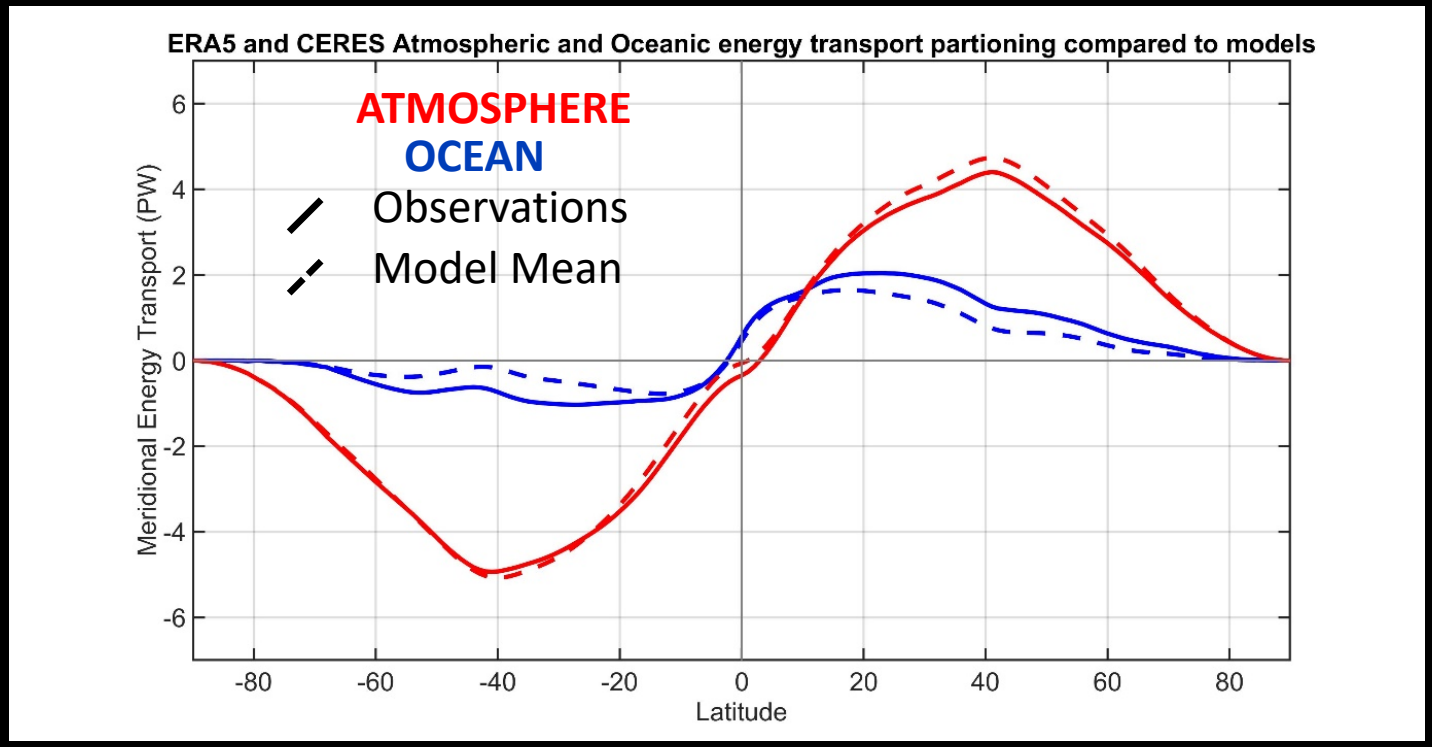
Are climate models biased in the atmosphere-ocean partitioning of poleward energy transport?



Aaron Donohoe – Polar Science Center,
Applied Physics Lab., U. Washington
Robert Fajber –UW Dept. of atmospheric science
Kyle Armour – UW Oceanography

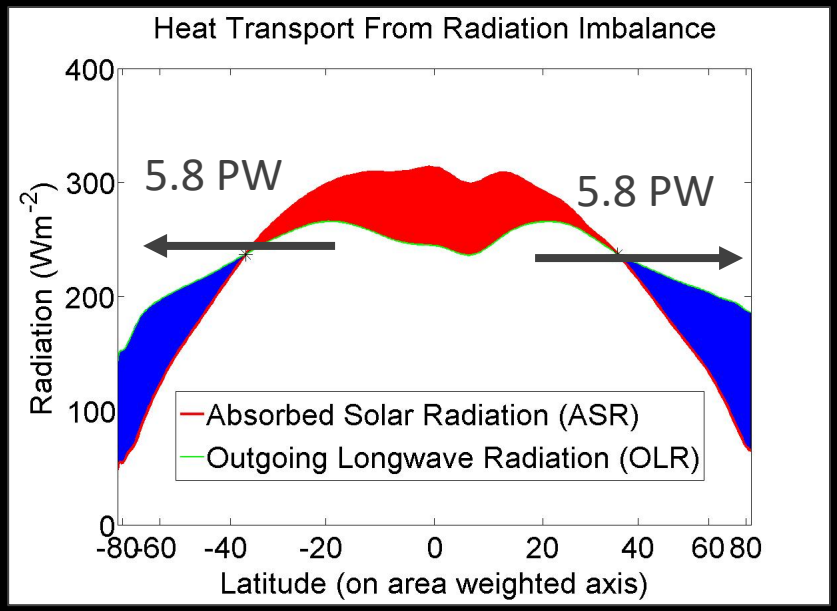
MAPP
Modeling, Analysis, Predictions, and Projections

UCAR COMMUNITY PROGRAMS | CPAESS

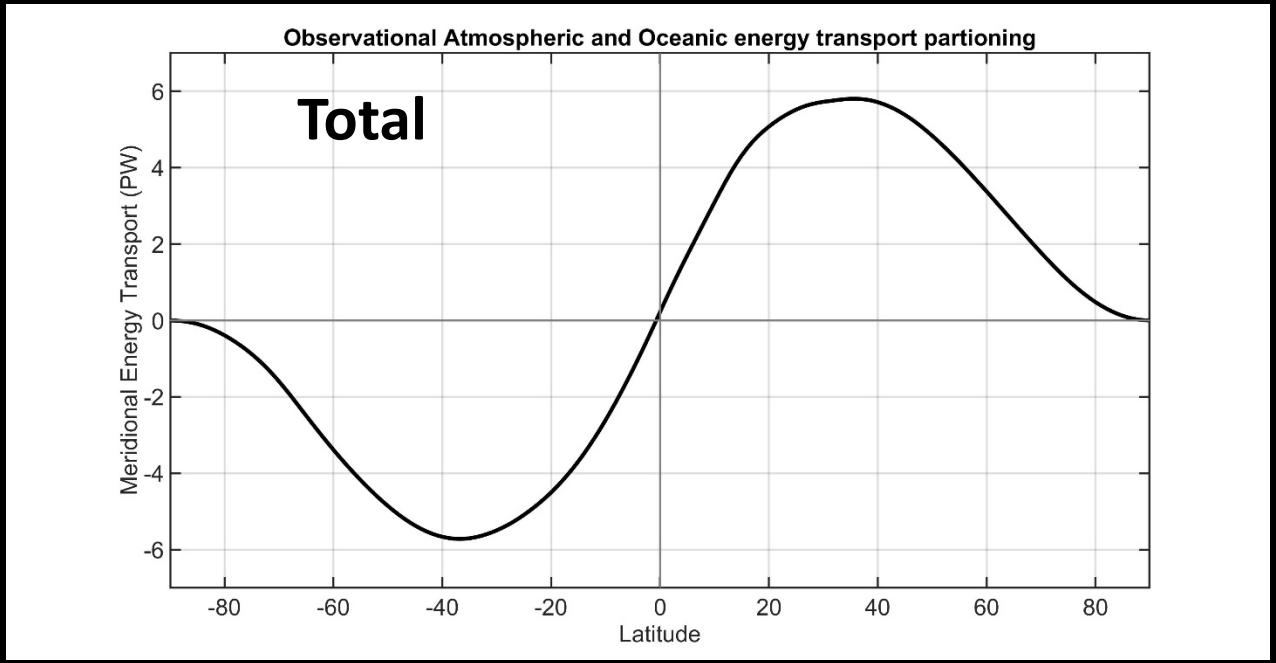
School of Oceanography
University of Washington

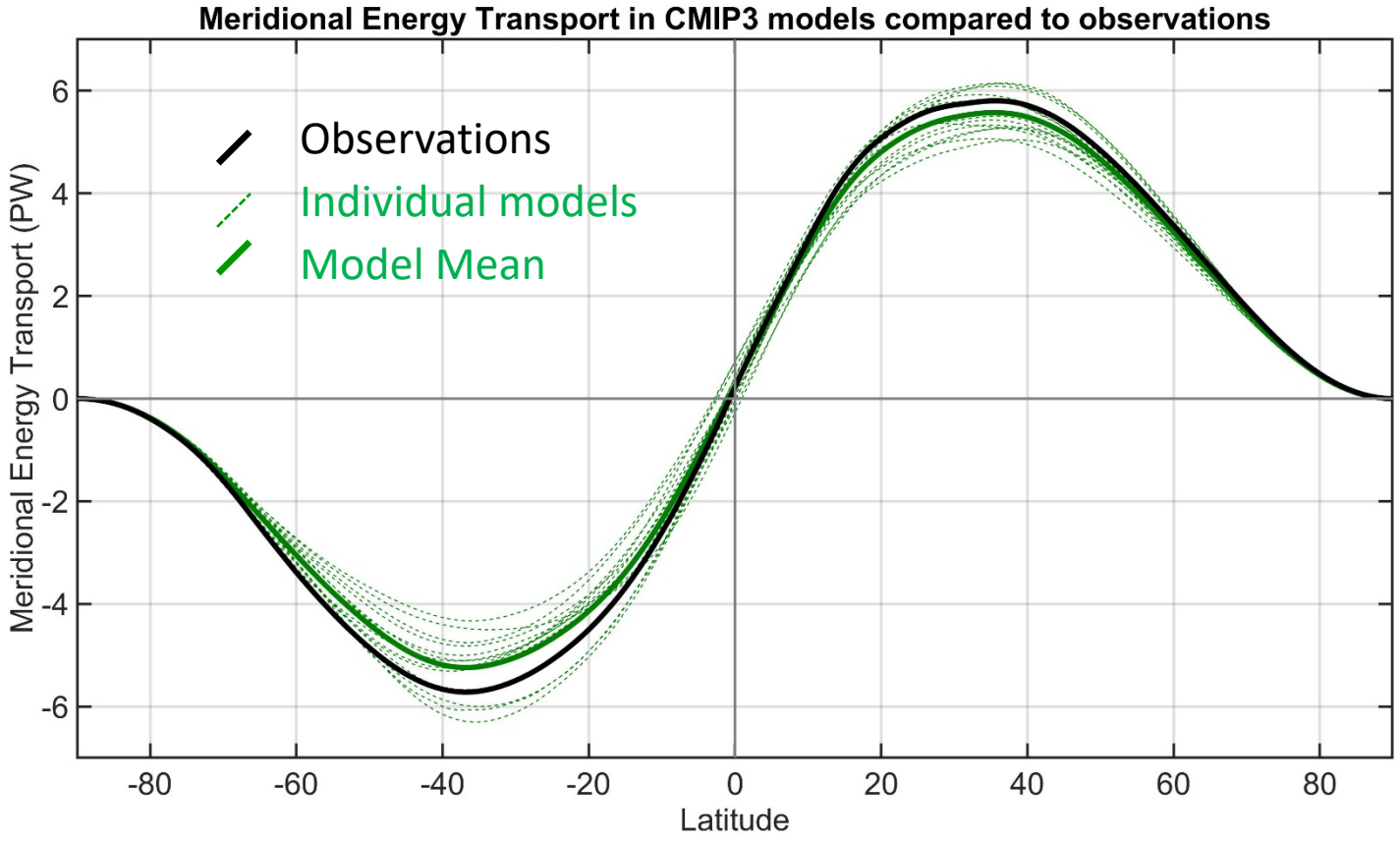
Applied Physics Laboratory
University of Washington

UNIVERSITY of WASHINGTON



Total (atmosphere plus ocean) energy transport from satellite top of atmosphere (TOA) radiation (CERES EBAF).

