Understanding Southern Ocean Influences on Climate

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Collaborators
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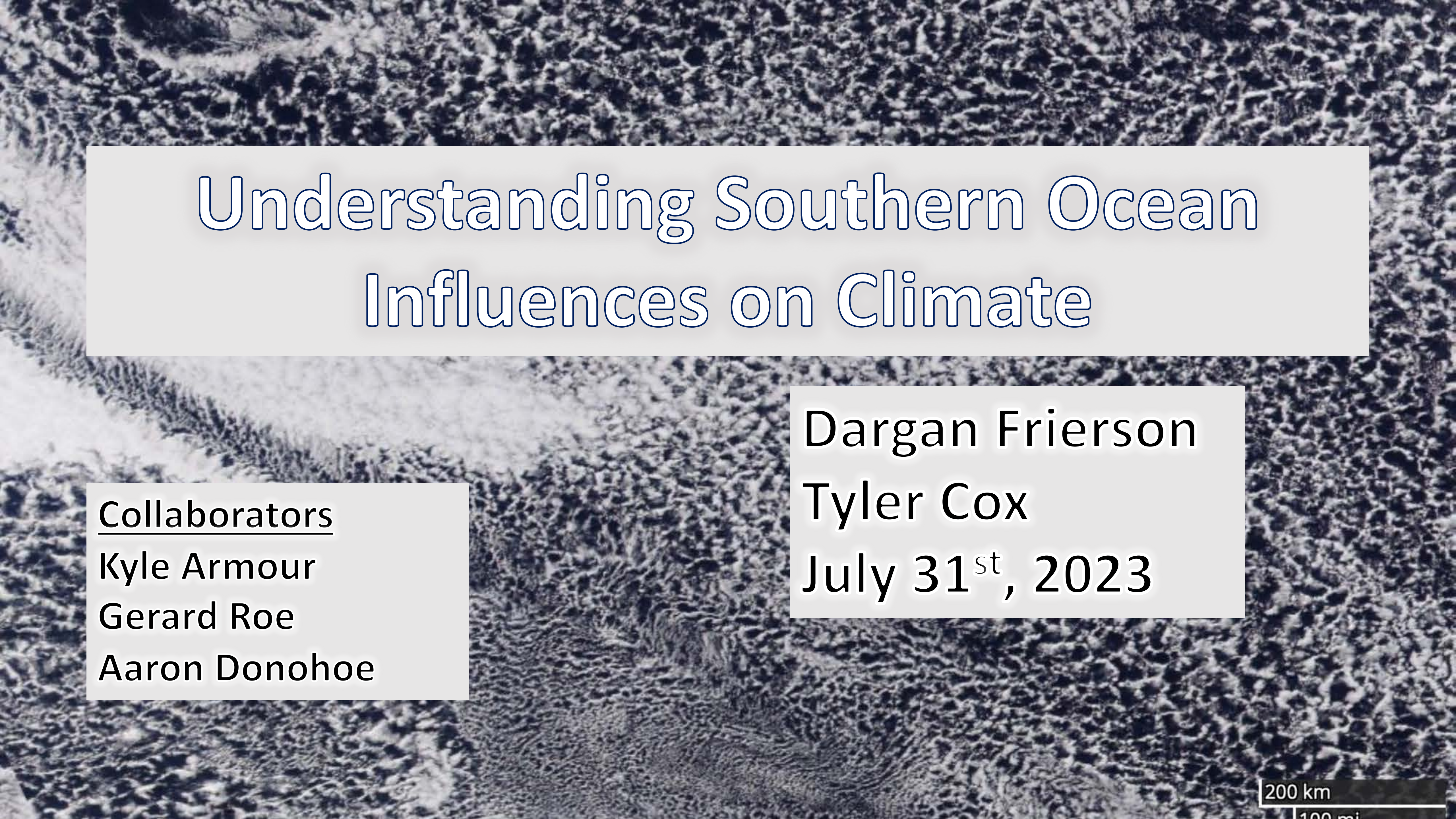
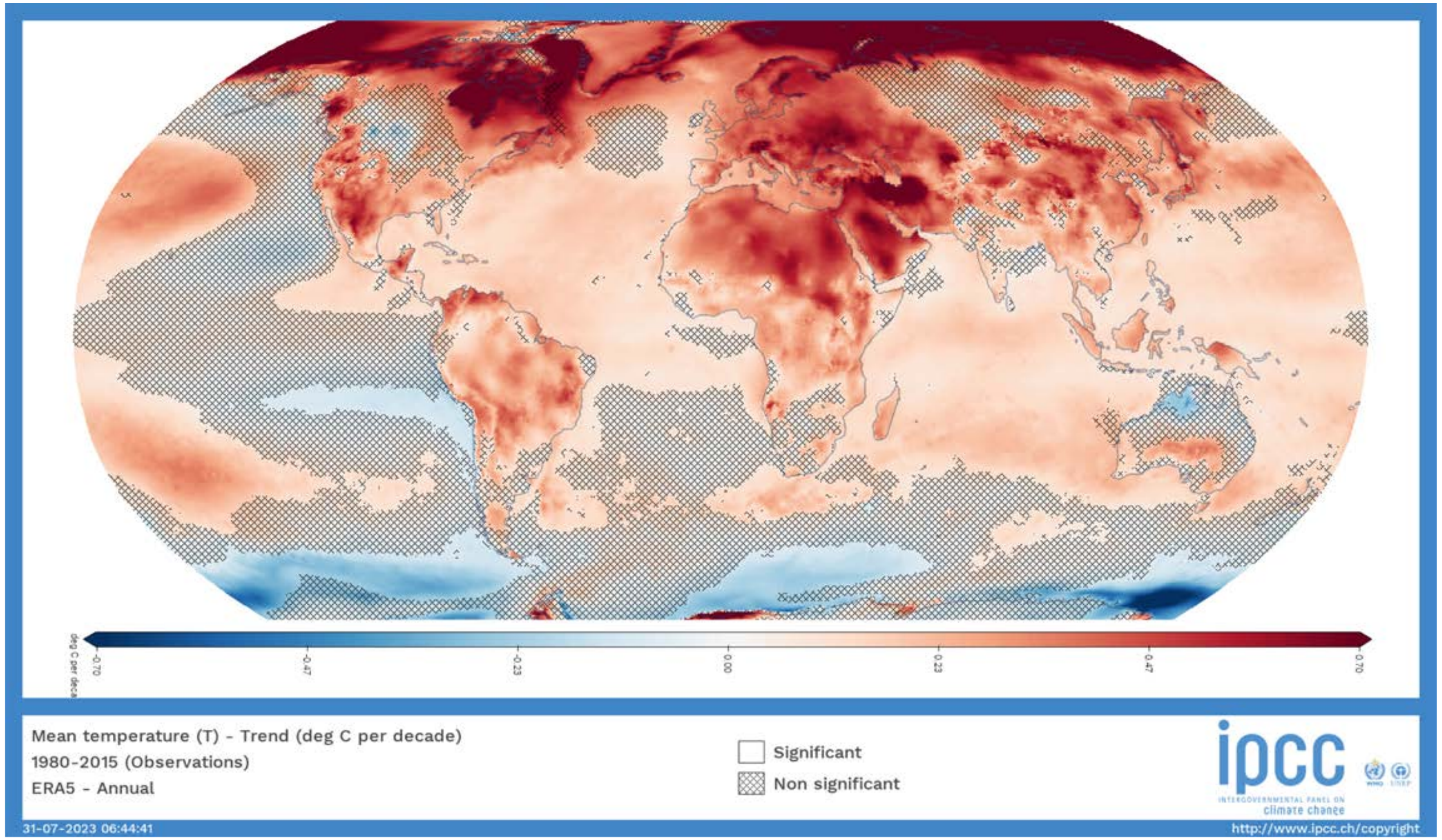


Understanding The Southern Ocean in Flux

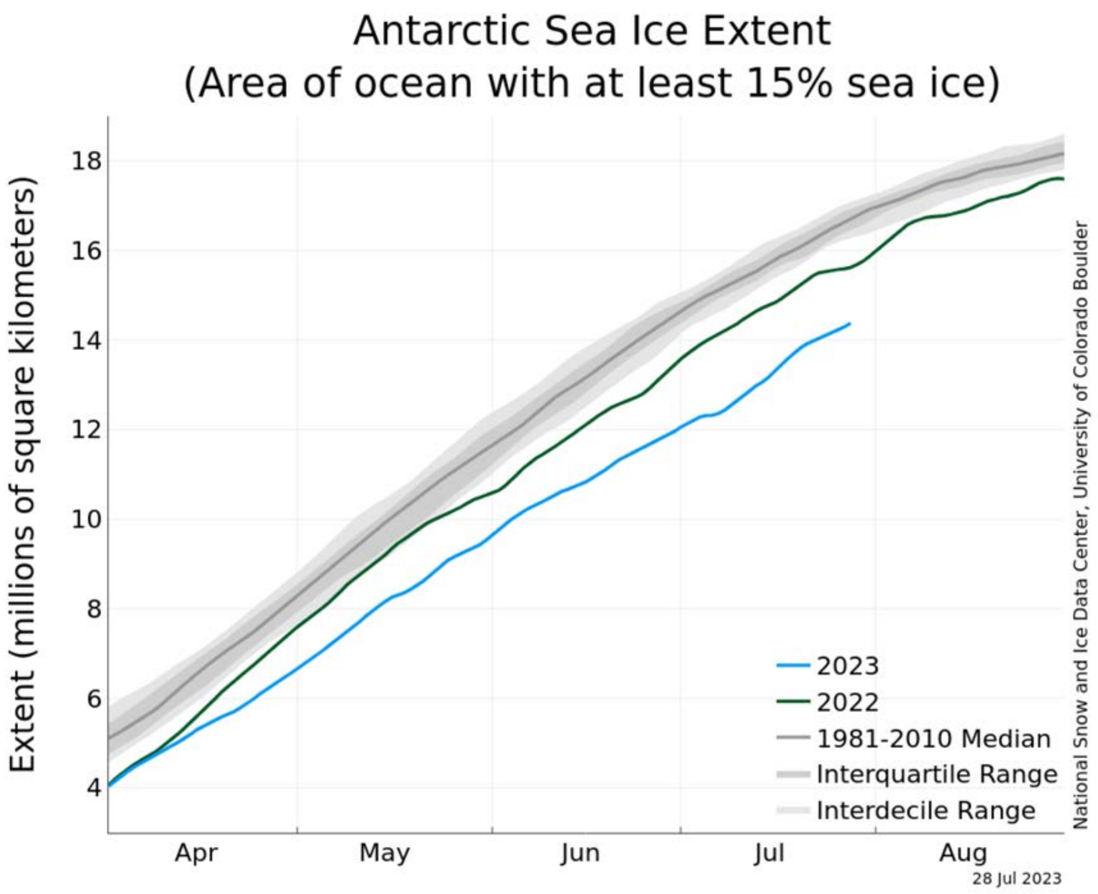
- Need to understand dynamics of Southern Ocean and its connections in the face of uncertainty

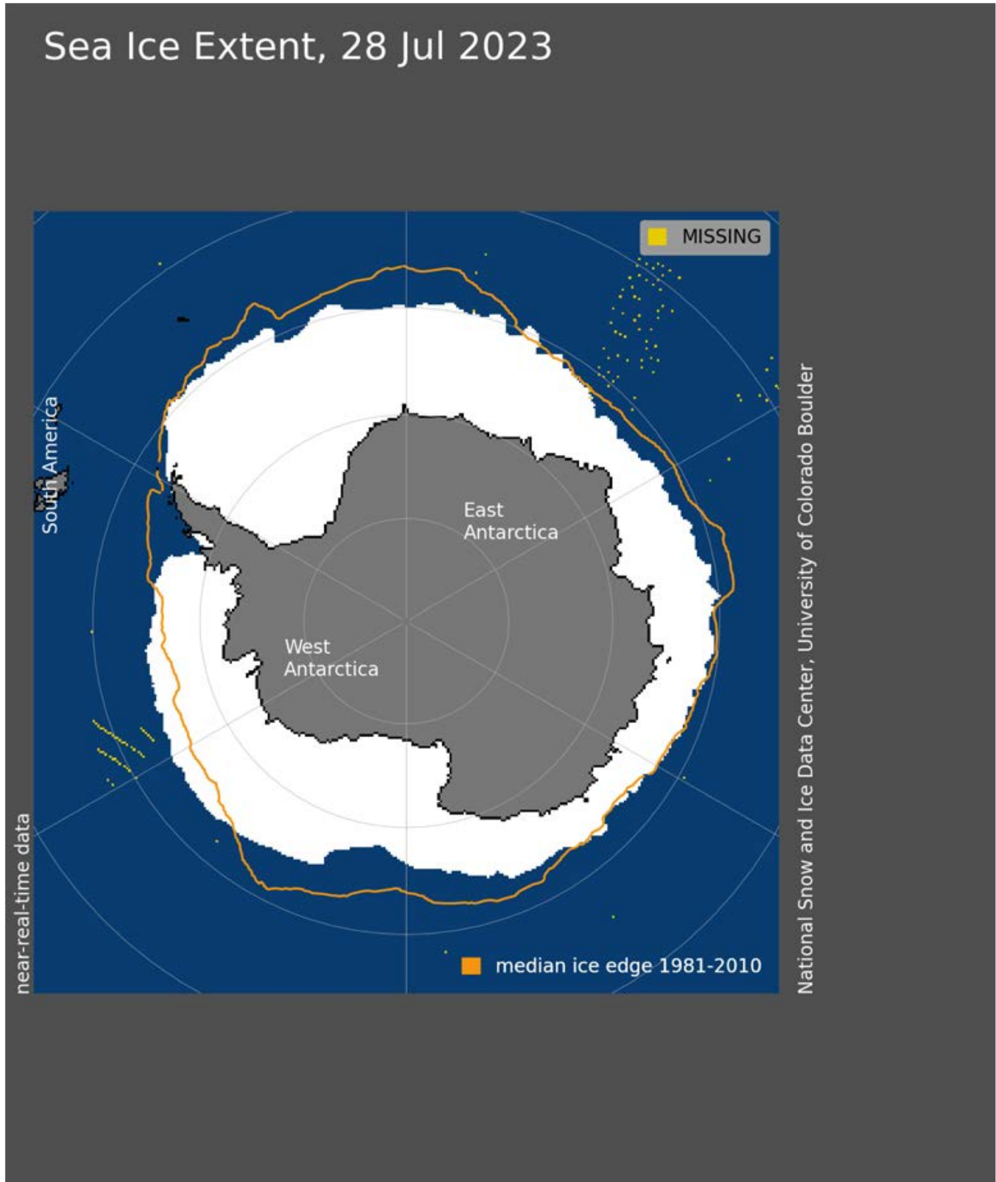
- Including unpredicted cooling from 1980-2015 (ERA 5 trends) →



Understanding The Southern Ocean in Flux

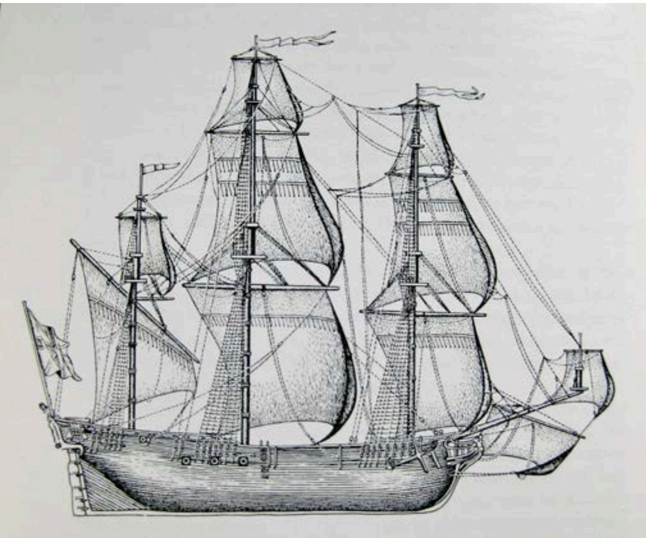
- To be ready for future changes…

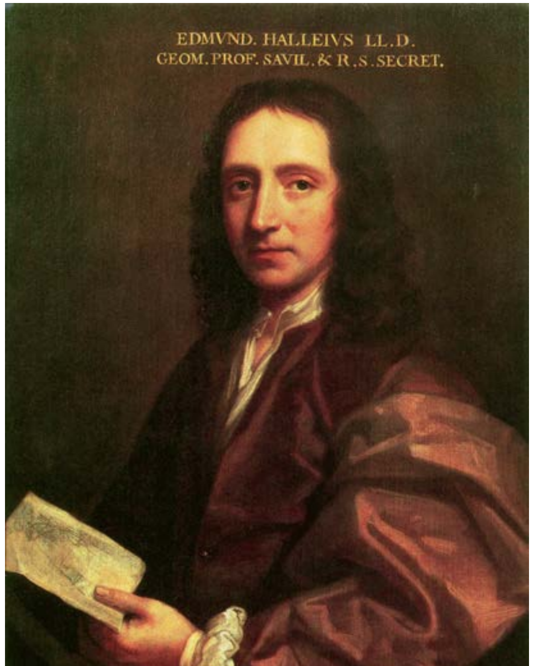




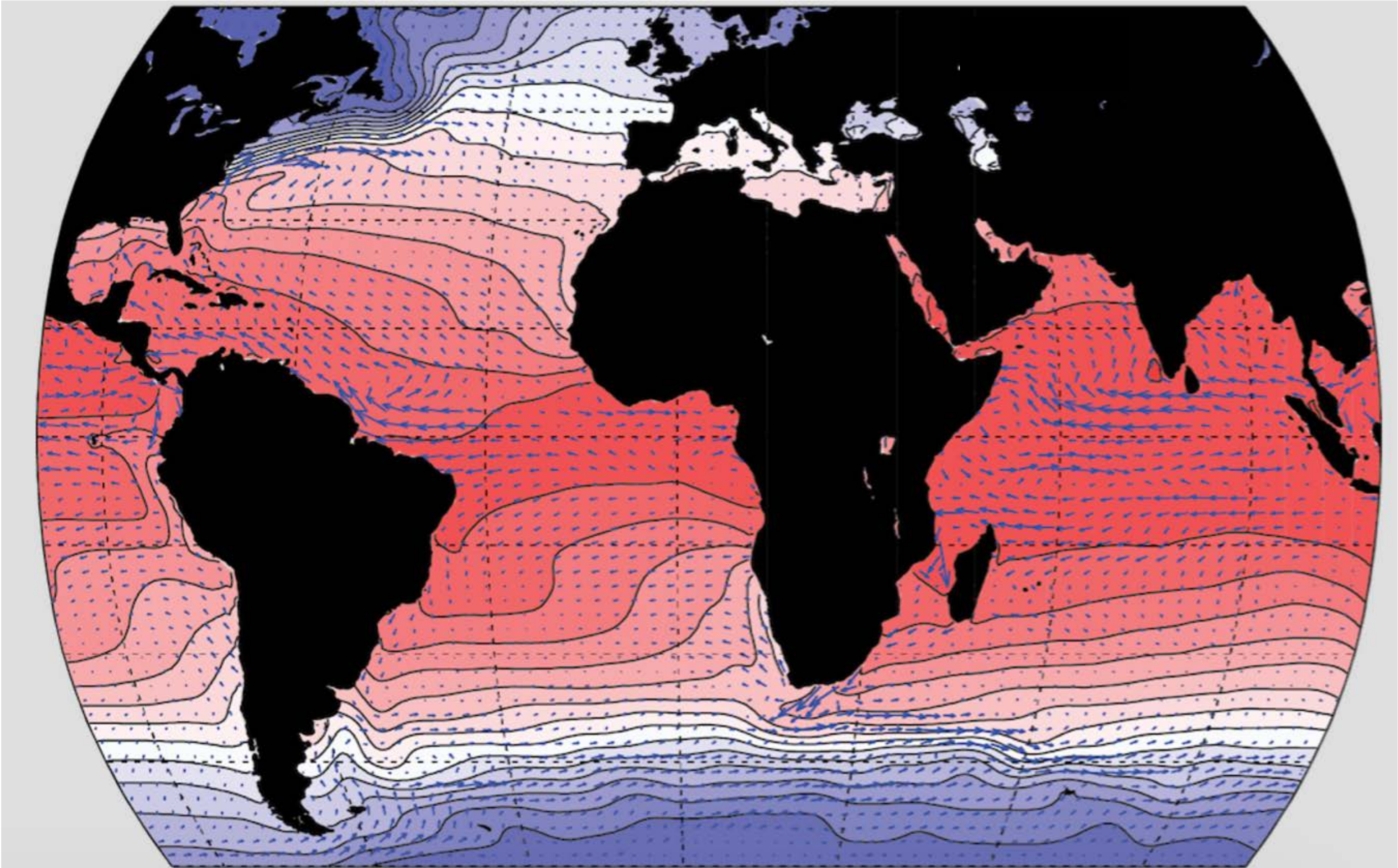
Early Southern Ocean Discoveries

- Edmond Halley led the first ever *purely* scientific voyage in 1700
- Crossed the Antarctic polar front
- Mentions in his journals how *cold* the Southern Ocean was





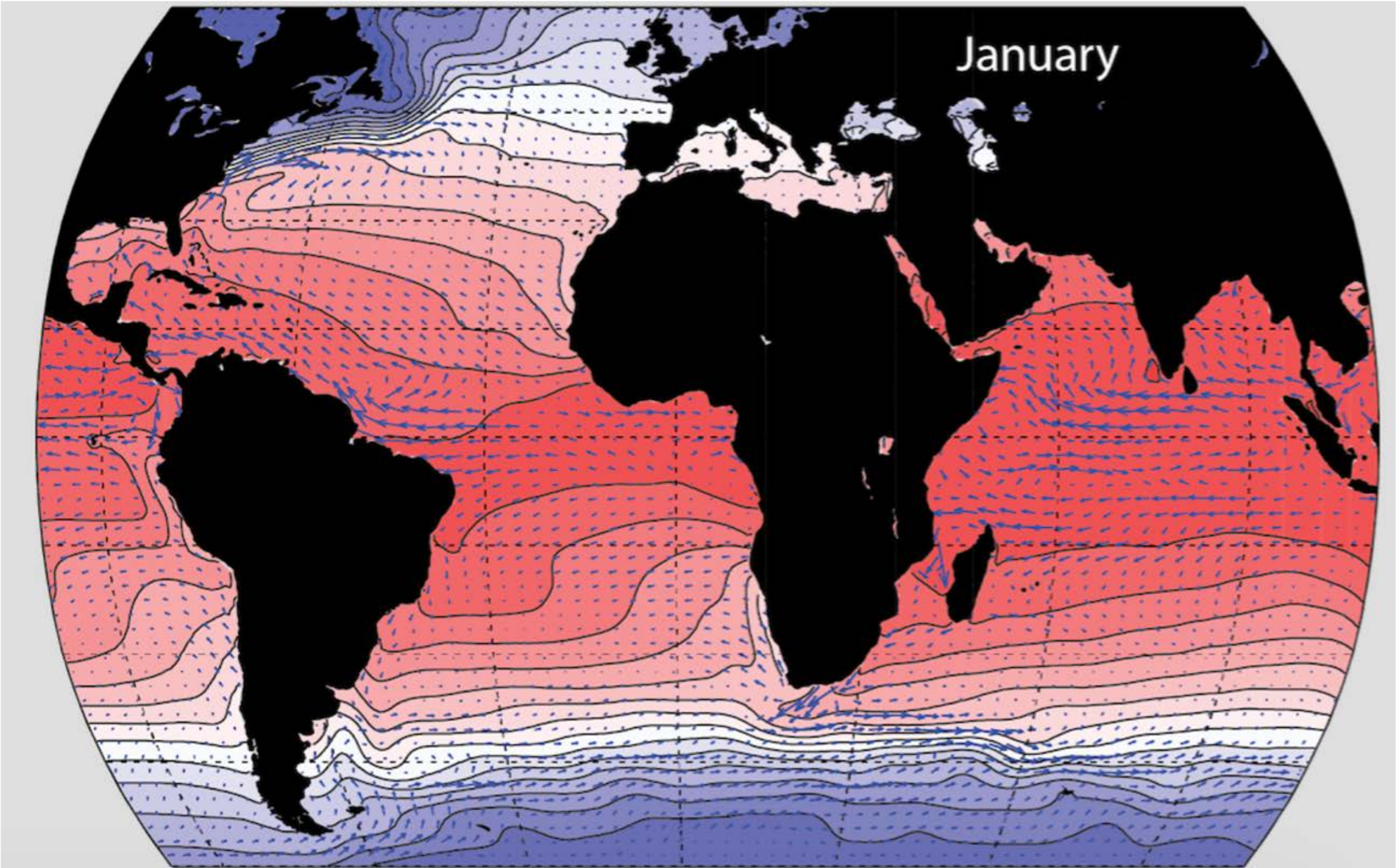
It’s really **cold** in the Southern Ocean



It's really **cold** in the Southern Ocean

- Average temp at 52.5^o **S** (farthest south Halley went): 4^o C in summer!

