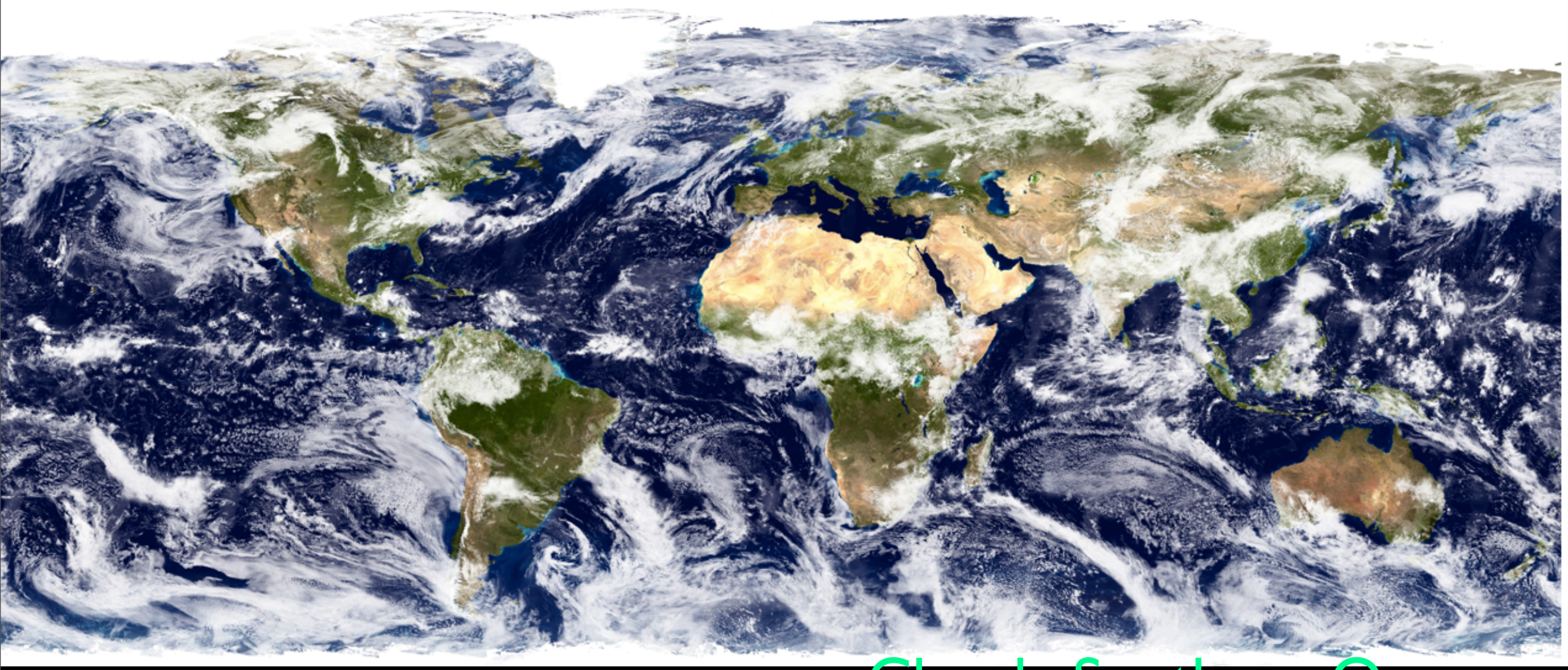
A New Look at the Double ITCZ Problem: Connections to Cloud Biases over Southern Ocean

Yen-Ting Hwang and Dargan Frierson
University of Washington

NASA Goddard Space Flight Center image of clouds

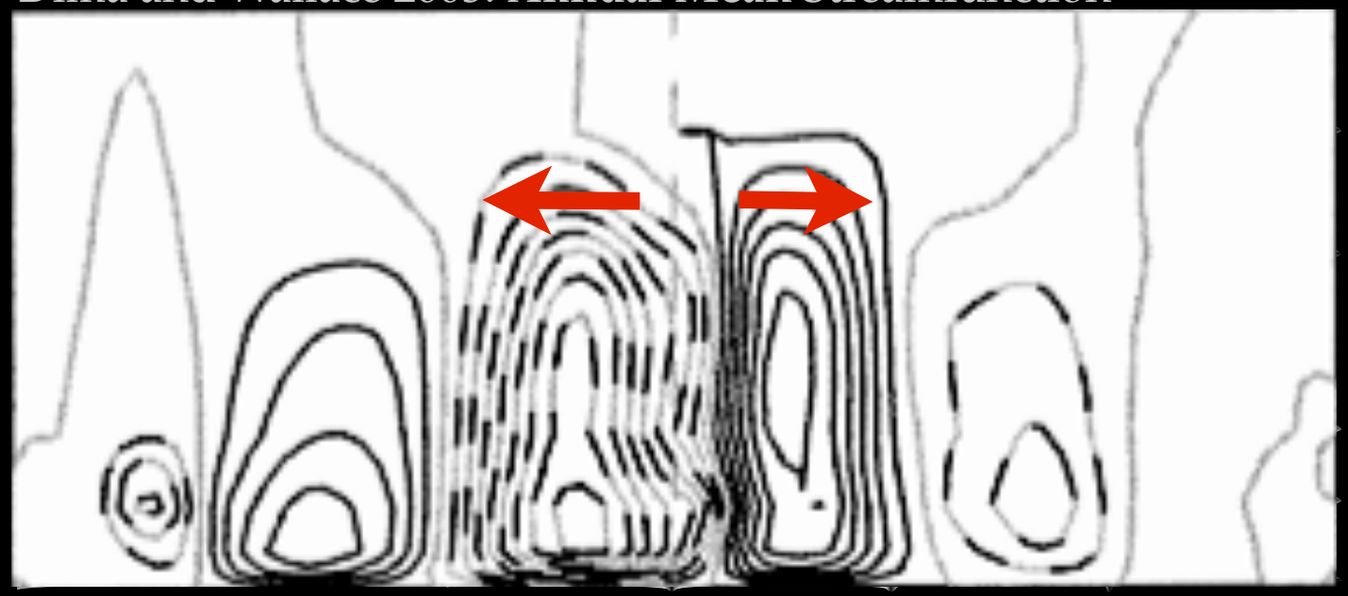


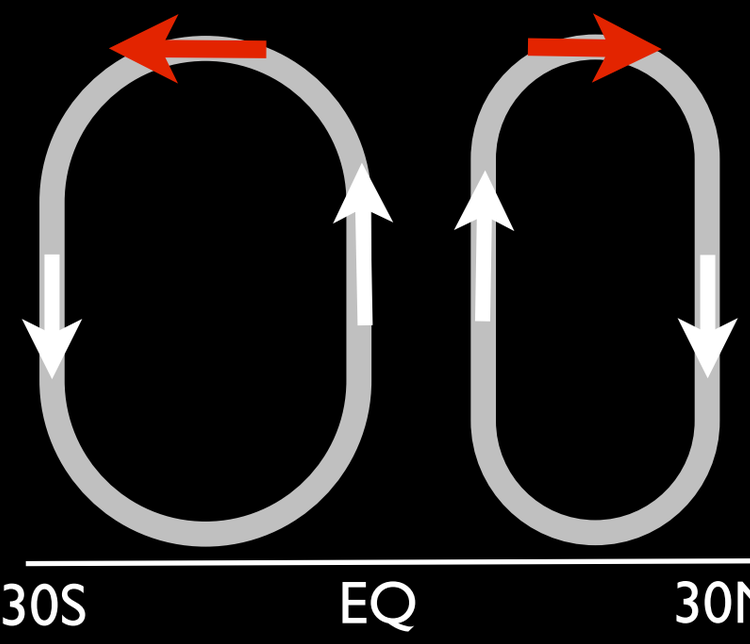
Cloudy Southern Ocean

The Theory

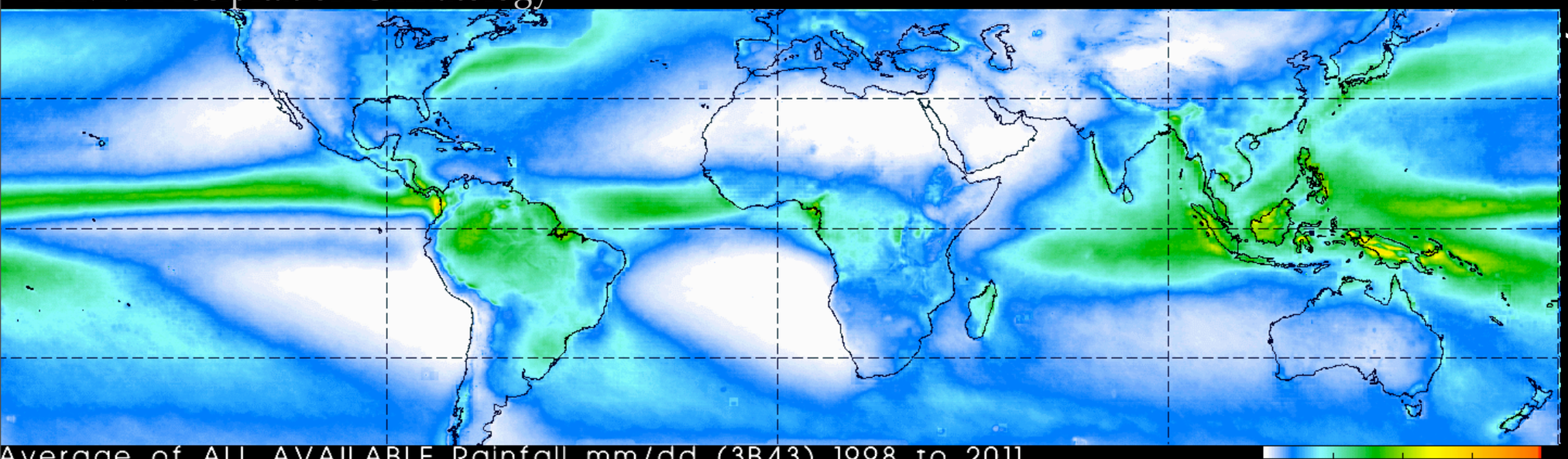
Linking Energy Transport with ITCZ

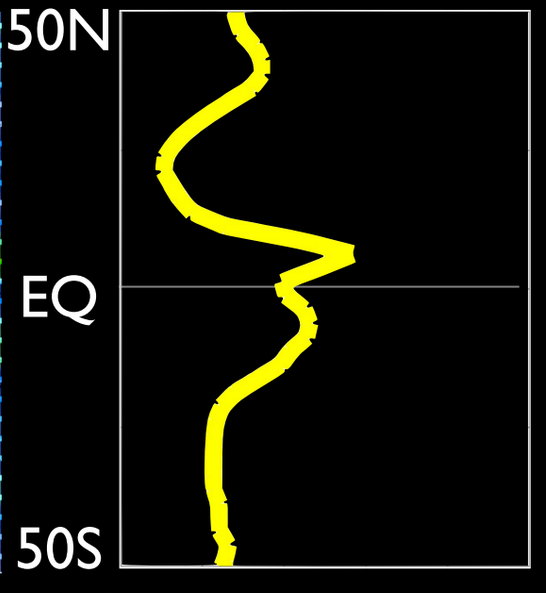
Dima and Wallace 2003: **Annual Mean** Streamfunction





TRMM Precipitation Climatology





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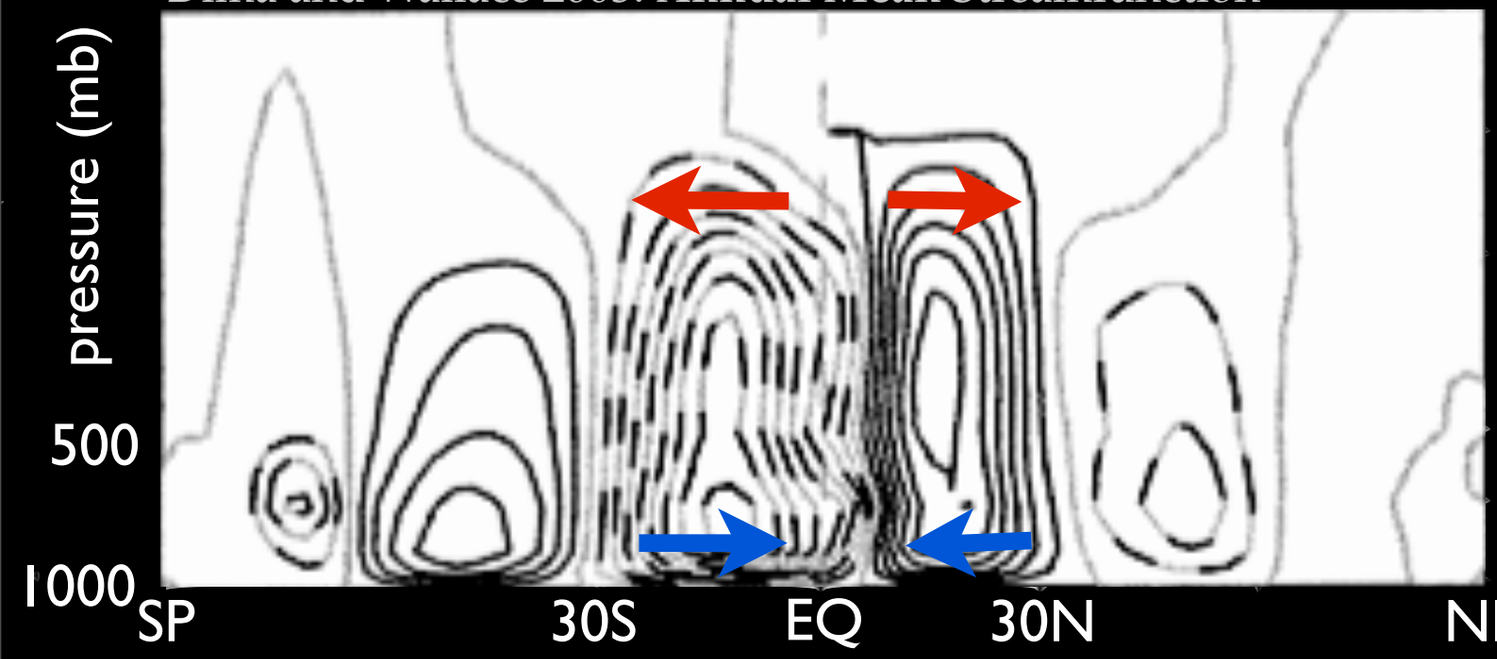

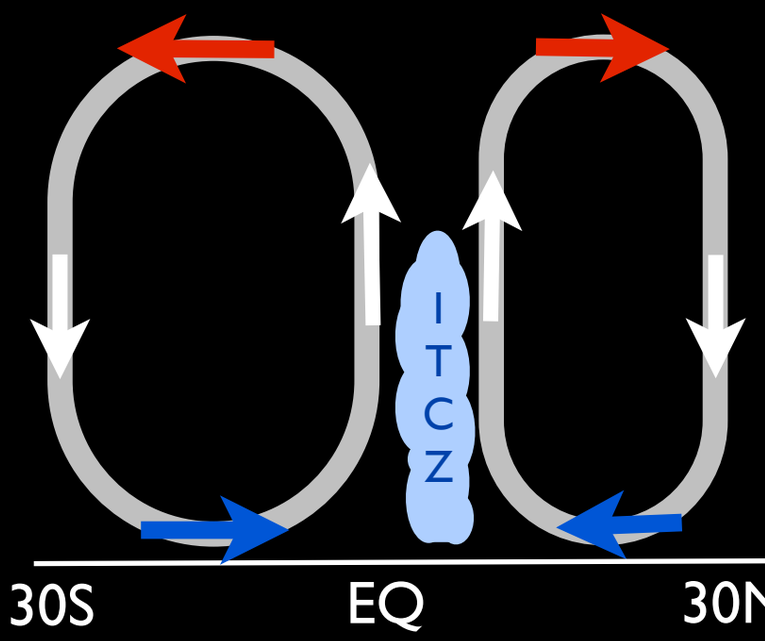

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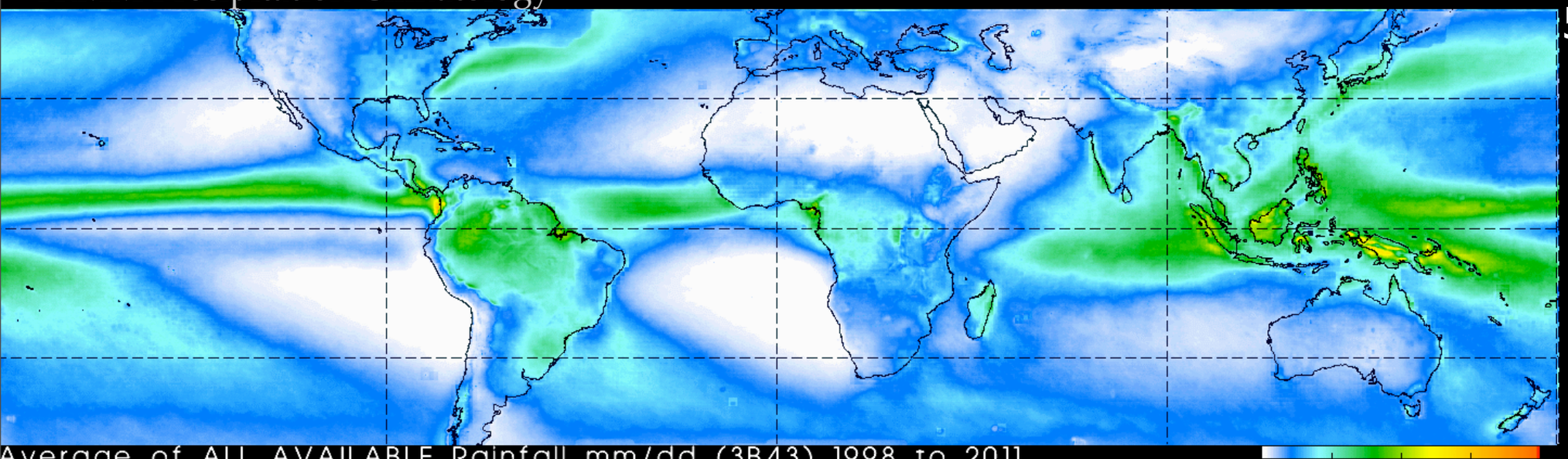
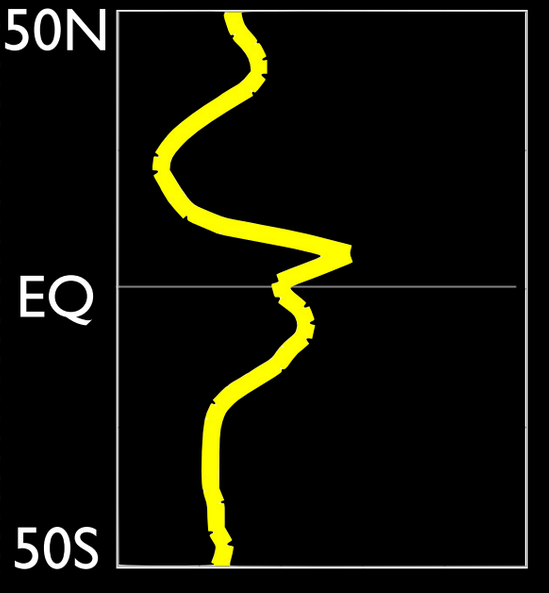
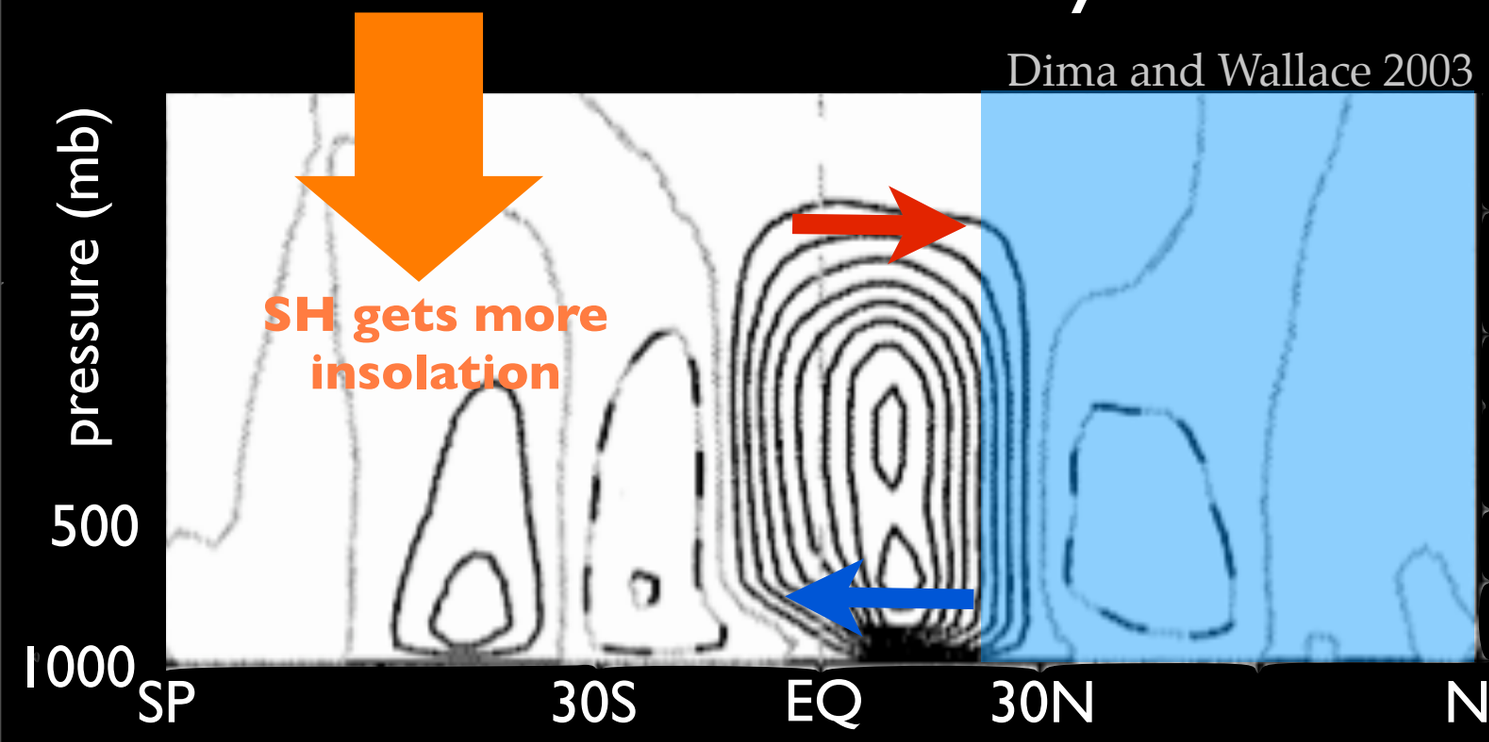


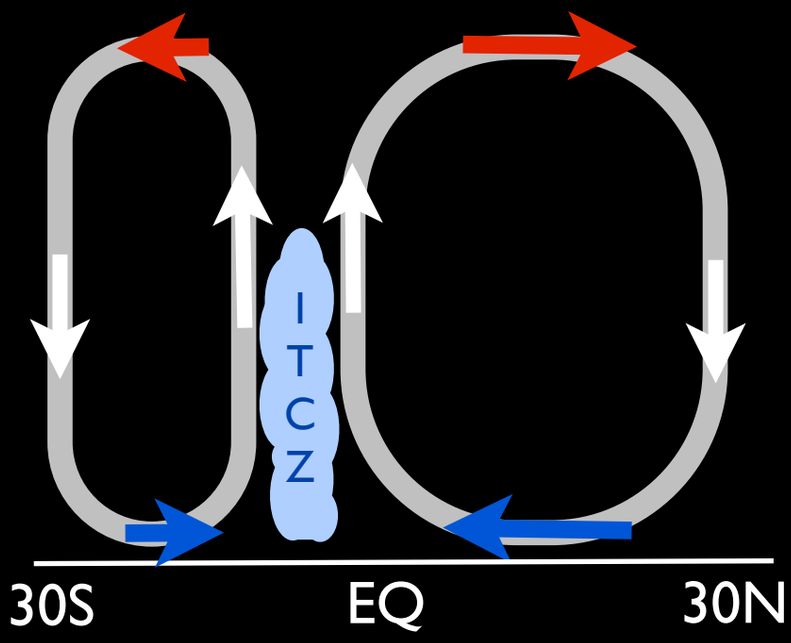


The Theory

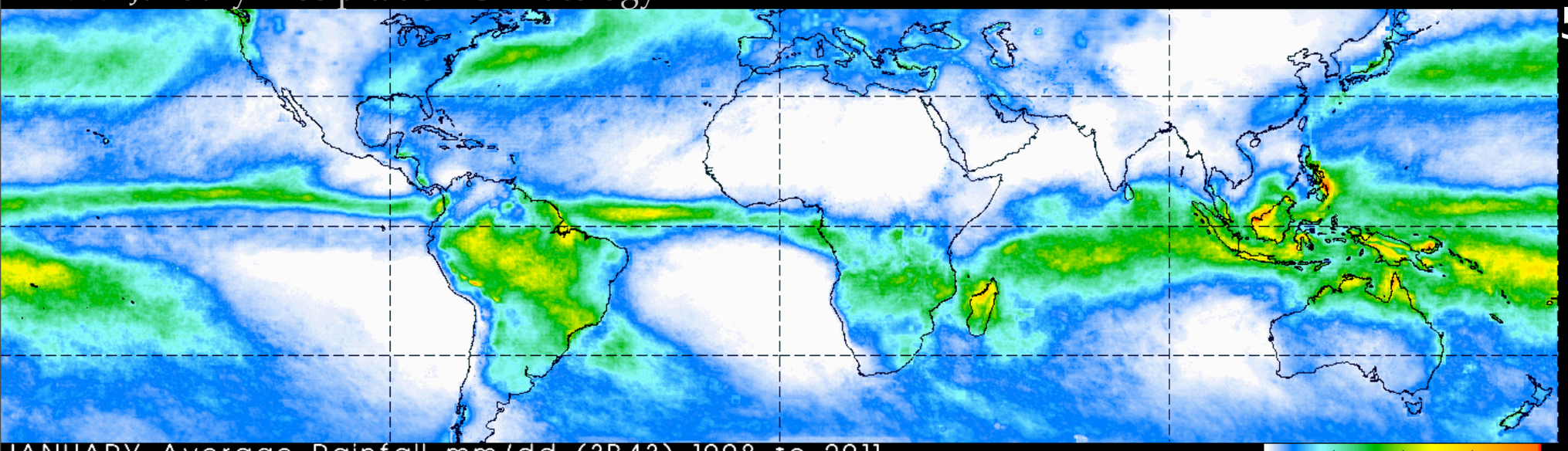
Seasonal Cycle -- Austral Summer

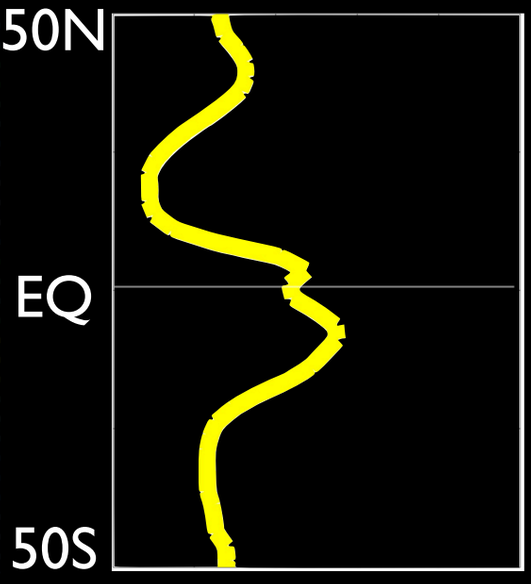
Dima and Wallace 2003





TRMM January Precipitation Climatology





The Theory

Seasonal Cycle -- Boreal Summer

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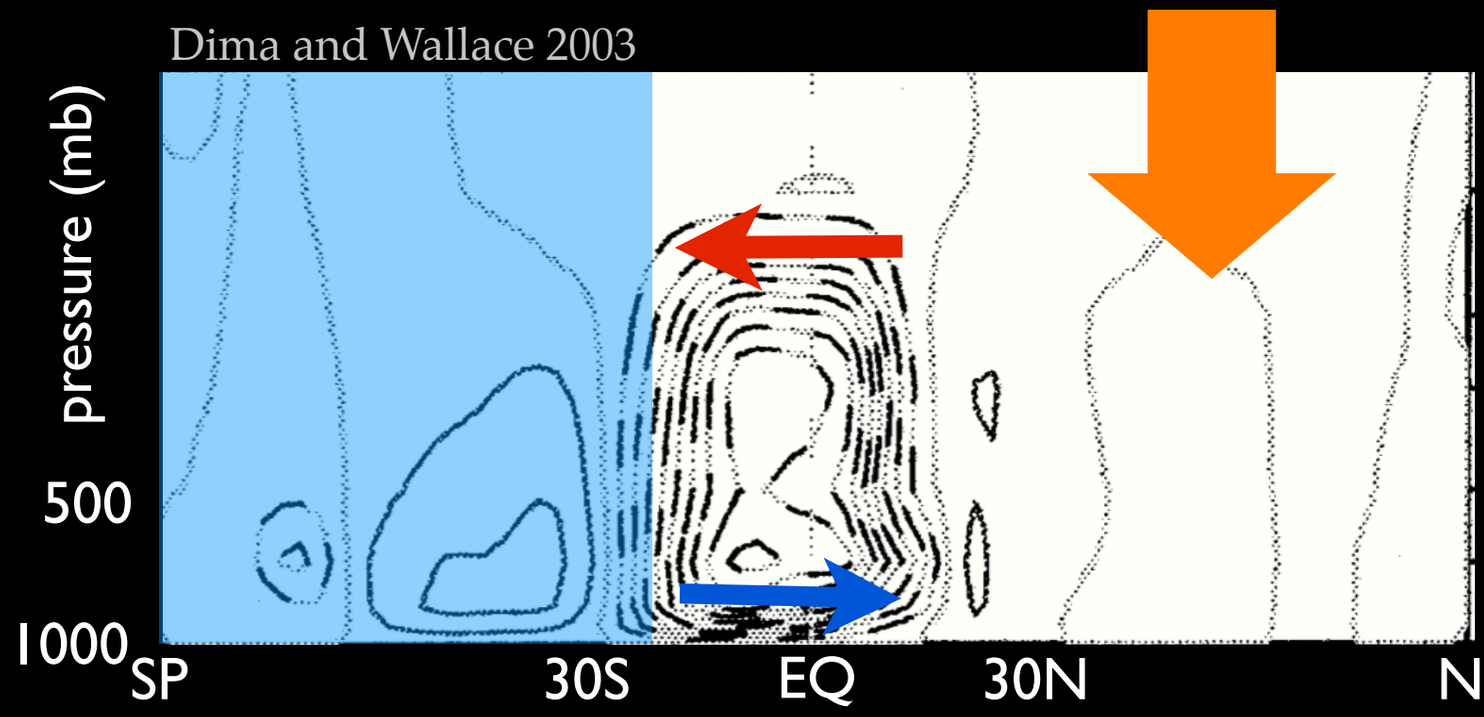
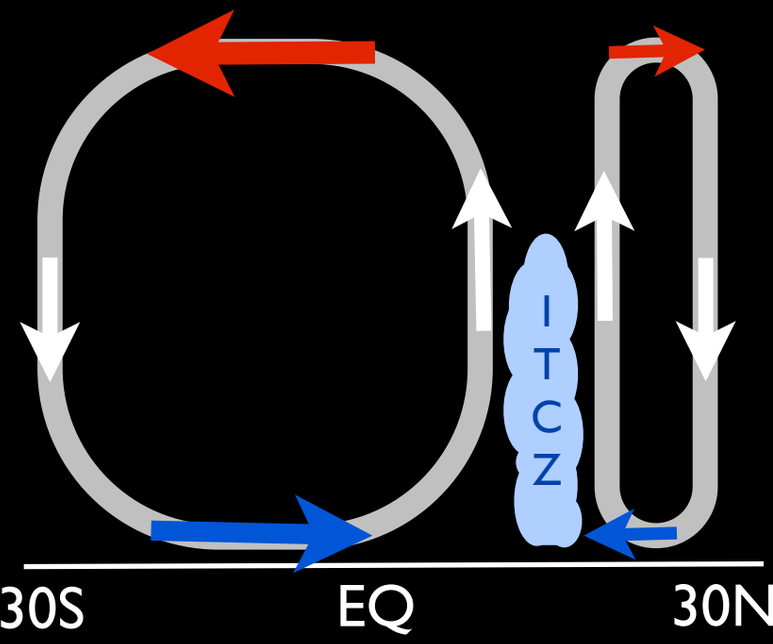
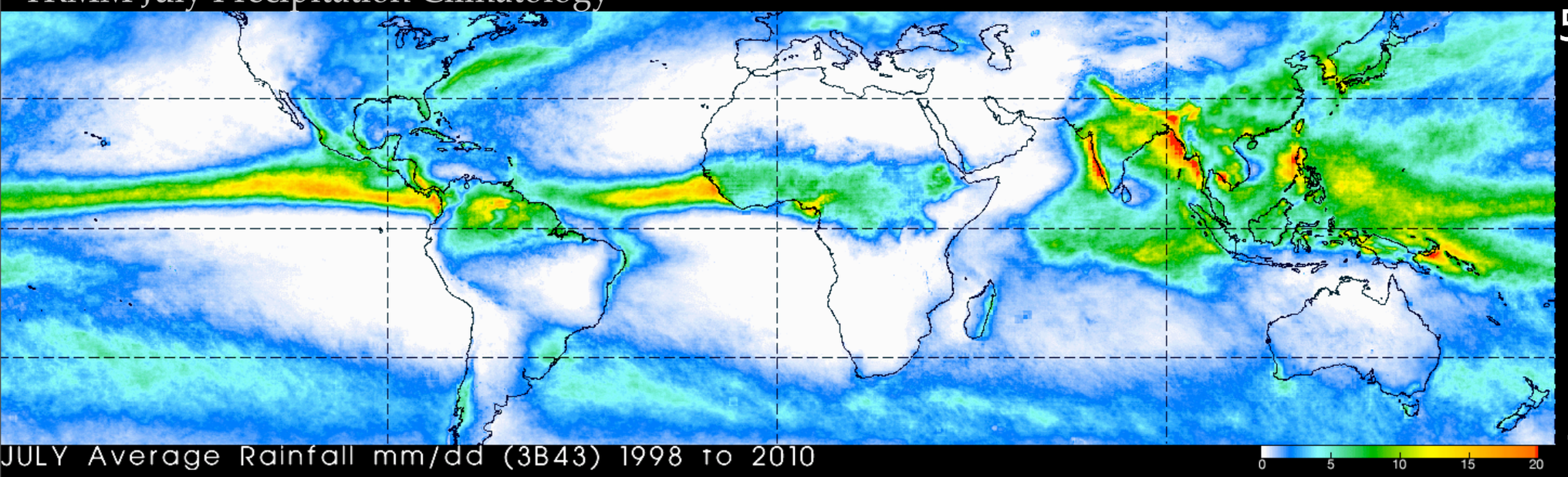
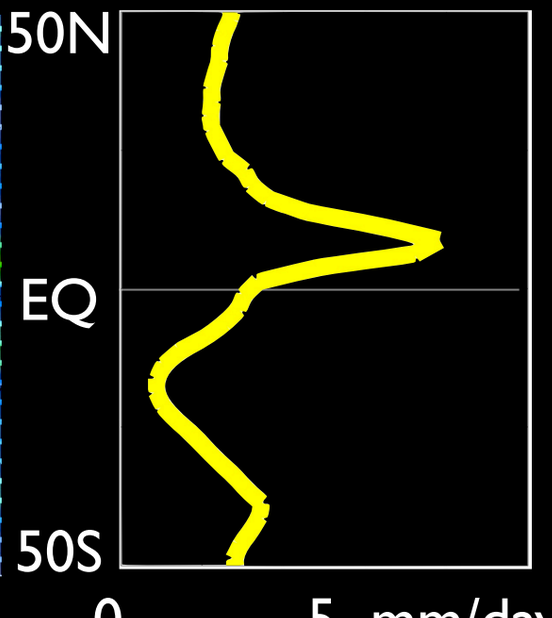


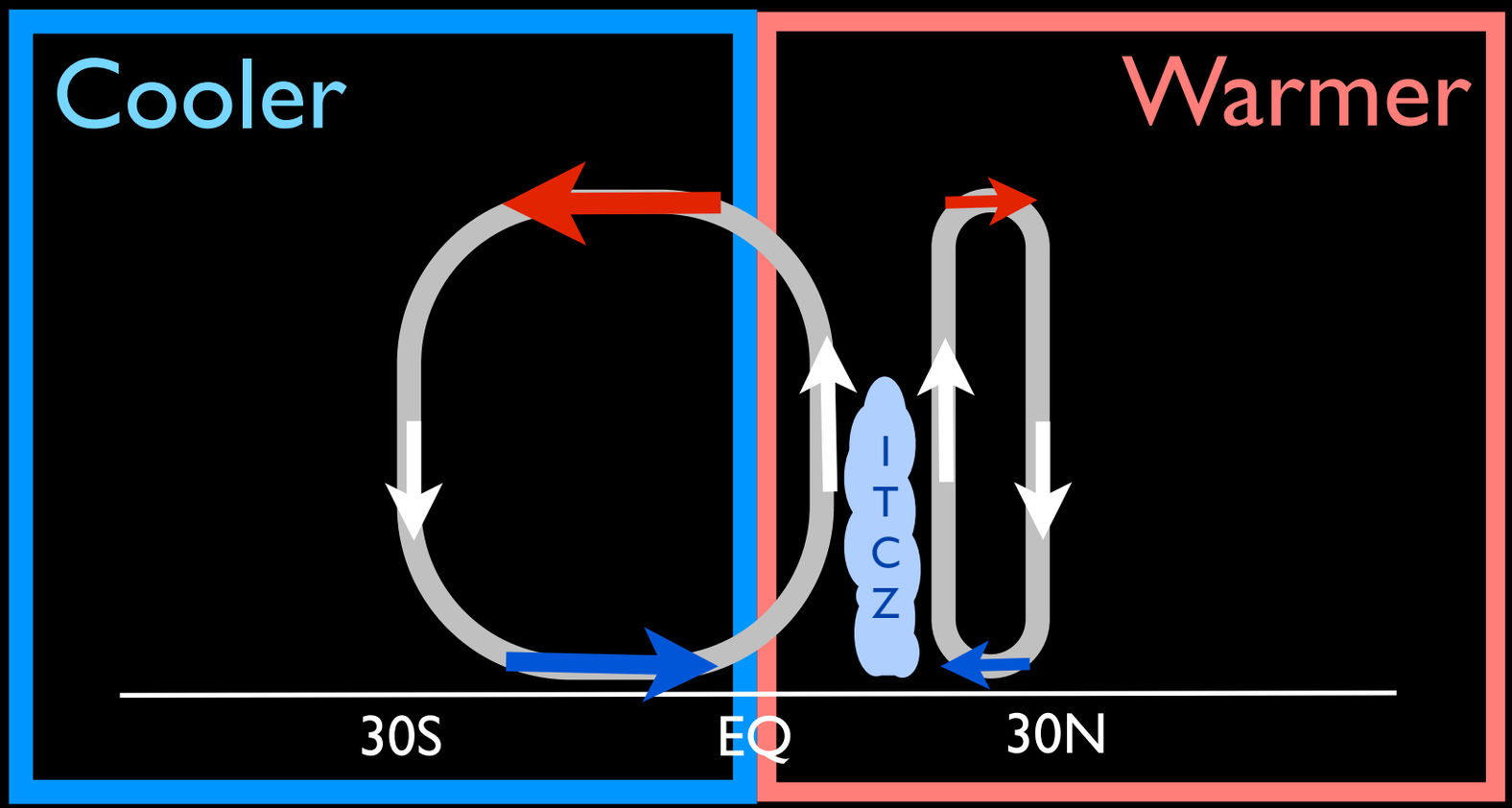


TRMM July Precipitation Climatology





ITCZ Shifts Toward the Warmth

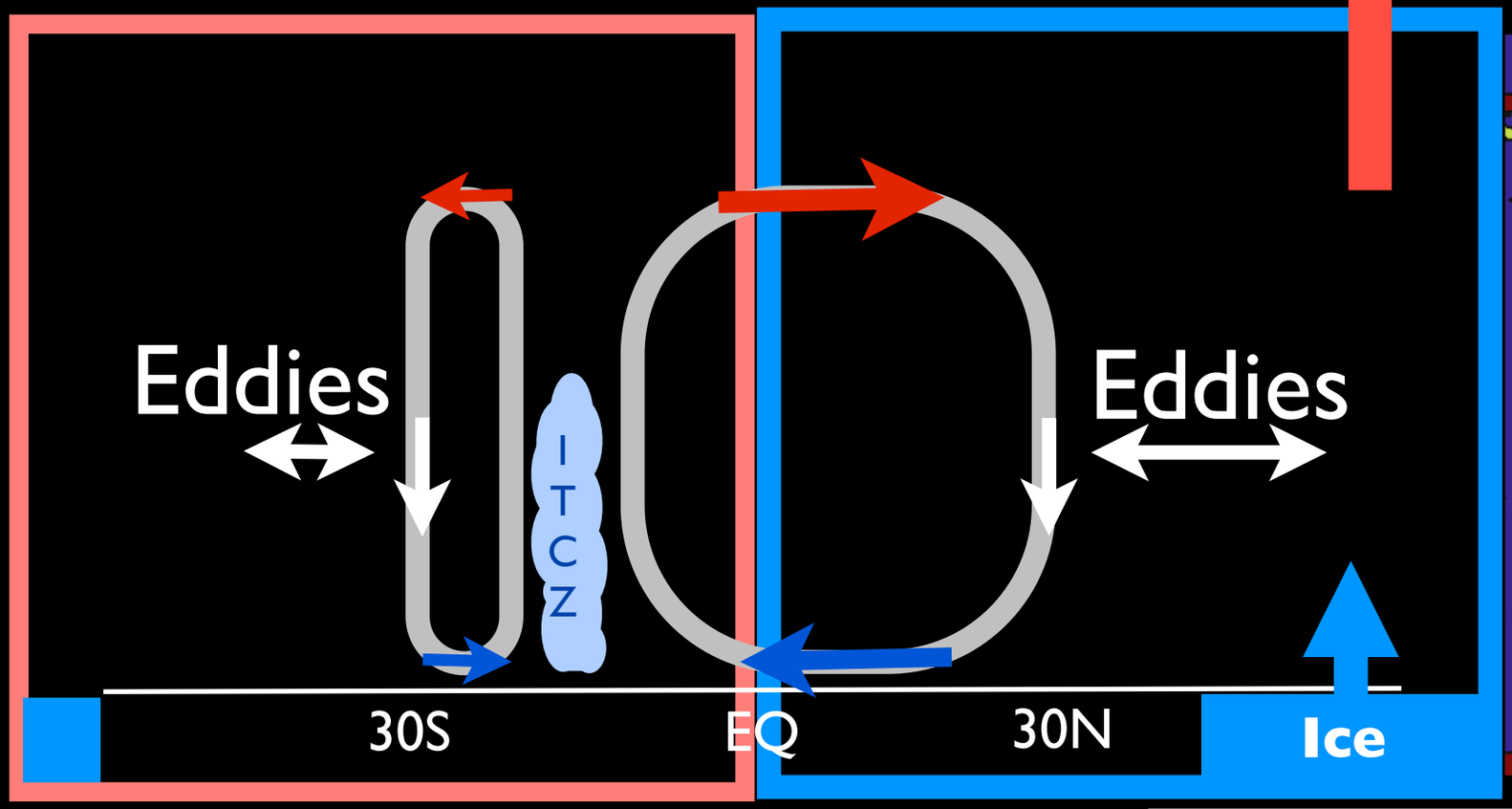


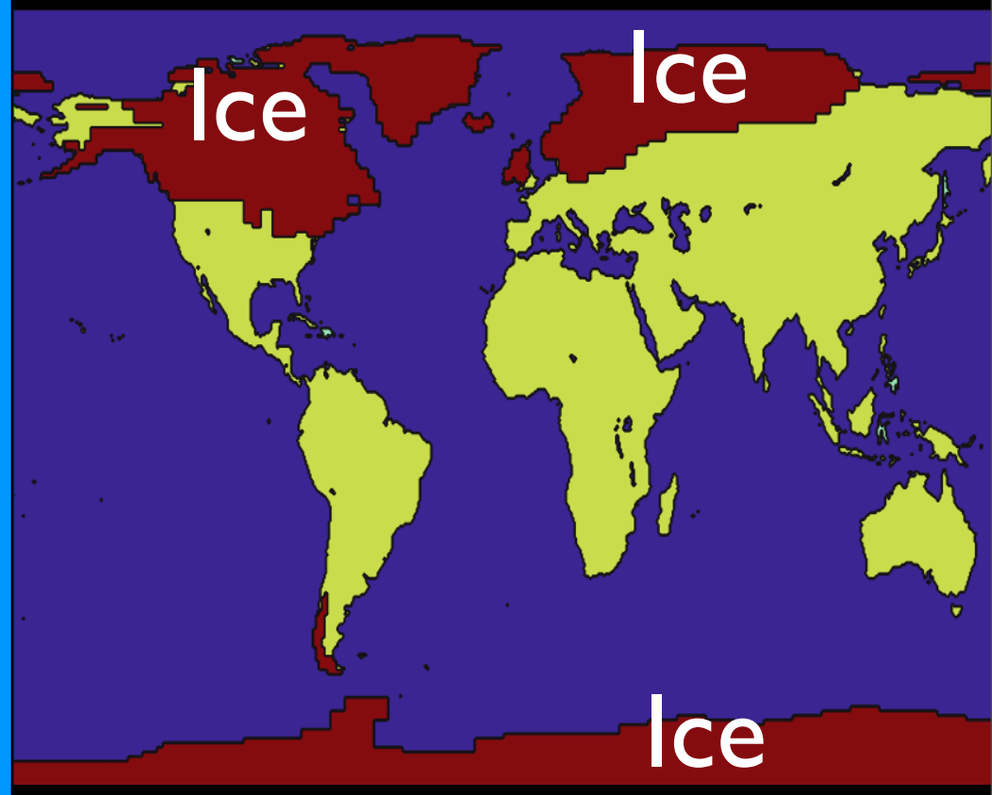
Hadley Cell always transports energy from the warmer to the cooler hemisphere.

⇩

ITCZ is located in the warmer hemisphere.

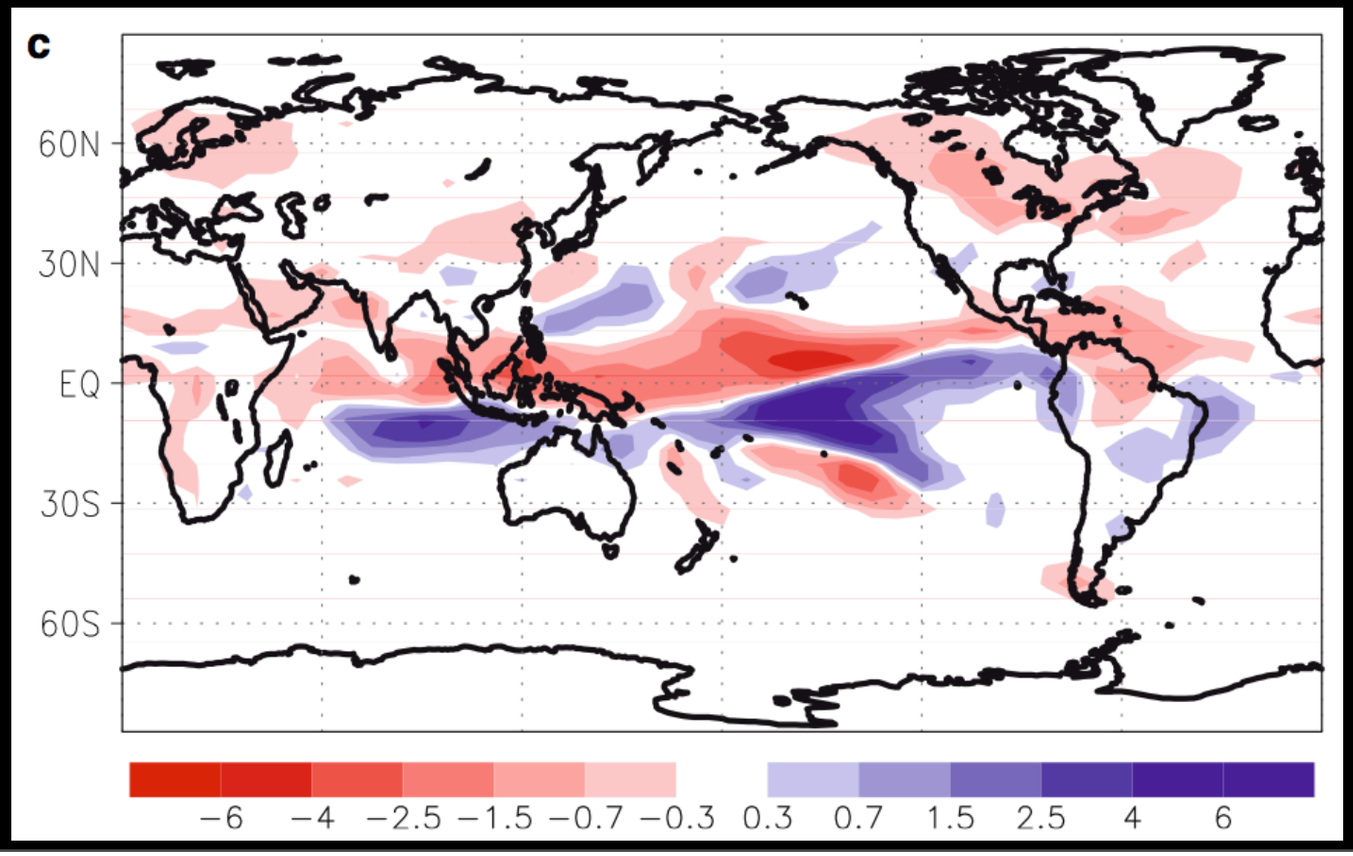
ITCZ Shifts Toward the Warmth



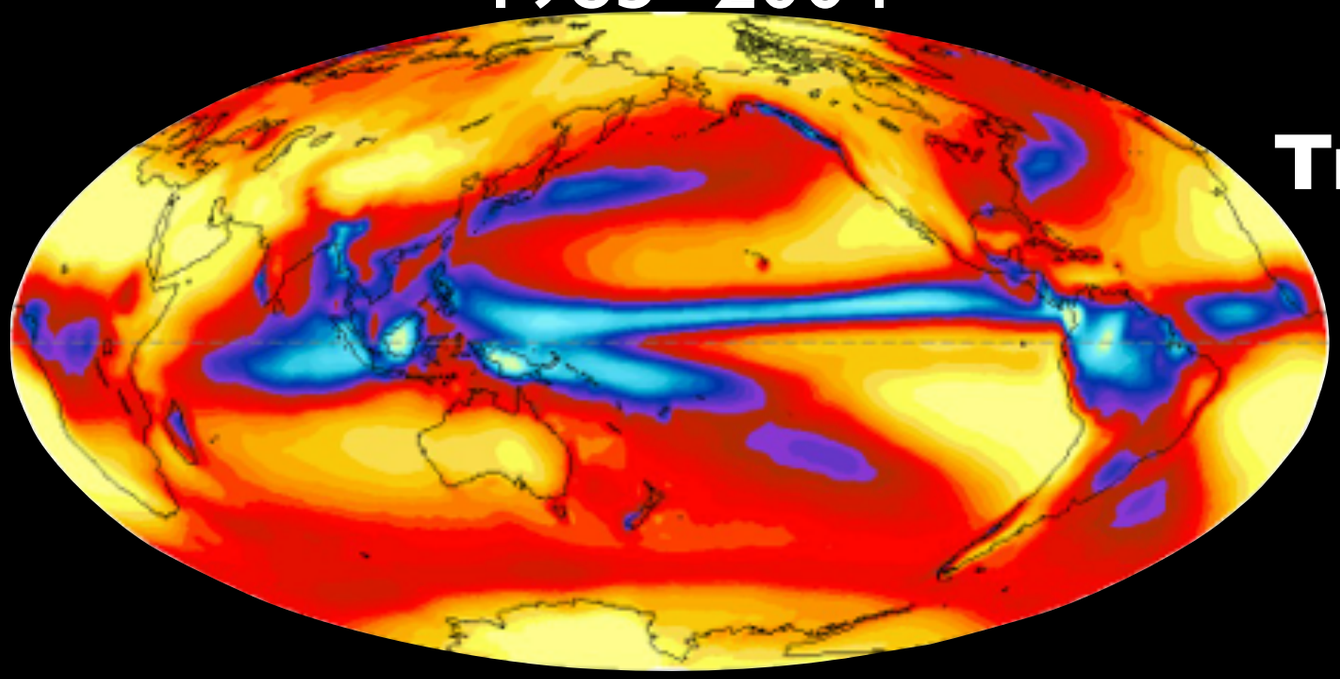


The tropics even responds to heating far away...
Chiang and Bitz 2005

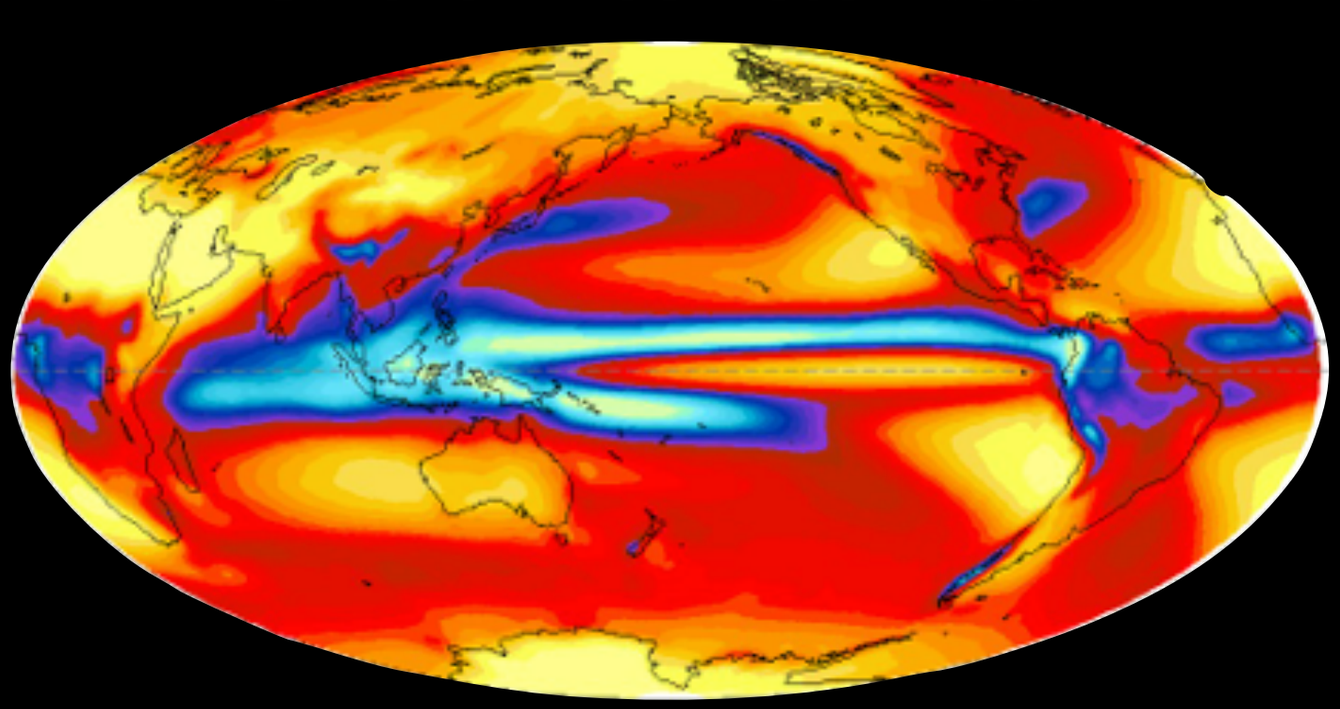
See also Kang et al. 2008, 2009
Broccoli et al. 2006, Zang and Delworth 2005,
Frierson and Hwang 2012,
Hwang et al. 2013

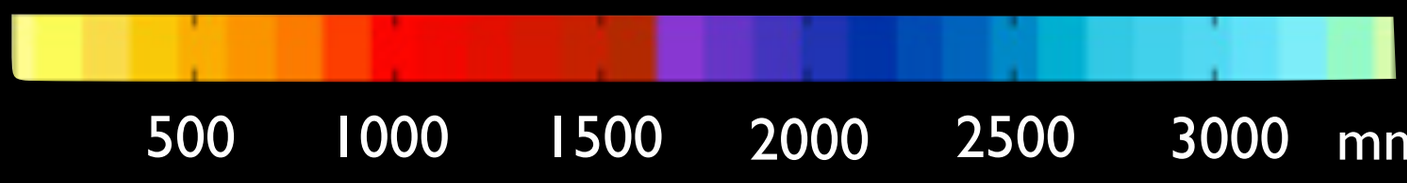


GPCP Annual Mean Precipitation
1985~2004



CMIP5 Ensemble Mean





Tropical Precipitation Biases :

(1) Excessive Precipitation in the most of the tropics
(Note observation is uncertain)

(2) Precipitation minimize too much at the EQ

(3) Excessive Precipitation is more severe in the SH tropics than the NH tropics (the skewness)

(4) SPCZ being too horizontal (not tilted)

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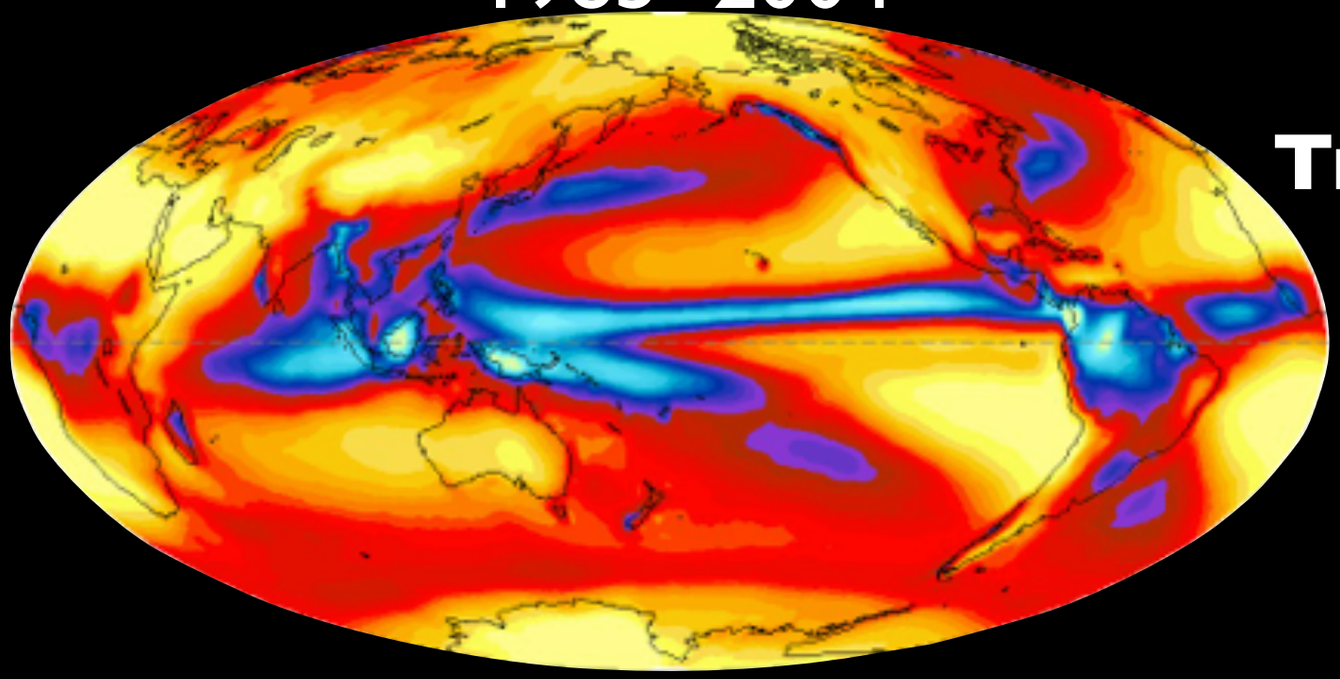

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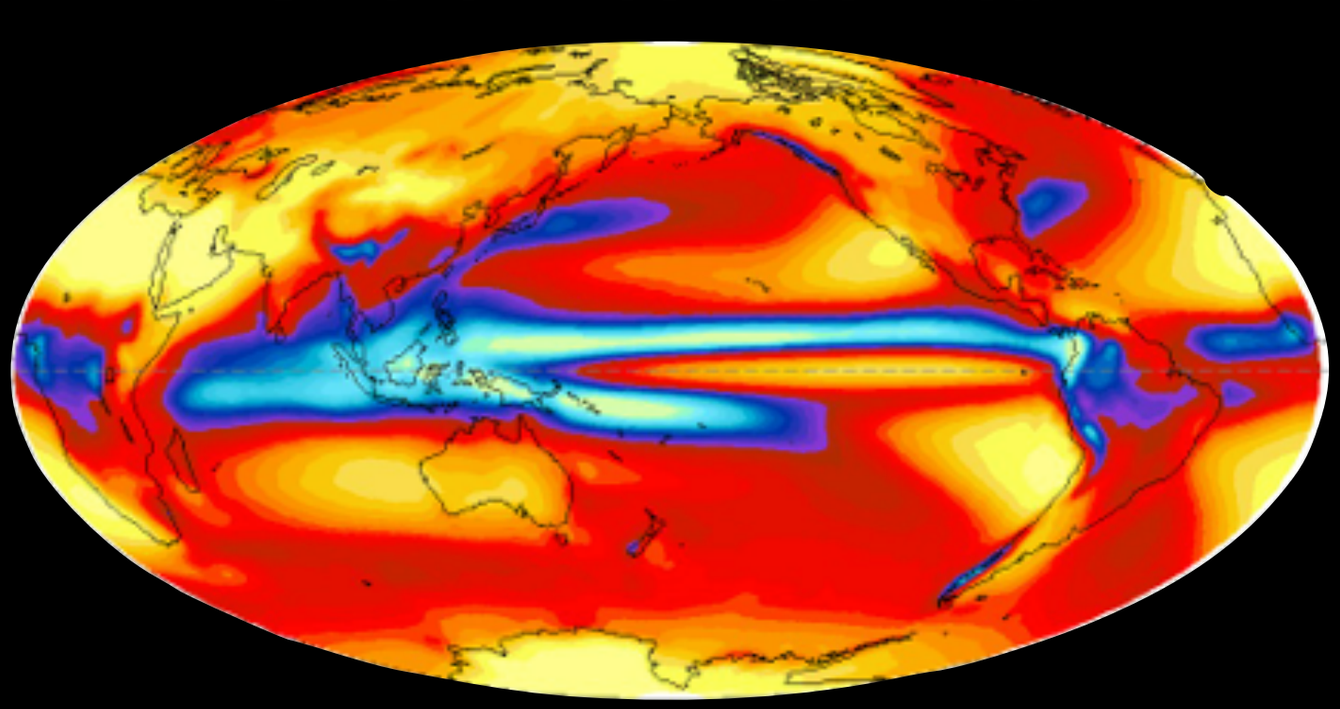

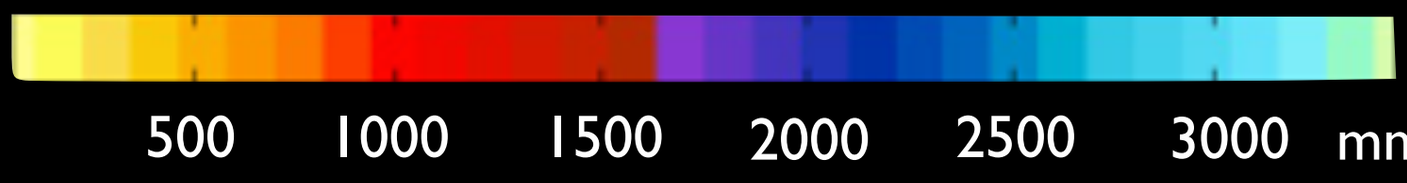

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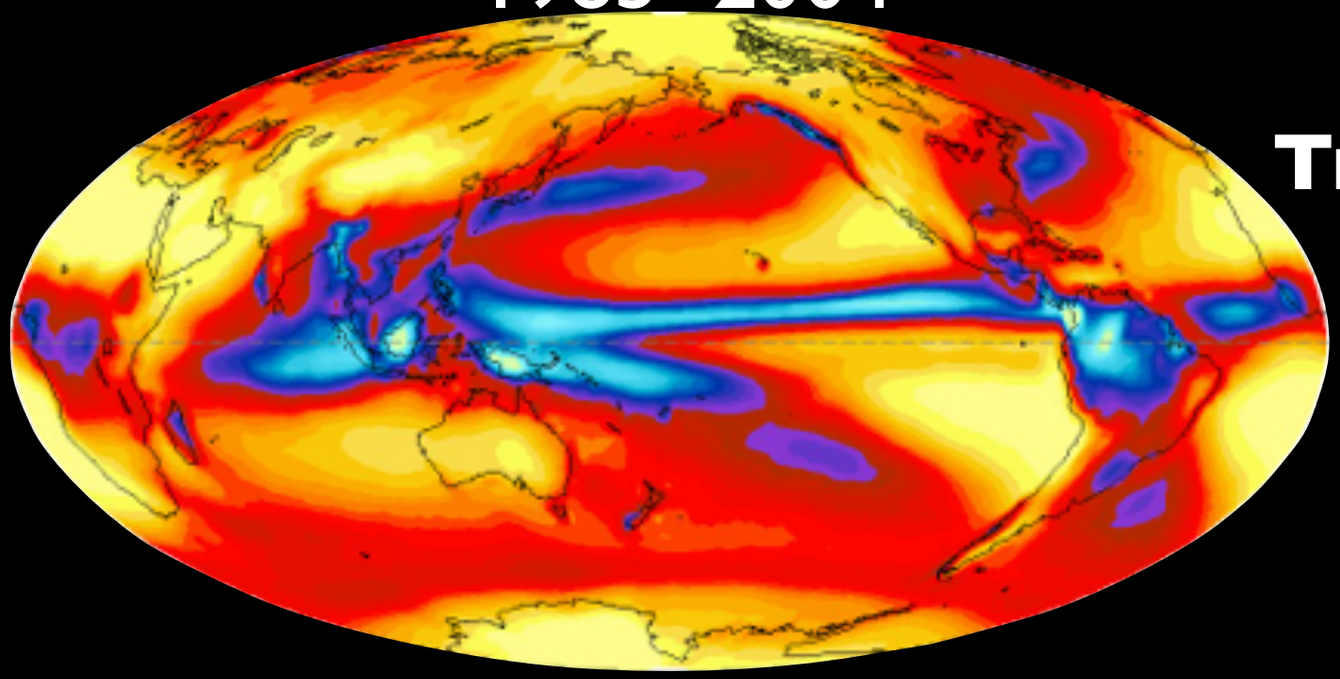

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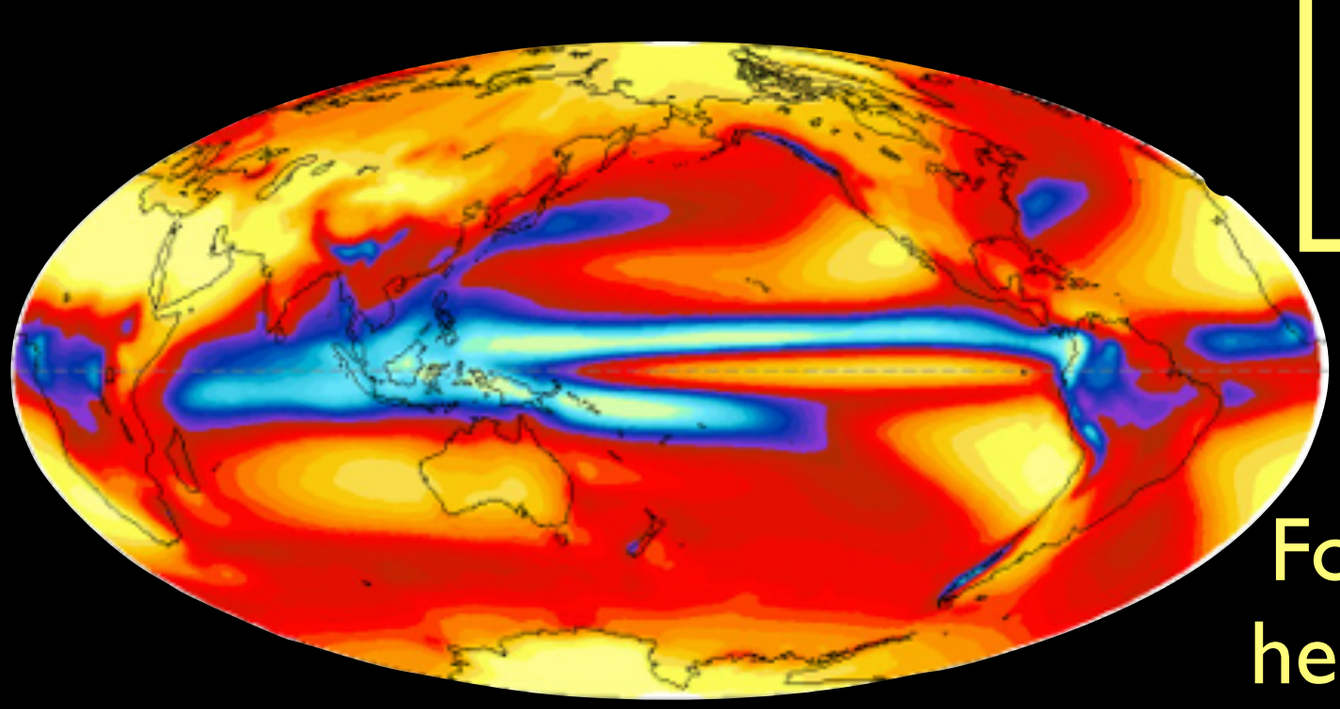

500 1000 1500 2000 2500 3000 mm/year

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Focus: GCMs do not simulate the hemispheric asymmetry in tropical circulation in observations

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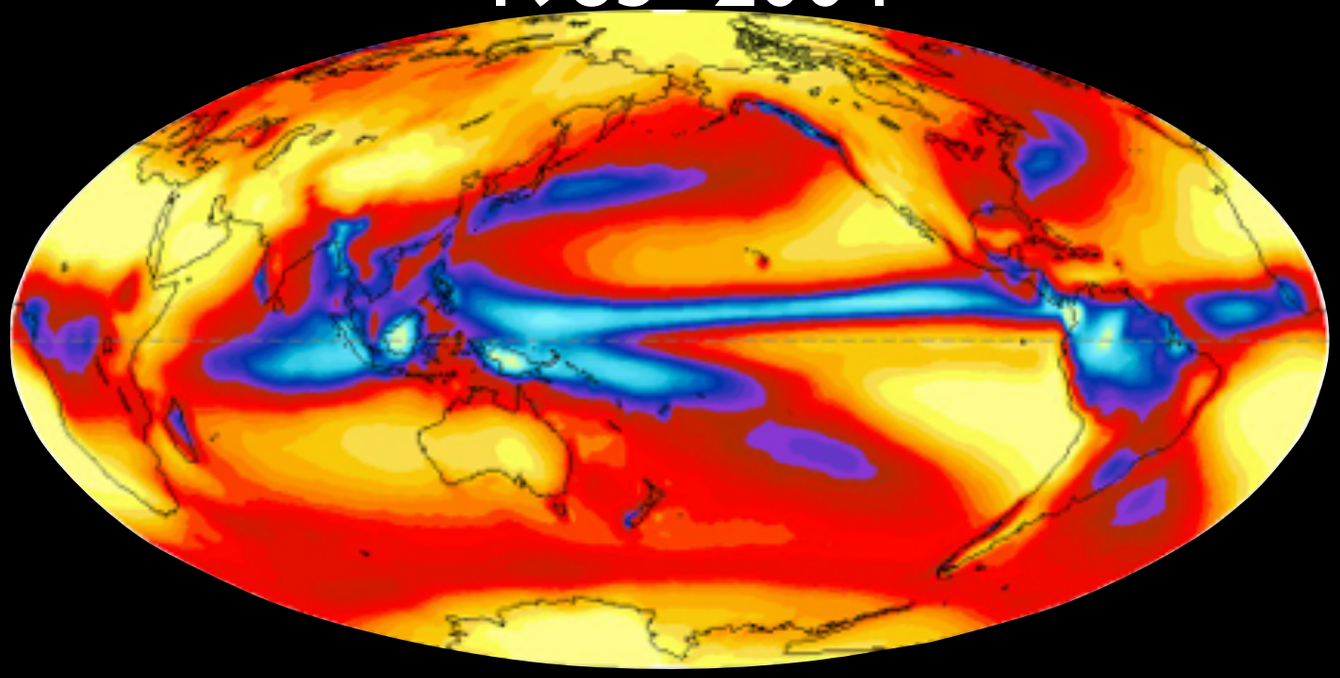

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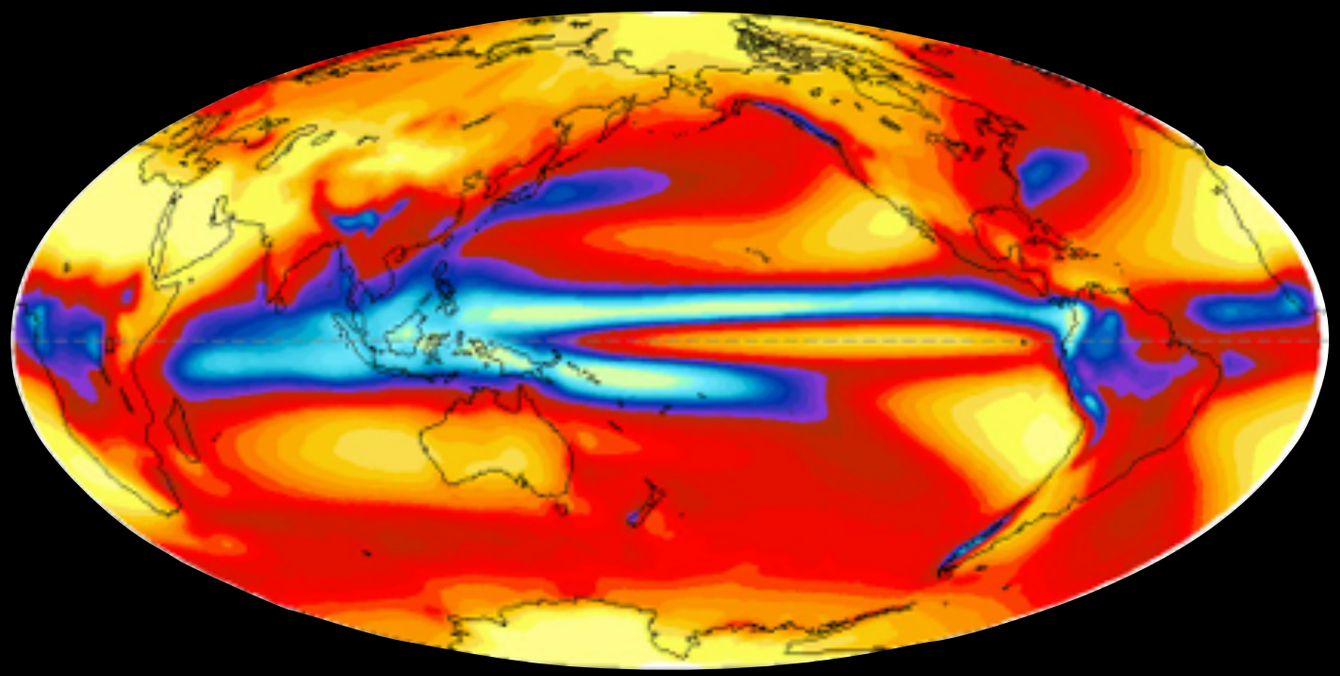

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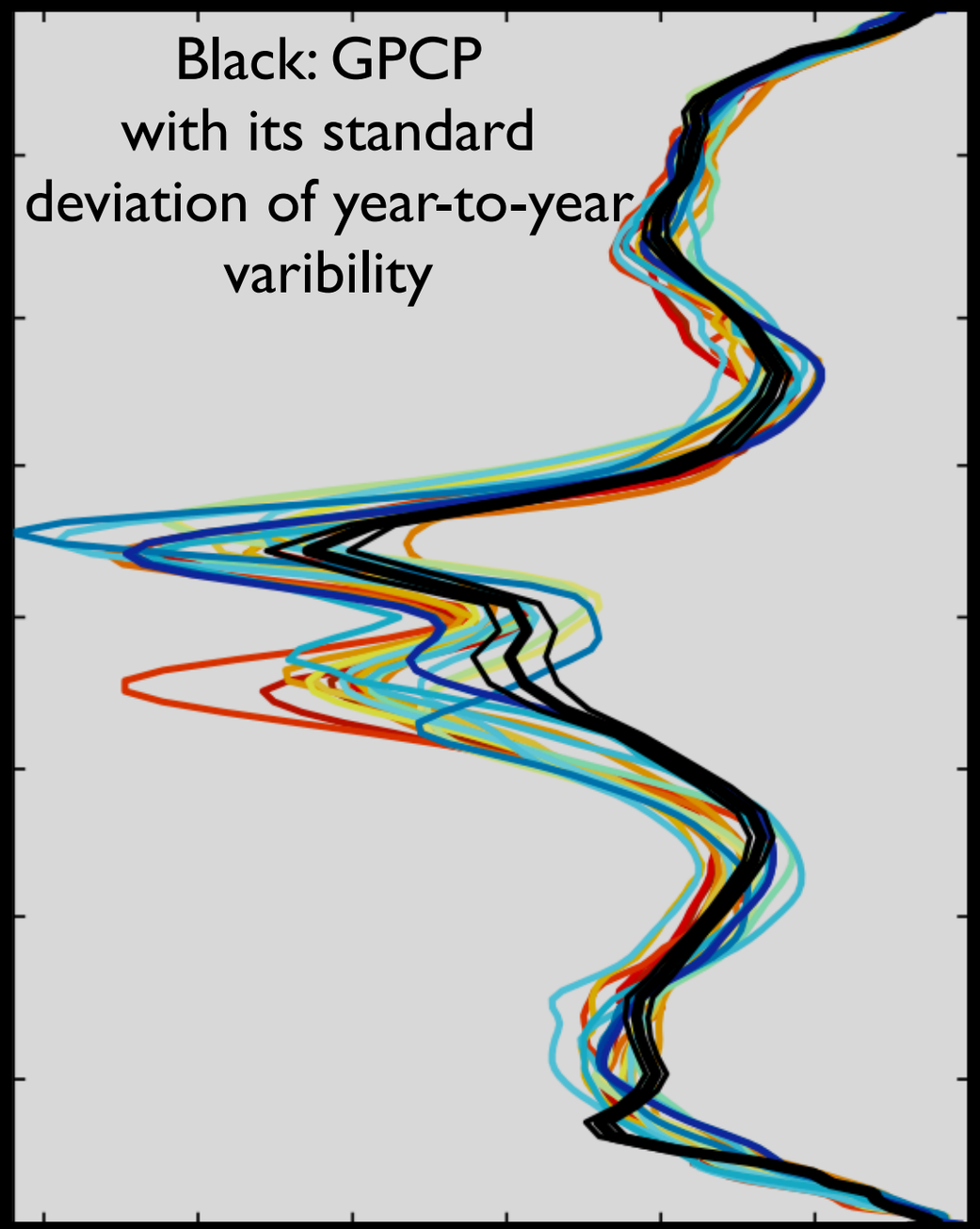
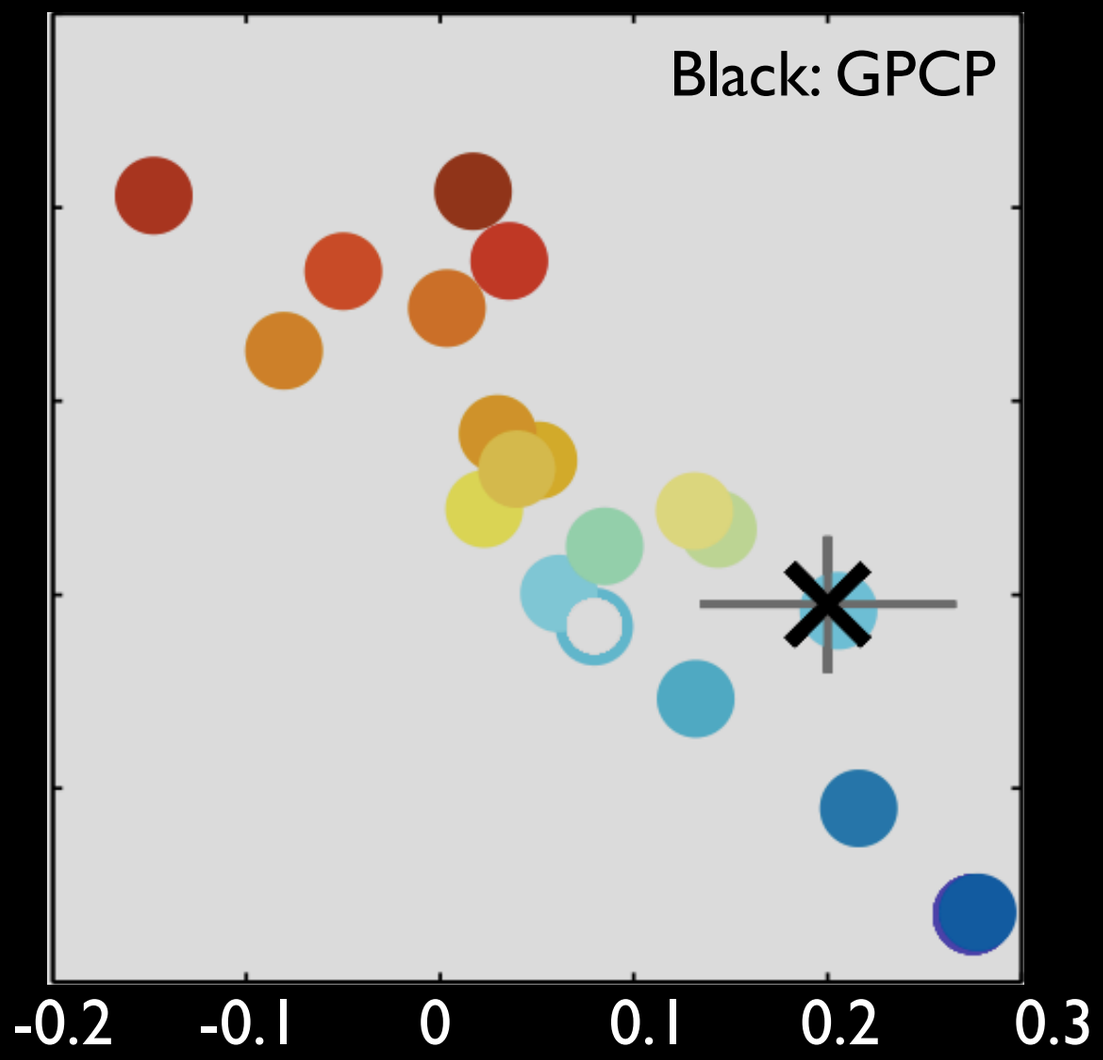
Zonal Mean
(each line is one GCM)





Precipitation Asymmetry Index
(EQ~20N - EQ~20S) / 20S~20N

Most GCMs simulate too little skewness in tropical precipitation, some even have more precipitation in SH tropics!

Zonal Mean
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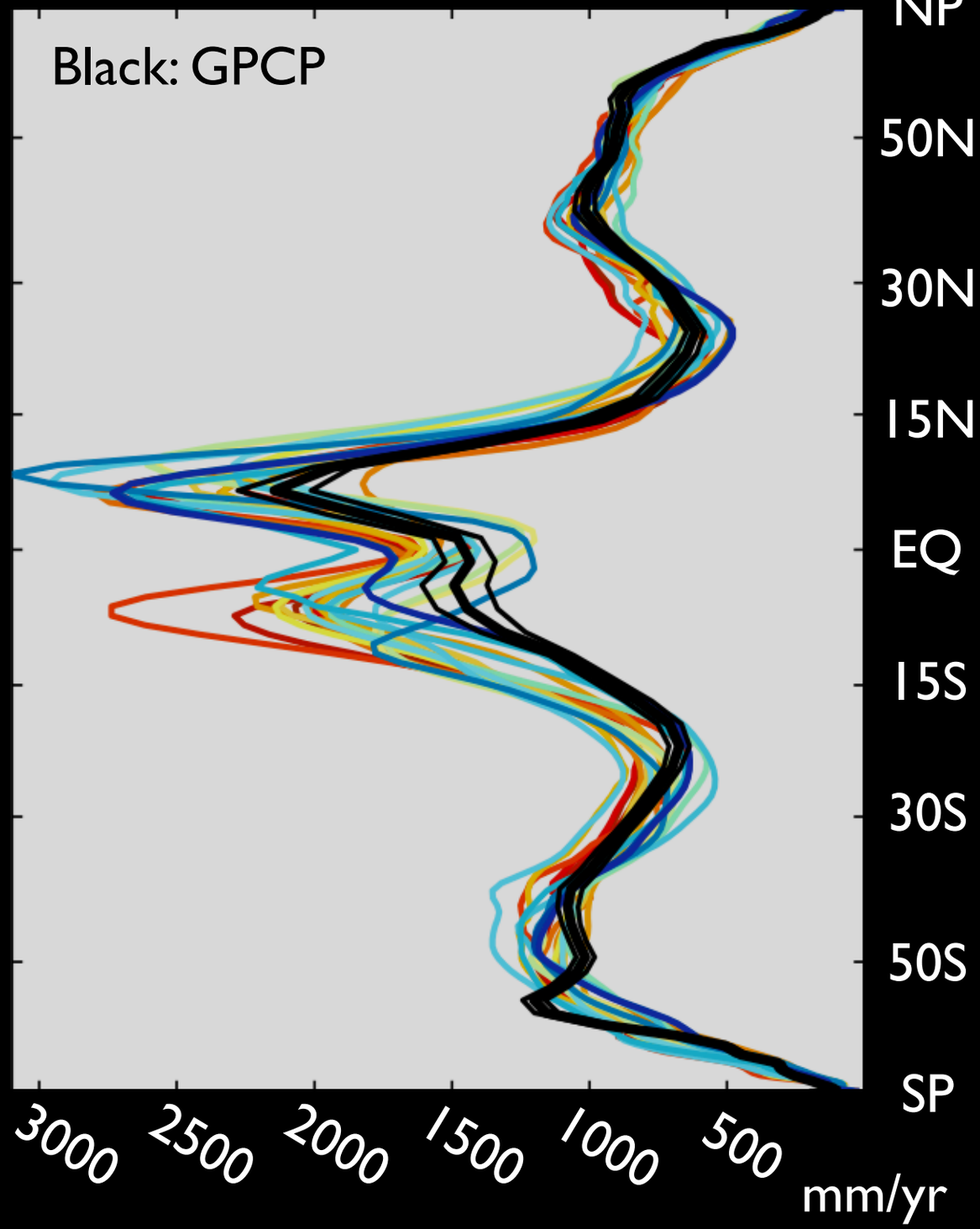

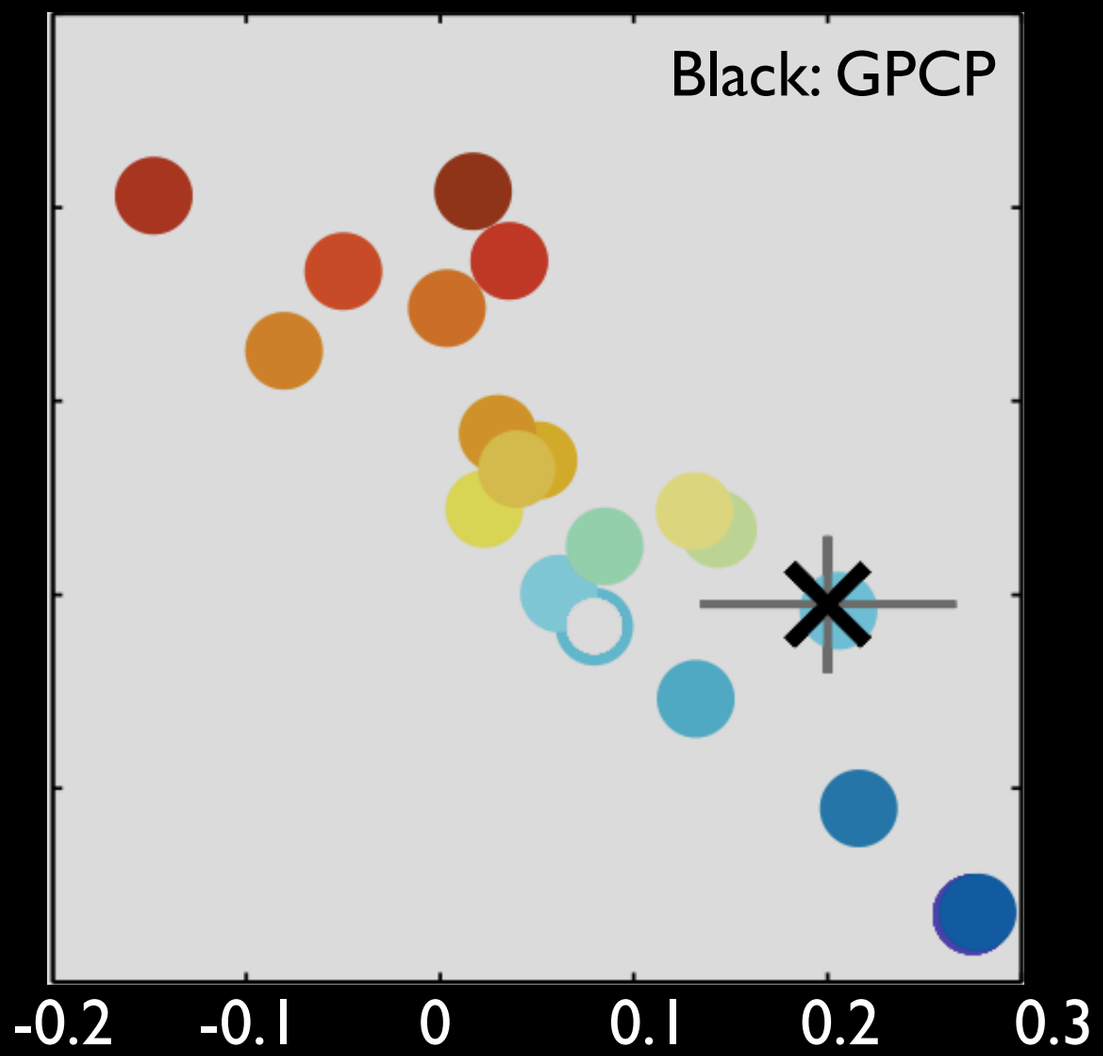

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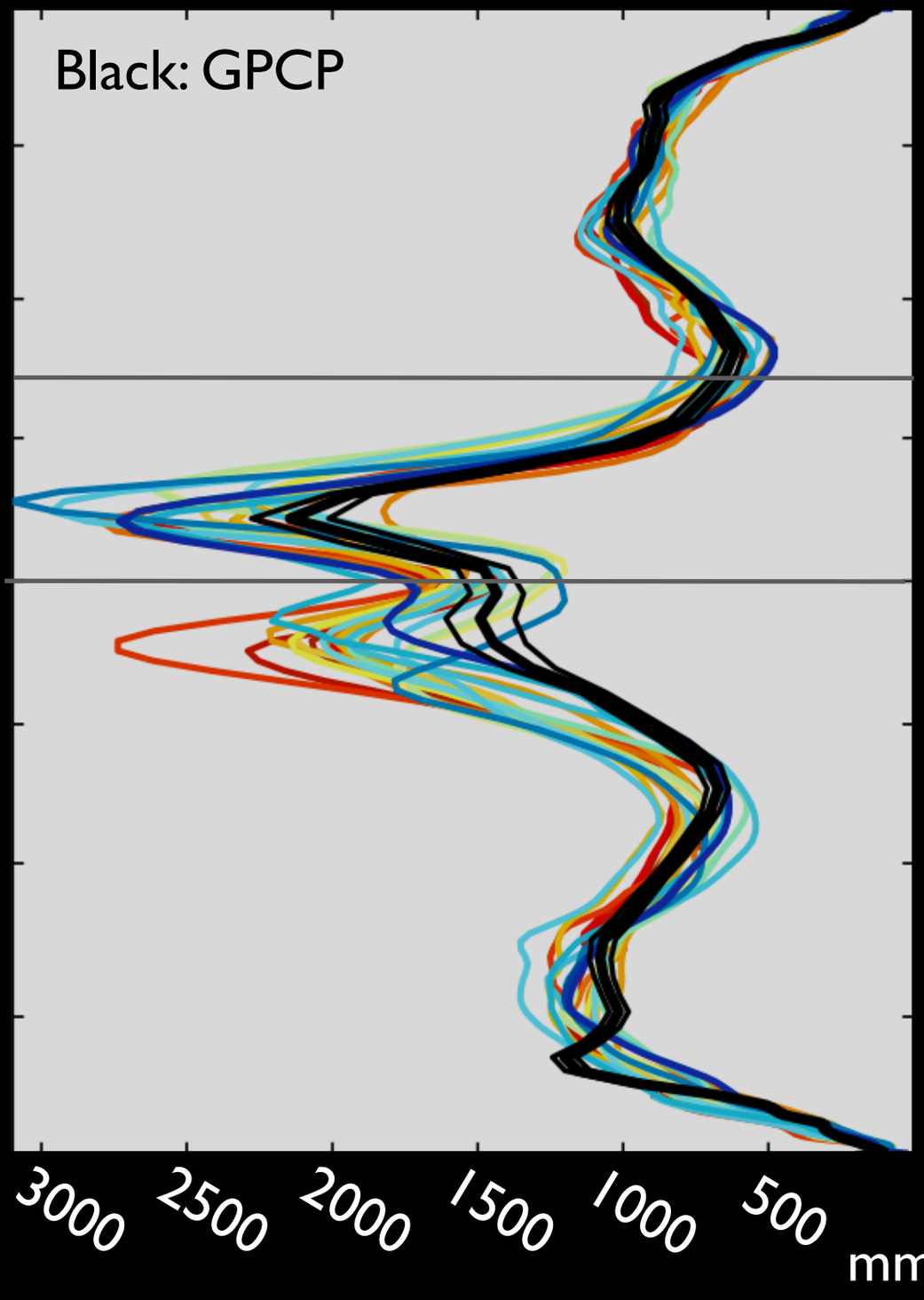

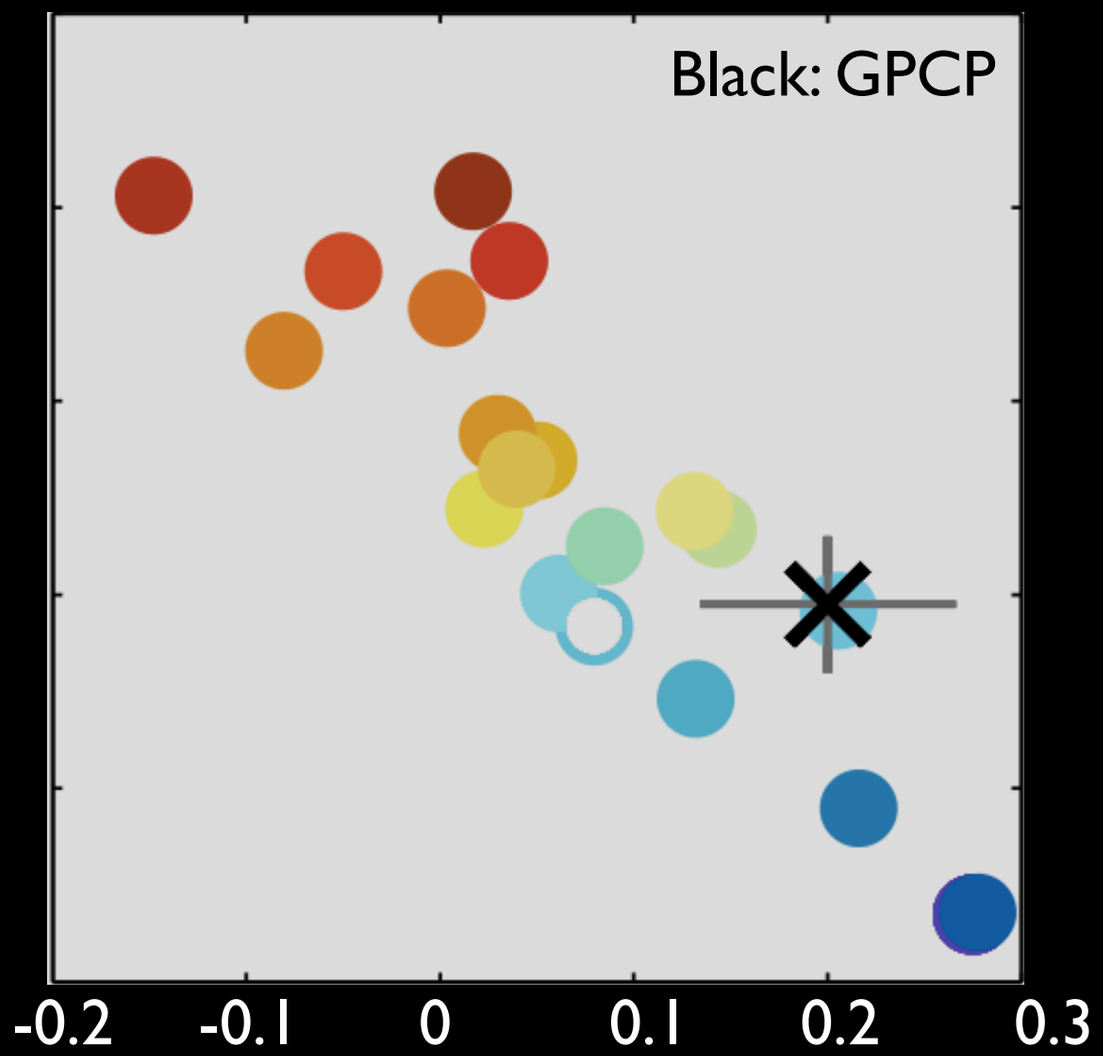

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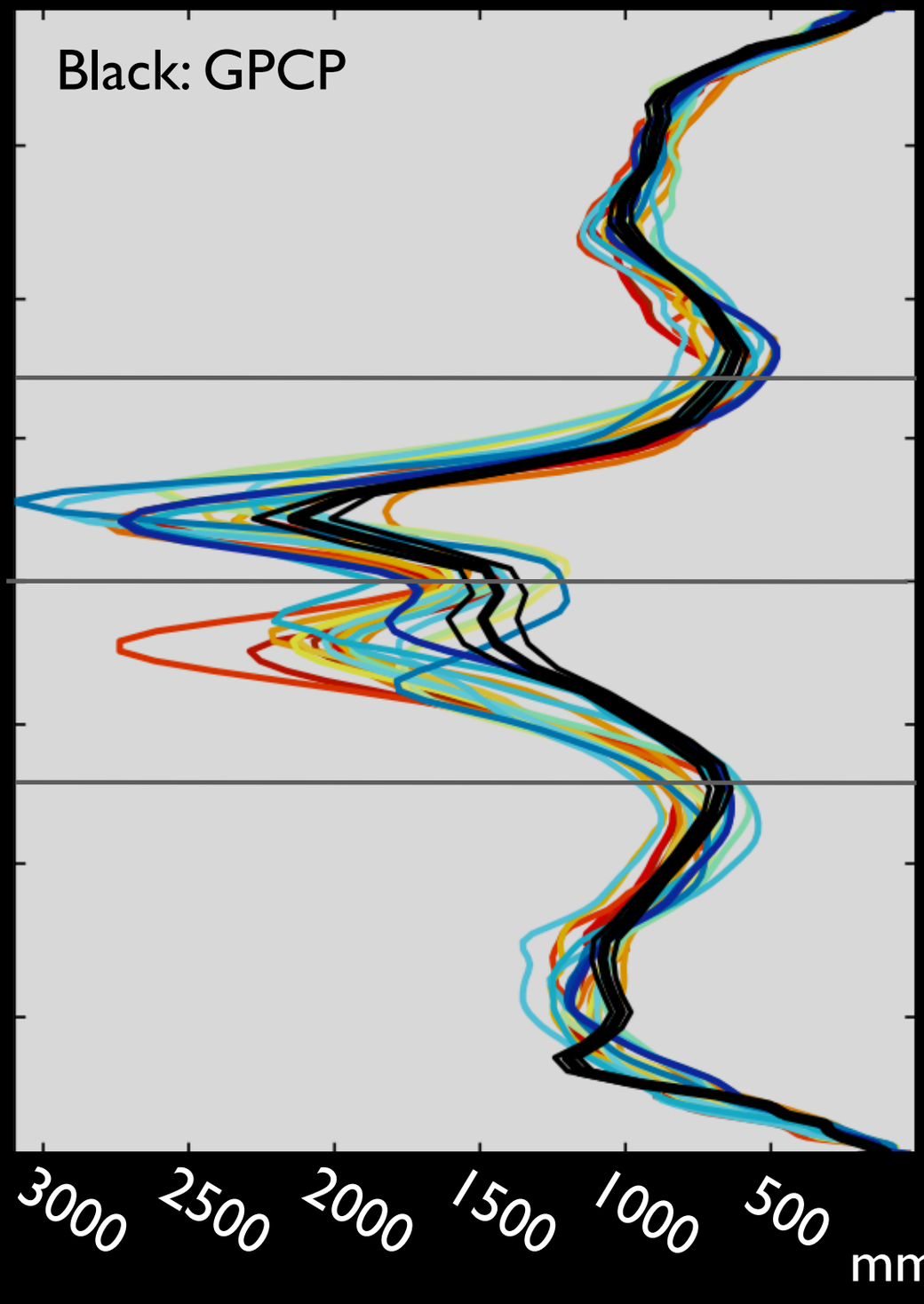

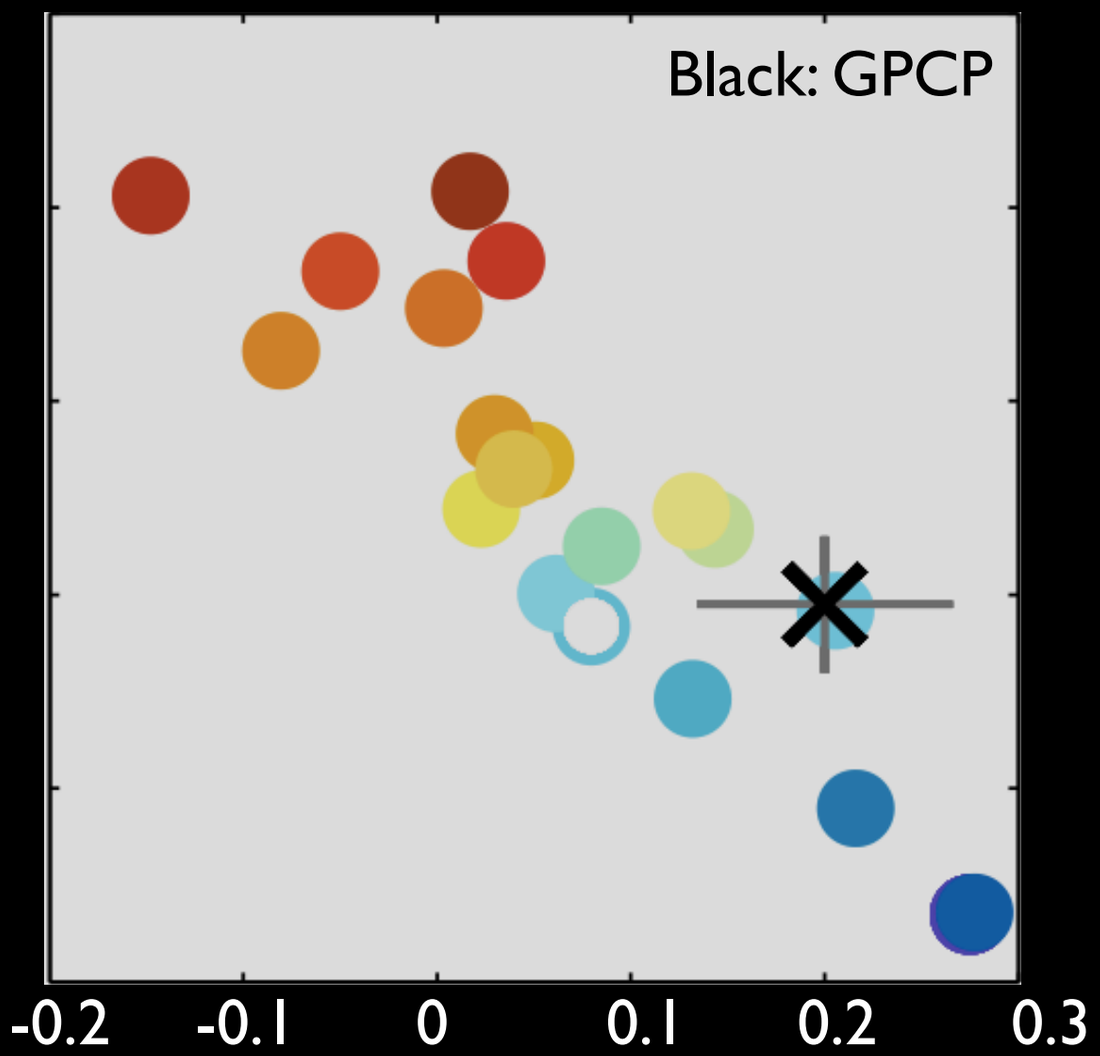

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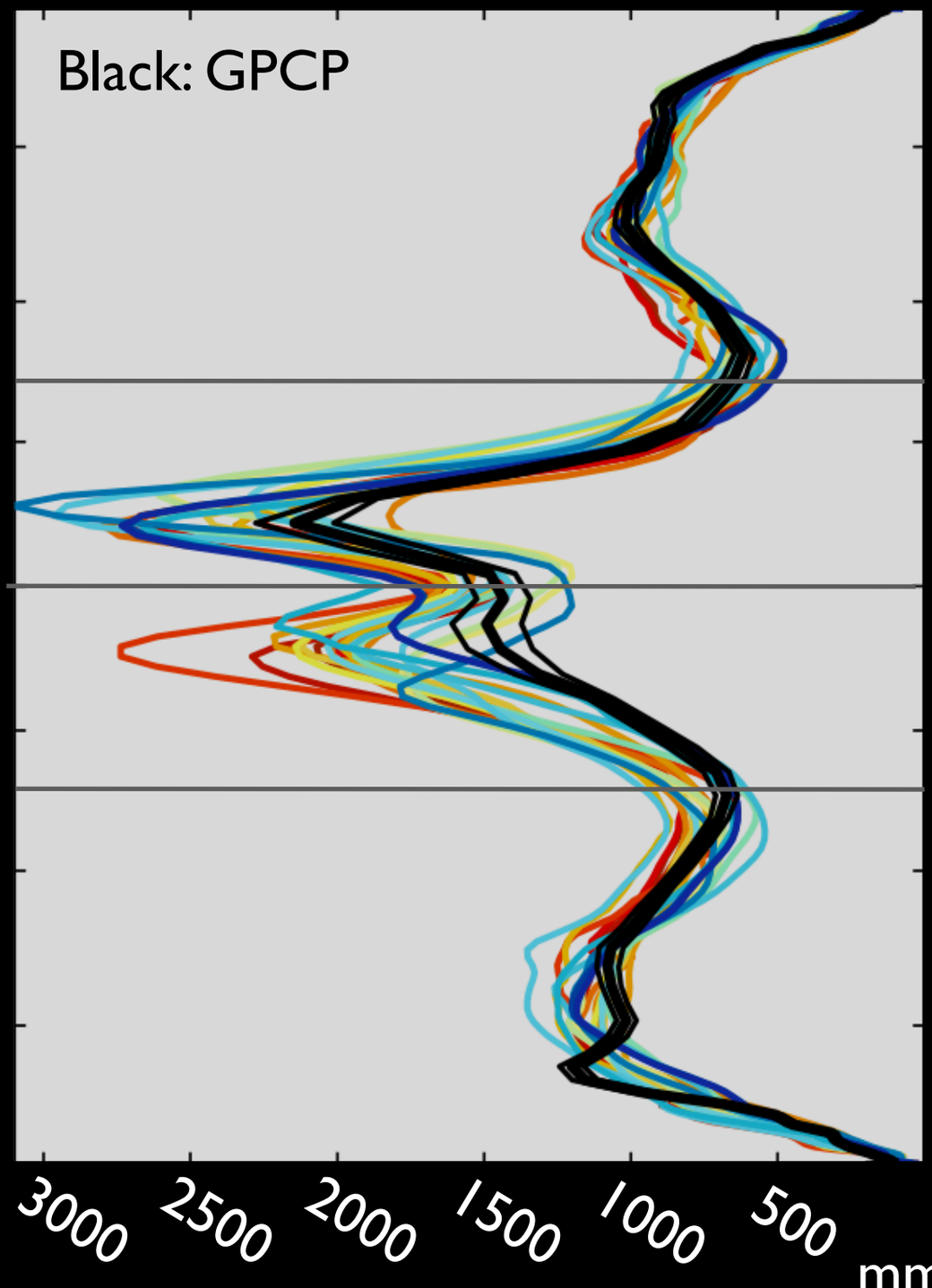


The Precipitation Asymmetry Index is highly correlated (R=0.92) with GCMs' Hadley Cell Center, defined as the latitude where streamufnction changes sign at 500mb, ranging from 3S to 9N

Cross-EQ Atmospheric Energy Transport (PW)

0.4
0.2
0
-0.2
-0.4

Black: GPCP &
ERA-I reanalysis
Gray lines: standard
deviation of inter-
annual variability

-0.2 -0.1 0 0.1 0.2 0.3

Precipitation Asymmetry Index
(EQ~20N - EQ~20S) / 20S~20N

Zonal Mean
(each line is one GCM)

Black: GPCP

NP
50N
30N
15N
EQ
15S
30S
50S
SP

3000 2500 2000 1500 1000 500
mm/yr

Too much Northward
Energy Transport across the EQ

Atmospheric Energy Transport (PW)

Cross-EQ A

0.4
0.2
0
-0.2
-0.4

Black: GPCP &
ERA-I reanalysis
Gray lines: standard
deviation of inter-
annual variability

R=-0.88

-0.2 -0.1 0 0.1 0.2 0.3

Precipitation Asymmetry Index
(EQ~20N - EQ~20S) / 20S~20N

Too much precipitation in SH tropics
(compare with NH)

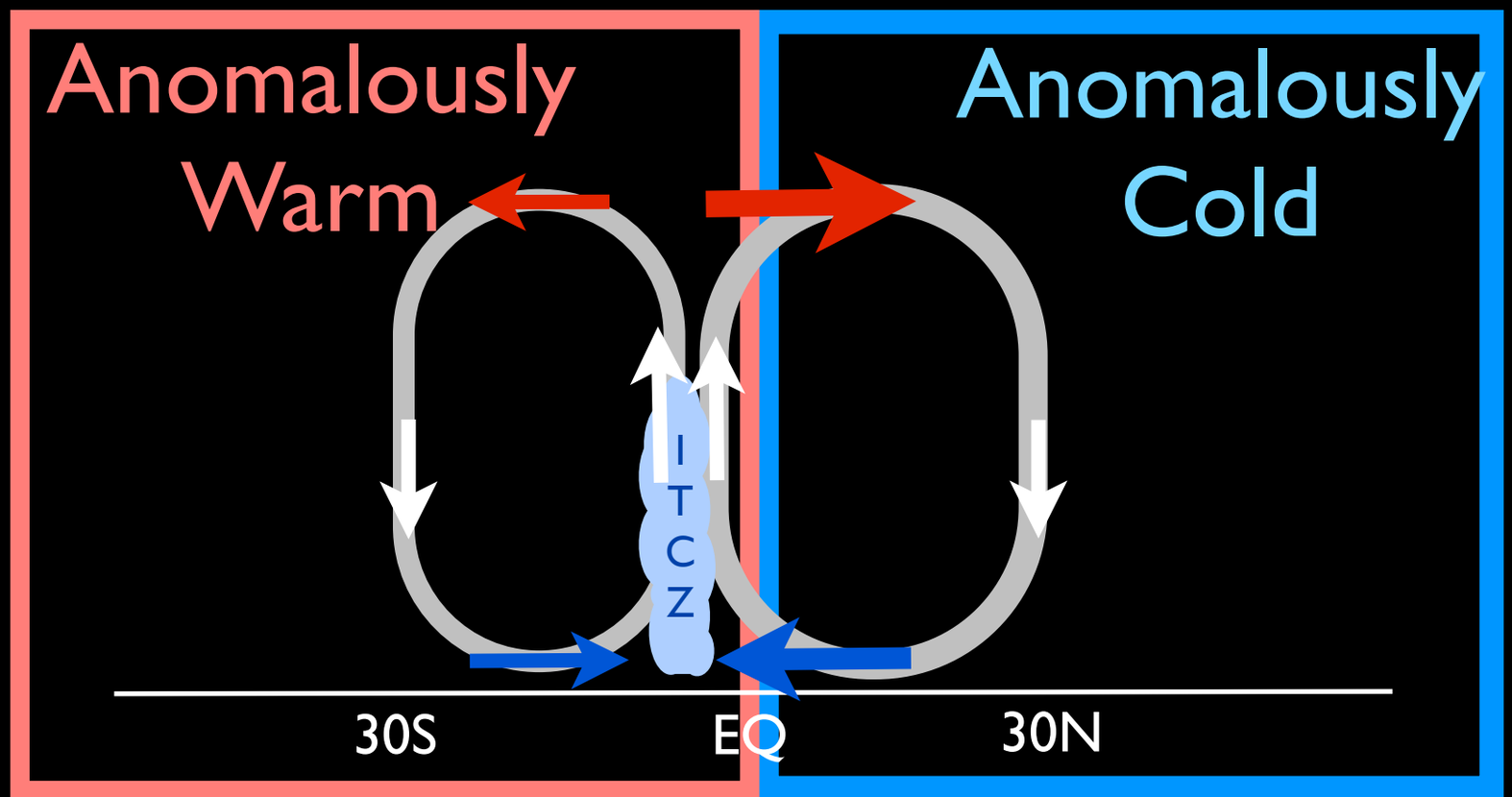
Zonal Mean
(each line is one GCM)

Black: GPCP

NP
50N
30N
15N
EQ
15S
30S
50S
SP

3000 2500 2000 1500 1000 500 mm/yr

What are the Causes for Too much Northward Energy Transport Across the Equator?



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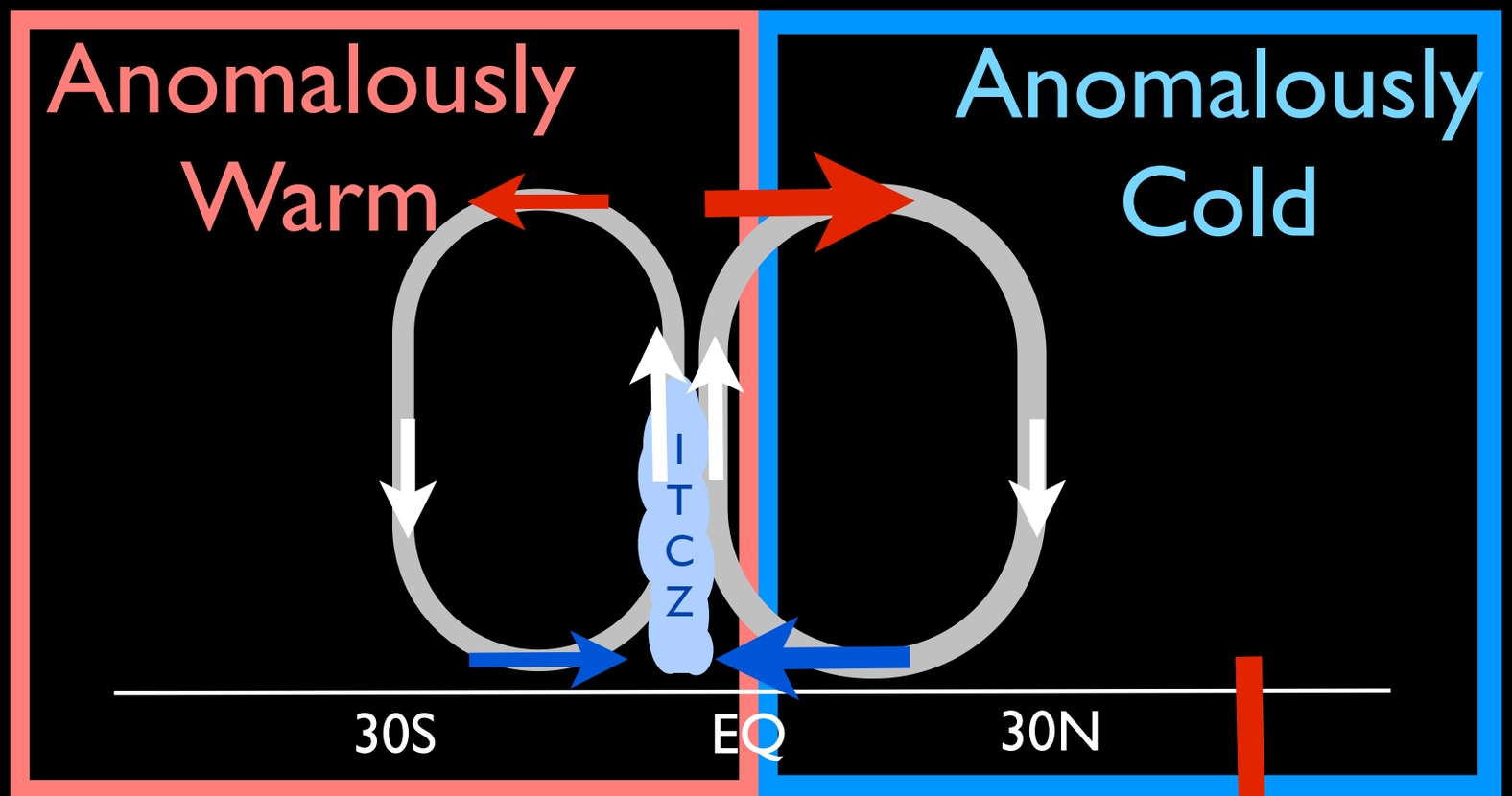
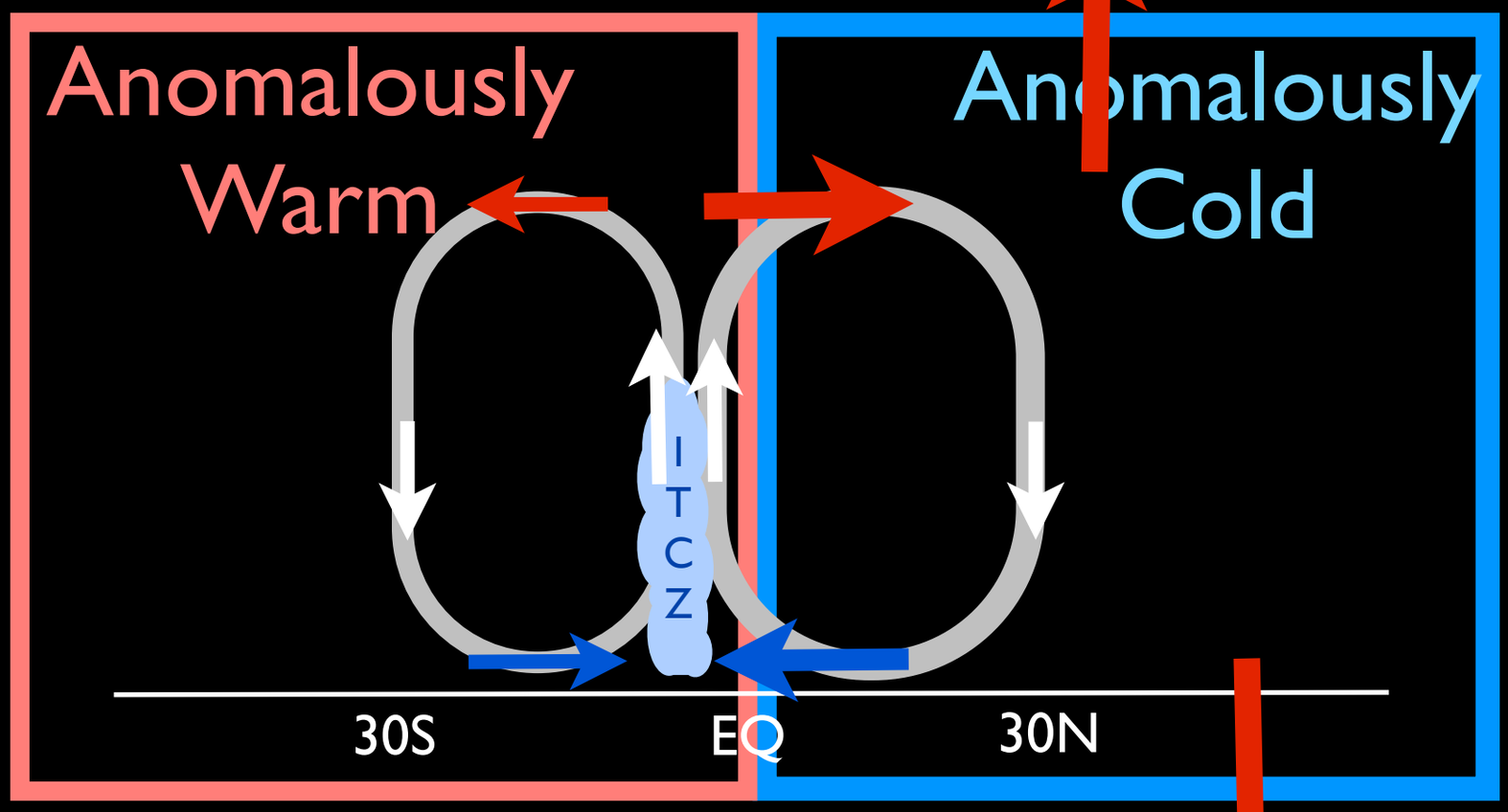


What are the Causes for Too much Northward Energy Transport Across the Equator?

radiate/reflect too much energy to space?

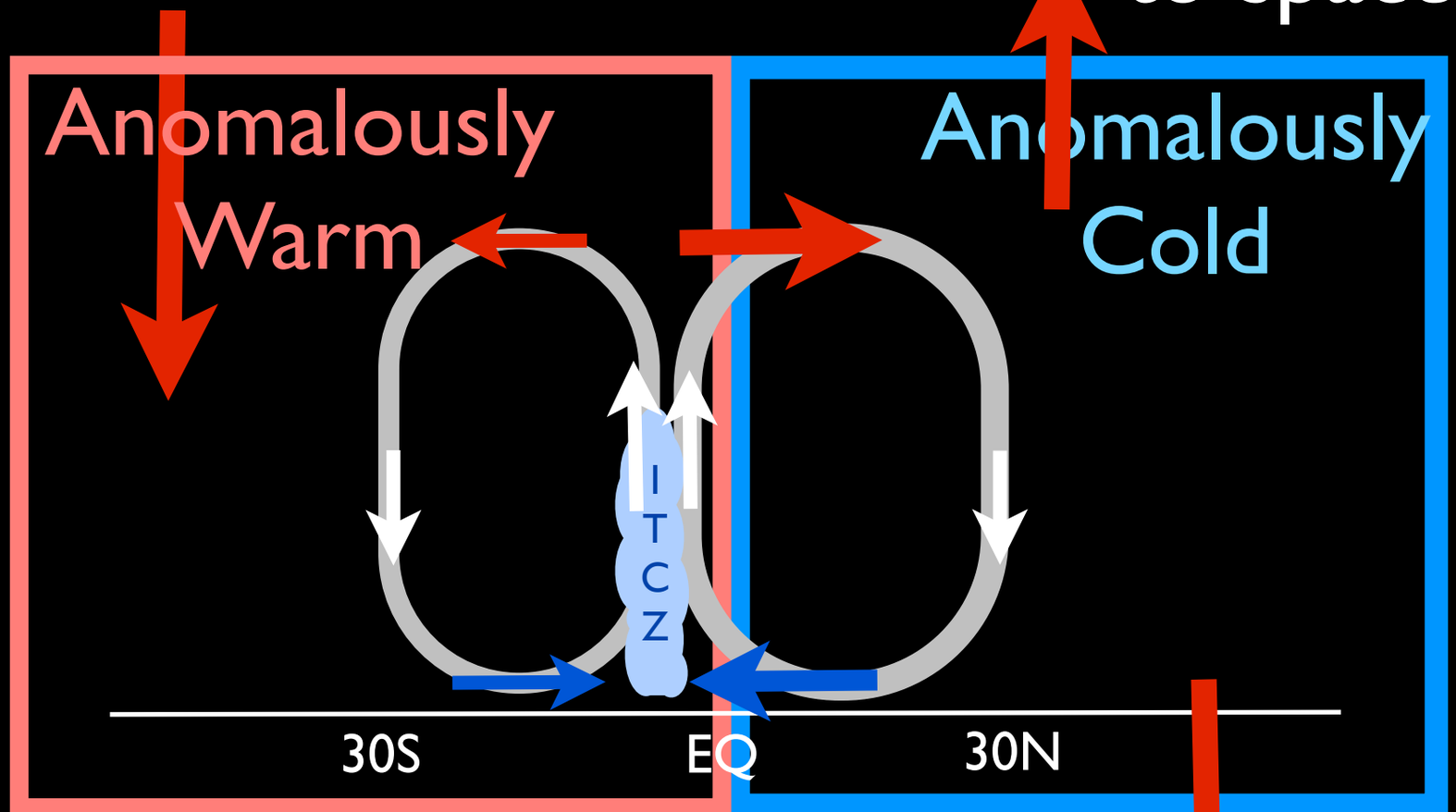


MOC too weak?

What are the Causes for Too much Northward Energy Transport Across the Equator?

too much insolation in the SH? (biases in planetary albedo)

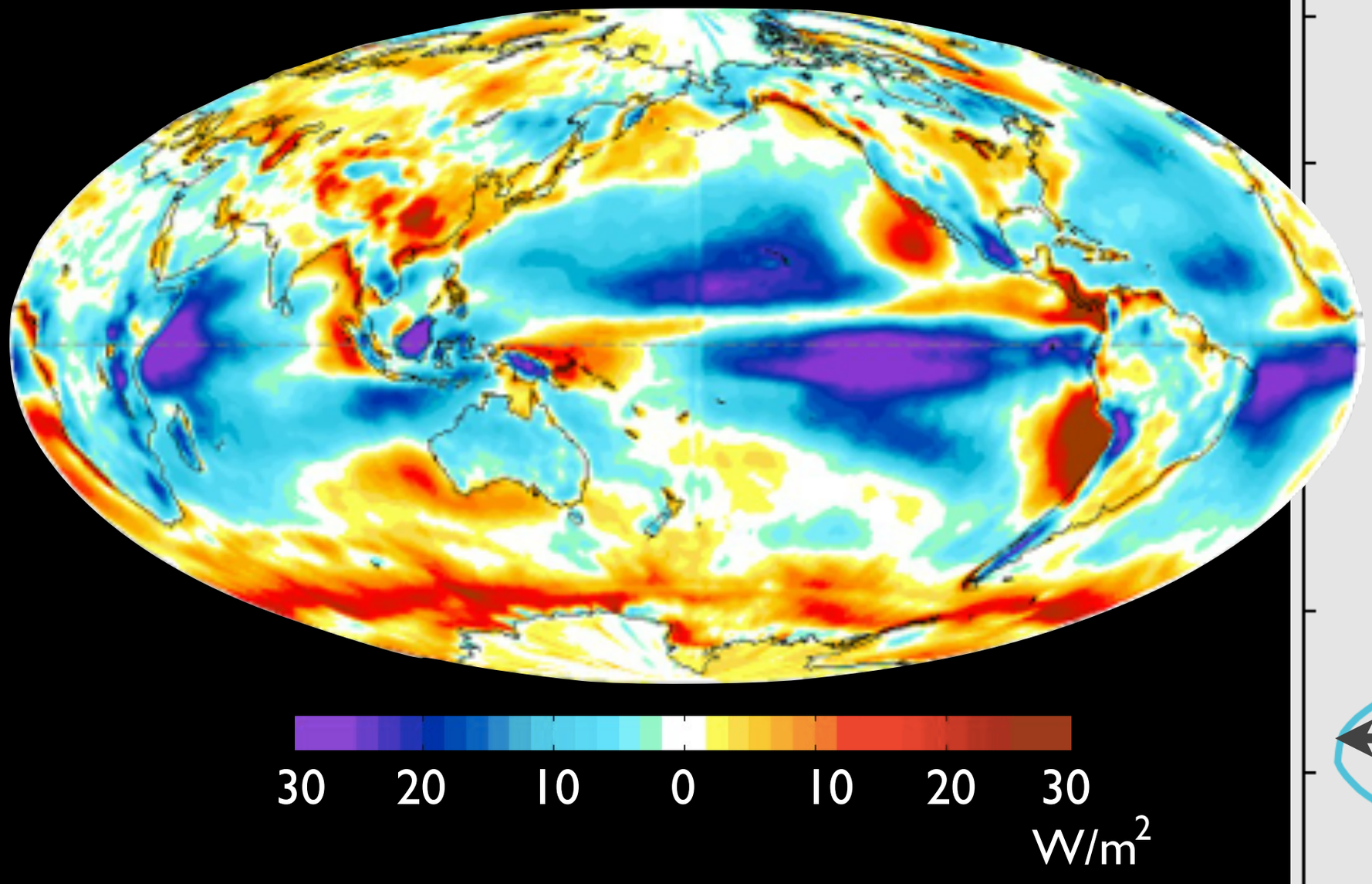
radiate/reflect too much energy to space?



MOC too weak?

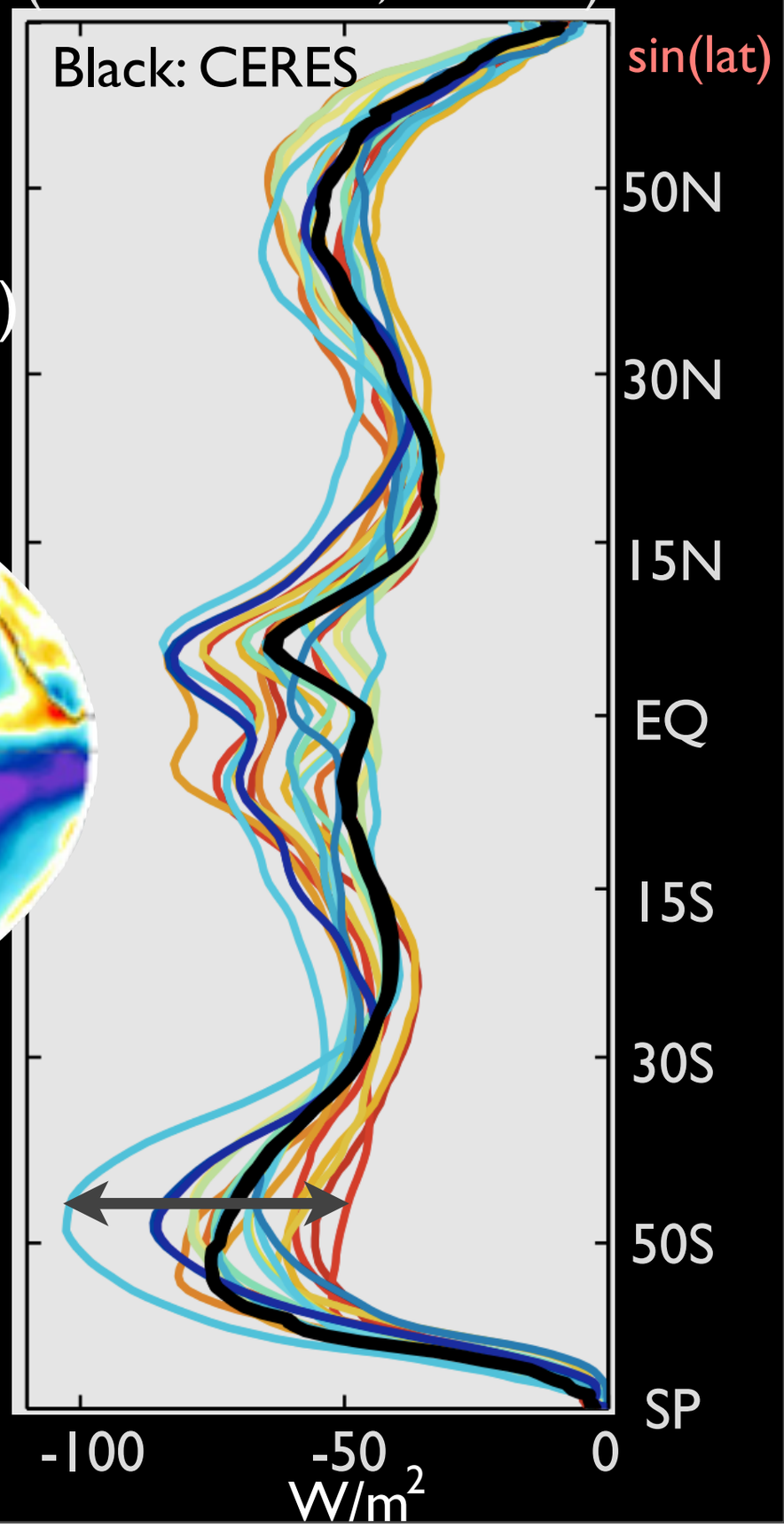
Biases in Shortwave Cloud Radiative Forcing (SW CRF)

CMIP5 Ensemble Model Mean Biases in SWCRF
(compare with CERES satellite observation 2000~2011)



See also Trenberth and Fasullo 2010 for CMIP3

Annual Mean Zonal Mean
SW CRF
(absolute value, not bais)



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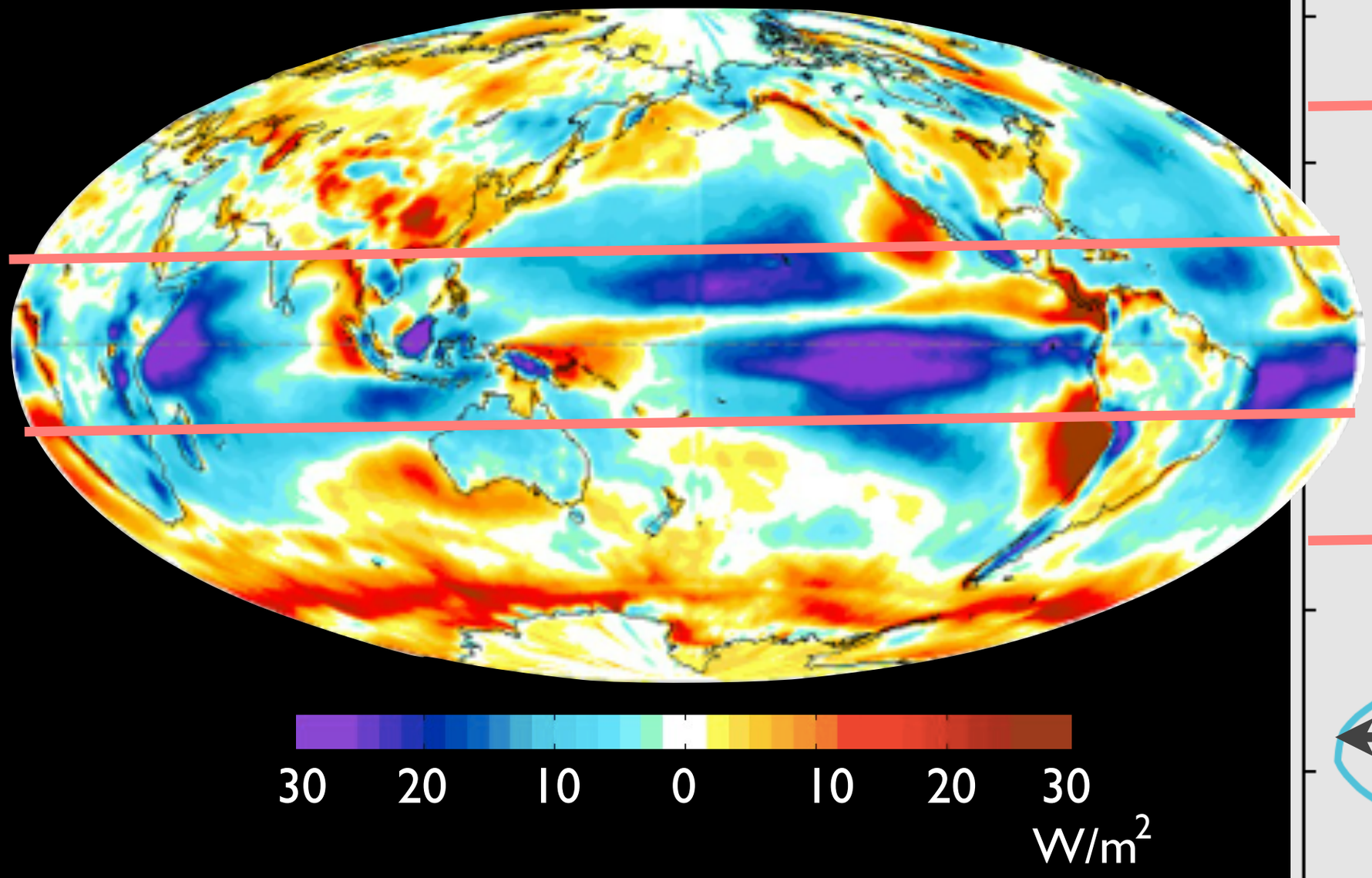

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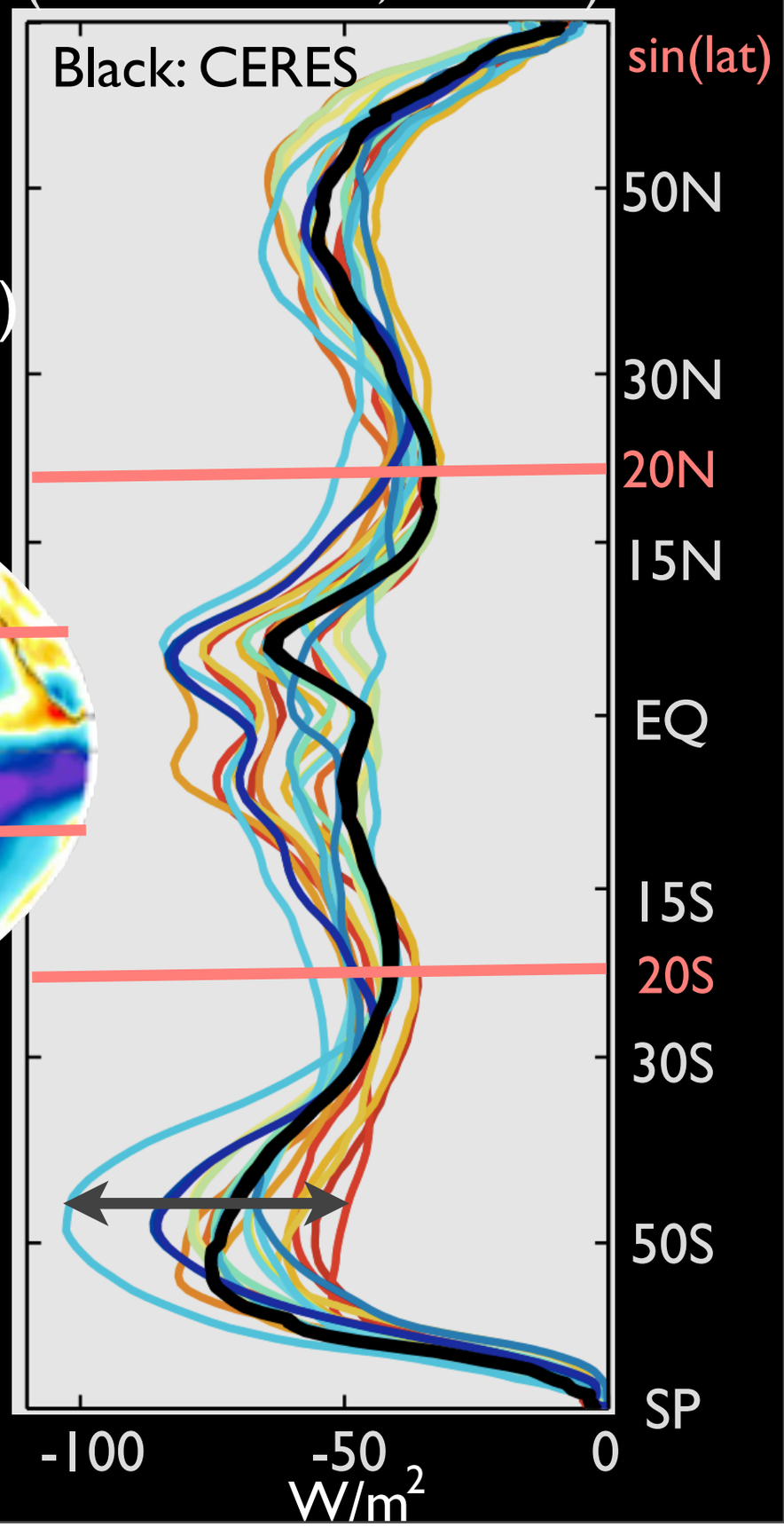

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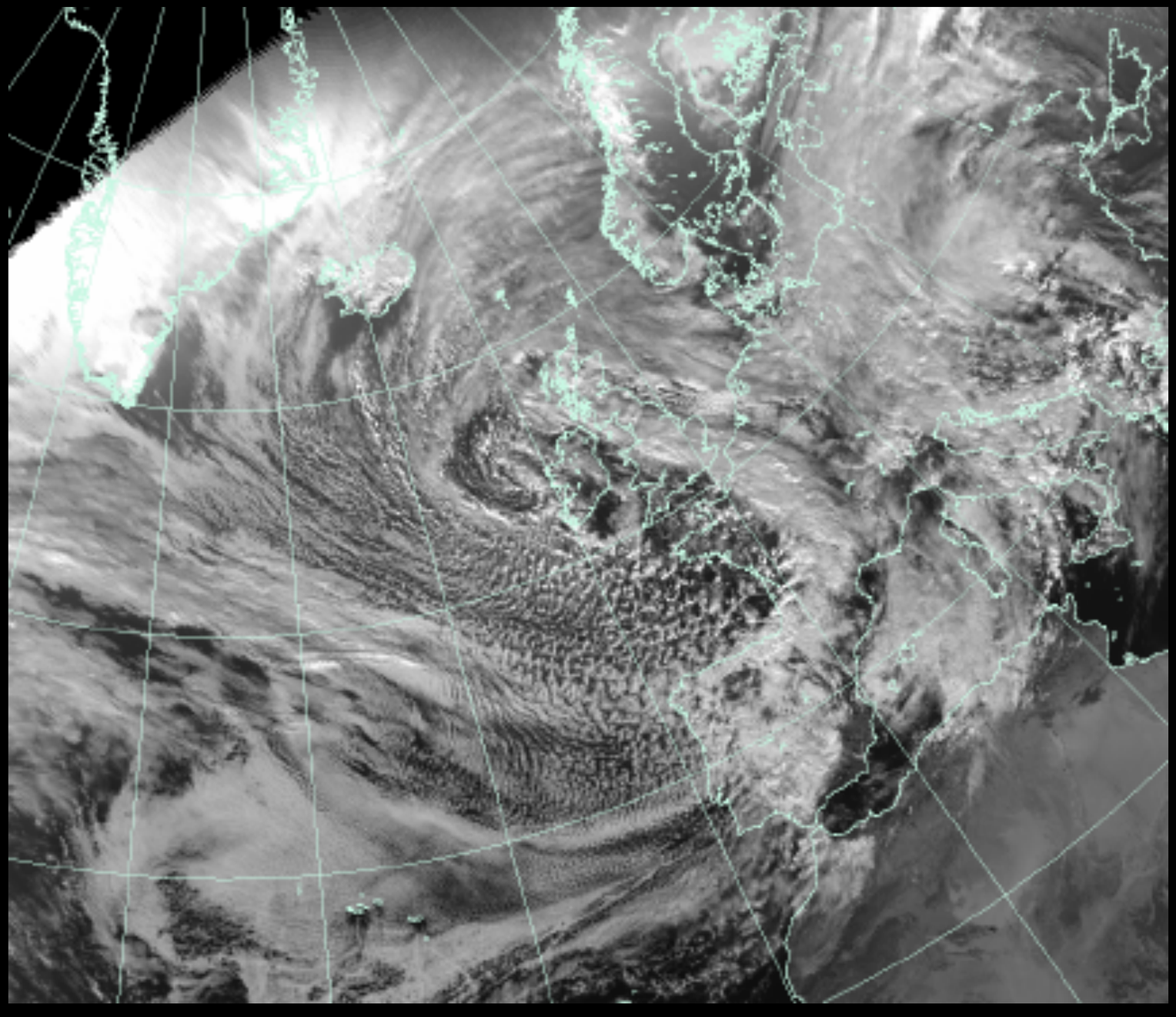
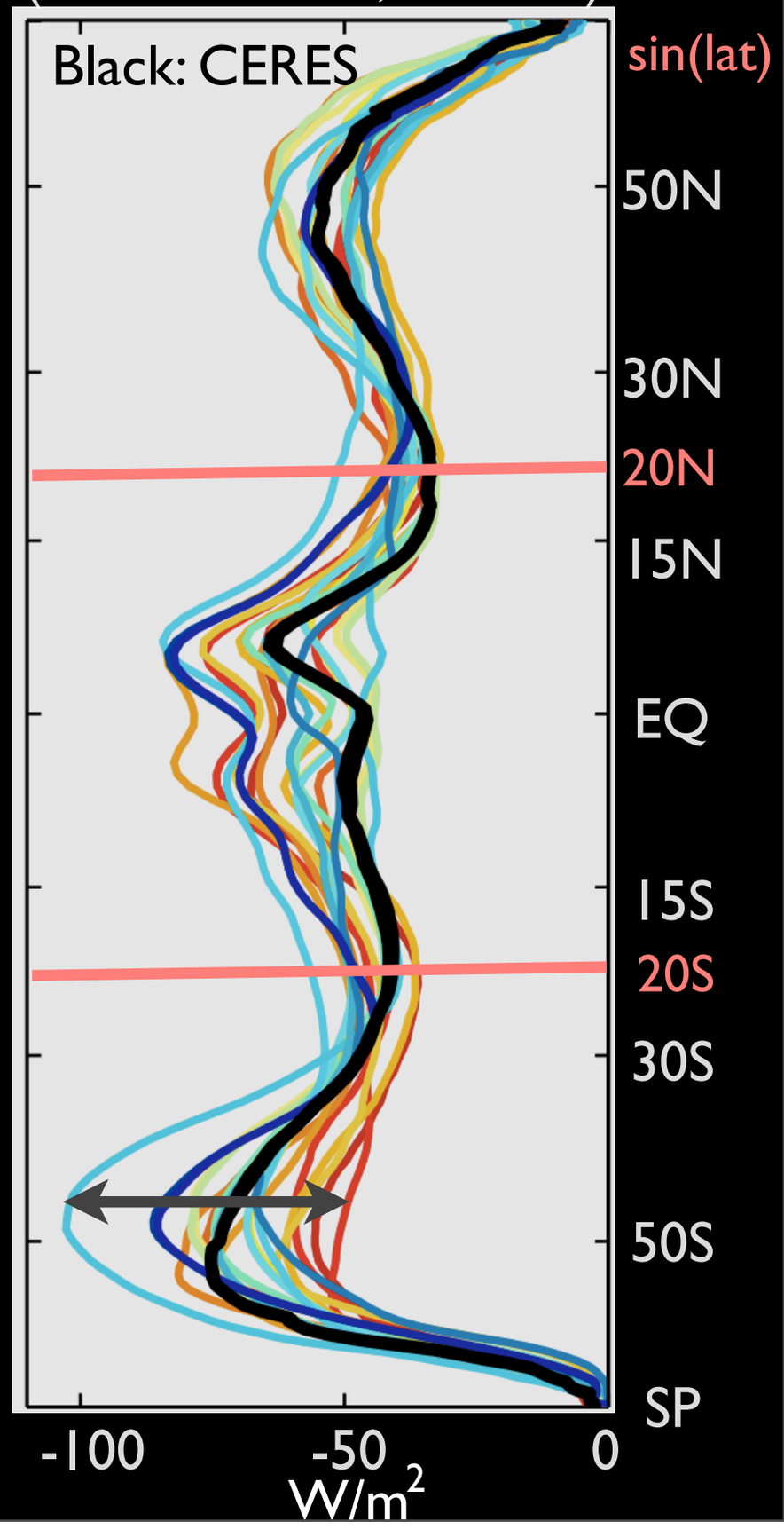
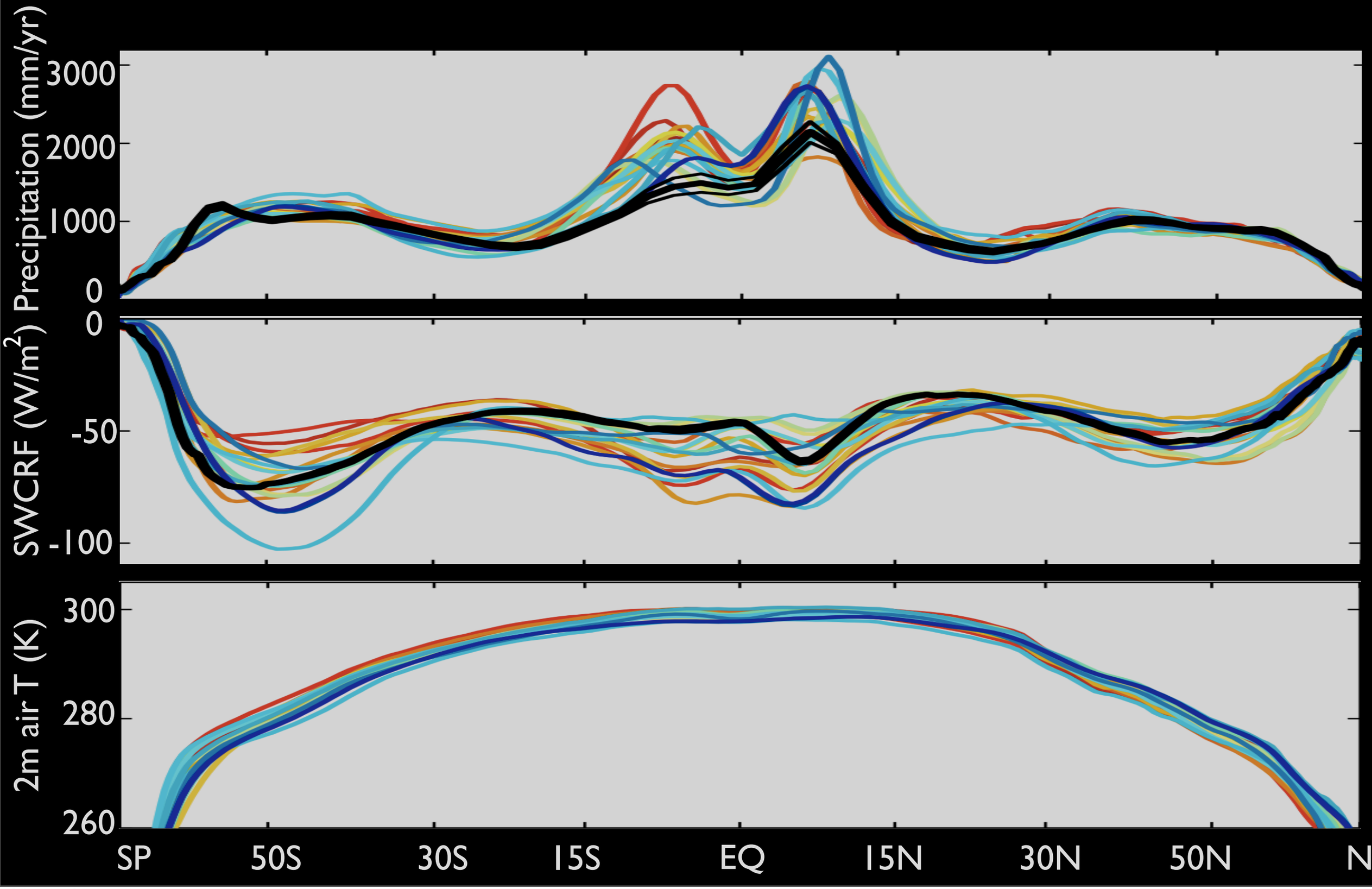


Bodas-Salcedo et al. in prep.

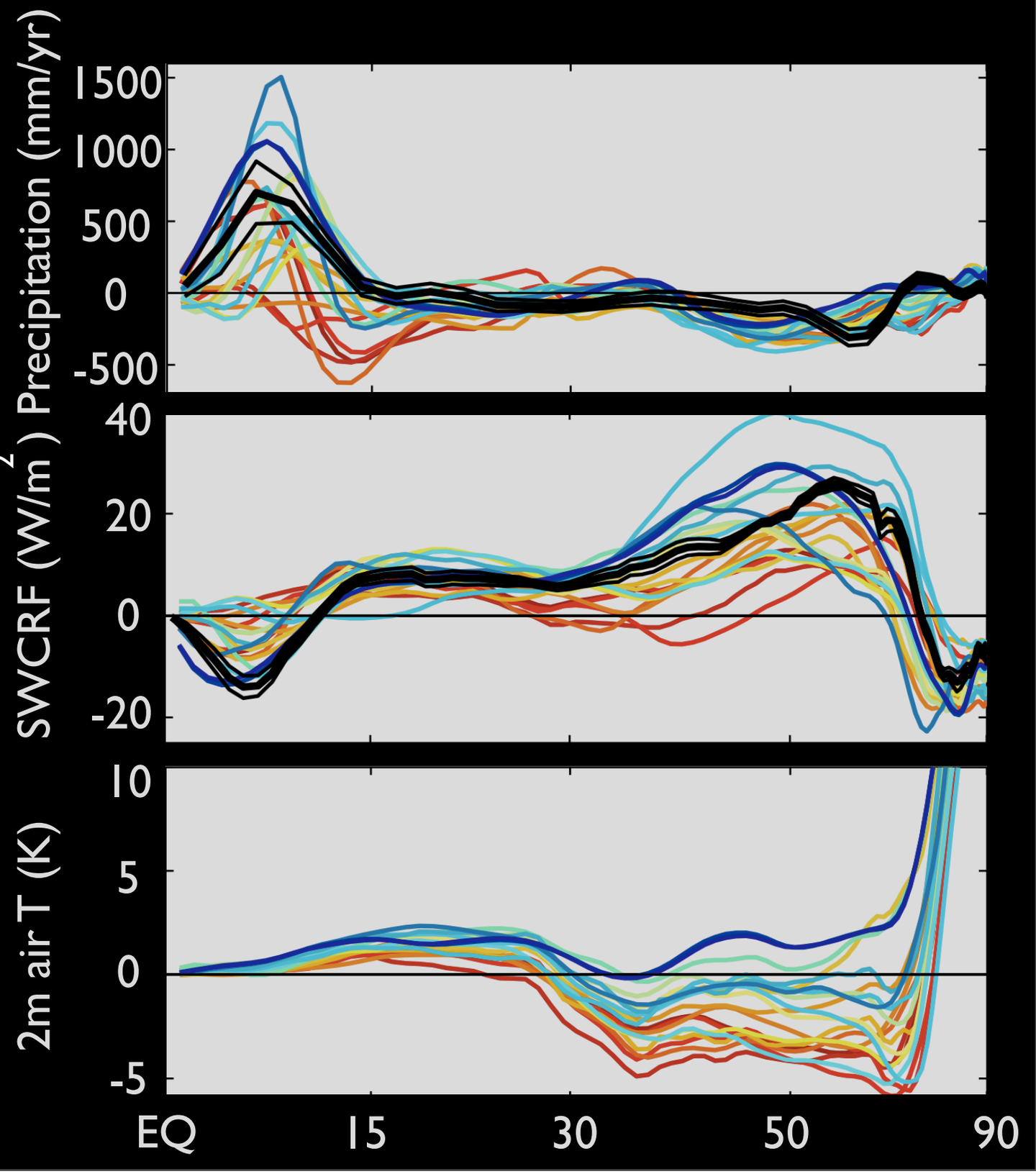
Annual Mean Zonal Mean
SW CRF
(absolute value, not bais)



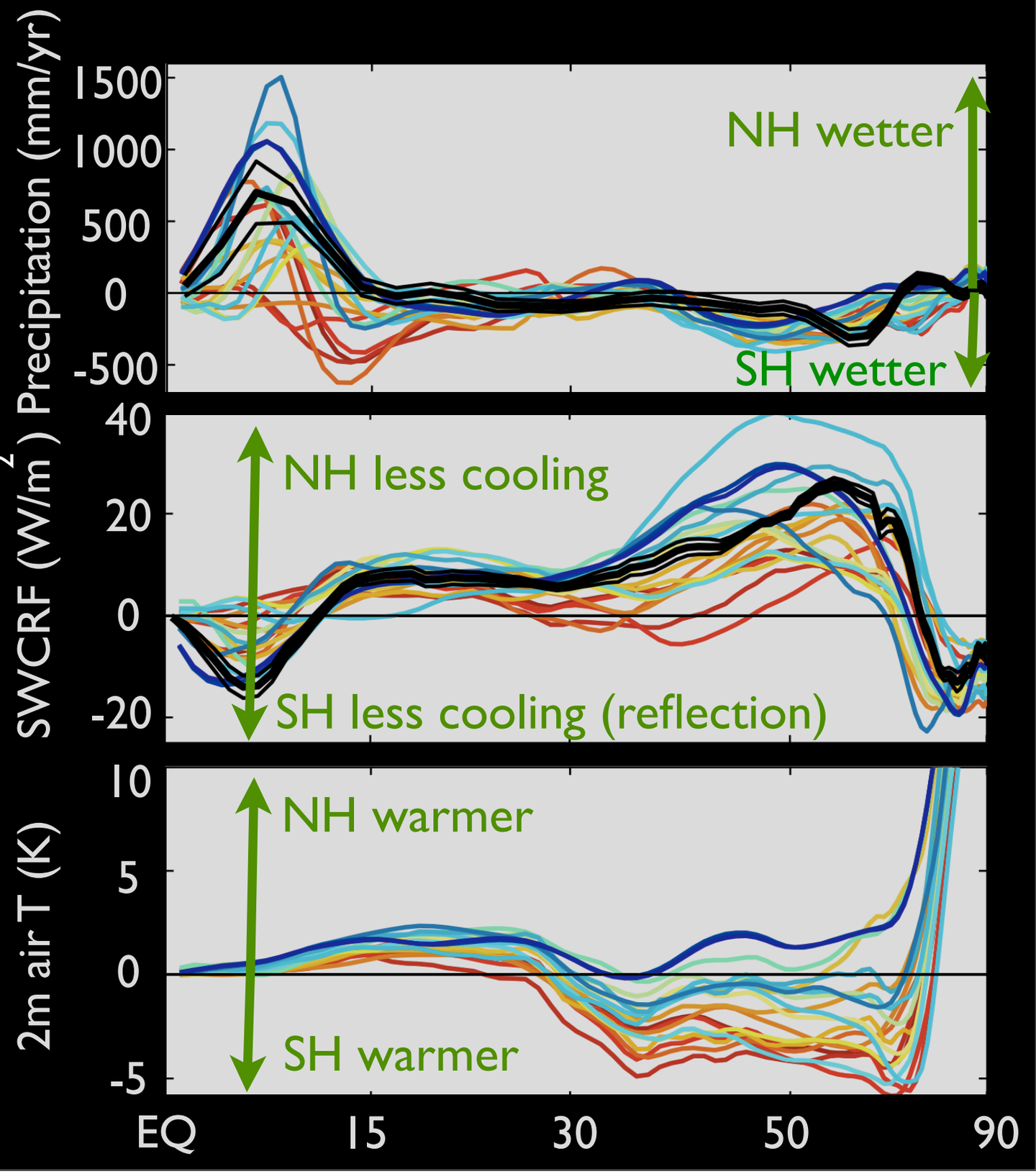
Can Cloud Biases Over Southern Ocean Affect Tropical Precipitation that's so far away?



NH minus SH


Precipitation (mm/yr)
1500
1000
500
0
-500
SWCRF (W/m 2)
40
20
0
-20
2m air T (K)
10
5
0
-5
EQ
15
30
50
90

NH minus SH

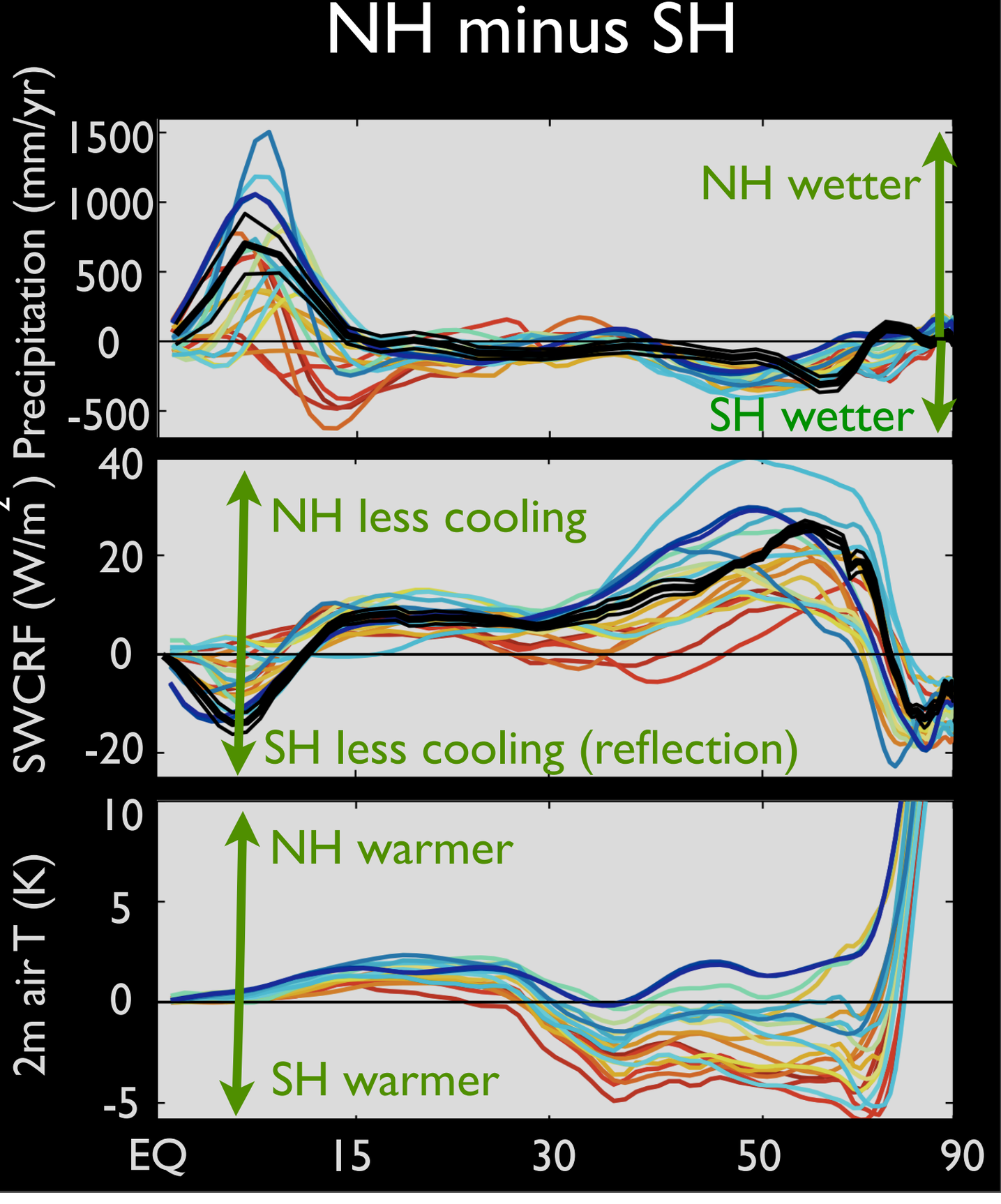

Precipitation (mm/yr)
1500
1000
500
0
-500
NH wetter
SH wetter
SWCRF (W/m2)
40
20
0
-20
NH less cooling
SH less cooling (reflection)
2m air T (K)
10
5
0
-5
NH warmer
SH warmer
EQ
15
30
50
90

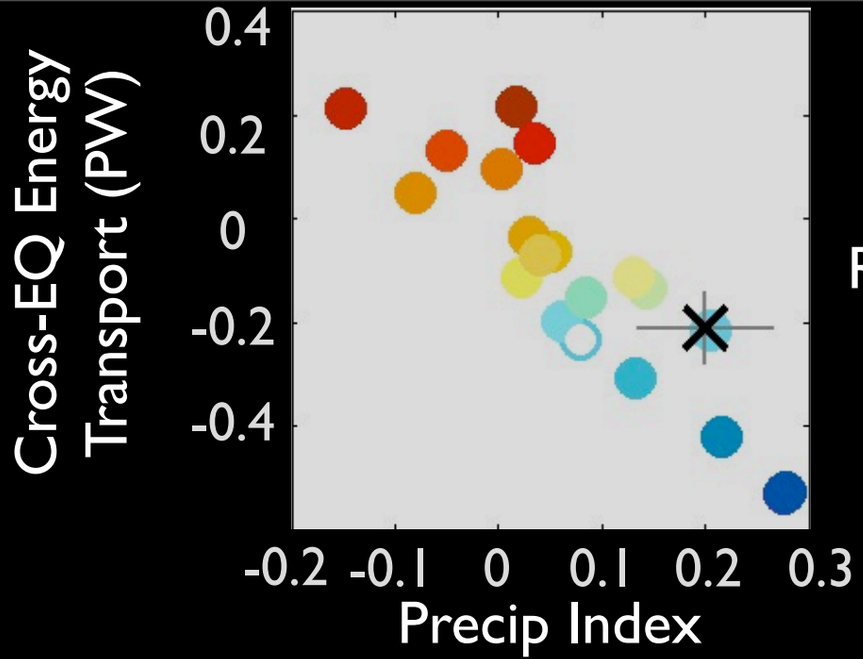
Red Models:
Larger northward cross-EQ atmos. energy transport

More precipitation in the SH Tropics

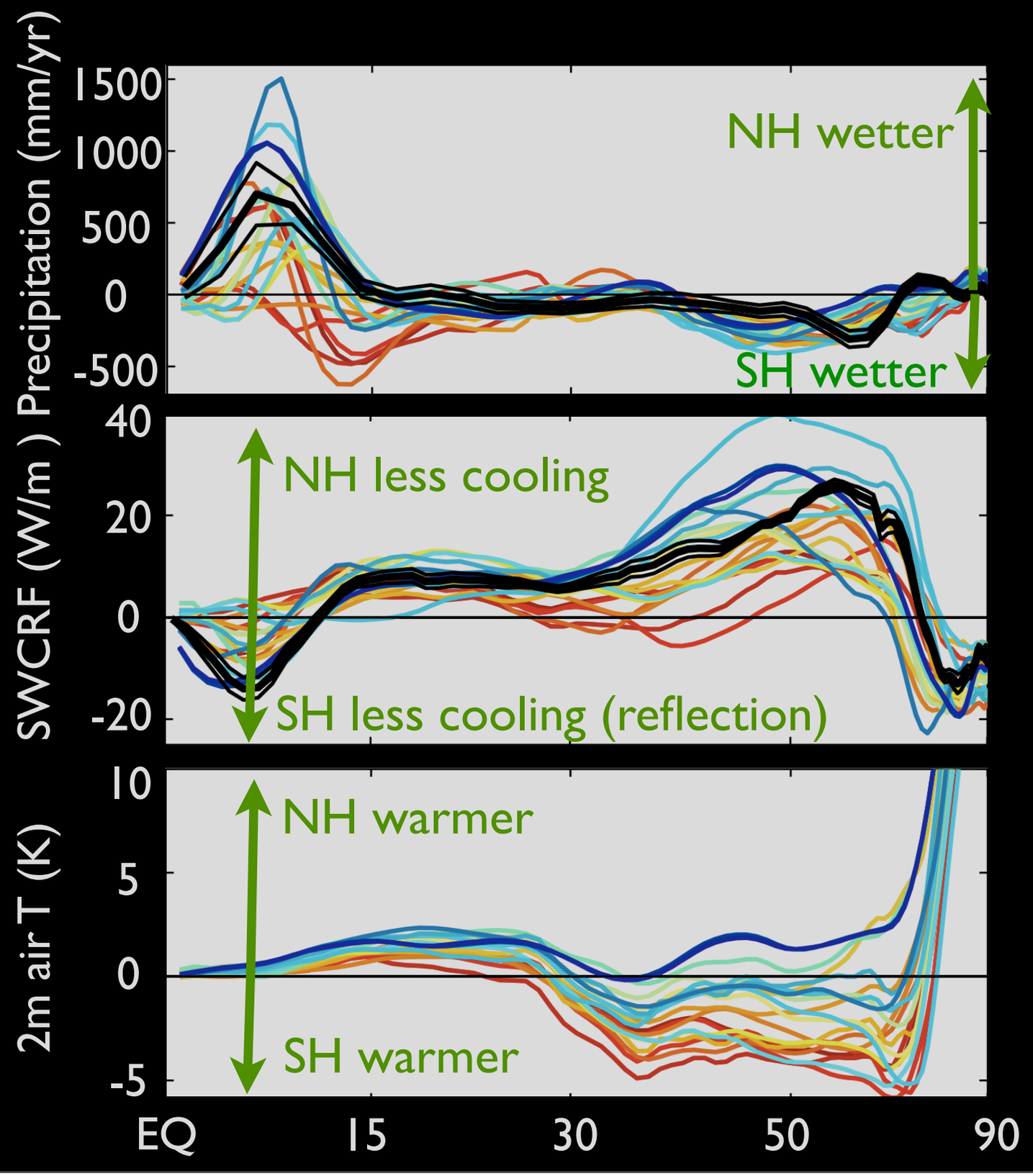
Less cooling from clouds in SH mid-to-high latitudes

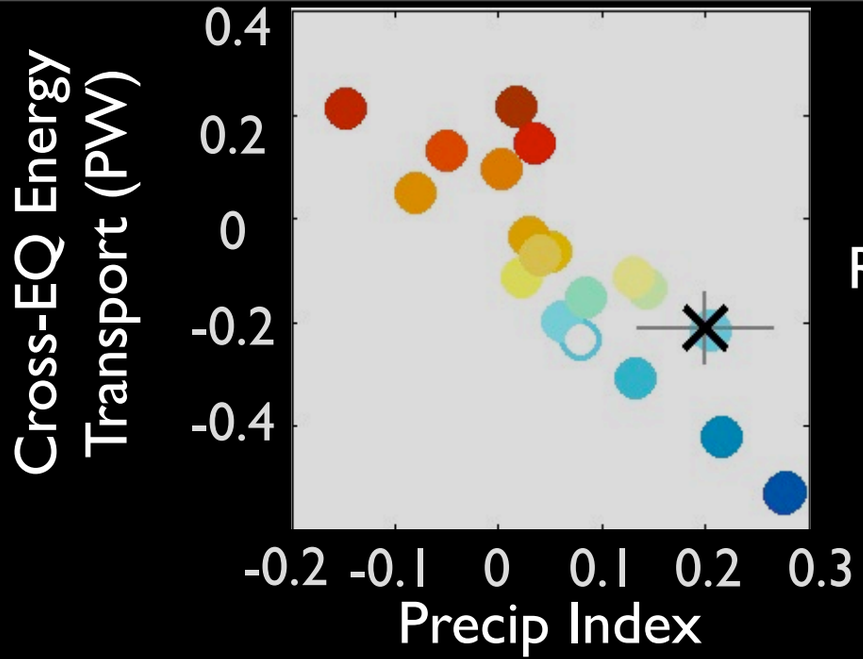
Anomalously hot in SH mid-to-high latitudes (compare with NH)



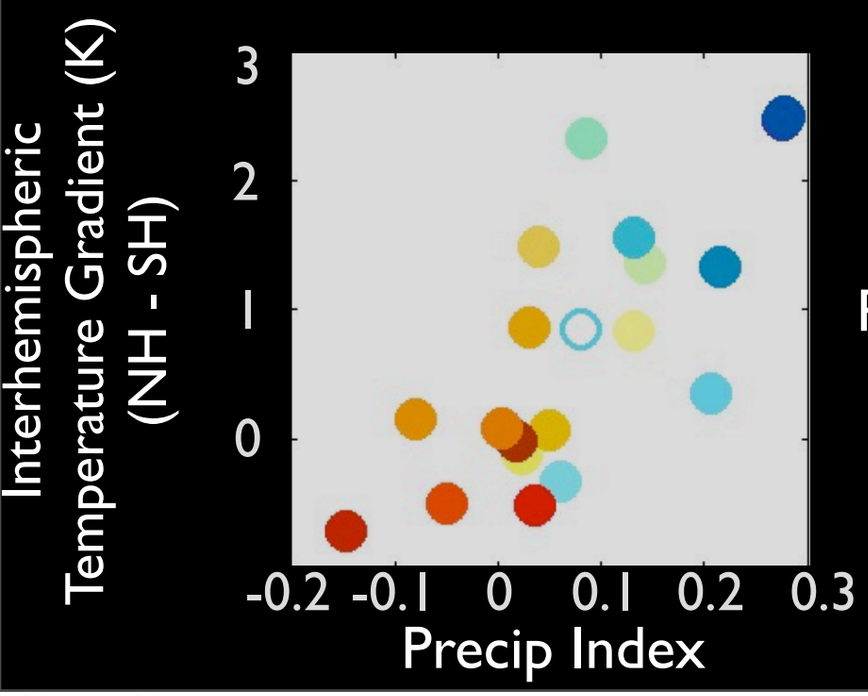

Cross-EQ Energy Transport (PW)
0.4
0.2
0
-0.2
-0.4
-0.2 -0.1 0 0.1 0.2 0.3
Precip Index

R=-0.88

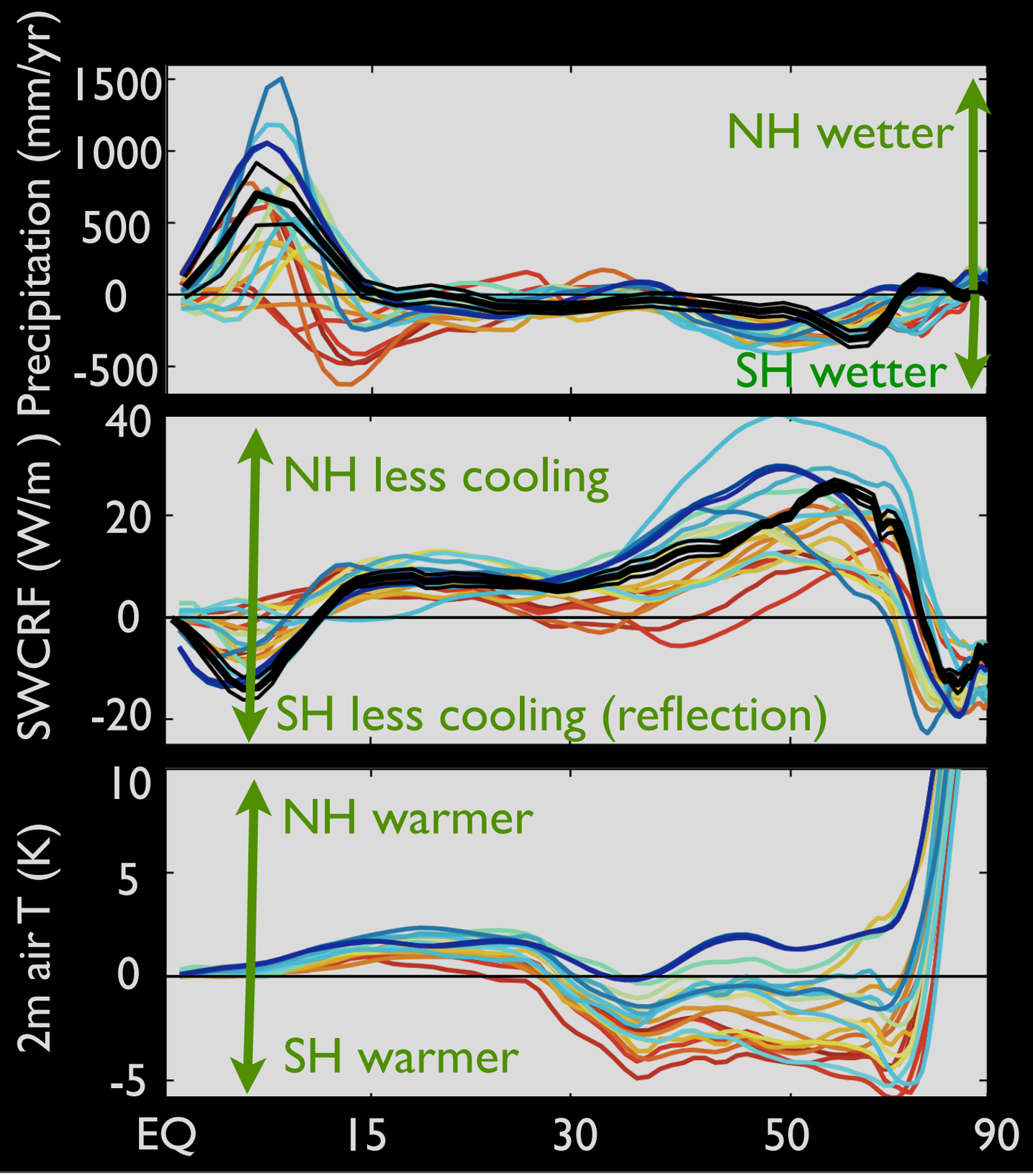

NH minus SH
Precipitation (mm/yr)
1500
1000
500
0
-500
NH wetter
SH wetter
SWCRF (W/m)
40
20
0
-20
NH less cooling
SH less cooling (reflection)
2m air T (K)
10
5
0
-5
NH warmer
SH warmer
EQ
15
30
50
90


Cross-EQ Energy Transport (PW)
0.4
0.2
0
-0.2
-0.4
-0.2 -0.1 0 0.1 0.2 0.3
Precip Index

R=-0.88


Interhemispheric Temperature Gradient (K) (NH - SH)
3
2
1
0
-0.2 -0.1 0 0.1 0.2 0.3
Precip Index

R=0.73


NH minus SH
Precipitation (mm/yr)
1500
1000
500
0
-500
NH wetter
SH wetter
SWCRF (W/m)
40
20
0
-20
NH less cooling
SH less cooling (reflection)
2m air T (K)
10
5
0
-5
NH warmer
SH warmer
EQ
15
30
50
90

Cross-EQ Energy Transport (PW)

0.4
0.2
0
-0.2
-0.4

-0.2 -0.1 0 0.1 0.2 0.3
Precip Index

R=-0.88

SWCRF 20N~NP - 20S~SP (W/m^2)

20
15
10
5

-0.2 -0.1 0 0.1 0.2 0.3
Precip Index

R=0.64

Interhemispheric Temperature Gradient (K) (NH - SH)

3
2
1
0

-0.2 -0.1 0 0.1 0.2 0.3
Precip Index

R=0.73

NH minus SH

) Precipitation (mm/yr)

1500
1000
500
0
-500

NH wetter
SH wetter

SWCRF (W/m)

40
20
0
-20

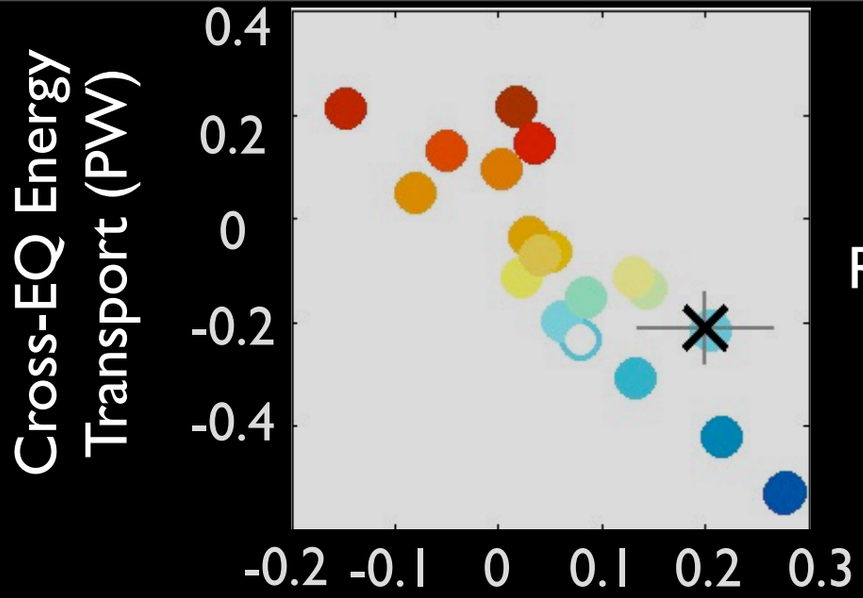
NH less cooling
SH less cooling (reflection)

2m air T (K)

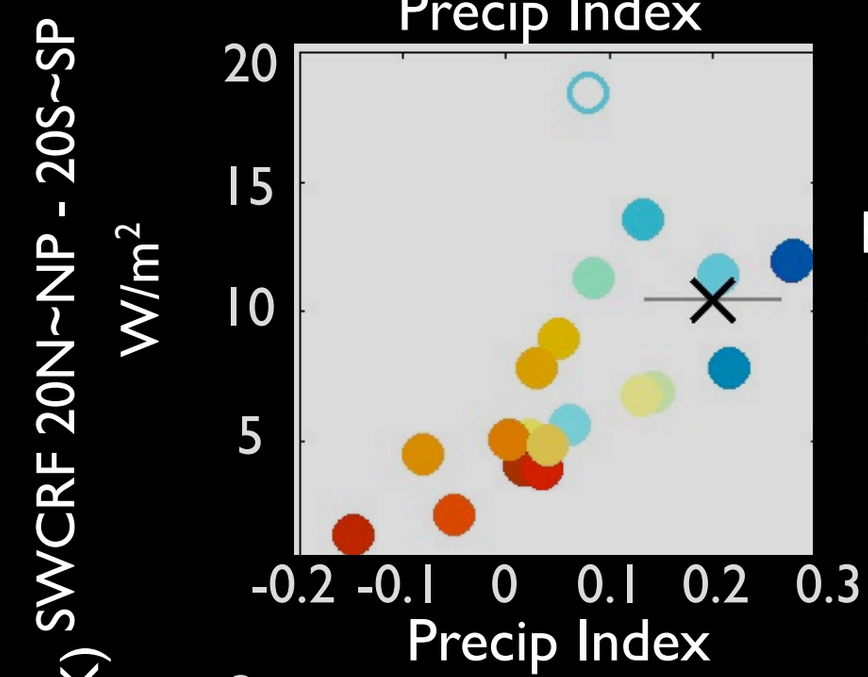
10
5
0
-5

NH warmer
SH warmer

EQ 15 30 50 90

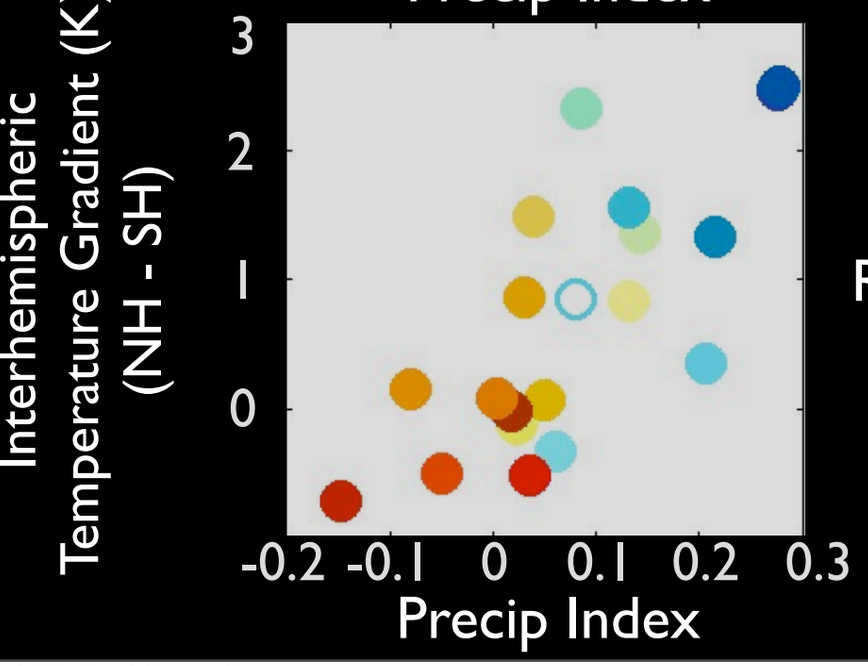


R=-0.88

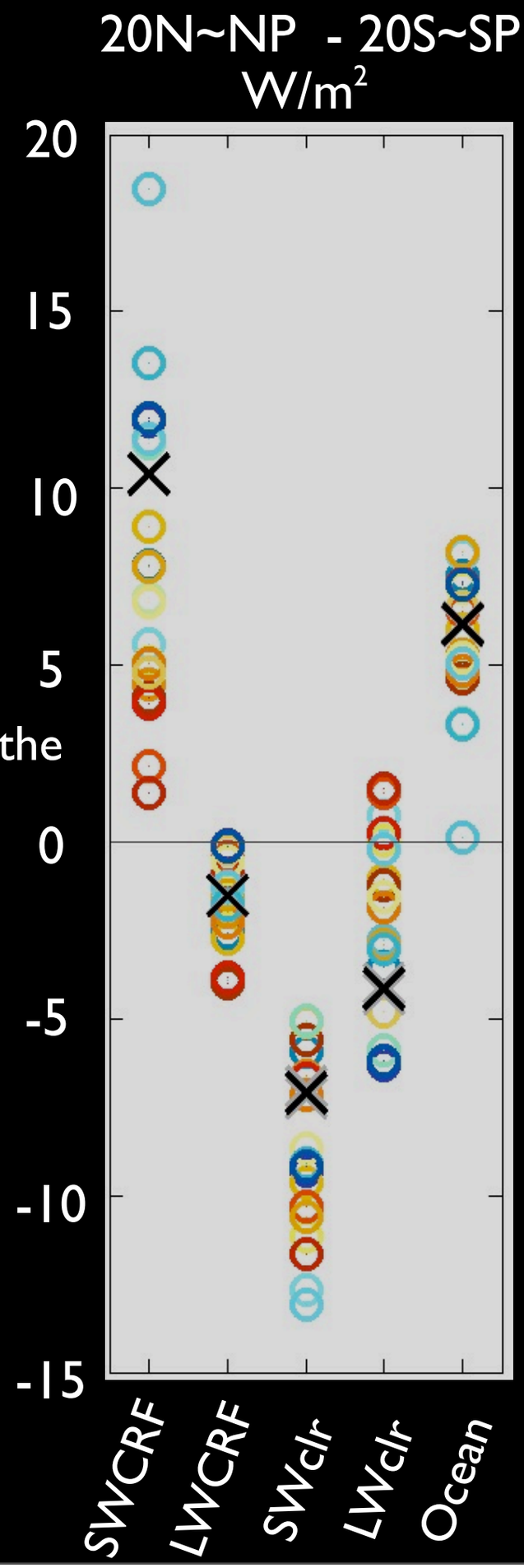


R=0.64

R=0.80 without the open circle



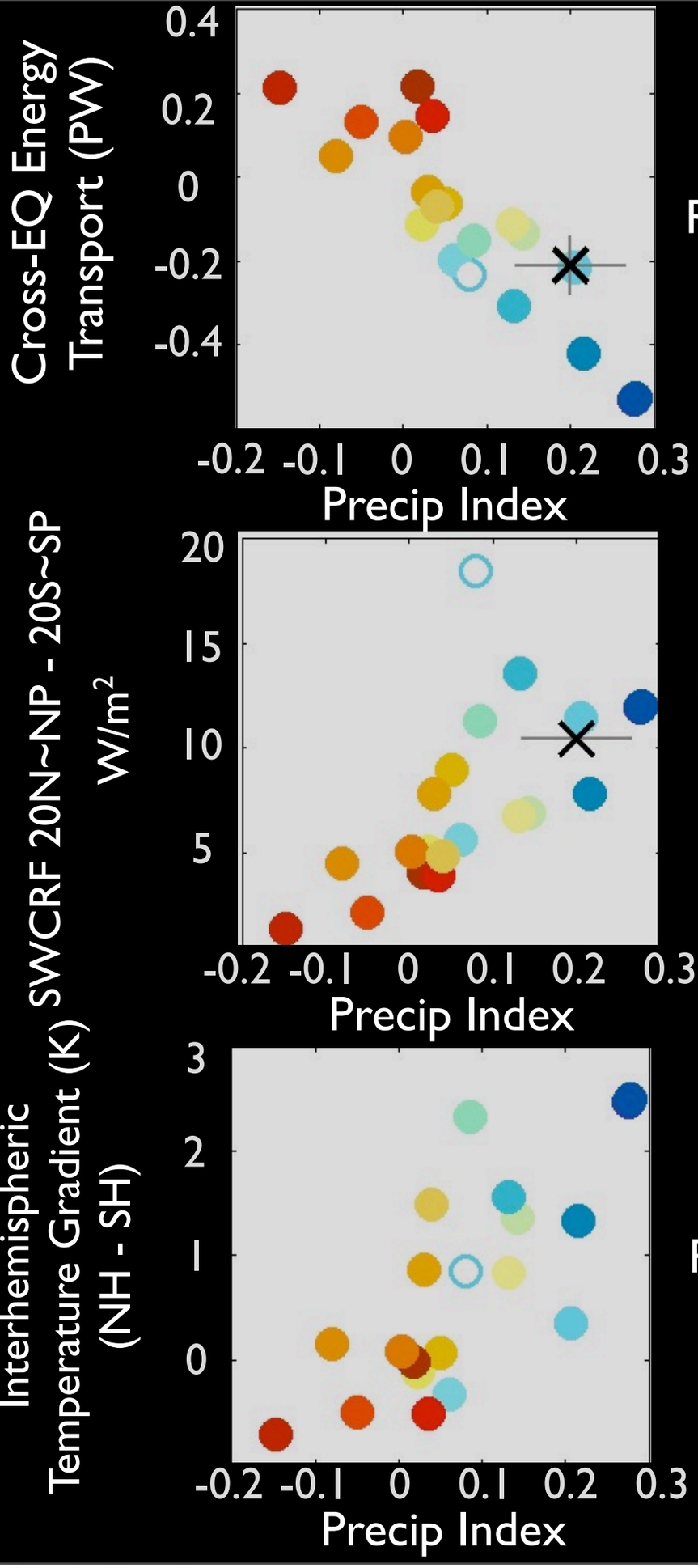
R=0.73

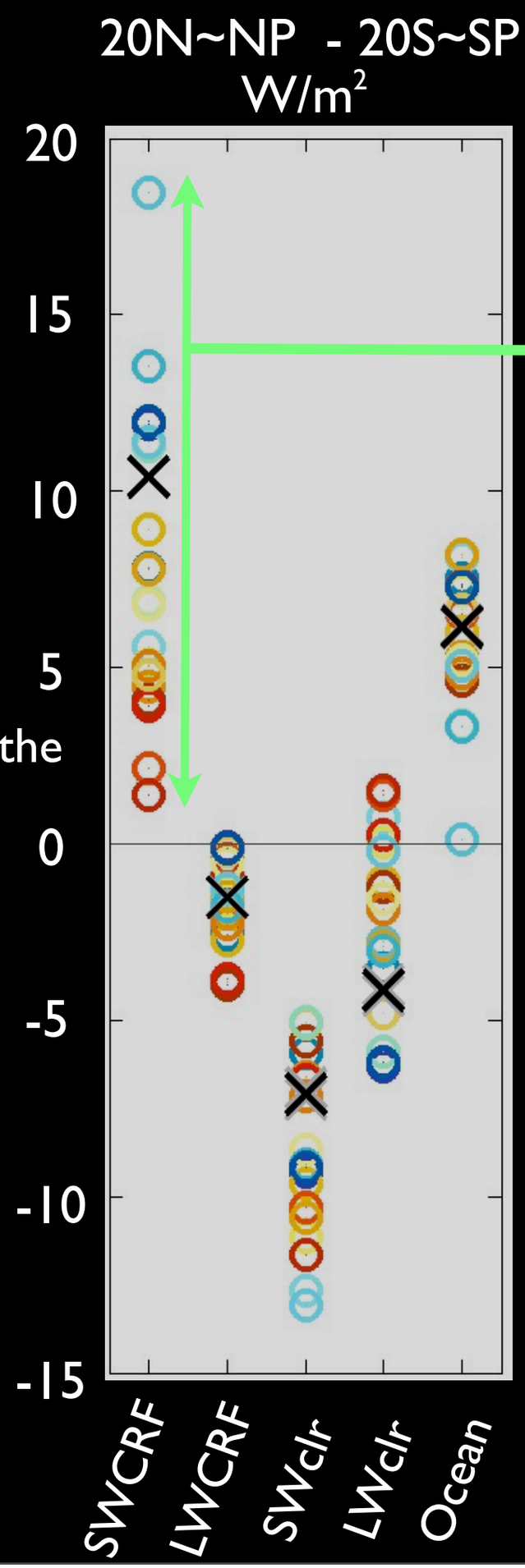


black cross:
CERES observations

Note:
Correlation does not proof causality!
However,
(1) modeling experiments
(2) Bodas-Salcedo et al. 2012
(3) similar cloud biases exist in reanalysis simulations.

Hwang and Frierson, 2013, PNAS





black cross:
CERES observations

SW CRF explains most of the GCMs spread and biases

Note:
Correlation does not proof causality!
However,
(1) modeling experiments
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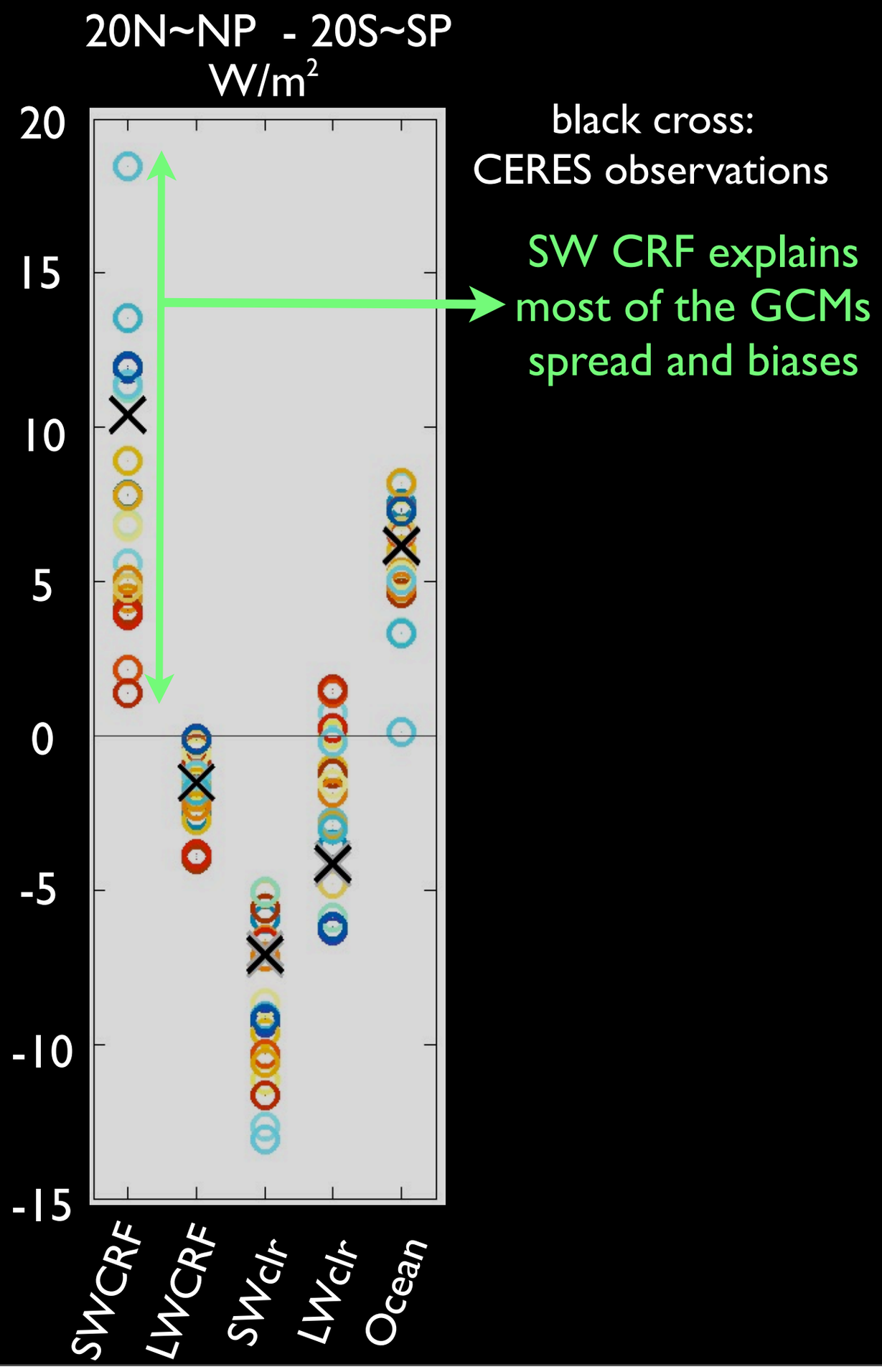
Hwang and Frierson, 2013, PNAS

Biases in Jet Latitudes

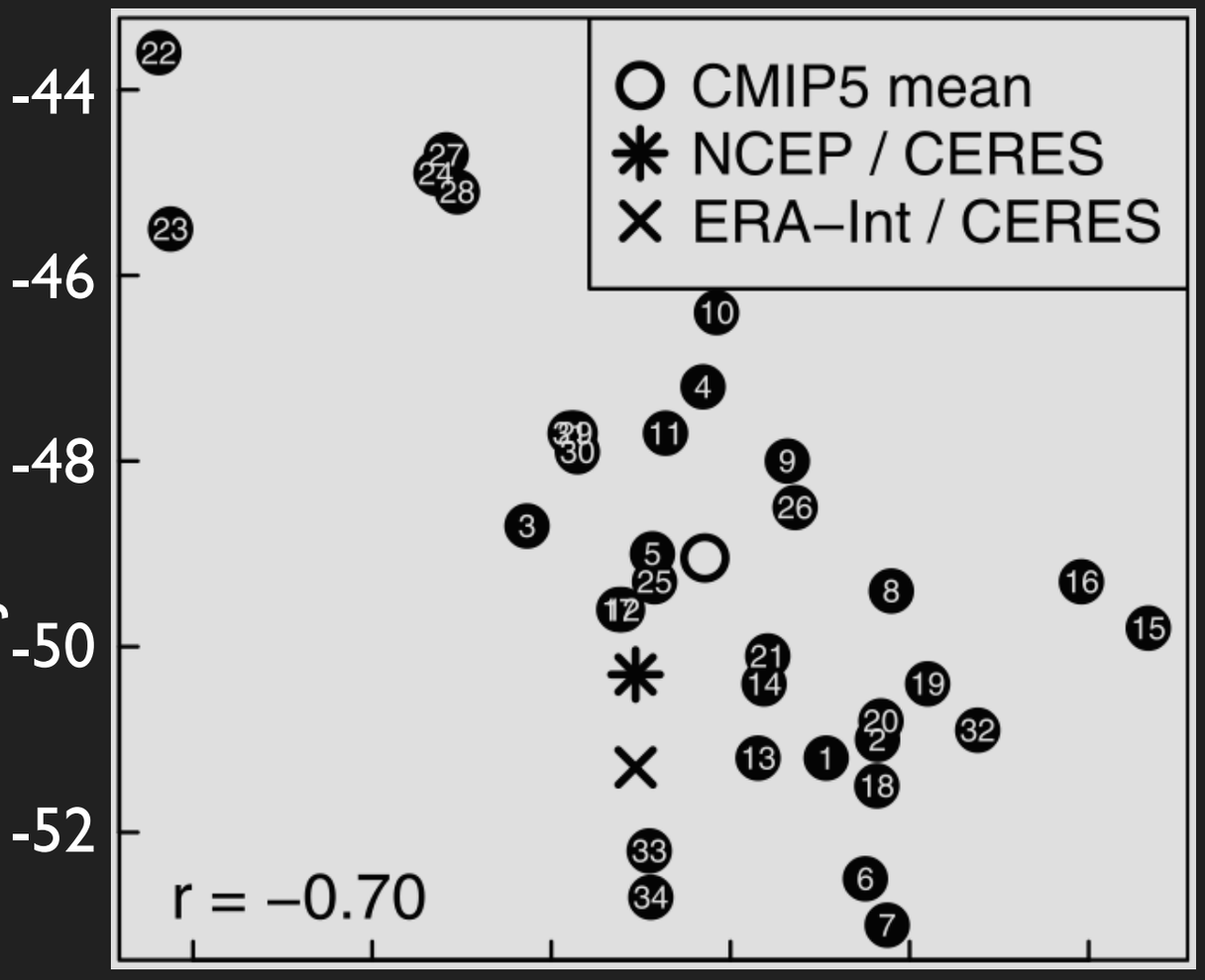


black cross:
CERES observations

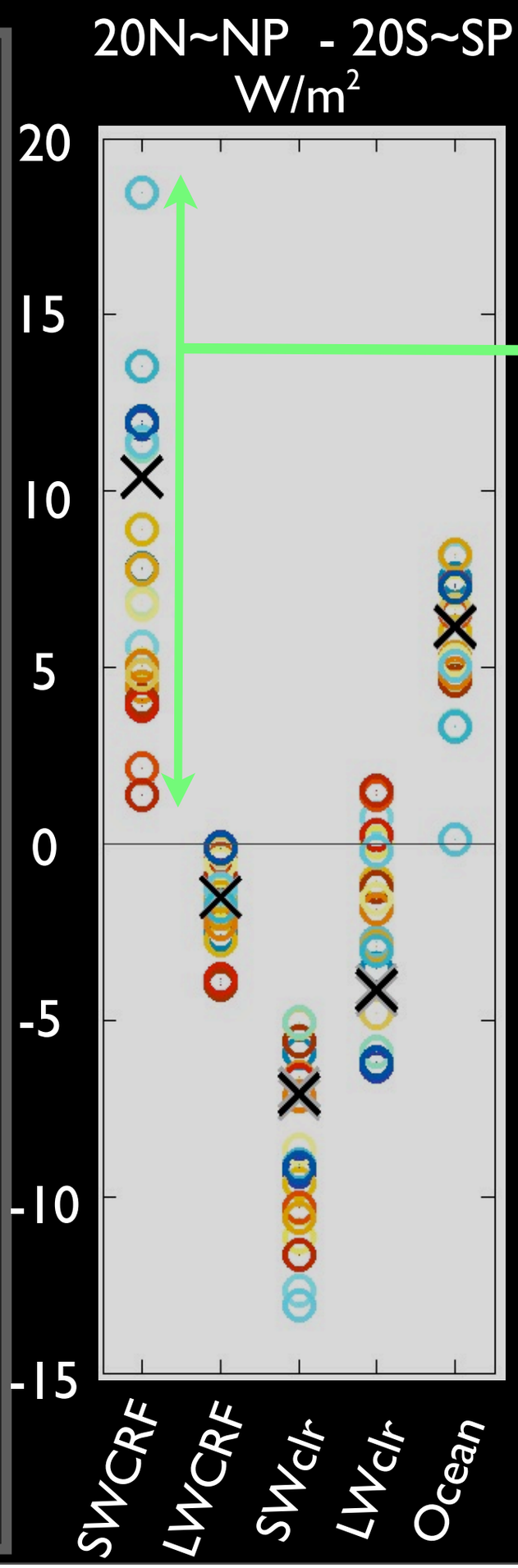
SW CRF explains most of the GCMs spread and biases

Biases in Jet Latitudes

SH Jet Latitude vs.
SW Cloud Radiative Forcing



Ceppi, Hwang, Frierson, and Hartmann 2012

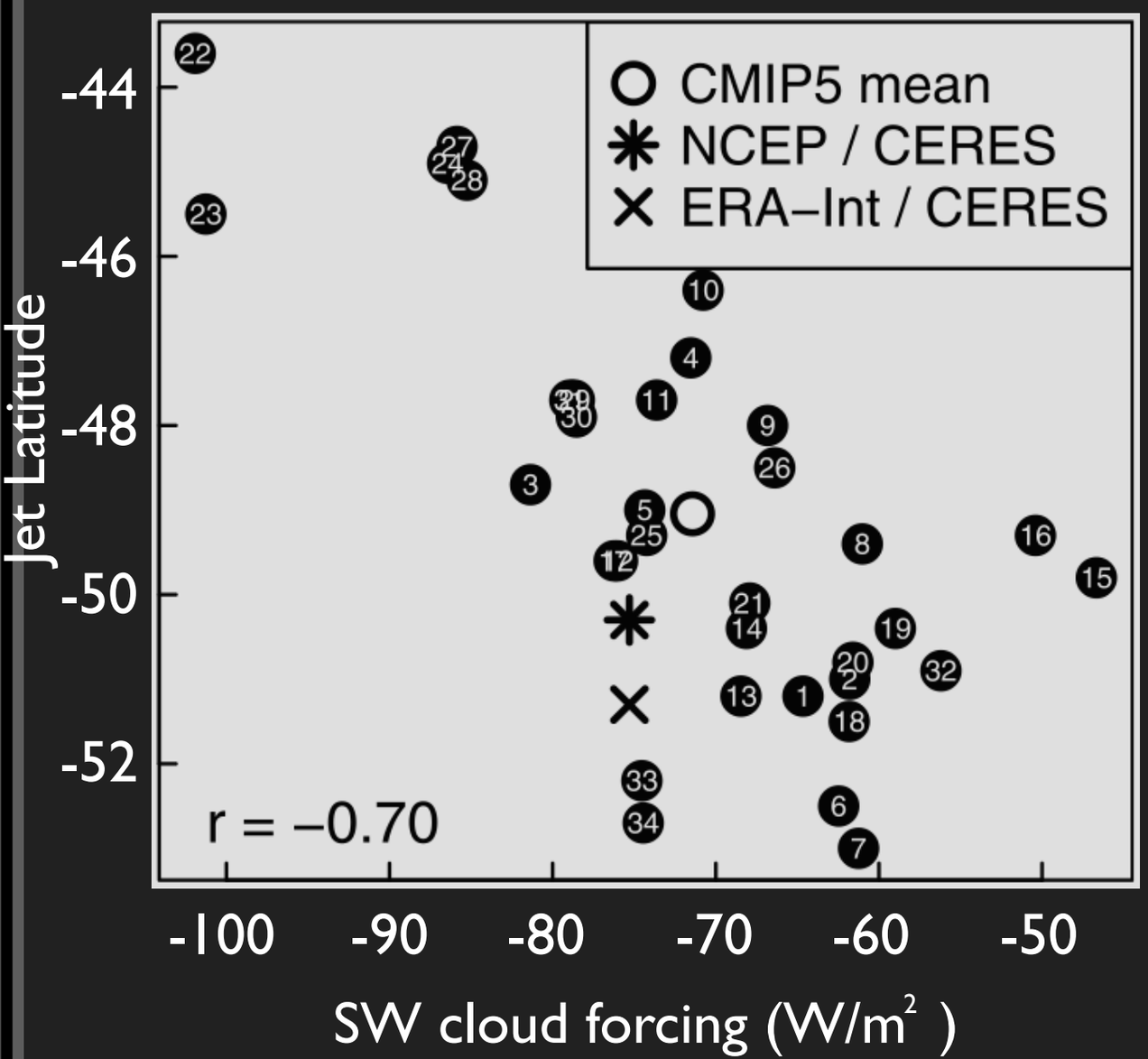


black cross:
CERES observations

SW CRF explains most of the GCMs spread and biases

Biases in Jet Latitudes

SH Jet Latitude vs.
SW Cloud Radiative Forcing

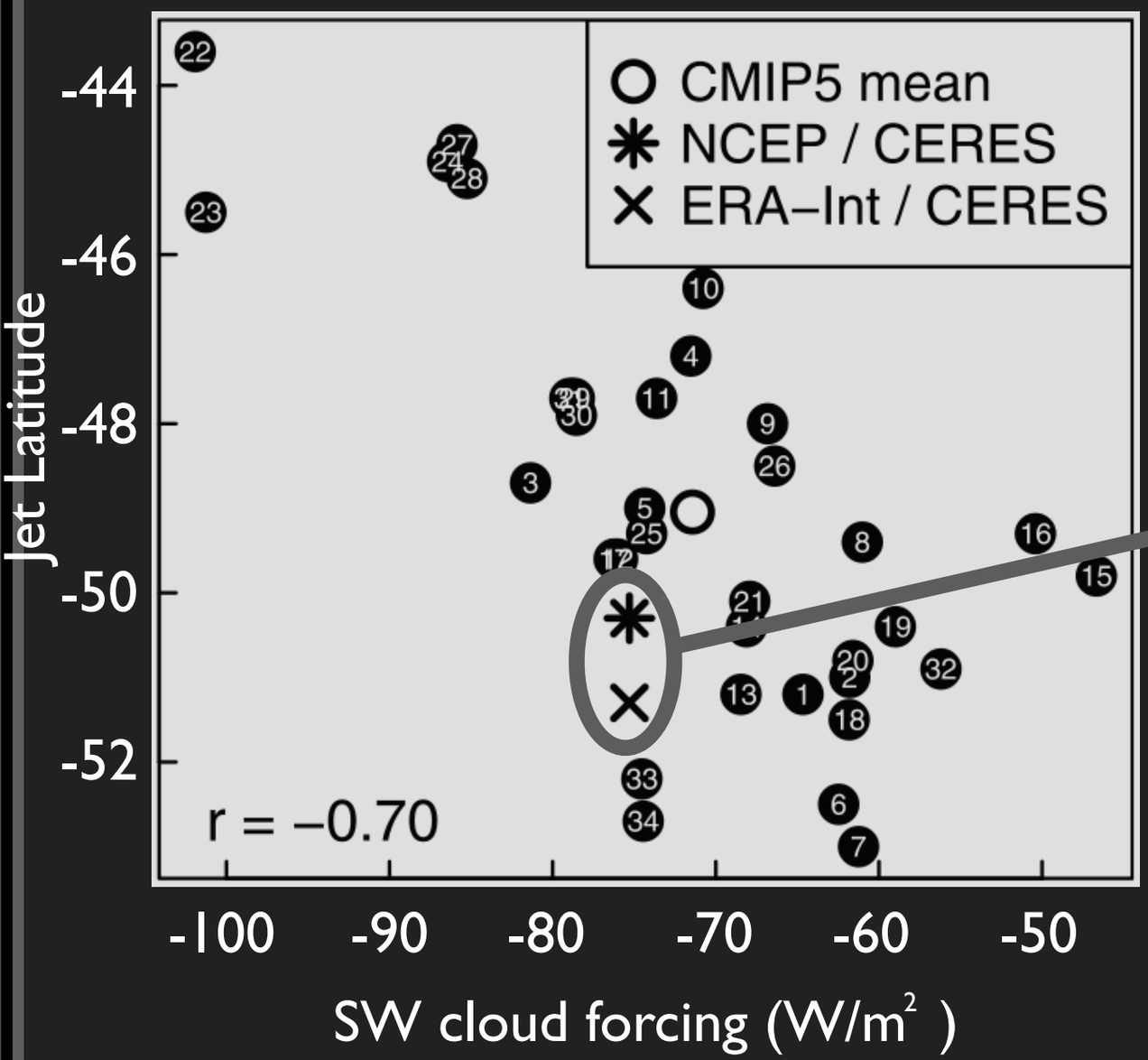


Ceppi, Hwang, Frierson, and Hartmann 2012

Anomalous warming in midlats shifts baroclinicity poleward, results in poleward shifted jet

Biases in Jet Latitudes

SH Jet Latitude vs.
SW Cloud Radiative Forcing



Ceppi, Hwang, Frierson, and Hartmann 2012

Anomalous warming in midlats shifts baroclinicity poleward, results in poleward shifted jet

Obs are not on the best fit line though – there must be additional problems

Take Home Messages

Biases in a particular region in GCMs may affect climate in other regions through energy transport.

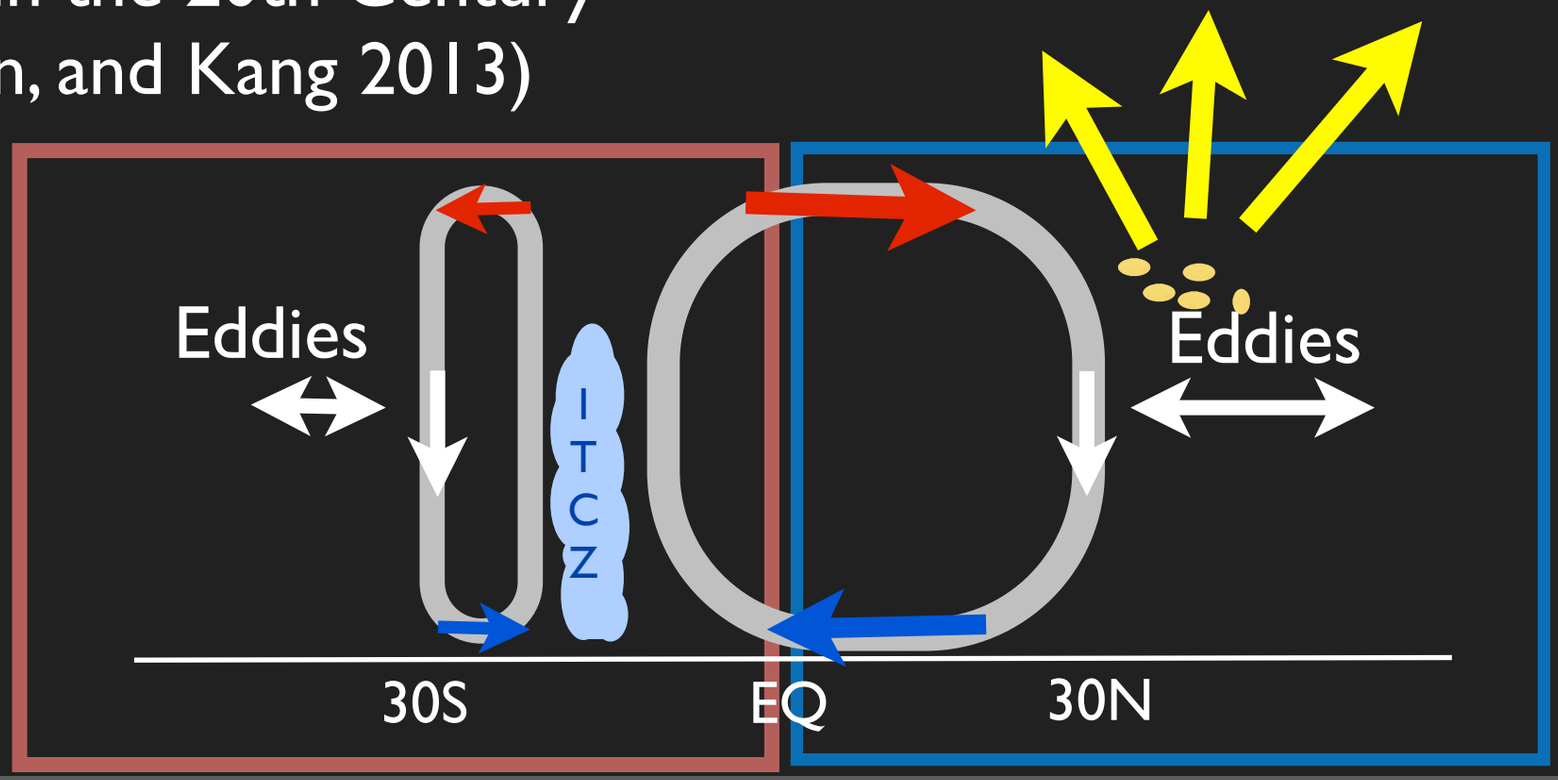
1. Do not neglect remote regions!
2. Be careful when interpreting results from AMIP simulations and different versions of models.

Hwang and Frierson 2013, PNAS

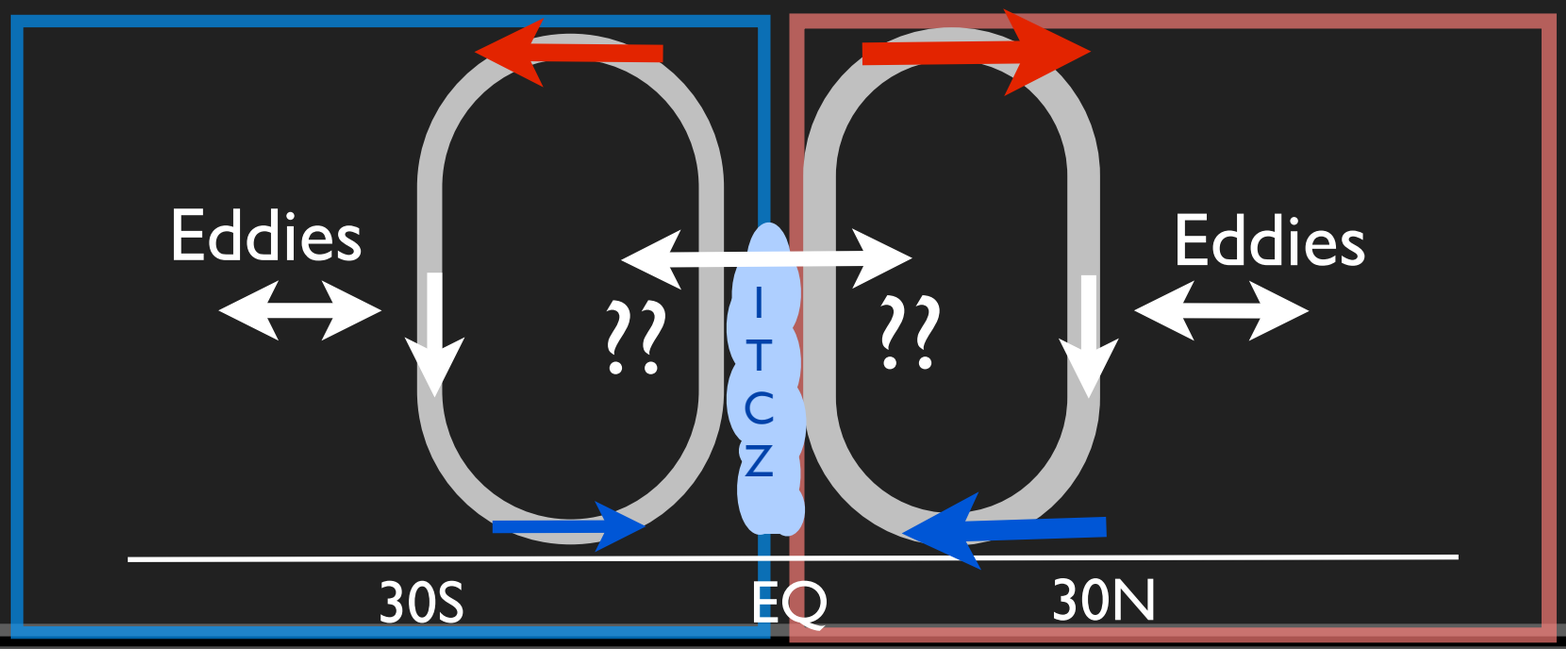
Thanks for listening.
Questions?

Similar Framework Used in Other Studies

Southward Shift in the 20th Century
(Hwang, Frierson, and Kang 2013)



Global Warming Scenarios
(Frierson and Hwang 2012, Friedman, Hwang, Chiang, and Frierson *in press*)



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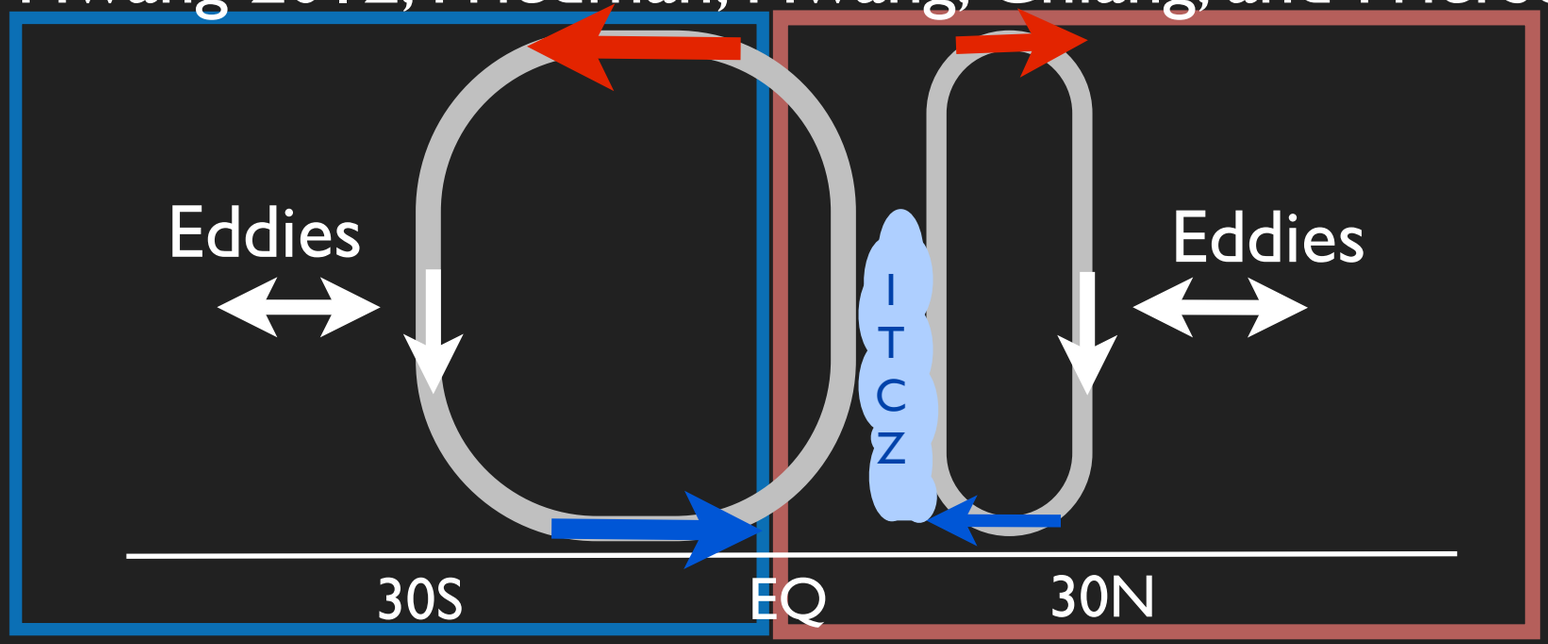
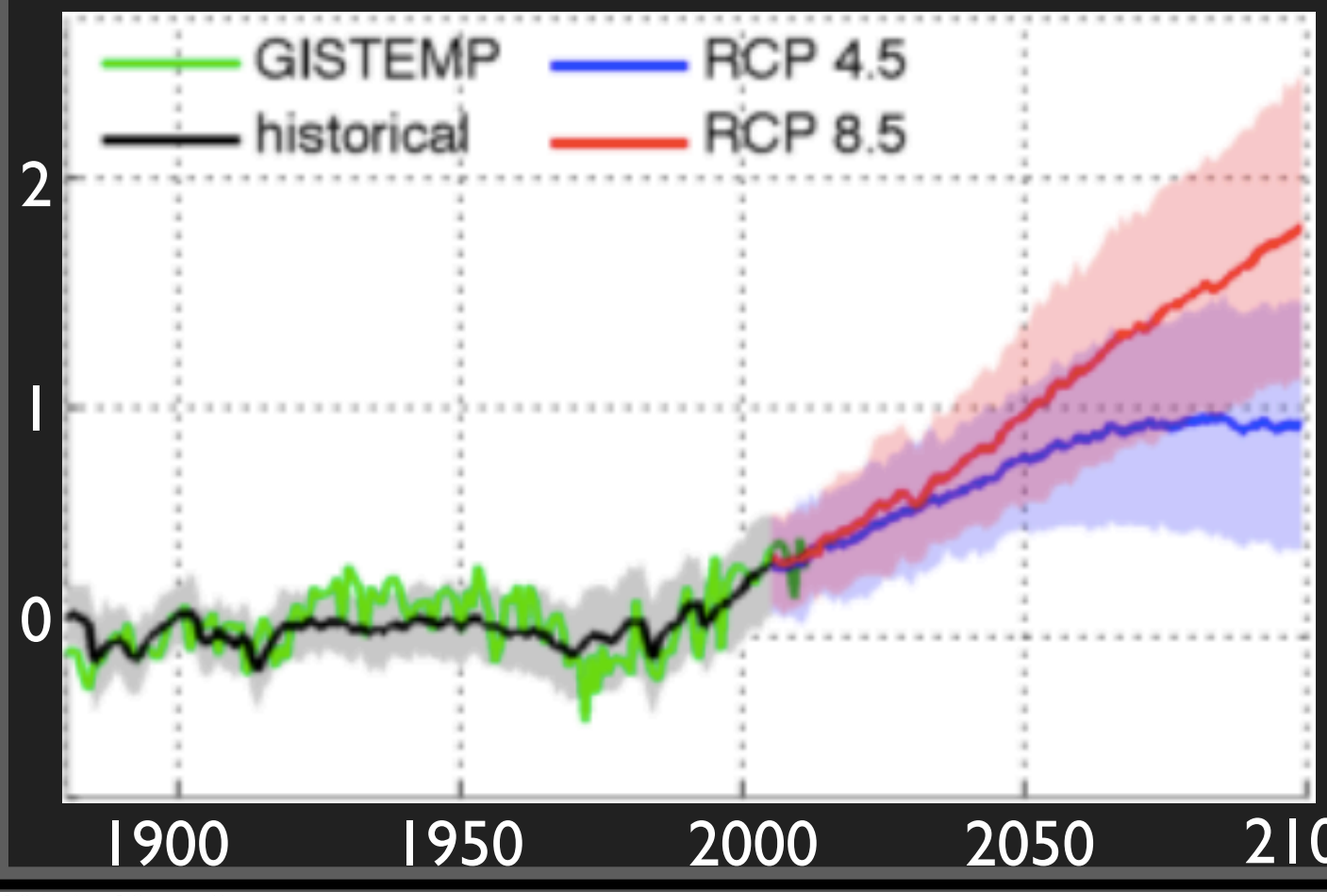
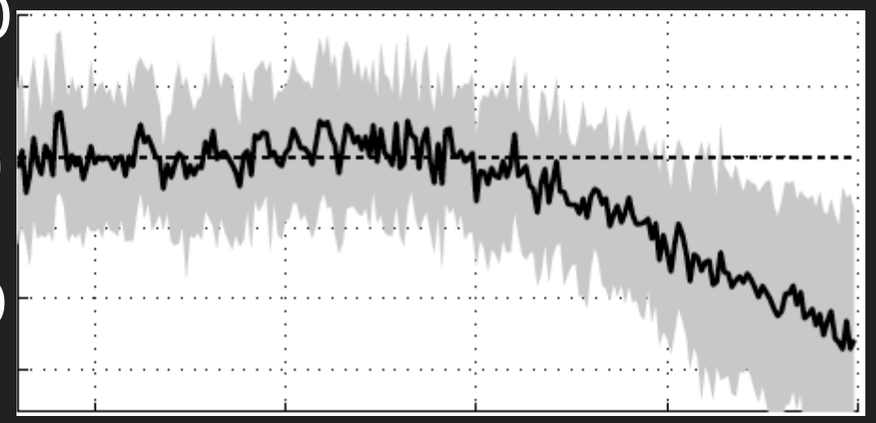




NH Stream-function (Sv)



SH Stream-function (Sv)