Current Status of CESM3 development simulations

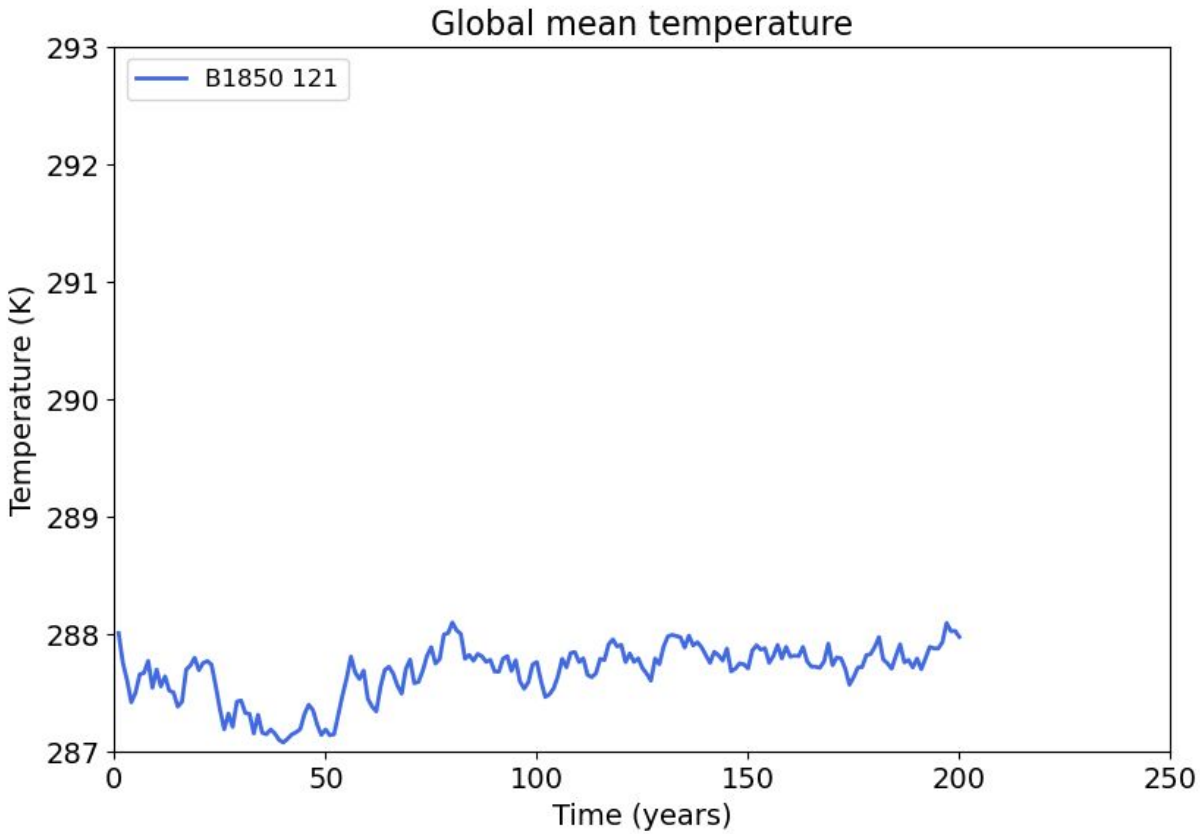
Isla Simpson, with contributions from many others

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.

Simulations

CESM3 development simulations (121 series):

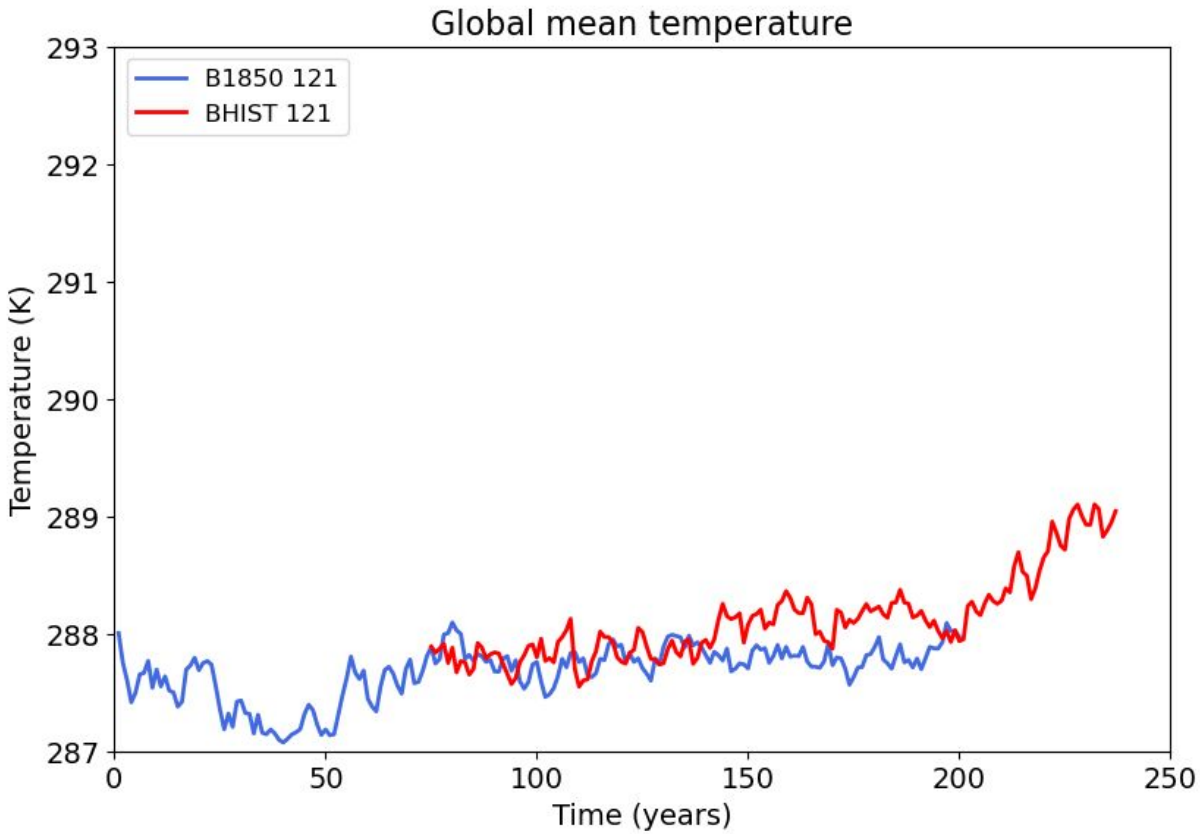
- piControl, 200 years (B1850 121)



Simulations

CESM3 development simulations (121 series):

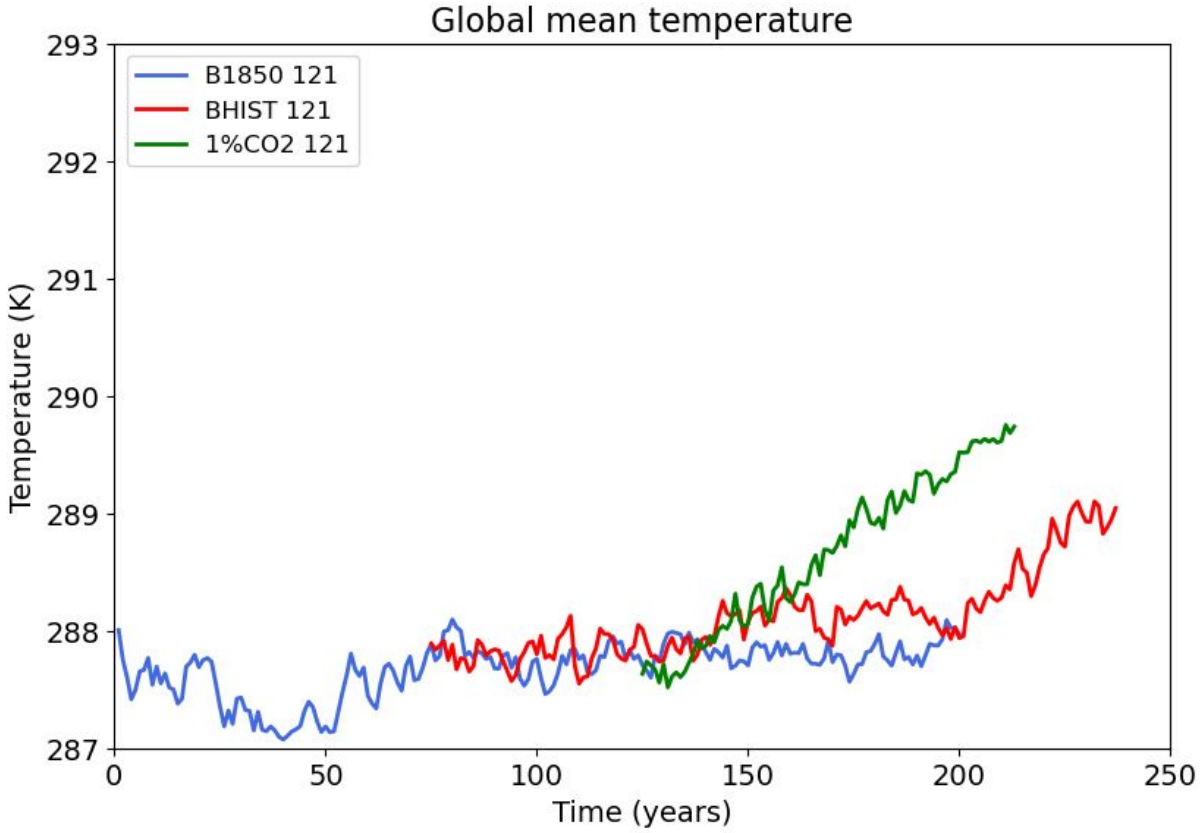
- piControl, 200 years (B1850 121)
- Historical, started from year 75 of piControl (BHIST 121)



Simulations

CESM3 development simulations (121 series):

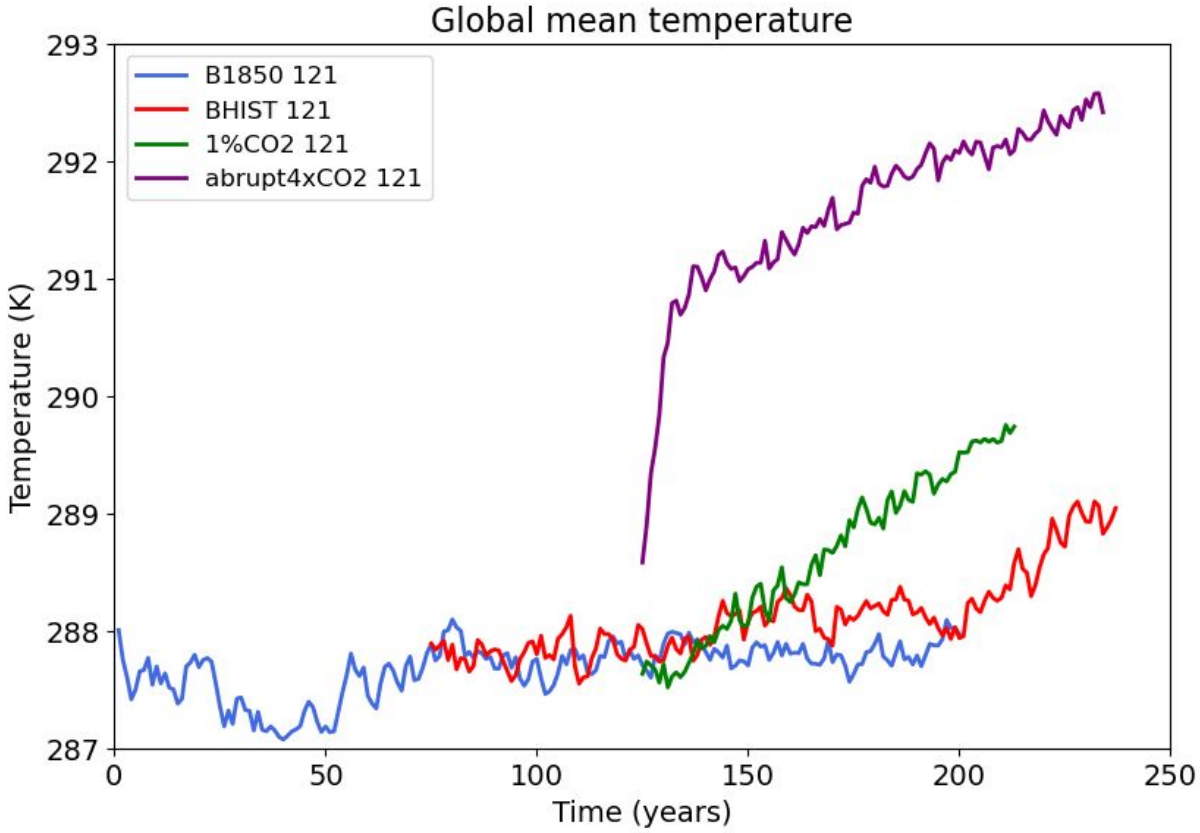
- piControl, 200 years (B1850 121)
- Historical, started from year 75 of piControl (BHIST 121)
- 1%CO2, started from year 125 of piControl (1%CO2 121)



Simulations

CESM3 development simulations (121 series):

- piControl, 200 years (B1850 121)
- Historical, started from year 75 of piControl (BHIST 121)
- 1%CO2, started from year 125 of piControl (1%CO2 121)
- abrupt4xCO2, started from year 125 of piControl (abrupt4xCO2 121)

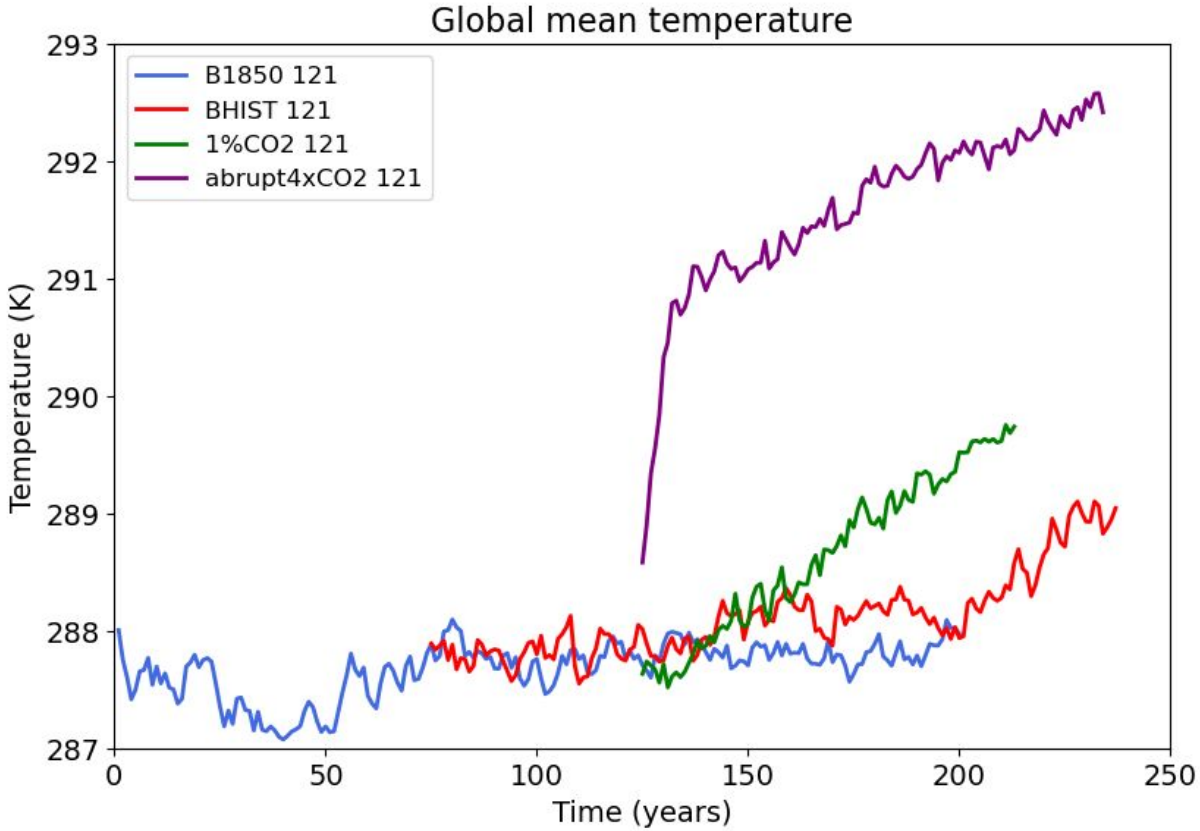


Simulations

CESM3 development simulations (121 series):

- piControl, 200 years (B1850 121)
- Historical, started from year 75 of piControl (BHIST 121)
- 1%CO2, started from year 125 of piControl (1%CO2 121)
- abrupt4xCO2, started from year 125 of piControl (abrupt4xCO2 121)

This does not reflect the final state of CESM3. Rather this is reflecting the current state of the CESM3 development simulations.



Simulations

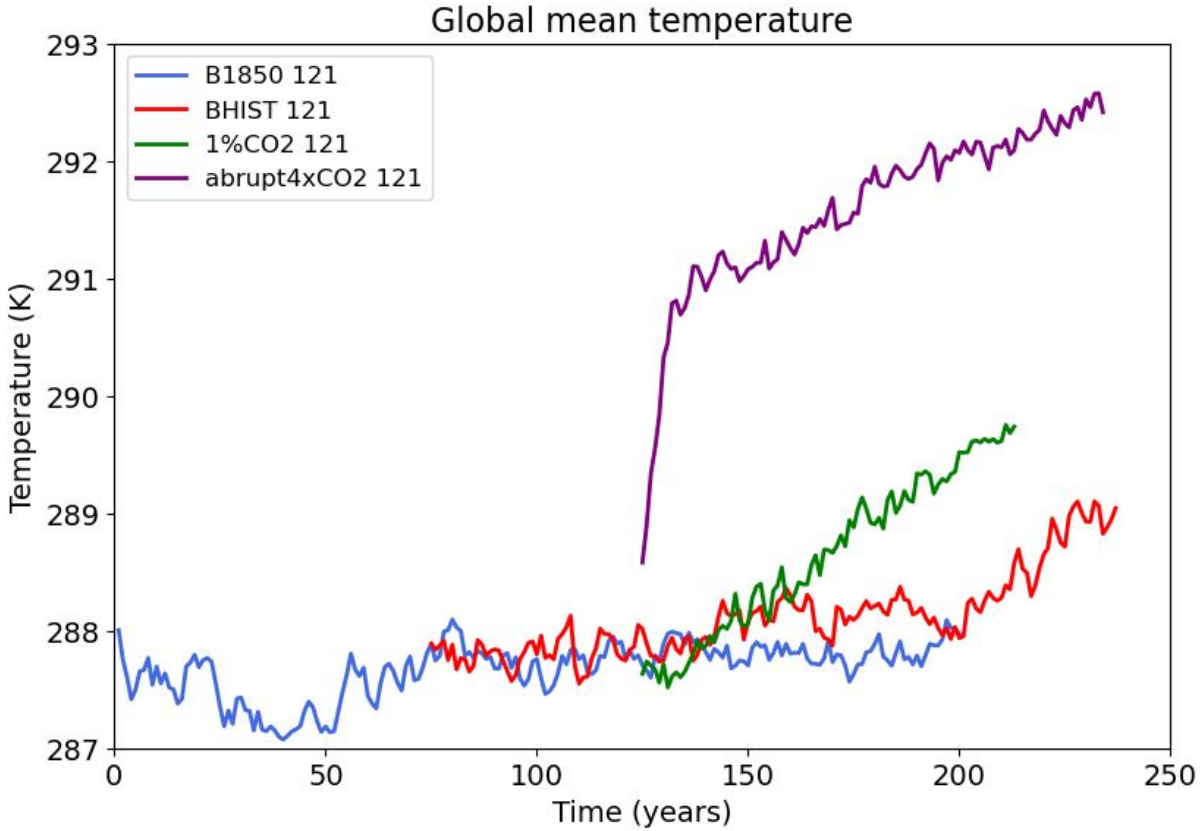
CESM3 development simulations (121 series):

- piControl, 200 years (B1850 121)
- Historical, started from year 75 of piControl (BHIST 121)
- 1%CO2, started from year 125 of piControl (1%CO2 121)
- abrupt4xCO2, started from year 125 of piControl (abrupt4xCO2 121)

This does not reflect the final state of CESM3. Rather this is reflecting the current state of the CESM3 development simulations.

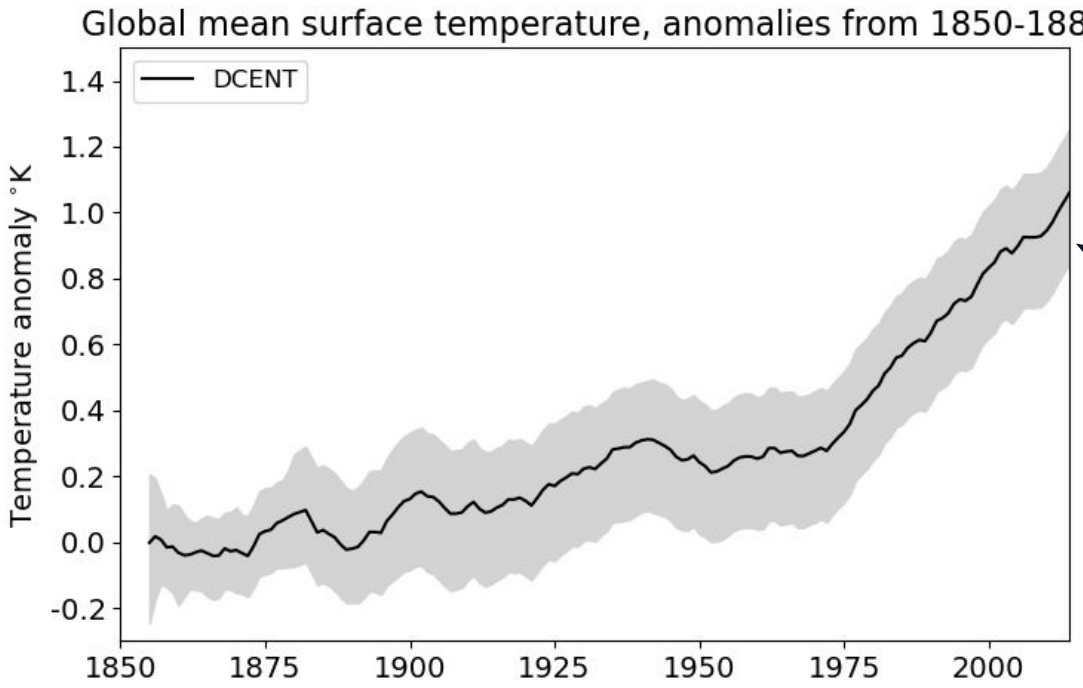
Compare with:

- CESM2 large ensemble, 50 members (LENS2)
- CMIP6 models
- Observation-based data



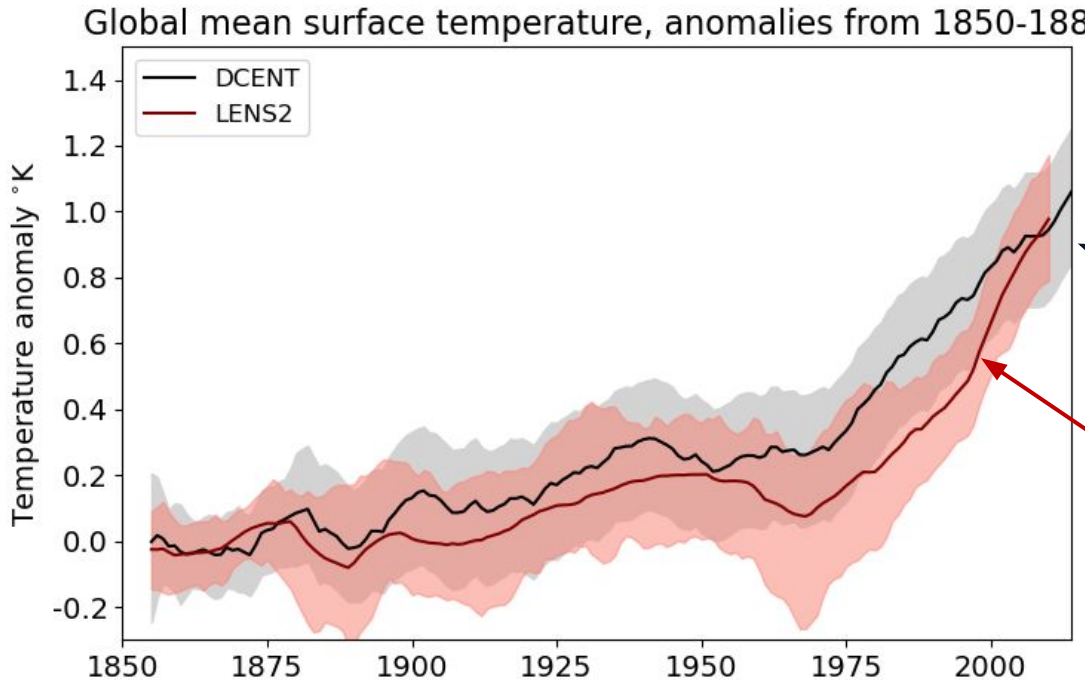
Global mean surface temperature evolution

10 year running mean global mean surface temperature



The DCENT observation-based surface temperature
200 member ensemble
(Chan et al. 2024)

10 year running mean global mean surface temperature

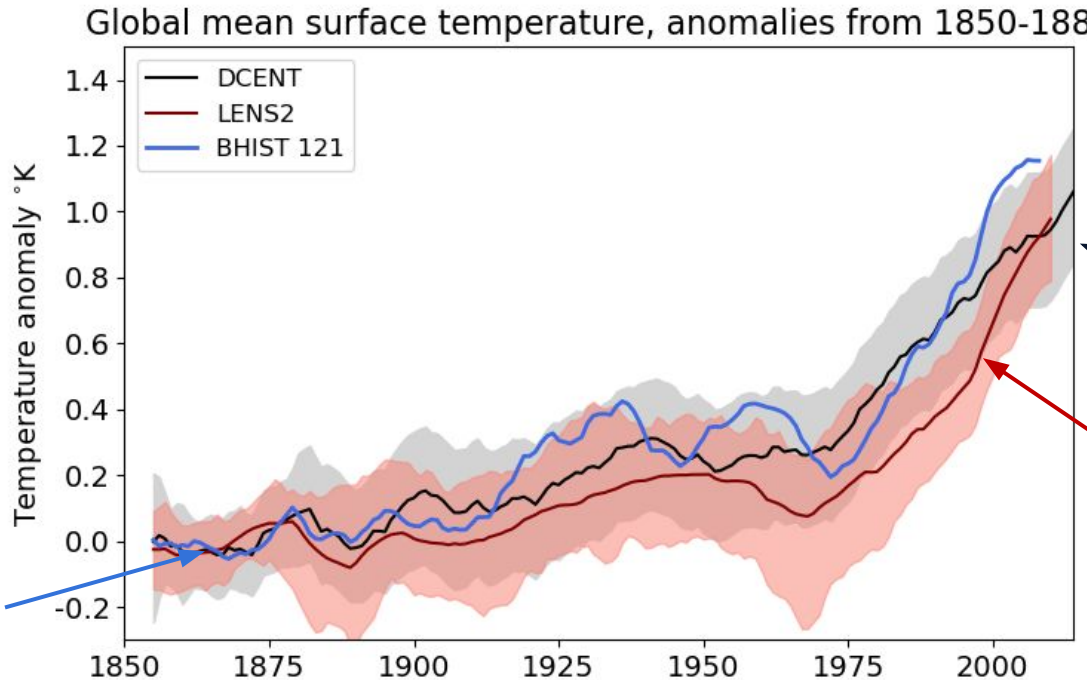


The DCENT observation-based SST 200 member ensemble (Chan et al. 2024)

CESM2 large ensemble (first 50 members) i.e., not smoothed biomass burning

(TREFHT over land, TS over ocean)

10 year running mean global mean surface temperature



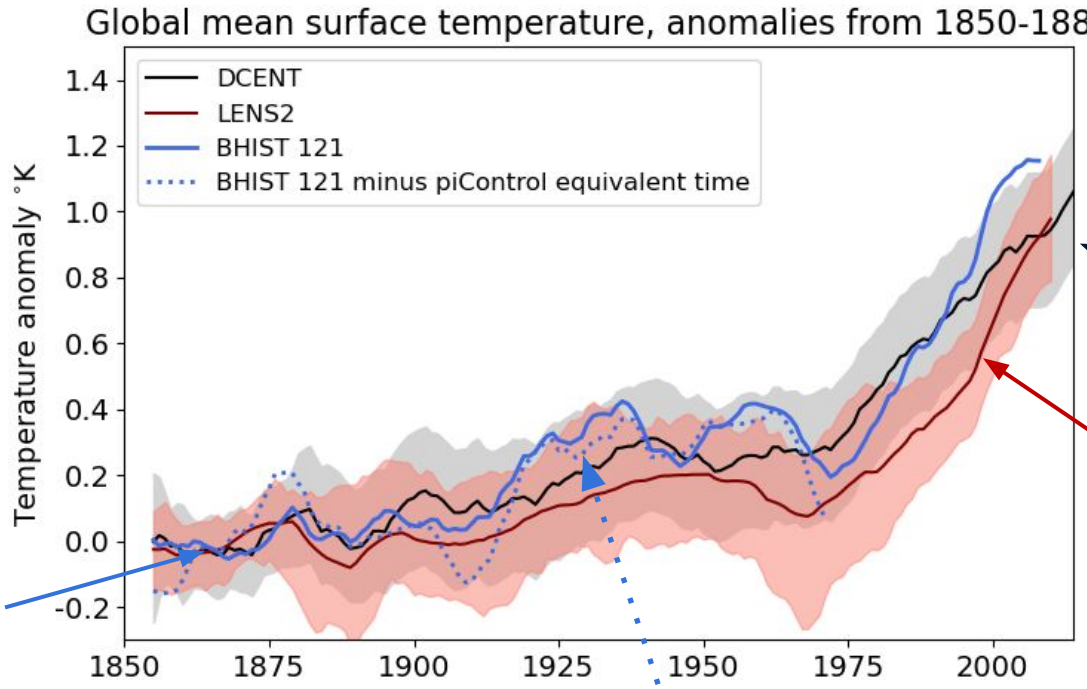
Latest CESM3 development simulation

The DCENT observation-based surface temperature
200 member ensemble
(Chan et al. 2024)

CESM2 large ensemble (first 50 members) i.e., not smoothed biomass burning

(TREFHT over land, TS over ocean)

10 year running mean global mean surface temperature



The DCENT observation-based surface temperature 200 member ensemble (Chan et al. 2024)

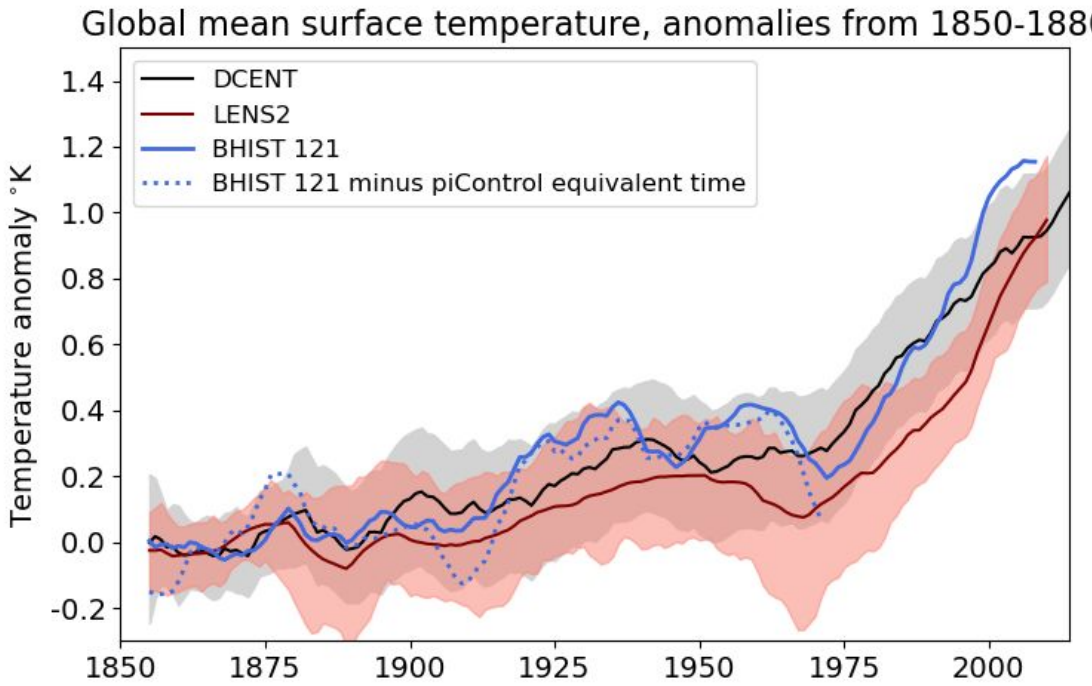
CESM2 large ensemble (first 50 members) i.e., not smoothed biomass burning

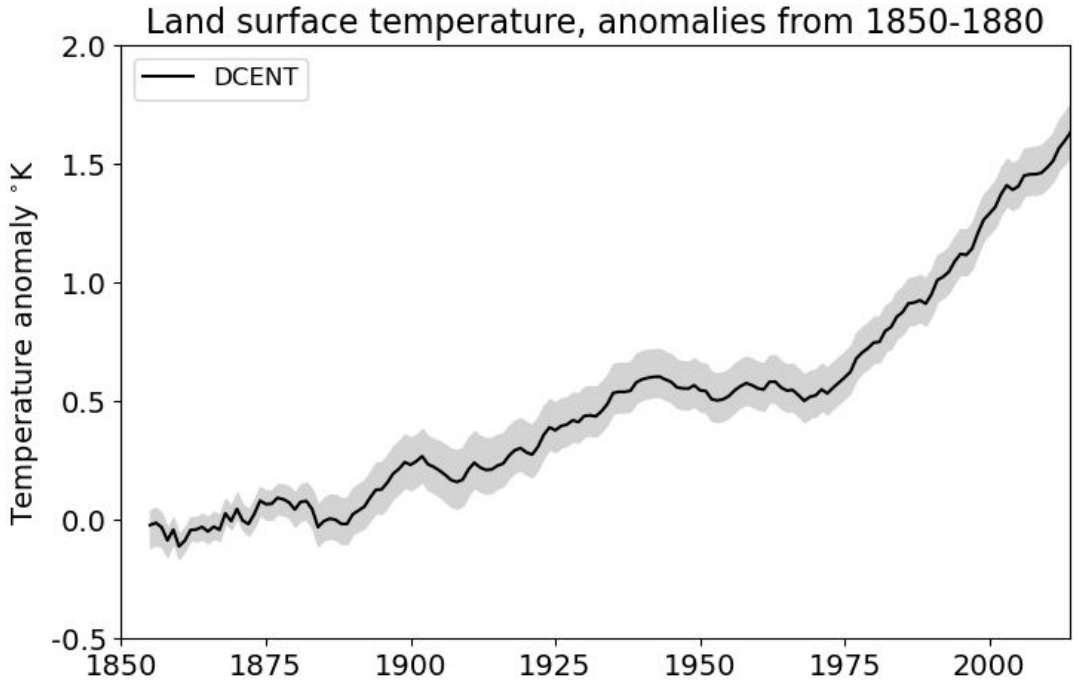
(TREFHT over land, TS over ocean)

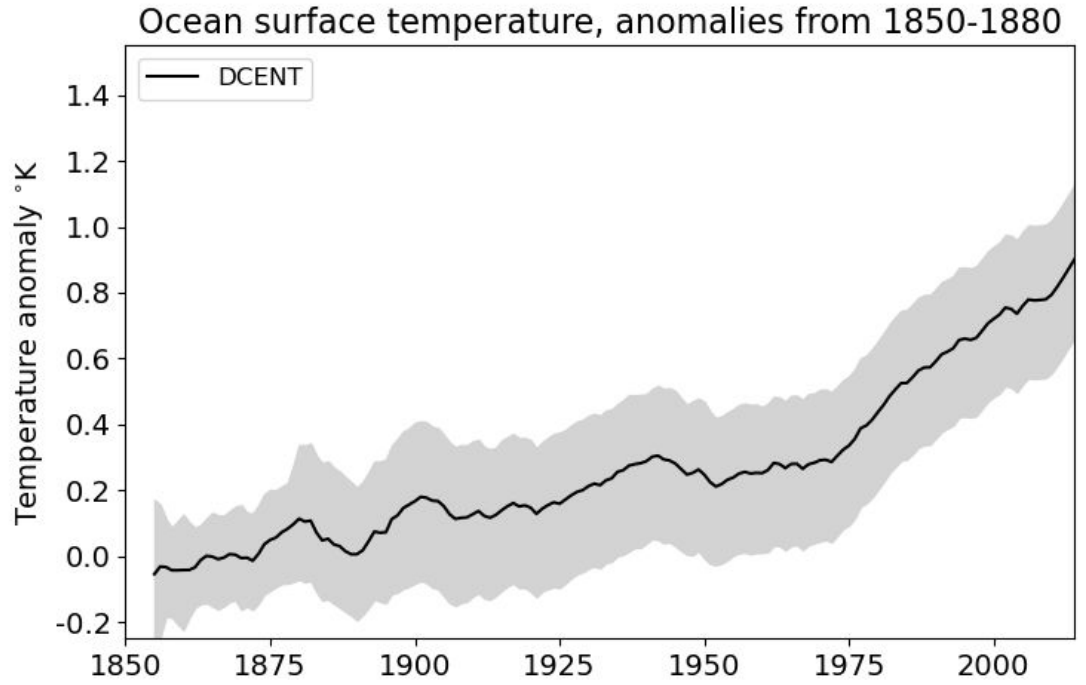
Latest CESM3 development simulation

Removing the equivalent 10-year running mean of the piControl following initialization of the historical

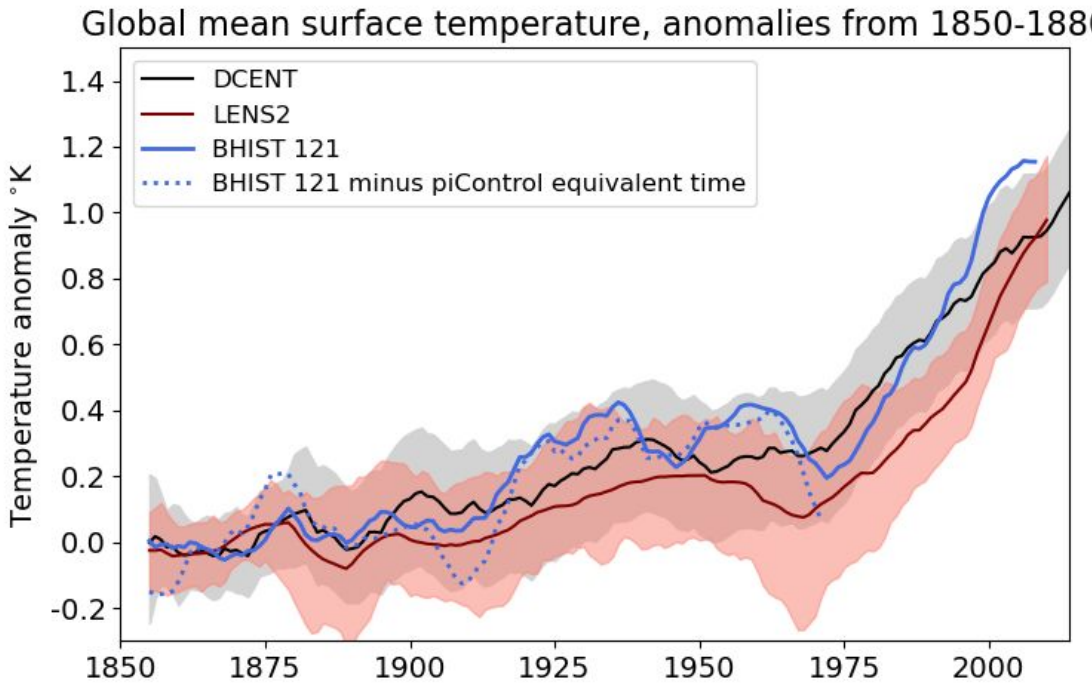
10 year running mean global mean surface temperature