- Avg temp at 52.5^o **N** (off coast of England): 8^o C in winter!



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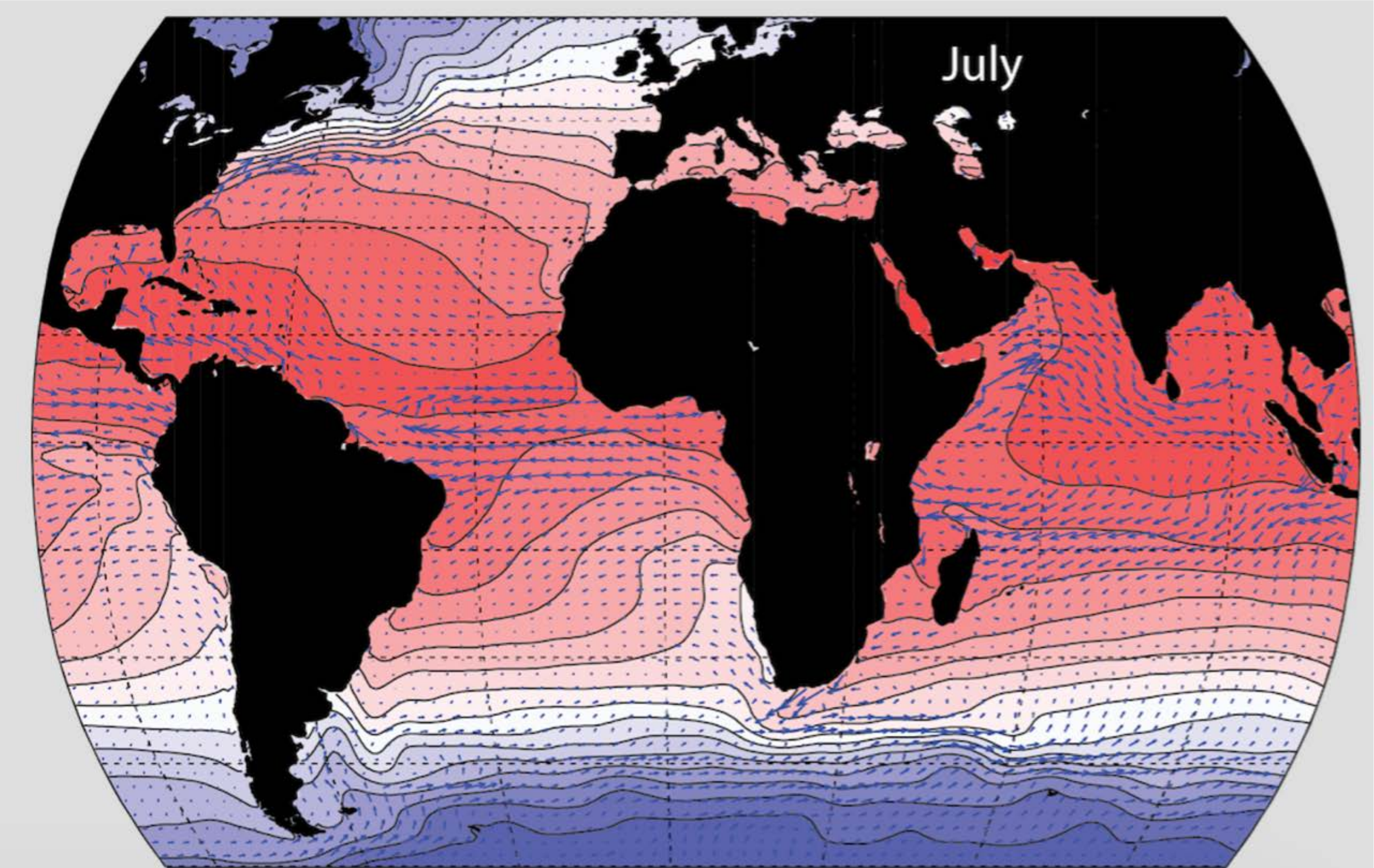
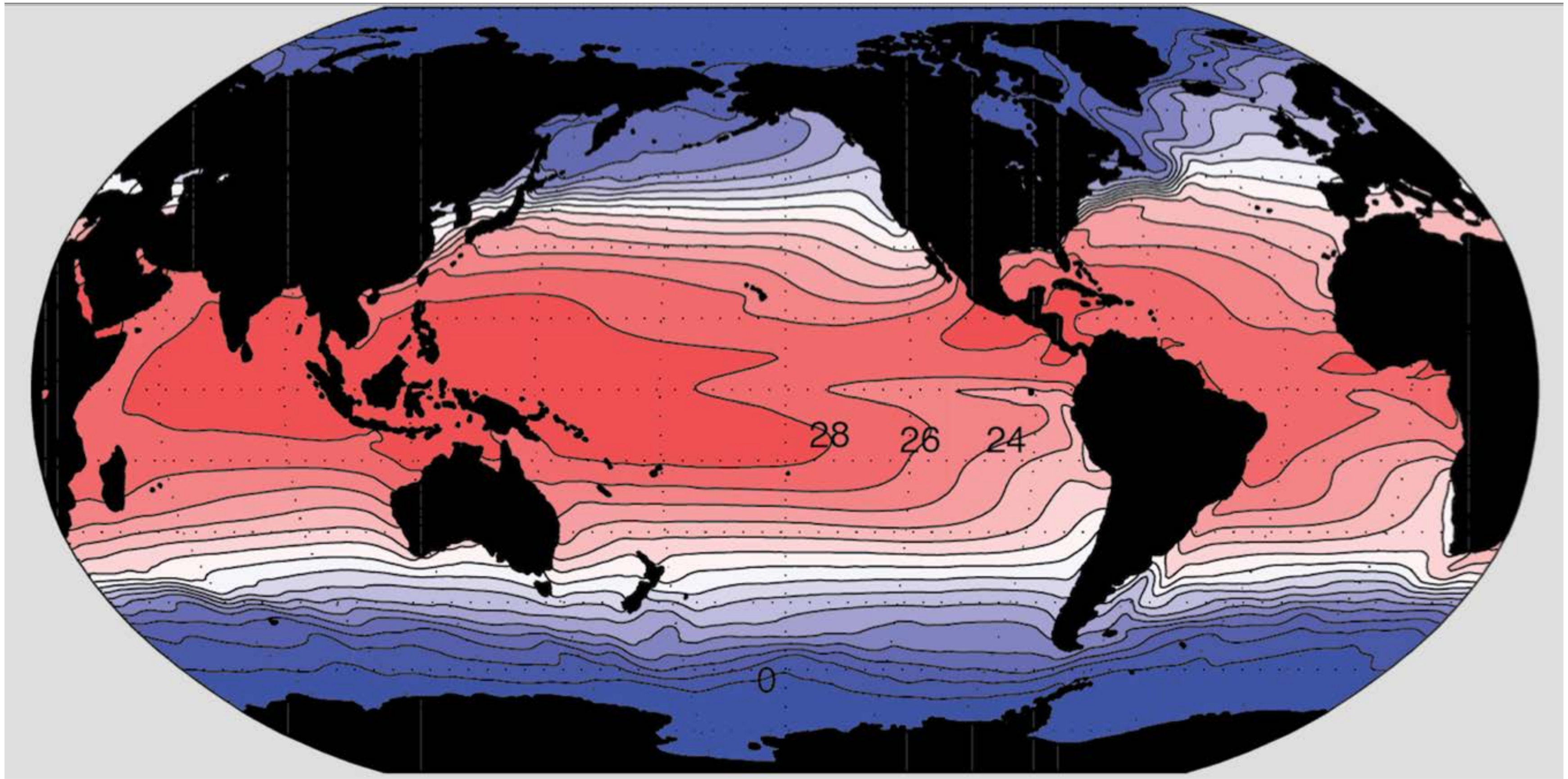


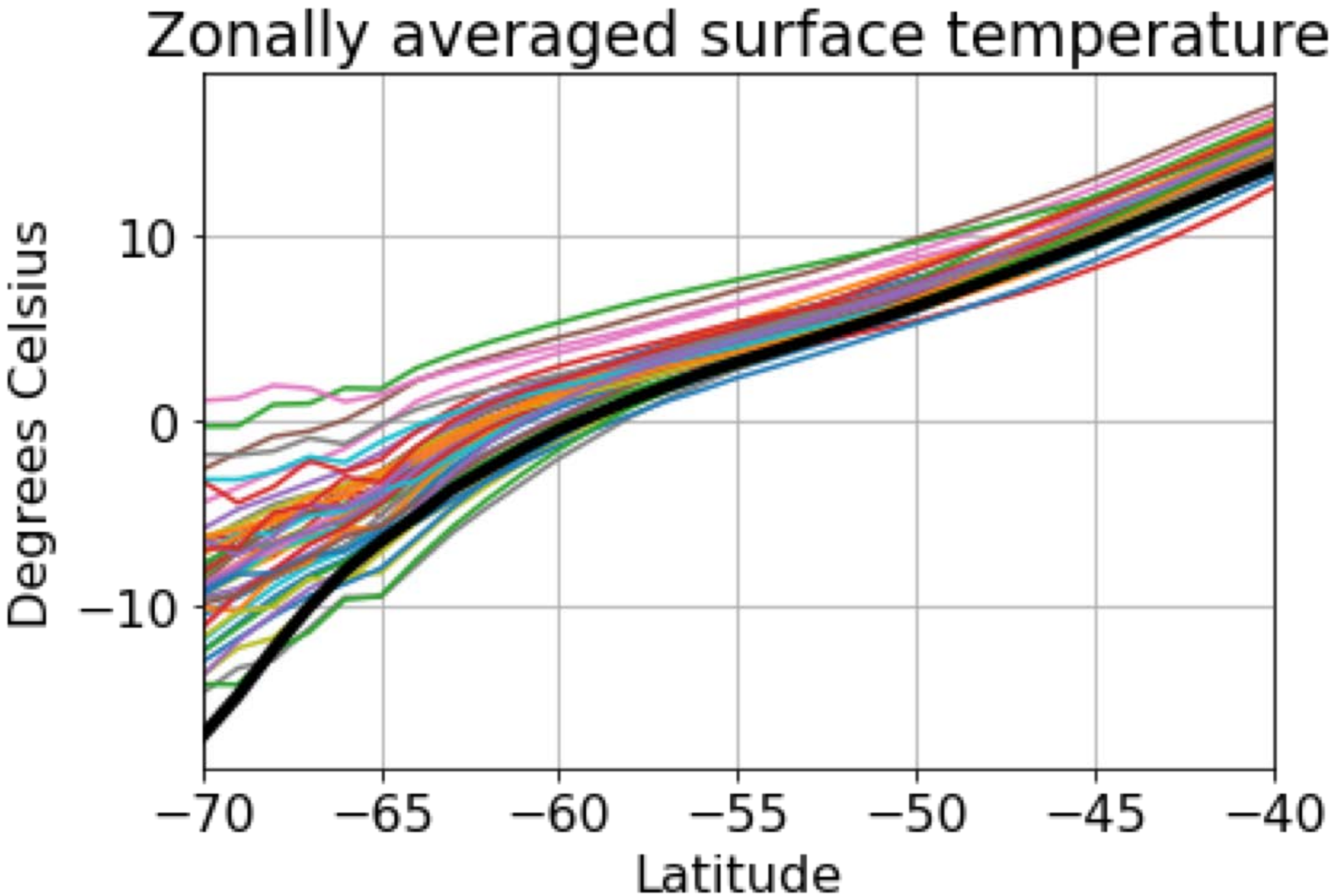
It's really **cold** in the Southern Ocean

- Annual mean



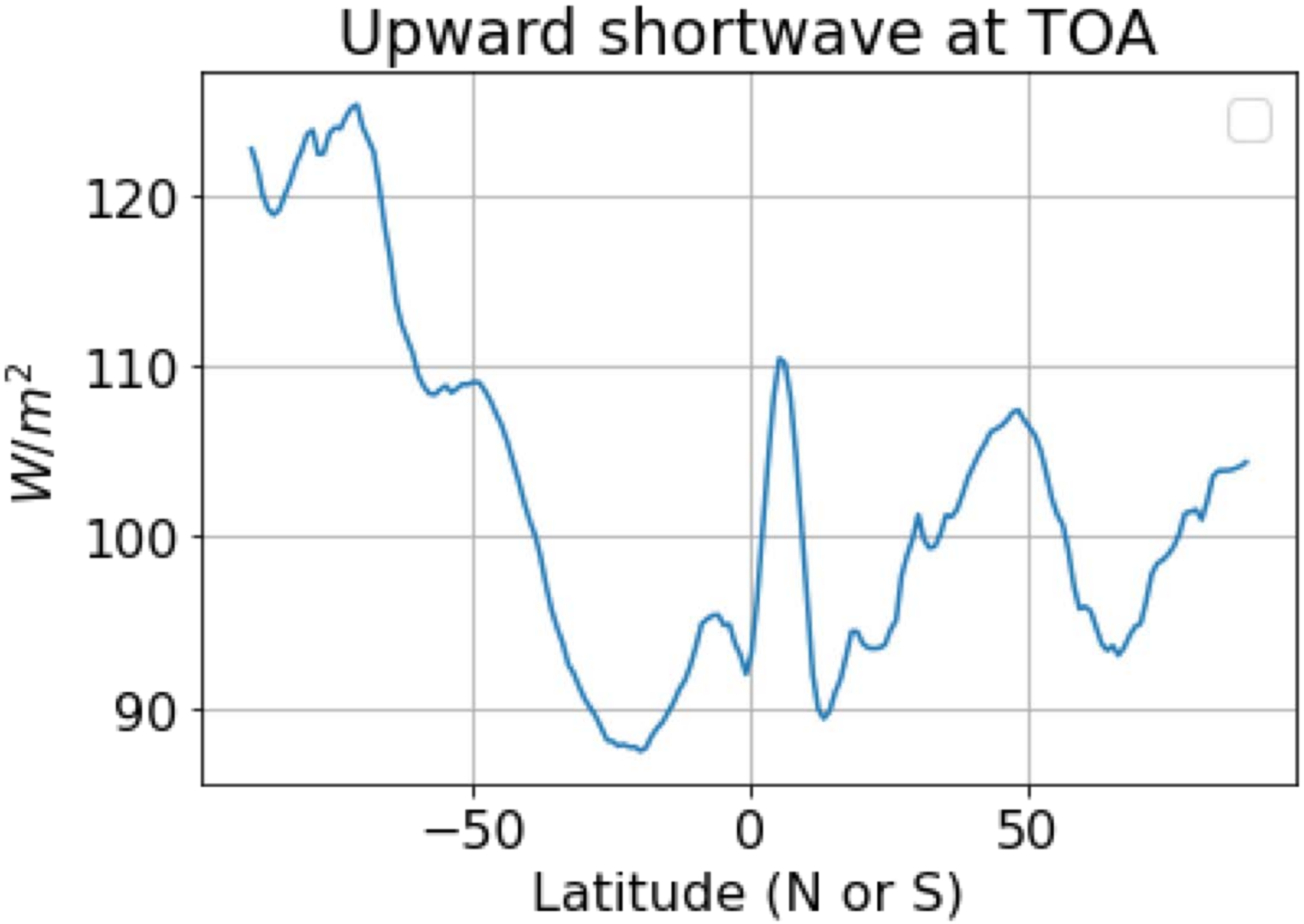
Models Struggle to Produce Cold Enough Temps

- Historical simulations from 31 CMIP6 GCMs
- Annual mean surface temperature (1980-2014)
- Reanalysis in **black**
- Increasingly large errors at higher latitude



Also very large reflection of solar radiation

- Lots of SW radiation reflected back to space in SH high latitudes (CERES 4.2 Climatology)