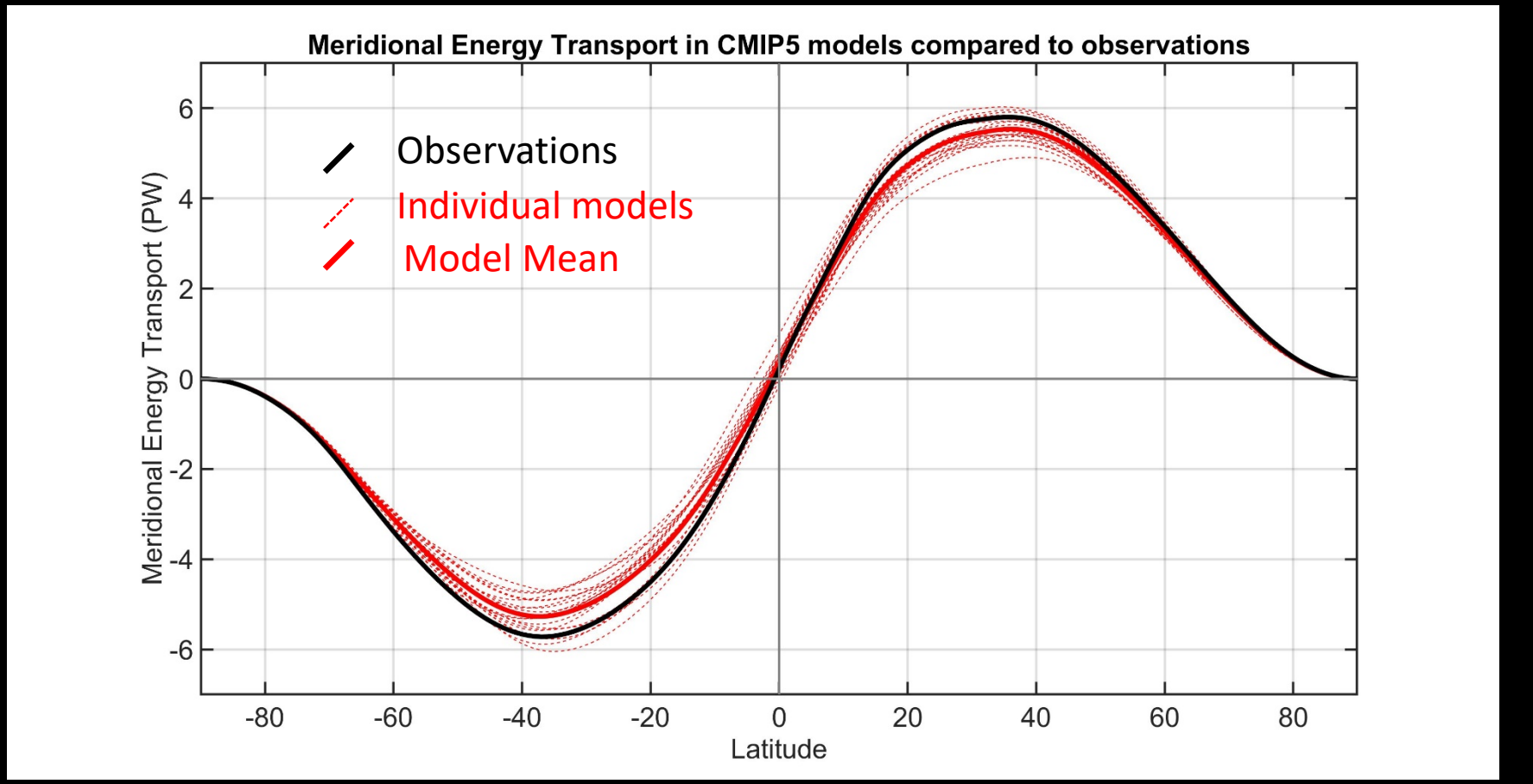


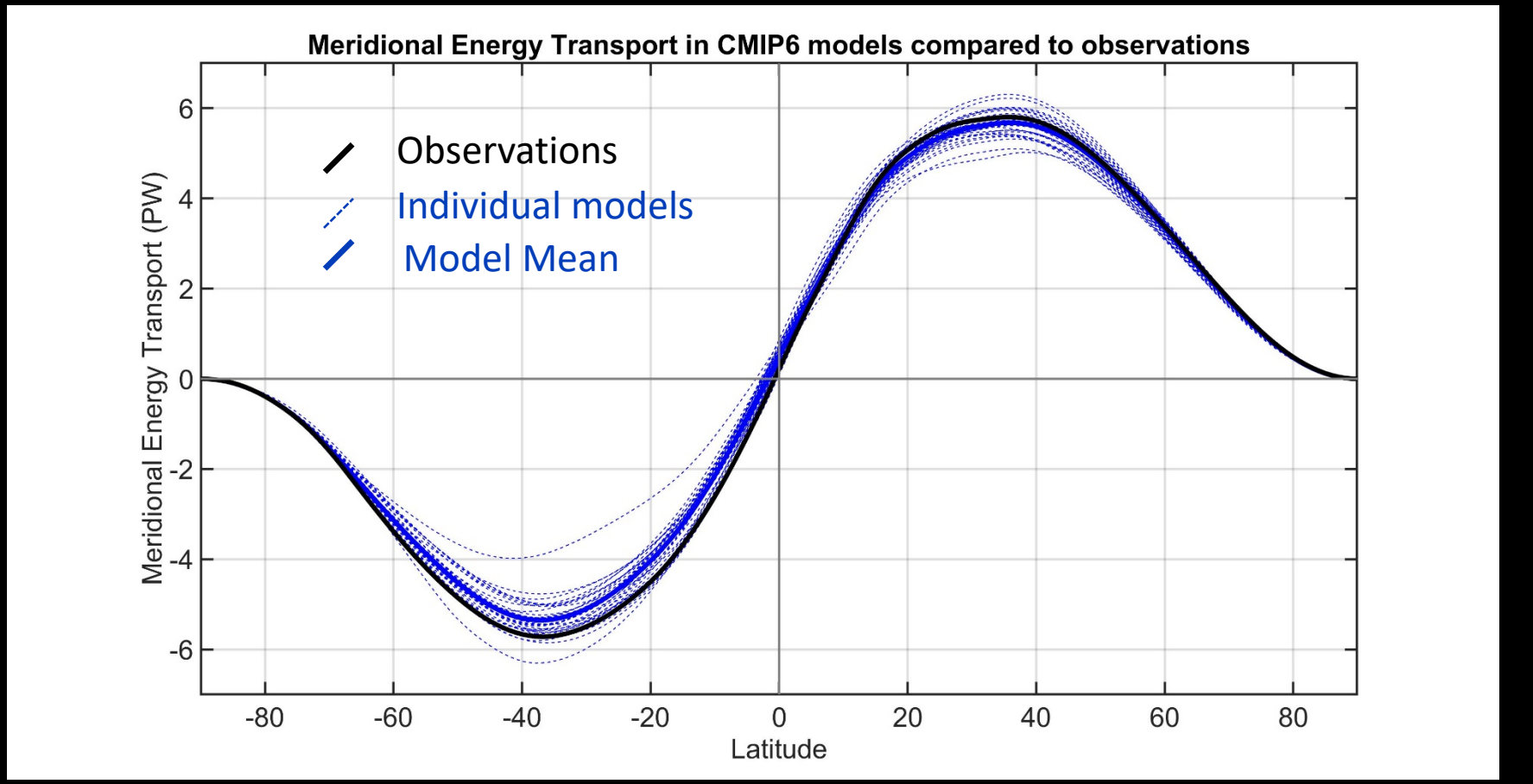


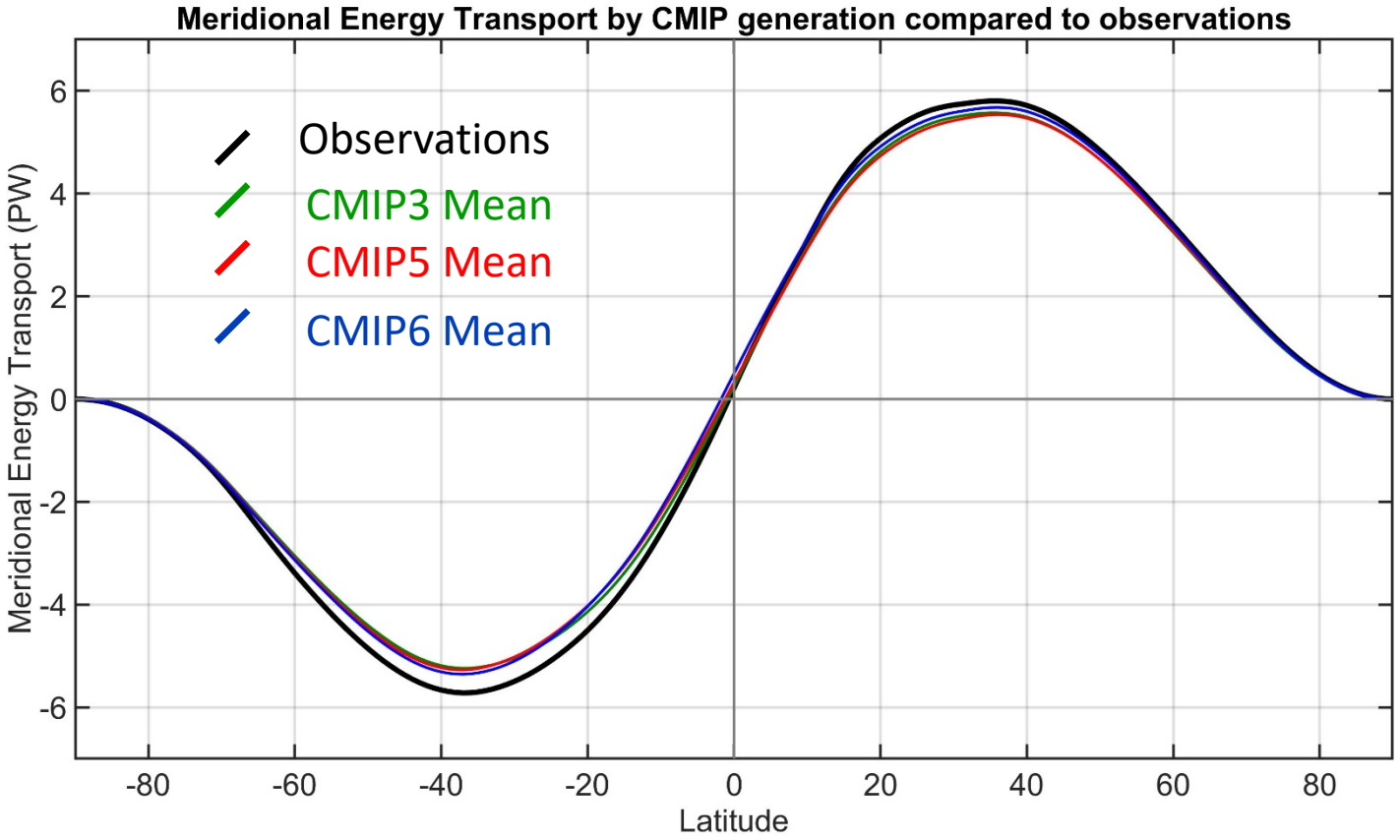
Total (atmosphere plus ocean) meridional heat transport varies by about 20% between models.

→ Also biased low relative to observations especially in the SH

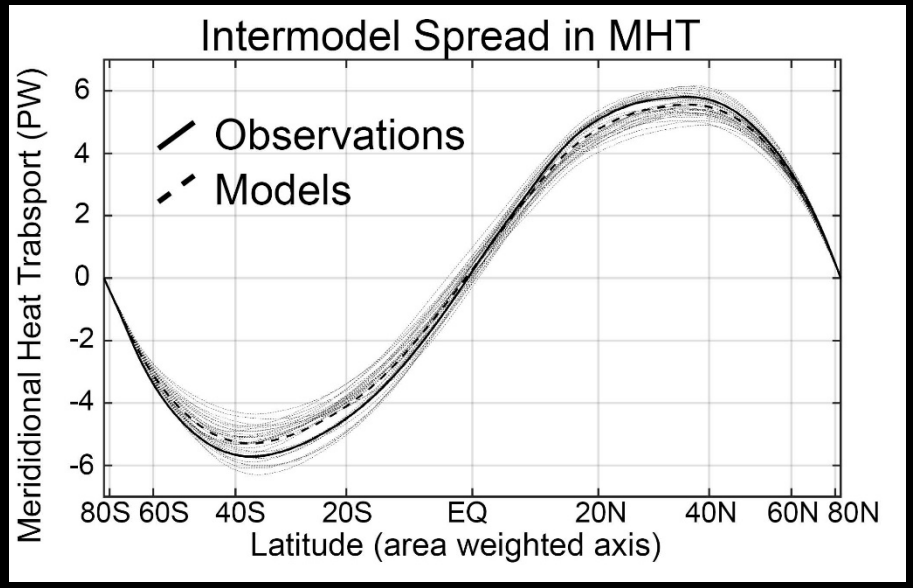
Donohoe and Battisti (2012). What determined meridional heat transport in climate models. J. Climate.

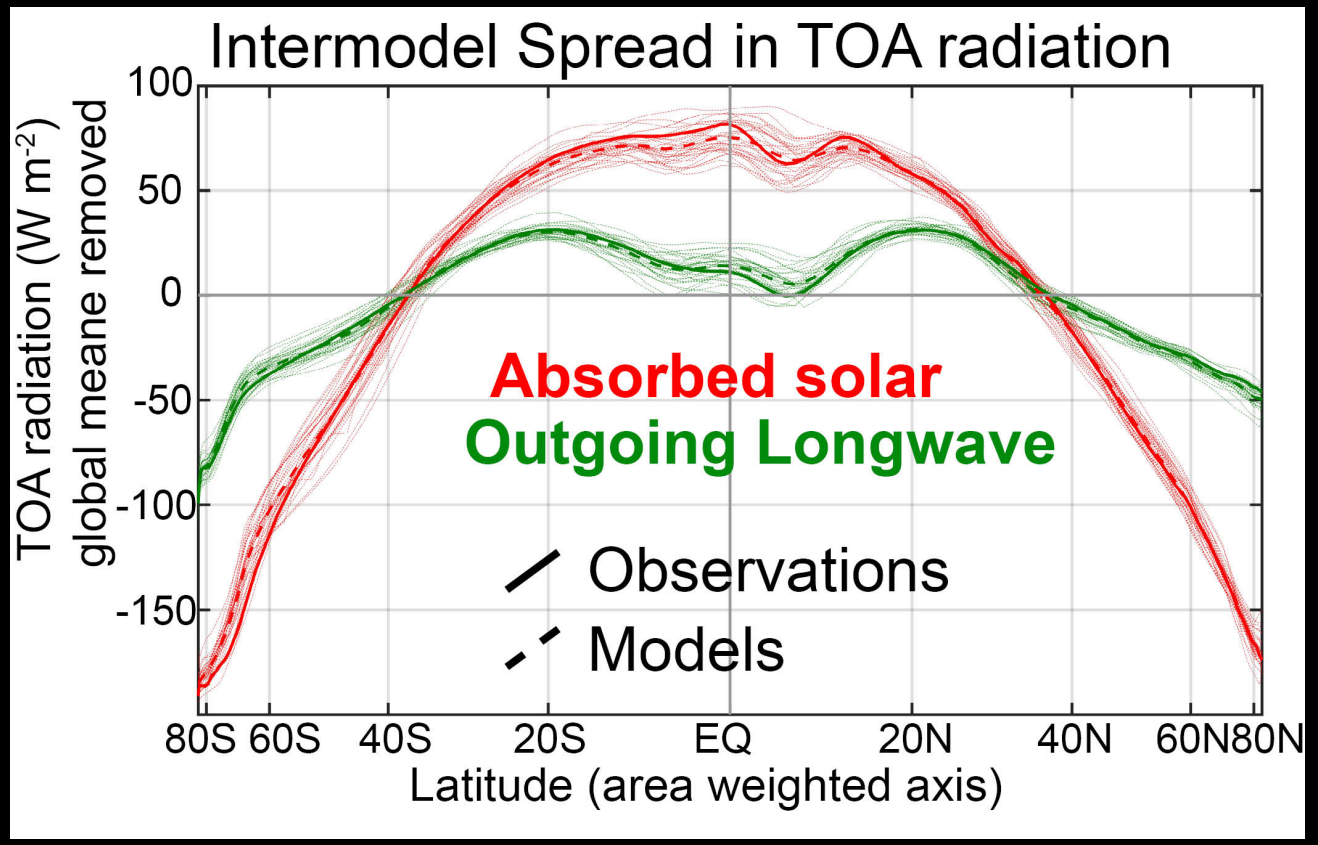

Meridional Energy Transport in CMIP5 models compared to observations
Observations
Individual models
Model Mean
Meridional Energy Transport (PW)
6
4
2
0
-2
-4
-6
-80
-60
-40
-20
0
20
40
60
80
Latitude


Meridional Energy Transport in CMIP6 models compared to observations
Observations
Individual models
Model Mean
Meridional Energy Transport (PW)
6
4
2
0
-2
-4
-6
-80
-60
-40
-20
0
20
40
60
80
Latitude



Inter-model spread and bias in MHT is persistent across generations of CMIP models


Intermodel Spread in MHT
Merididional Heat Trabsport (PW)
6
4
2
0
-2
-4
-6
Observations
Models
80S 60S 40S 20S EQ 20N 40N 60N 80N
Latitude (area weighted axis)


Intermodel Spread in TOA radiation
TOA radiation (W m-2)
global meane removed
100
50
0
-50
-100
-150
Absorbed solar
Outgoing Longwave
Observations
Models
80S 60S 40S 20S EQ 20N 40N 60N80N
Latitude (area weighted axis)