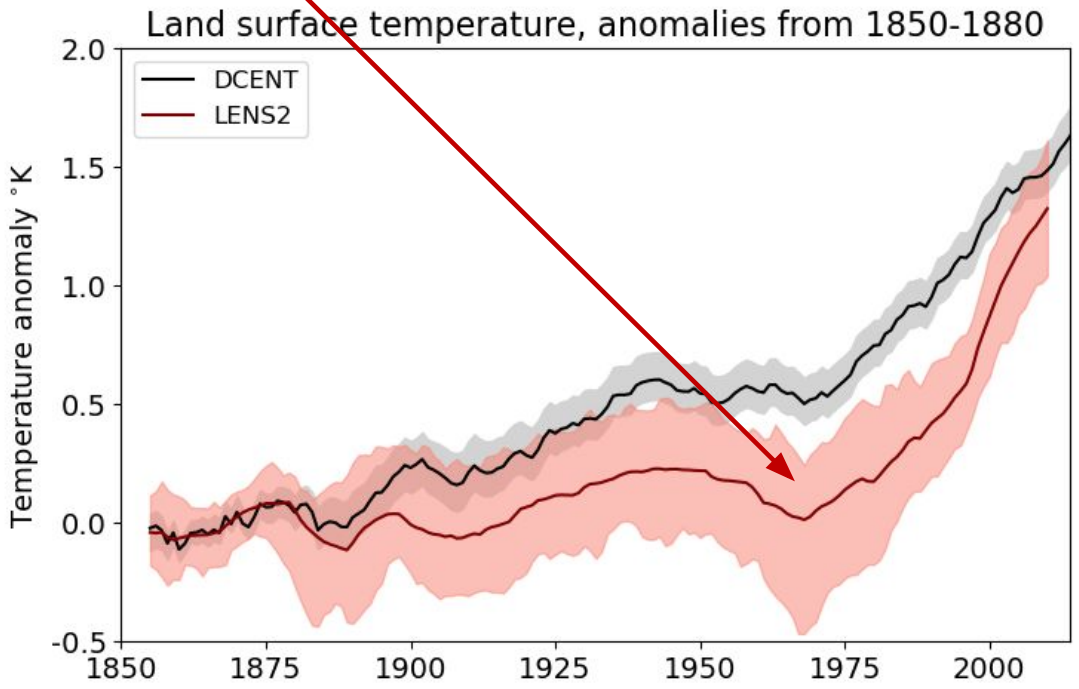


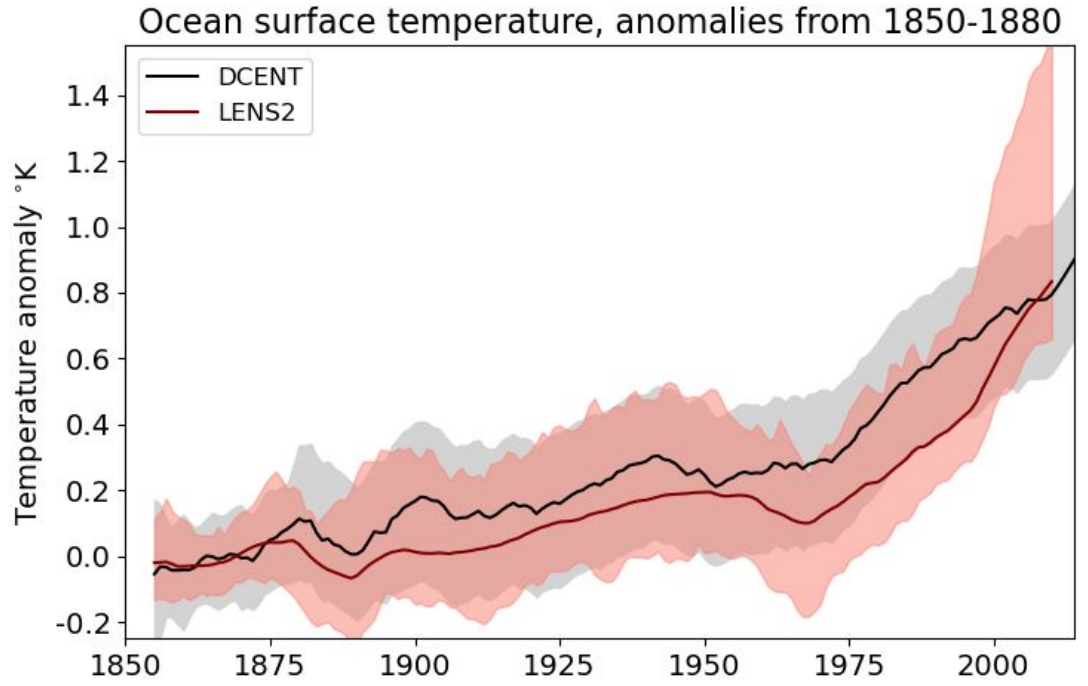


10 year running mean global mean surface temperature

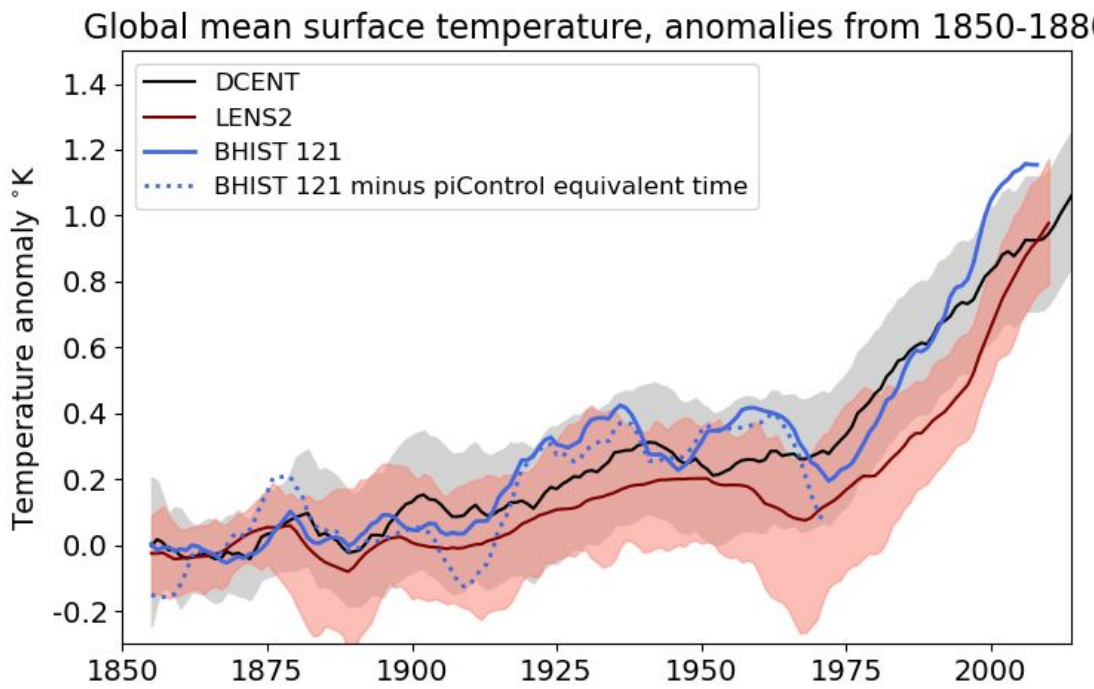


CESM2 didn't warm enough over the land over much of the 20th century

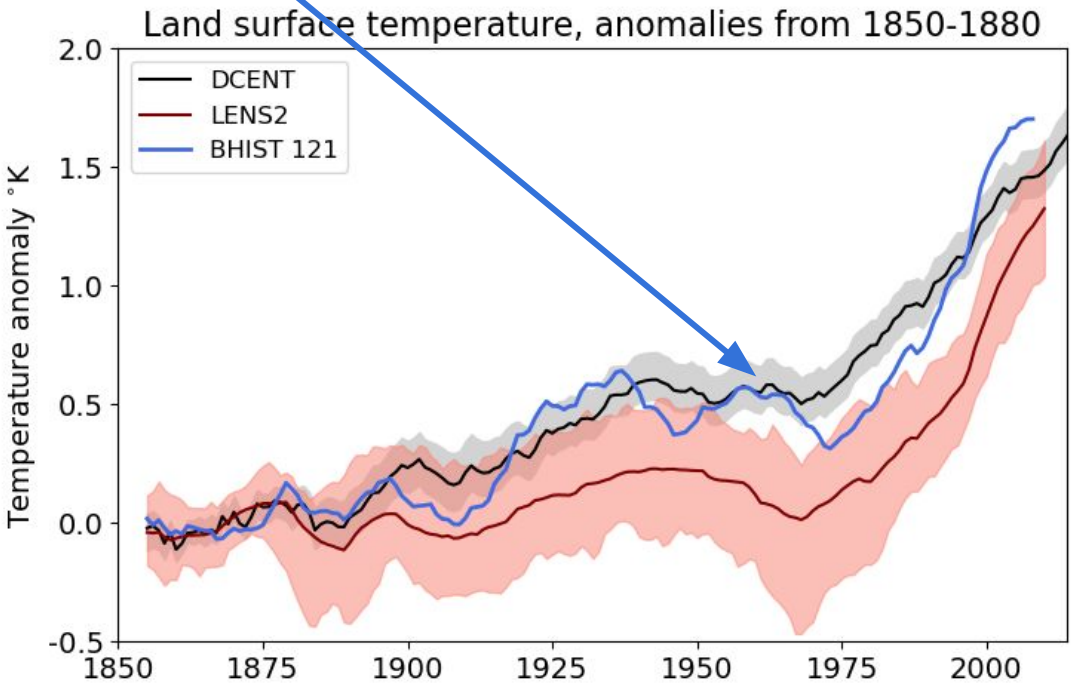


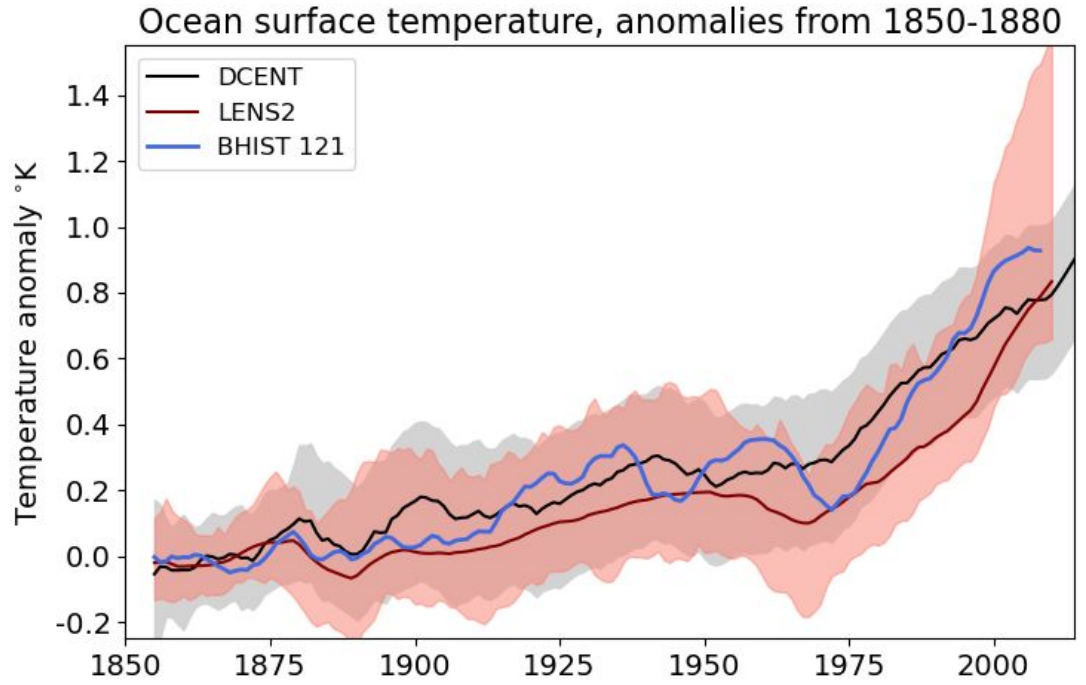


10 year running mean global mean surface temperature

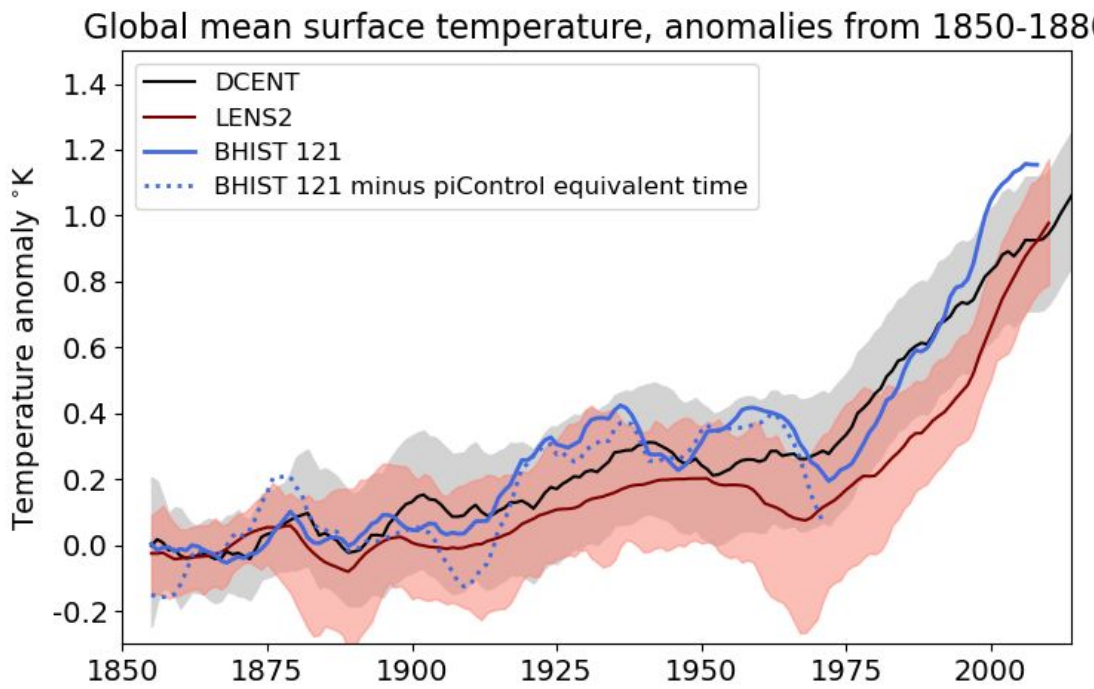


CESM3 development run is much better!





10 year running mean global mean surface temperature

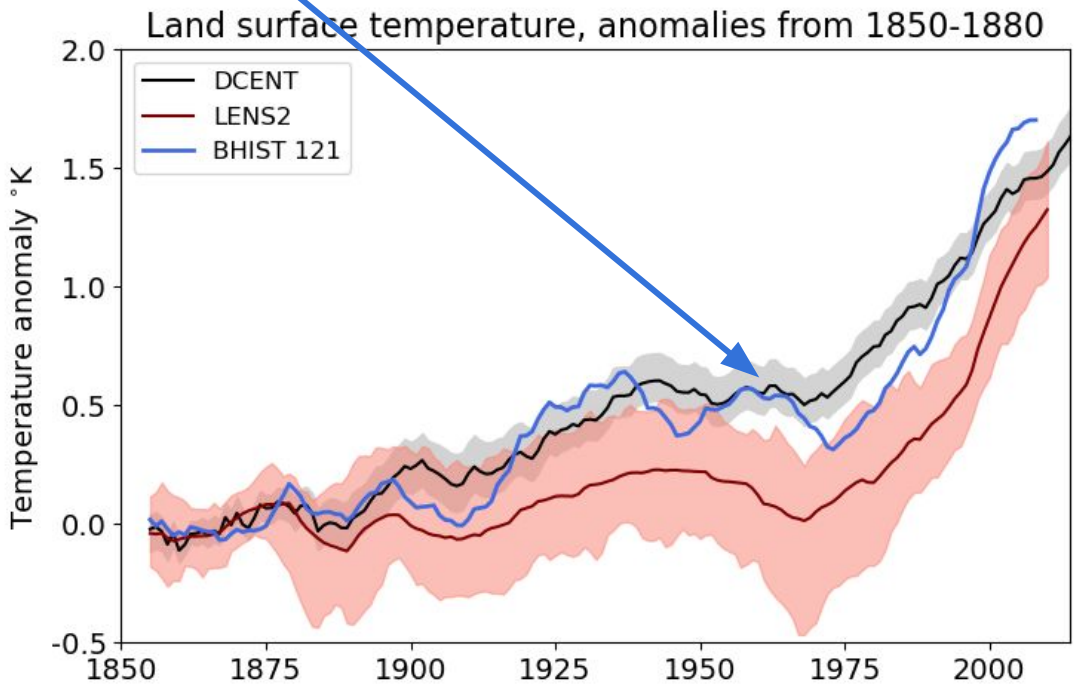


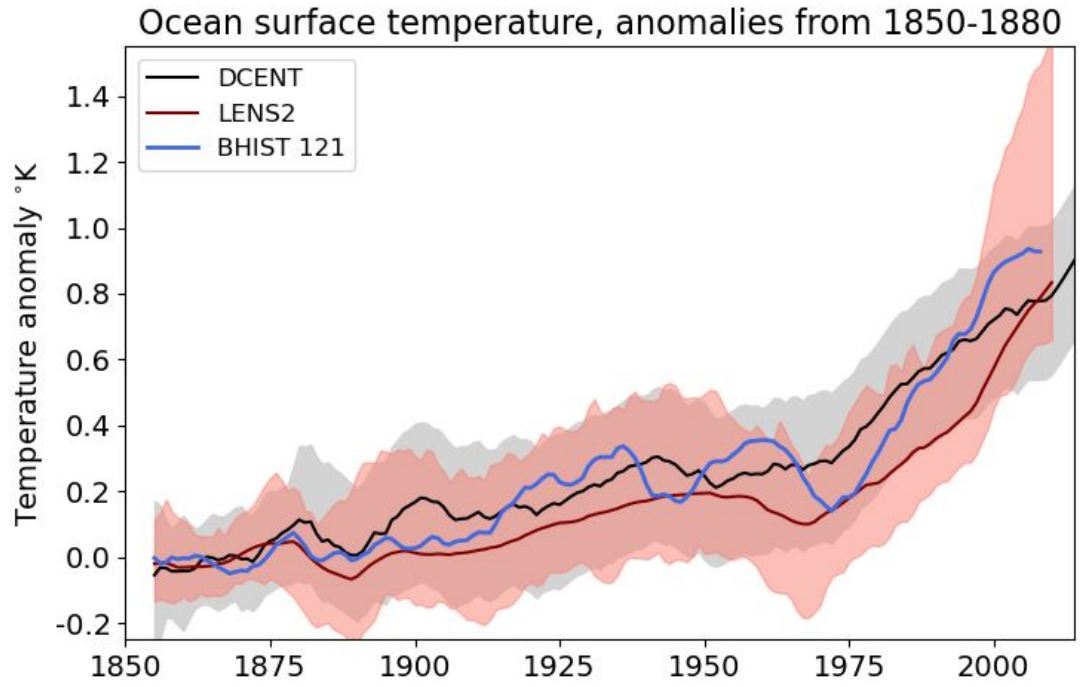
We suspect these improvements are related to changes in aerosol effects.

Aerosol Radiative Forcing:

-1.65 In CESM2 (Medeiros et al. 2020)
-0.5 in earlier CESM3

CESM3 development run is much better!

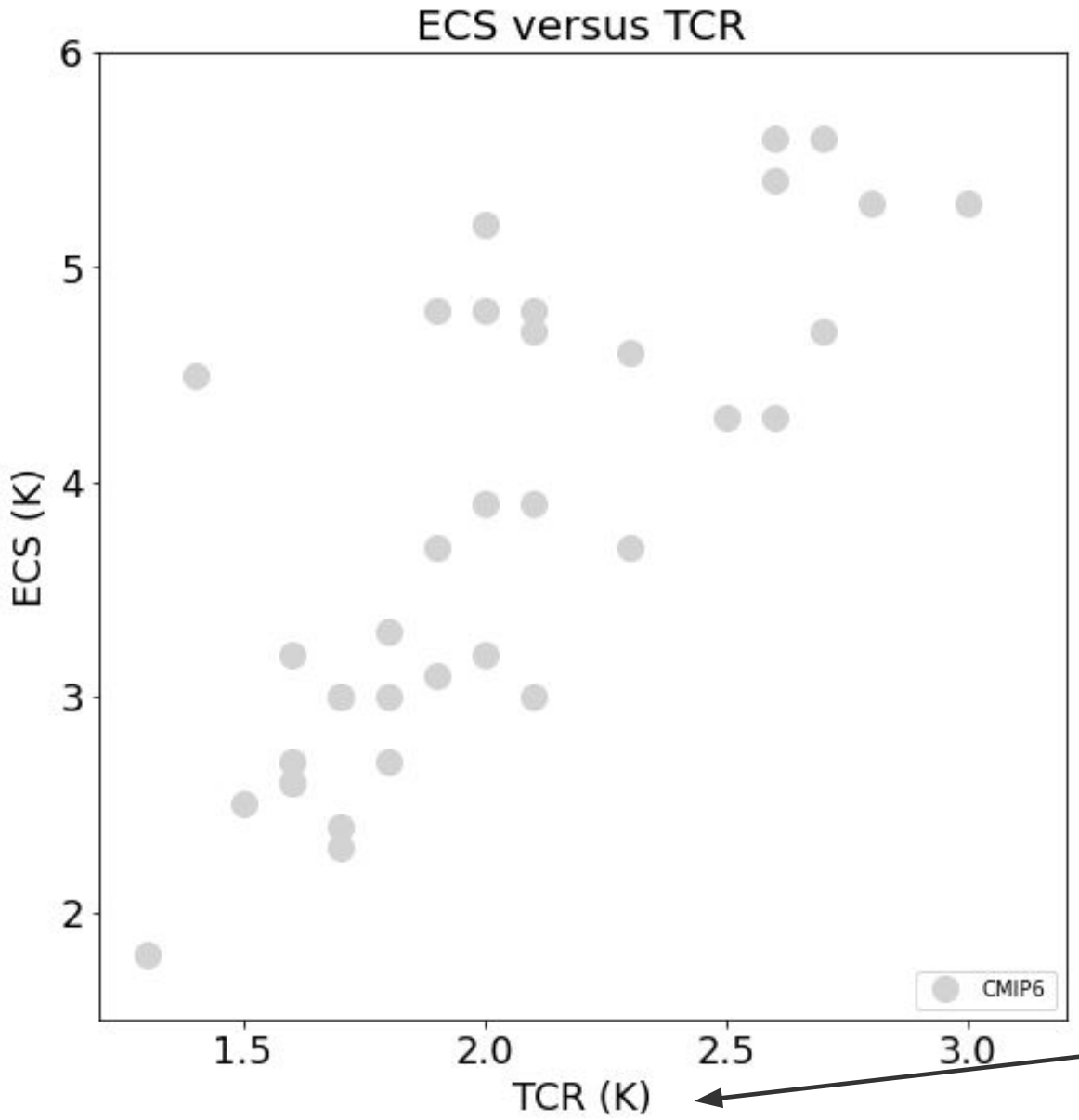




Climate sensitivity and TCR

ECS vs TCR

Equilibrium Climate Sensitivity derived using the Gregory method with 150 years of abrupt4xCO2 simulations

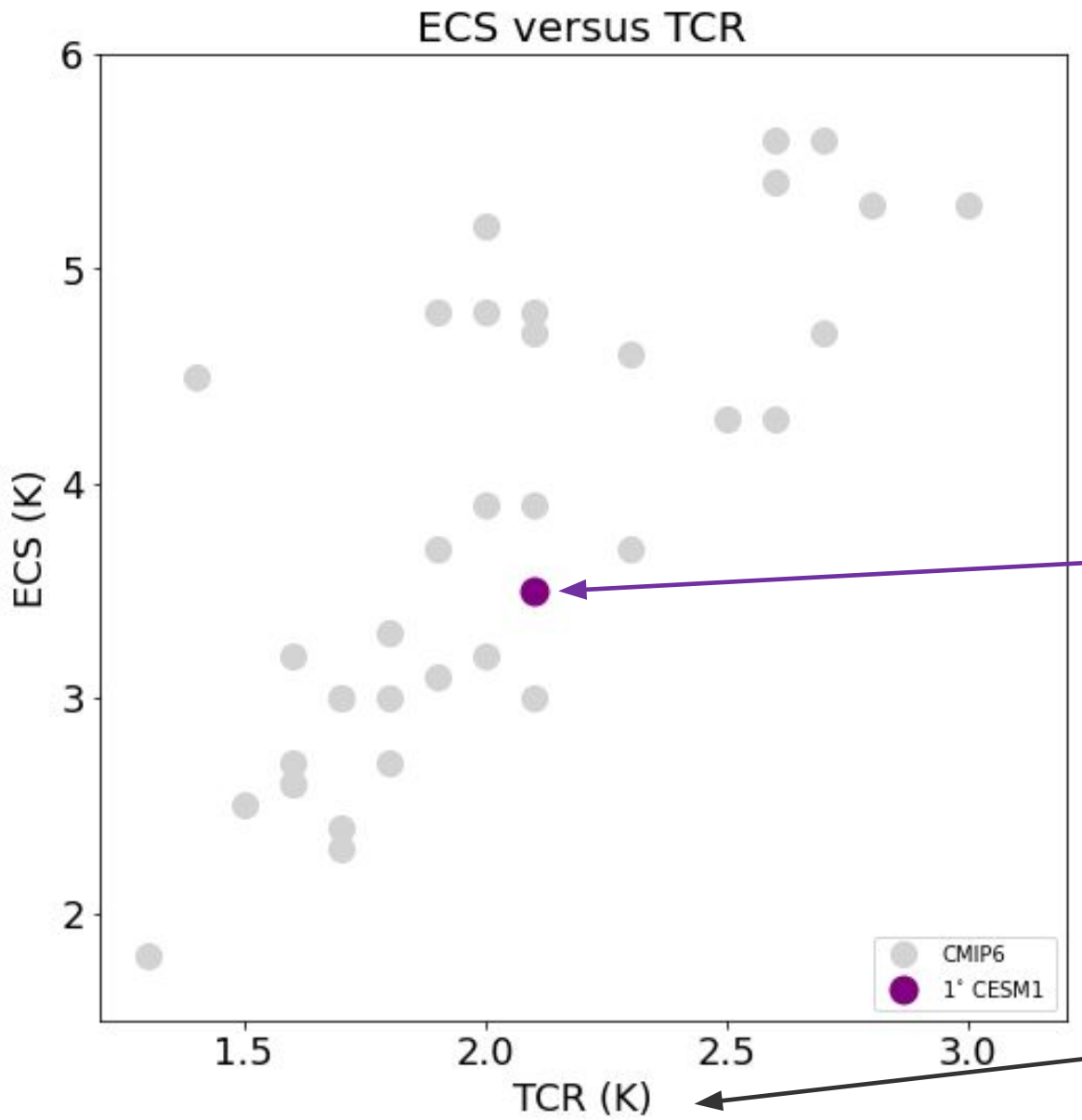


Transient Climate Response = the global mean temperature change at the time of CO2 doubling in a 1% per year CO2 increase experiment

Duffy et al, submitted

ECS vs TCR

Equilibrium Climate Sensitivity derived using the Gregory method with 150 years of abrupt4xCO2 simulations



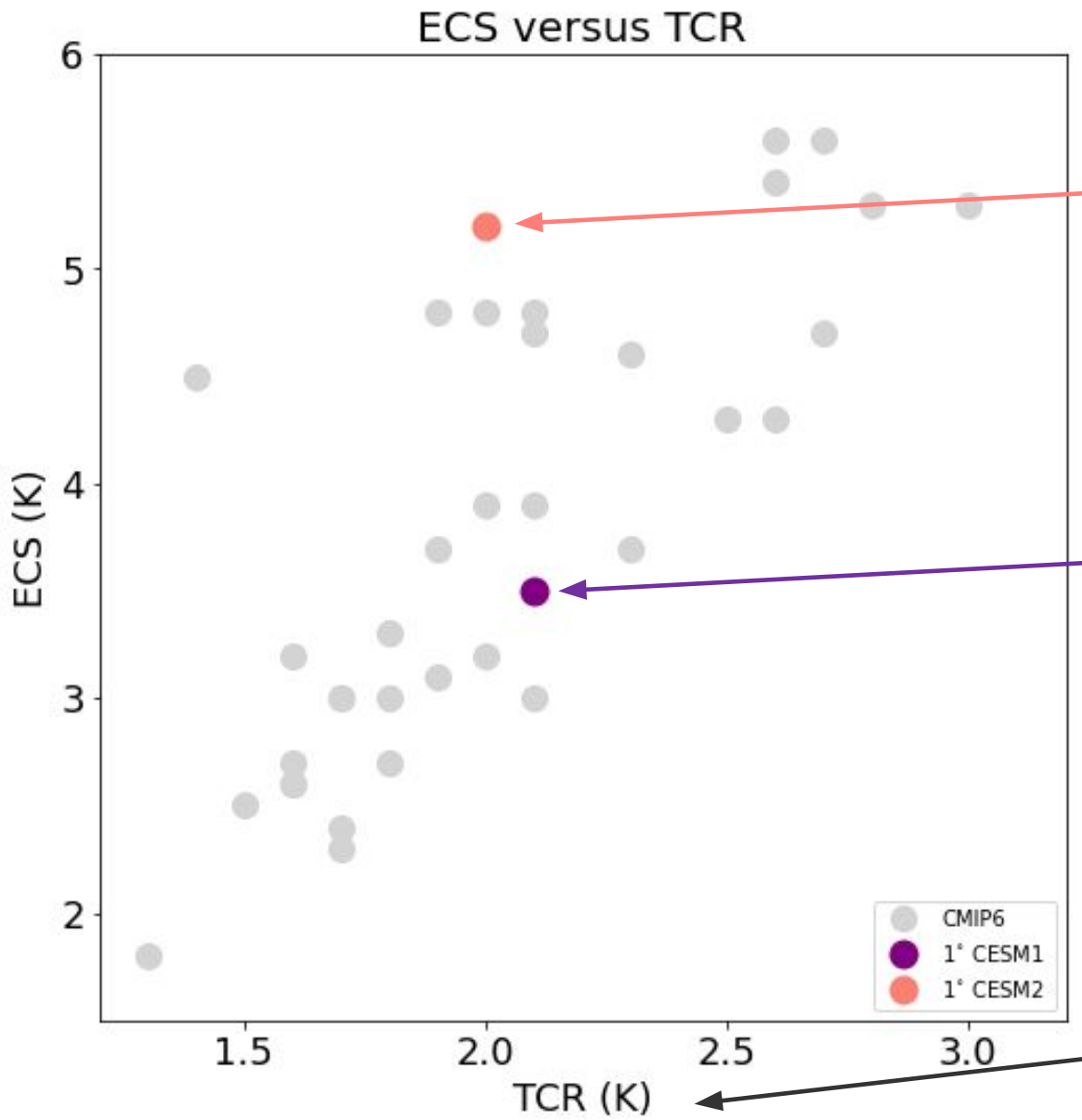
CESM1

Transient Climate Response = the global mean temperature change at the time of CO2 doubling in a 1% per year CO2 increase experiment

Duffy et al, submitted

ECS vs TCR

Equilibrium Climate Sensitivity derived using the Gregory method with 150 years of abrupt4xCO2 simulations



CESM2

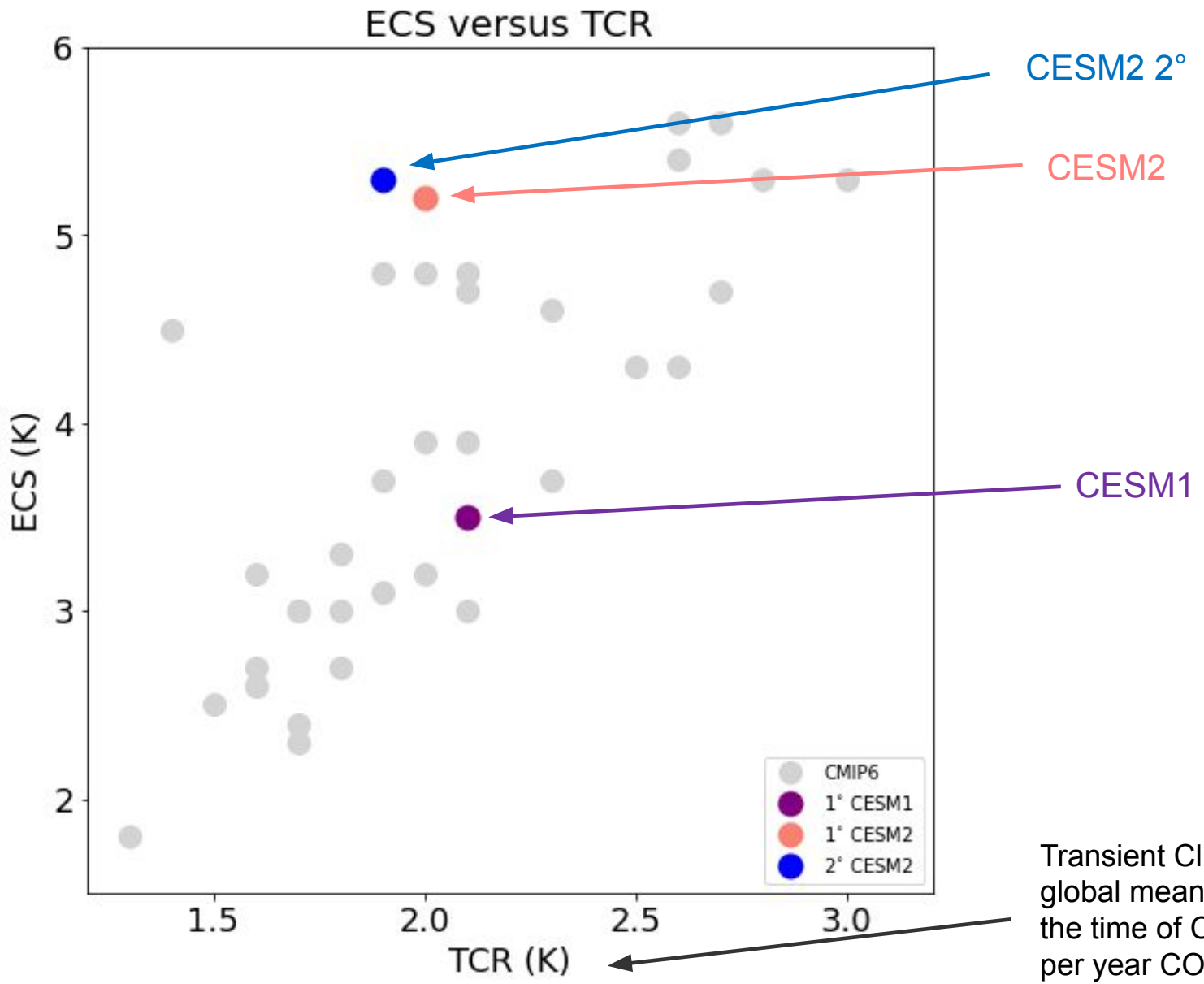
CESM1

Transient Climate Response = the global mean temperature change at the time of CO2 doubling in a 1% per year CO2 increase experiment

Duffy et al, submitted

ECS vs TCR

Equilibrium Climate Sensitivity derived using the Gregory method with 150 years of abrupt4xCO2 simulations



CESM2 2°

CESM2

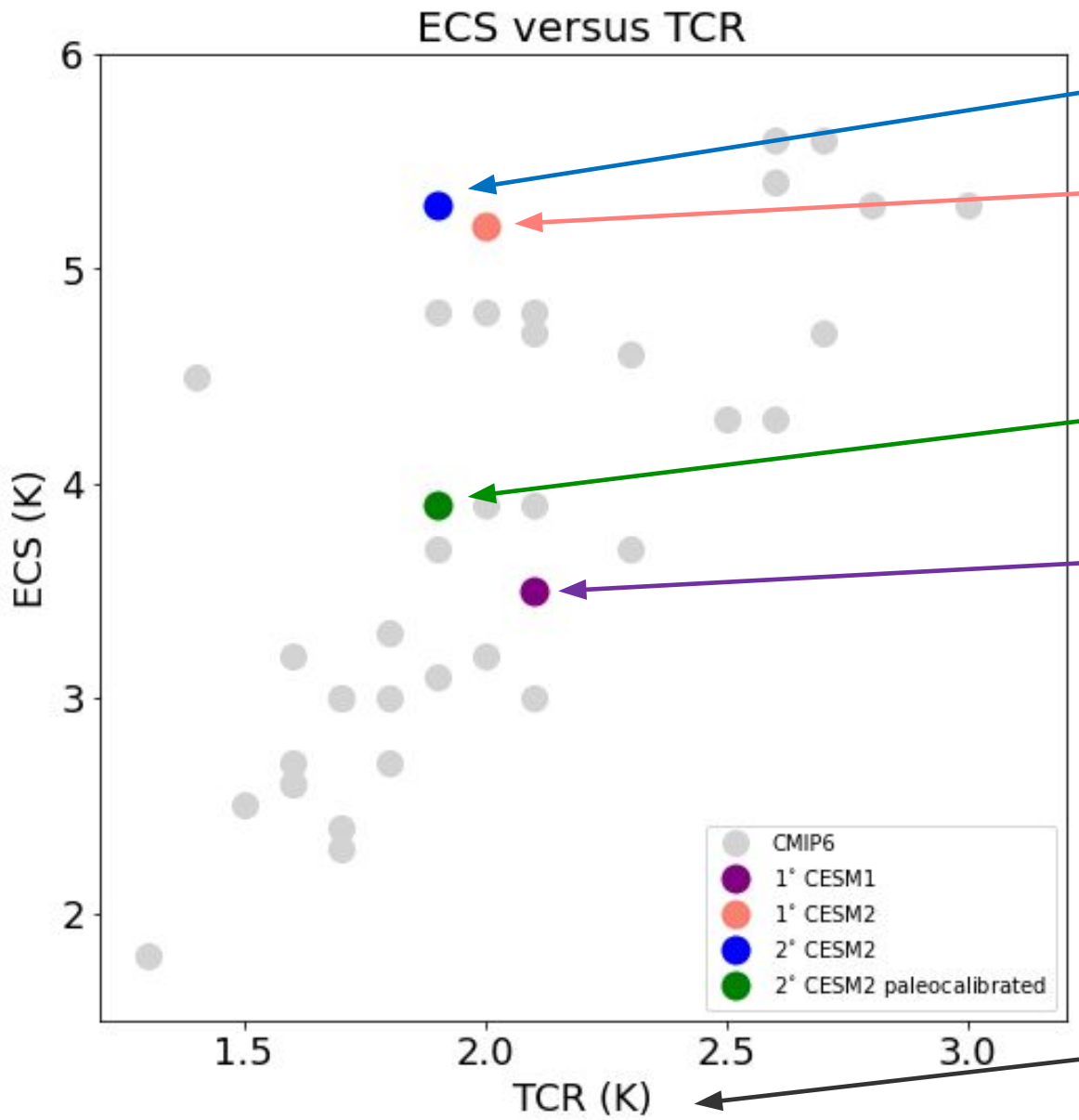
CESM1

Transient Climate Response = the global mean temperature change at the time of CO2 doubling in a 1% per year CO2 increase experiment