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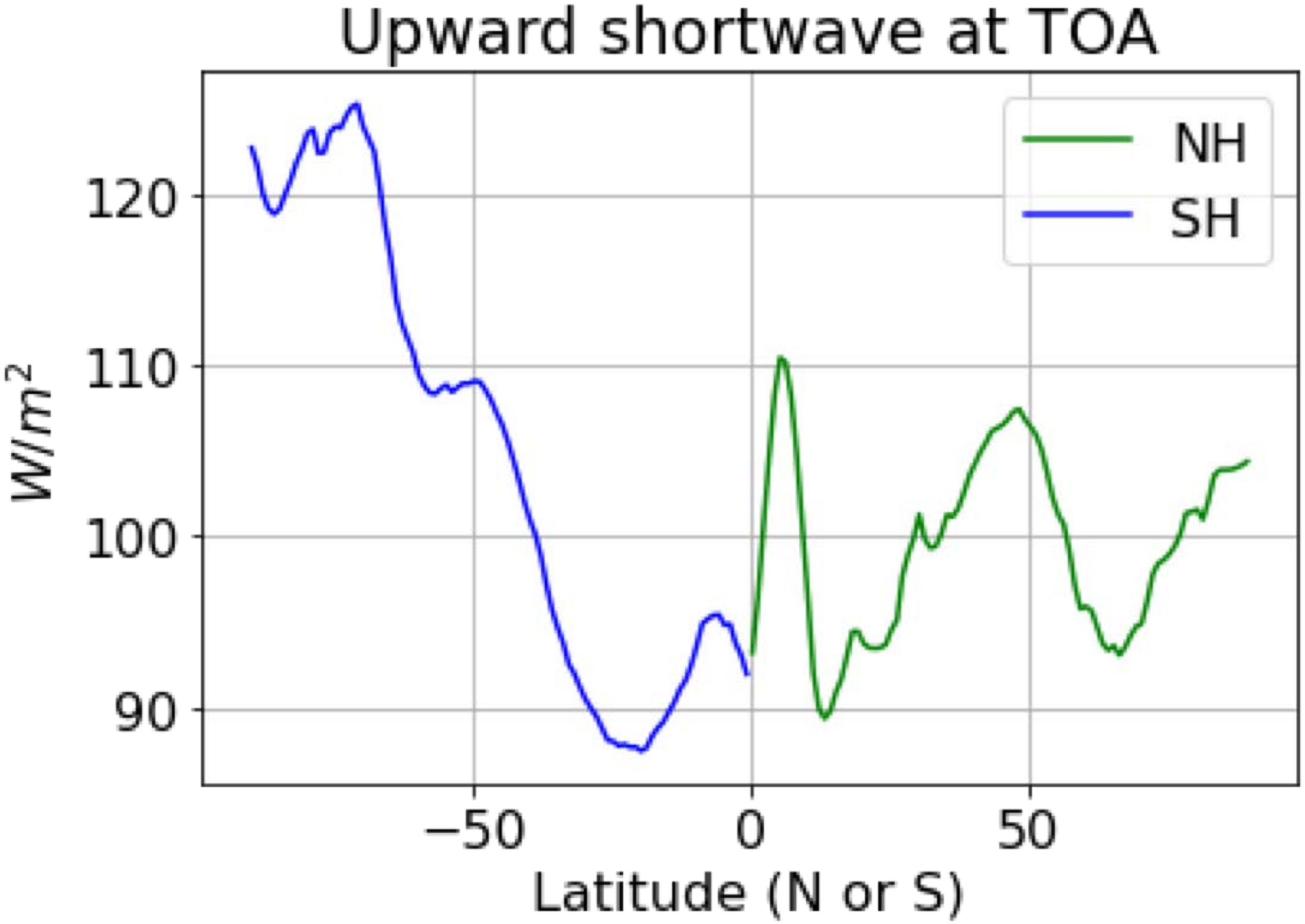
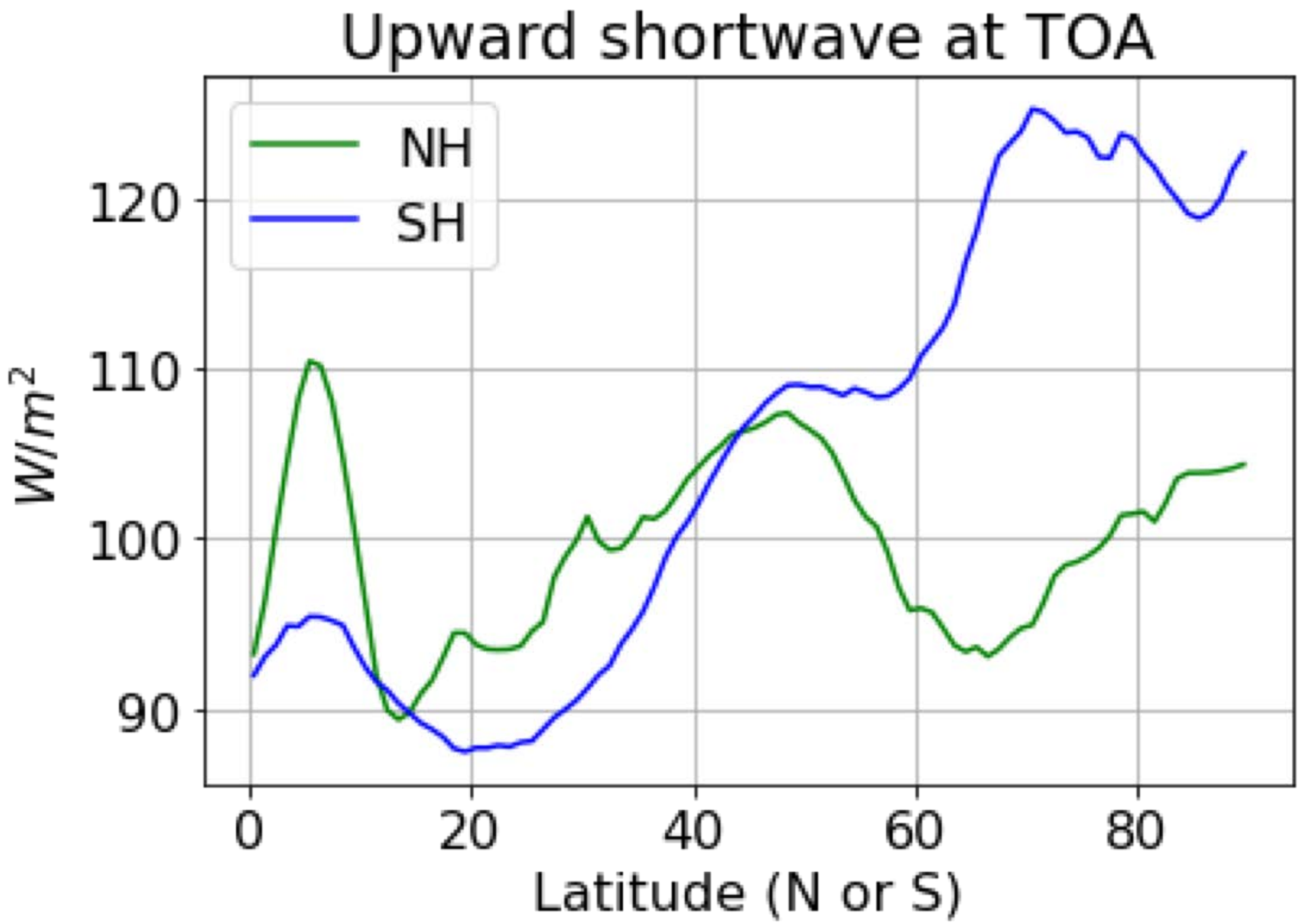


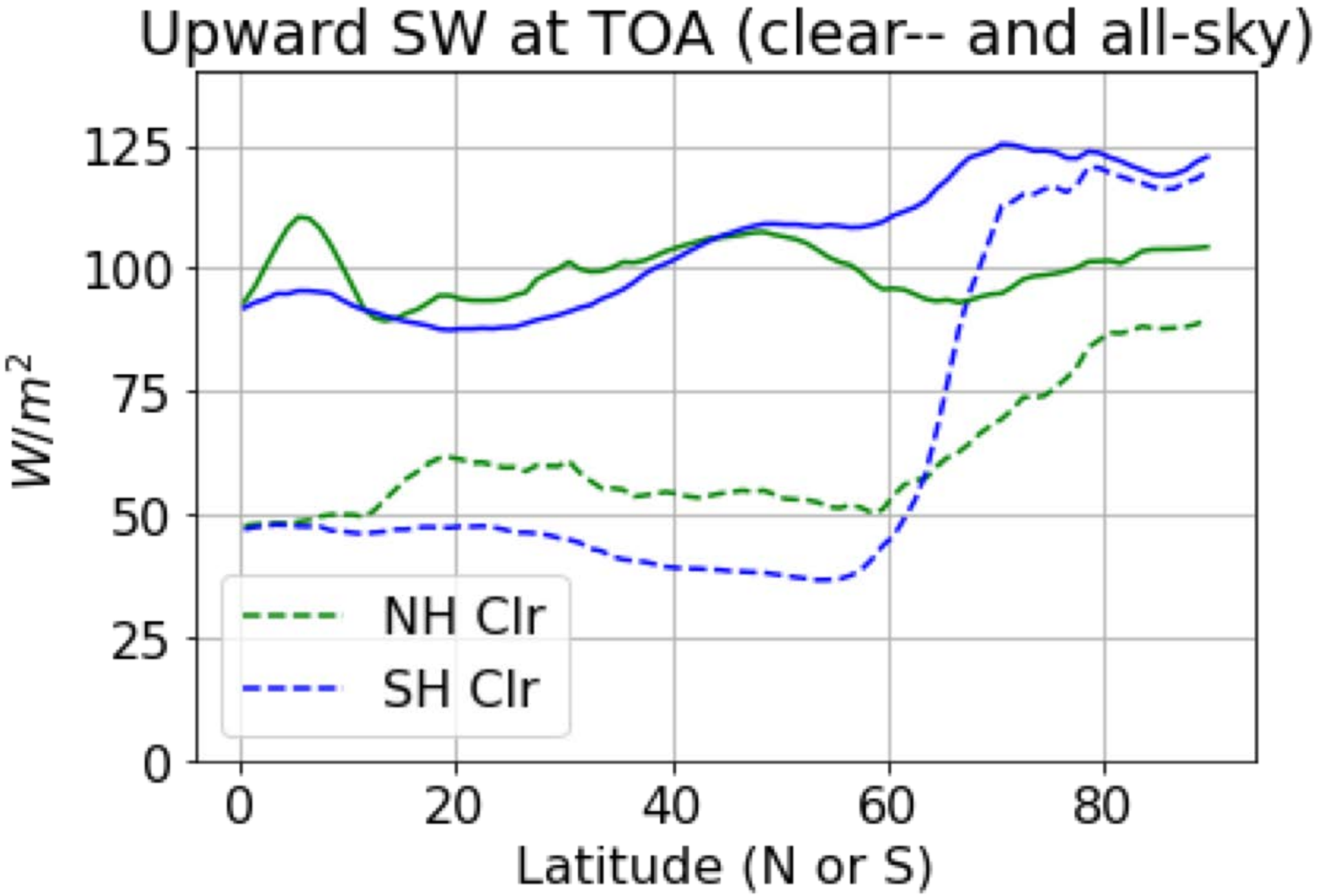
Compare SH with NH

- Lots of reflection from 50-90 S



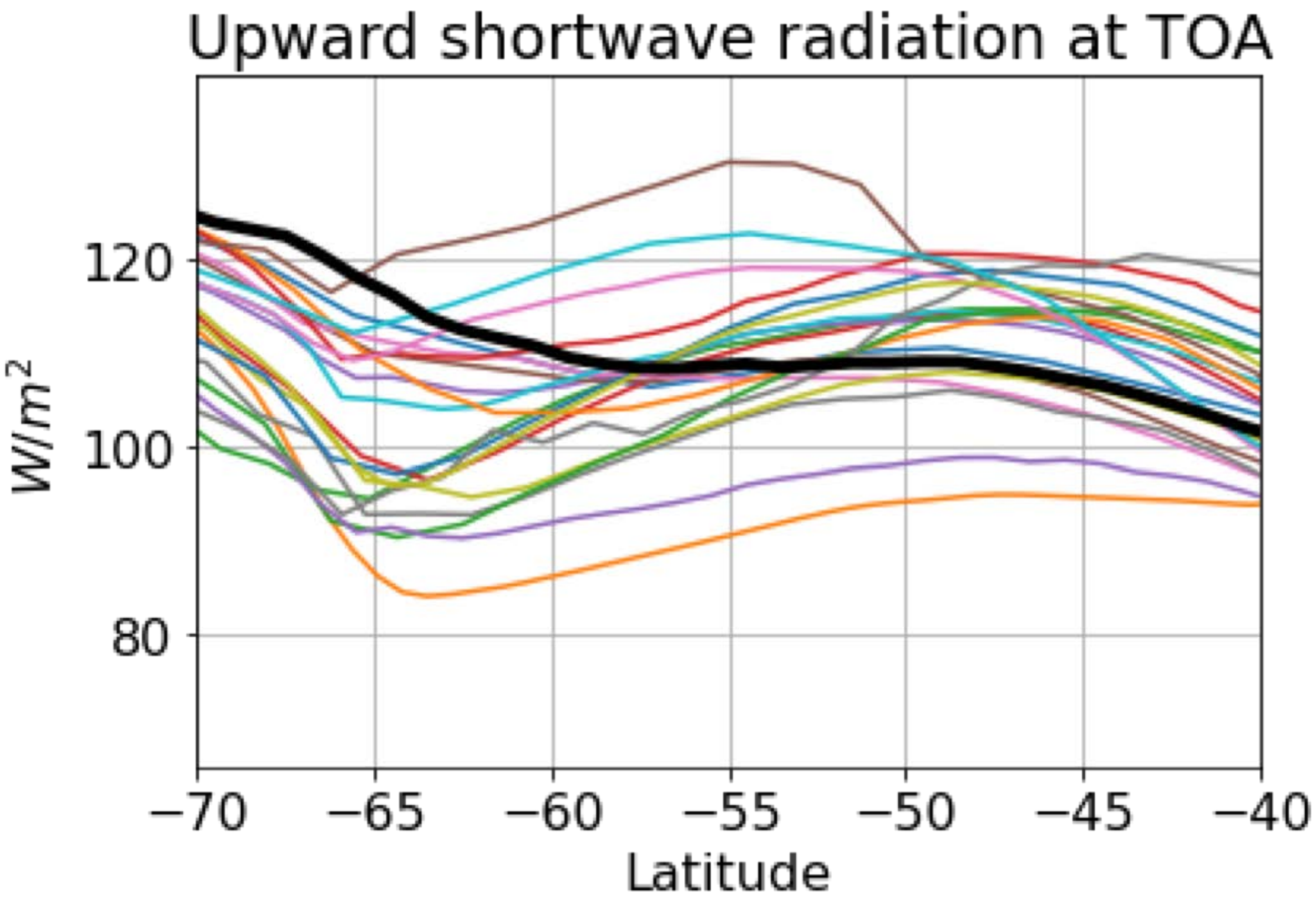
Compare SH with NH, Clear Sky and All Sky

- Much of the difference is due to surface albedo at high latitudes
  - But clouds over the Southern Ocean matter too!



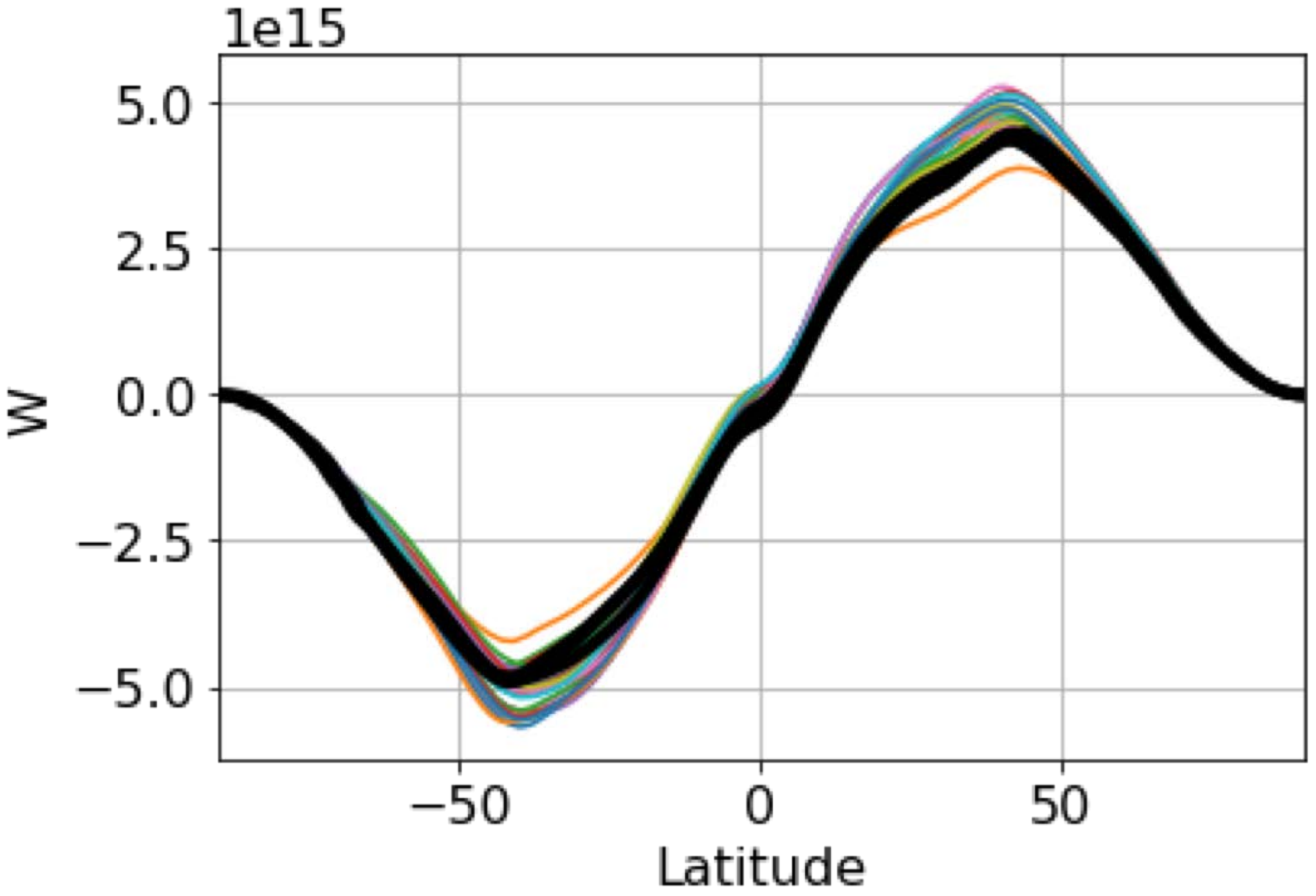
Model Simulation of Upward SW at TOA

- Historical model simulations of upward SW and CERES (black)



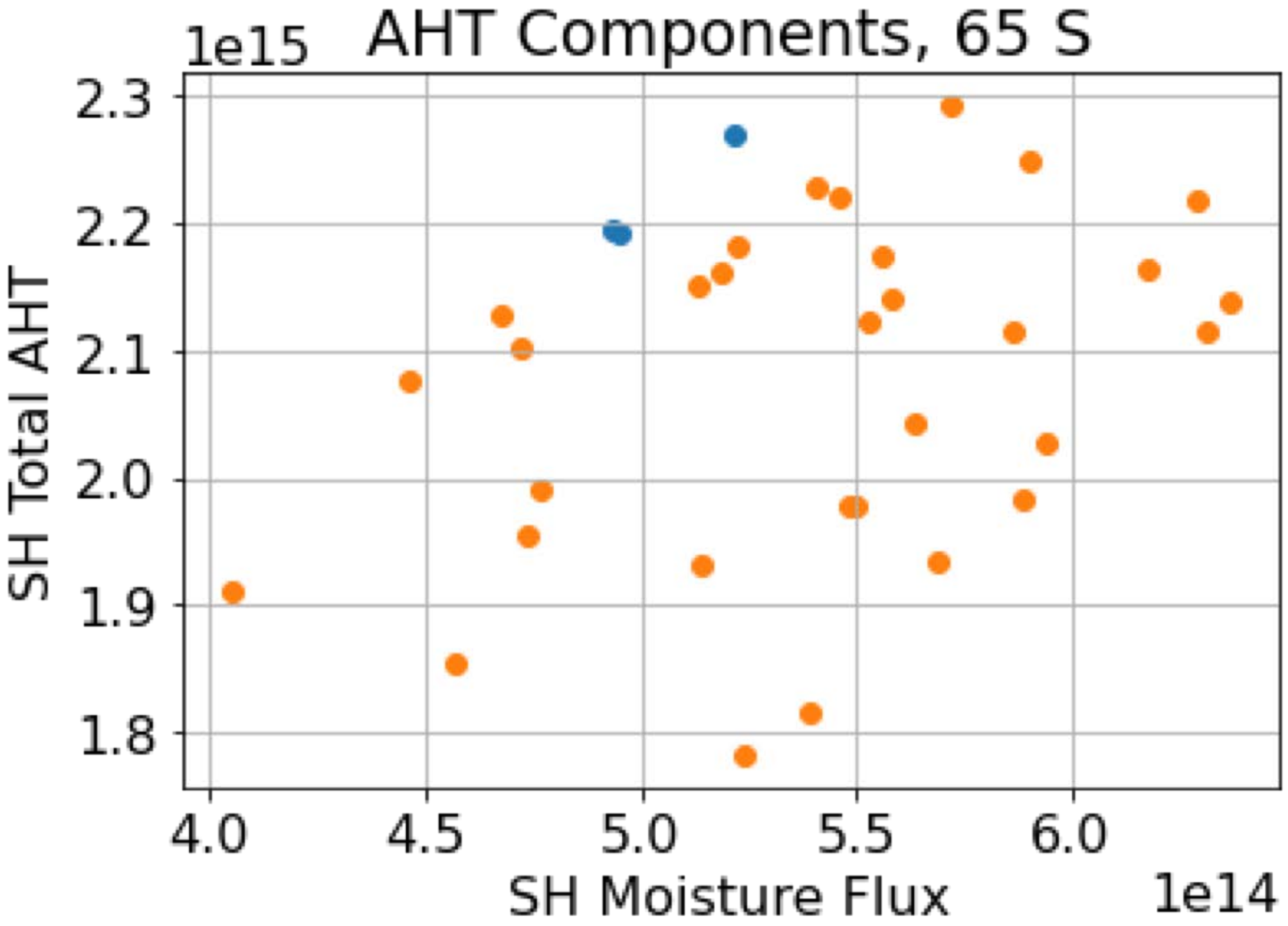
Energy Transports Connect Latitudes

- Especially underestimated southward transport in Southern Ocean
  - This spreads the warmer temperatures equatorward