Atmospheric energy transport calculated from ERA5 high frequency reanalysis

$$AHT(\phi) = -\frac{2\pi a \cos(\phi)}{g} \int_{p_s}^{0} \underbrace{[\bar{V}][\overline{MSE}]}_{MOC} + \underbrace{\overline{[V]'[MSE]'}}_{TOC} + \underbrace{[V^*MSE^*]}_{Stat.eddy} + \underbrace{[\overline{V^{*\prime}MSE^{*\prime}}]}_{Trans.eddy} dp$$

* = Departure from zonal mean -- [ ]

' = Departure from time mean -- $\overline{\ }$

MSE = moist static energy

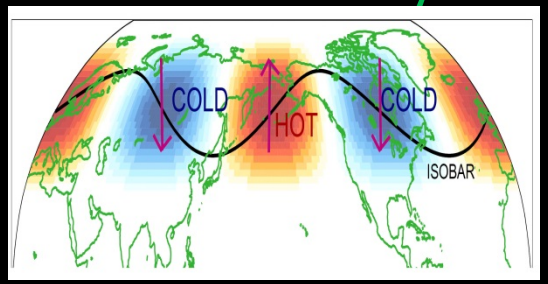
= CpT + LQ +gZ

MOC dominates in the deep tropics – Hadley cell

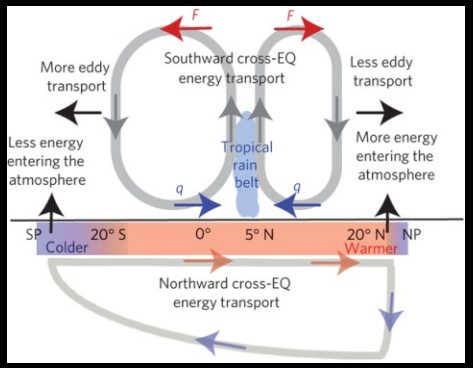
Stationary eddies stronger in NH

Transient eddies dominate the mid-latitudes

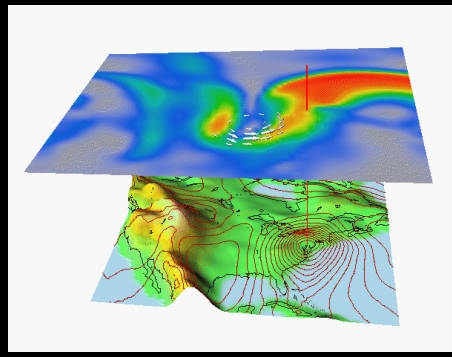
Stationary

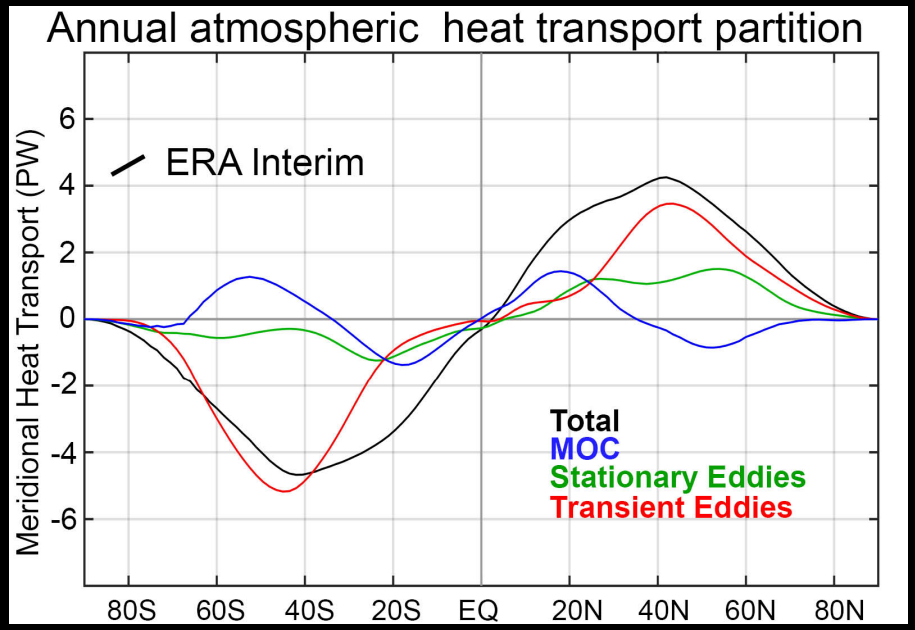


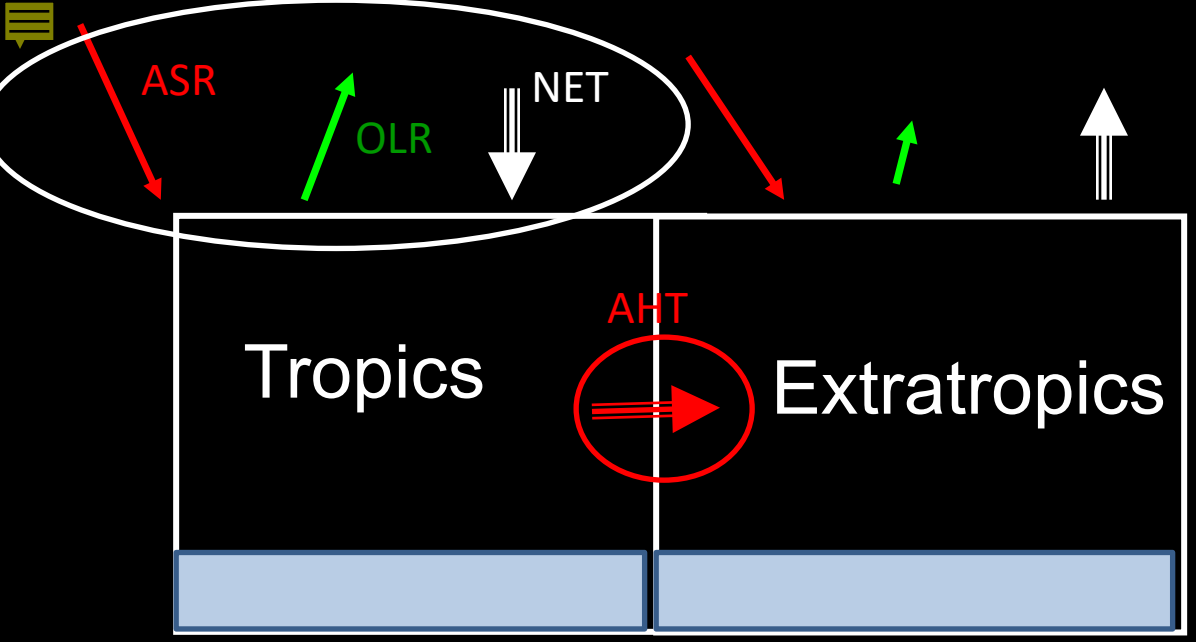
MOC Overturning



Transient

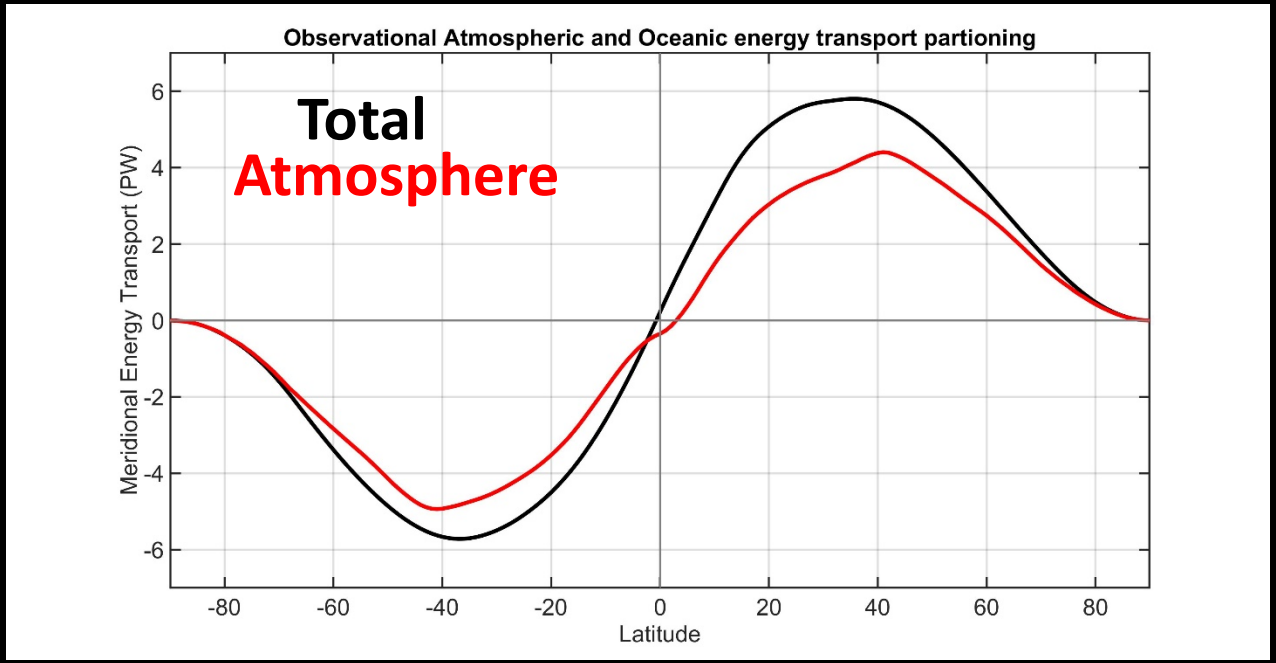


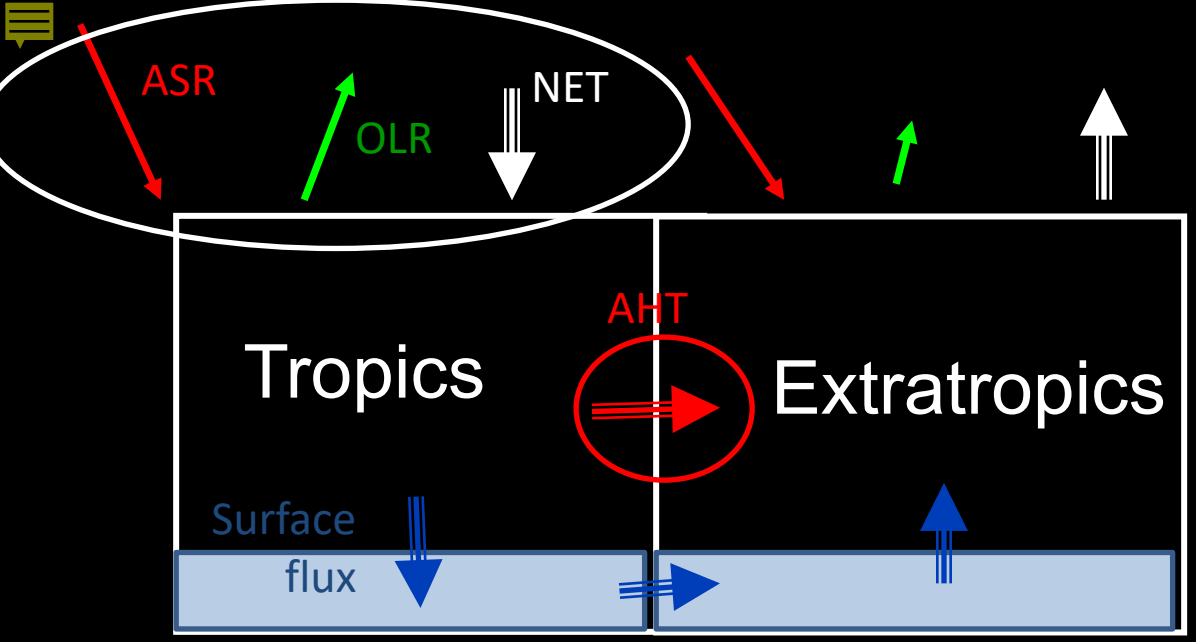




Total (atmosphere plus ocean) energy transport from TOA radiation (CERES satellite).

Atmospheric energy transport from 6 hourly ERA5 reanalysis dynamics calculation

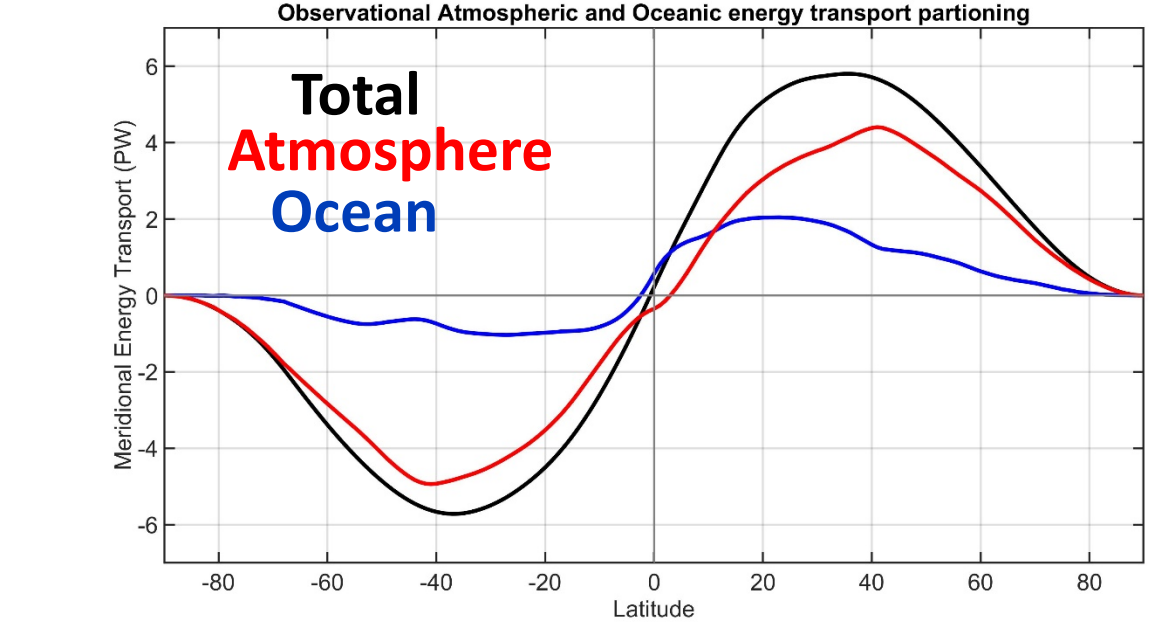


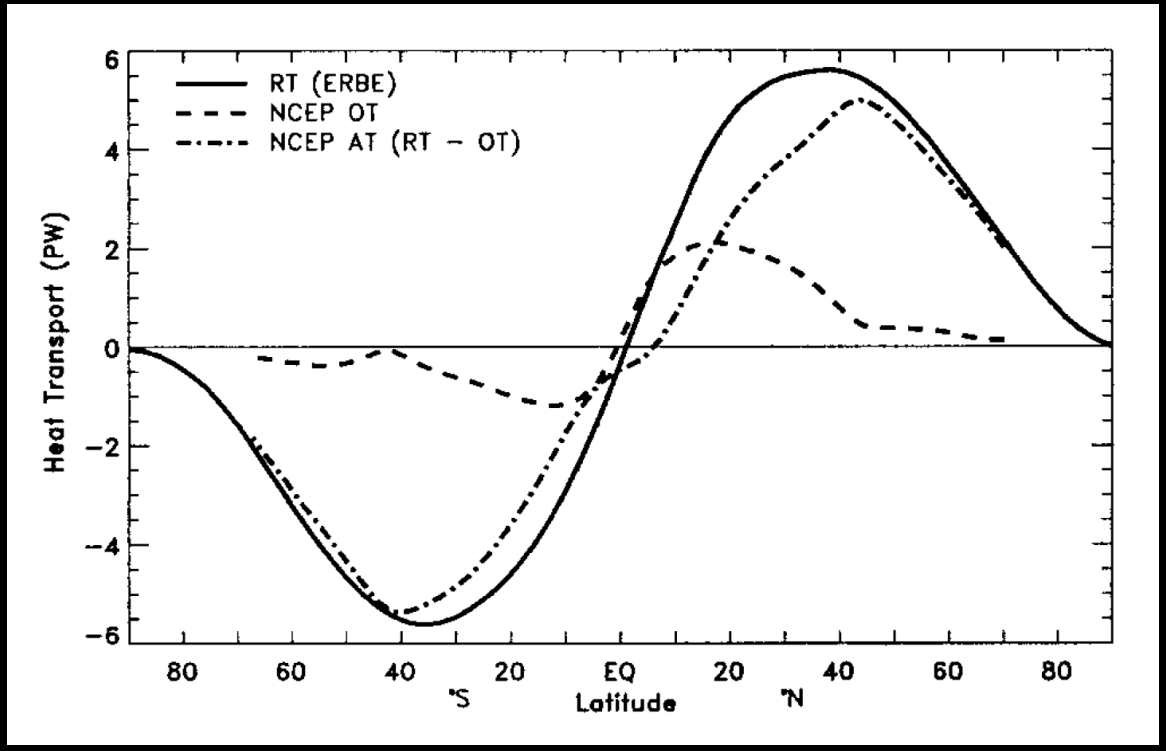


Total (atmosphere plus ocean) energy transport from TOA radiation (CERES satellite).