Duffy et al, submitted

ECS vs TCR

Equilibrium Climate Sensitivity derived using the Gregory method with 150 years of abrupt4xCO2 simulations



CESM2 2°

CESM2

Paleocalibrated CESM2 2°
Zhu et al (2021)

CESM1

Transient Climate Response = the global mean temperature change at the time of CO2 doubling in a 1% per year CO2 increase experiment

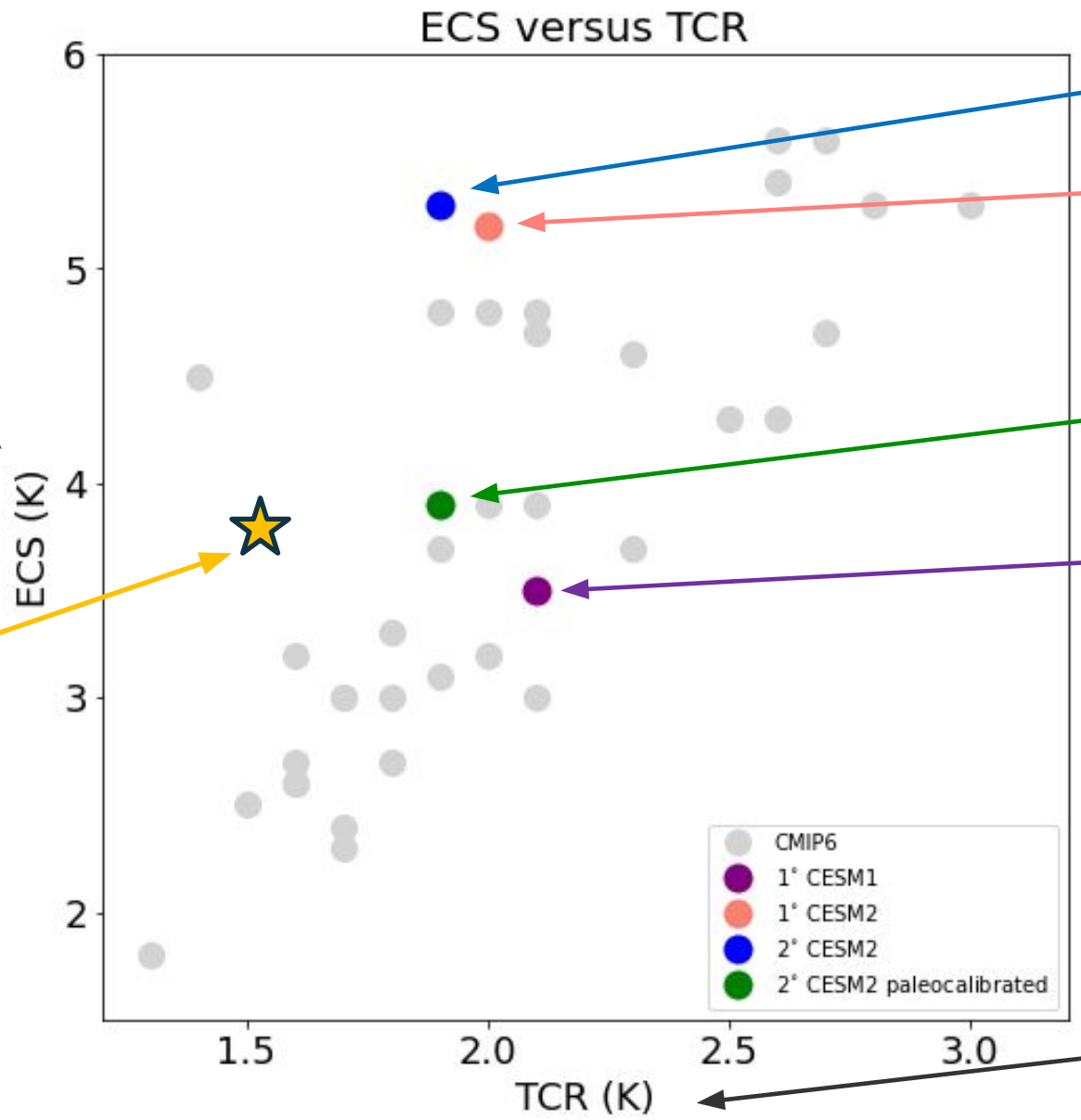
Duffy et al, submitted

ECS vs TCR

Equilibrium Climate Sensitivity derived using the Gregory method with 150 years of abrupt4xCO2 simulations

121 configuration

(Thanks to Cecile Hannay)



CESM2 2°

CESM2

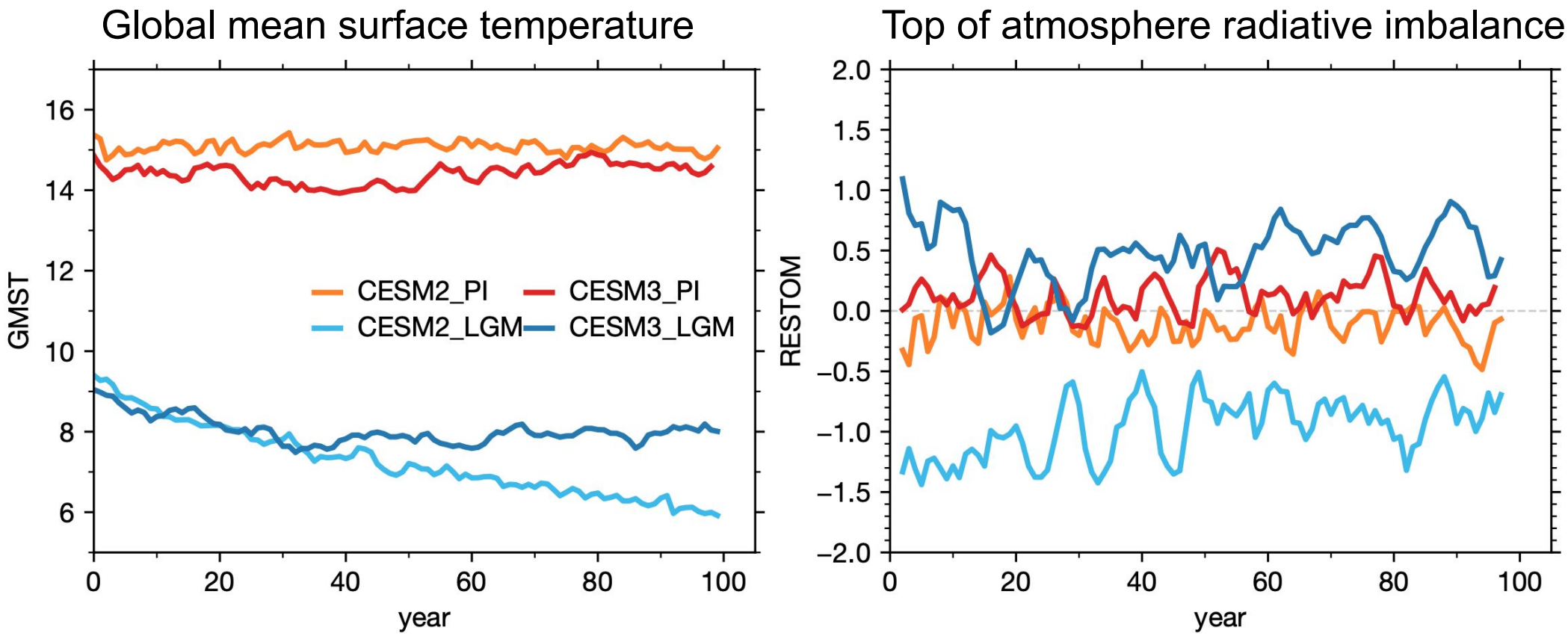
Paleocalibrated CESM2 2°
Zhu et al (2021)

CESM1

Transient Climate Response = the global mean temperature change at the time of CO2 doubling in a 1% per year CO2 increase experiment

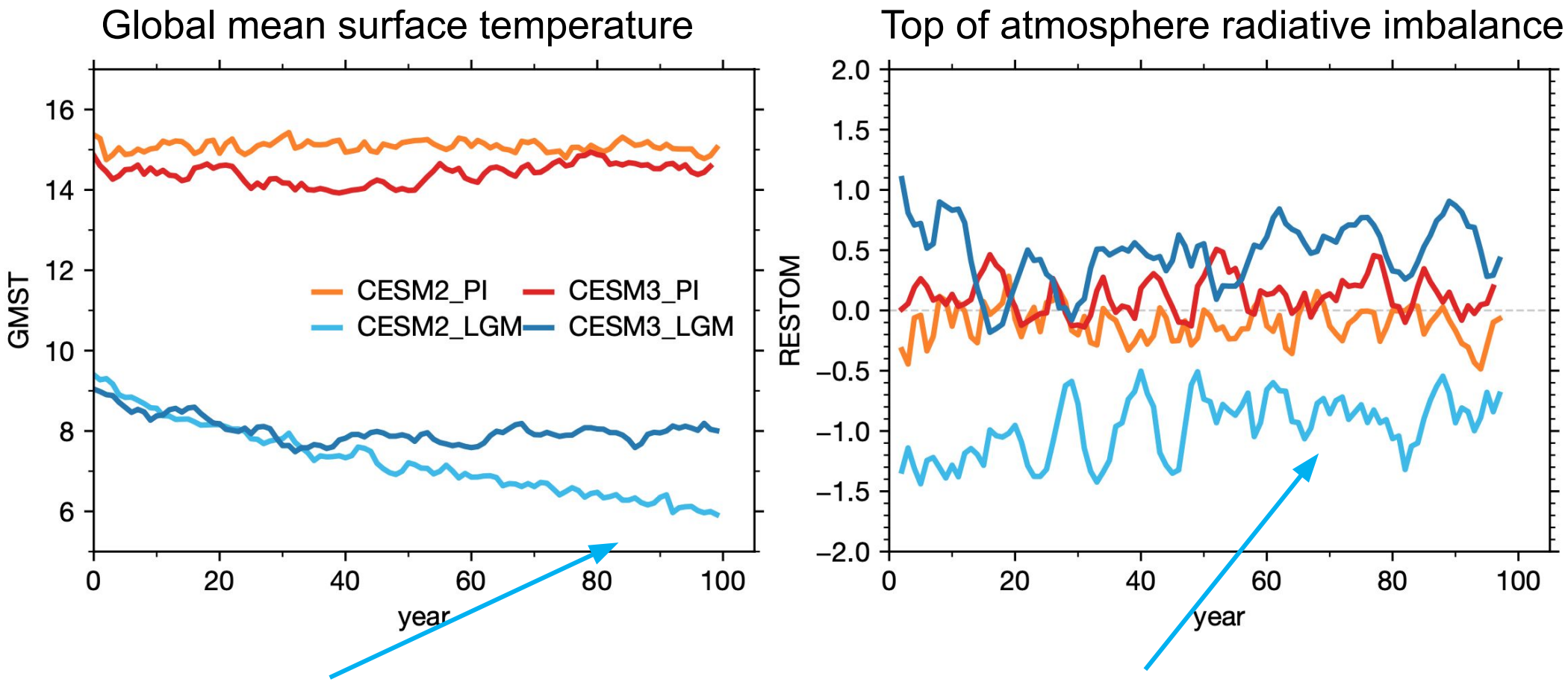
LGM in CESM3

Figure from Jiang Zhu:



LGM in CESM3

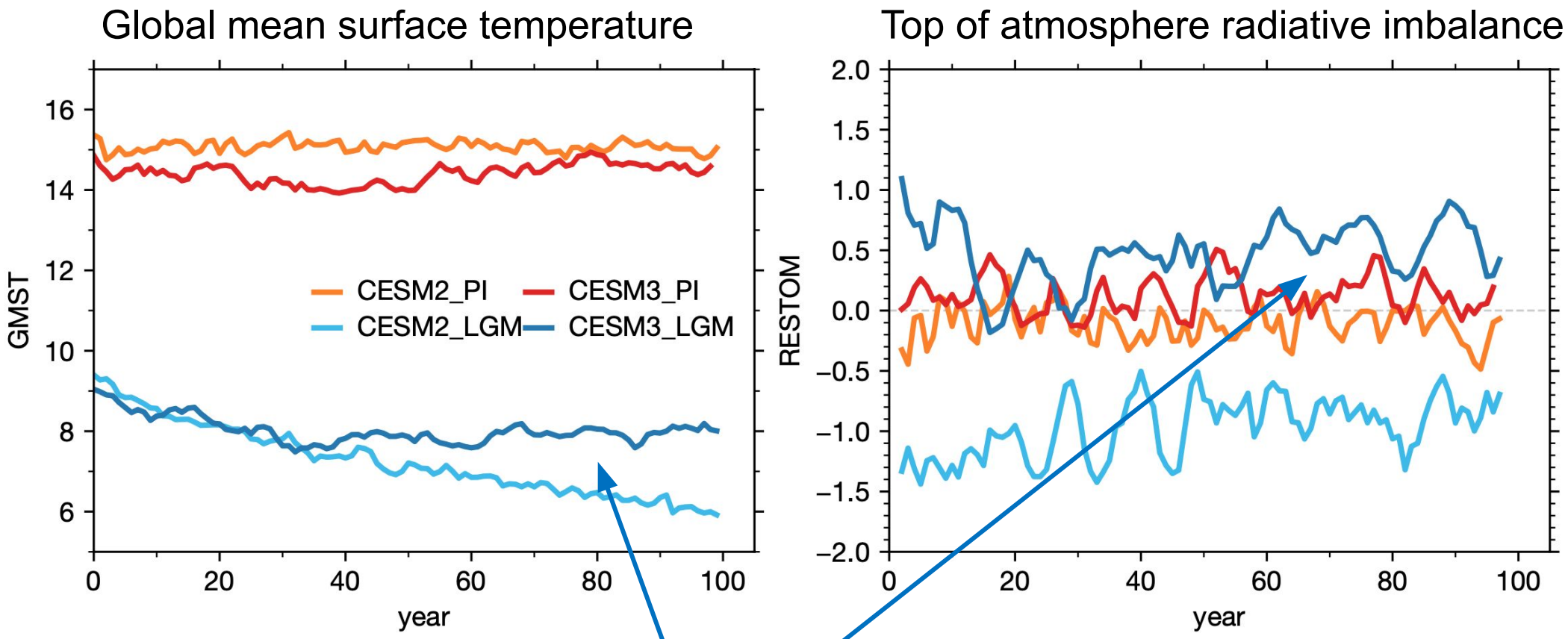
Figure from Jiang Zhu:



CESM2 got really cold and continues to get cold as a result of the negative TOA radiative imbalance

LGM in CESM3

Figure from Jiang Zhu:



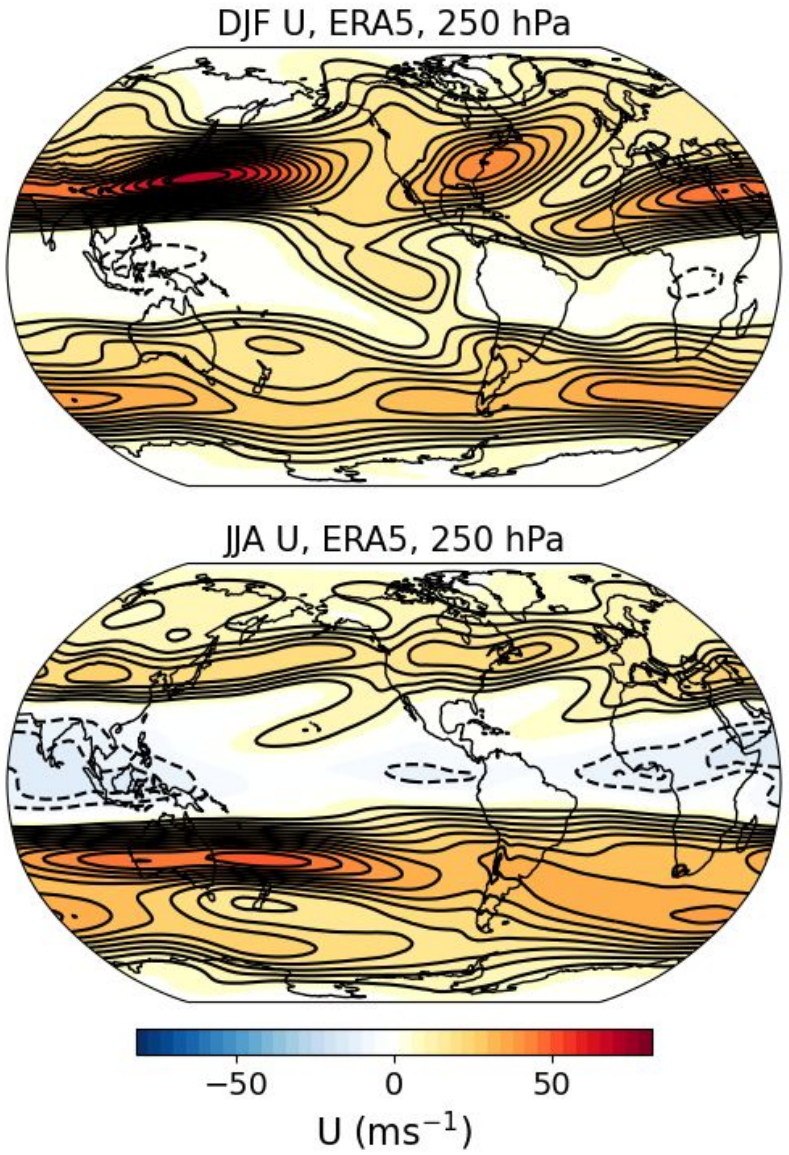
CESM2 got really cold and continues to get cold as a result of the negative TOA radiative imbalance

CESM3 is reaching an equilibrium at less cold temperatures. Jiang says it's good.

Basic large-scale circulation metrics

250 hPa zonal wind

ERA5

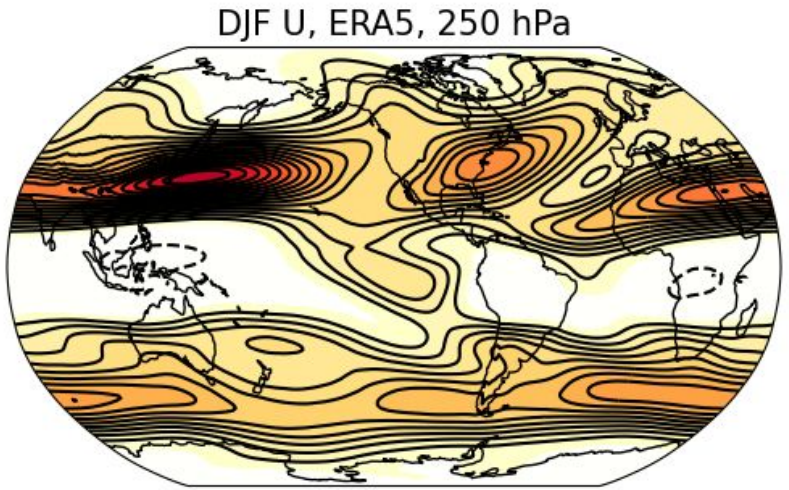


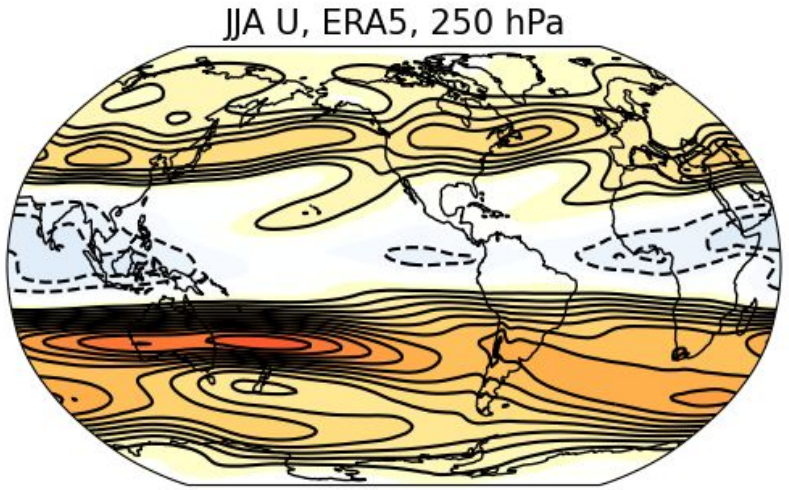
DJF

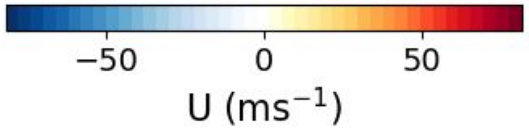
JJA

250 hPa zonal wind

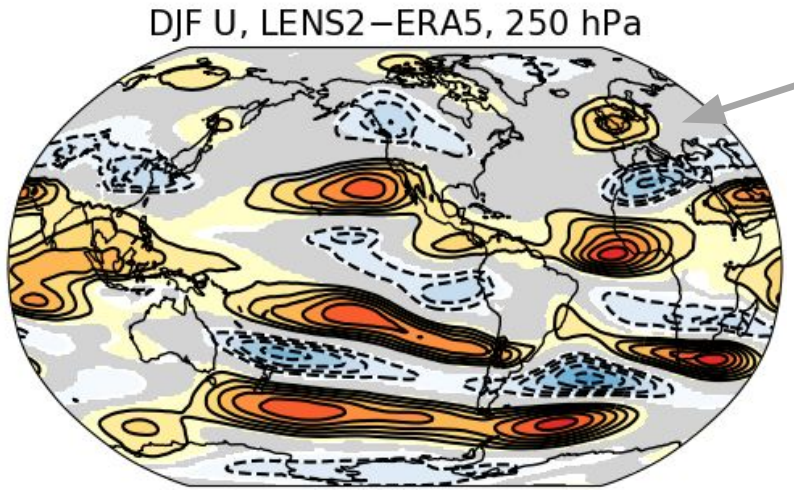
ERA5

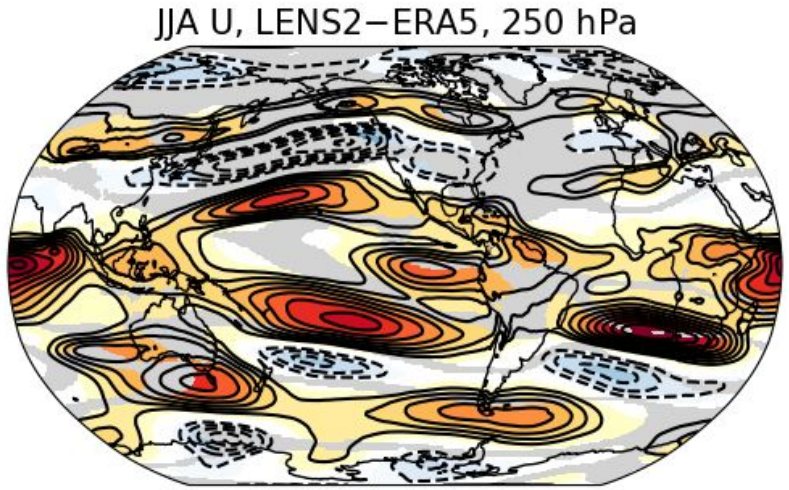


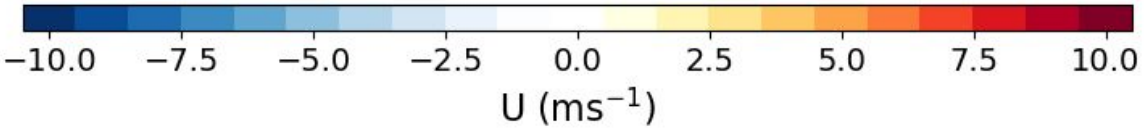




CESM2 – ERA5





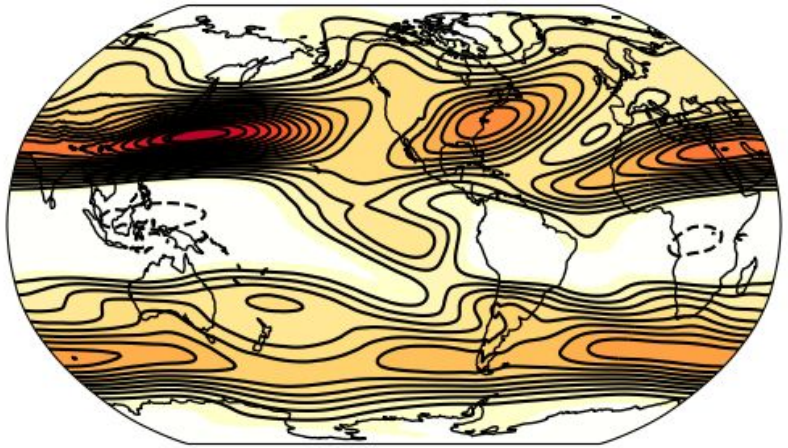


Gray = where ERA5 lies within the LENS2 spread

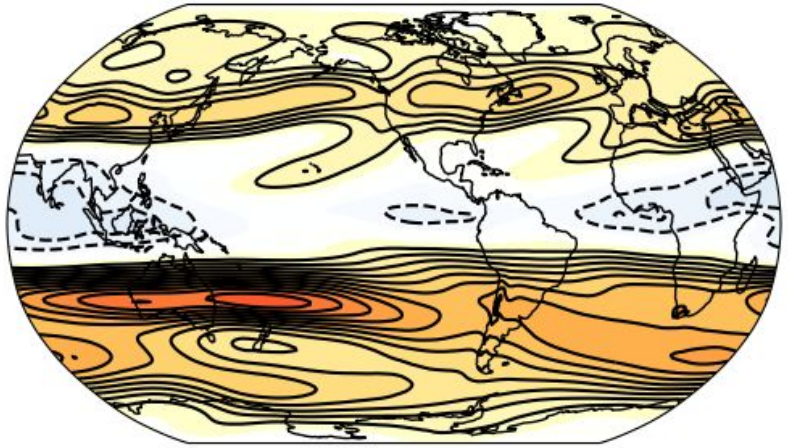
250 hPa zonal wind

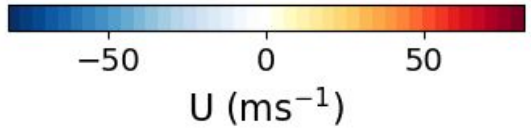
ERA5

DJF U, ERA5, 250 hPa



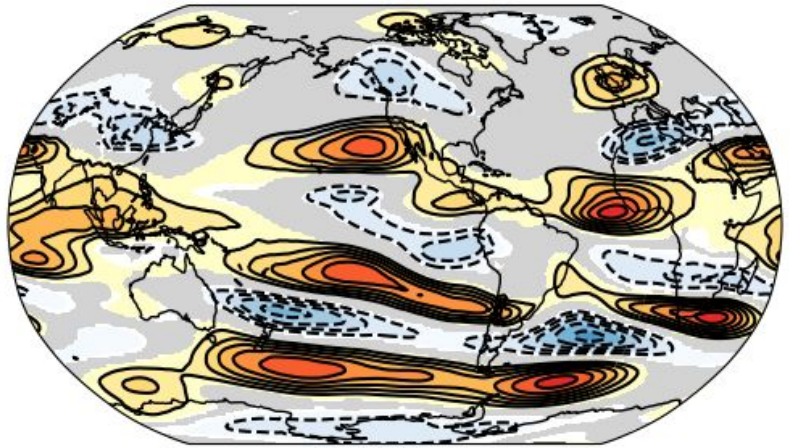
JJA U, ERA5, 250 hPa



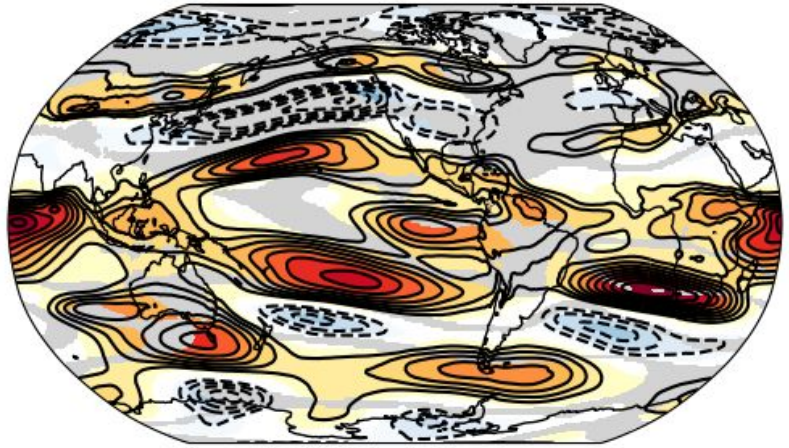


CESM2 – ERA5

DJF U, LENS2−ERA5, 250 hPa

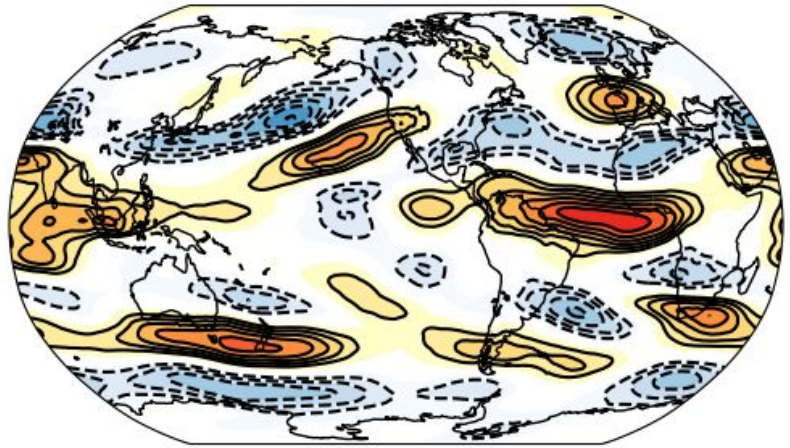


JJA U, LENS2−ERA5, 250 hPa

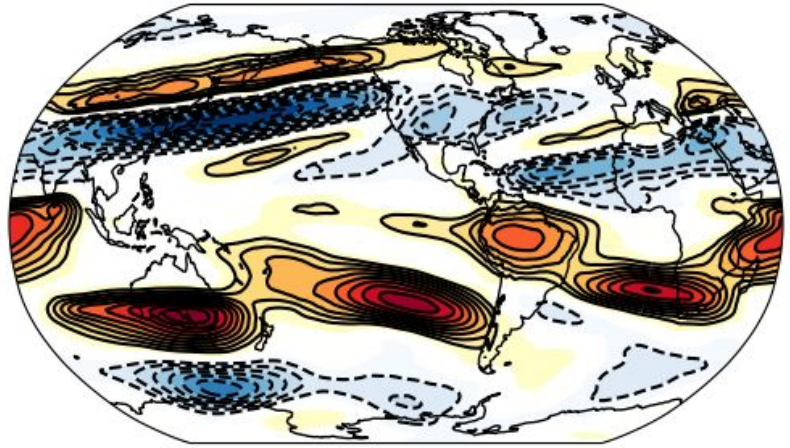


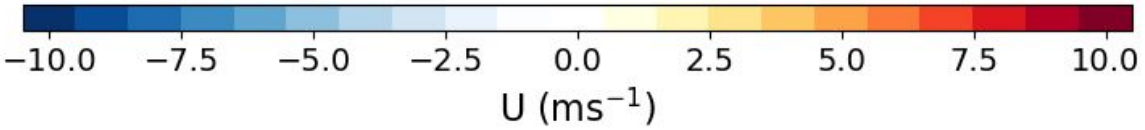
CESM3 – ERA5

DJF U, 121 BHIST − ERA5, 250 hPa



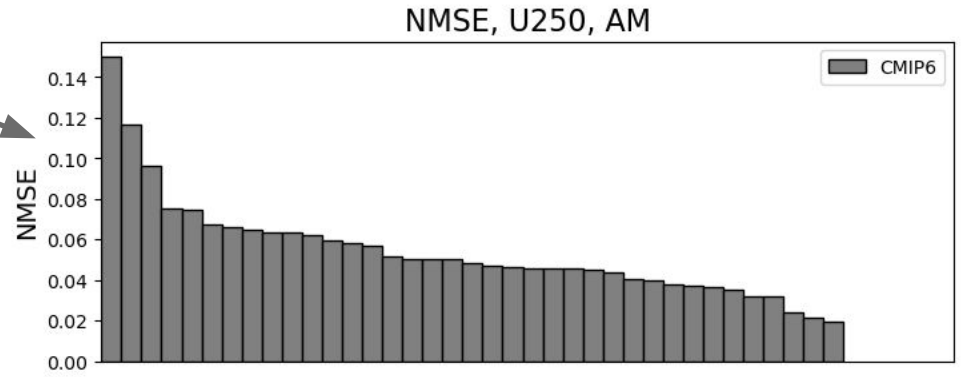
JJA U, 121 BHIST − ERA5, 250 hPa





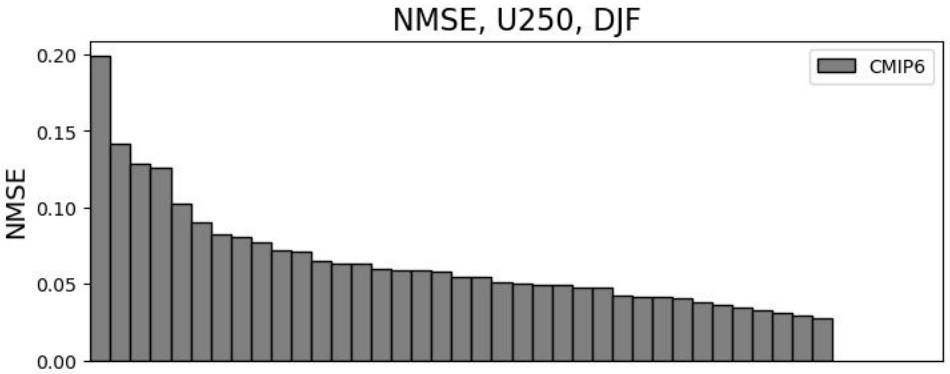
250 hPa zonal wind, Normalized mean squared error, global mean