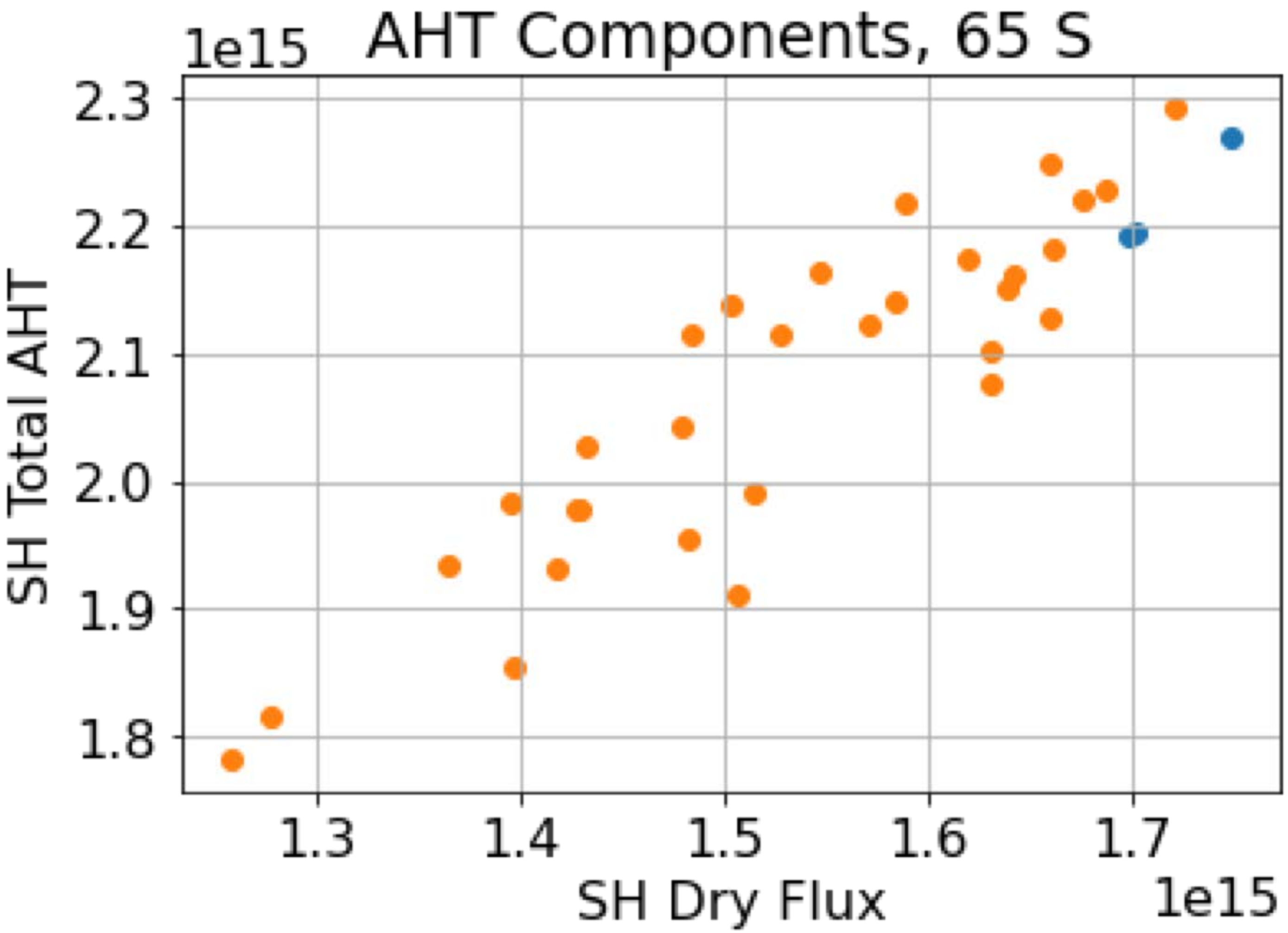
Southern Ocean Energy Transports

- Moisture flux is about right on average, total flux is underestimated



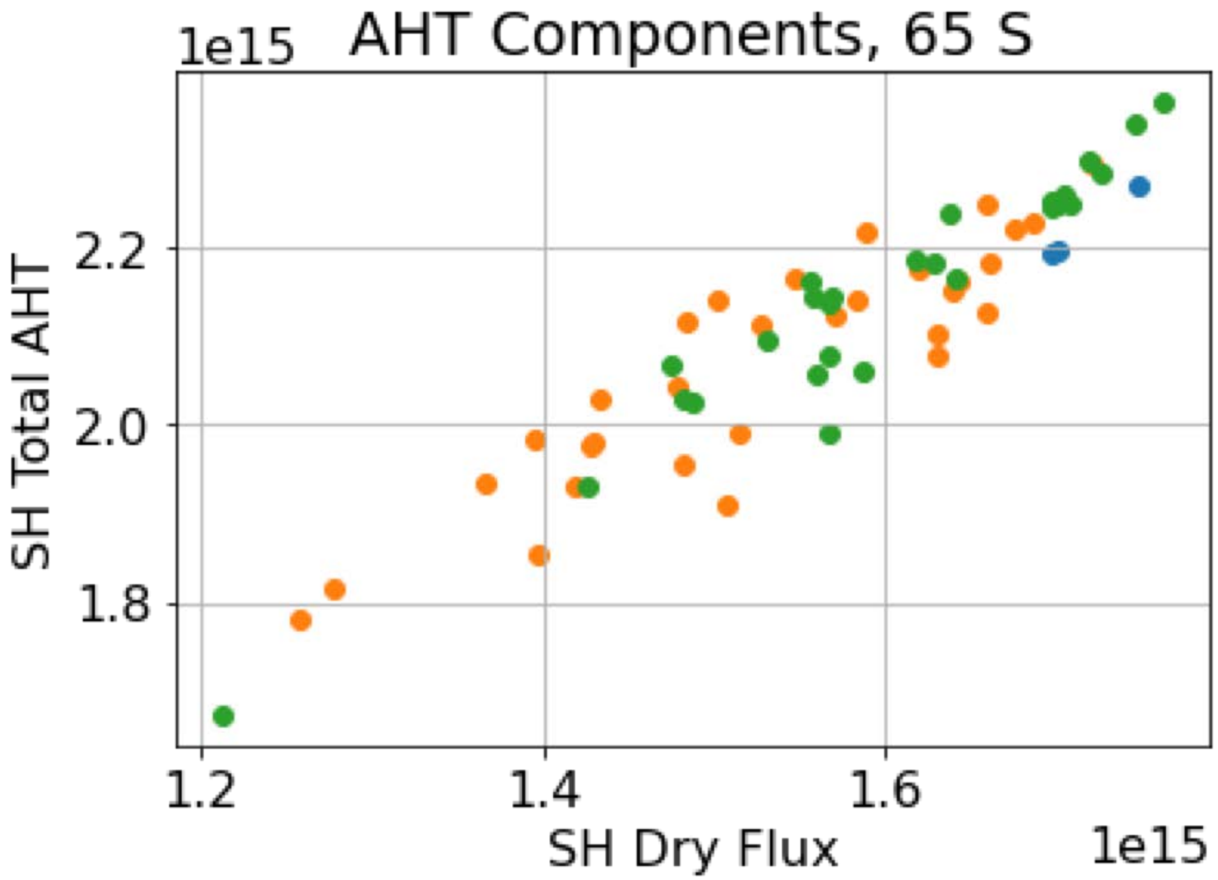
Southern Ocean Energy Transports

- Models underestimate dry static energy flux



Southern Ocean Energy Transports

- Adding AMIP (fixed historical SST) simulations in green
  - These have better agreement with observed fluxes (but not perfect!)



Let’s examine AHT trends!

- 3 reanalysis datasets
  - ERA5, JRA-55, and MERRA2
- CMIP6 model simulations
  - 31 coupled models – have fully interactive oceans and atmosphere
  - 28 atmosphere-only (AMIP) models – have oceans with sea-surface temperatures (SST) that are set to observed values. This can help us isolate the role of ocean SST trends in influencing AHT trends
  - CESM2-LE – A 100-member coupled ensemble
- Overall this is ~100TB of data!
  - Shows the importance of having tools to deal with large datasets

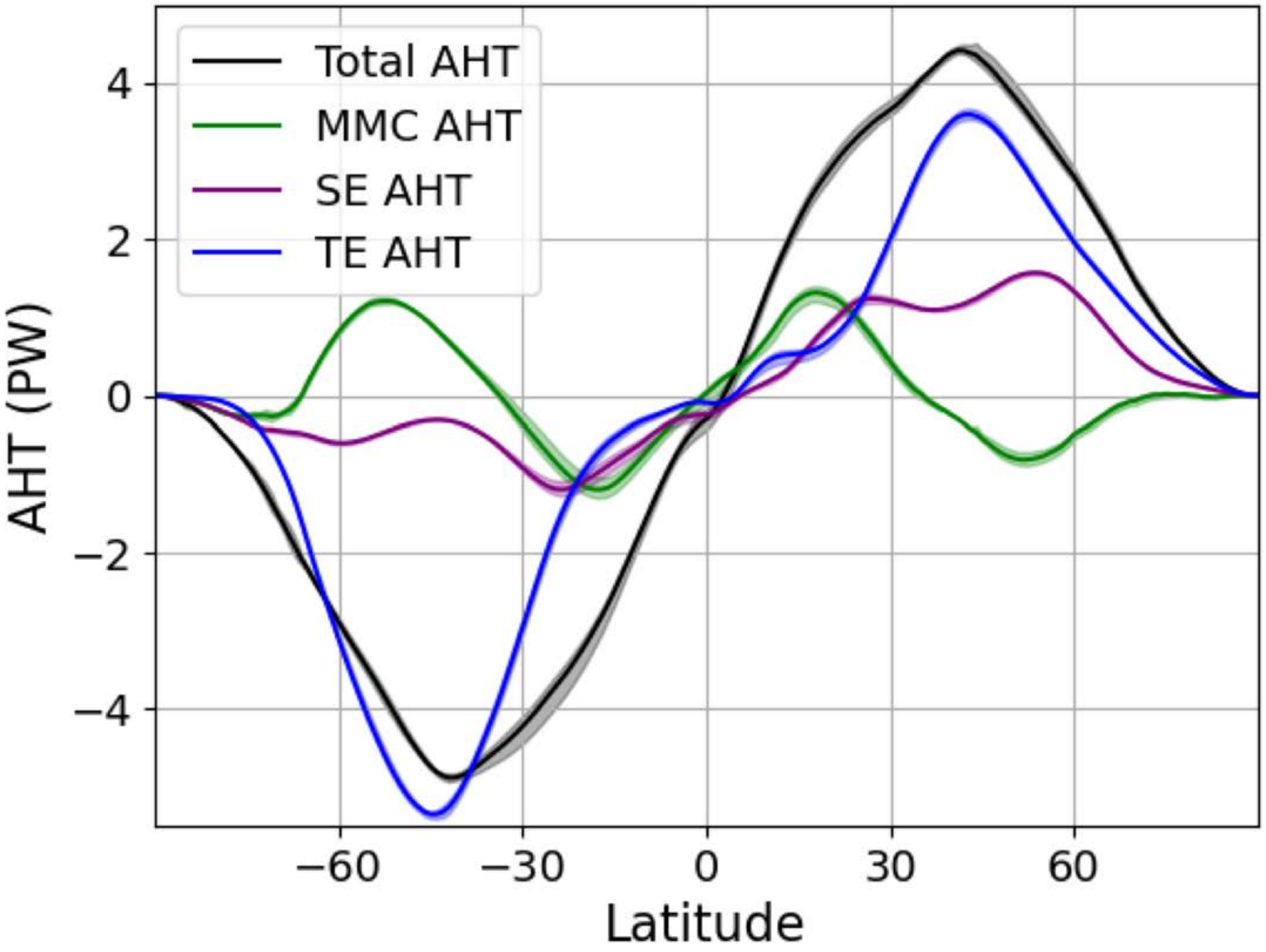
Climatological AHT

MMC: Mean meridional circulation

SE: Stationary eddy

TE: Transient eddy

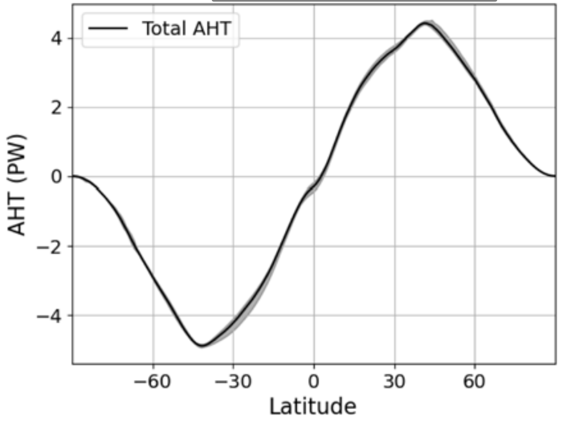
Total AHT = MMC AHT + SE AHT + TE AHT



Shading denotes range across 3 reanalyses

AHT Trends

Climatology



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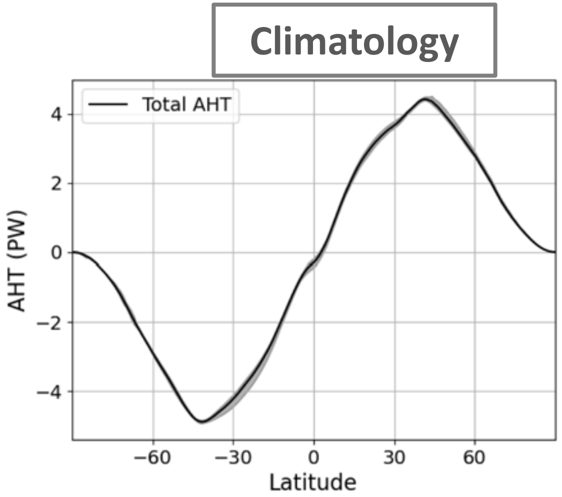
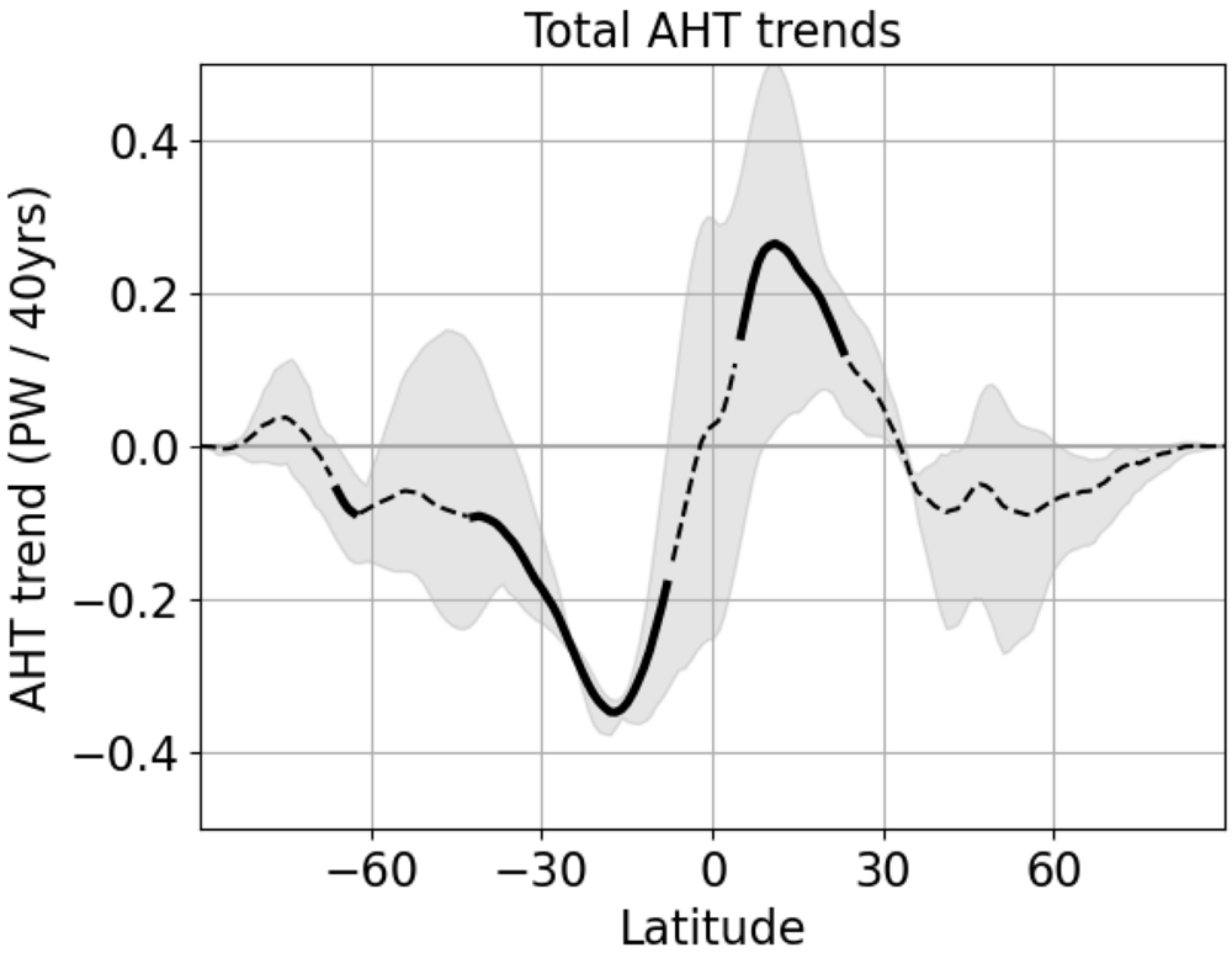
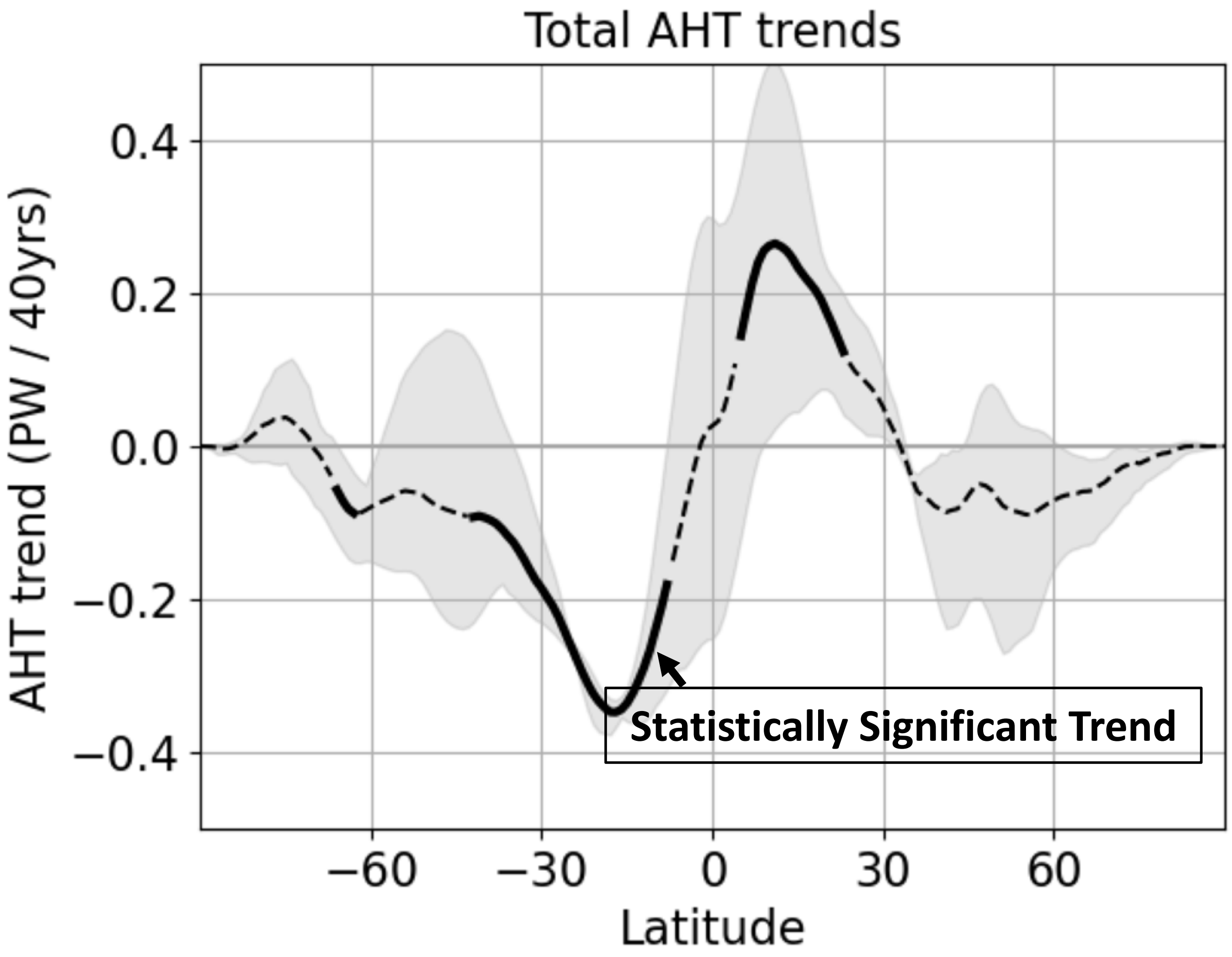
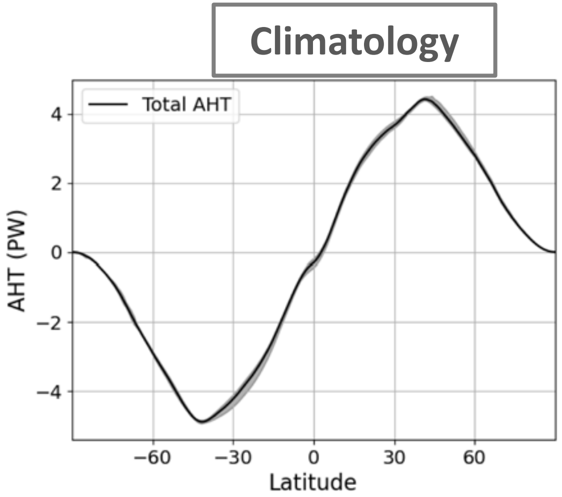




Trends are linear trends from 1980-2014

AHT Trends





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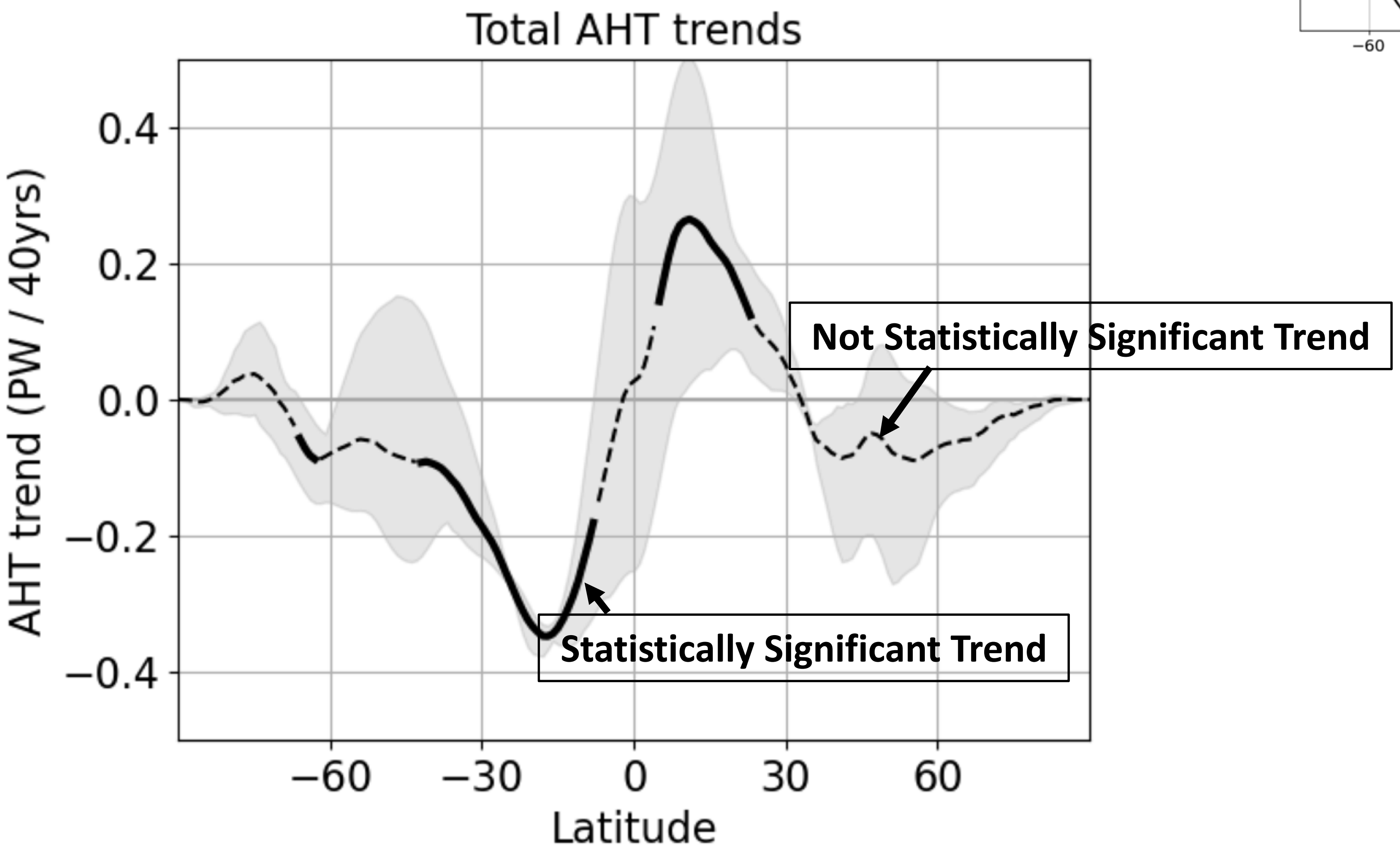