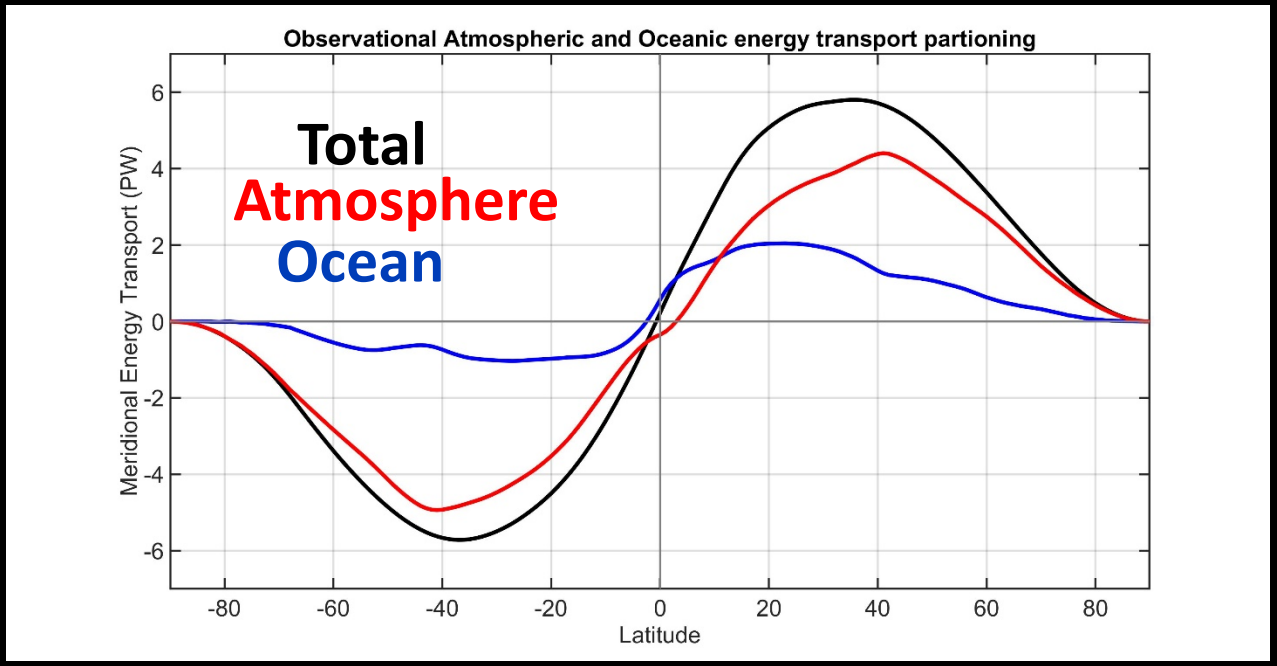
Atmospheric energy transport from 6 hourly ERA5 reanalysis dynamics calculation

Ocean heat transport as the residual = Total - atmos



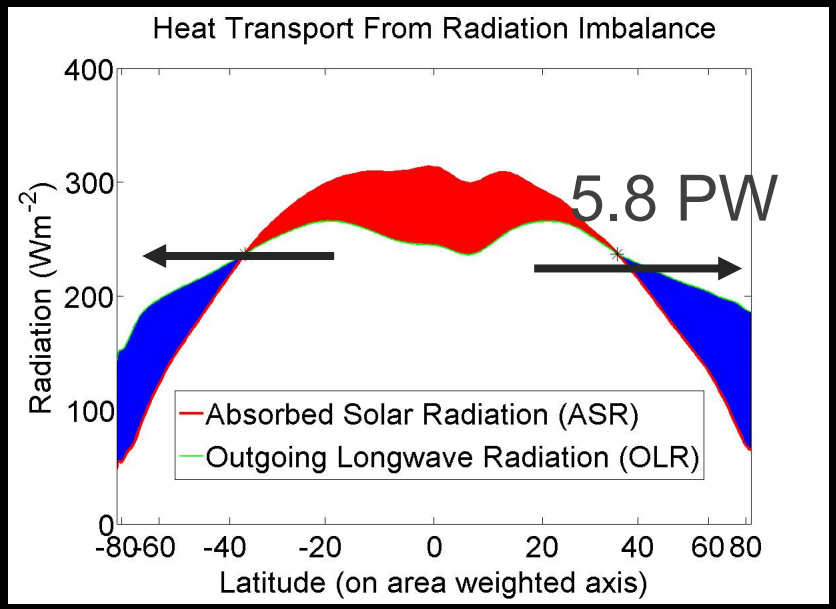


This strategy was pioneered by Trenberth and Caron (2001)



Model partitioning of AHT/OHT

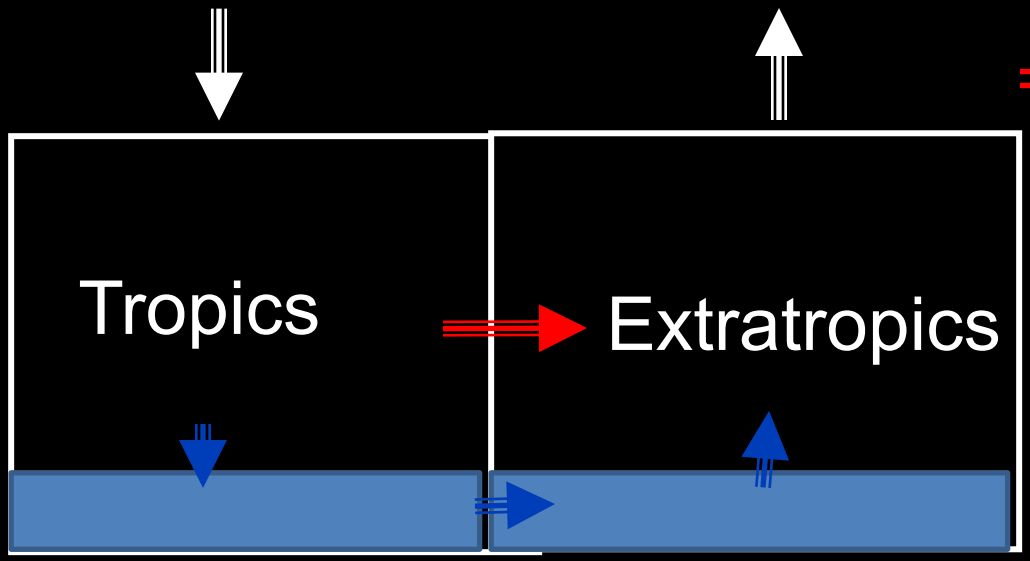
MHT from Radiation



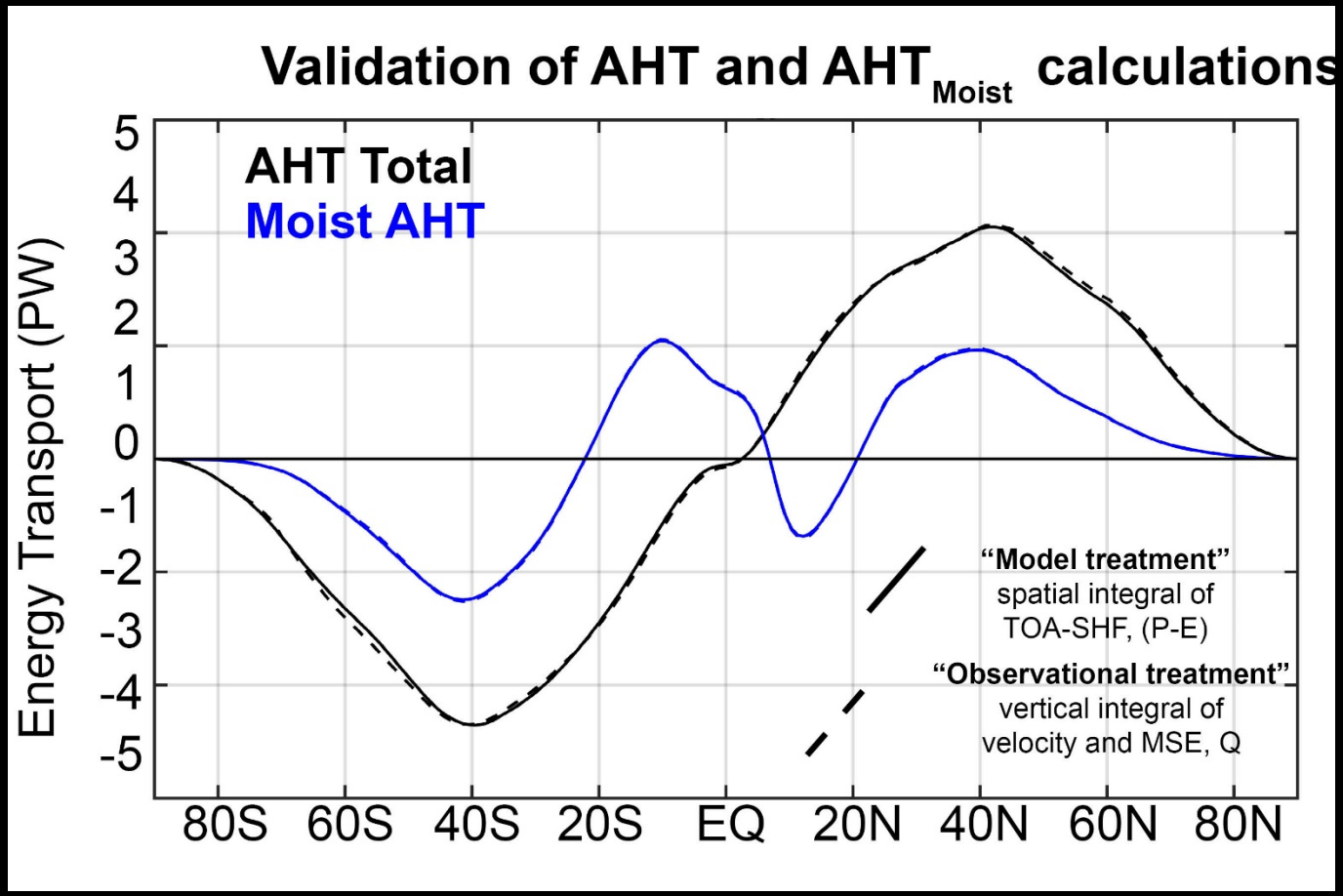
Total heat transport (MHT) = Integral of TOA radiation

Ocean heat Transport (OHT) = Integral of Surface heat Flux (SHF)

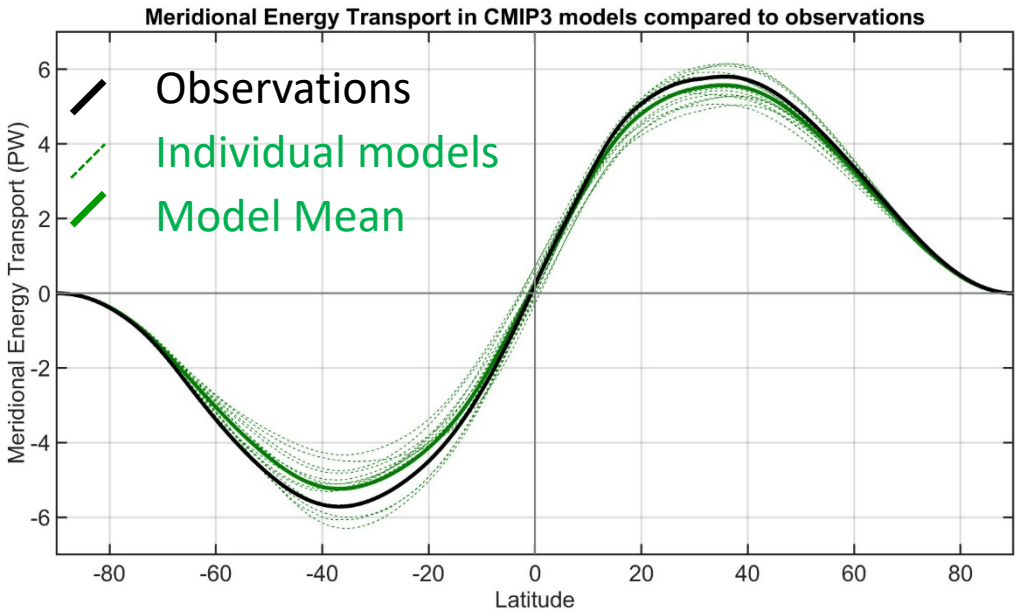
Atmospheric heat transport (AHT)
AHT = MHT – OHT
= Integral (TOA – SHF)



