Differences in Poleward Energy Transport between Two Versions of the Community Earth System Model

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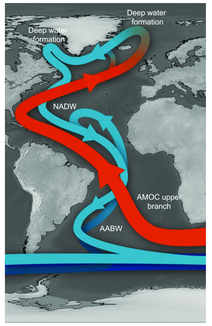
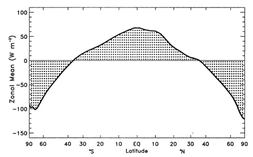
1. Motivation

Atlantic Meridional Overturning Circulation (AMOC)



Schematic representation of the main components of the Atlantic Meridional Overturning Circulation (AMOC), Crivellari (2018)

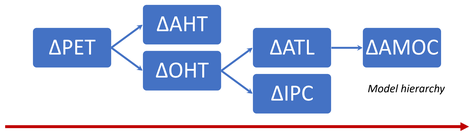
Poleward Energy Transport (PET)



TOA annualized ERBE zonal mean net radiation (W m^{-2}) for Feb 1985–Apr 1989, Trenberth et al. (2001)

- Previous works by Menary et al. (2020) and Robson et al. (2022) have CMIP6 models (like CESM2) exhibit a greater AMOC response to historical forcing versus CMIP5 models (like CESM1).
- Recent work by Needham & Randall (2023) concluded that aerosols contributed to the large anomaly in PET in the second half of the 20th century in CESM2.
- In this study, we will examine the two models to see how different CESM2 and CESM1 are.

2. Objectives and Methodology



Model hierarchy

This study utilizes model data from both CESM1 and CESM2 to answer our motivating objectives:

1. Characterize how PET varies between the two models
2. Confirm that a difference in AMOC response to aerosol forcing contributes to the difference in PET
3. Uncover what physical process may be different in the models, causing the difference in PET

Data:

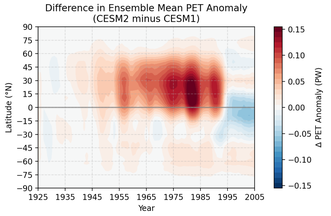
1. CESM Data Ranges:
- CESM1: 1921 – 2005 (annual/monthly data)
- CESM2: 1851 – 2014 (annual/monthly data)

2. Choosing a Common Period:
- Chose years 1925 – 2005

3. Defining Baseline Climatology Period:
- Chose years 1925 – 1940
- 'Anomaly' defined as difference from climatological mean

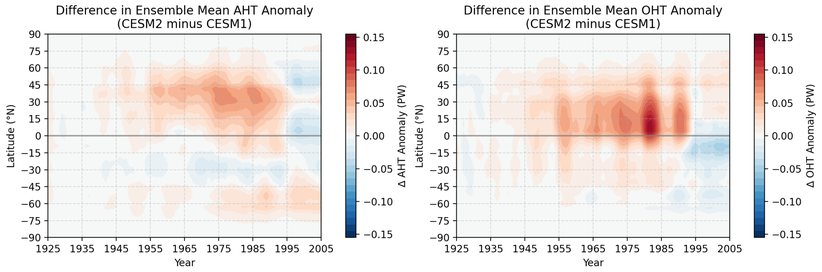
For the first part of our study, we analyze the differences in PET between each version of CESM.

3. Model Difference Breakdown

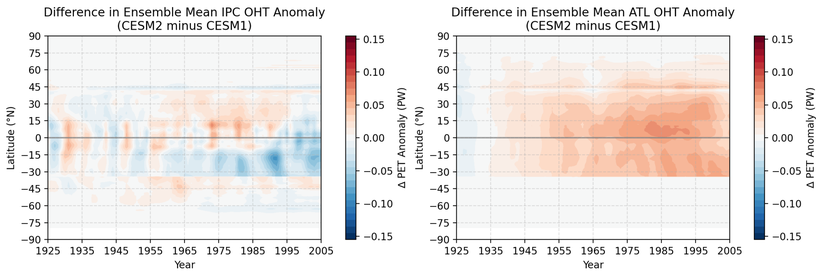


- Zonally-integrated PET anomaly difference between each model, with a large dissimilarity from years 1955 to 1995
- Concentrated in the Northern Hemisphere (NH), especially just north of the equator
- CESM2 transports more energy northward in the NH during this time period versus CESM1.

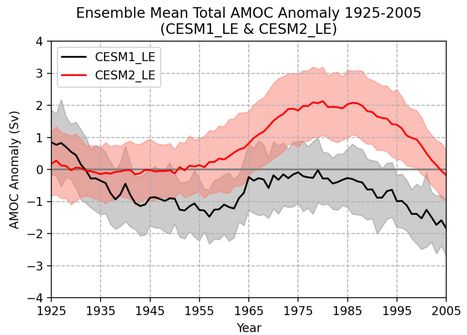
- We separate PET into its elements, AHT & OHT
- Examine which component is contributing more to the difference in PET between the two models:



- Both OHT & AHT are significantly different, however ΔOHT > ΔAHT
- Due to time limitations, we choose to pursue OHT and break it down into its parts:



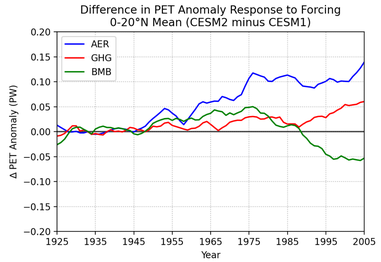
- The difference in Atlantic OHT is larger than Indo-Pacific OHT, especially at and just north of the equator, in latitudes from 0°N to 20°N
- Now, we examine the strength of the AMOC (defined as an annual maximum of the flow rate at a depth below 500m) in the two models, as the AMOC is the main driver of OHT in the Atlantic Ocean



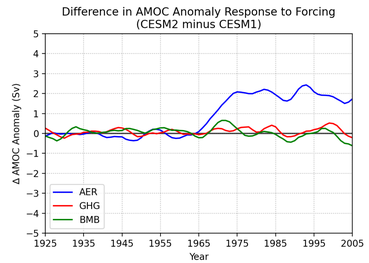
- The ensemble mean AMOC anomaly of each model, with shading representing +/- σ.
- **We conclude that differences in the AMOC strength are contributing significantly to the increased PET anomaly observed in CESM2**
- Why are the AMOC anomalies in each model unalike?

4. Examining the Effects of Forcings

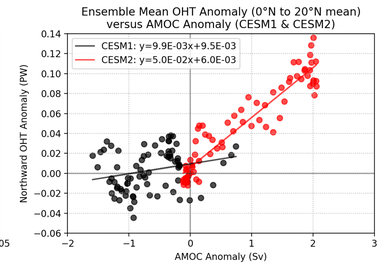
- To confirm that a difference in PET anomaly between CESM1 & 2 is due to a difference in AMOC response to aerosol forcing, we investigate single-forcing runs of each model.
- This allows for the direct comparison of how each model responds to each kind of forcing:



- The greatest difference in PET is due to Aerosol (AER) forcing, versus Greenhouse Gases (GHG) and Biomass Burning (BMB)



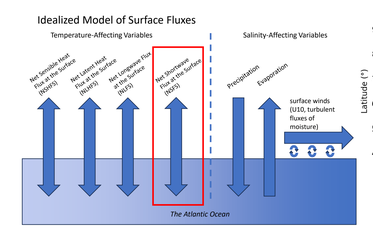
- The difference in AMOC anomaly response to Aerosol (AER) forcing was the most significant
- The differences in PET and AMOC anomaly responses to aerosol forcing seem to mirror each other
- We now examine how correlated these two variables are



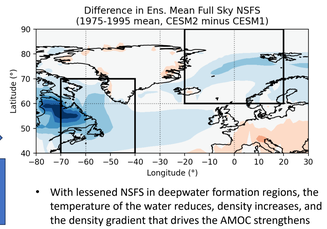
- OHT anomalies are driven by changes in AMOC, with larger changes found in CESM2
- **We conclude that the greater AMOC response to aerosol forcing is causing a greater effect on OHT and PET in CESM2**

5. Linking Atmospheric Aerosols to an Undersea Current

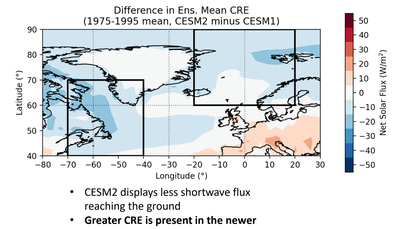
- We have found that the difference in AMOC response to aerosol forcing is contributing towards the difference in PET between CESM1 & 2
- In this next section, we examine the differences in certain physical processes that affect the strength of the AMOC
- We investigate a period where the AMOC anomaly difference between the two models was the greatest: 1975 through 1995
- Boxed regions represent areas of the AMOC's deepwater formation



- For this portion of the study, we examine what is affecting the Net Shortwave Flux at the Surface (NSFS).



- With lessened NSFS in deepwater formation regions, the temperature of the water reduces, density increases, and the density gradient that drives the AMOC strengthens
- This is indeed the case with the AMOC during 1975 through 1995, so we move forward onto Cloud Radiative Effect (CRE)



- CESM2 displays less shortwave flux reaching the ground
- **Greater CRE is present in the newer model**
- **A stronger CRE from aerosol forcing?**

6. Conclusions

- **CESM2 exhibits much larger PET & AMOC anomalies versus CESM1**
- **A greater PET anomaly in CESM2 versus CESM1 can be attributed to an increased AMOC response to aerosol forcing in CESM2**
- **The cloud radiative effect in the North Atlantic during 1975-1995 in CESM2 is significantly larger versus CESM1, which may have contributed to cooler SSTs that intensified the AMOC**

7. Future Work

- Inspect Atmospheric Heat Transport (AHT) differences
- Examine dissimilarities in clouds' effect on longwave flux at the surface
- Study contrasts in sensible & latent heat fluxes at the surface
- Consider differences in precipitation/evaporation processes & turbulent fluxes of moisture's effect on seawater salinity

8. Acknowledgements

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- Model data collection was handled by Michael Needham of CSU.
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9. References

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