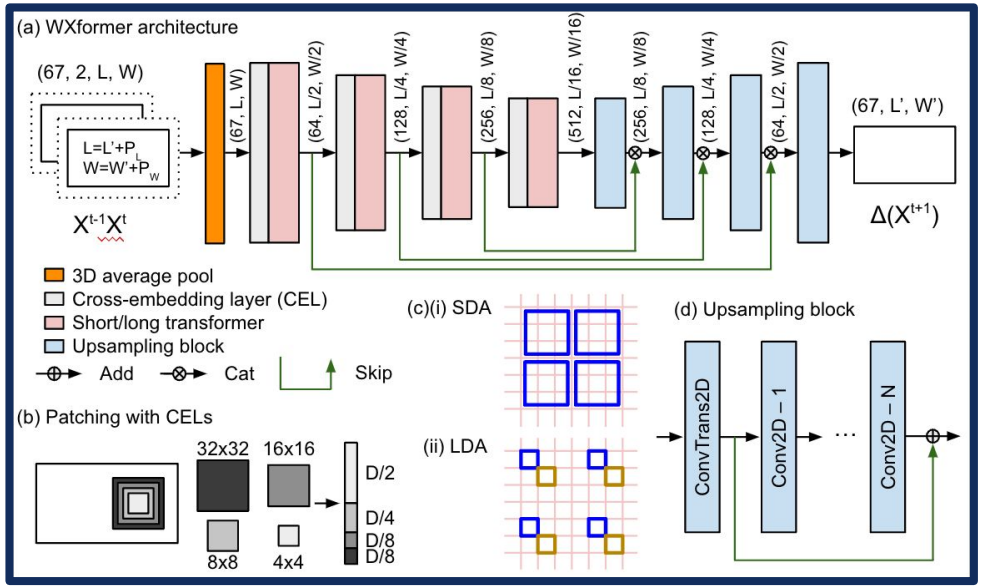
- Research platform for understanding of best practices for training and operating global and regional AI weather prediction models
- Why develop and support an AI NWP platform at NSF NCAR?
  - NSF NCAR and community experts lead model development and evaluation
  - Tailor platform to NSF NCAR priorities, computing, and datasets
  - Chance to produce unique advances rather than always playing catch-up
- How to support CREDIT with limited internal staff capacity?
  - Clear limits on level of user support
  - Staged beta releases with trusted users
  - Utilize NCAR and open source tools
  - Focus on NCAR's research strengths



Global model at 0.28’ resolution. Use machine learning to predict next state [1 hour or 6 hour] of the global atmosphere.

ERA5 Reanalysis [t_0]

Inputs y_t



ERA5 Reanalysis [t_1]