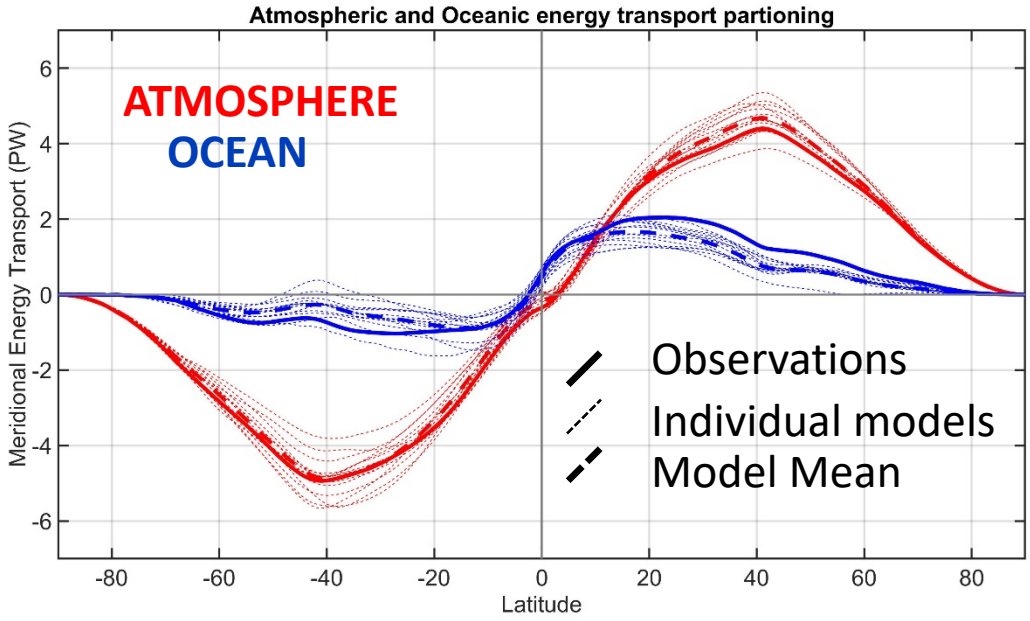
Consistency of “observational” and “model” based MHT calculation in a model simulation