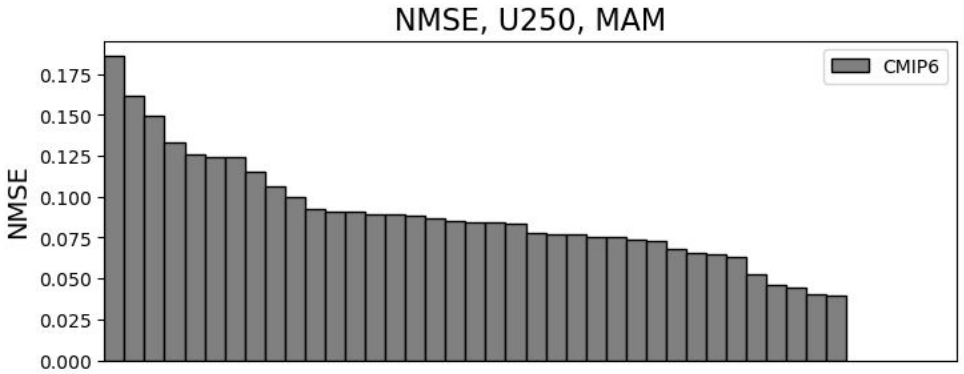
All the CMIP6 models

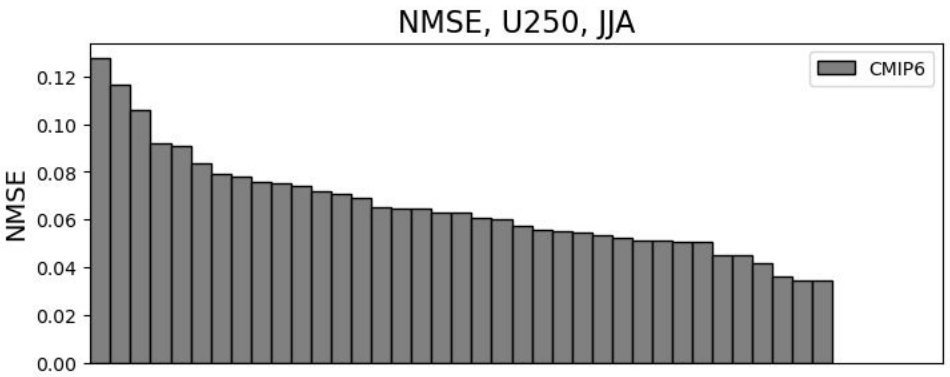


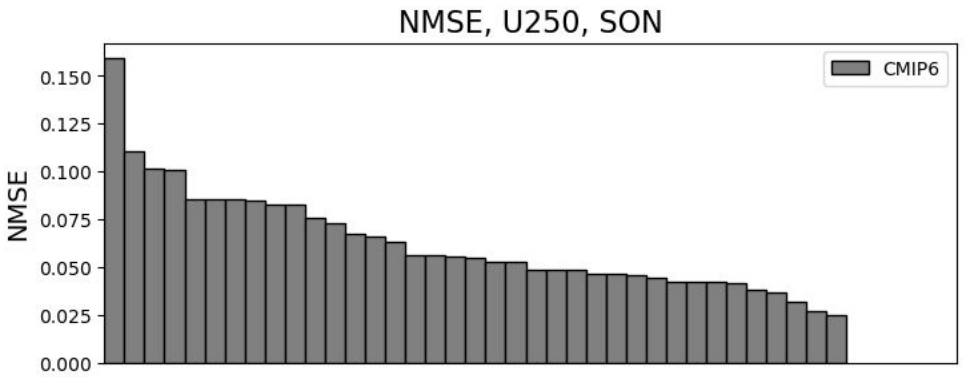
WORST

BEST



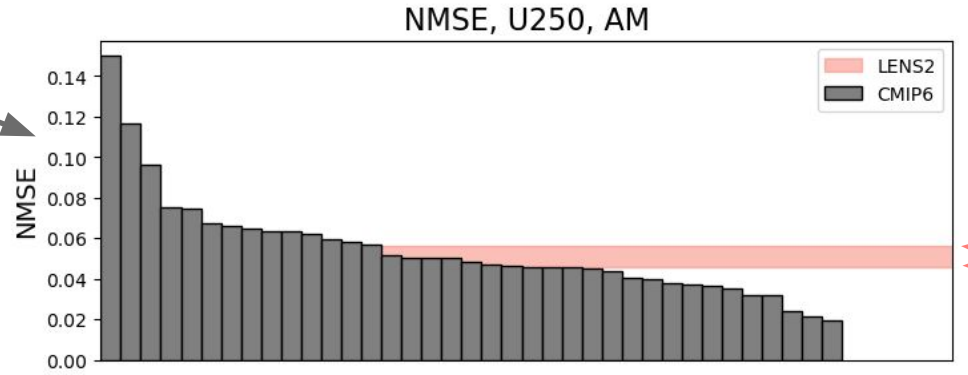






250 hPa zonal wind, Normalized mean squared error, global mean

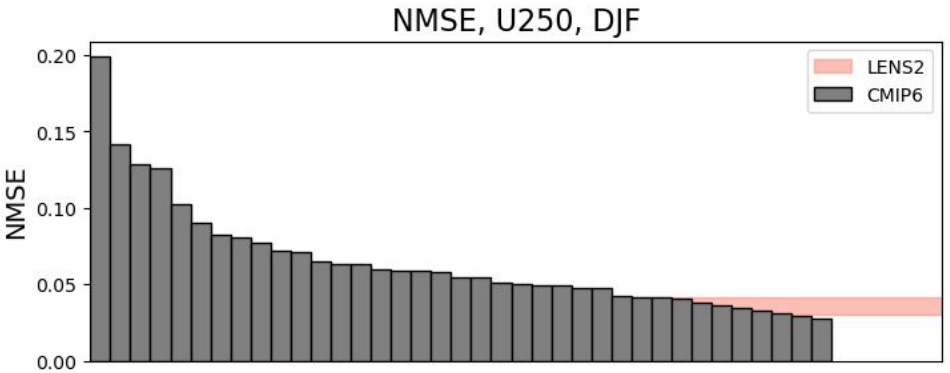
All the CMIP6 models

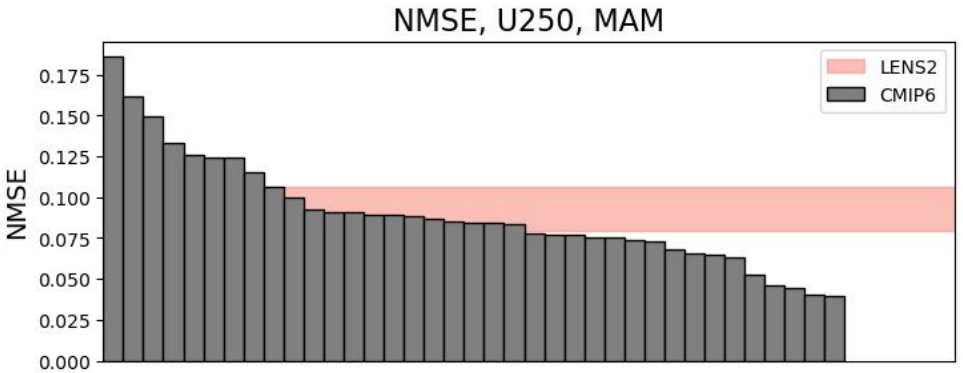


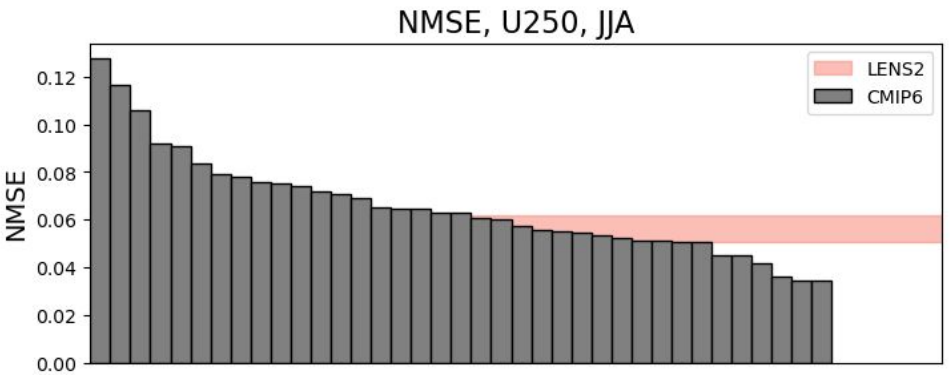
WORST

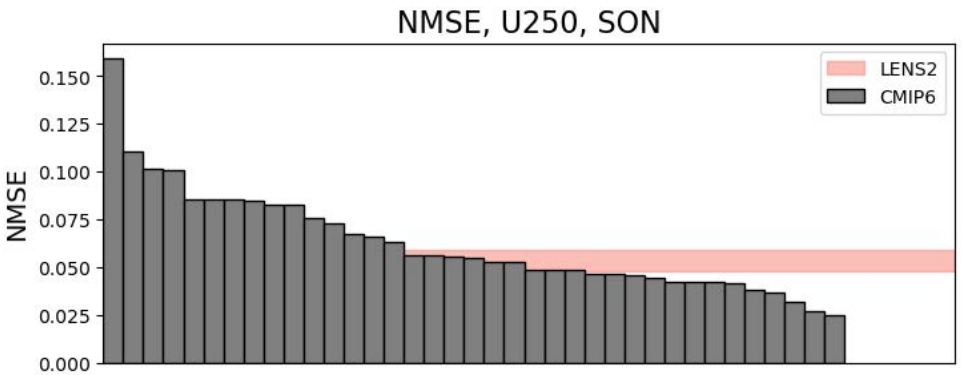
BEST

Spread of errors in the CESM2 large ensemble



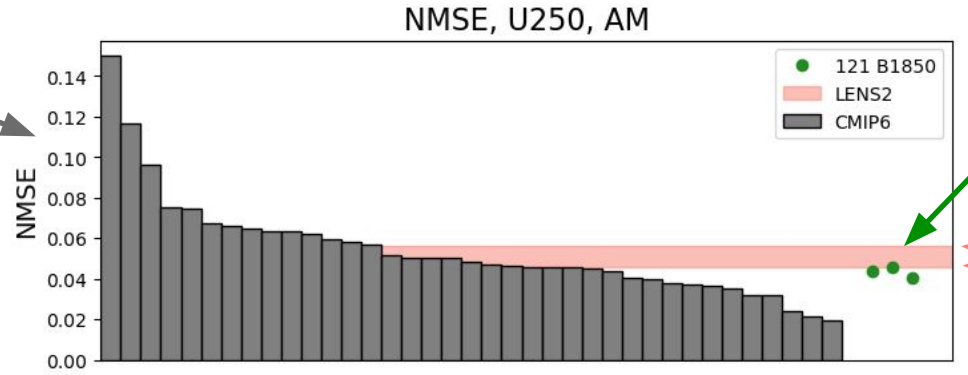






250 hPa zonal wind, Normalized mean squared error, global mean

All the CMIP6 models

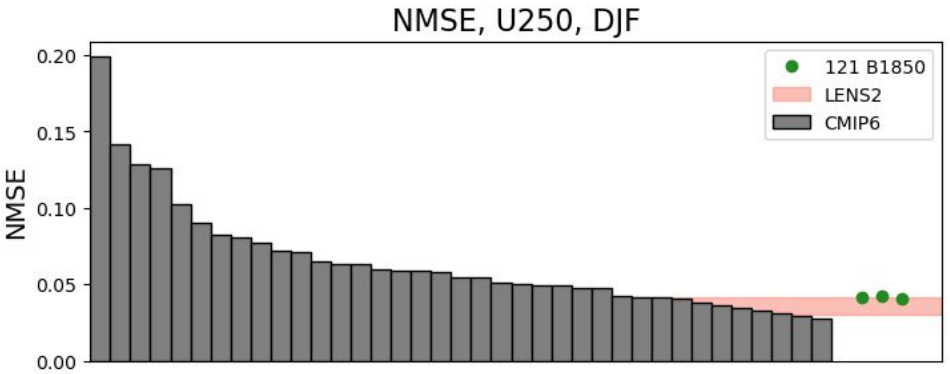


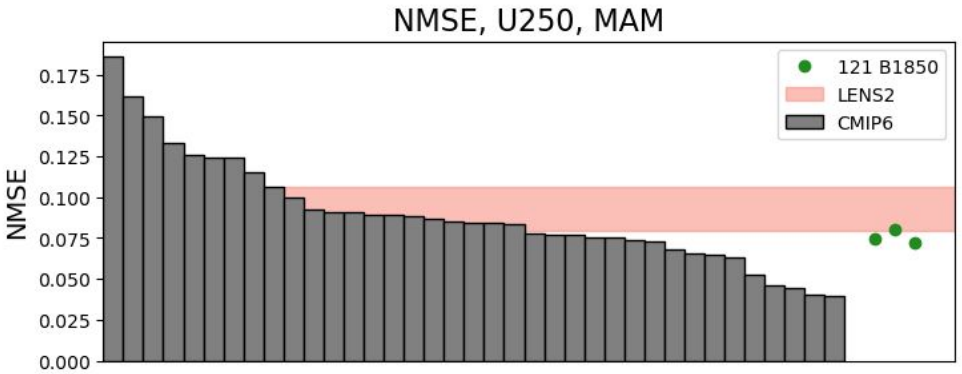
WORST

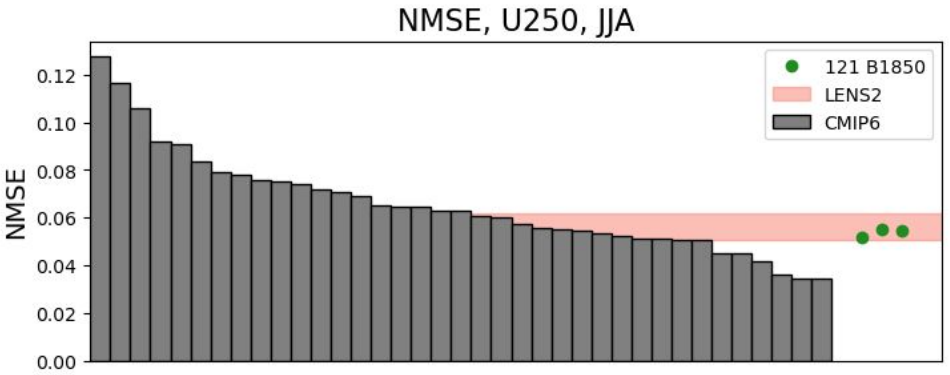
3, 45 year samples from B1850 121

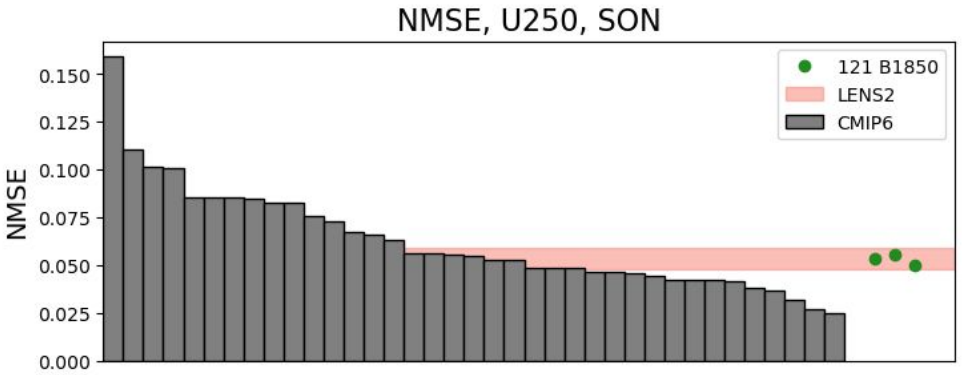
Spread of errors in the CESM2 large ensemble

BEST



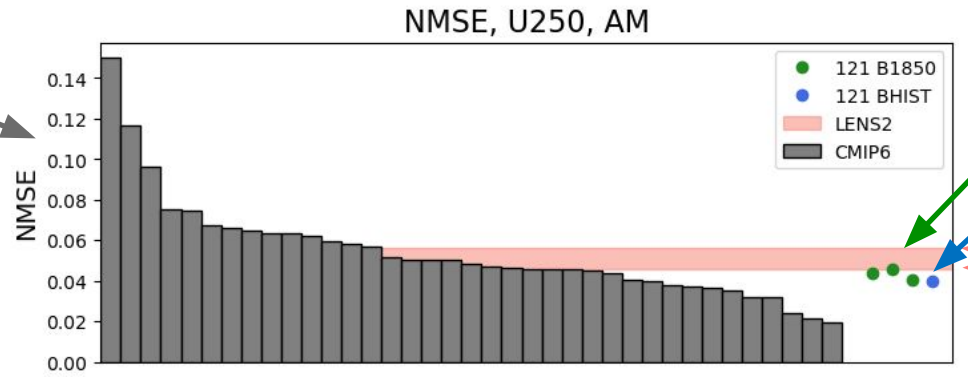






250 hPa zonal wind, Normalized mean squared error, global mean

All the CMIP6 models



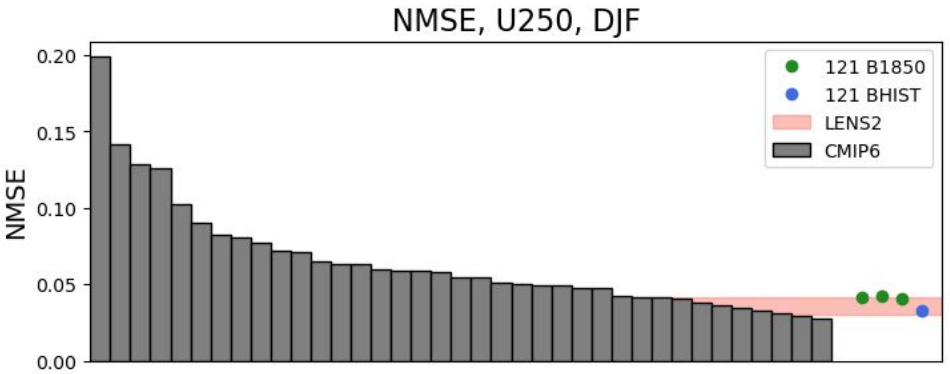
WORST

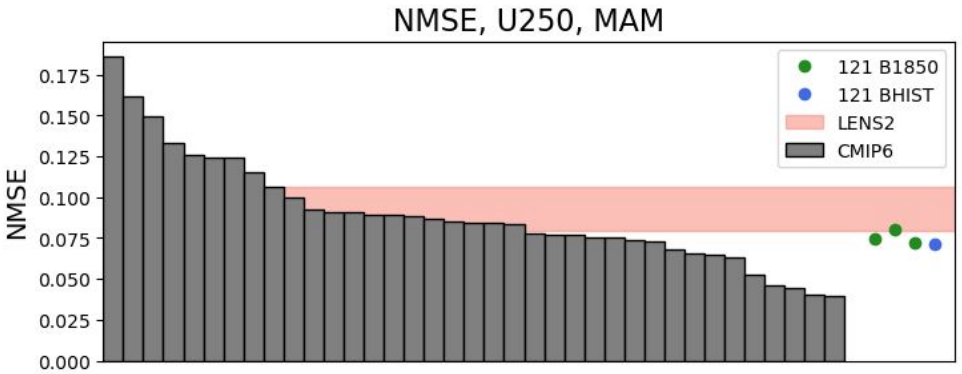
3, 45 year samples from B1850 121

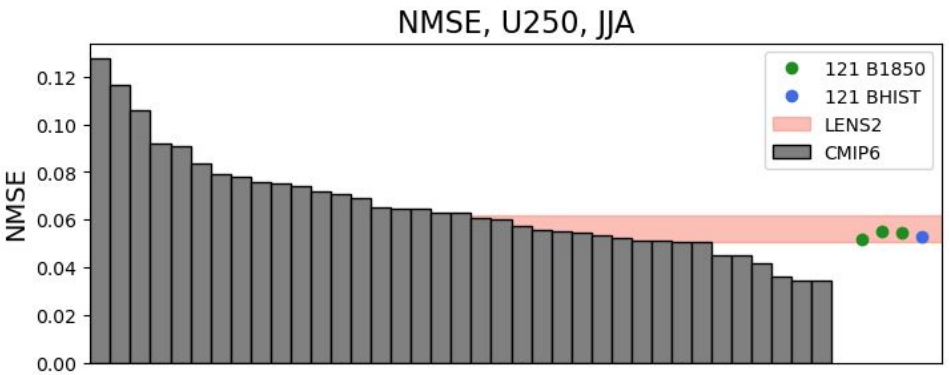
1979 to 2014 BHIST 121

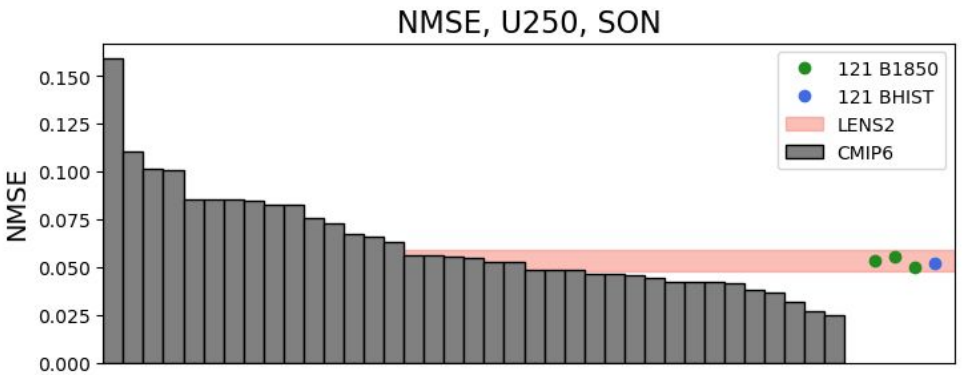
Spread of errors in the CESM2 large ensemble

BEST

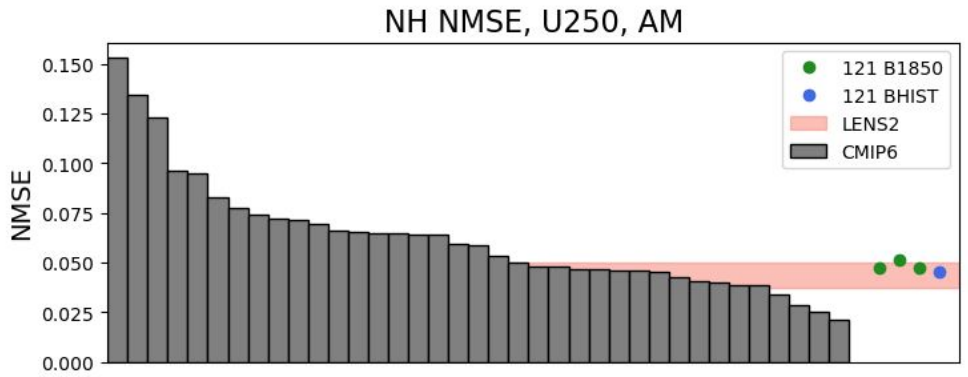


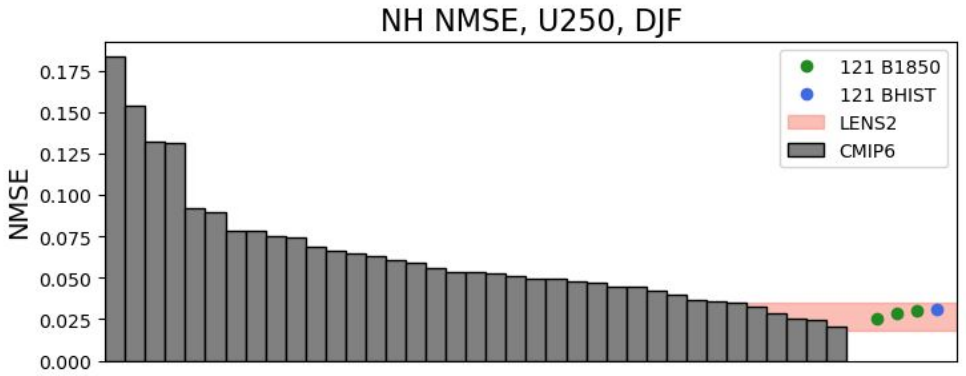


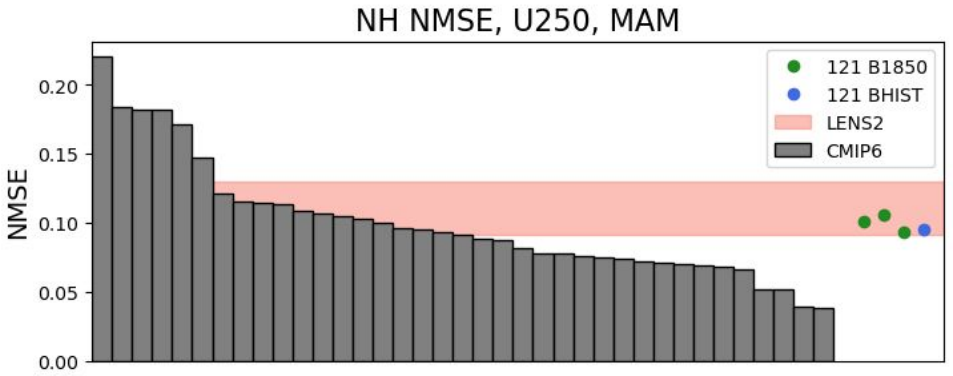


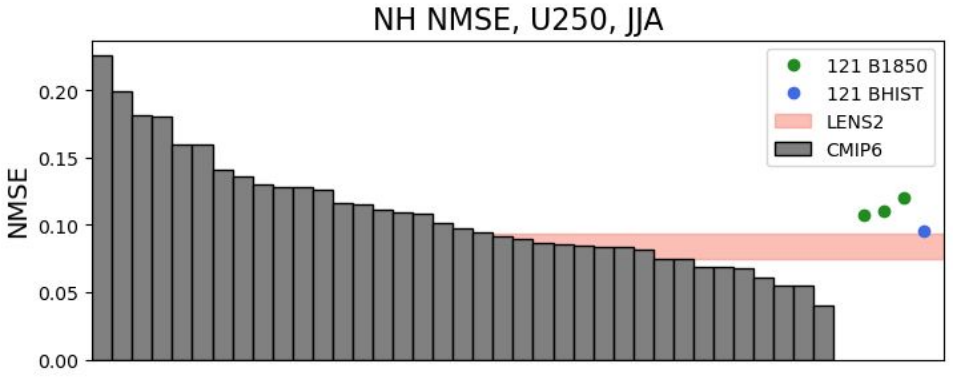


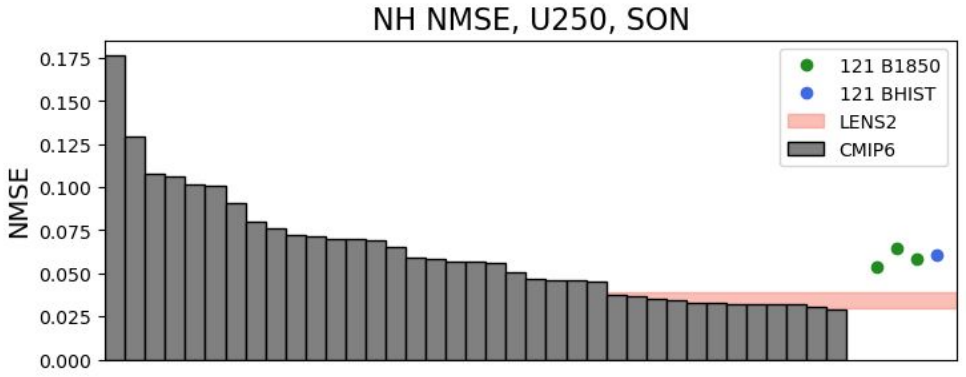
250 hPa zonal wind, Normalized mean squared error, Northern Hemisphere



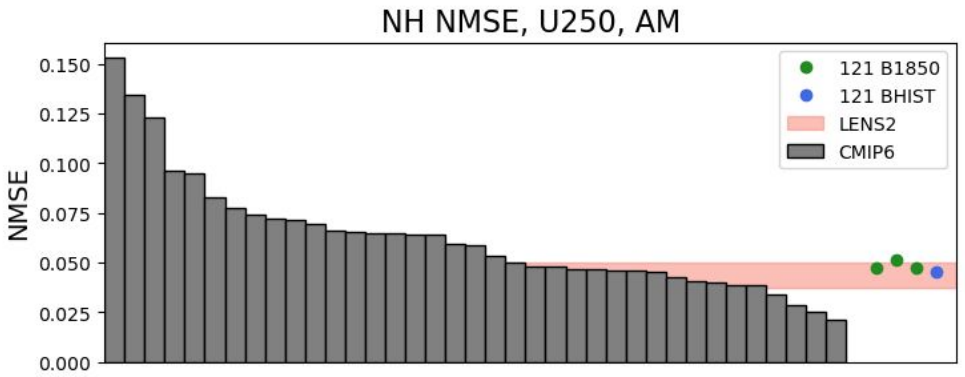




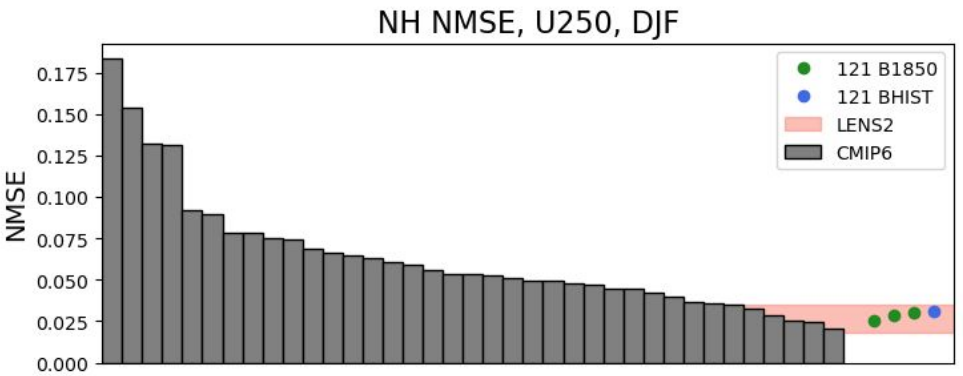


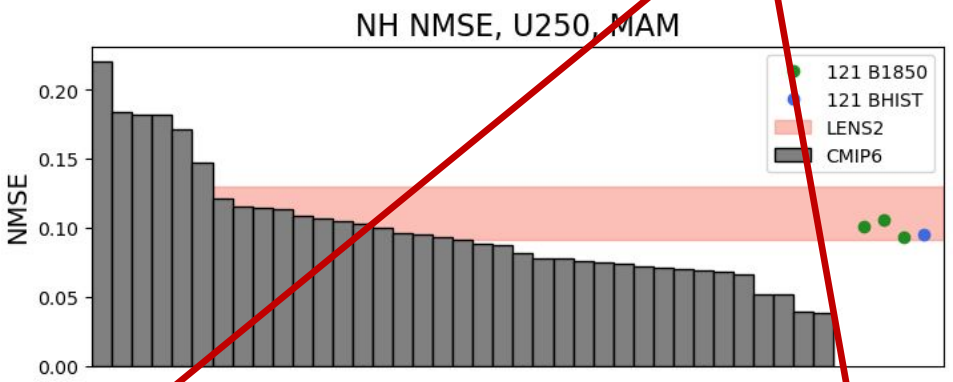


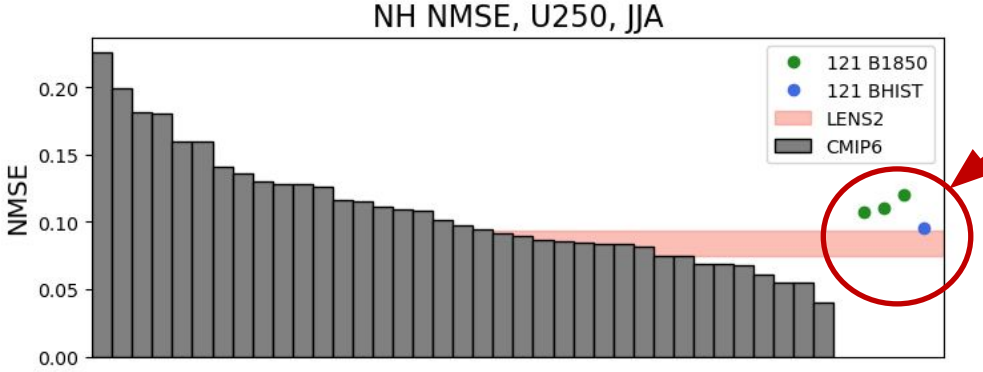
250 hPa zonal wind, Normalized mean squared error, Northern Hemisphere

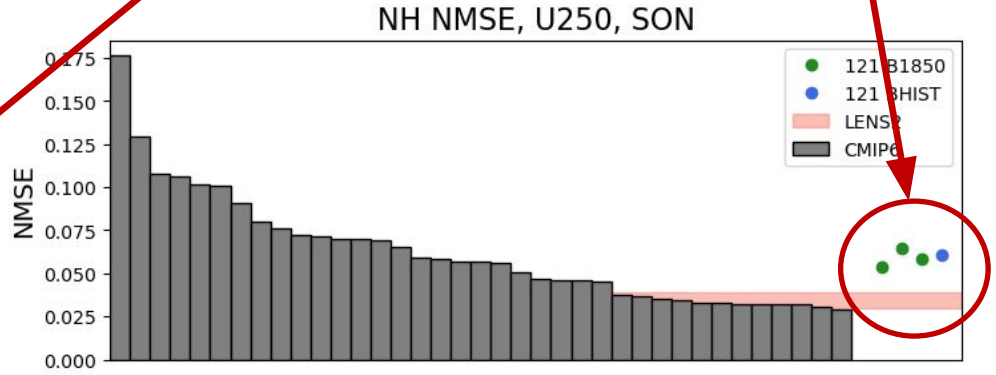


The NH errors have increased a bit in JJA and SON

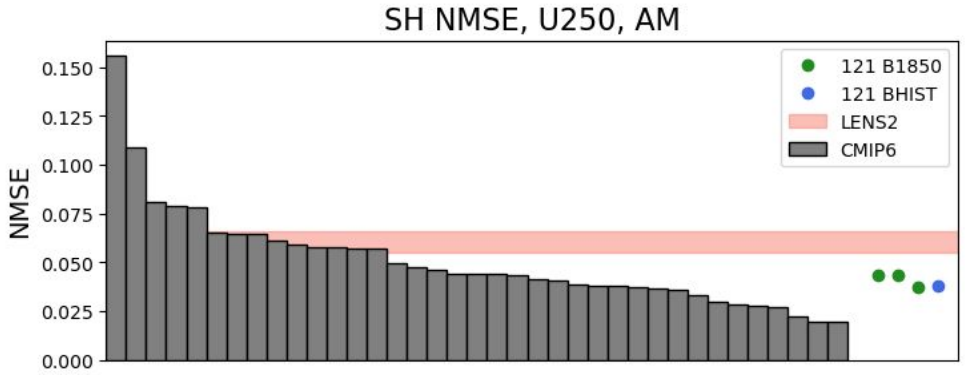


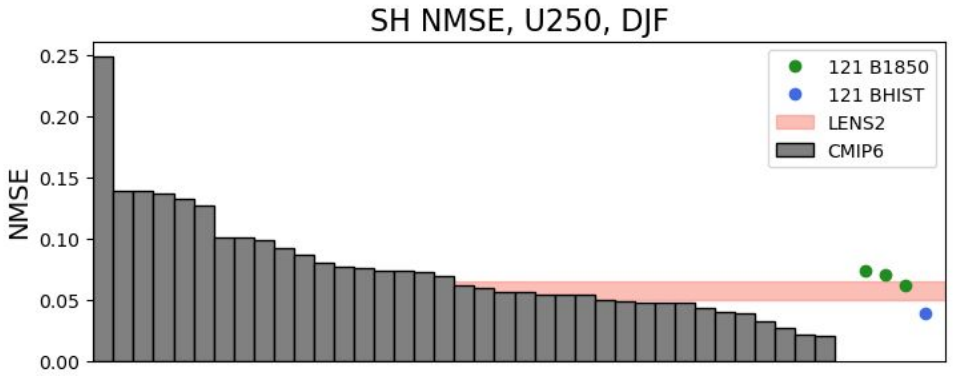


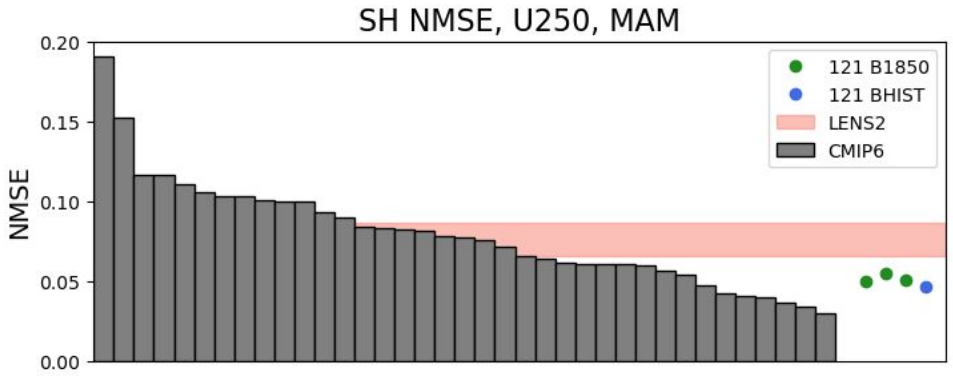


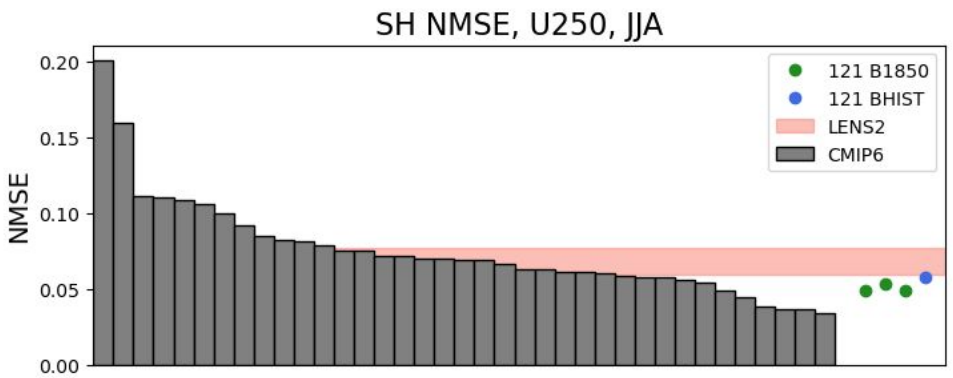


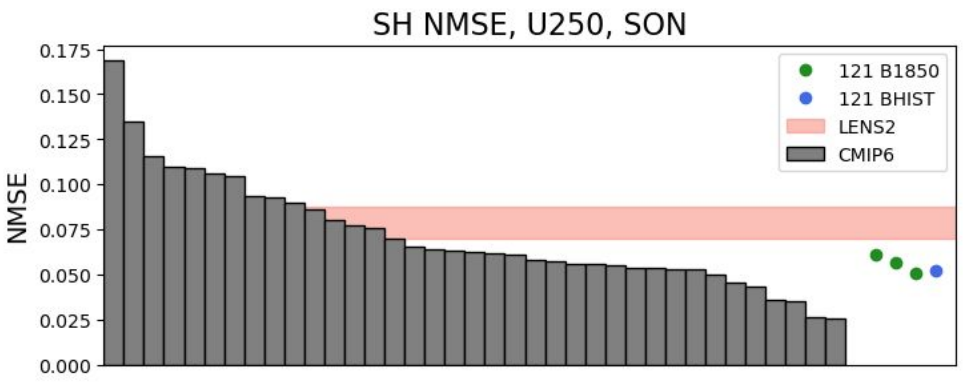
250 hPa zonal wind, Normalized mean squared error, Southern Hemisphere



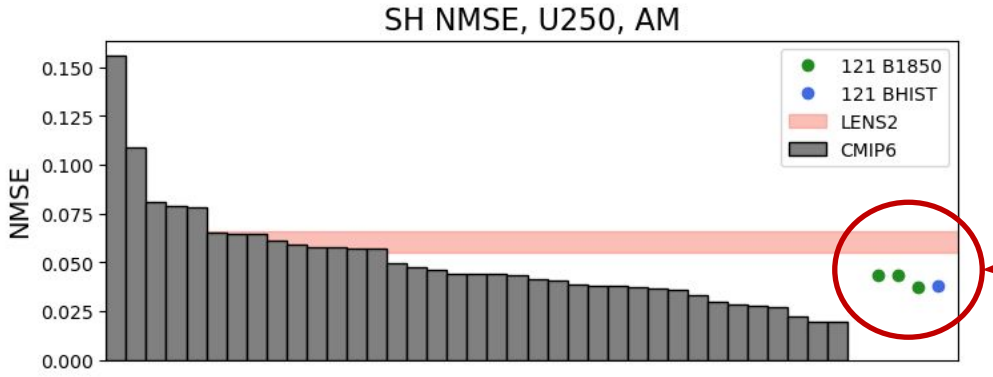




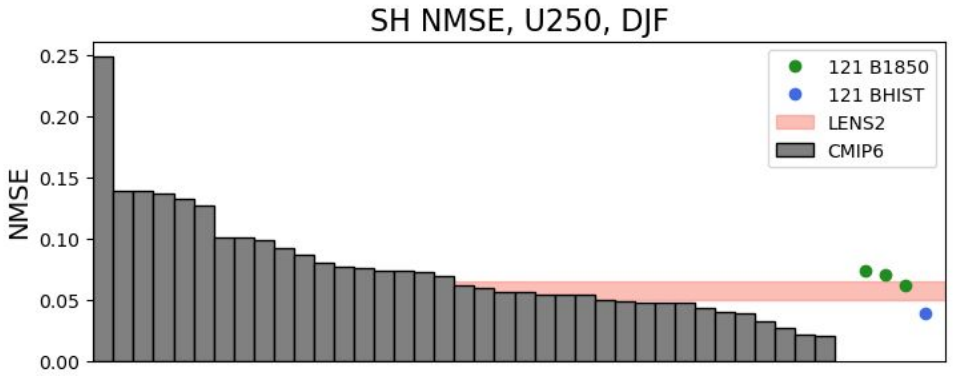


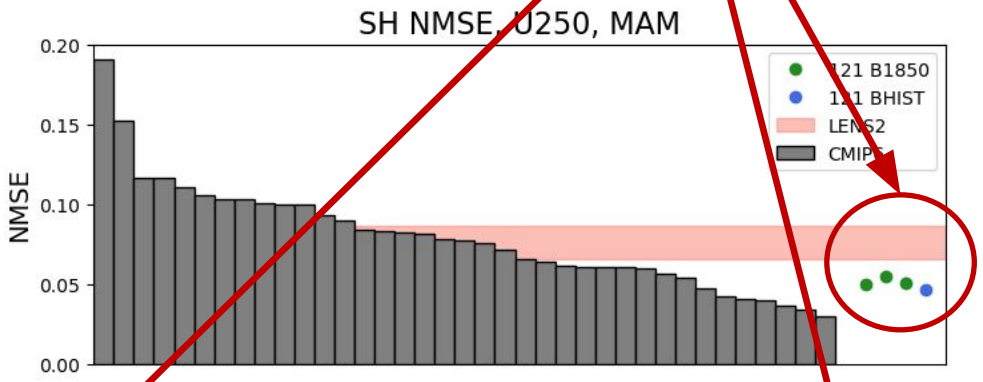


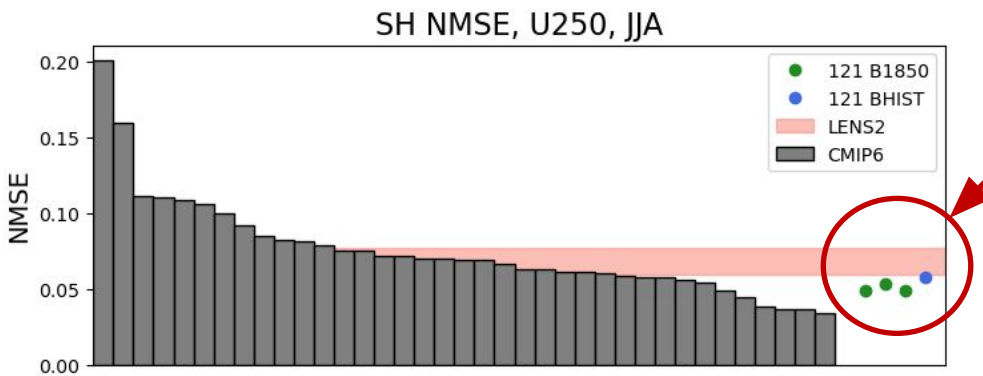
250 hPa zonal wind, Normalized mean squared error, Southern Hemisphere