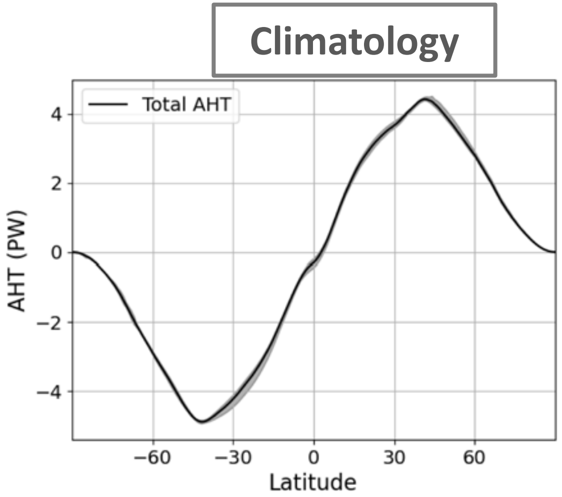

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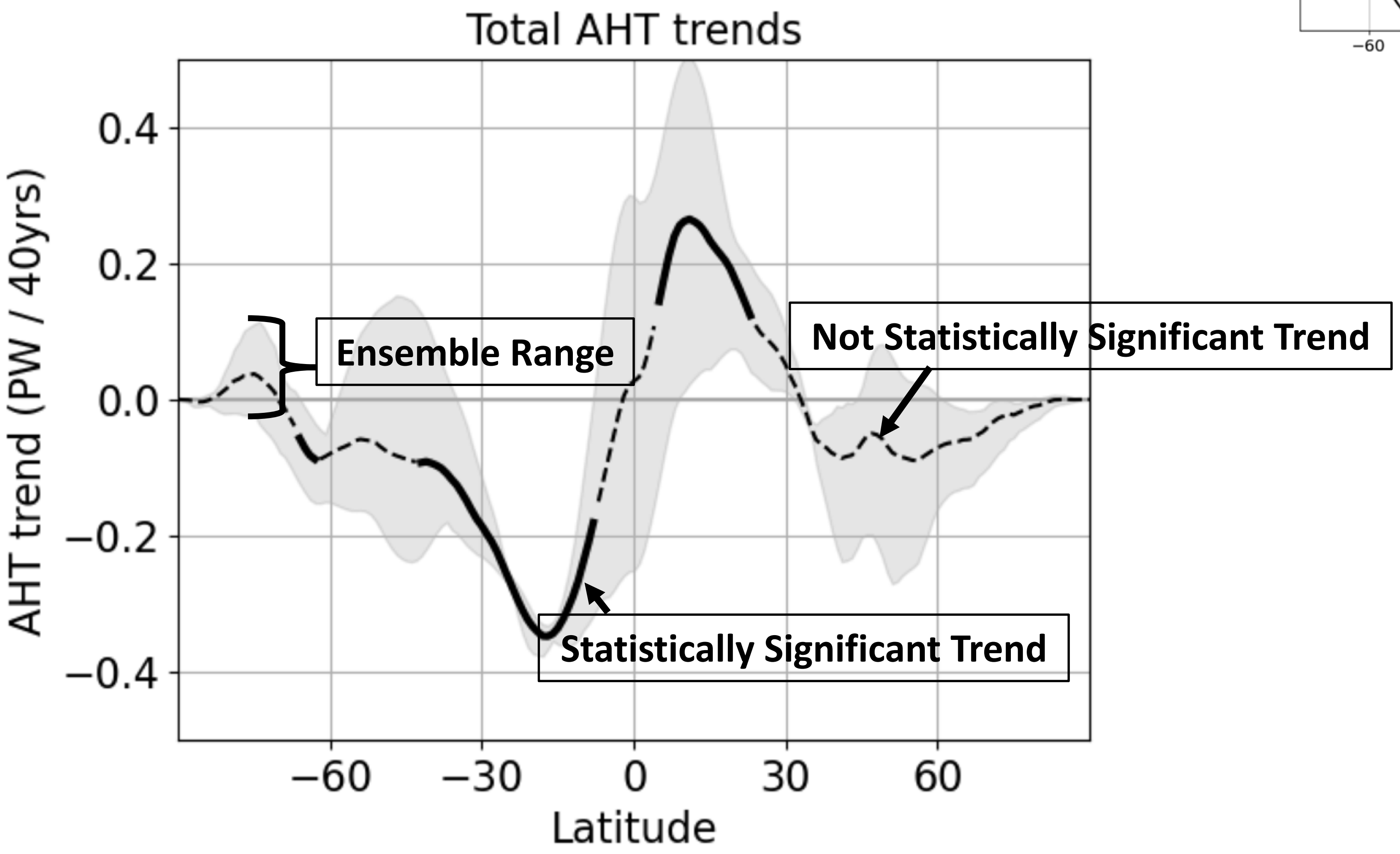

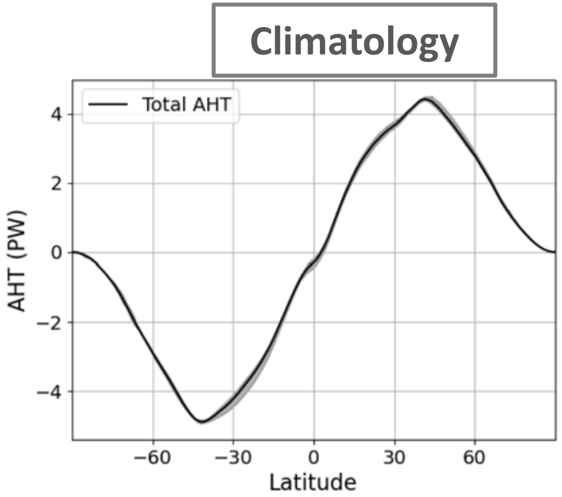

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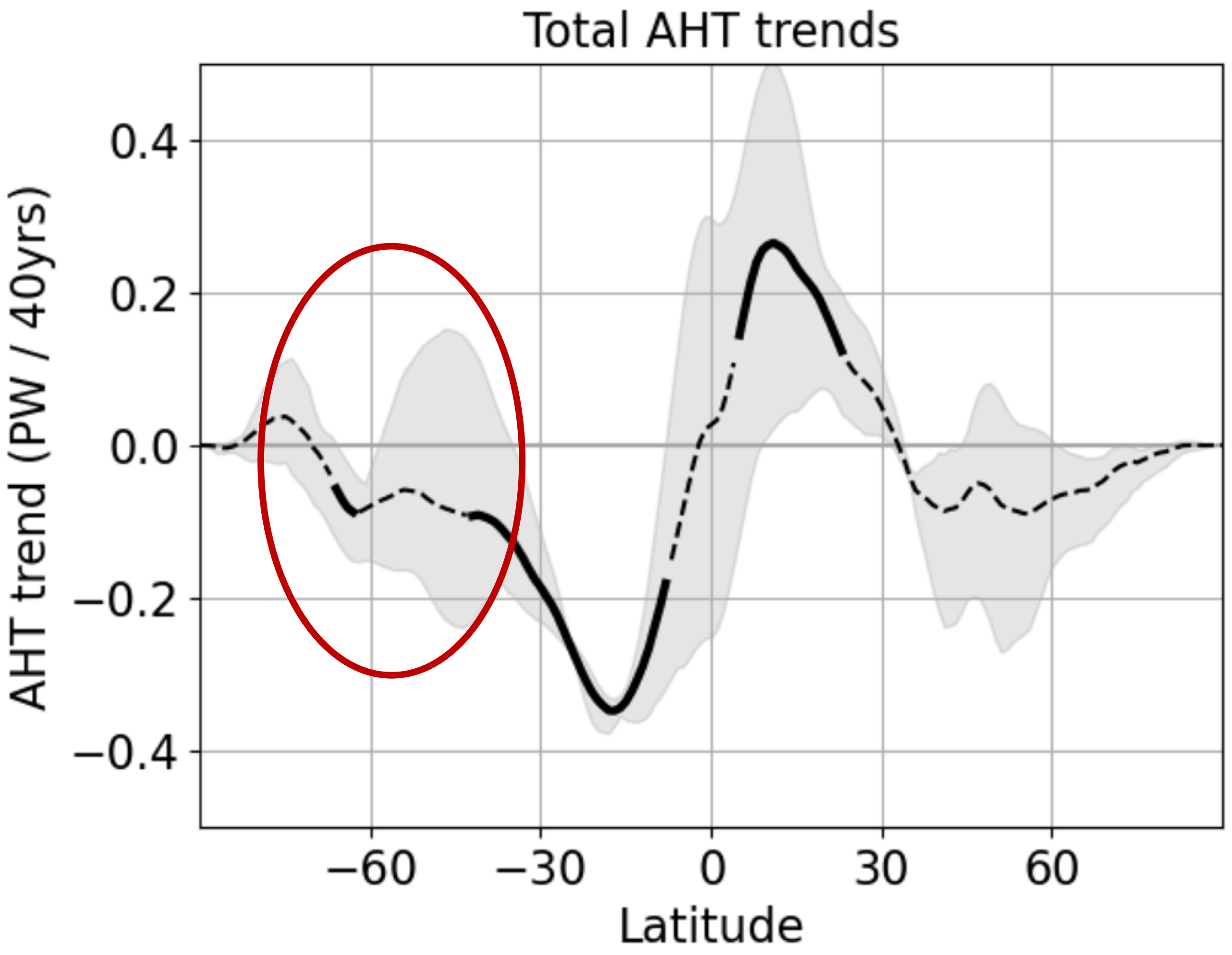

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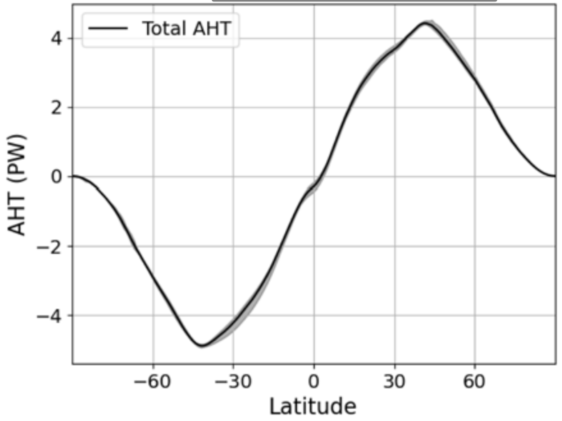

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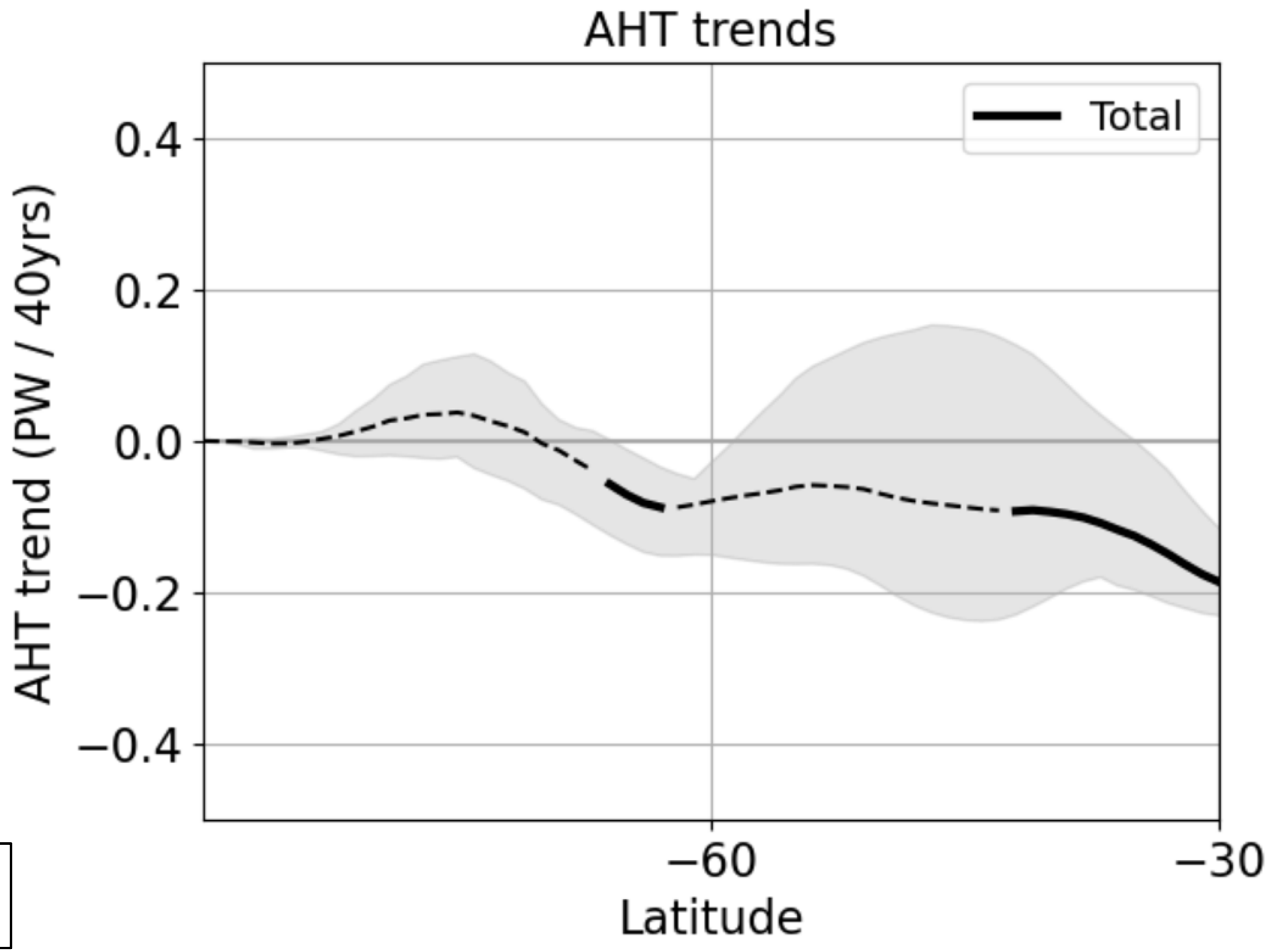
Southern Ocean AHT Trends in reanalysis



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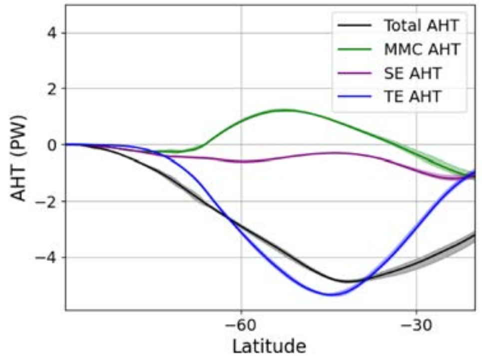

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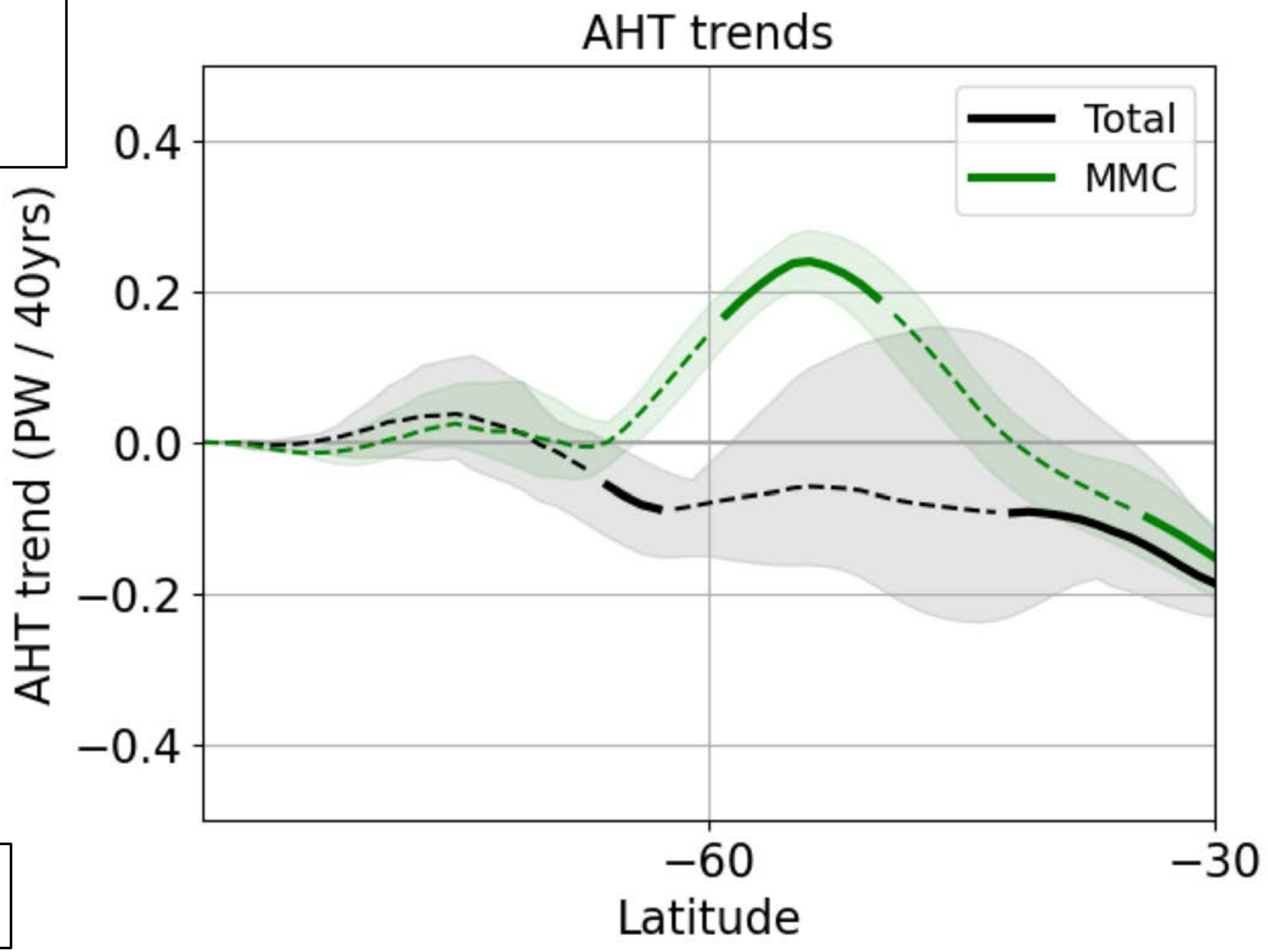

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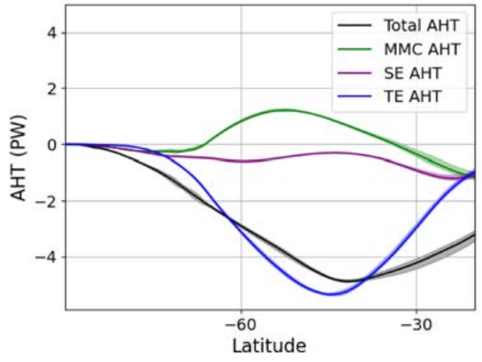

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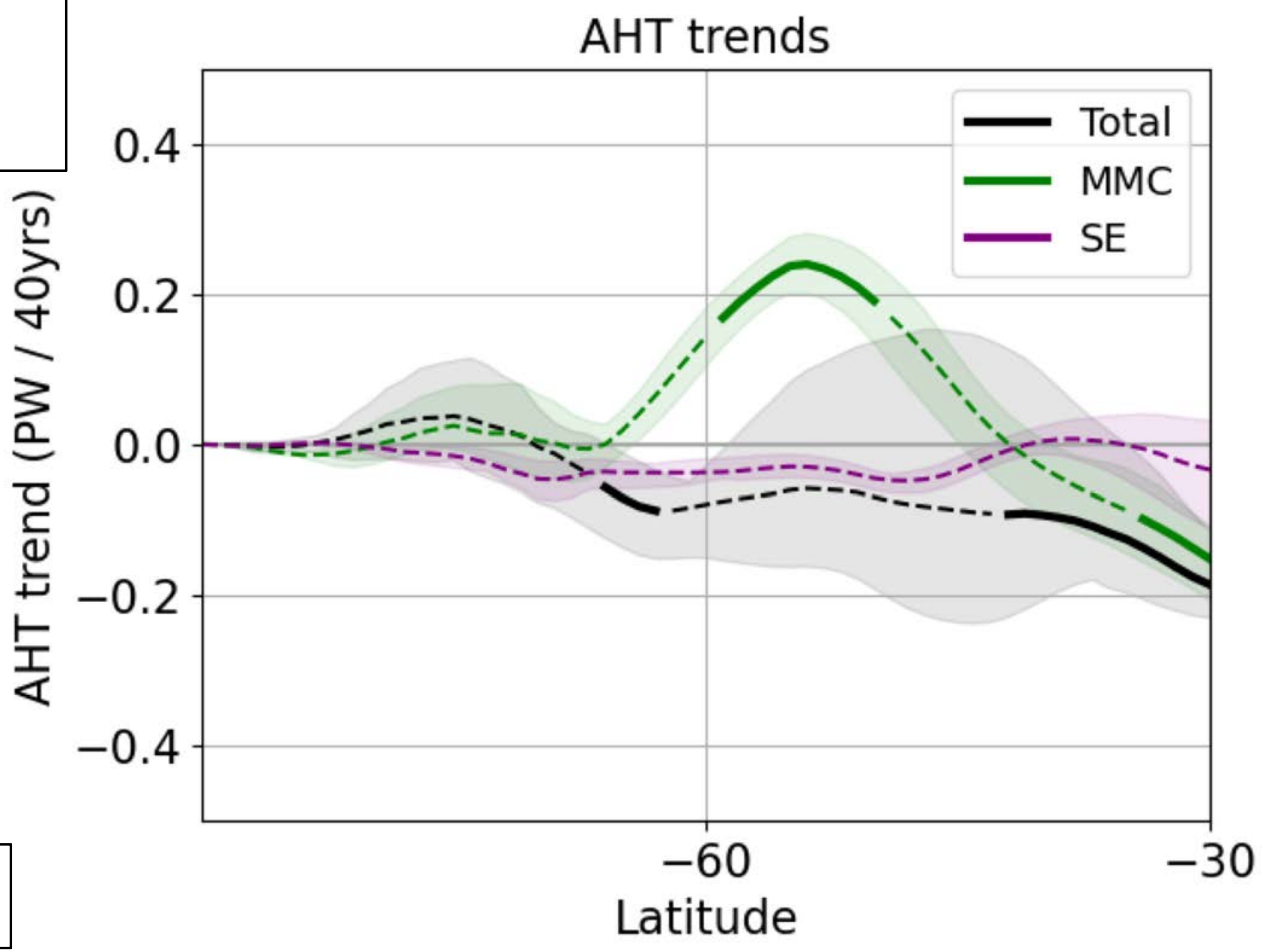