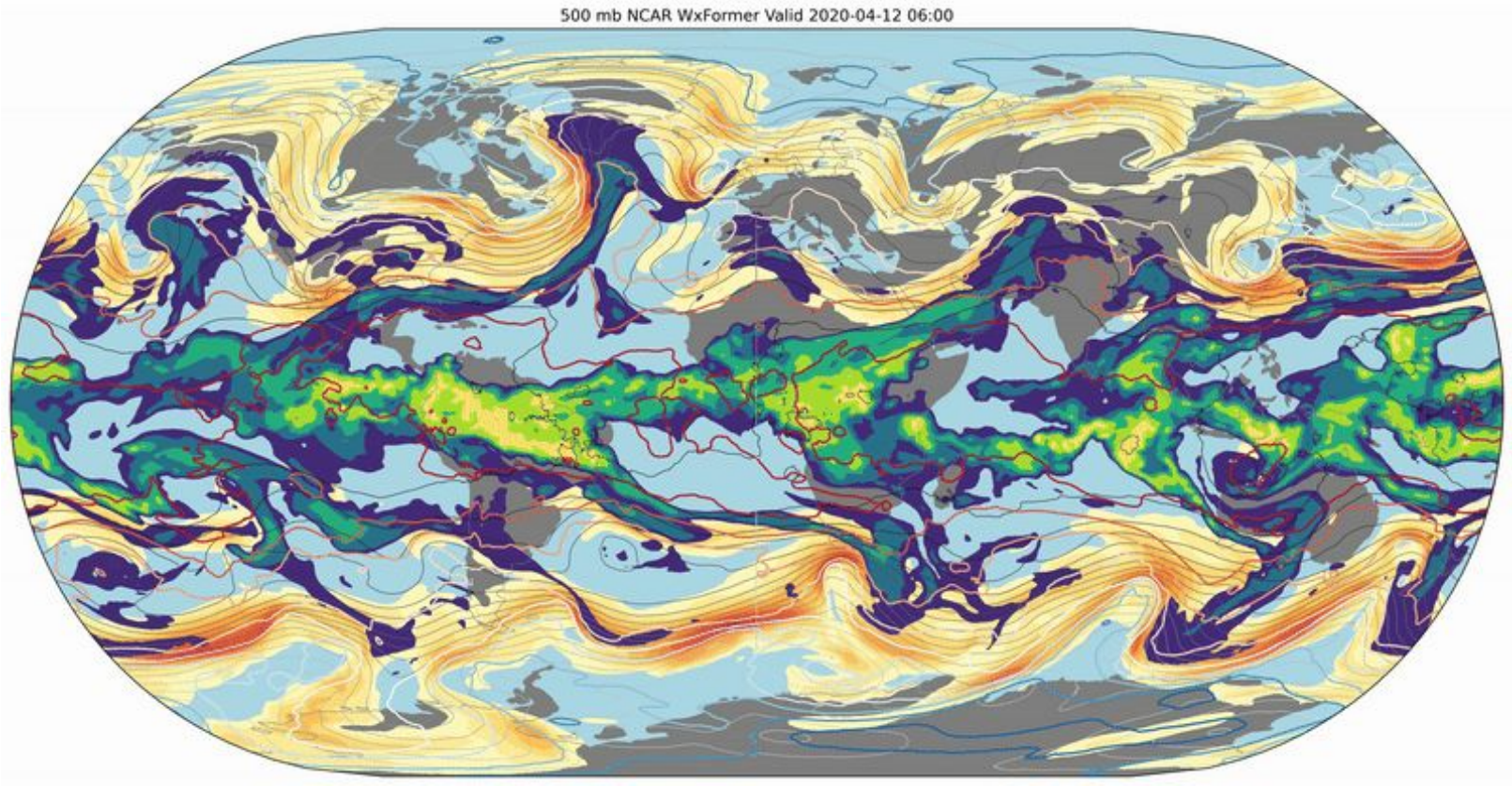
Outputs

WxFormer: NCARs *Machine Learning* Atmosphere EMULATOR

ERA5 Reanalysis