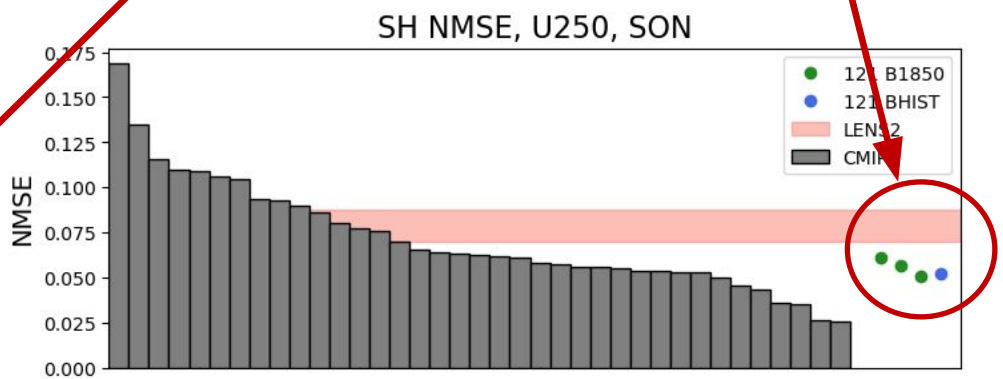


The SH has improved in most seasons and the annual mean 🙂



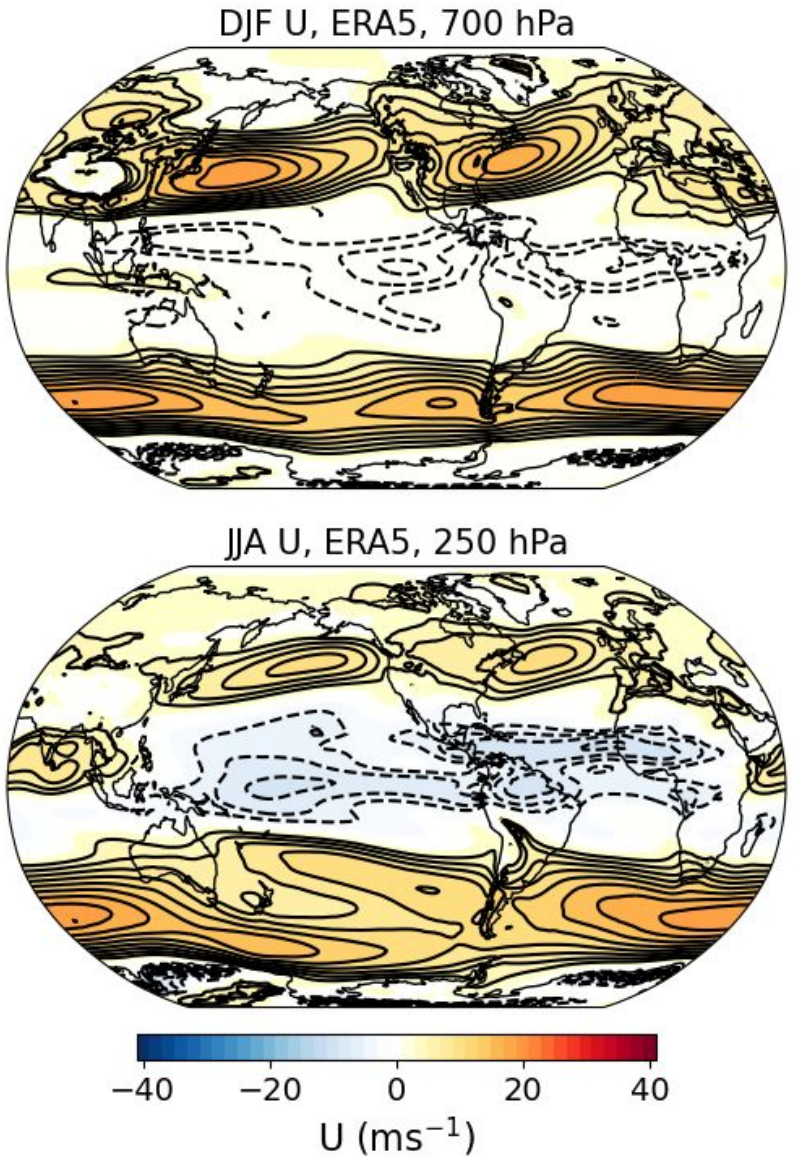






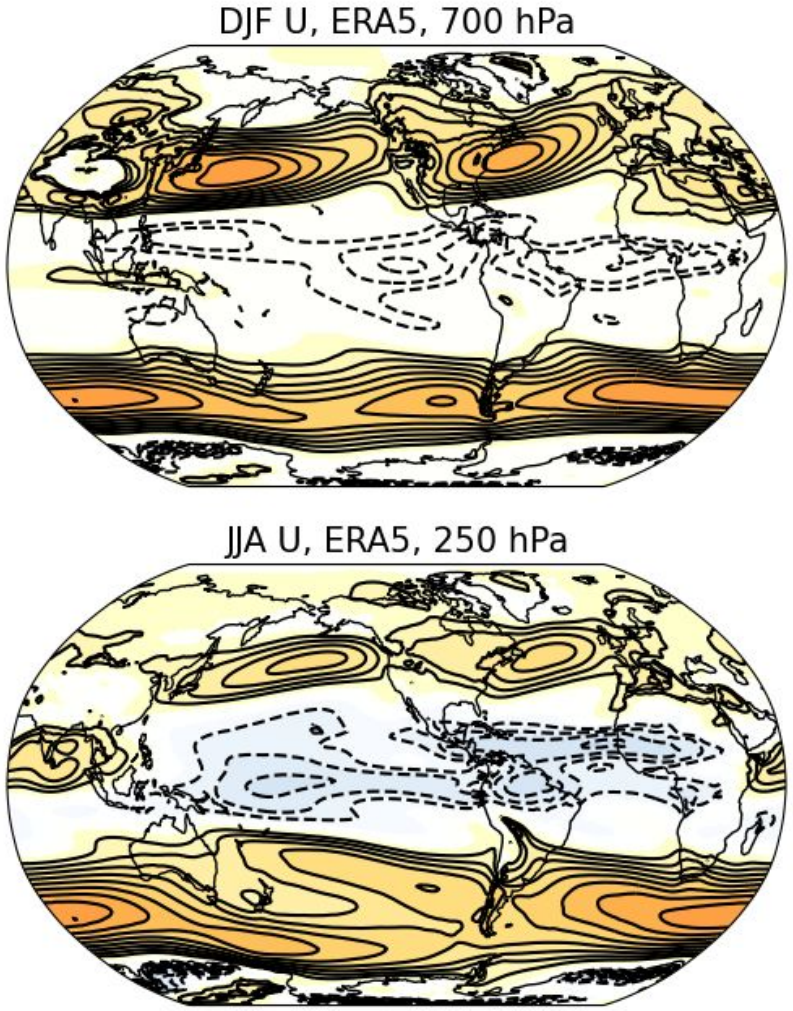
700 hPa zonal wind

ERA5

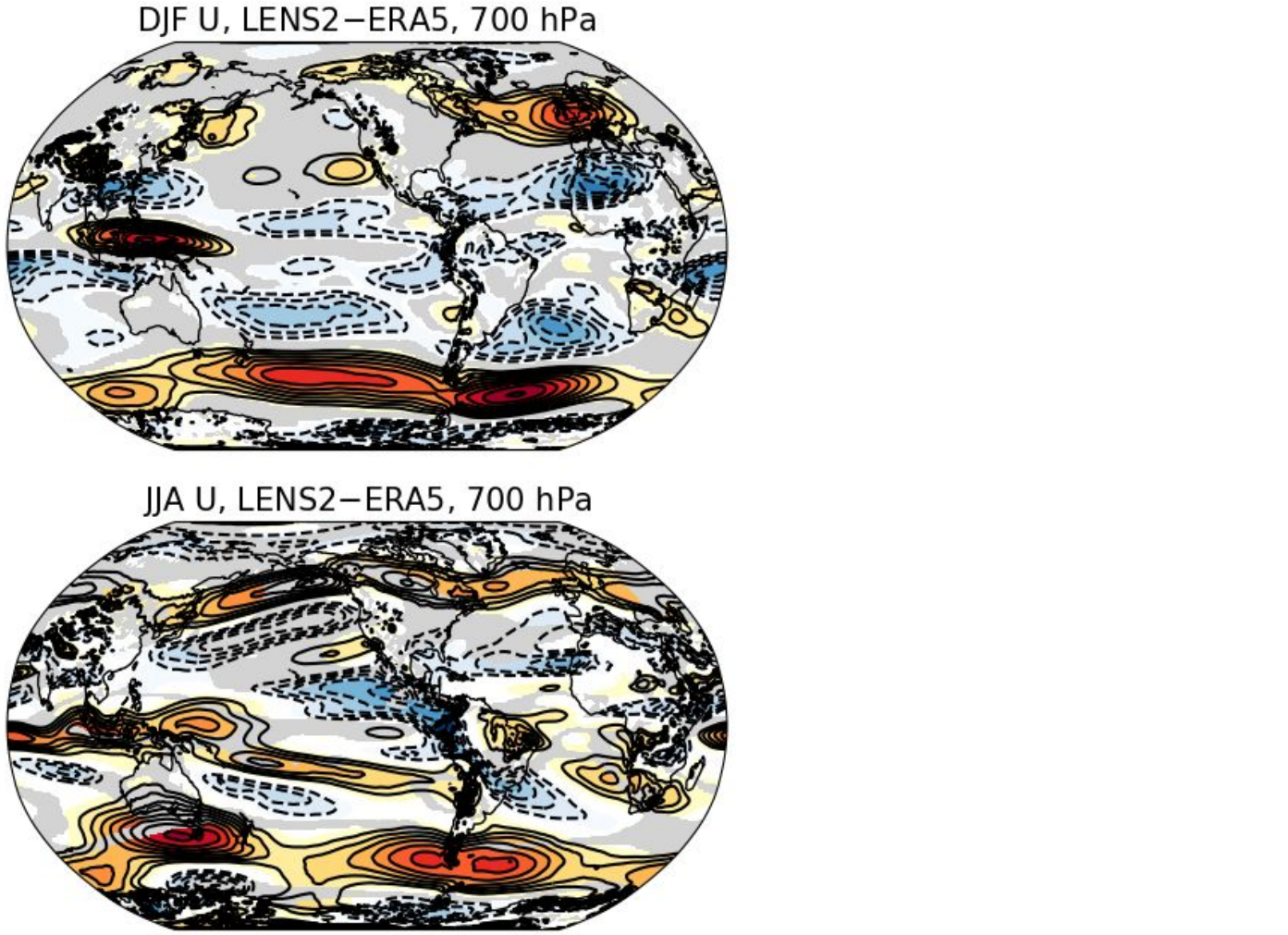


700 hPa zonal wind

ERA5

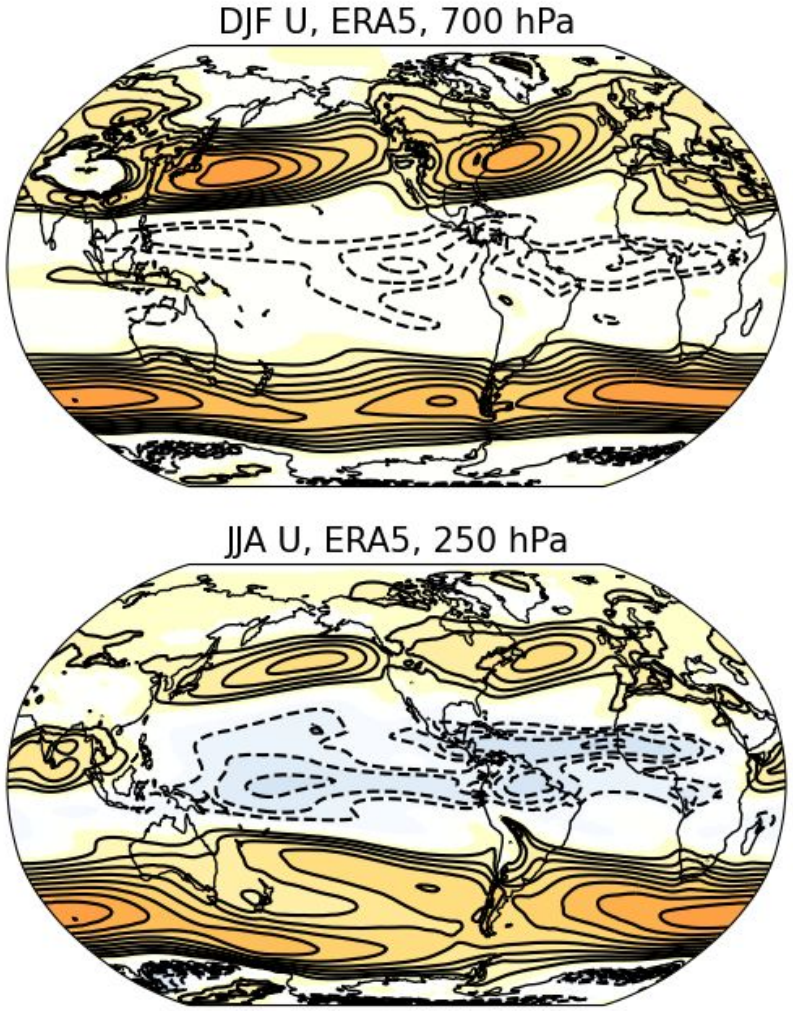


CESM2 – ERA5

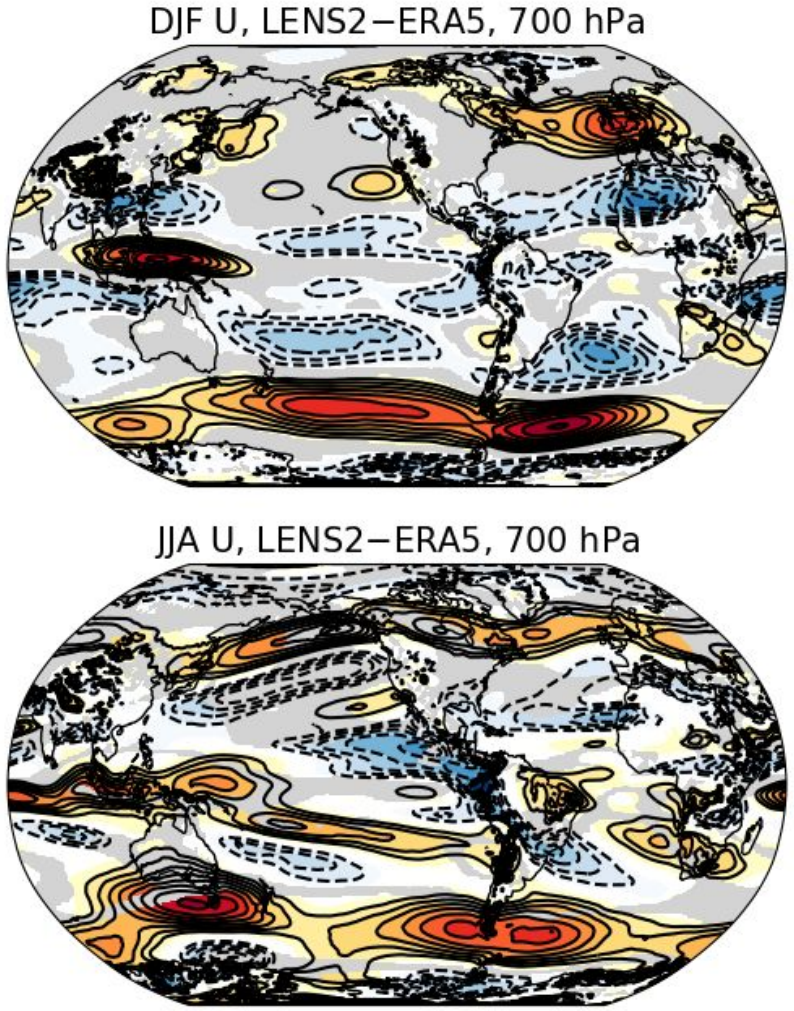


700 hPa zonal wind

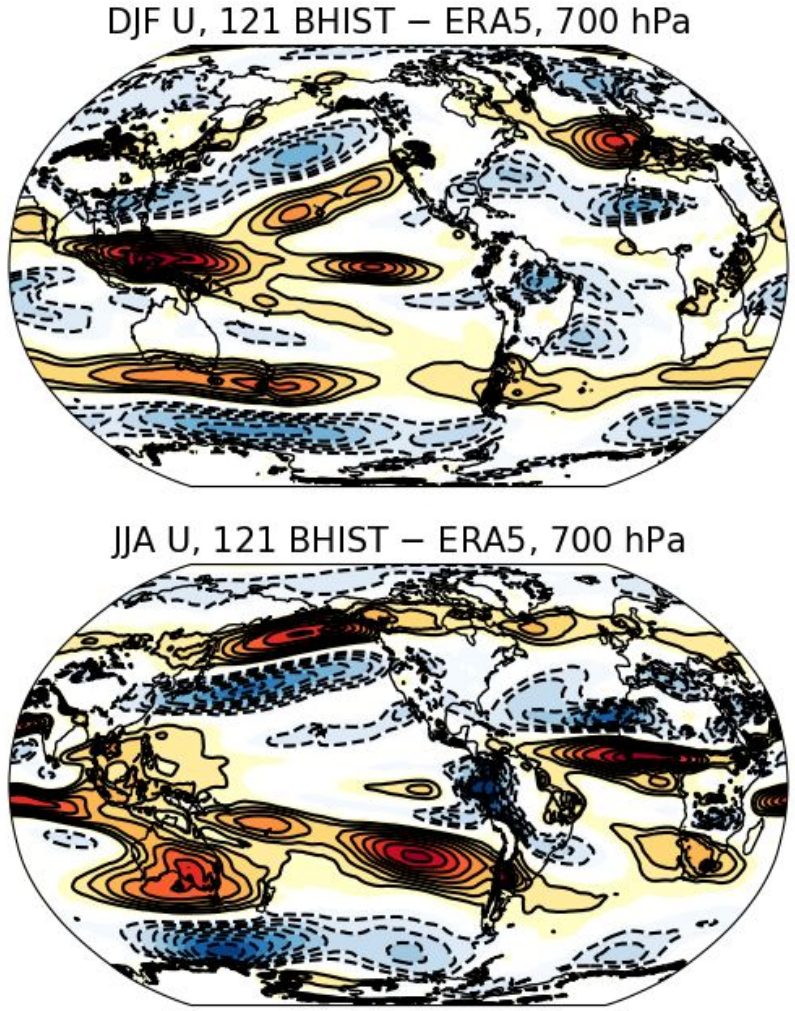
ERA5



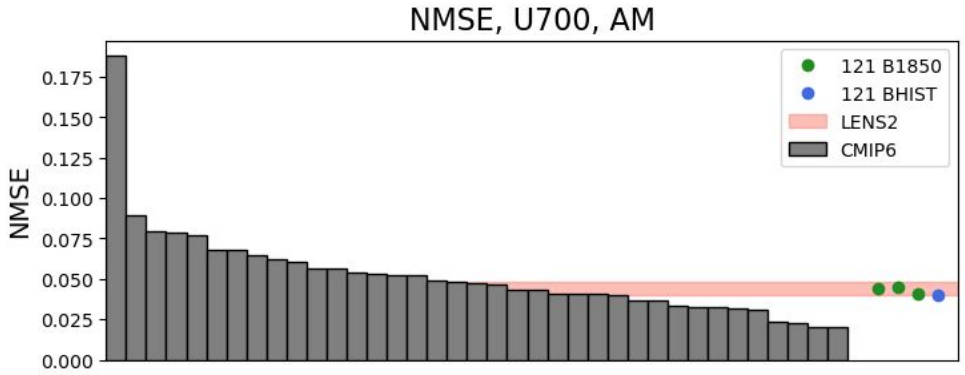
CESM2 – ERA5

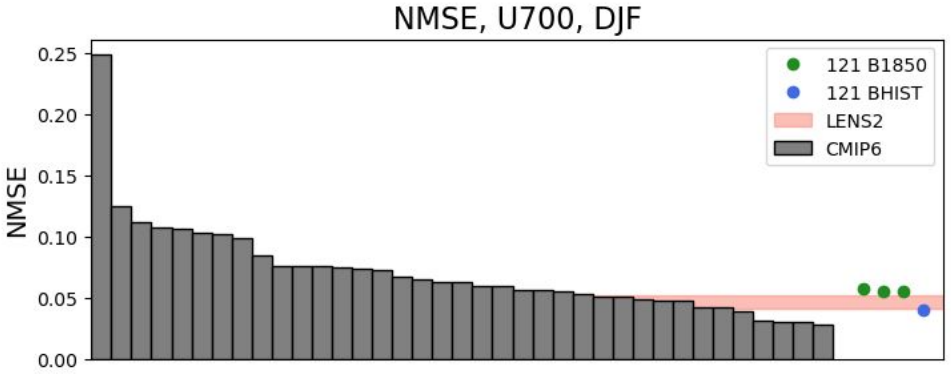


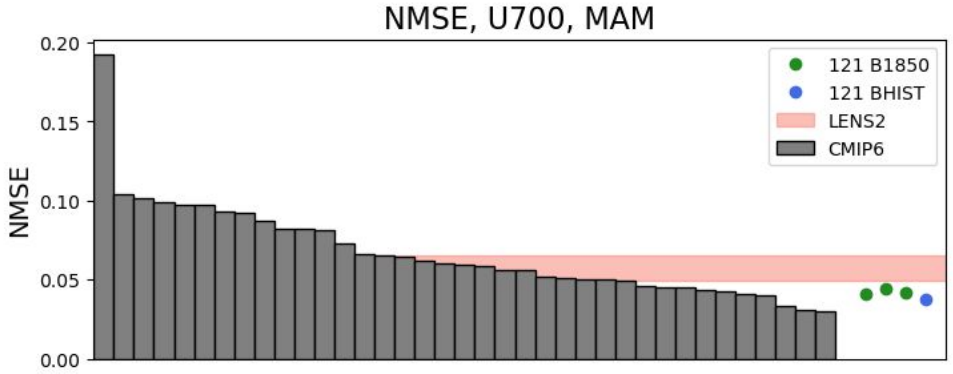
CESM3 – ERA5

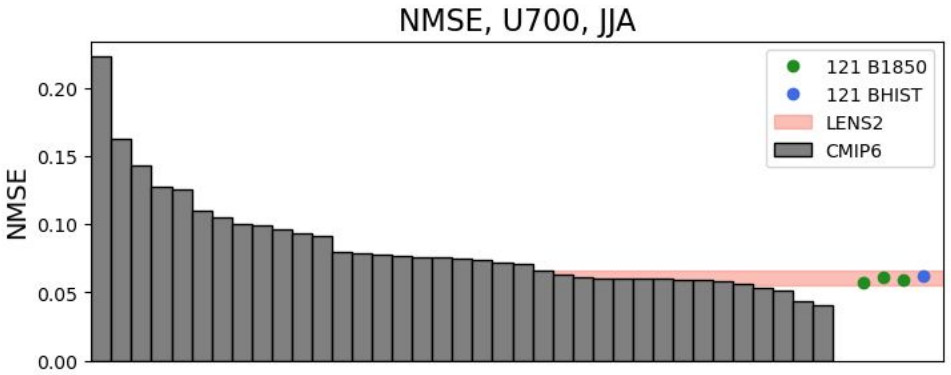


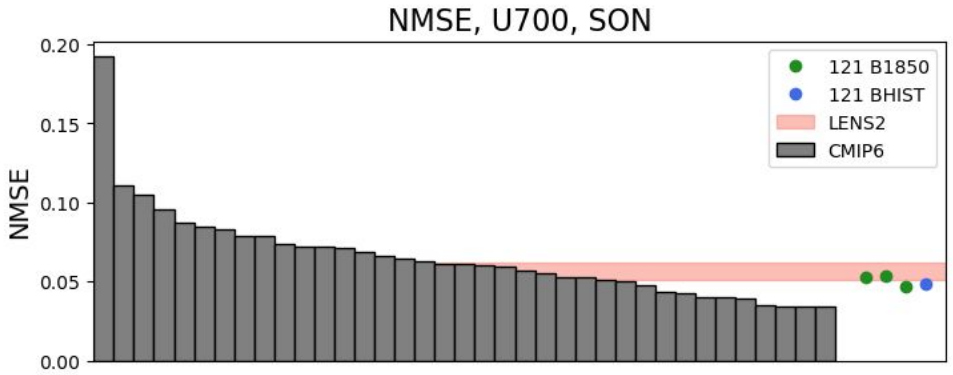
700 hPa zonal wind, Normalized mean squared error, global mean



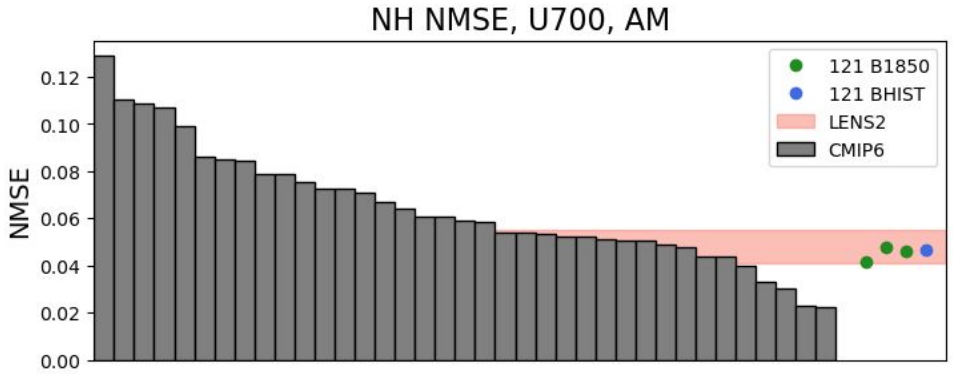


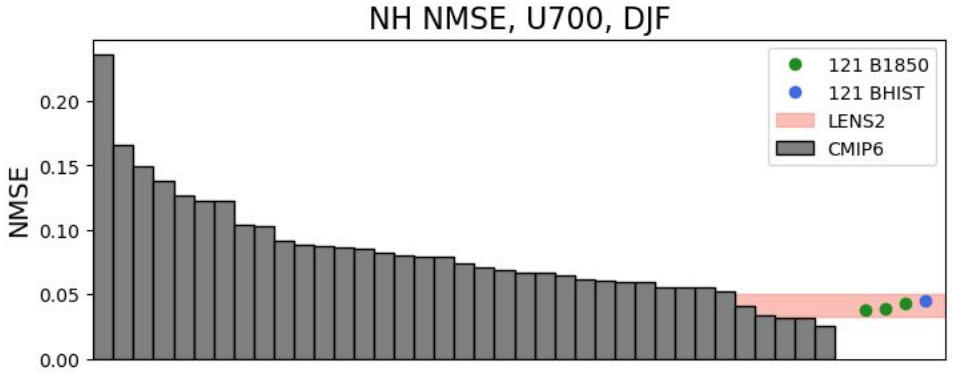


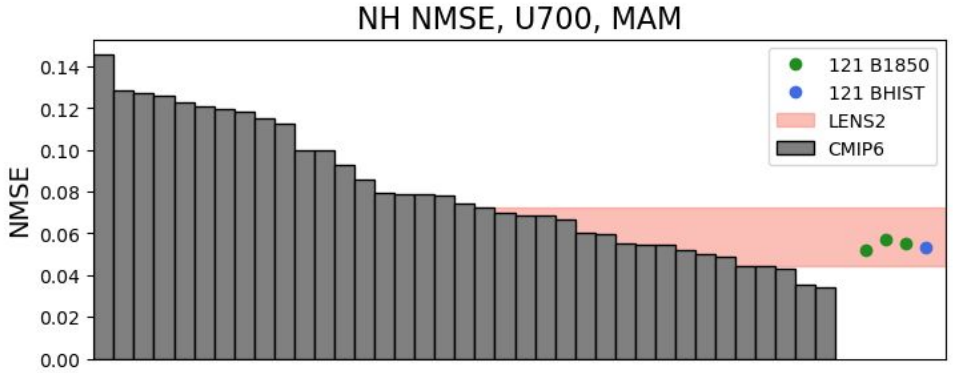


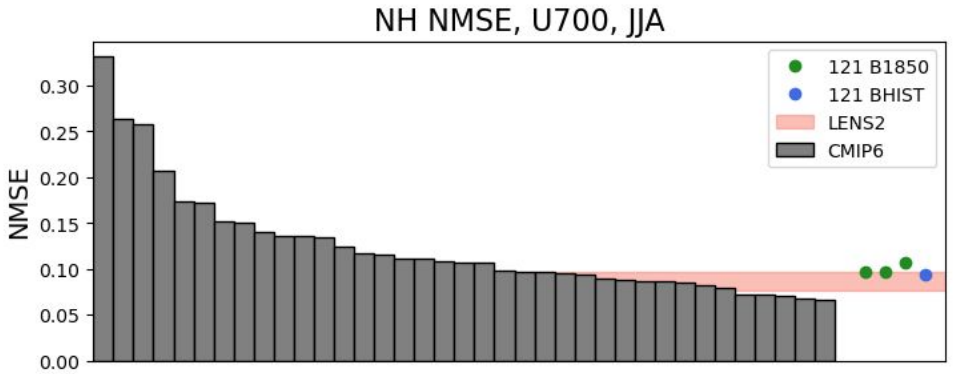


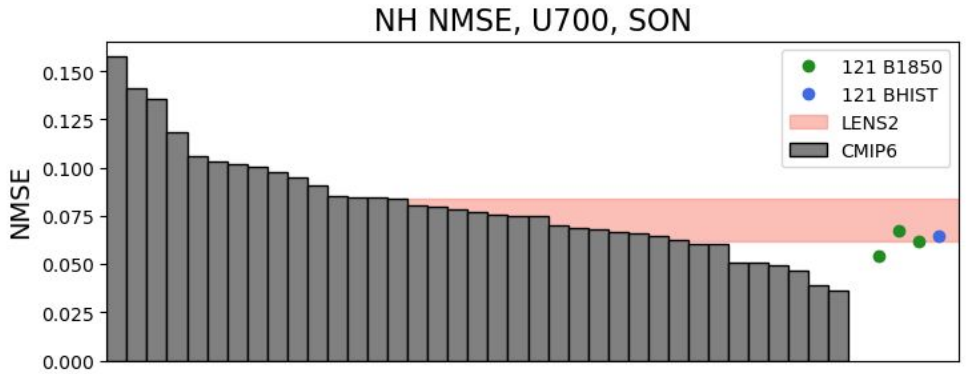
700 hPa zonal wind, Normalized mean squared error, northern hemisphere



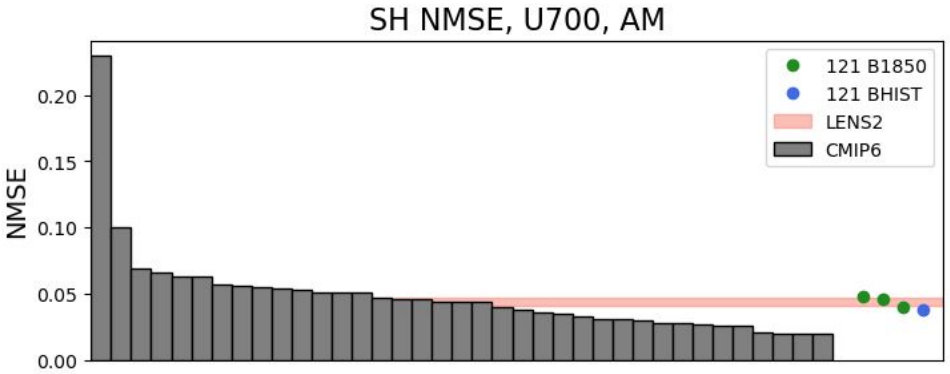




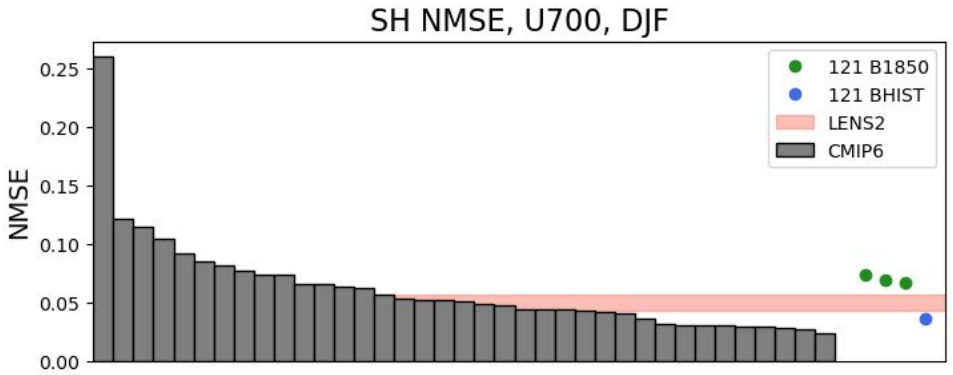


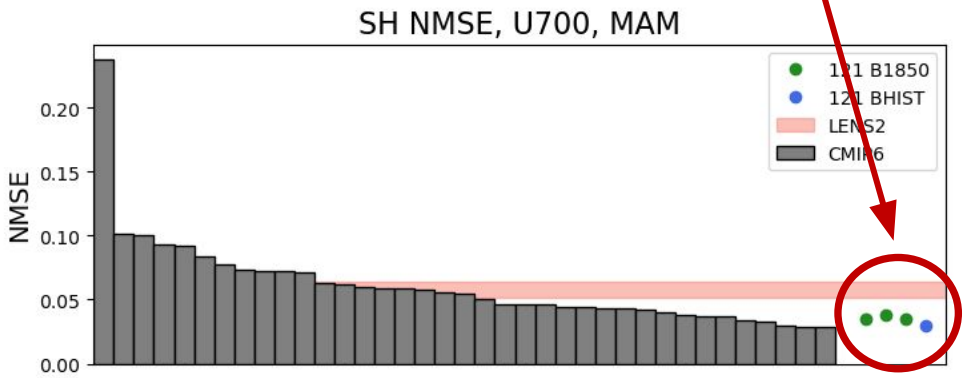


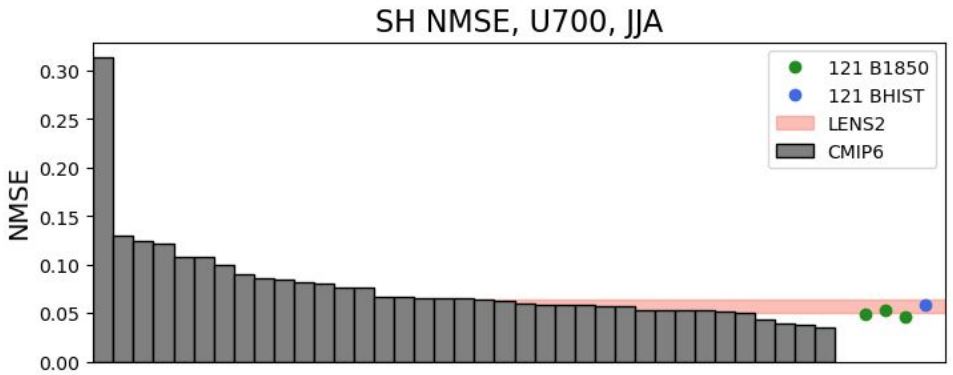
700 hPa zonal wind, Normalized mean squared error, southern hemisphere