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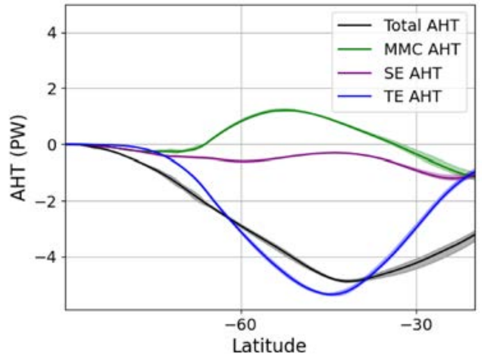

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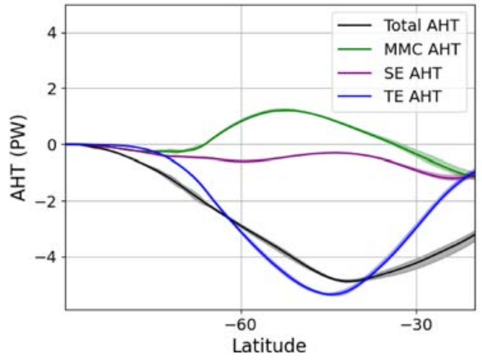
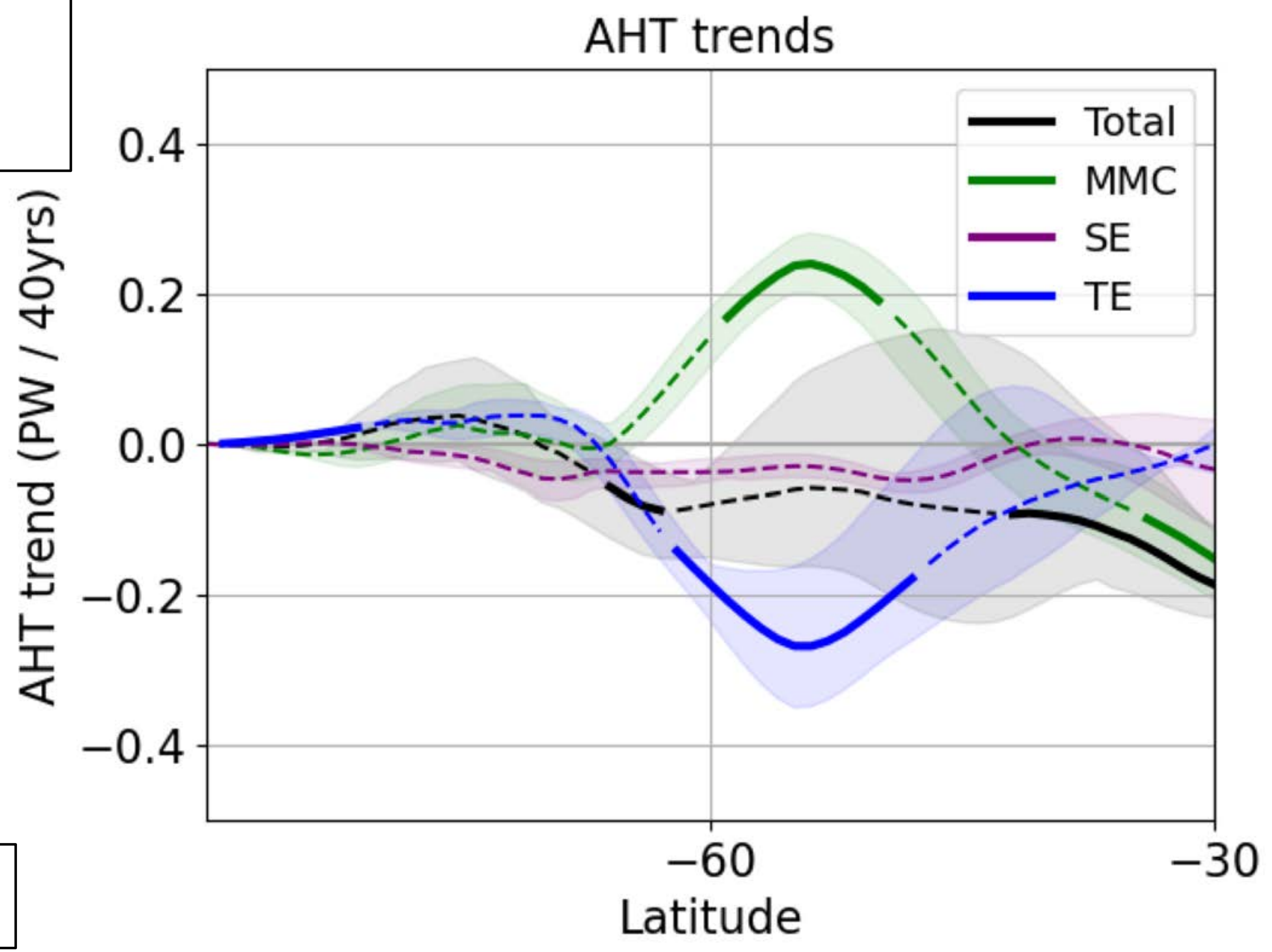


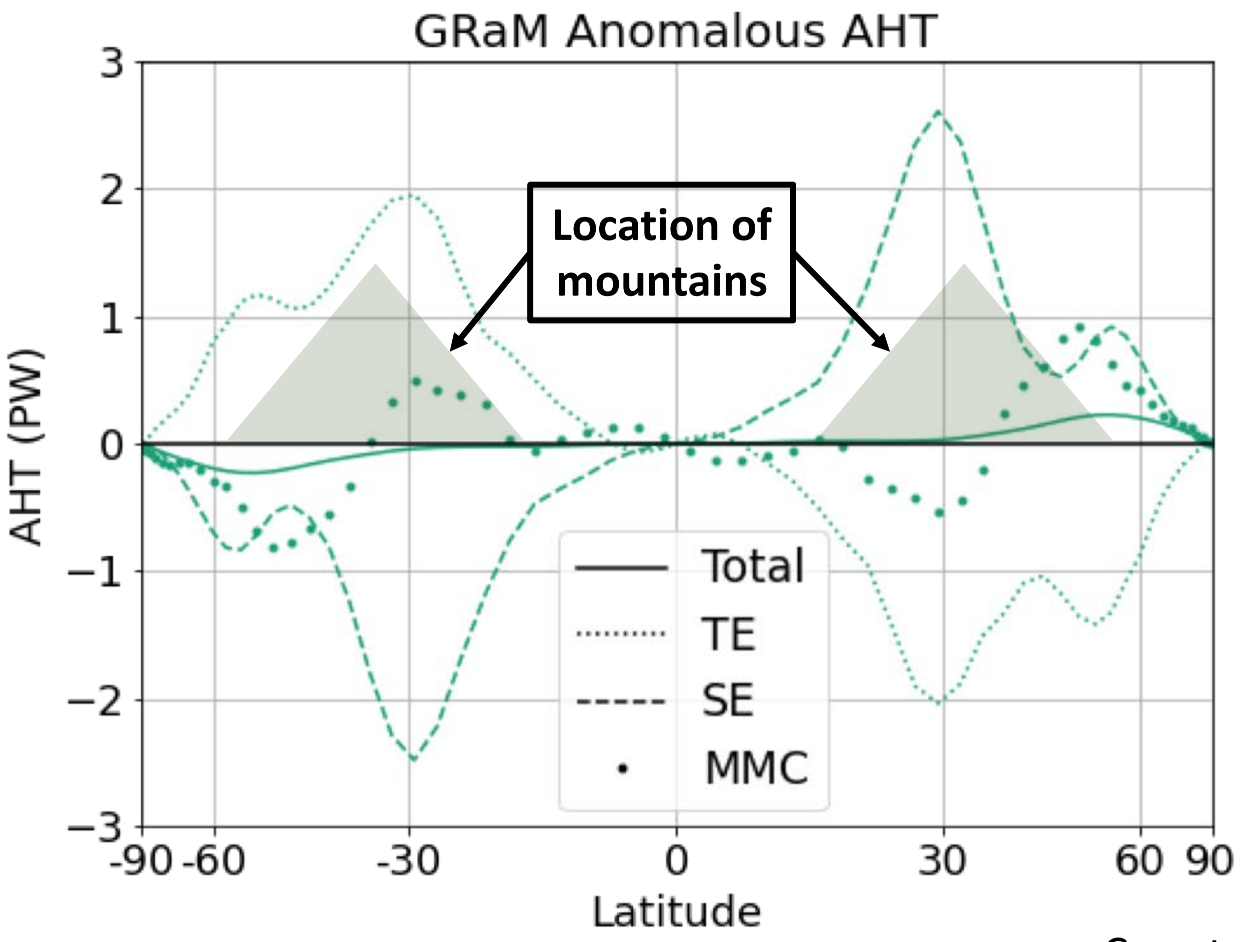


Compensation between AHT components results in small total AHT trend

Trends are linear trends from 1980-2014

Compensation between AHT components is a robust principle

- Adding mountains to a climate model simulation creates large AHT responses in individual AHT components
- Total AHT is relatively invariant due to compensation



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Cox et al., 2022

Southern Ocean AHT Trends in reanalysis

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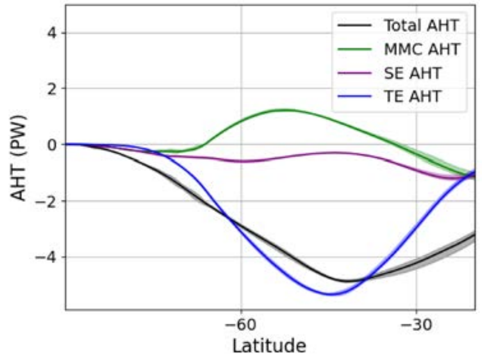
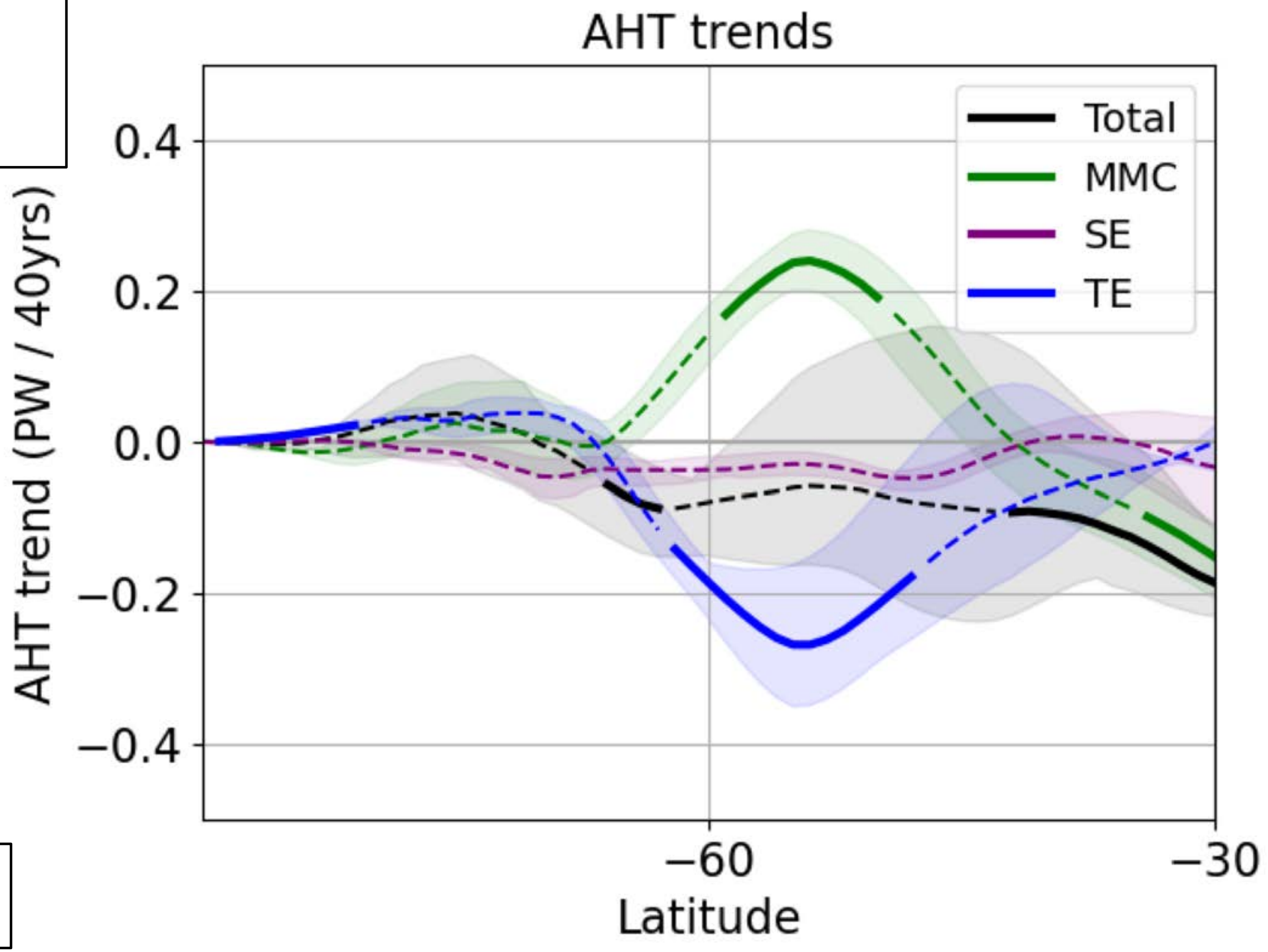
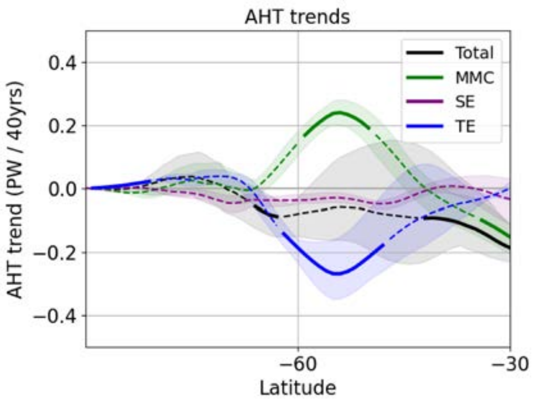




Do models show similar trends?

Trends are linear trends from 1980-2014

Southern Ocean AHT Trends



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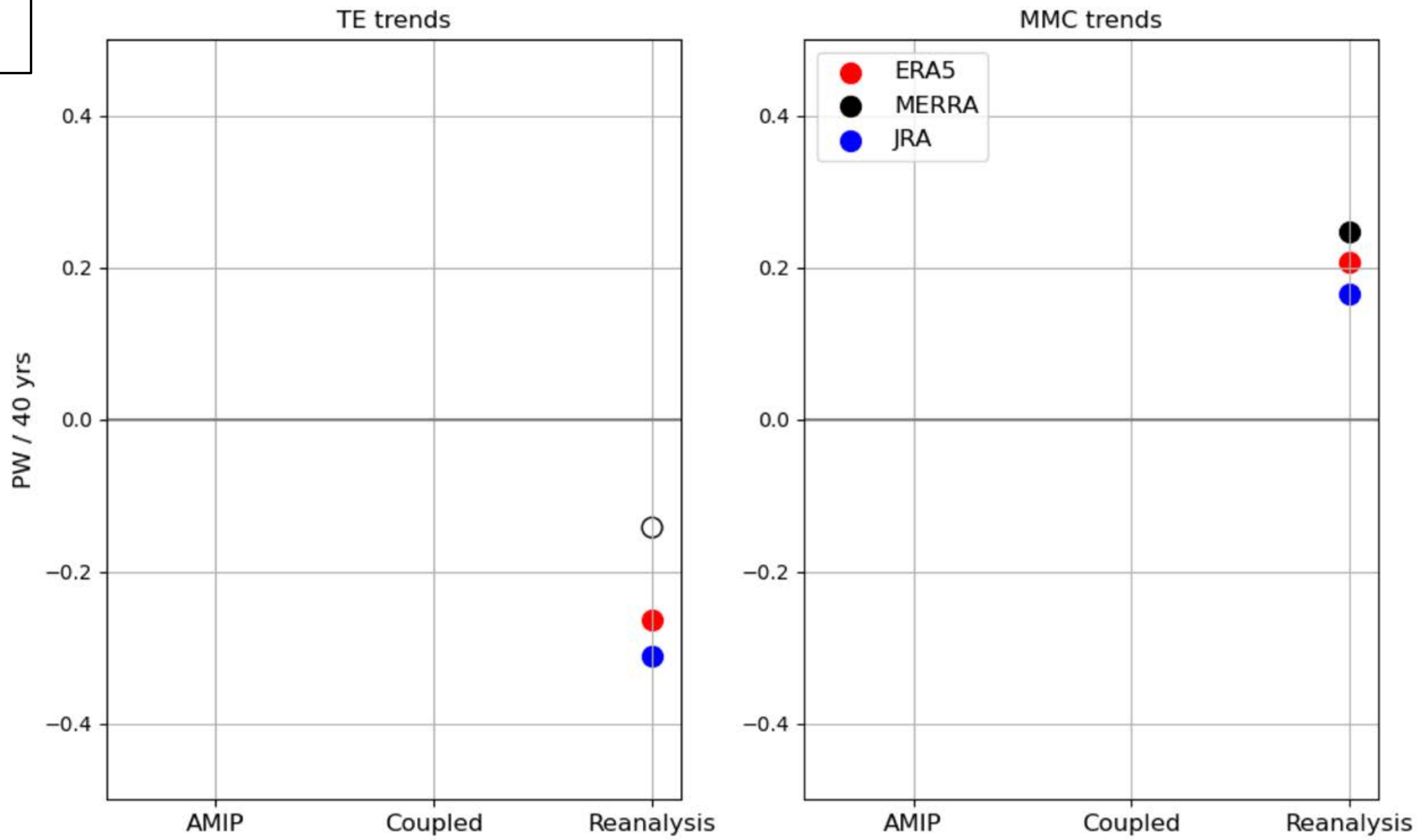

AMIP models use the observed SST trends

Trends are linear trends from 1980-2014 averaged from 50-60°S

Filled circles denote statistically significant trends

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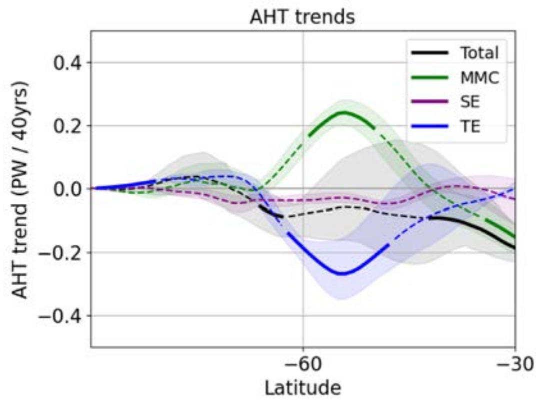