CMIP3 -- Partitioning of MHT

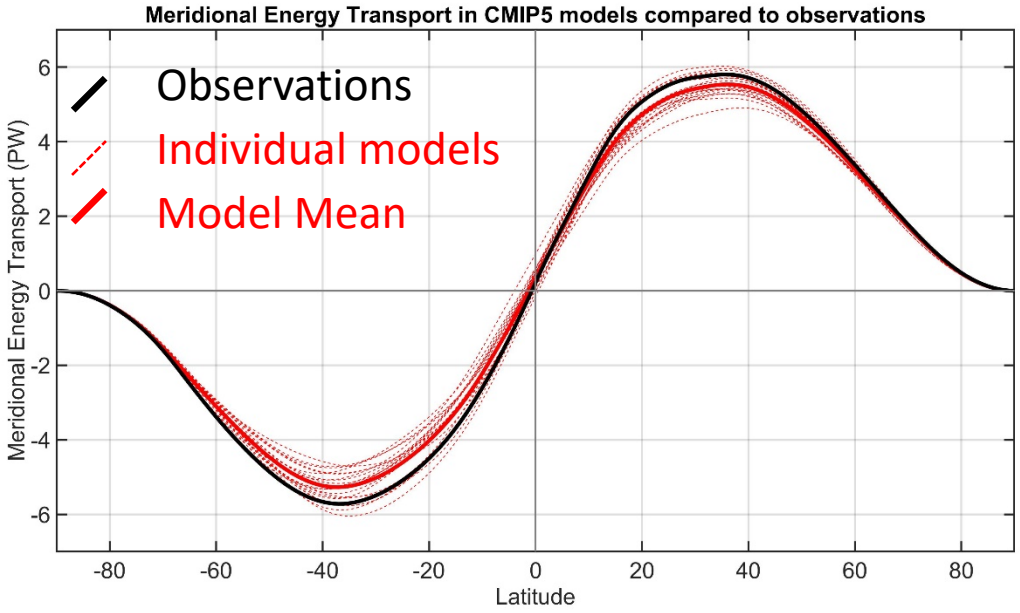


Total energy transport

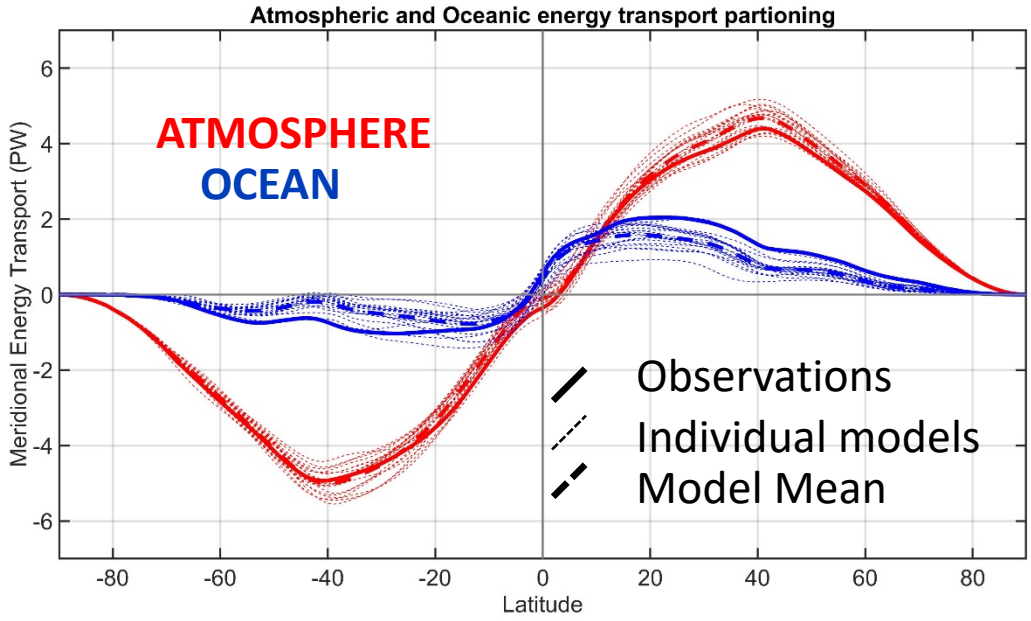


Atmosphere ocean partitioning

CMIP5

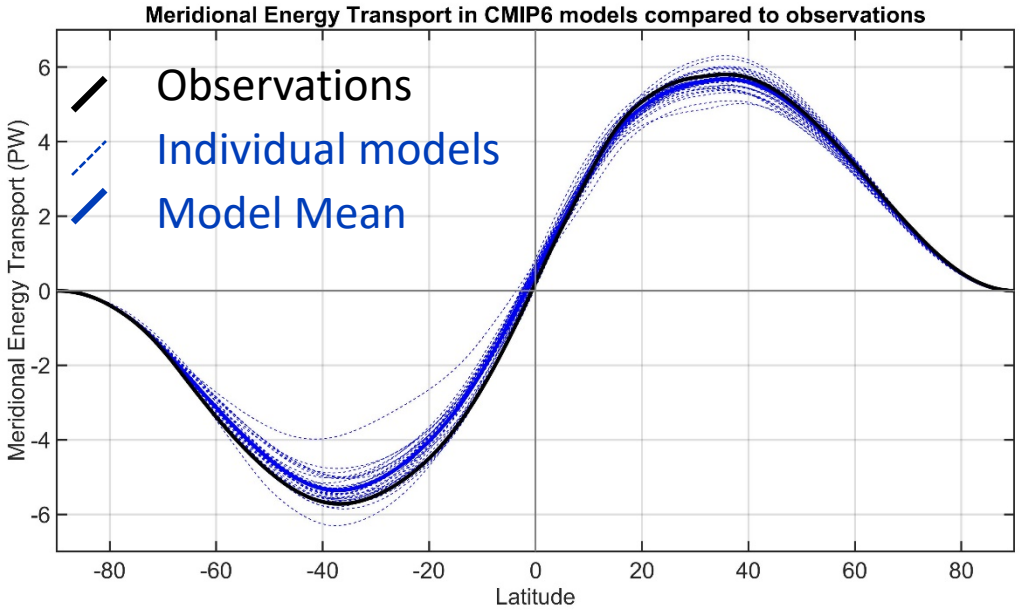


Total energy transport

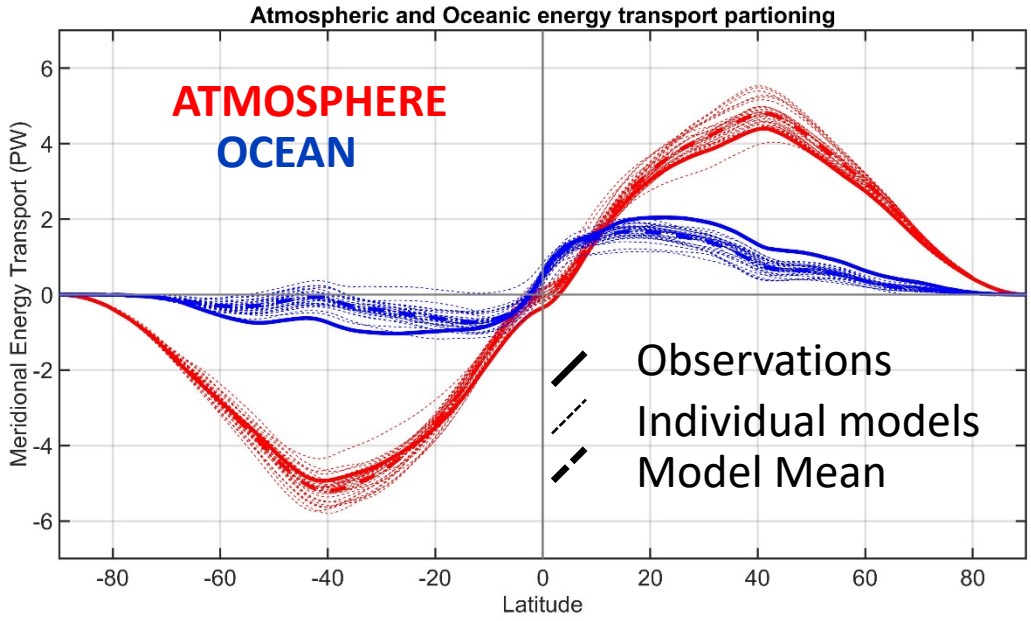


Atmosphere ocean partitioning

CMIP6

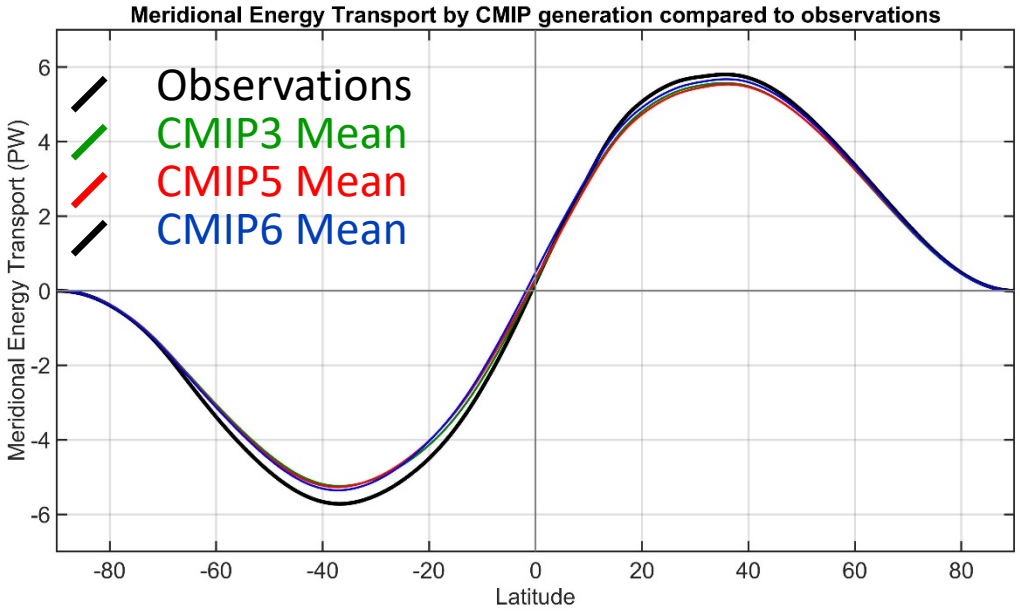


Total energy transport

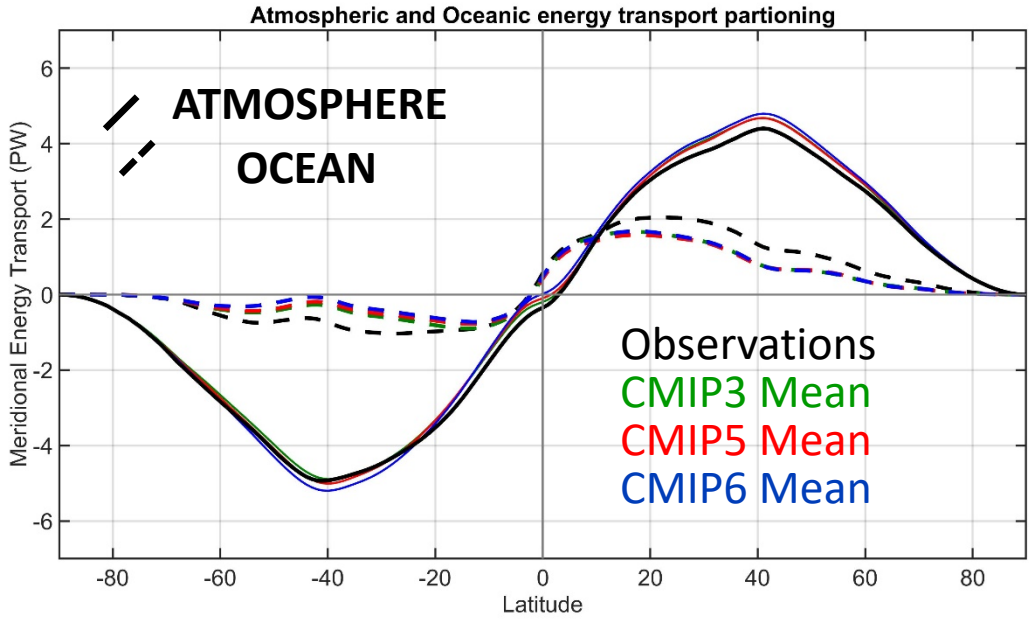


Atmosphere ocean partitioning

CMIP3 to 6 against observations

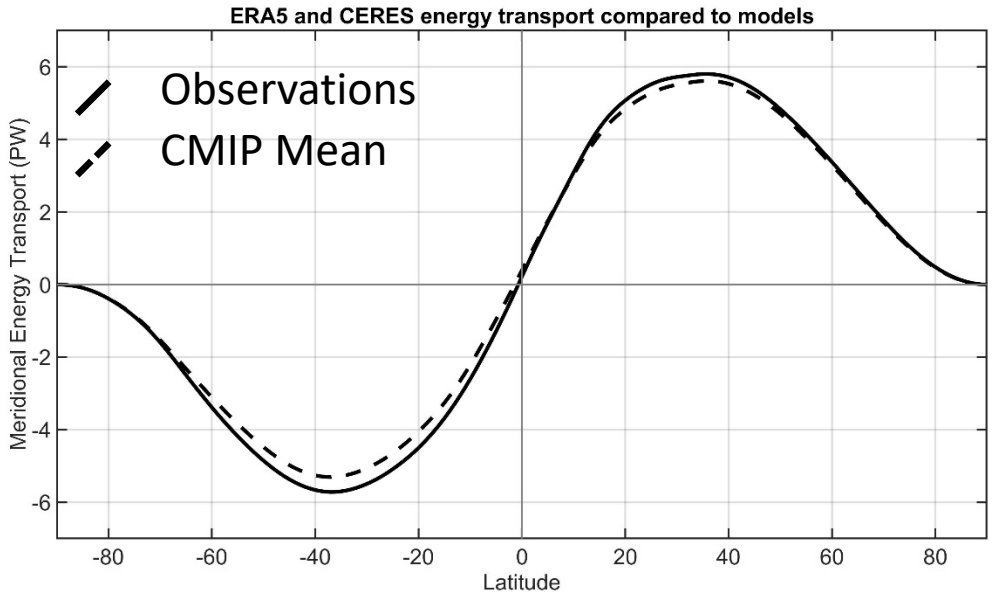


Total energy transport

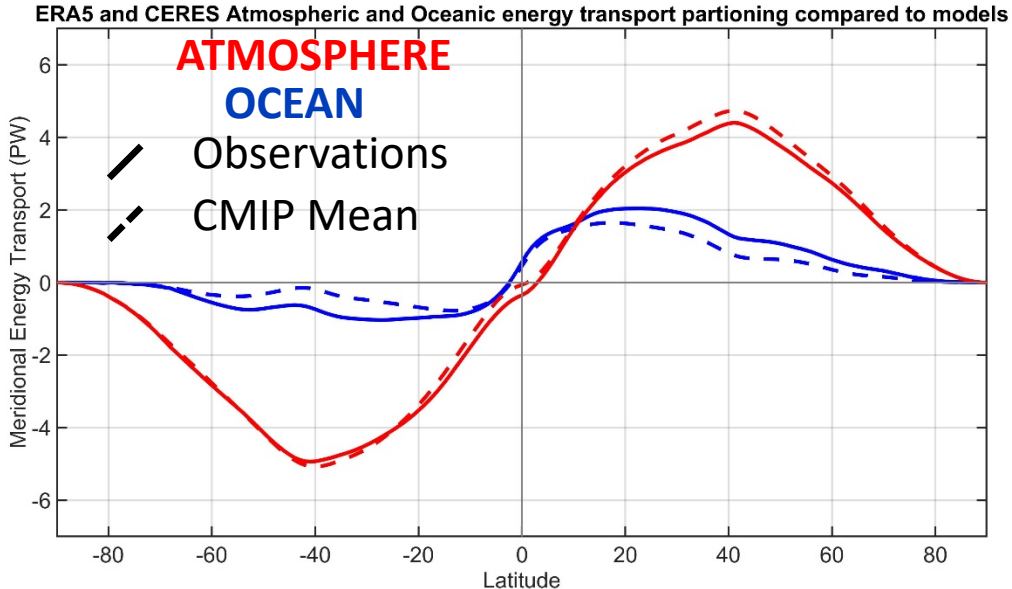


Atmosphere ocean partitioning

OBSERVATIONS FROM ERA5 and CERES

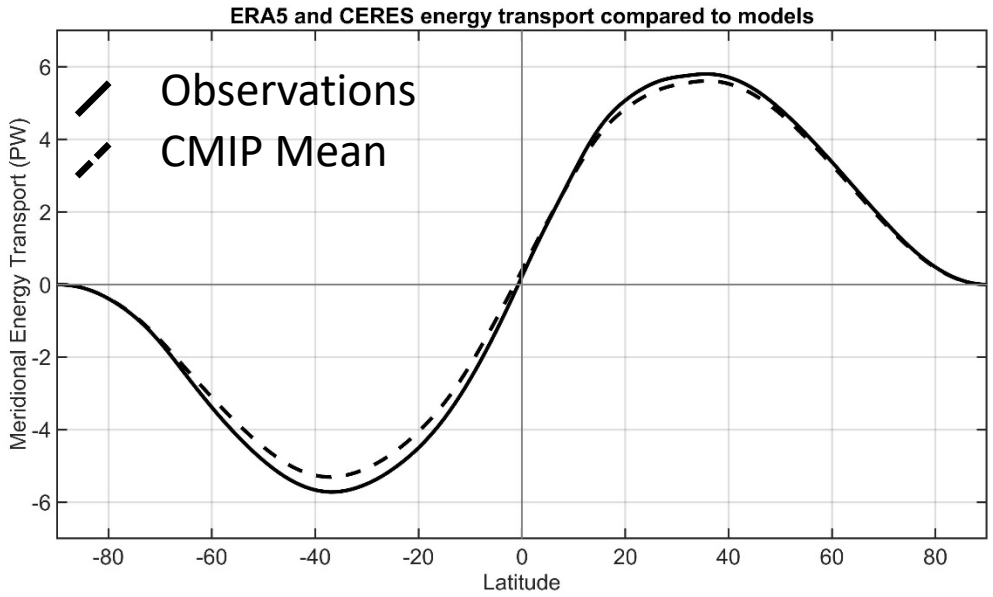


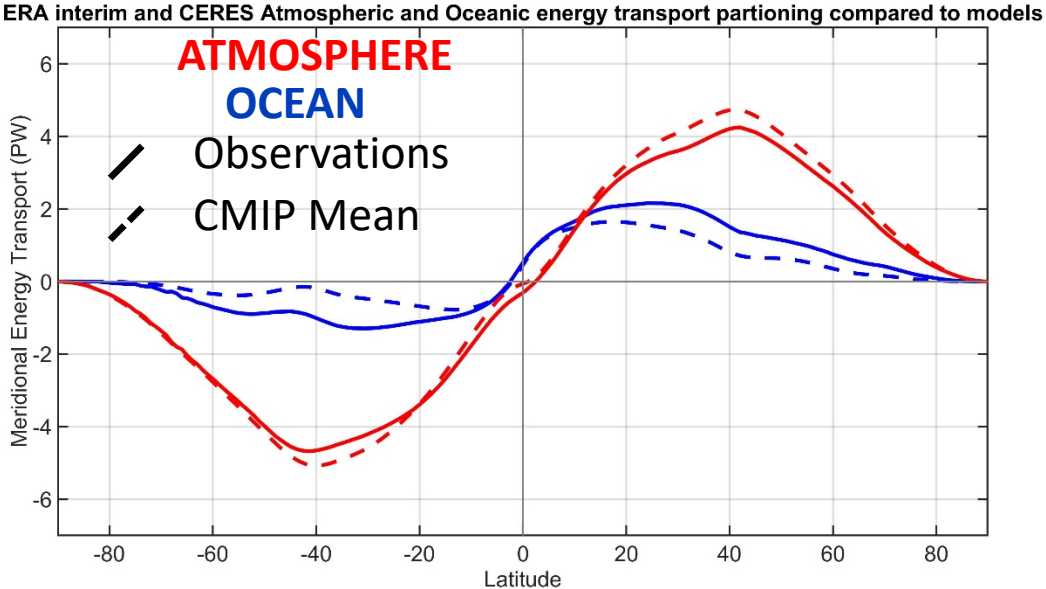
Total energy transport



Atmosphere ocean partitioning

OBSERVATIONS FROM ERA INTERIM and CERES

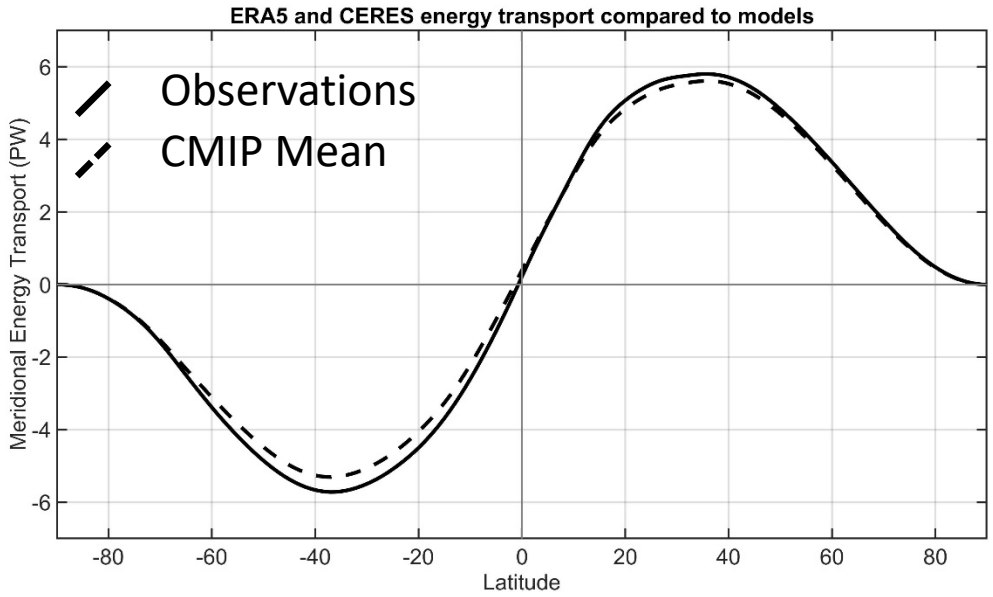


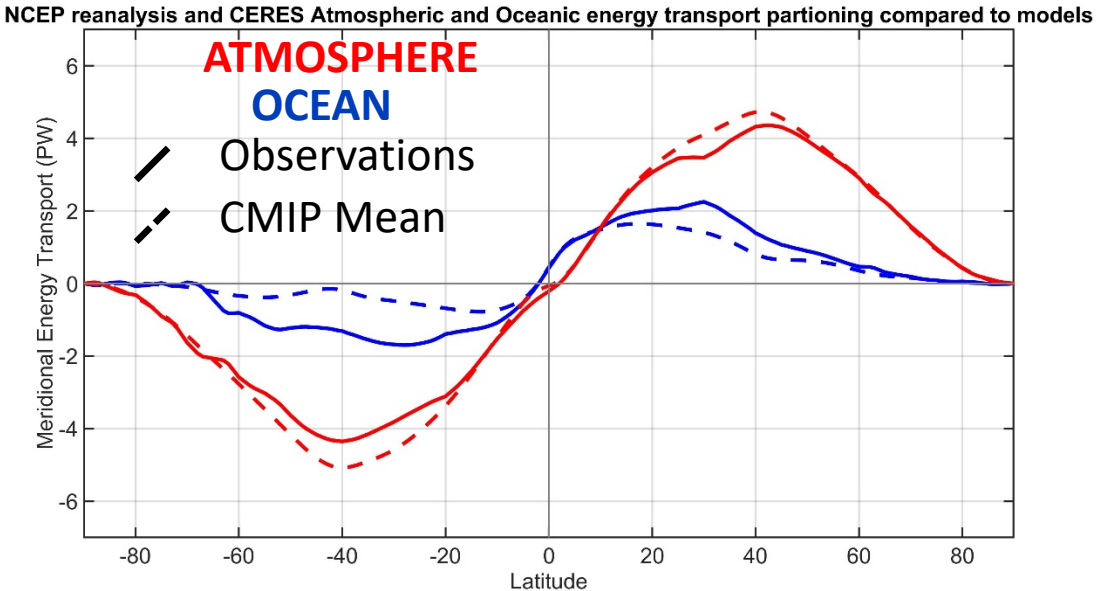


Total energy transport

Atmosphere ocean partitioning

OBSERVATIONS FROM NCEP reanalysis and CERES

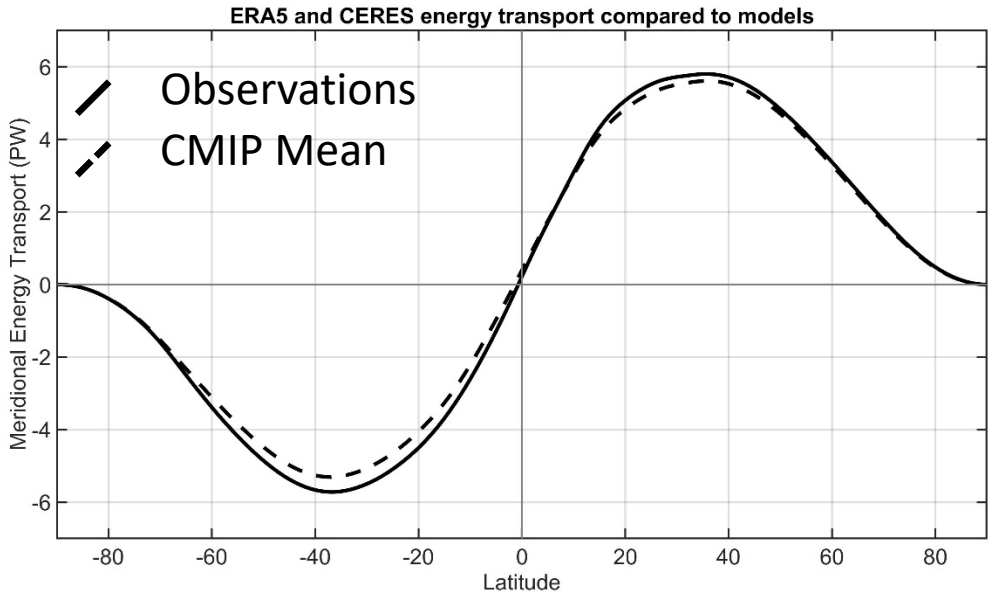




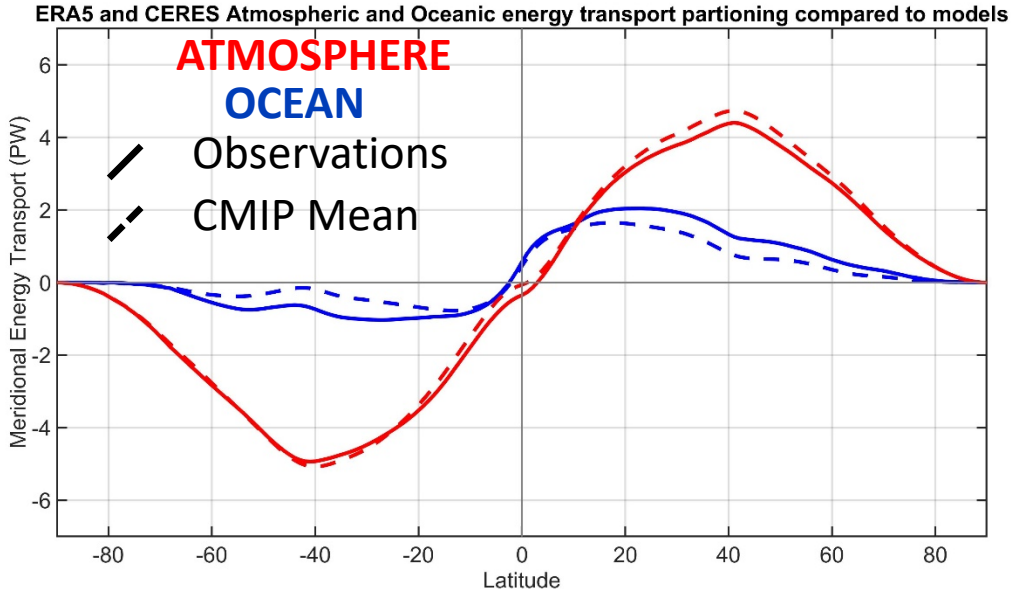
Total energy transport

Atmosphere ocean partitioning

OBSERVATIONS FROM ERA5 and CERES

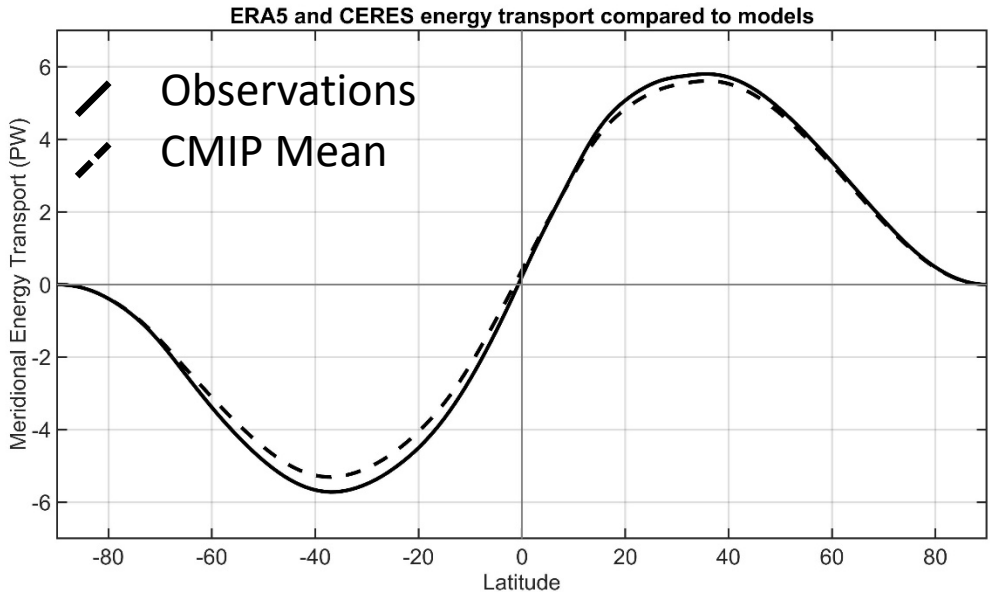


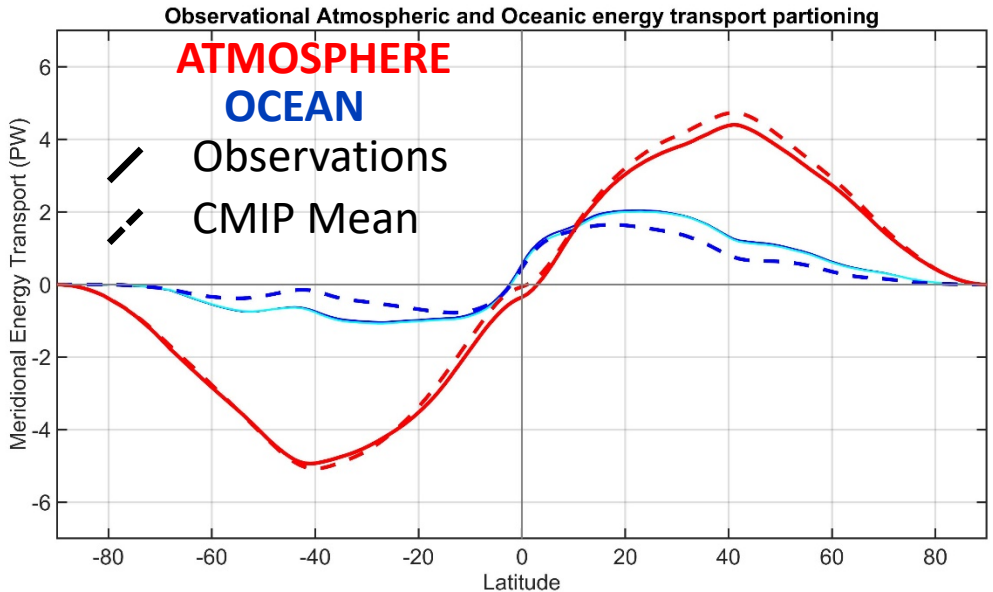
Total energy transport



Atmosphere ocean partitioning

Accounting for ocean heat content changes



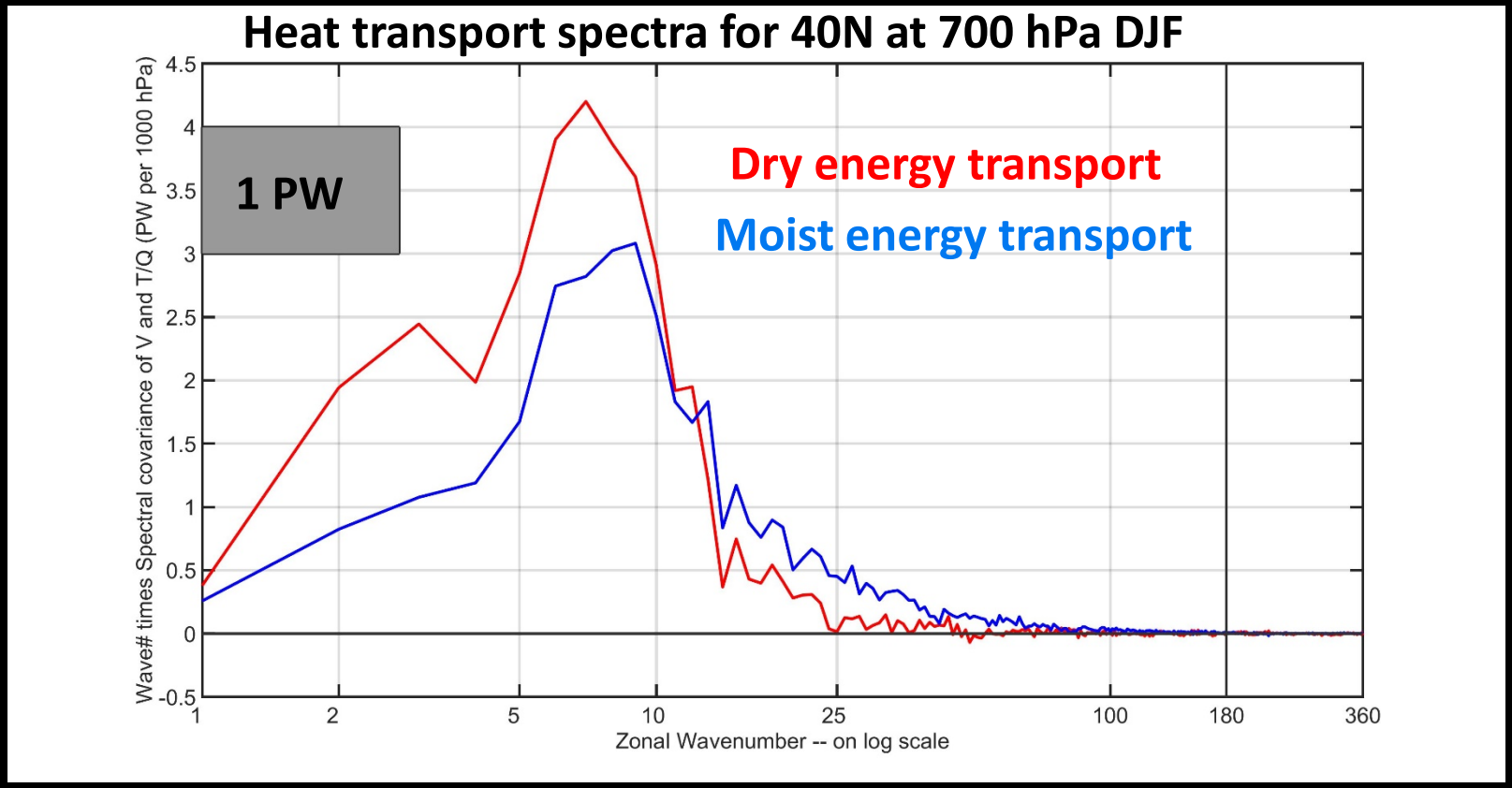


Total energy transport

Correcting for ocean heat content changes

From EN4 ocean reanalysis temperature trends

Does spatial resolution of atmospheric reanalysis miss heat transport at small scales? (NO!)



Truncation at 2^{o} resolution results in
0.009% and 0.021% loss of dry/moist heat transport

Partitioning of atmospheric energy by circulation type

$$AHT(\phi) = -\frac{2\pi a\cos(\phi)}{g}\int_{p_s}^{0} \underbrace{[\bar{V}][\overline{MSE}]}_{MOC} + \underbrace{\overline{[V]'[MSE]'}}_{TOC} + \underbrace{[V^*MSE^*]}_{Stat.eddy} + \underbrace{\overline{[V^{*\prime}MSE^{*\prime}]}}_{Trans.eddy}\, dp$$

* = Departure from zonal mean -- [ ]

' = Departure from time mean -- $\overline{\ }$

MSE = moist static energy

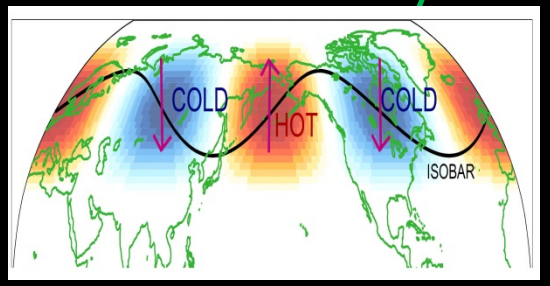
= CpT + LQ +gZ

MOC dominates in the deep tropics – Hadley cell

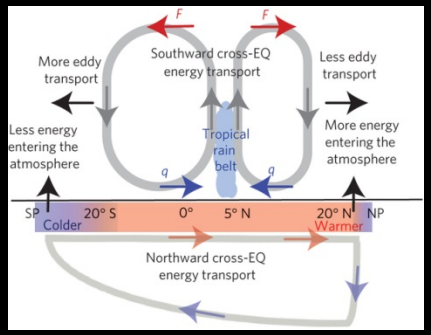
Stationary eddies stronger in NH

Transient eddies dominate the mid-latitudes

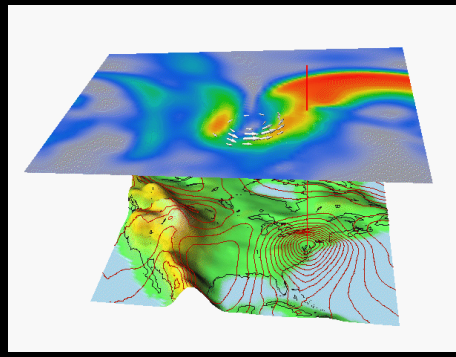
Stationary

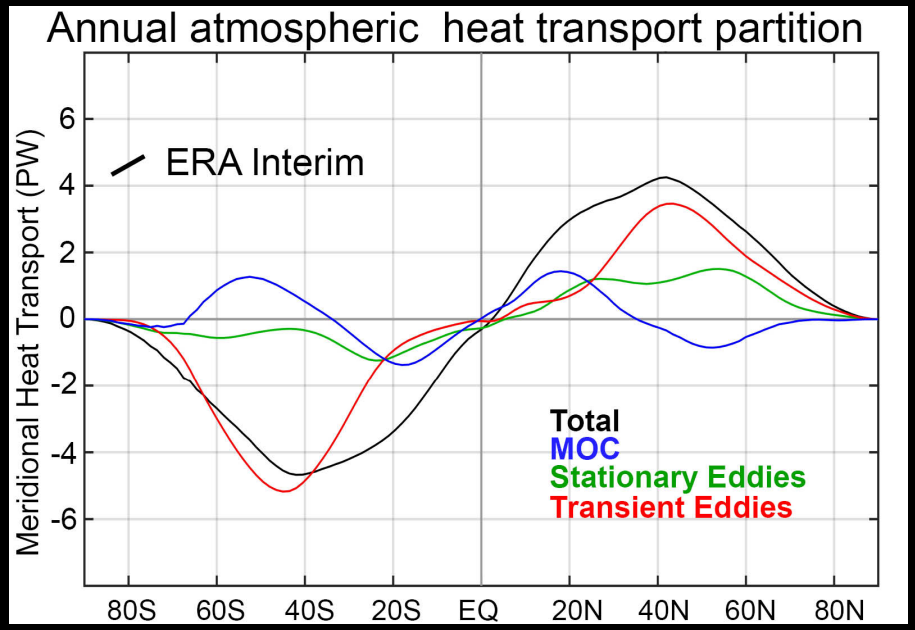


MOC Overturning

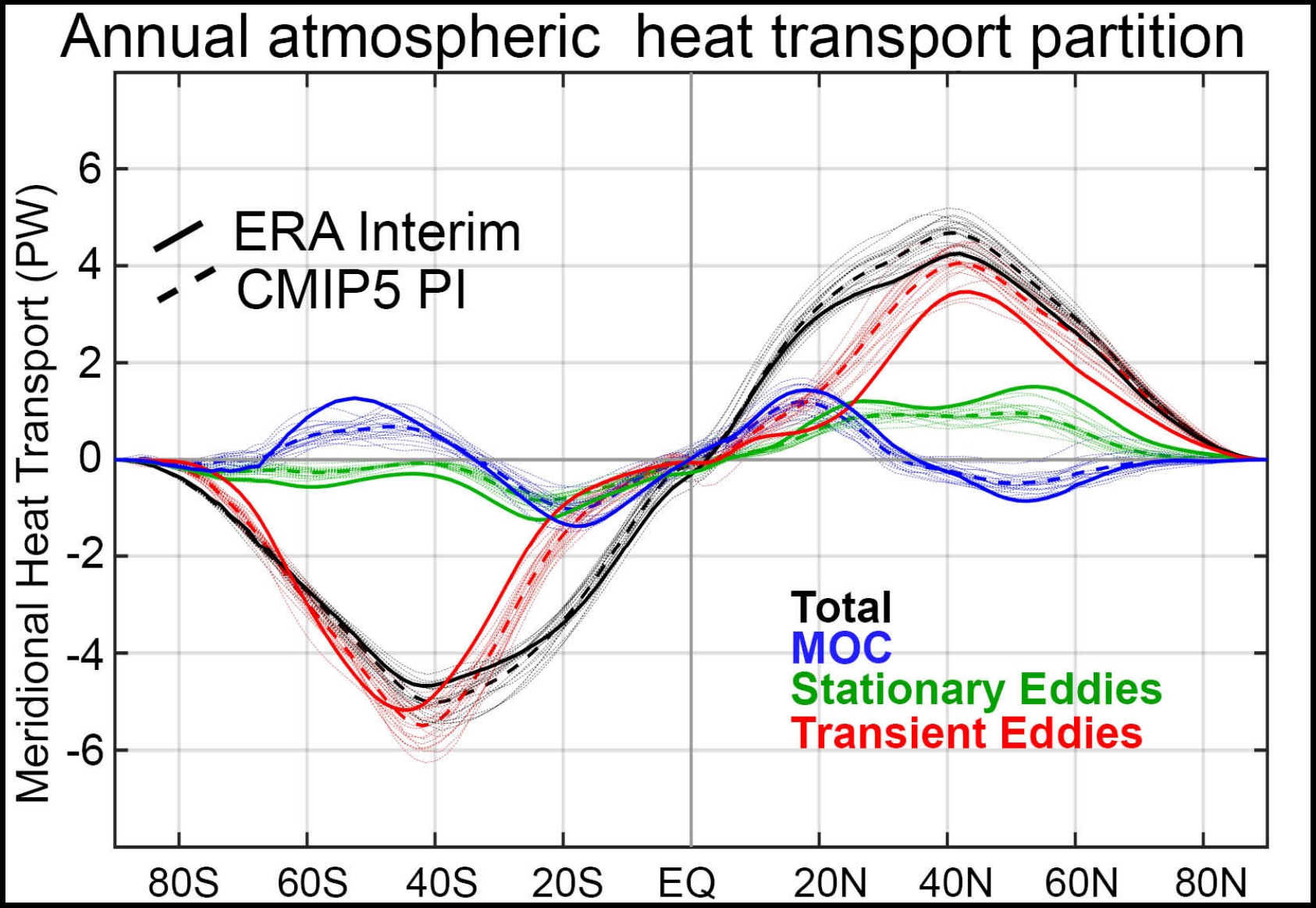


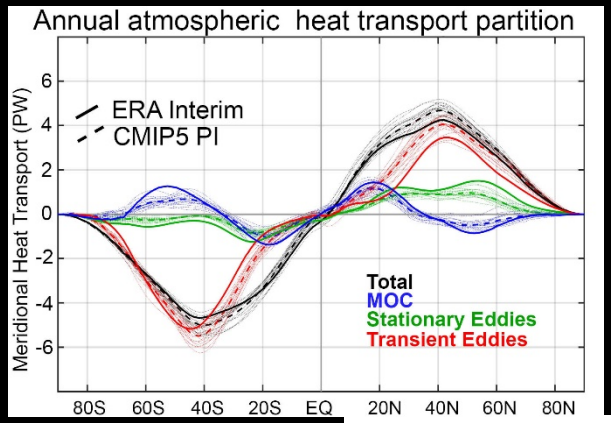
Transient



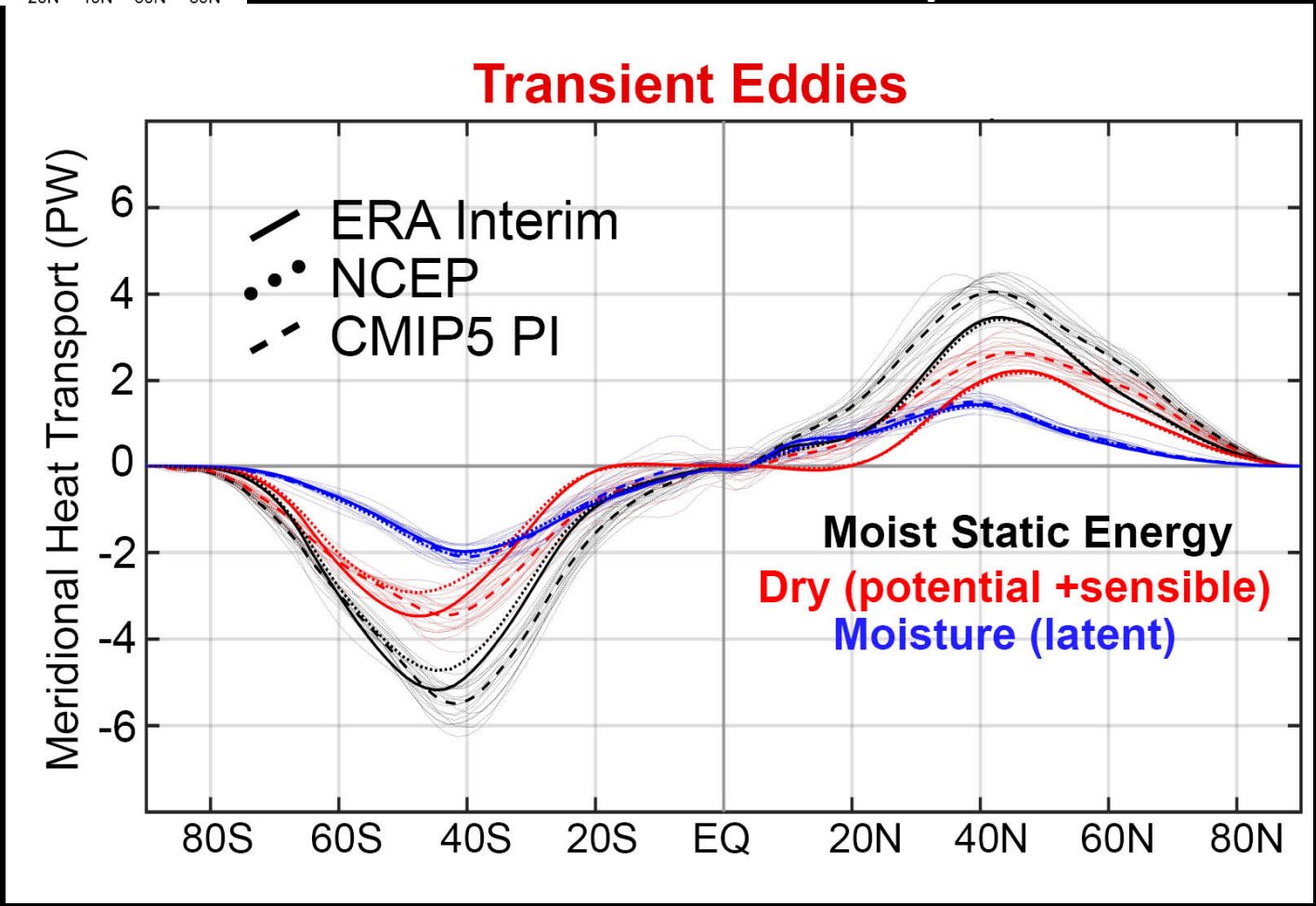


Observation vs. model AHT partitioning



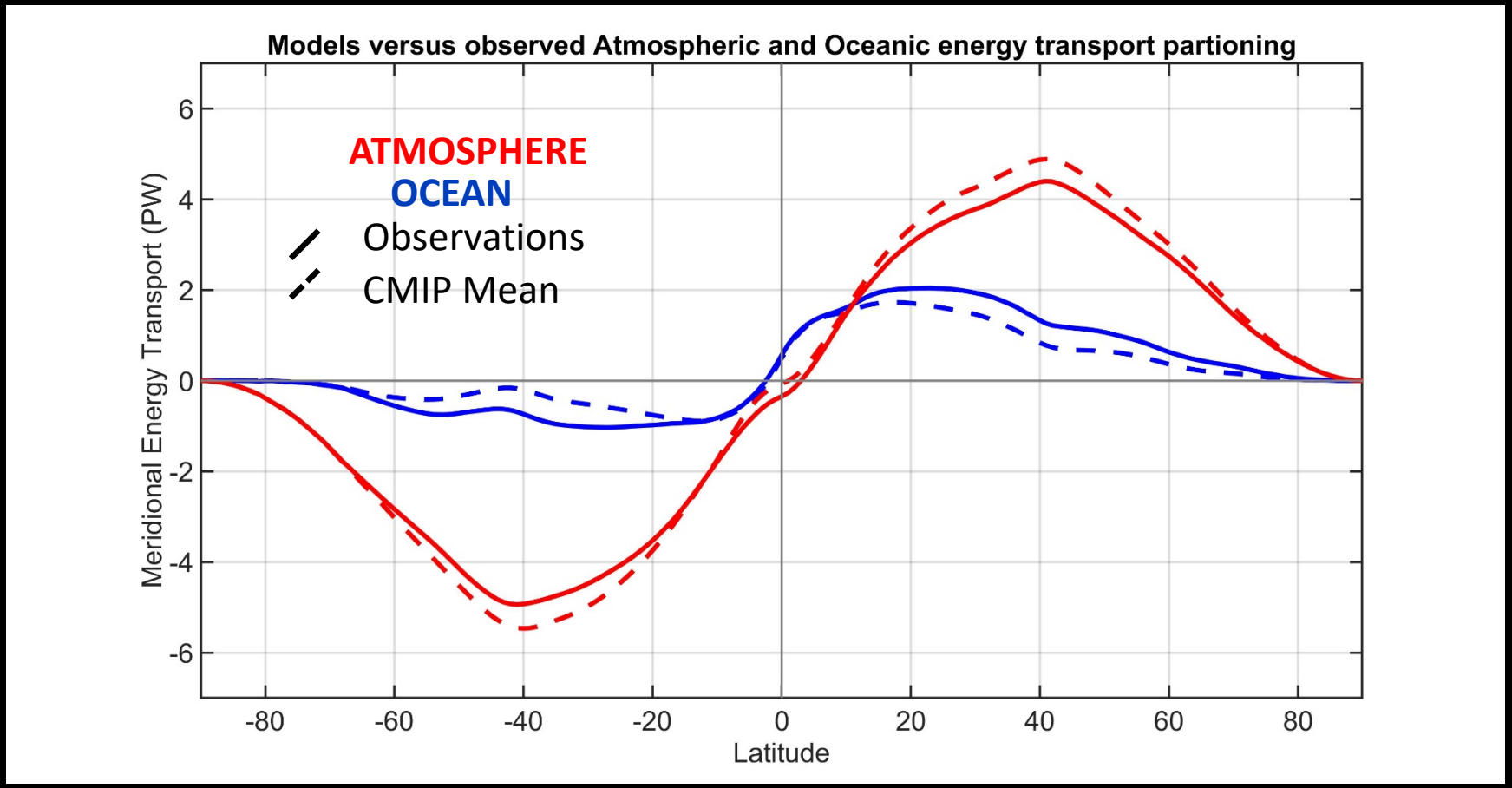


Model bias of enhanced transient eddy heat transport is due to sensible heat transport



Main conclusion: Models move too much energy through the atmosphere and too little through the ocean

Fractional AHT/OHT partitioning in models versus observations



AHT is determined by spatial structure of energy input into the atmosphere

↓

Evaporation is responsible for majority of the spatial anomalies in energy input to the atmosphere

1.) E-P = moist AHT

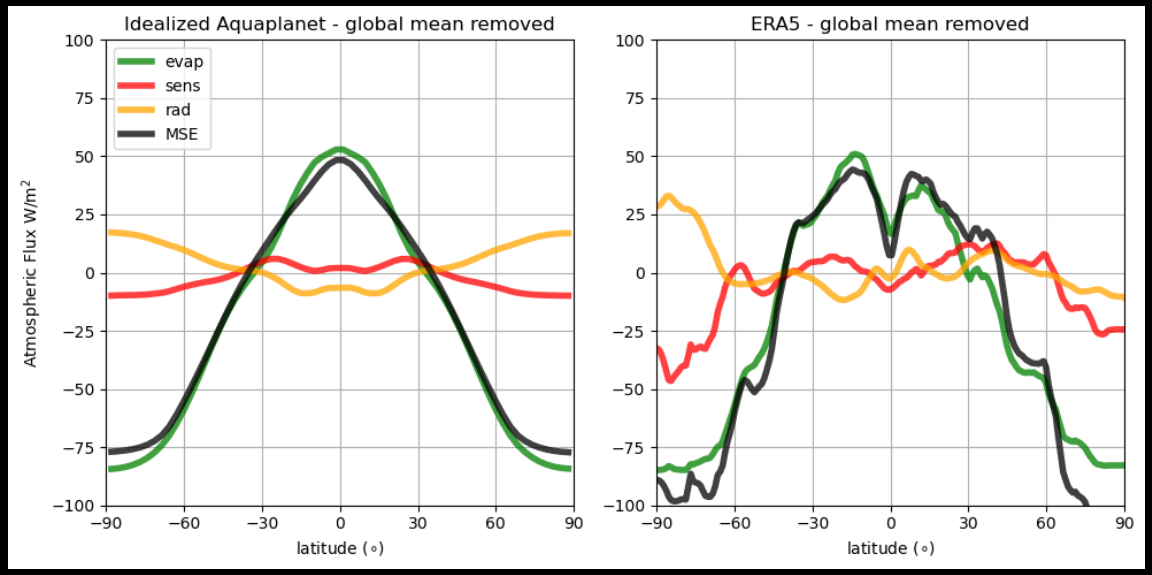
2.) P = condensational heating that drives dry AHT

↓

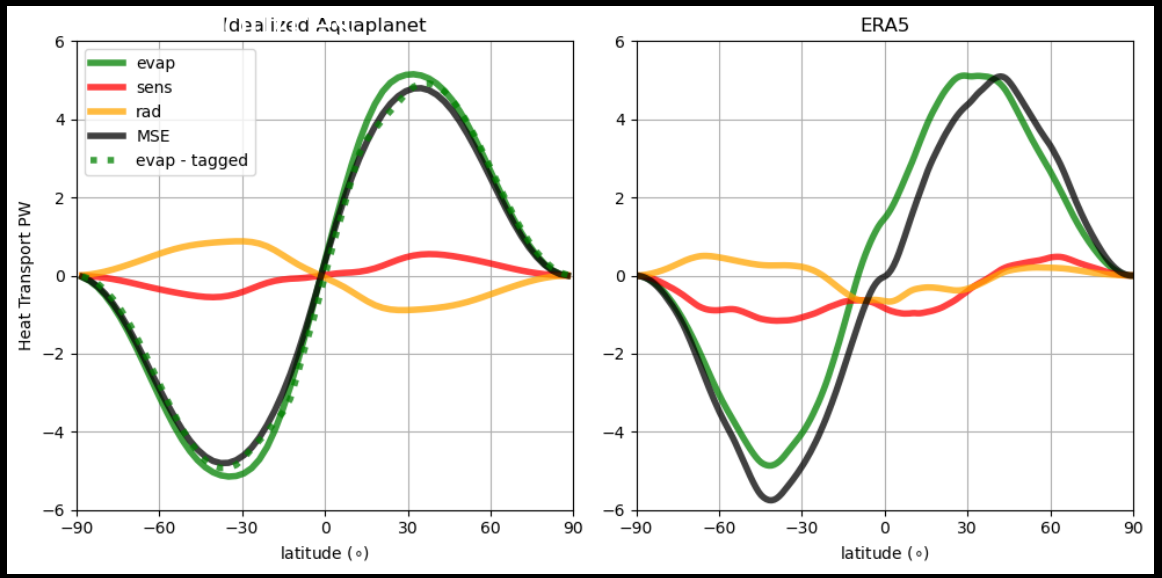
AHT is determined by evaporation!

AHT/OHT partitioning is controlled by sensitivity of evaporation to SST

Sources of atmospheric heating



AHT decomposed into heating



Models are biased toward too much evaporation globally

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Models transport too much energy through the atmosphere