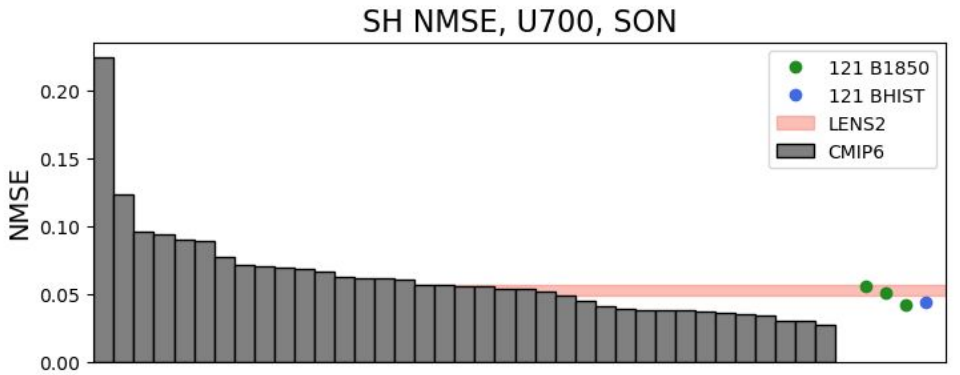


Improvements in SH fall



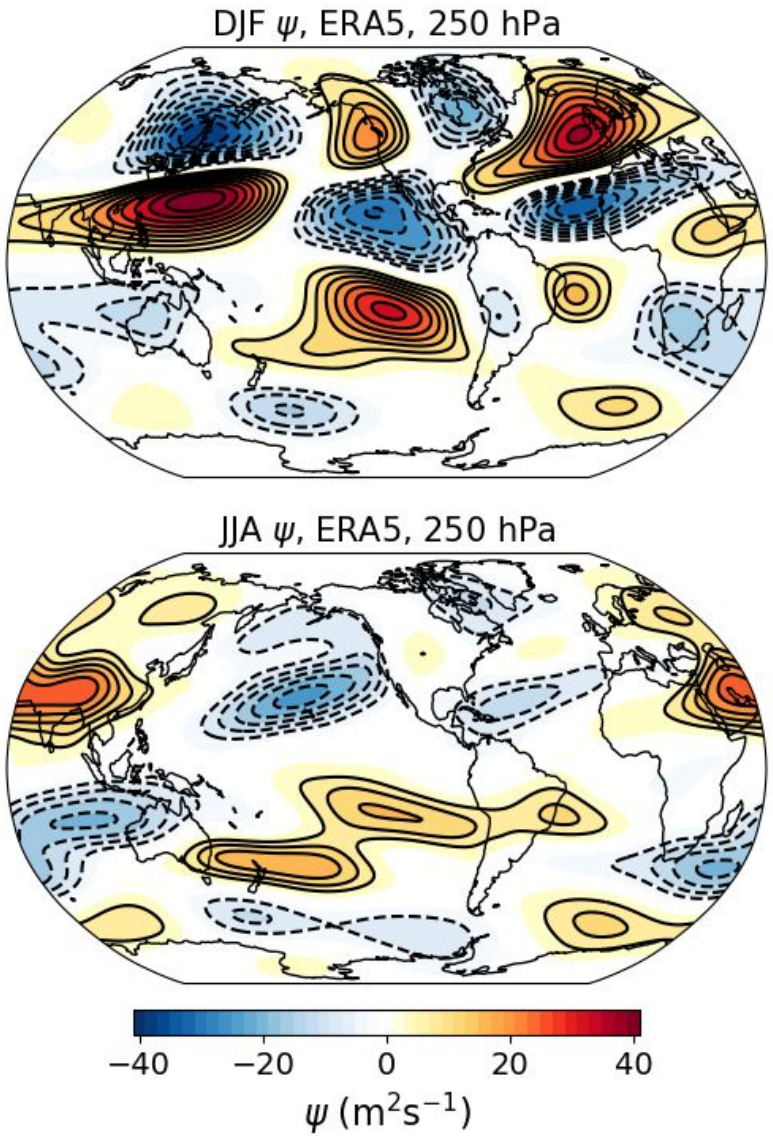






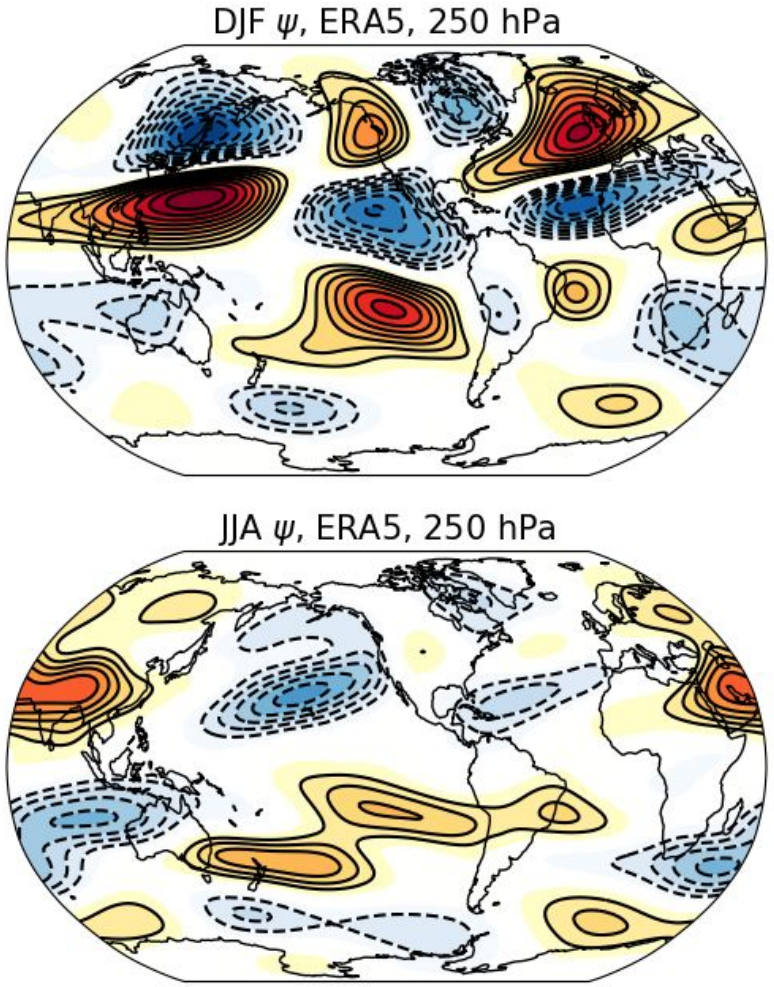
250 hPa eddy streamfunction

ERA5

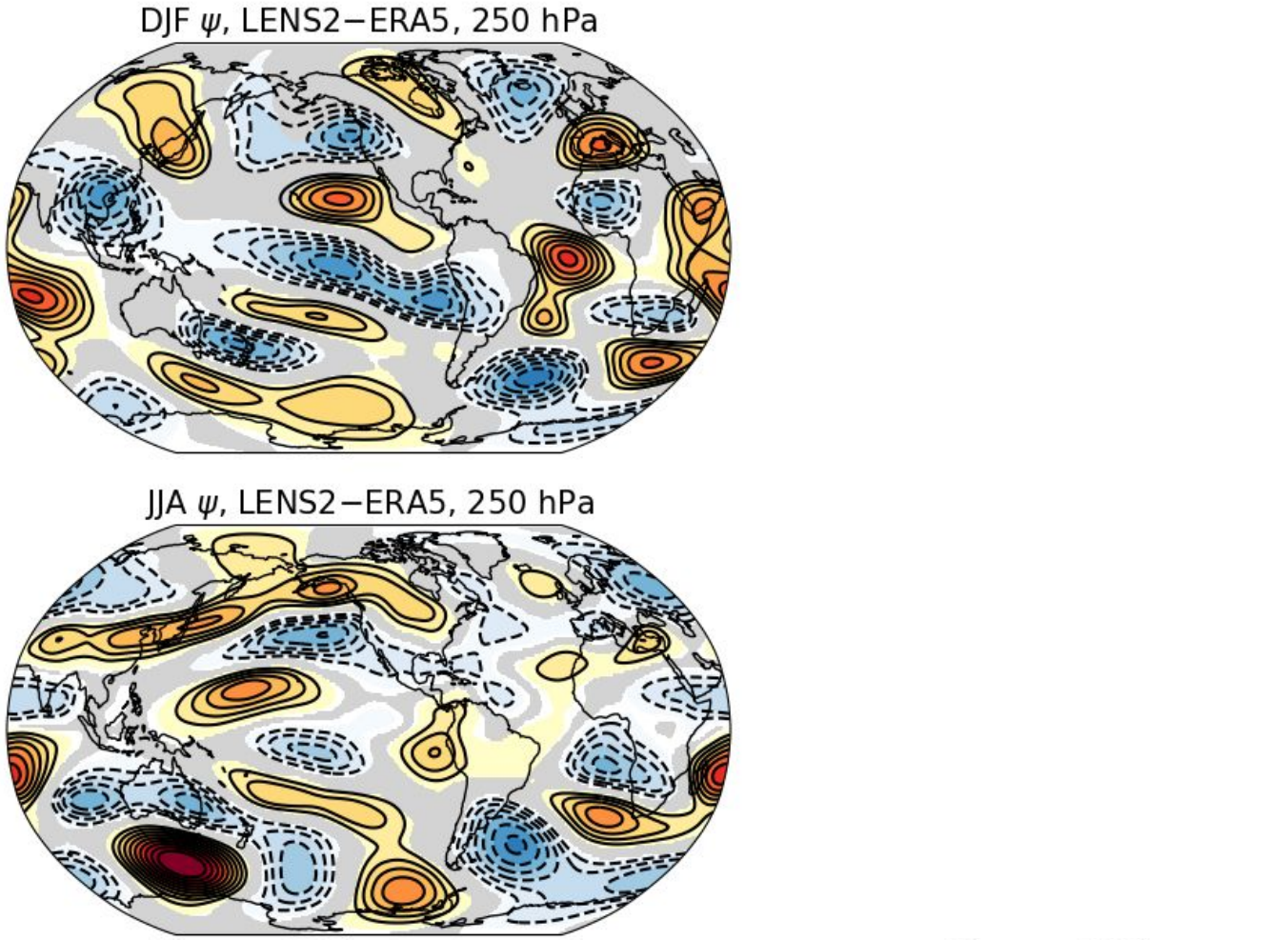


250 hPa eddy streamfunction

ERA5

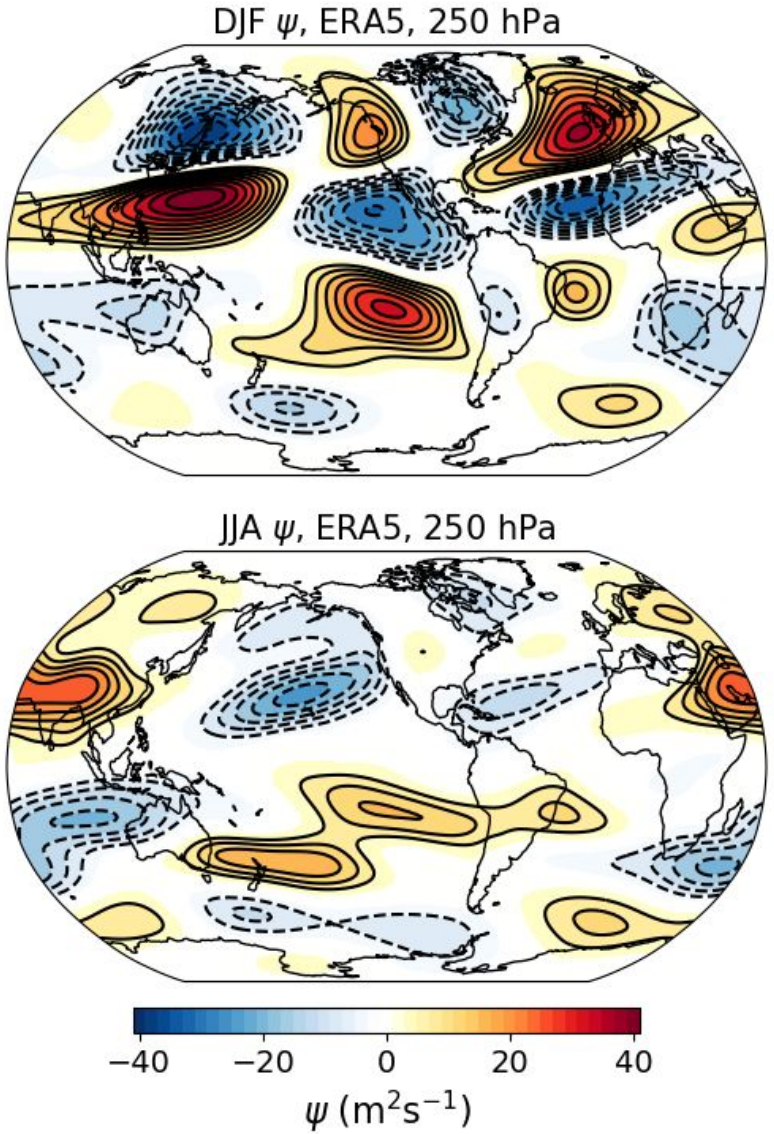


CESM2 – ERA5



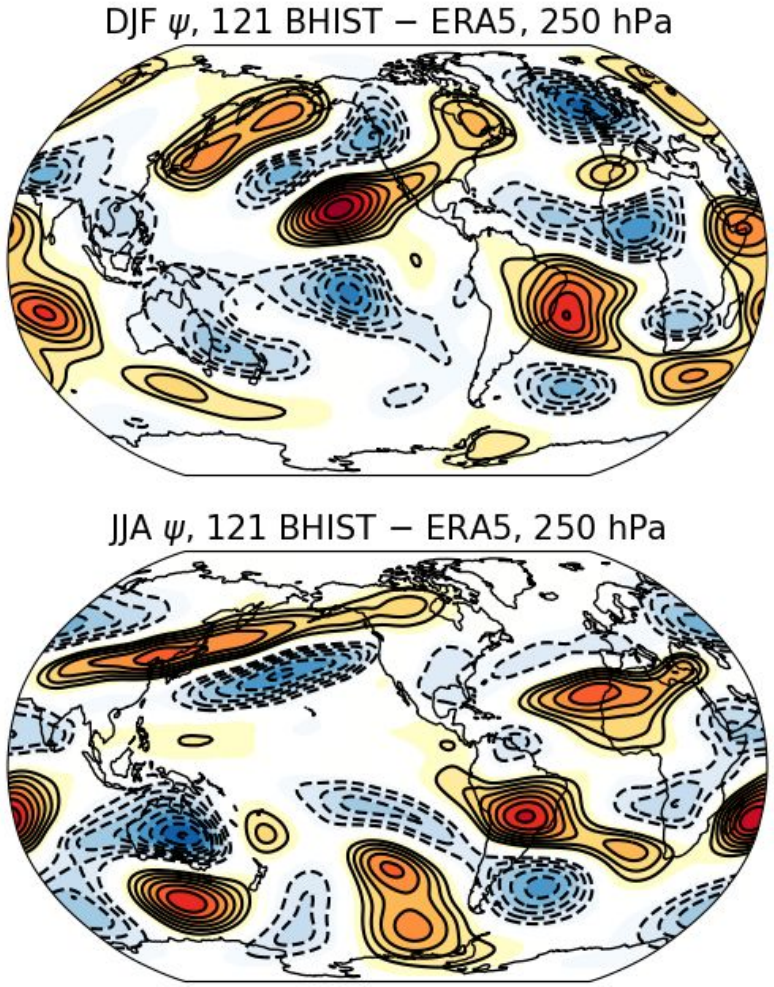
250 hPa eddy streamfunction

ERA5

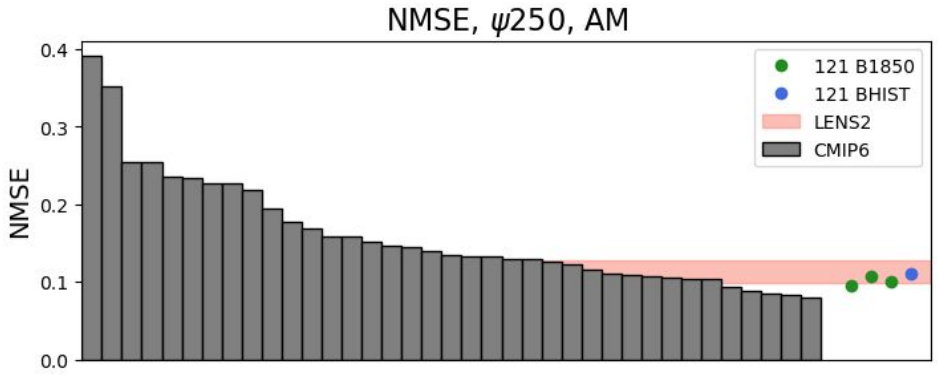


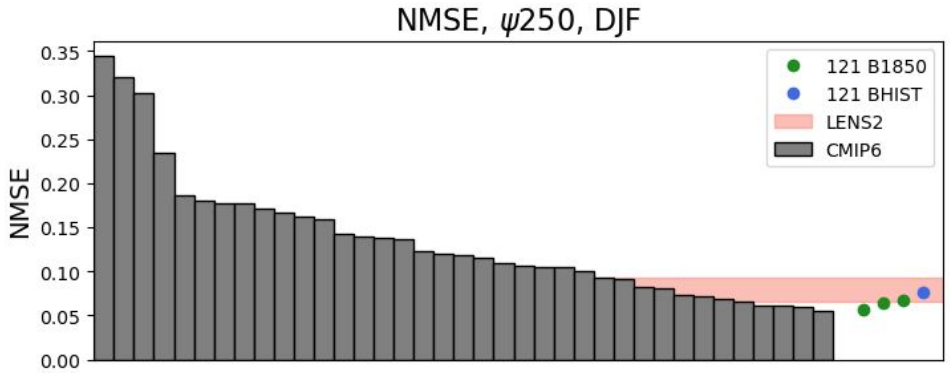
CESM2 – ERA5

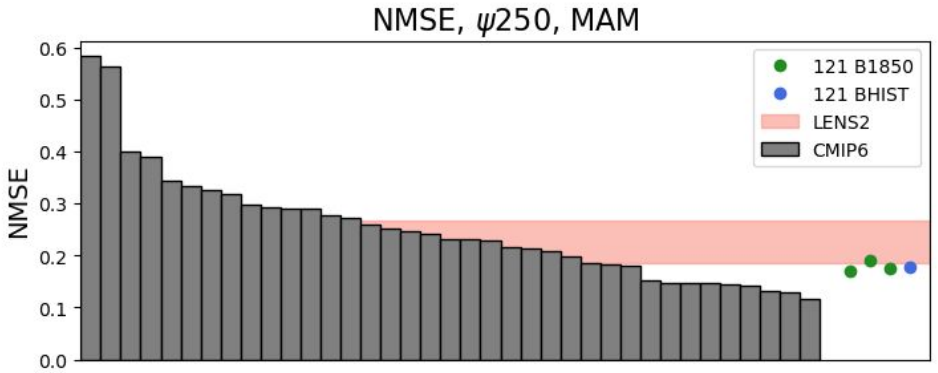
CESM3 – ERA5

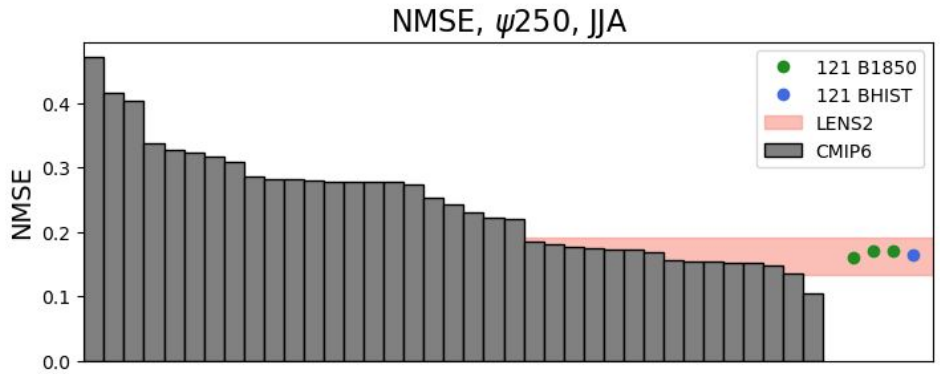


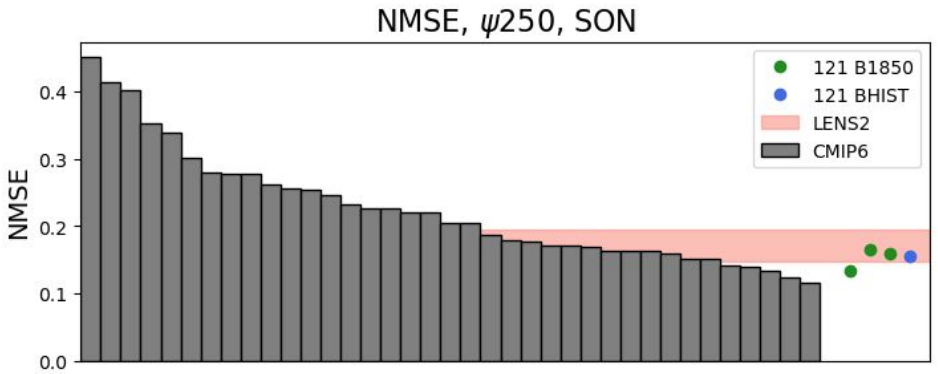
250 hPa eddy stream function, Normalized mean squared error, global mean



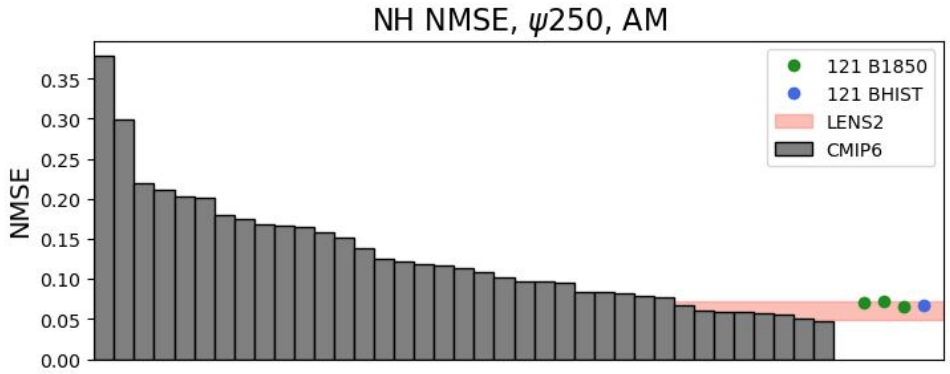


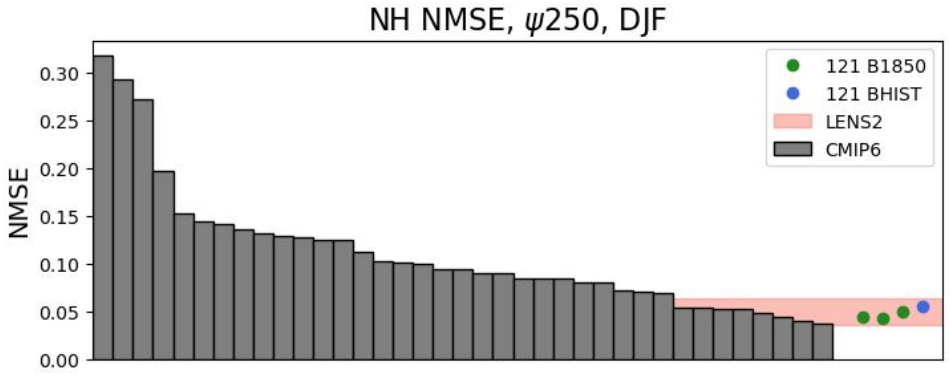


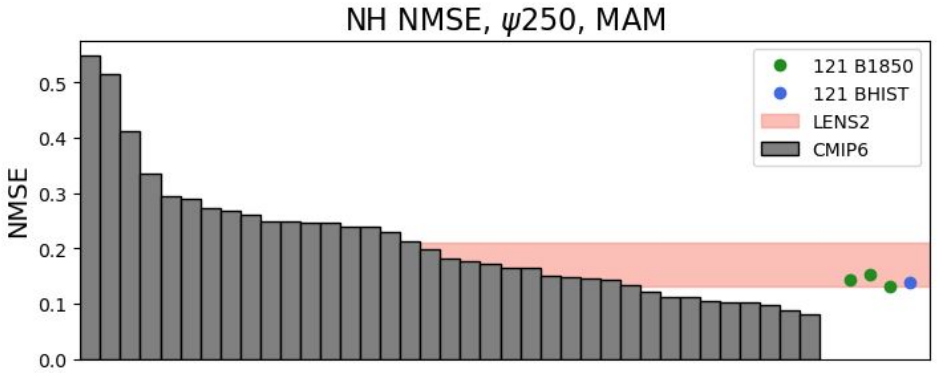


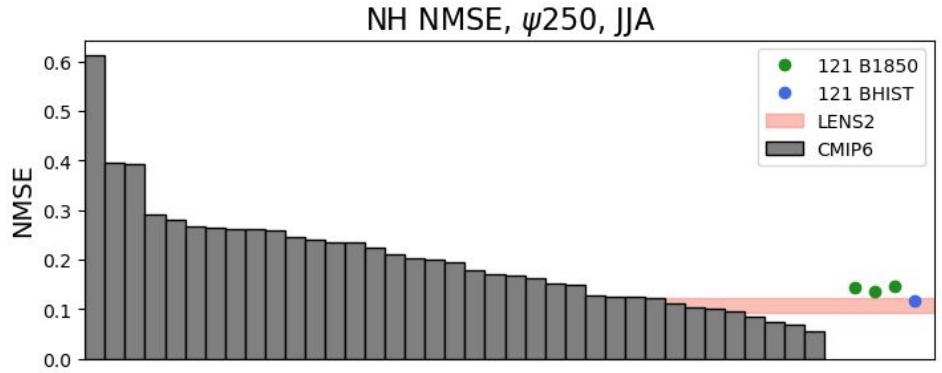


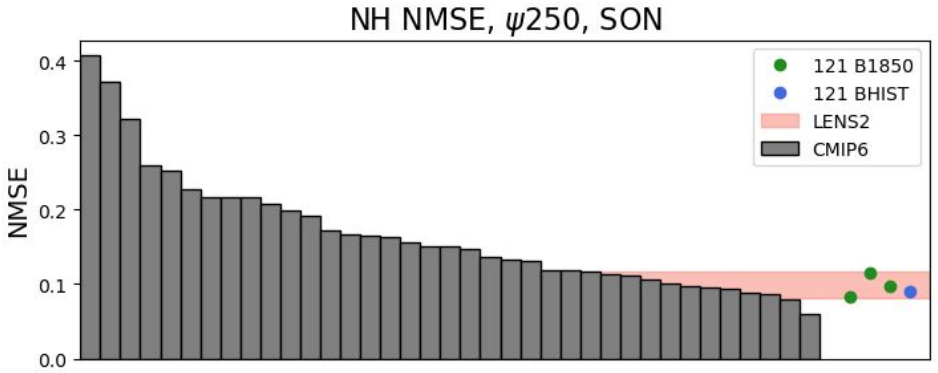
250 hPa eddy stream function, Normalized mean squared error, NH



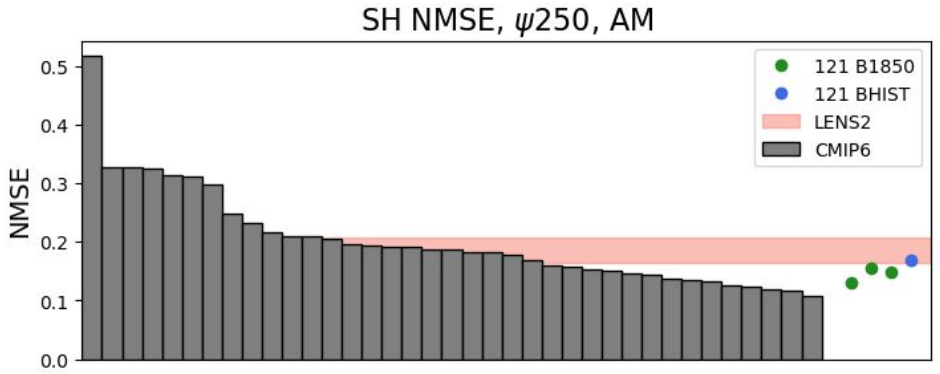


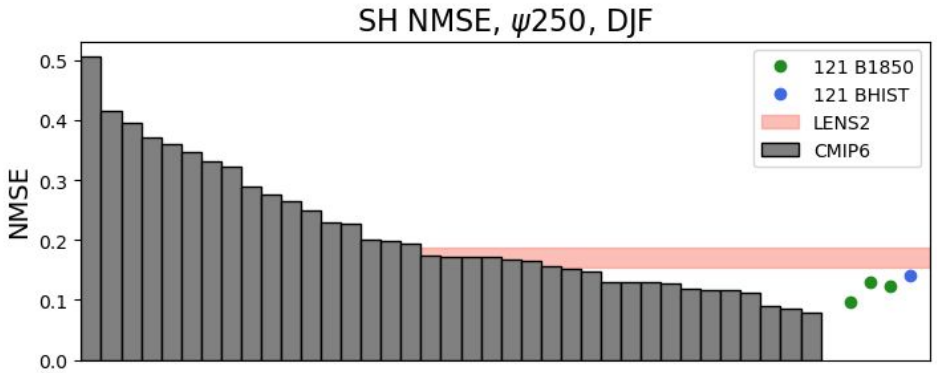


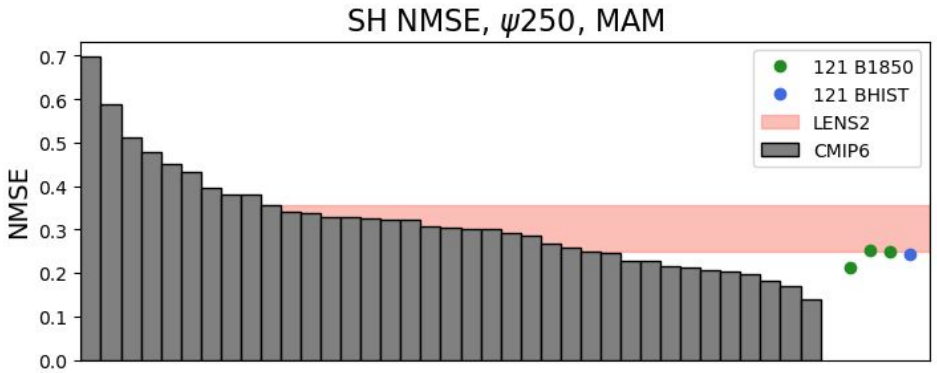


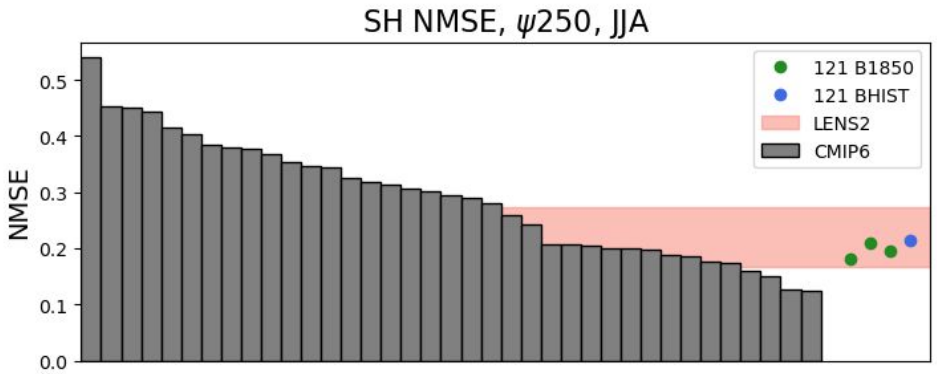


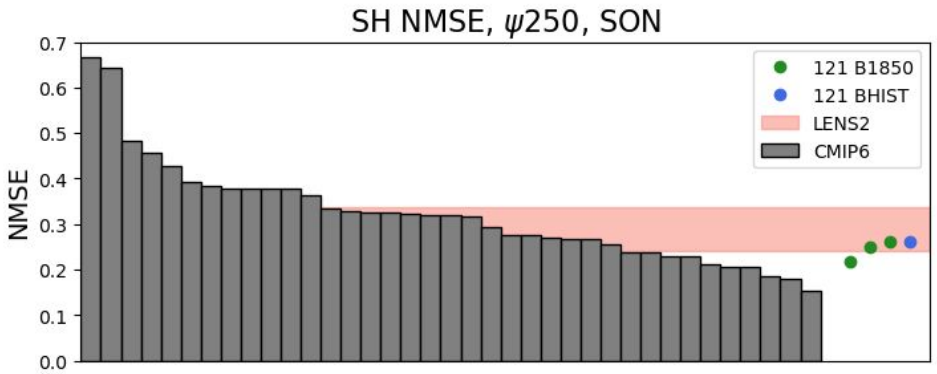
250 hPa eddy stream function, Normalized mean squared error, SH