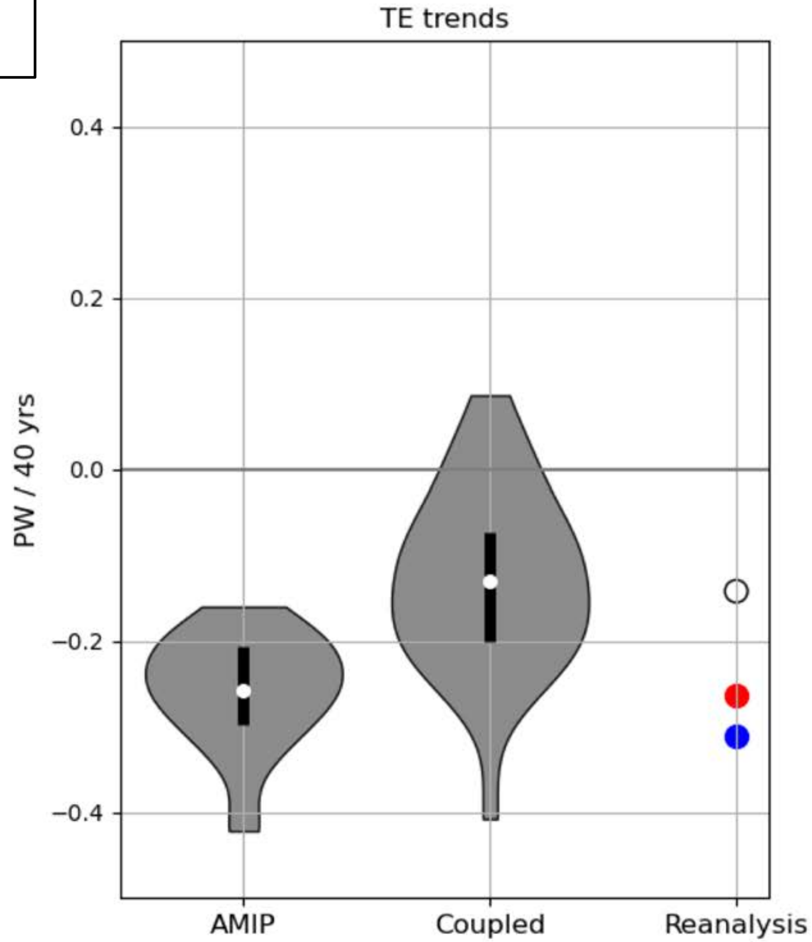

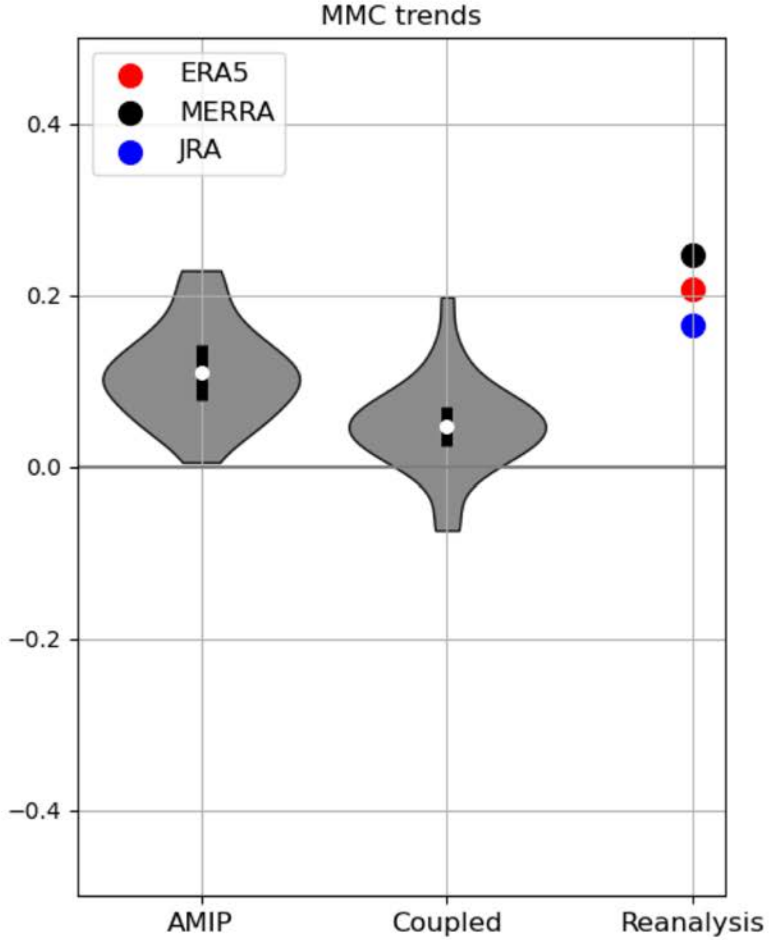

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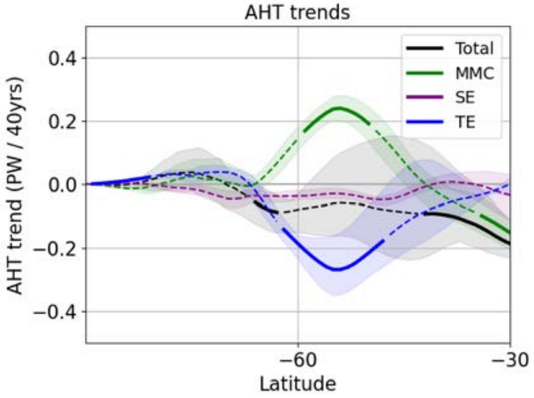

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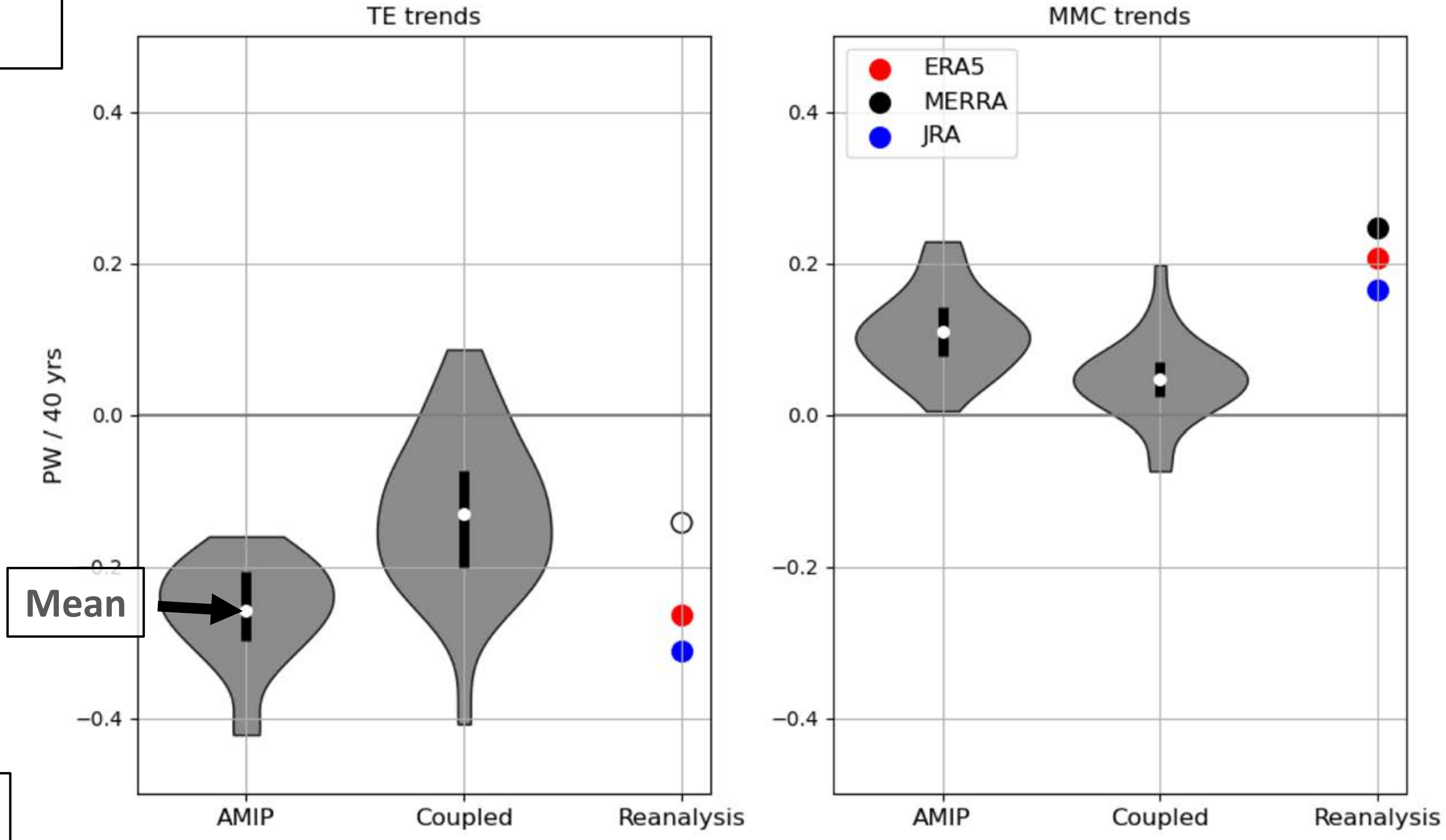

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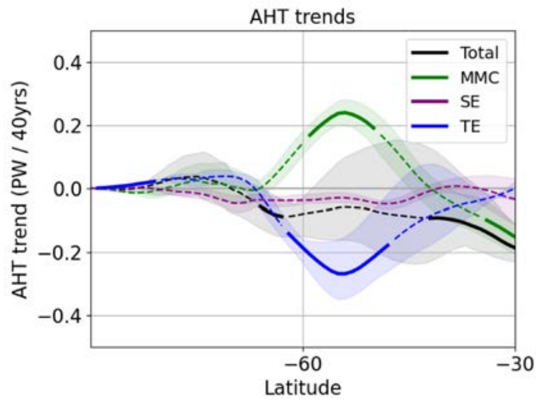

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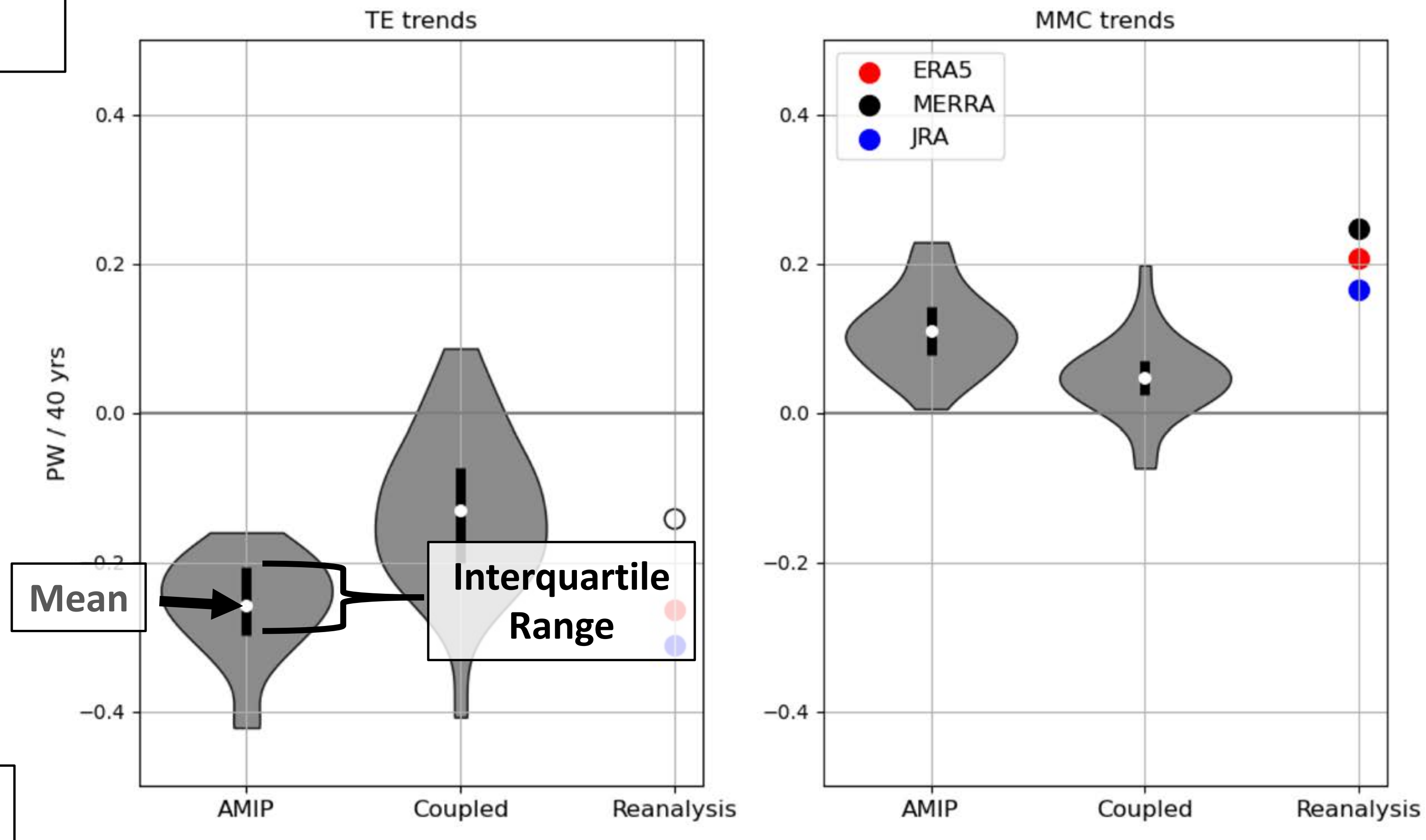

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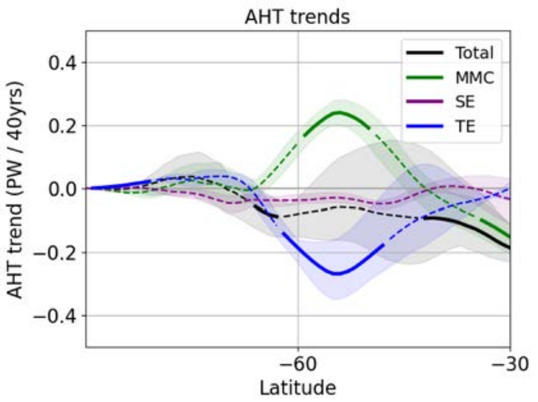

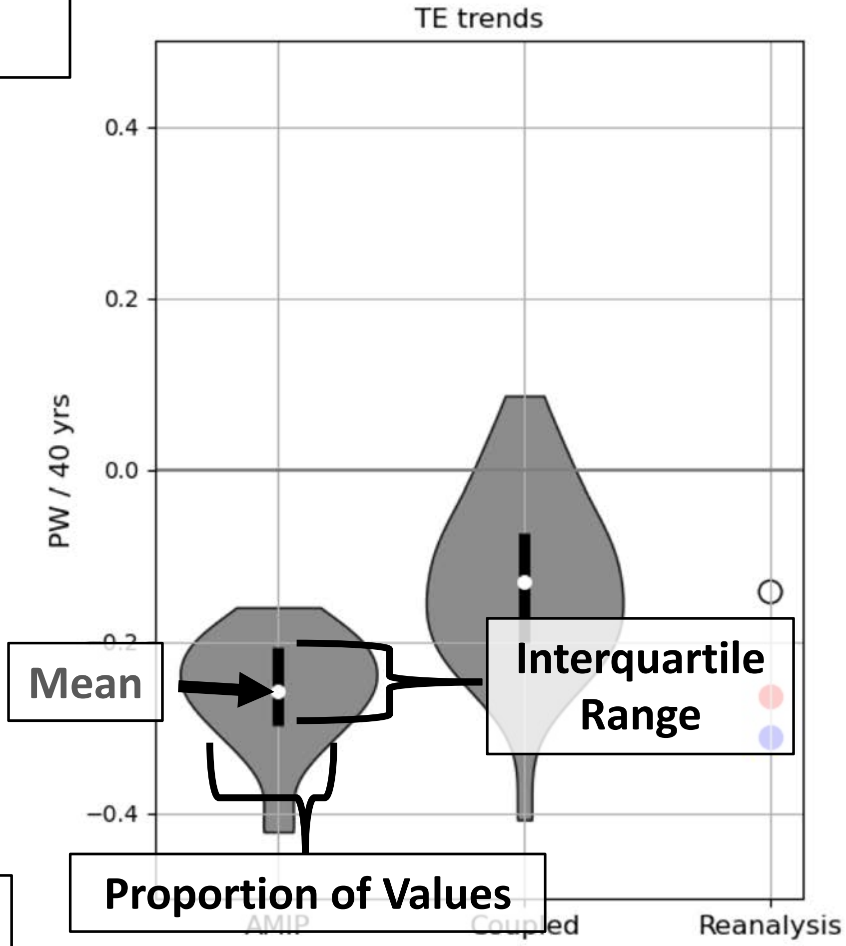

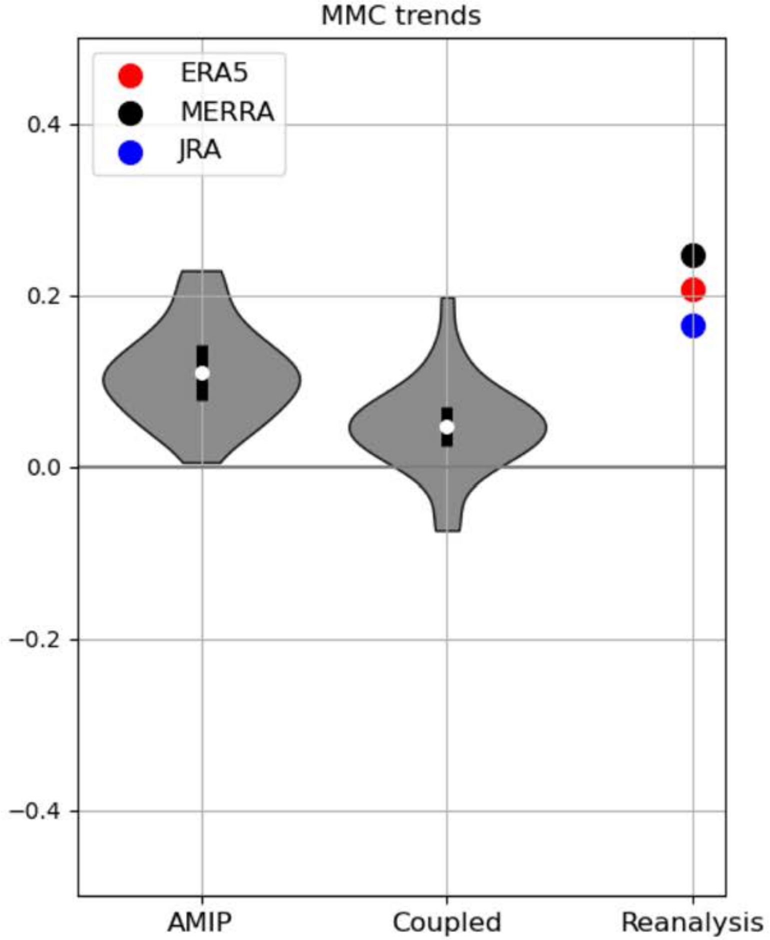

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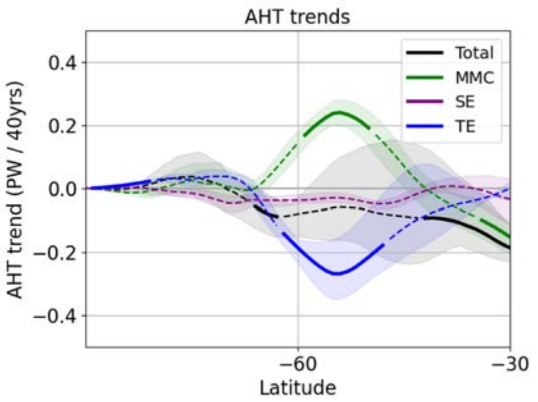

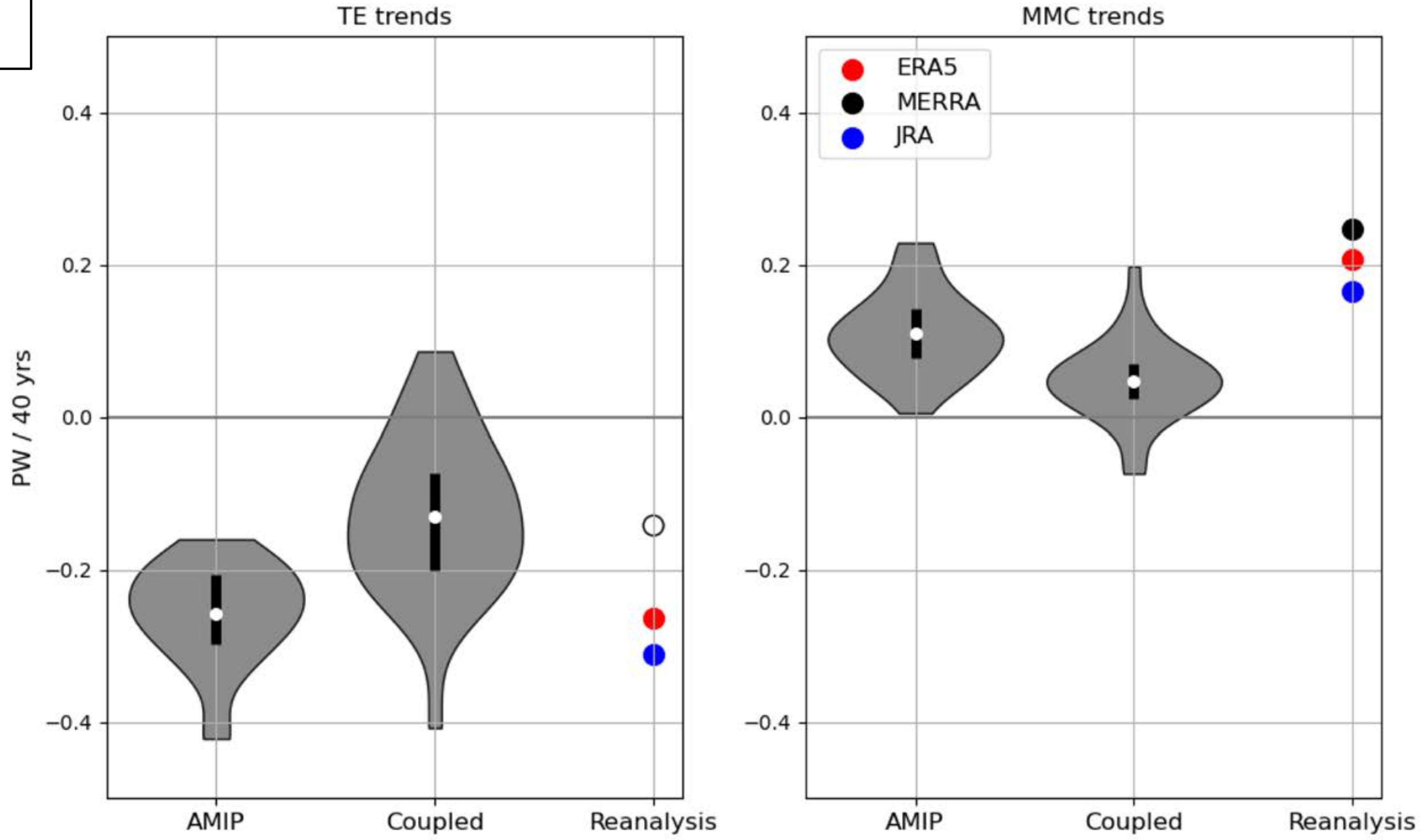

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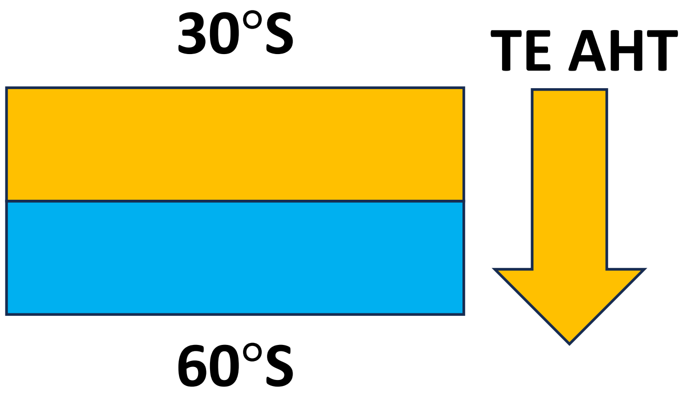
TE AHT is connected to meridional SST gradients