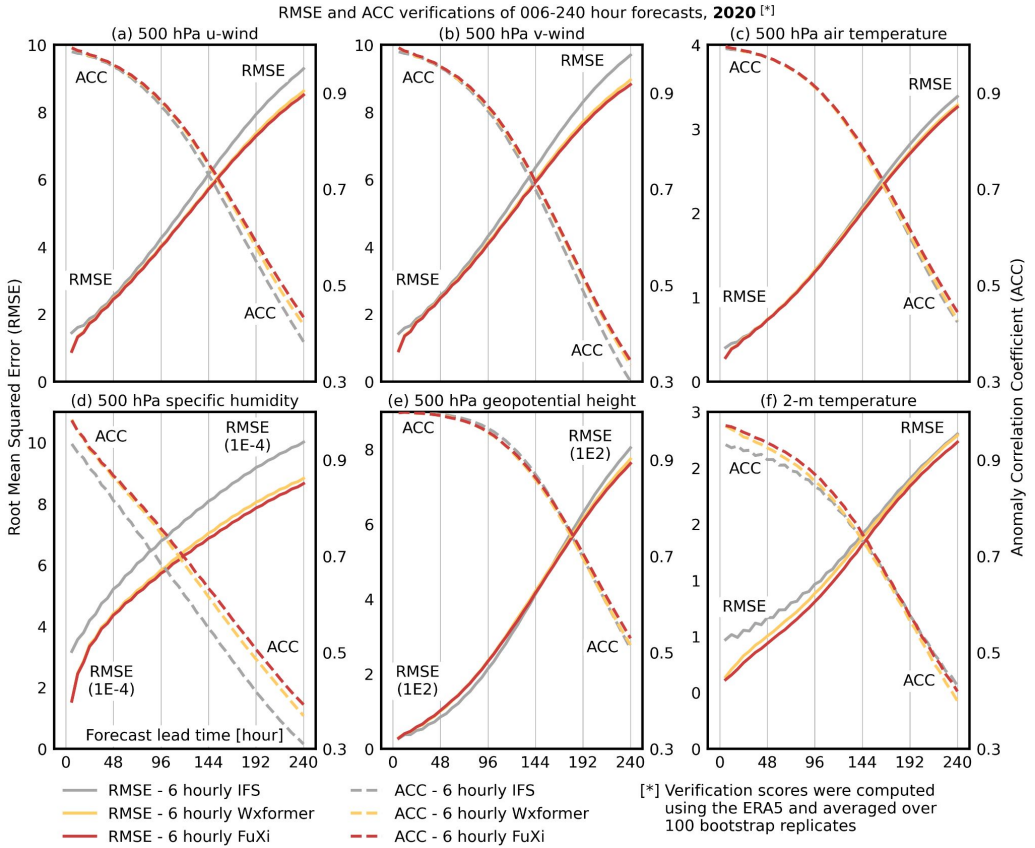
1979-2013: **Training**
2014-2017: **Validation** (select the best model)
2018-2021: **Testing** (the true holdout)