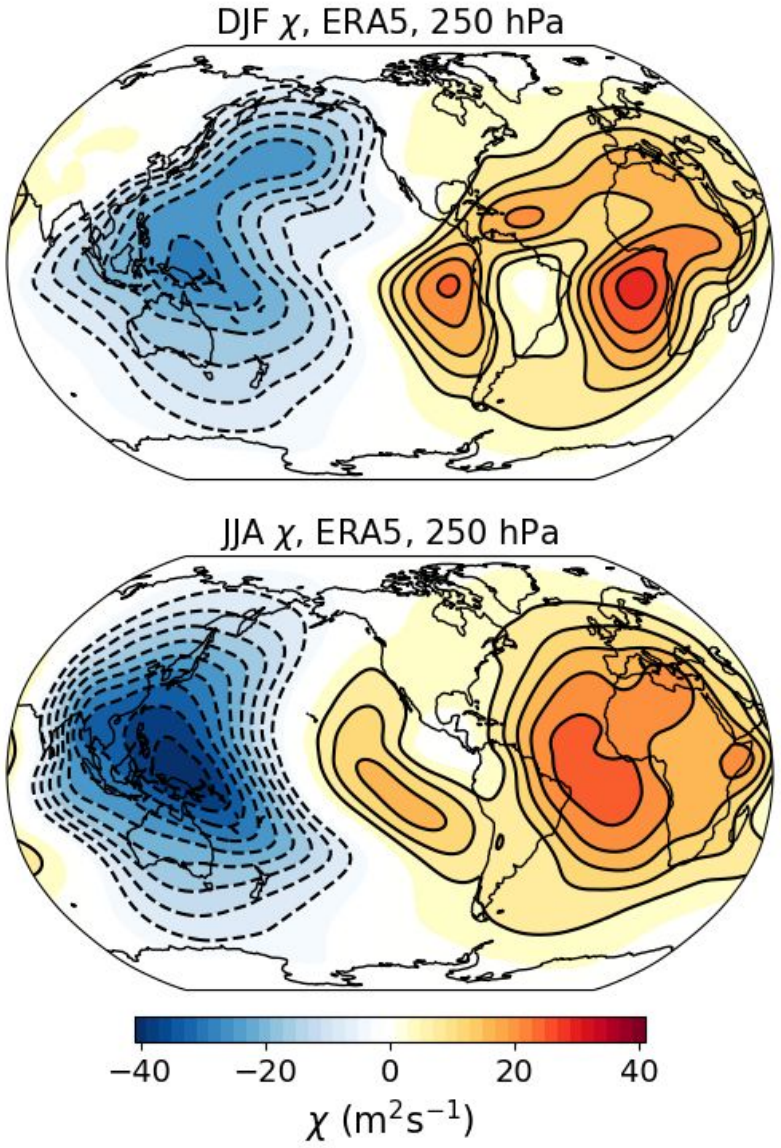






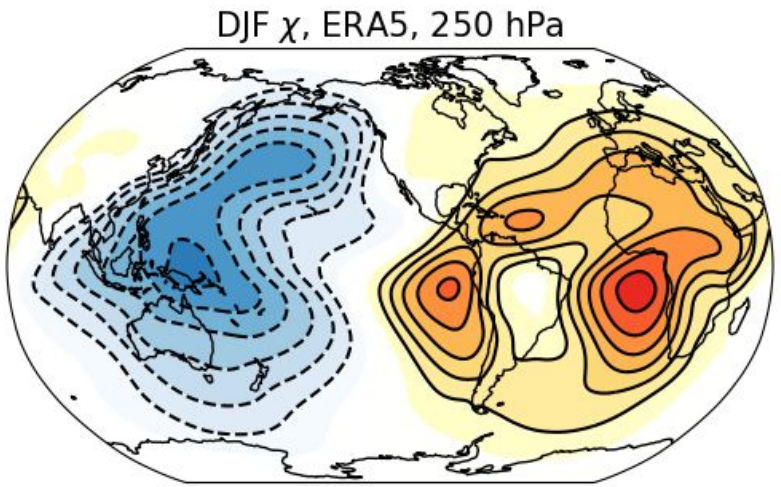
250 hPa velocity potential

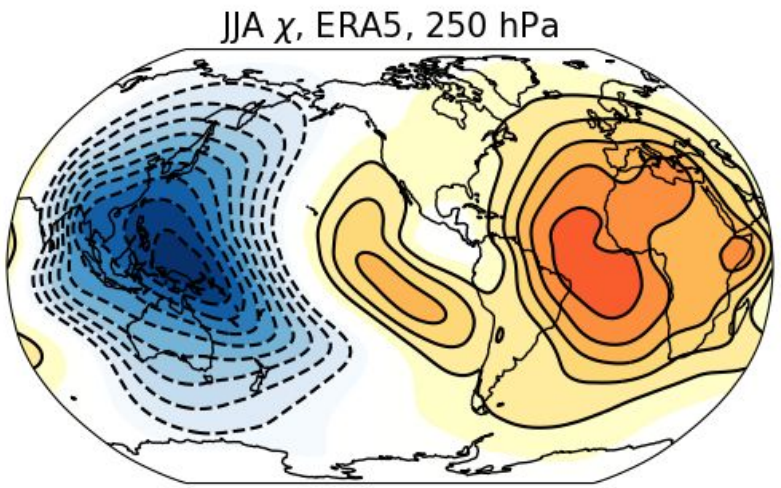
ERA5

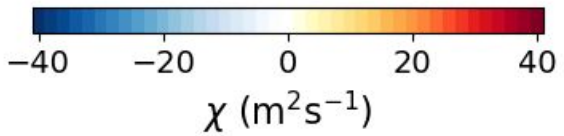


250 hPa velocity potential

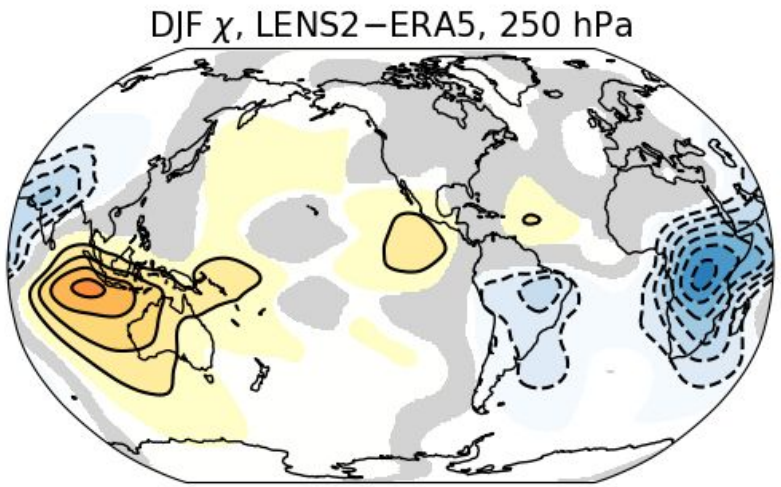
ERA5

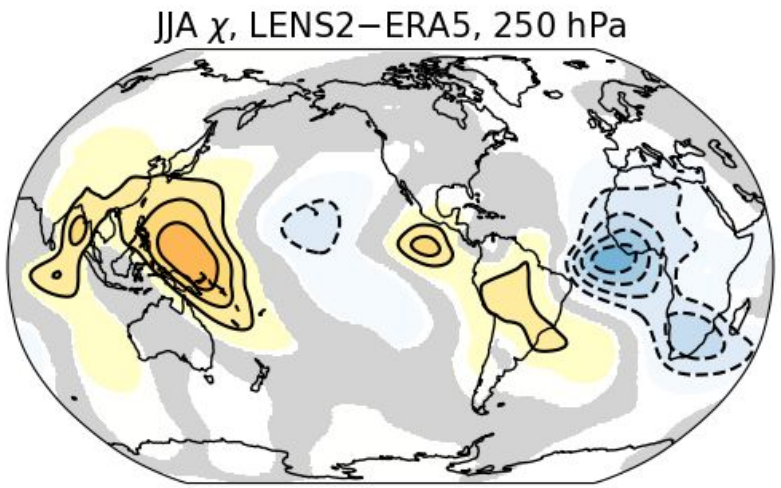


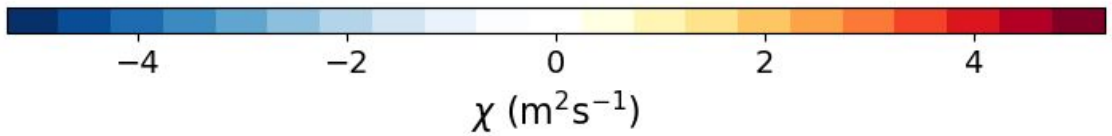




CESM2 – ERA5





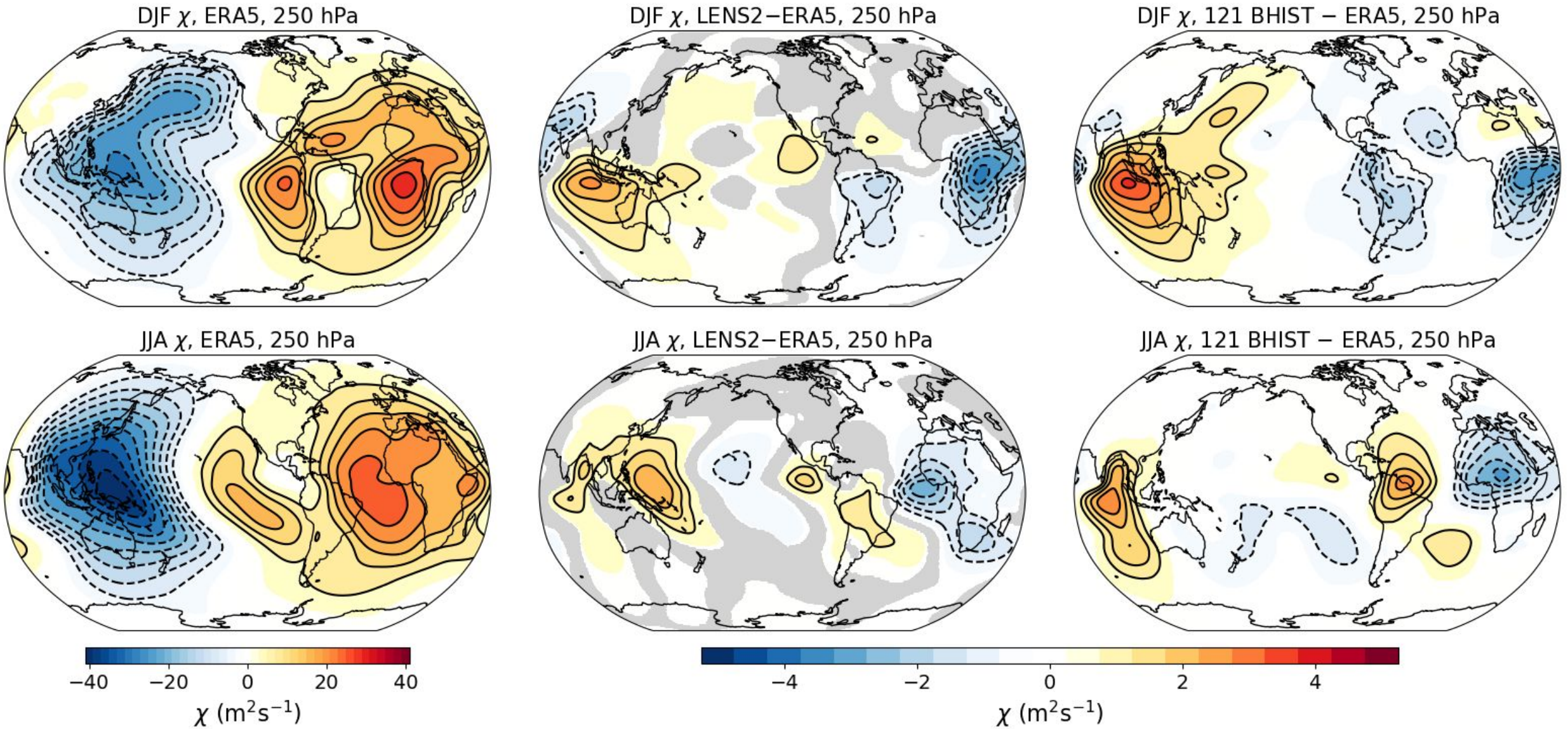


250 hPa velocity potential

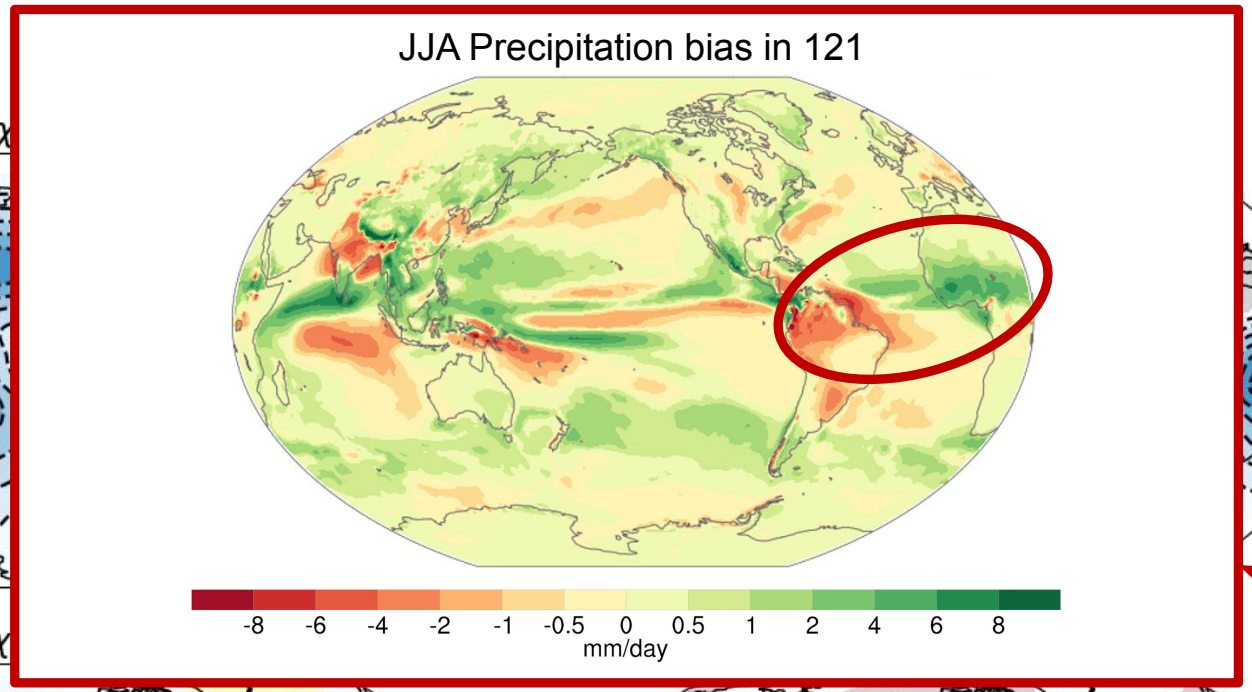
ERA5

CESM2 – ERA5

CESM3 – ERA5



250 hPa velocity potential



CESM3 – ERA5

DJF χ

DJF χ, 121 BHIST – ERA5, 250 hPa

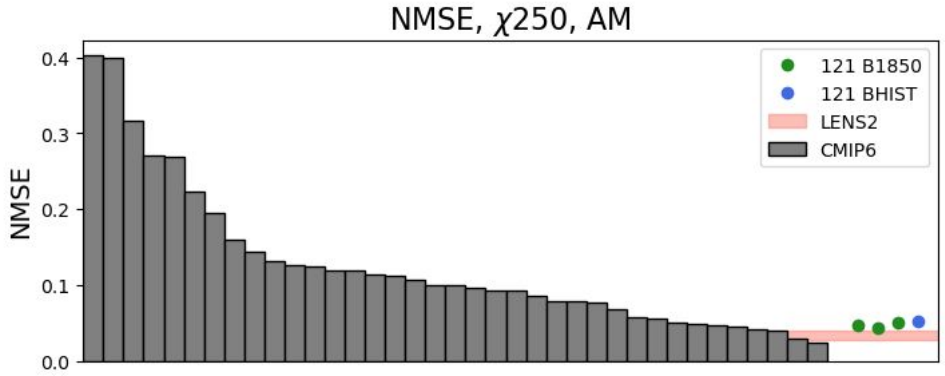
JJA χ

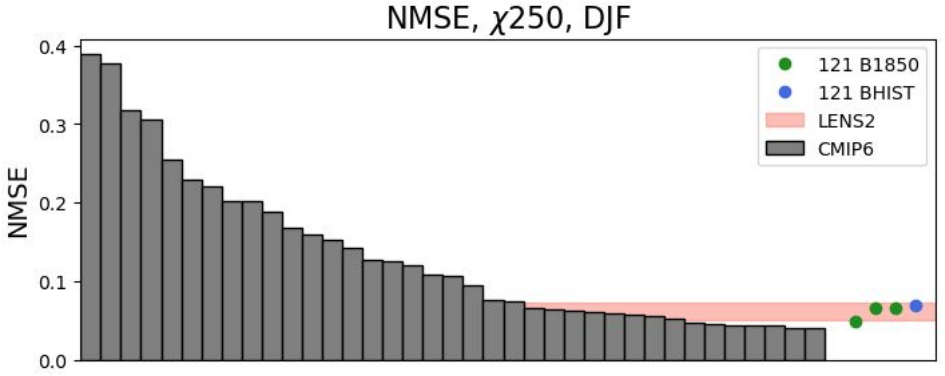
JJA χ, 121 BHIST – ERA5, 250 hPa

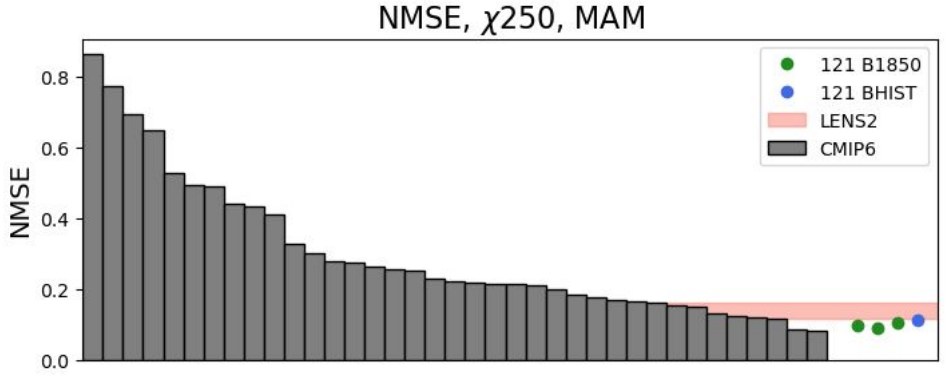
−40 −20 0 20 40
χ (m^2s^{-1})

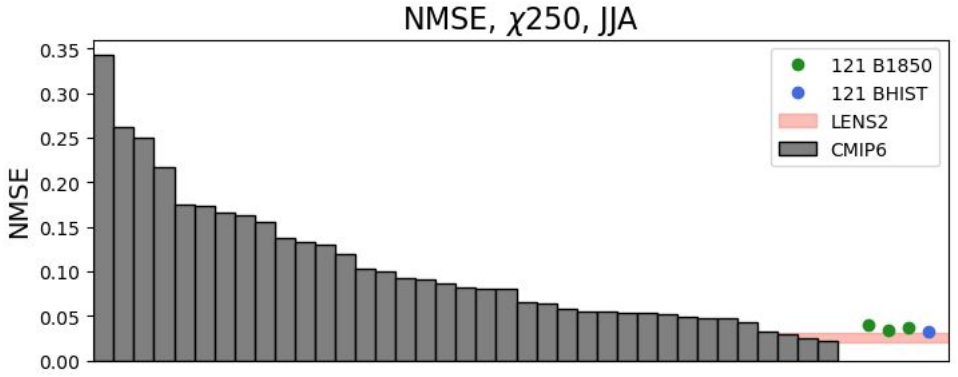
−4 −2 0 2 4
χ (m^2s^{-1})

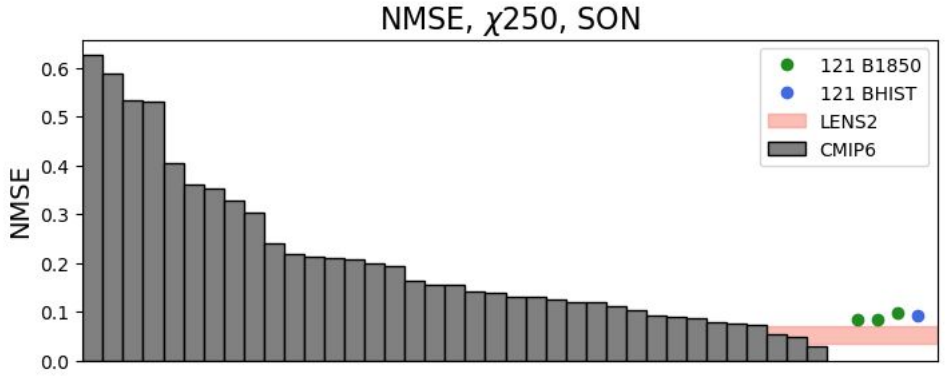
250 hPa velocity potential, Normalized mean squared error, Global





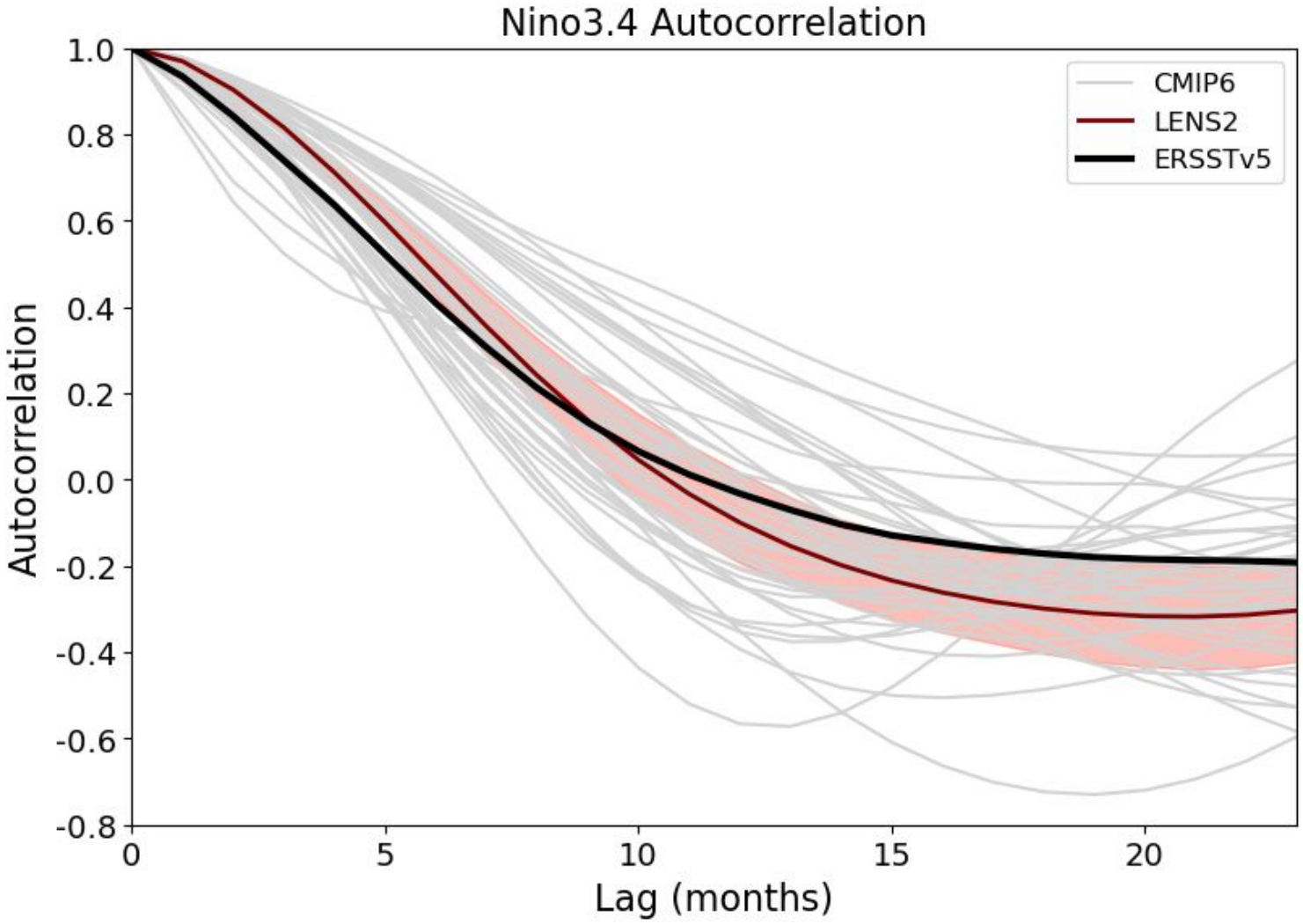






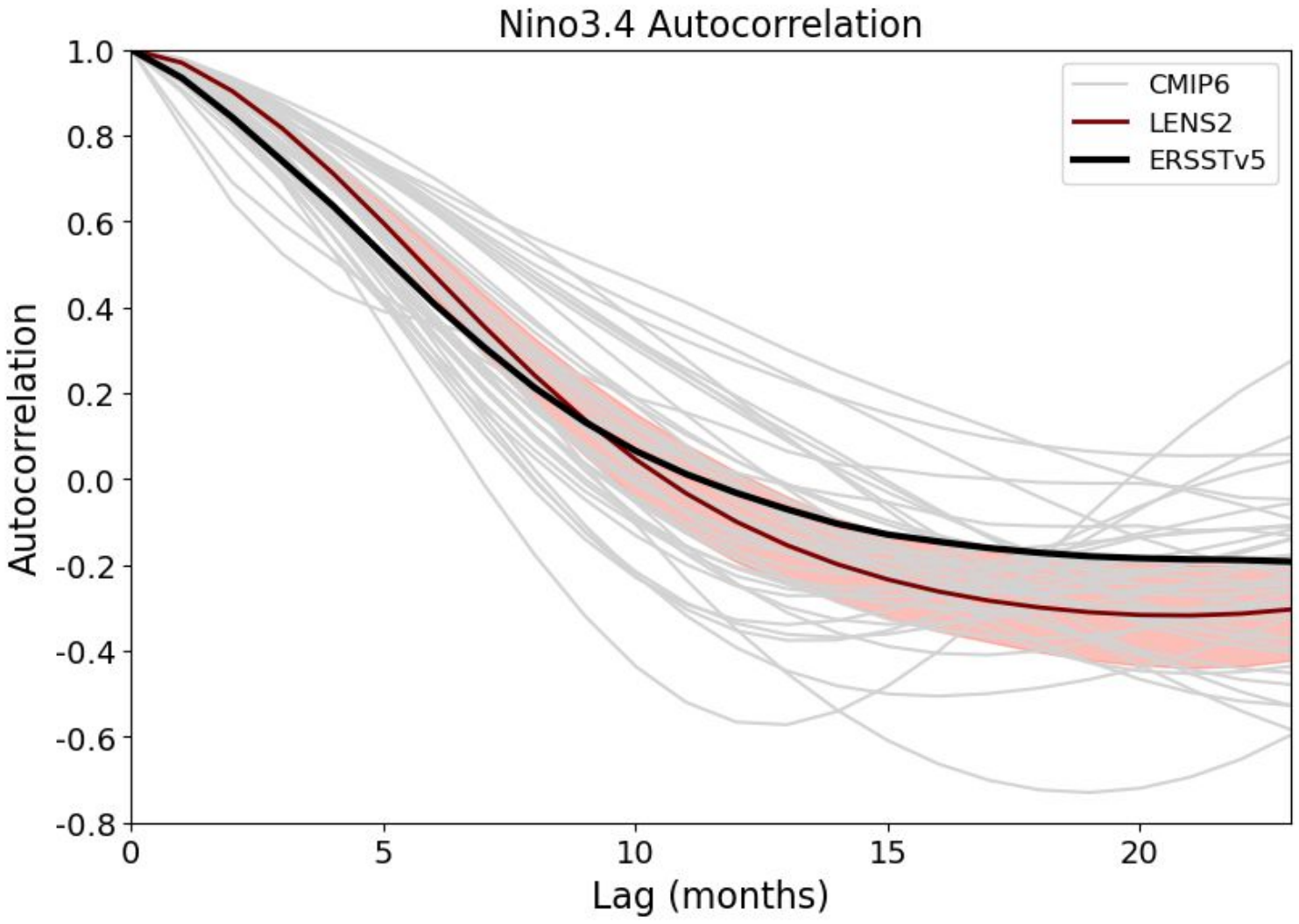
ENSO

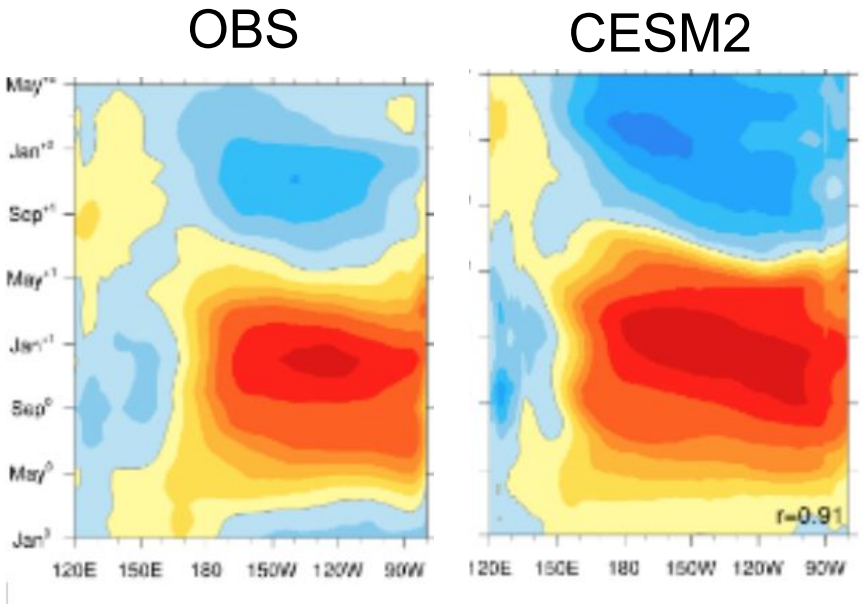
Nino3.4 autocorrelation and transition from El Nino to La Nina



CESM2 had a pretty good Nino3.4 autocorrelation

Nino3.4 autocorrelation and transition from El Nino to La Nina

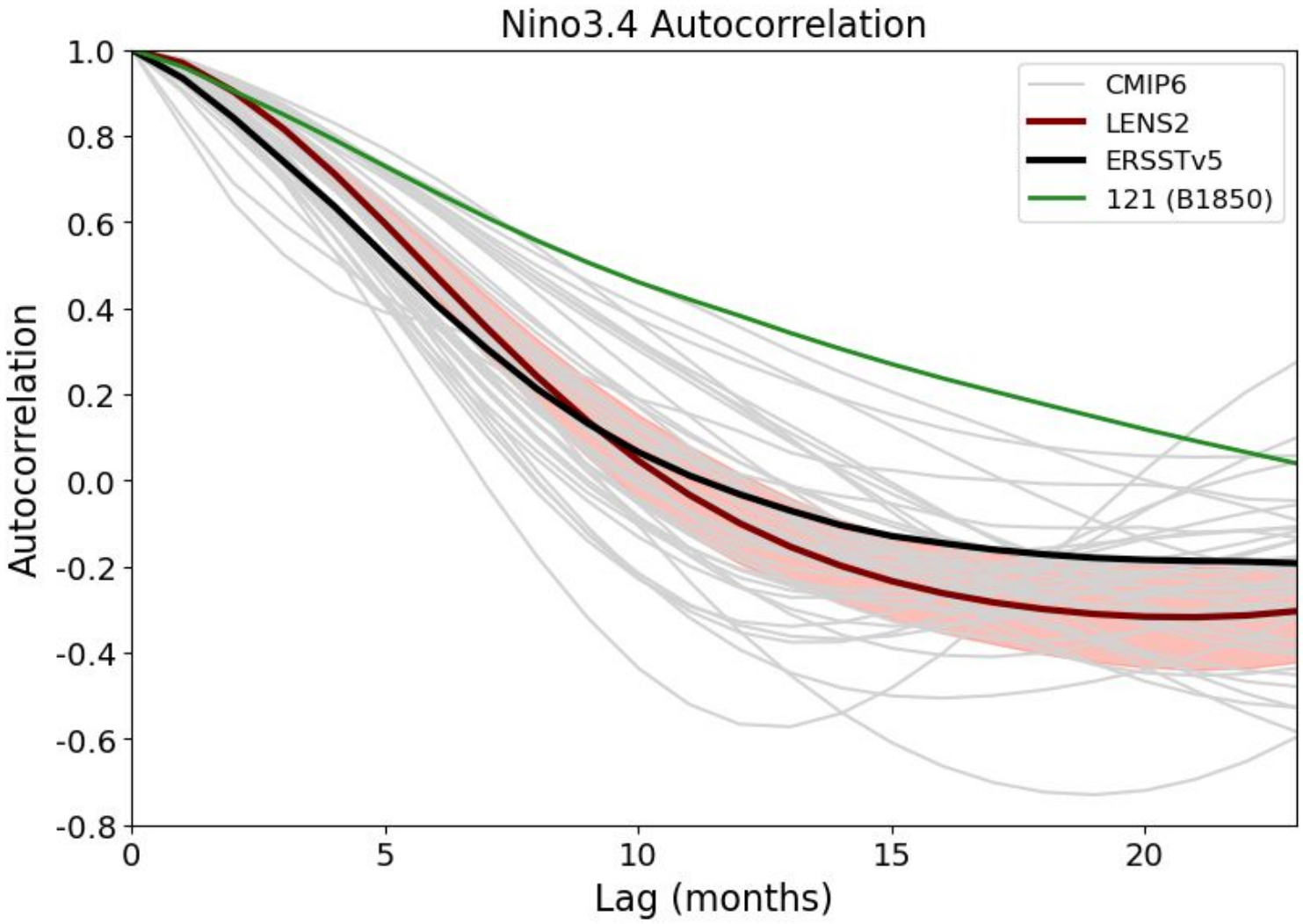




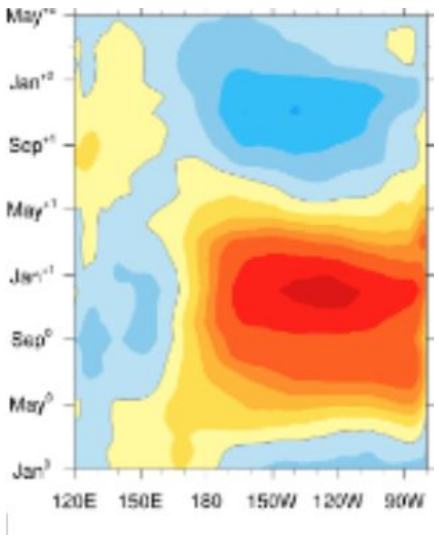
Hovmollers of tropical Pacific SSTs for El Nino events show it also captured the transition from El Nino to La Nina well

(Thanks to Adam Phillips for these CVDP plots)

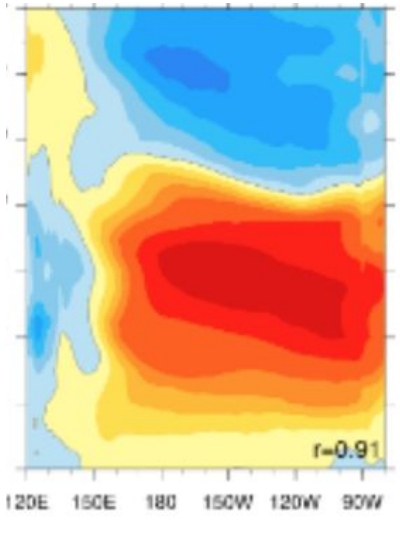
Nino3.4 autocorrelation and transition from El Nino to La Nina



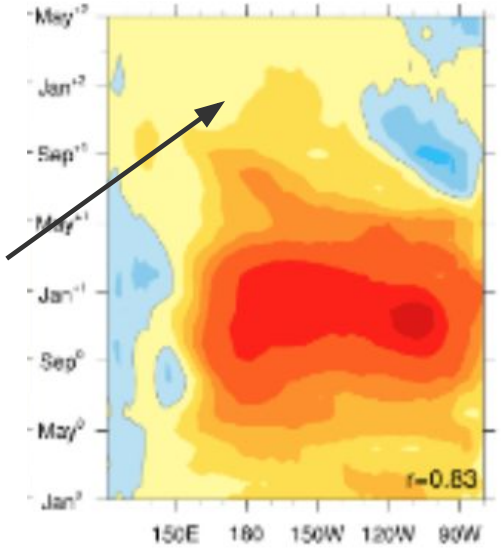
OBS



CESM2

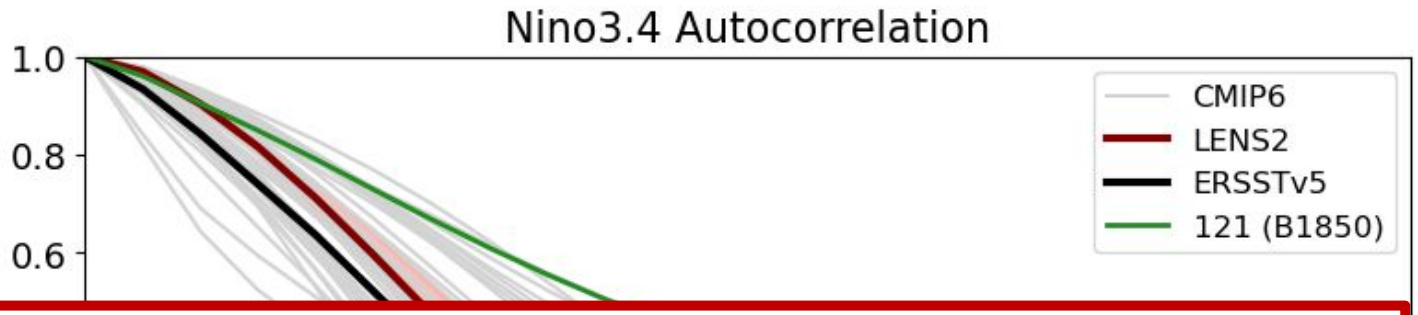


CESM3



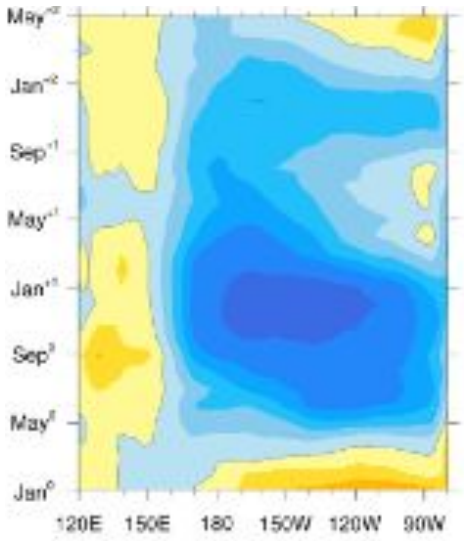
It's not transitioning into La Nina after El Nino quickly enough

Nino3.4 autocorrelation and transition from El Nino to La Nina

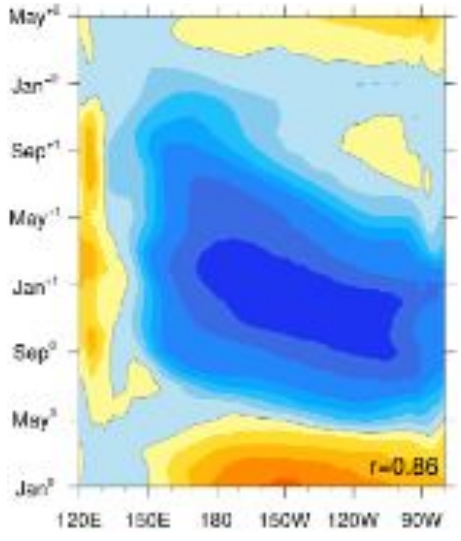


La Nina Hovmollers don't look bad

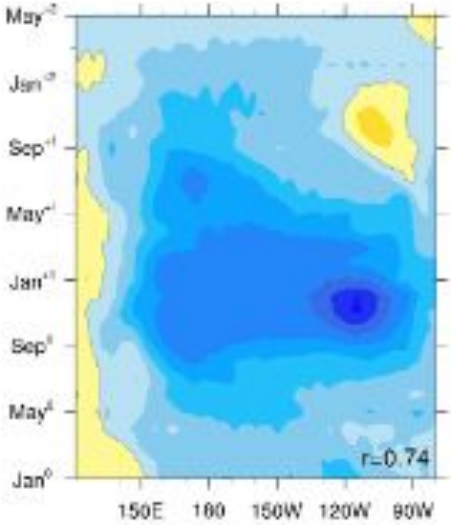
OBS



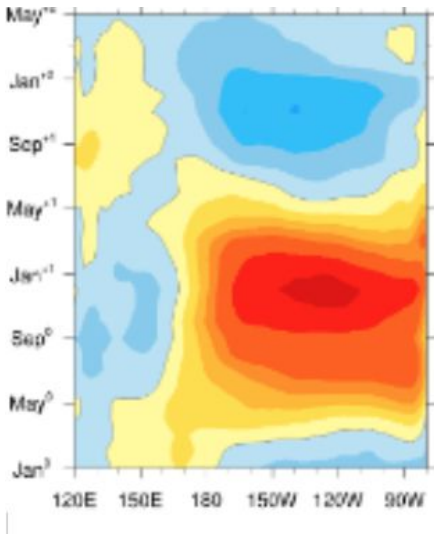
CESM2



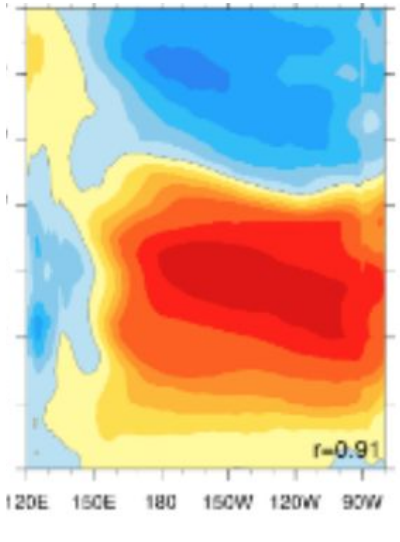
CESM3



OBS

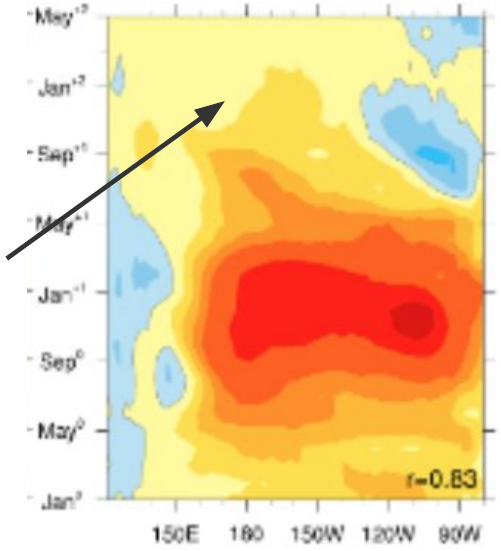


CESM2

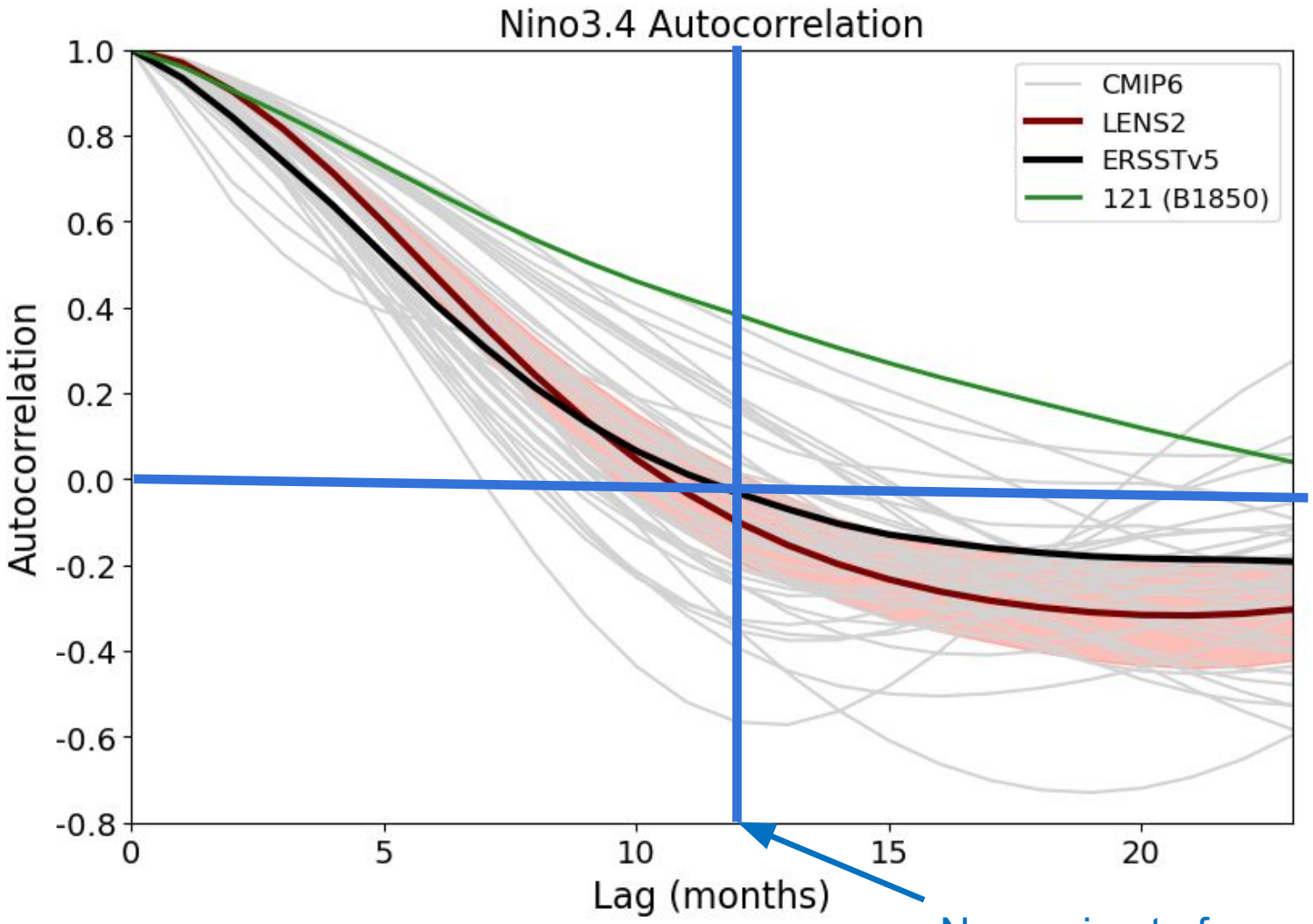


It's not transitioning into La Nina after El Nino quickly enough

CESM3

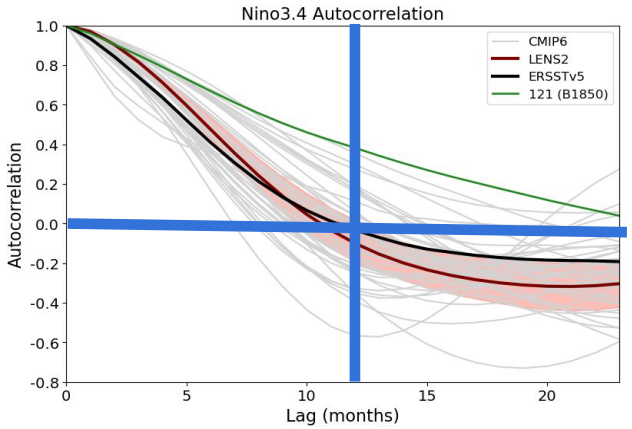


Nino3.4 autocorrelation and transition from El Nino to La Nina

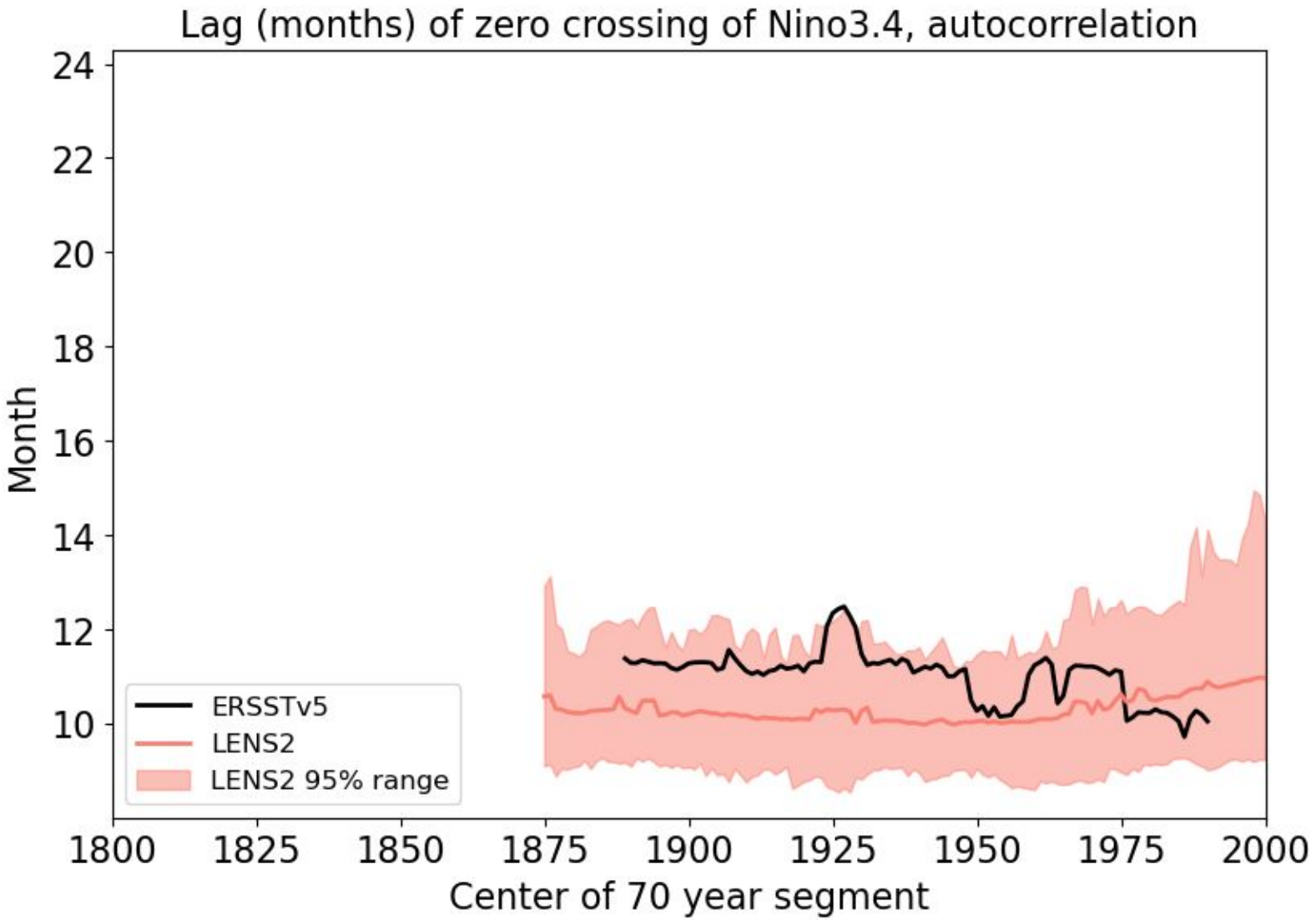


Now going to focus on the time at which the autocorrelation function crosses zero