TE AHT is connected to the strength of the meridional temperature gradient



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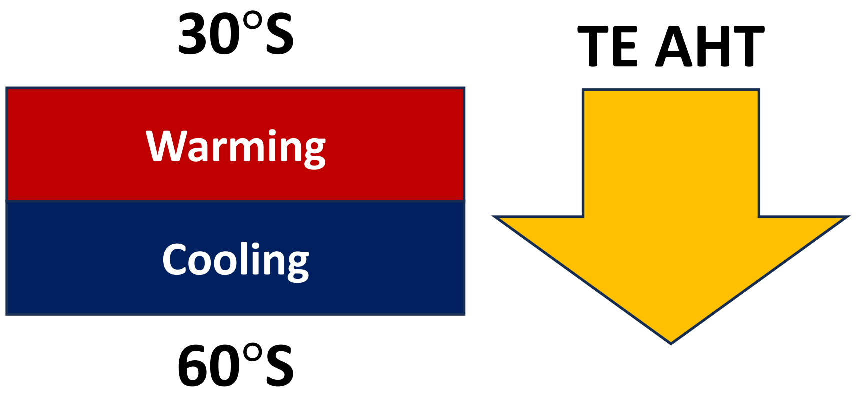

An increase in the meridional temperature gradient will increase the TE AHT

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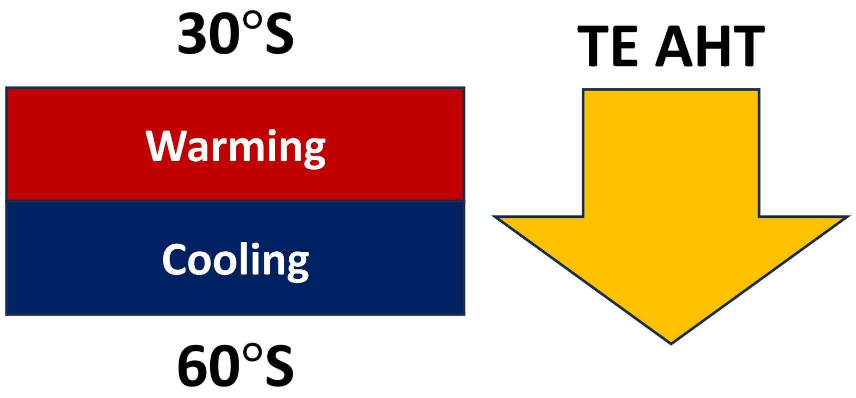
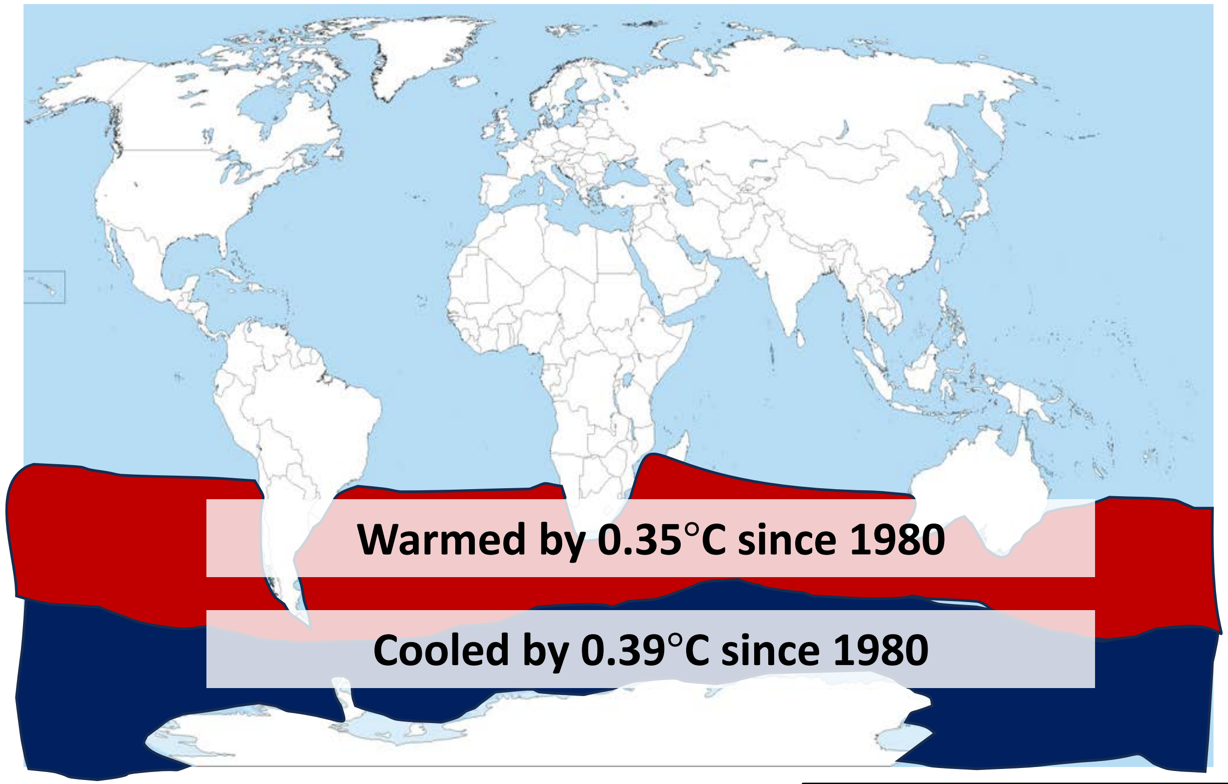


An increase in the meridional temperature gradient will increase the TE AHT

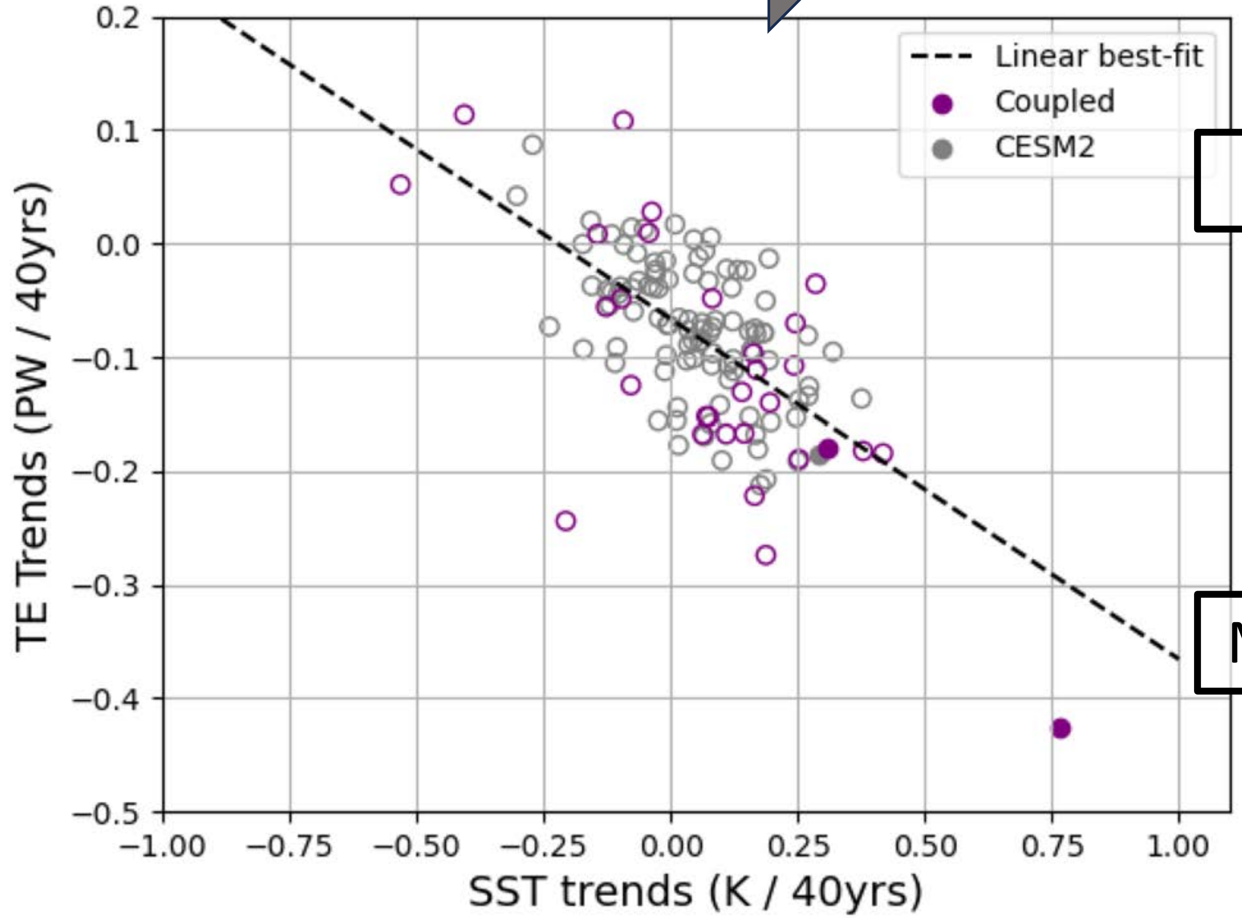


SST data from ERSSTv5

Southern Ocean SST differences partially control TE trends

SST Trends = [Mean SST trends (30-50°S)] – [Mean SST trends (50-65°S)]
TE trends evaluated at 55°S

Smaller SST difference → Larger SST difference



Less TE AHT → More TE AHT

SST: Sea-surface temperature
TE: Transient eddy

Trends are linear trends from 1980-2014

Filled circles denote statistically significant trends

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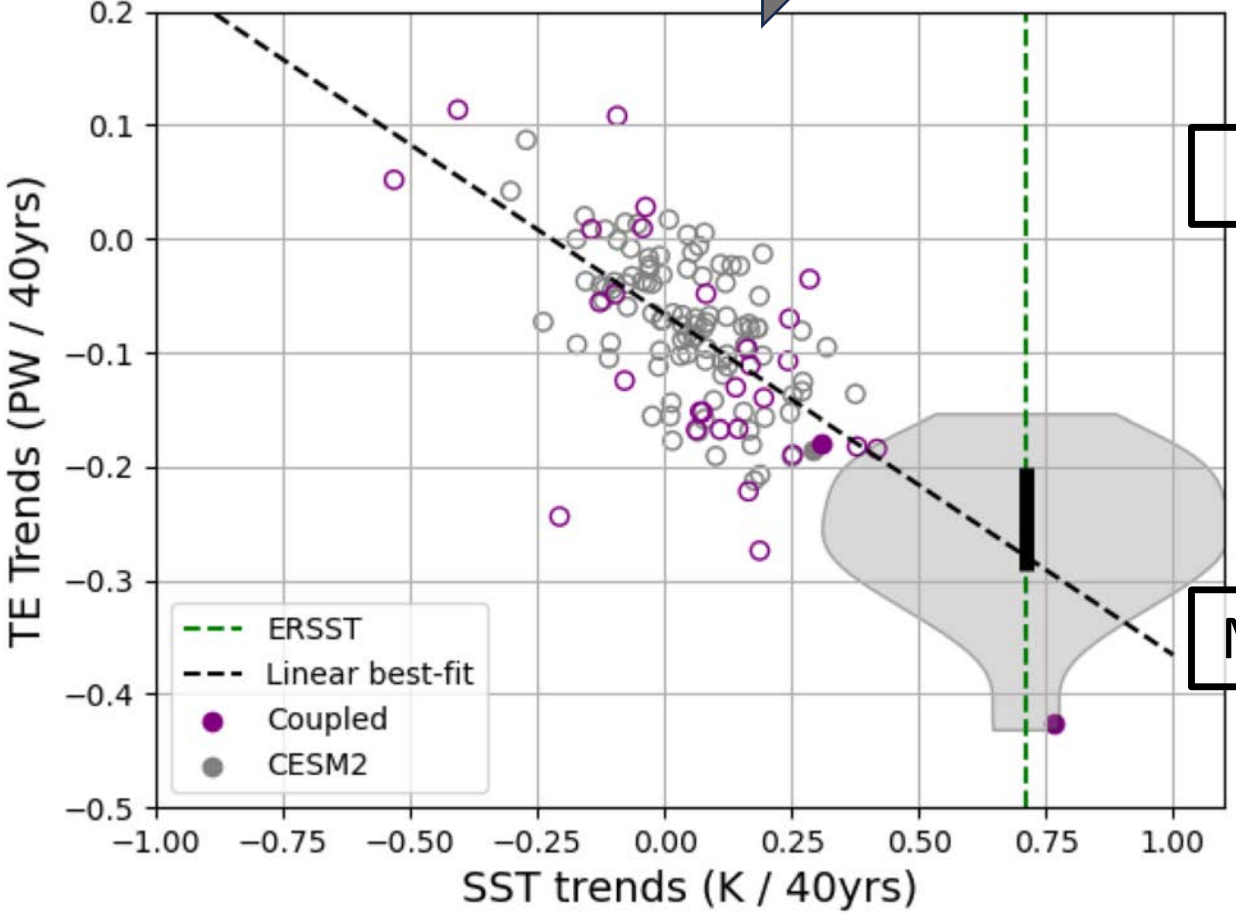

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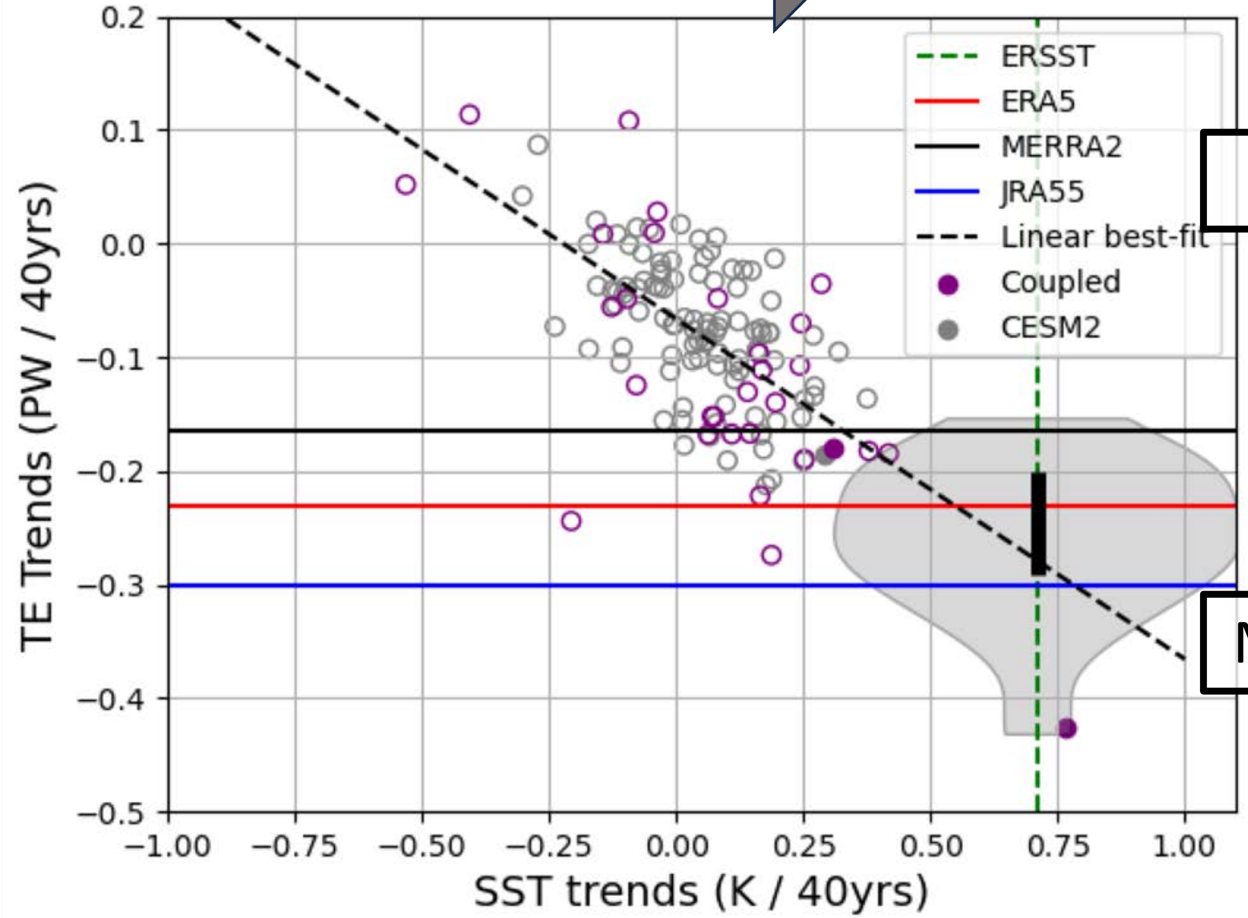

Less TE AHT → More TE AHT

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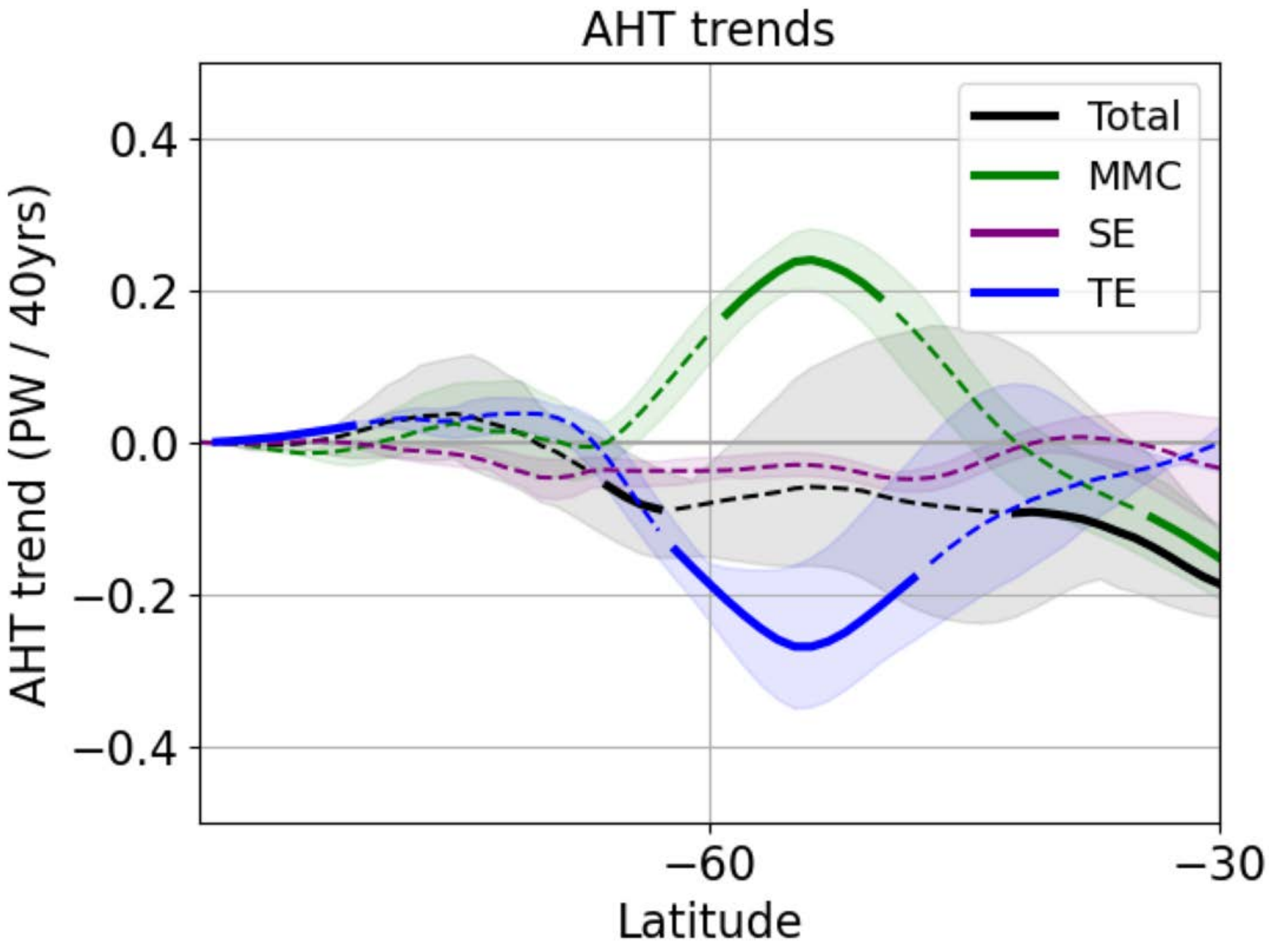
Southern Ocean AHT trend summary

- SST changes have driven TE AHT strengthening
- TE AHT strengthening has been countered by MMC AHT strengthening
    - Due to this compensation total AHT has not changed much



Summary

- Southern Ocean biases are large
- Biases will spread to other parts of the world via energy transports
- Atmospheric energy transports have changed due to SST gradient changes
  - Captured in models if SSTs are given (not in coupled models)