Five atmospheric state variables: U, V, T, Q at 15 levels
Surface Variables: PS, T2m
Forcing: TOA Short Wave Radiation, Topography, Land-Sea Mask
Diagnostic Variables: V500, U500, T500, Z500, Q500


500 mb NCAR WxFormer Valid 2020-04-12 06:00

Root Mean Squared Error (RMSE) and Anomaly Correlation Coefficient (ACC) out to 10 days for year 2020.

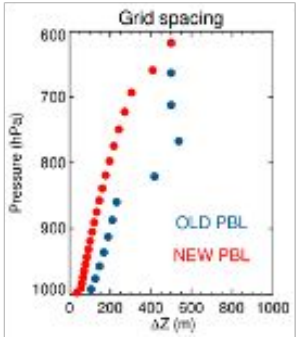
Gray: ECMWF IFS HRES
Yellow: NCAR WxFormer
Red: Fudan Fuxi



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

Convective gustiness parameterization

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

Indian Ocean biases have largely improved

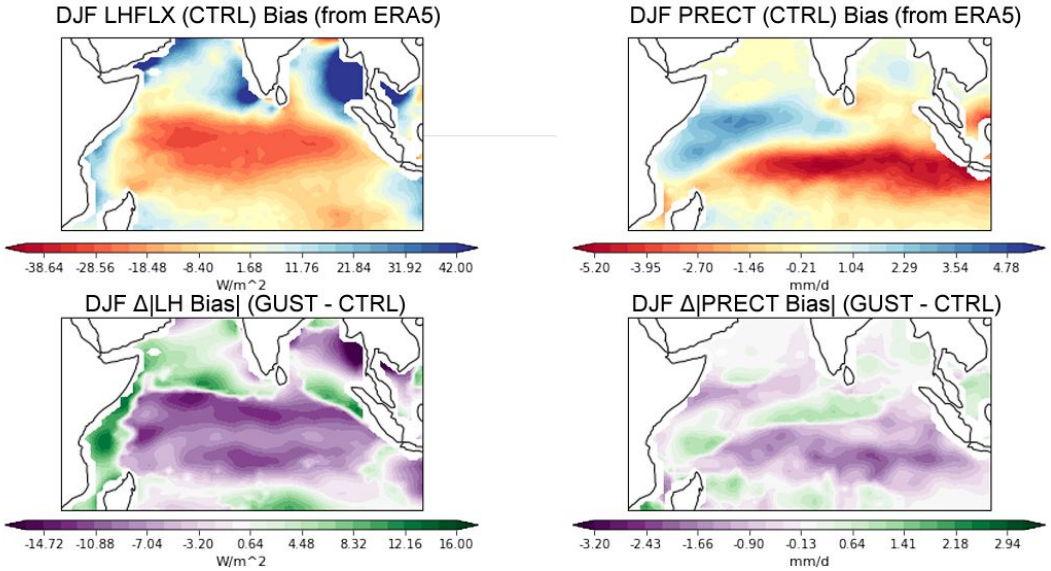
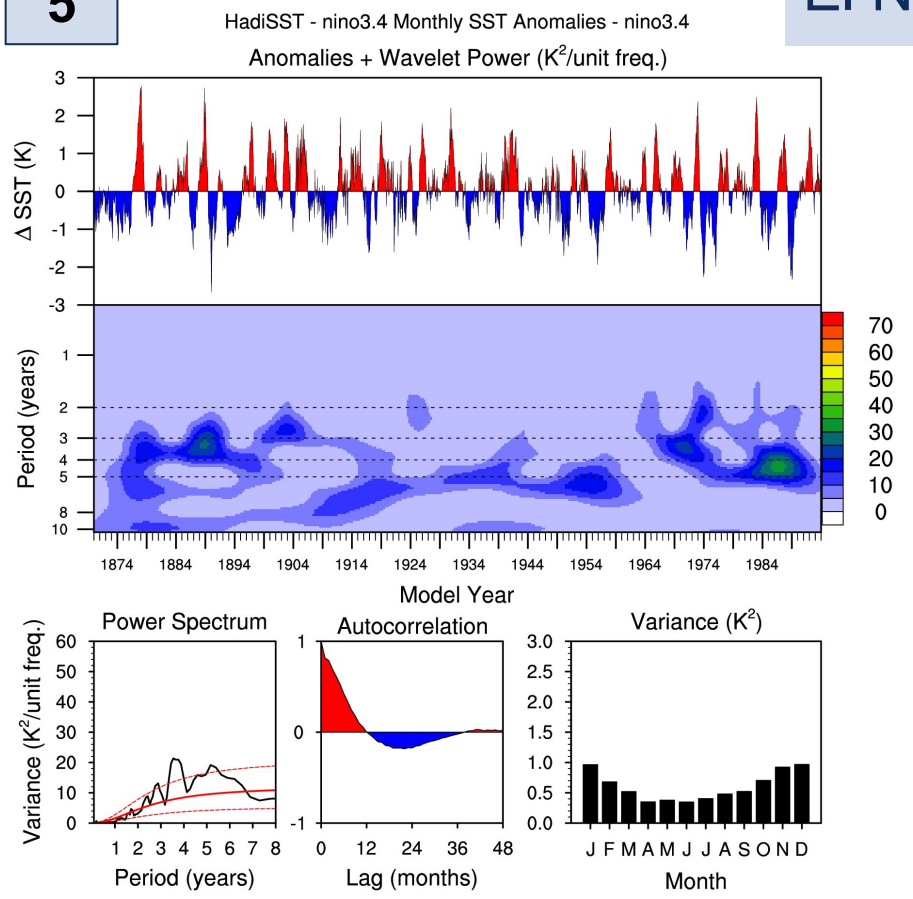


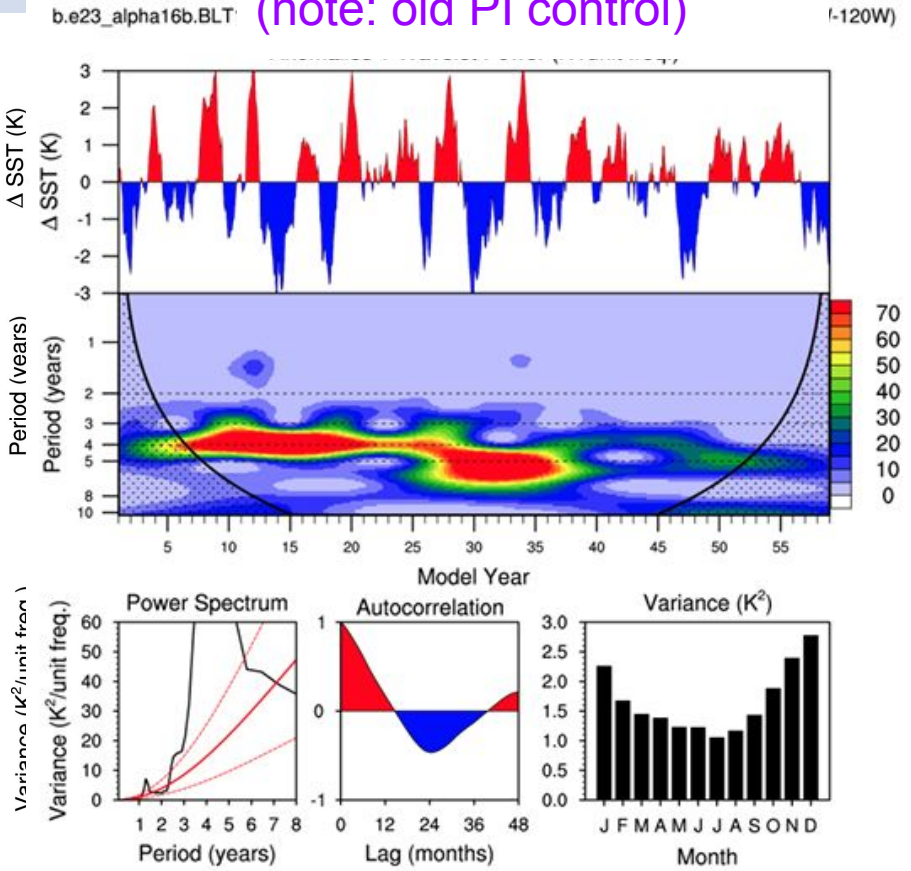
Figure courtesy of Meg Fowler

El Nino

HadiSST (Obs.)

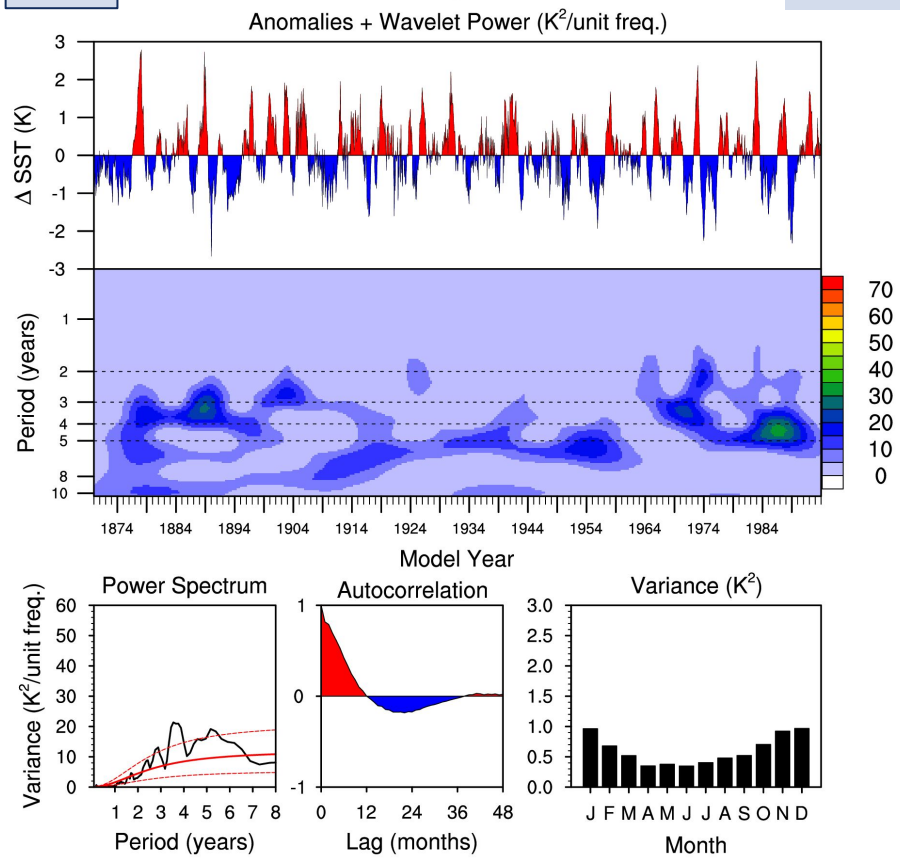


BLTHIST no gustiness (note: old PI control)



El Nino

HadiSST (Obs.)



BLTHIST (with gustiness and other other changes)