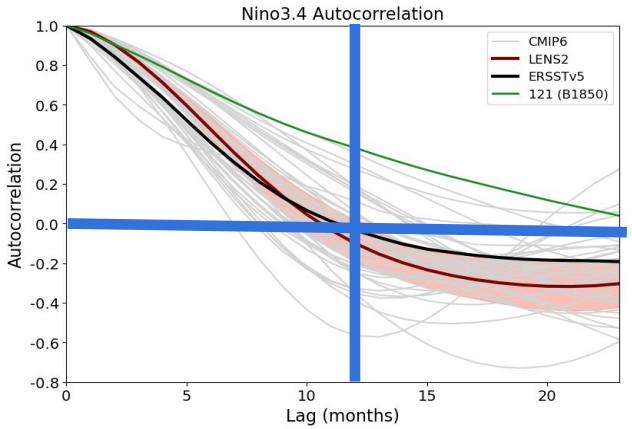
Nino3.4 autocorrelation and transition from El Nino to La Nina



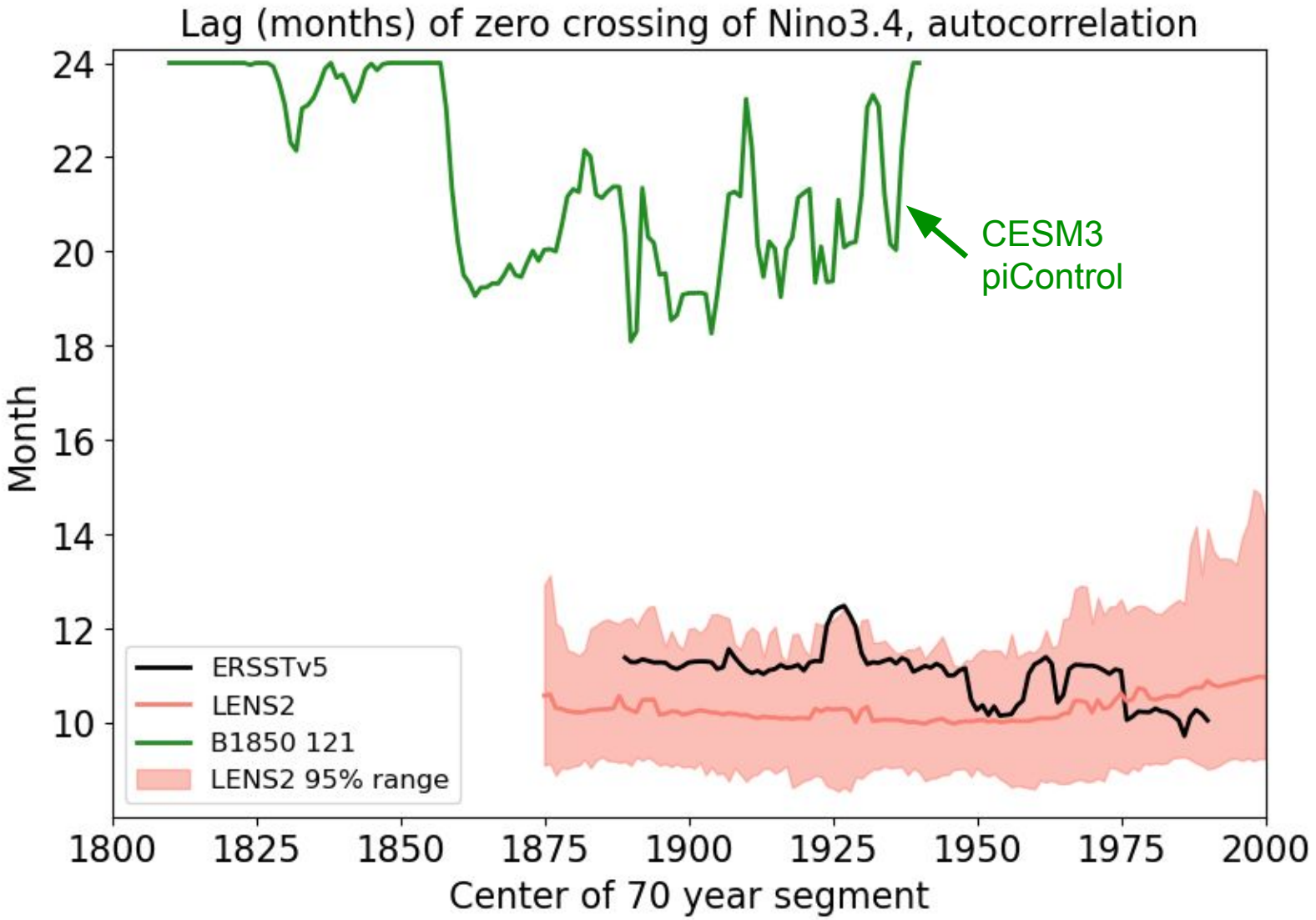
Time of zero crossing for rolling 70 year segments



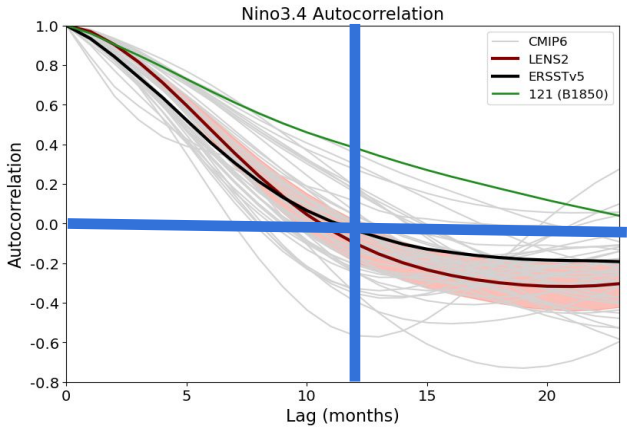
Nino3.4 autocorrelation and transition from El Nino to La Nina



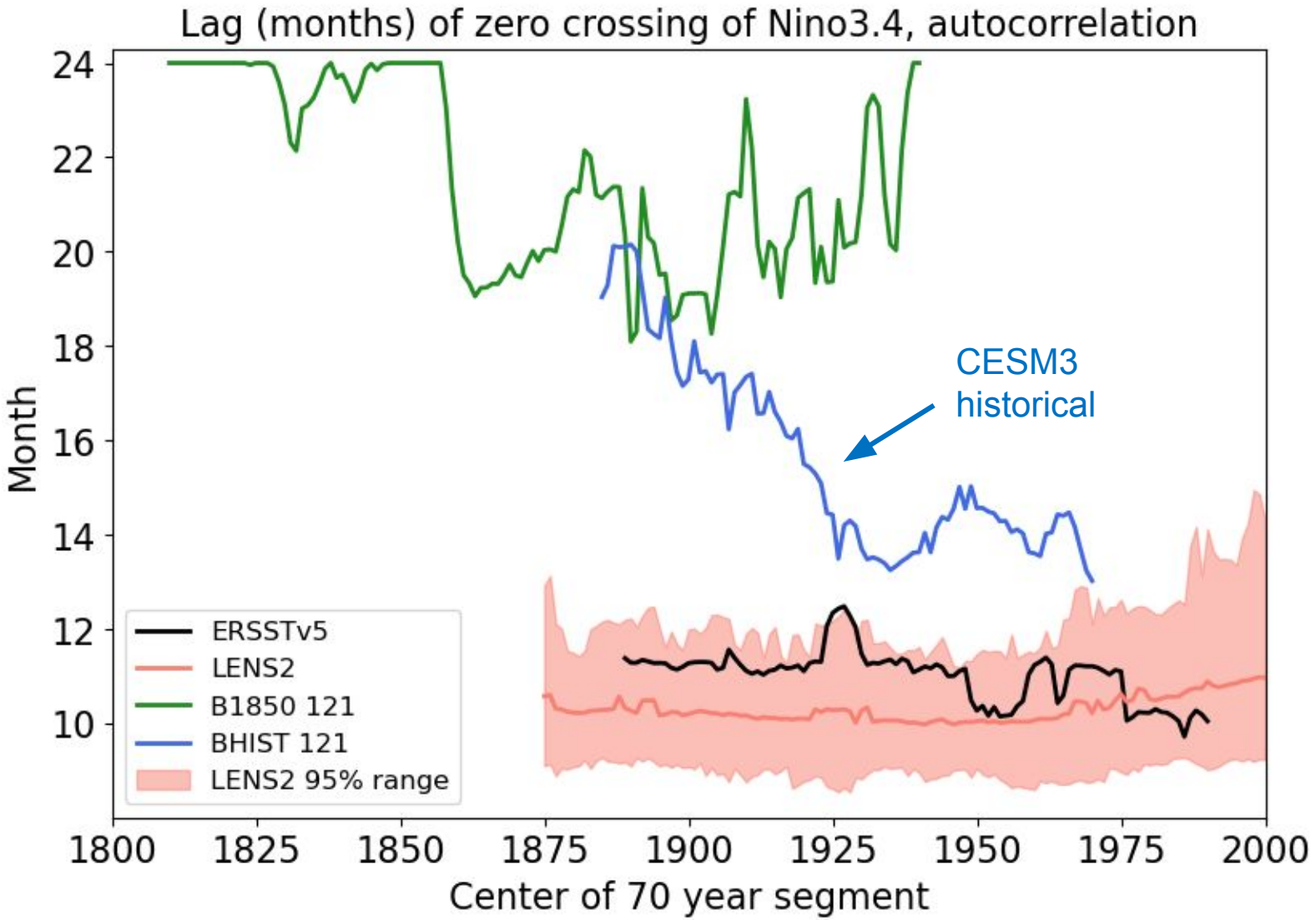
Time of zero crossing for rolling 70 year segments



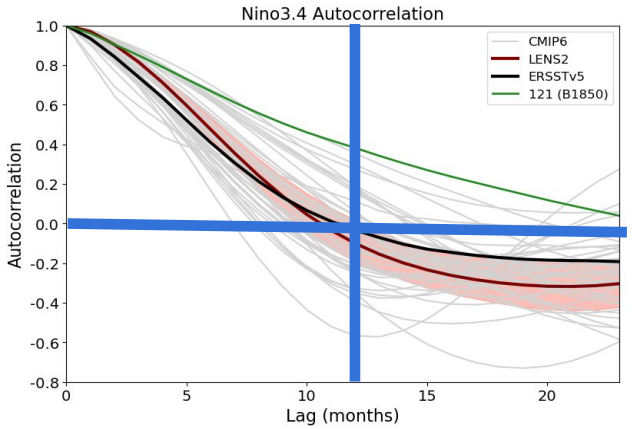
Nino3.4 autocorrelation and transition from El Nino to La Nina



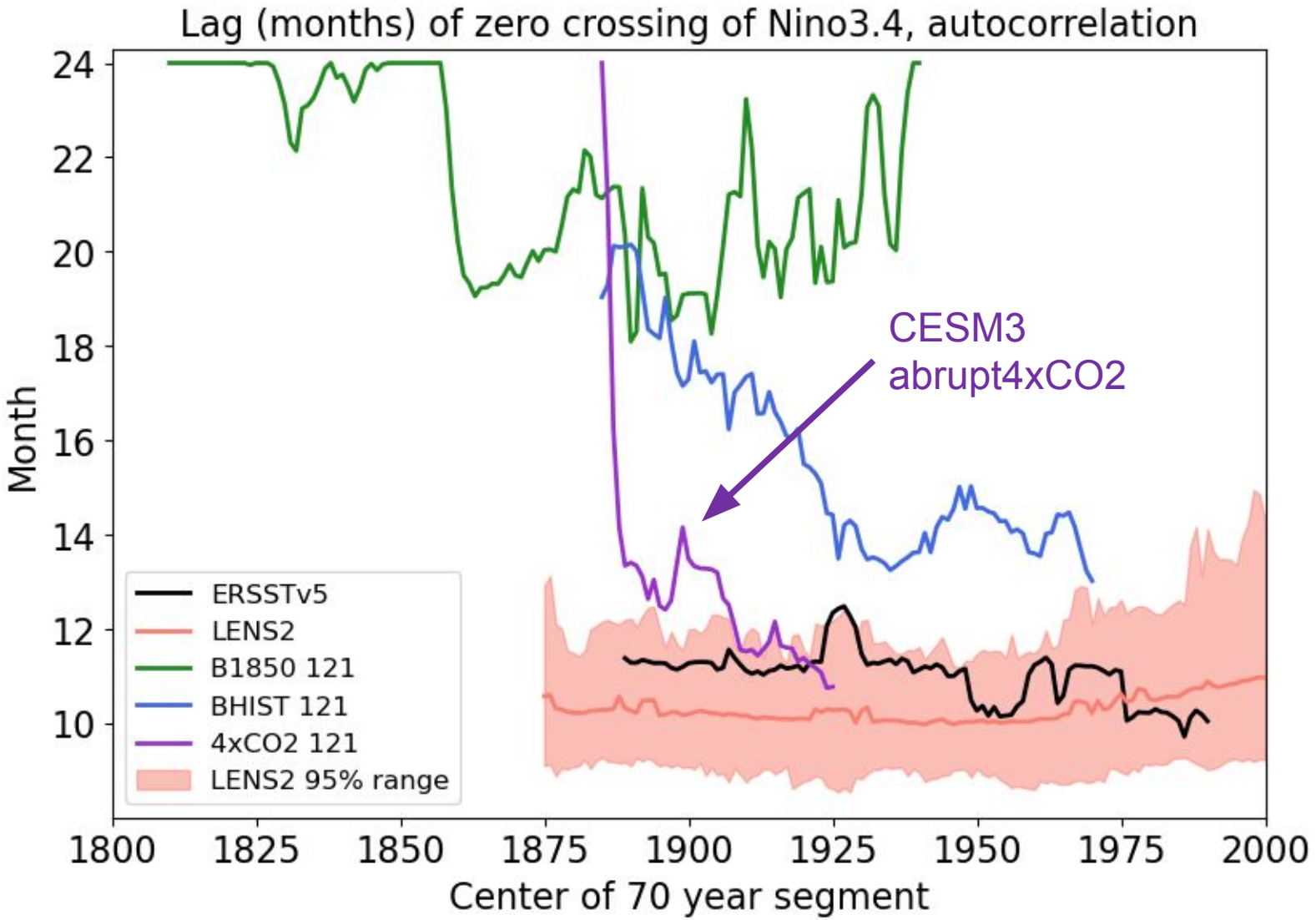
Time of zero crossing for rolling 70 year segments



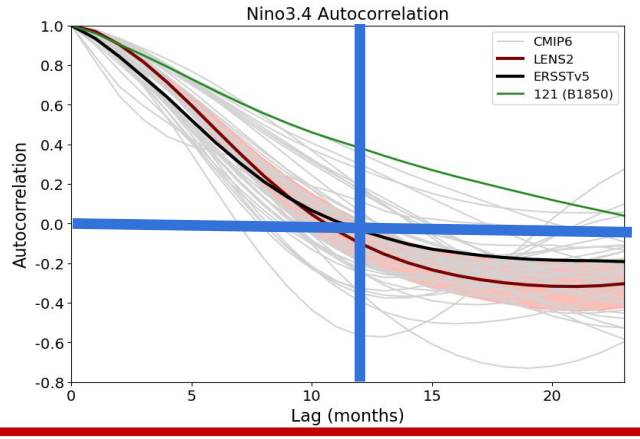
Nino3.4 autocorrelation and transition from El Nino to La Nina

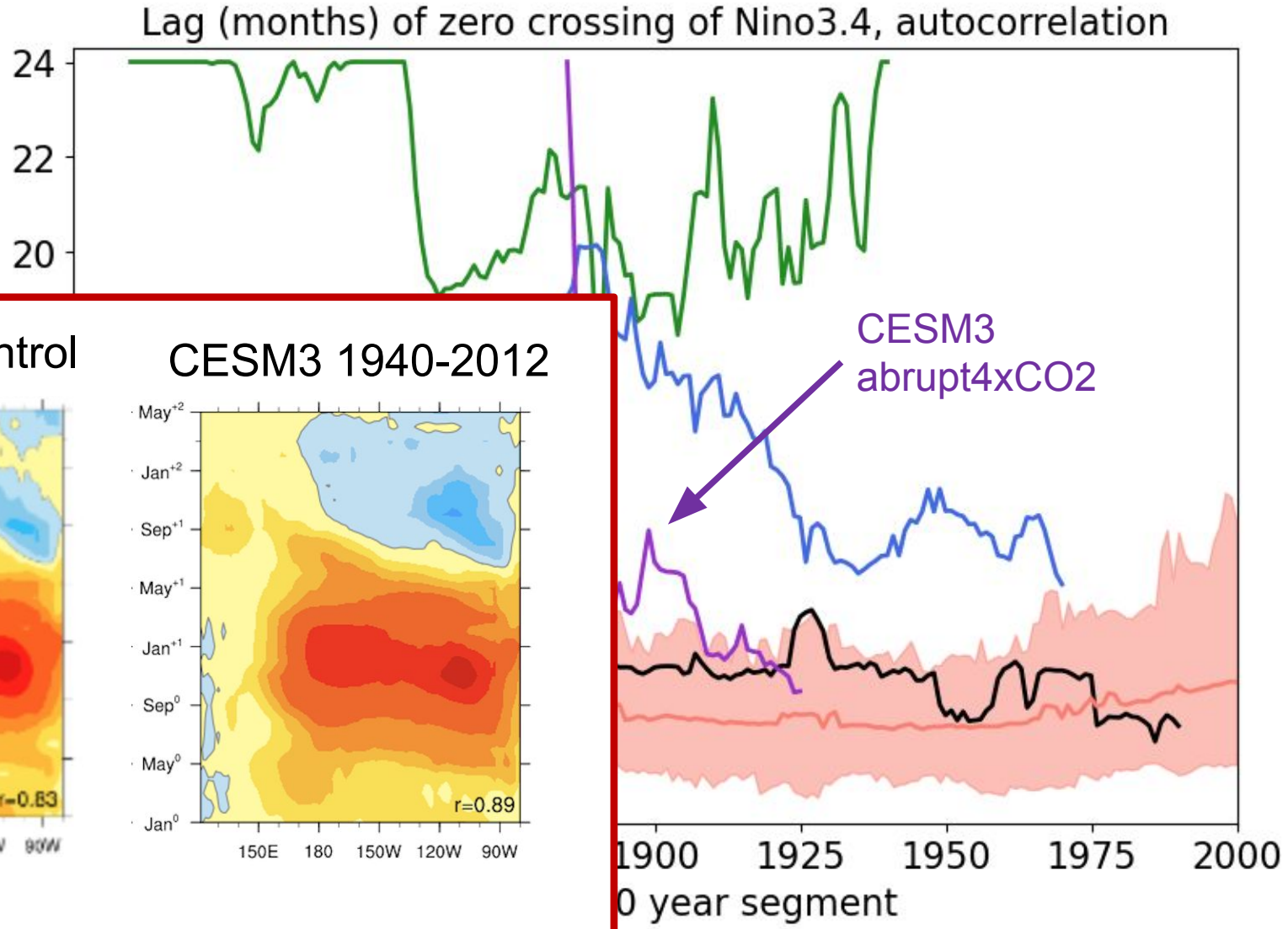


Time of zero crossing for rolling 70 year segments

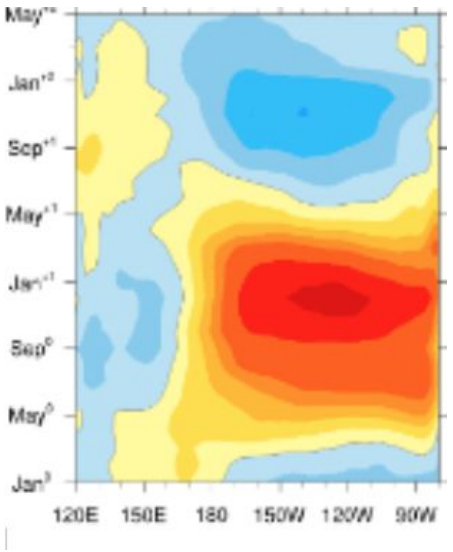


Nino3.4 autocorrelation and transition from El Nino to La Nina

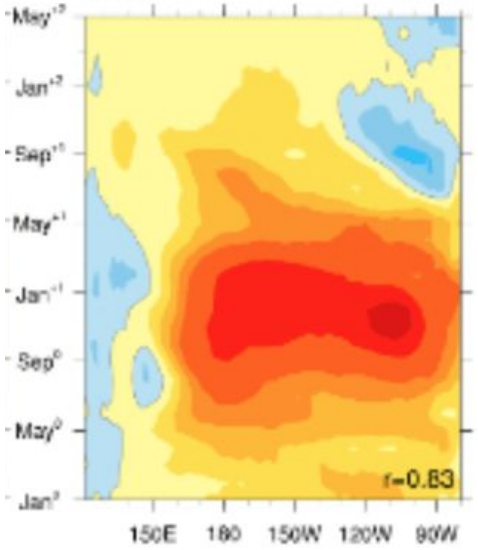




OBS

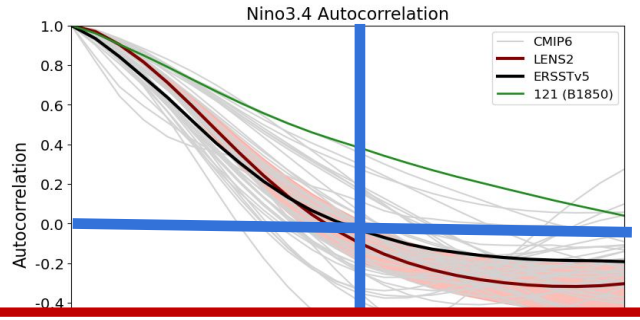


CESM3 piControl

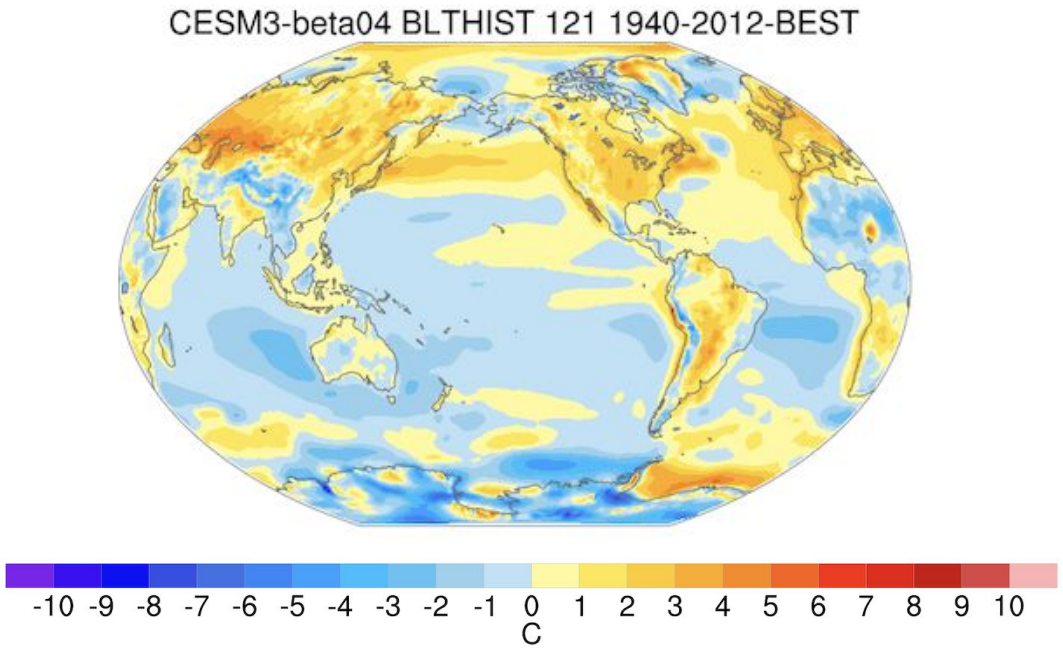


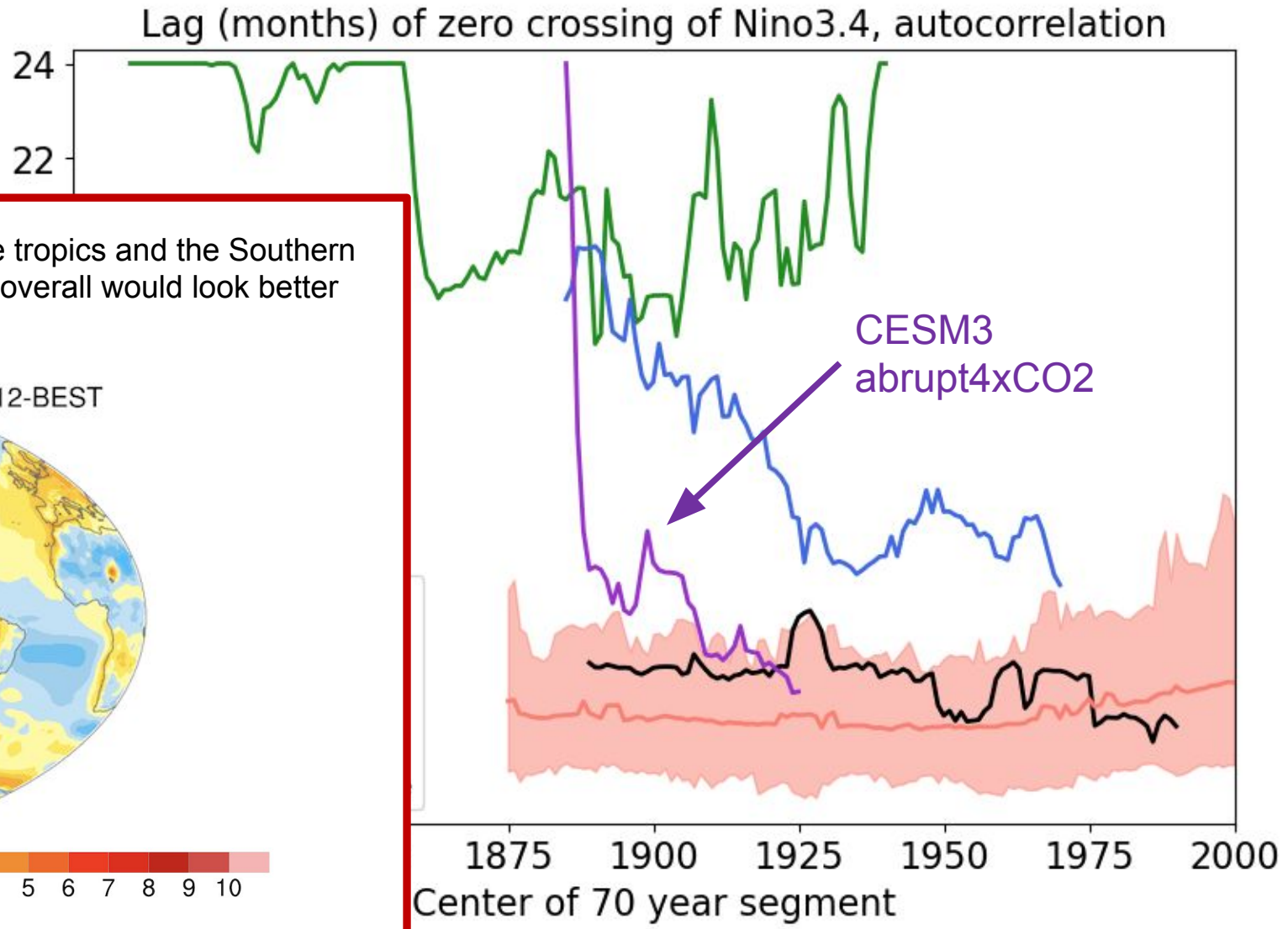
CESM3 1940-2012

Nino3.4 autocorrelation and transition from El Nino to La Nina



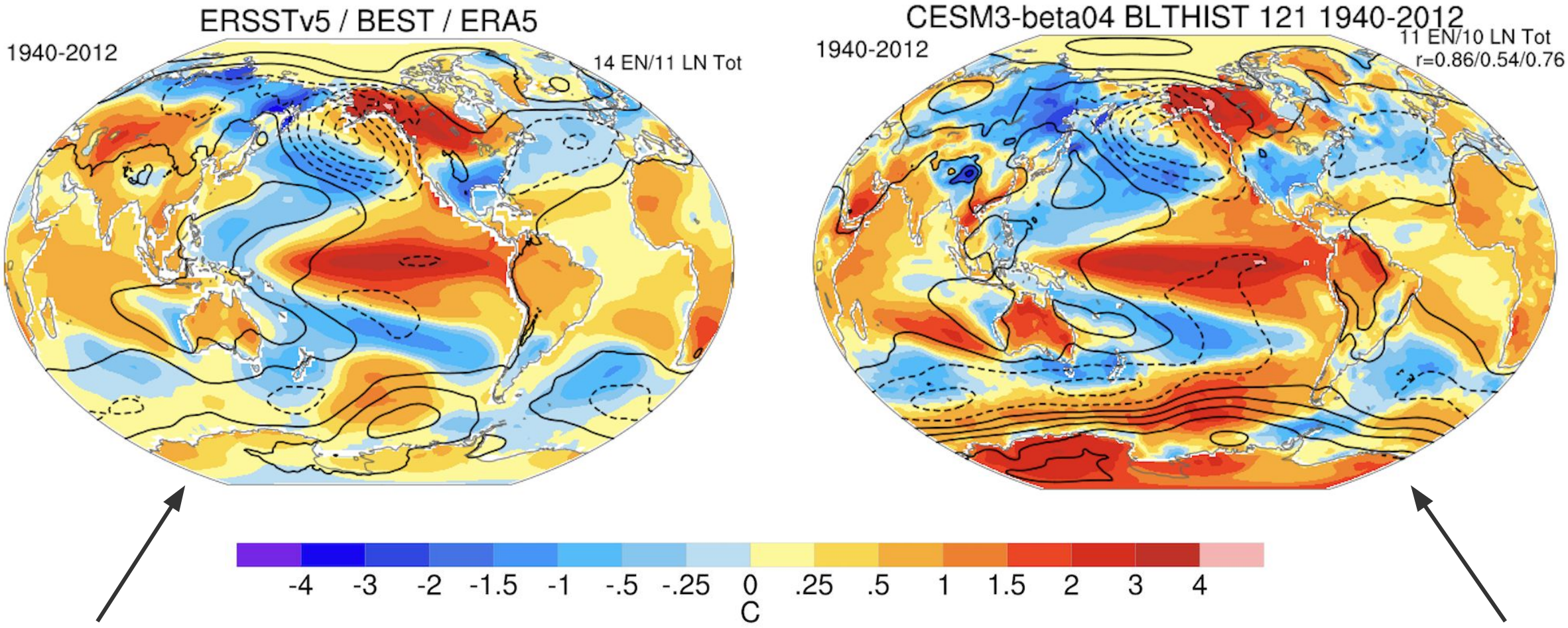
CESM3 is colder than observations over much of the tropics and the Southern Ocean, so maybe if we warm up a bit, temperatures overall would look better and ENSO would fall into place.





North Pacific ENSO teleconnections look good in the later part of the historical

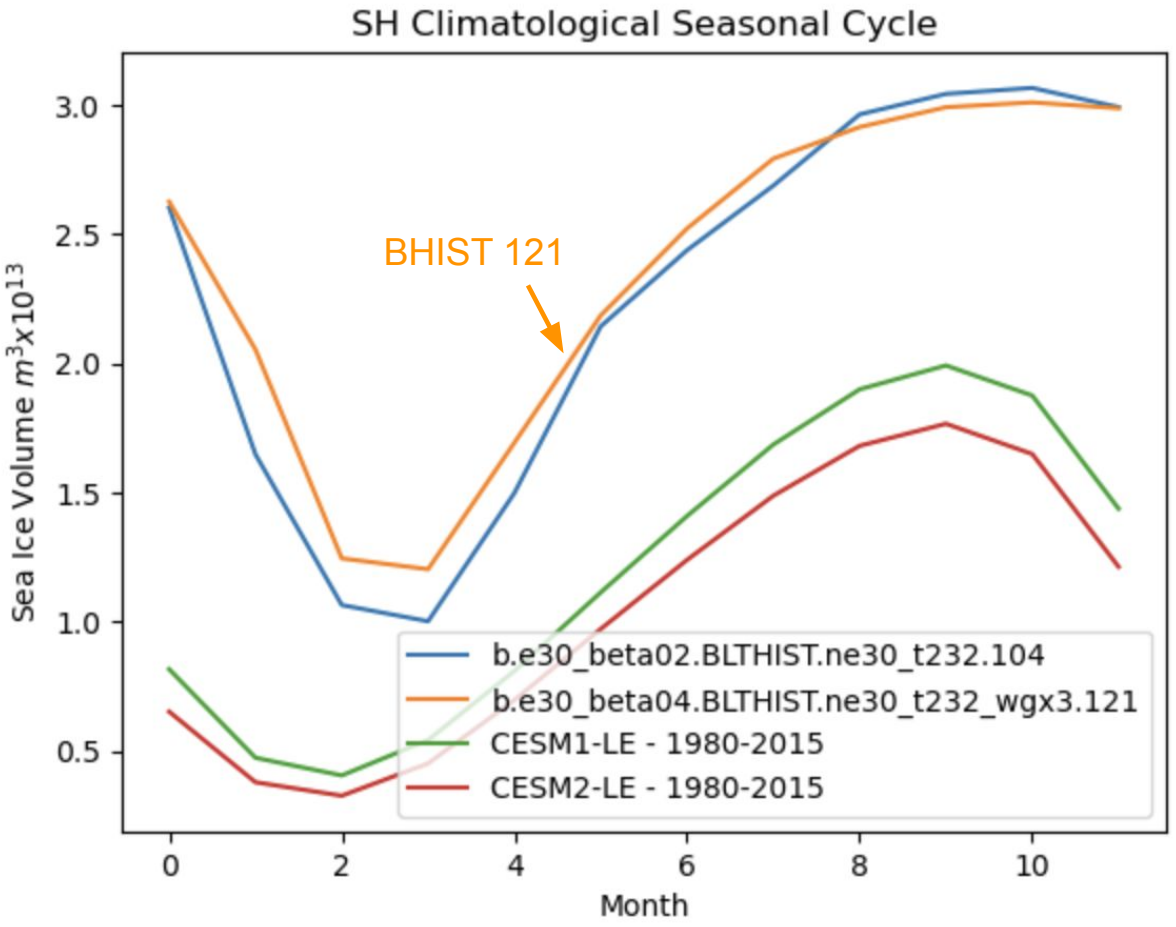
A comparison over 1940-2012

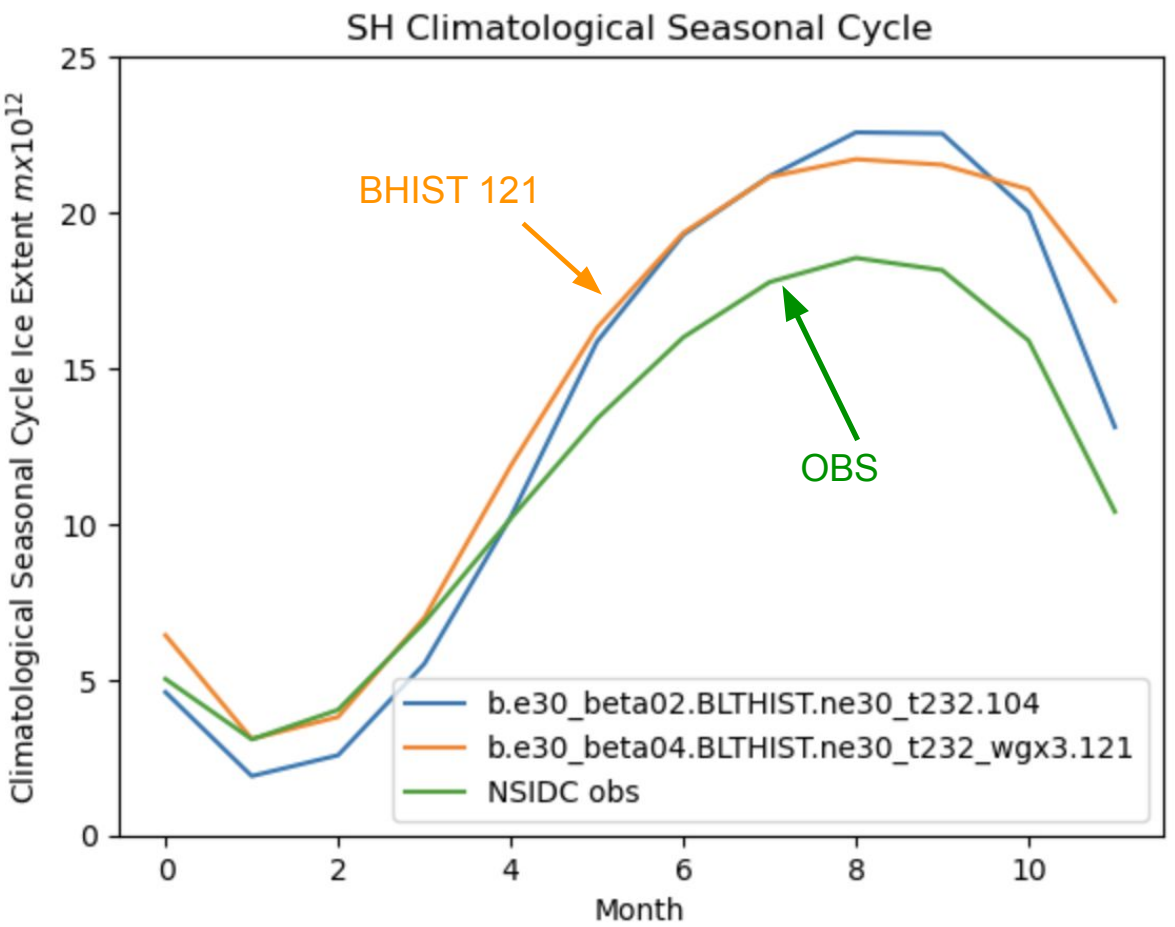


Thanks to Adam Phillips

Southern Hemisphere Sea Ice is too extensive

From Alice DuVivier:





Conclusions

- CESM3 has a lower ECS than CESM2
- CESM3 has an improved representation of the historical temperature evolution compared to CESM2, particularly over land.
- In general, the large scale circulation errors in CESM3 and CESM2 are comparable. CESM2 was a pretty good model among CMIP6.
  - We seem to have had some improvements in the Southern Hemisphere circulation.
  - We've had some degradations in the Northern Hemisphere circulation
  - We have an issue with precipitation biases over the Amazon and West Africa, which are likely connected.
- There are some issues with the ENSO representation. In particular with transitions from El Nino into La Nina and the autocorrelation timescale. These seem to get better as the model warms so it may not be an issue if we could warm up the base state a bit.
- Southern Hemisphere sea ice is too extensive.

Northern Hemisphere Sea Ice

From Alice DuVivier: