Dynamic and thermodynamic controls on midlatitude clouds: What can the observed satellite record teach us?

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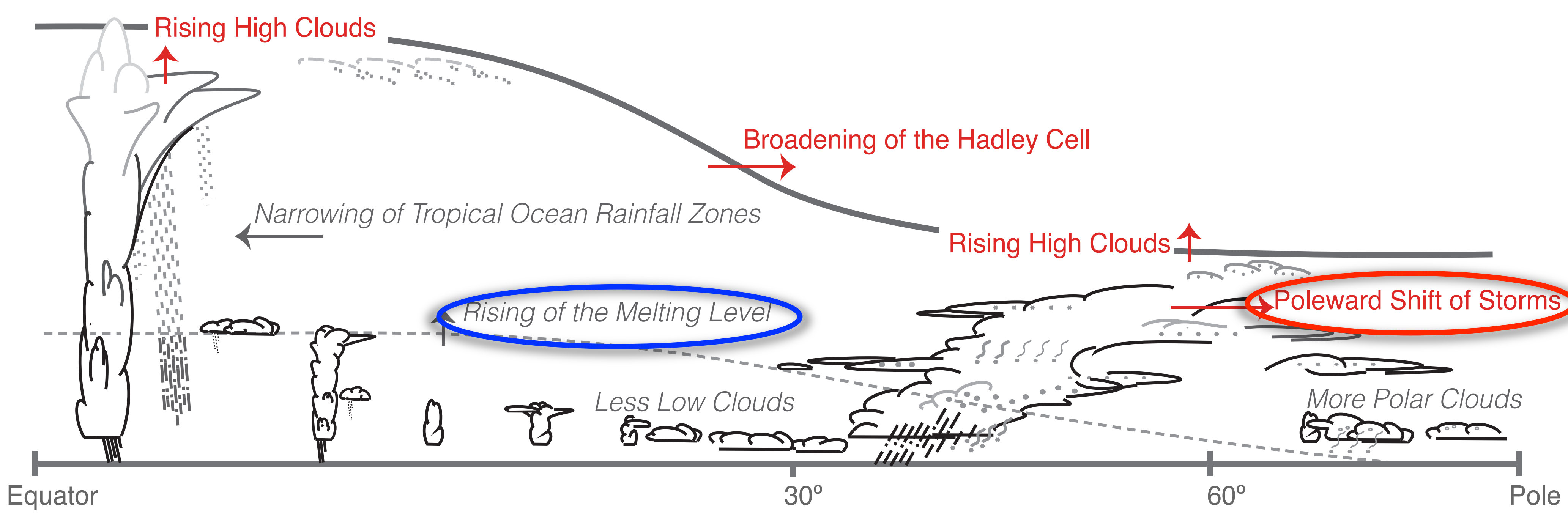
Introduction



IPCC AR5 (Chapter 7)

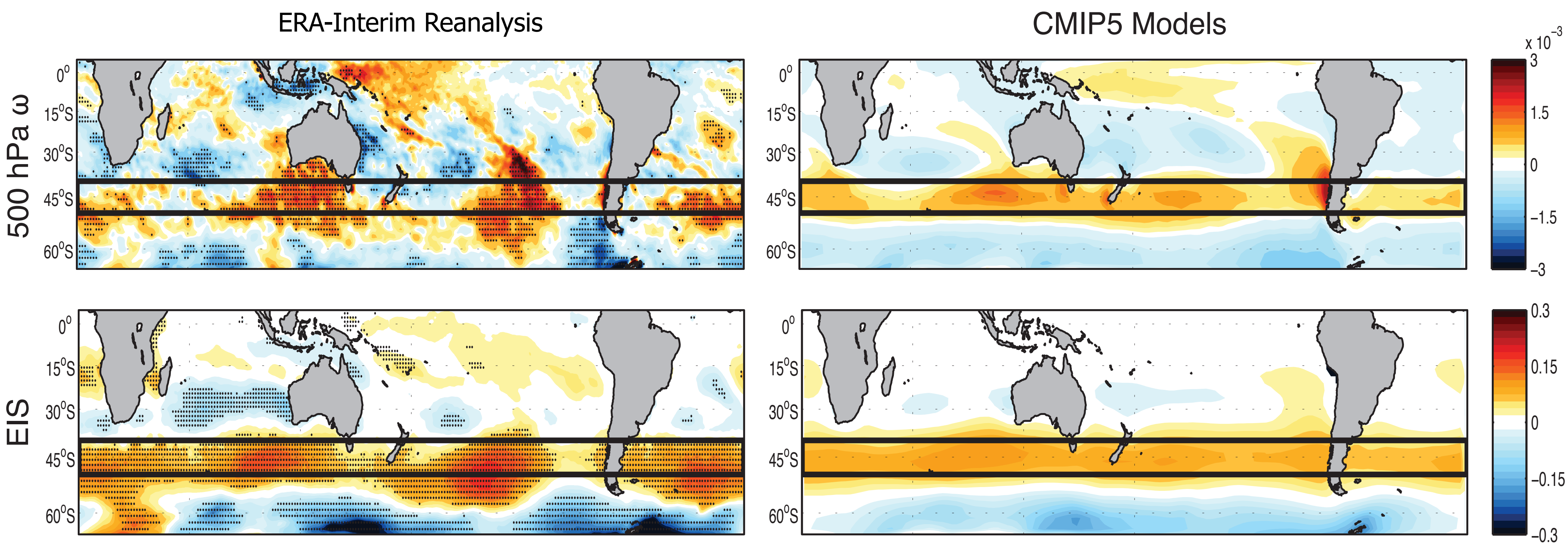
Can we put observational constraints on the dynamic and thermodynamic processes underlying midlatitude cloud feedbacks?

1) Positive cloud feedback with poleward shift of midlatitude jet stream

2) Negative cloud phase feedback at midlatitudes

Poleward Jet Shift: Dynamical Anomalies

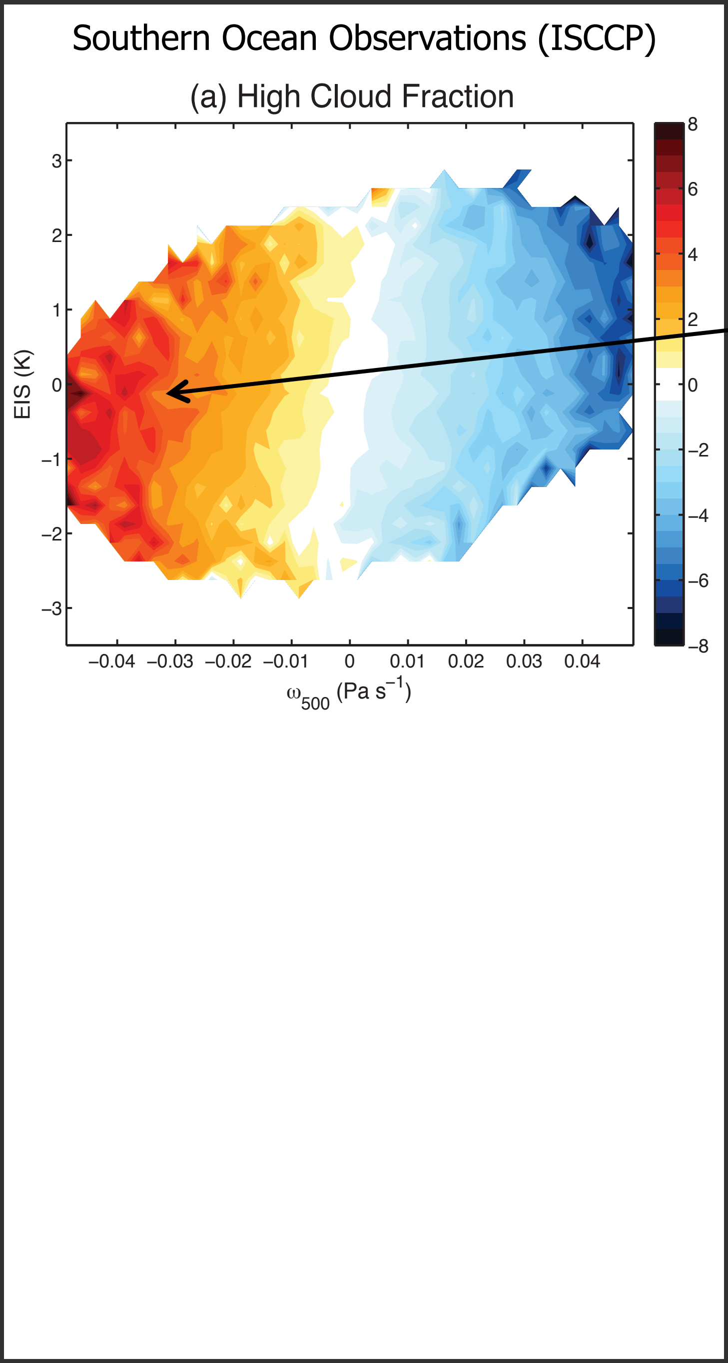
1° Poleward Jet Shift (Interannual Variability)



Grise and Medeiros (2016)

When the jet shifts poleward, downward vertical velocity and increased lower tropospheric stability (EIS) anomalies occur equatorward of the jet.

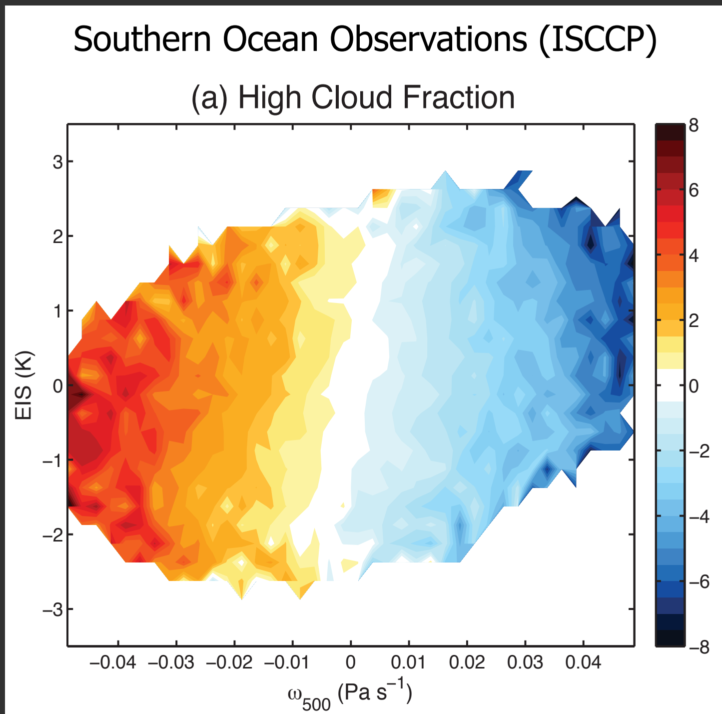
Poleward Jet Shift: Cloud Controlling Factors



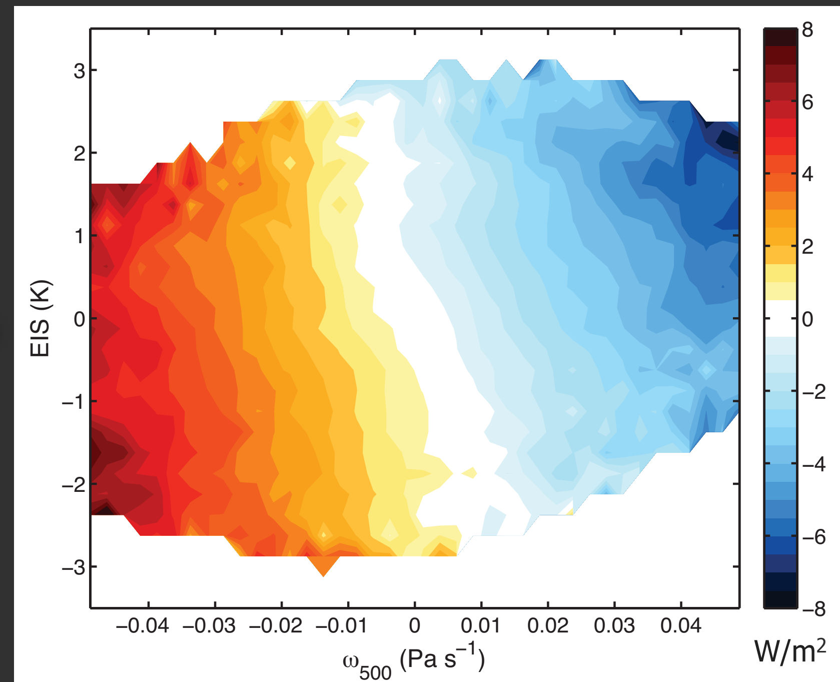
High clouds increase with upward vertical velocity anomalies.

Grise and Medeiros (2016)

Poleward Jet Shift: Cloud Controlling Factors



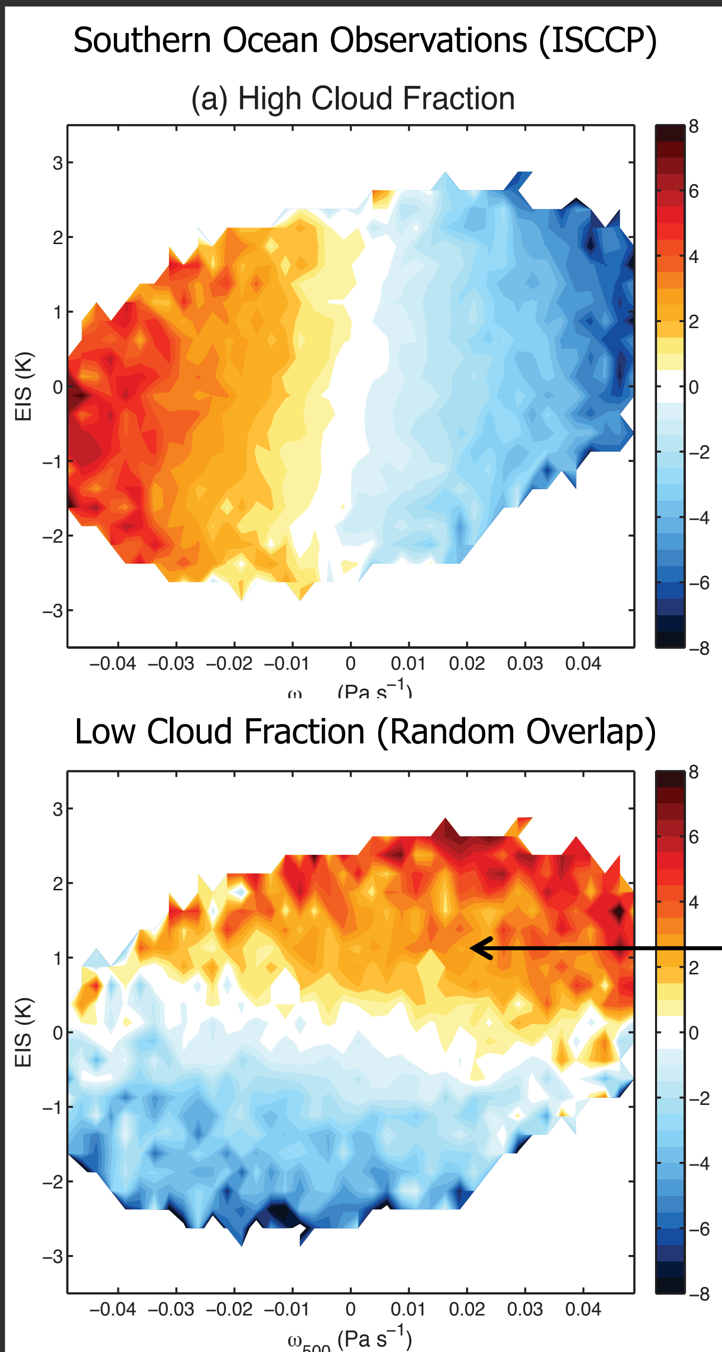
Longwave Cloud-Radiative Effect (CERES)



Longwave cloud-radiative effects also closely follow vertical motion.

Grise and Medeiros (2016)

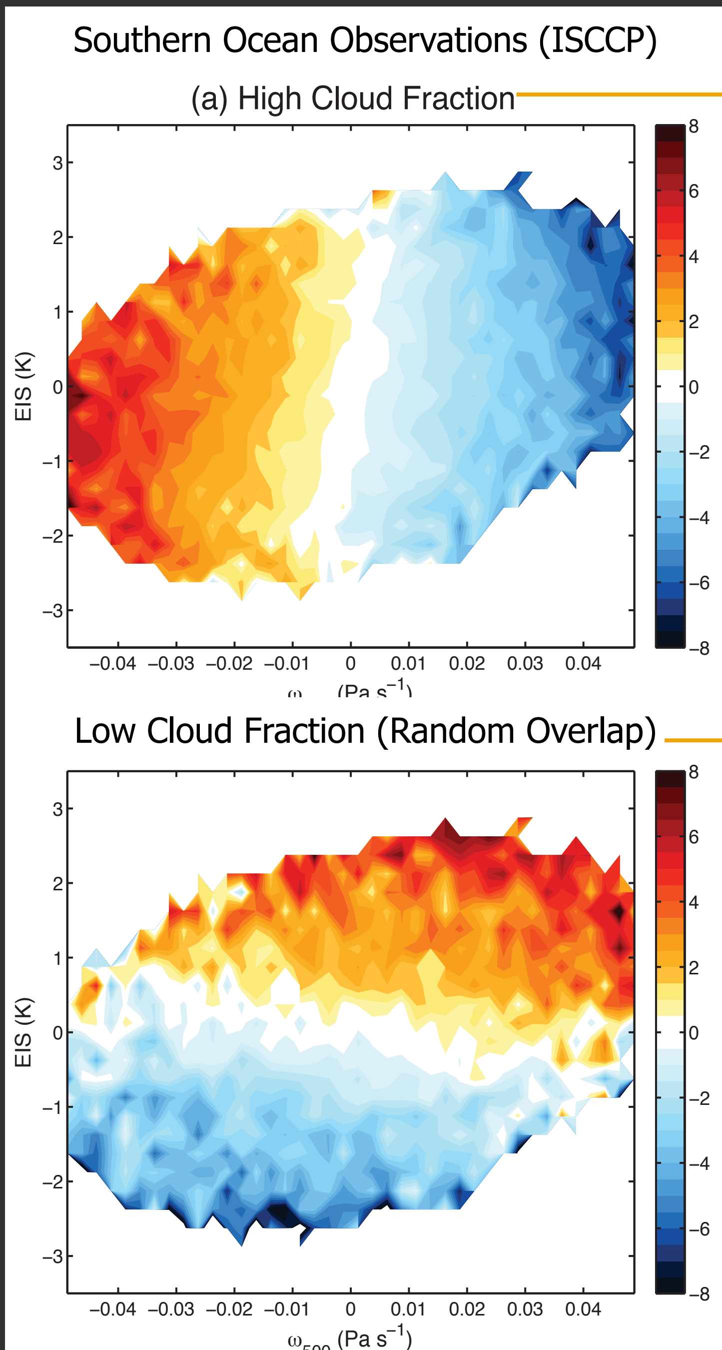
Poleward Jet Shift: Cloud Controlling Factors

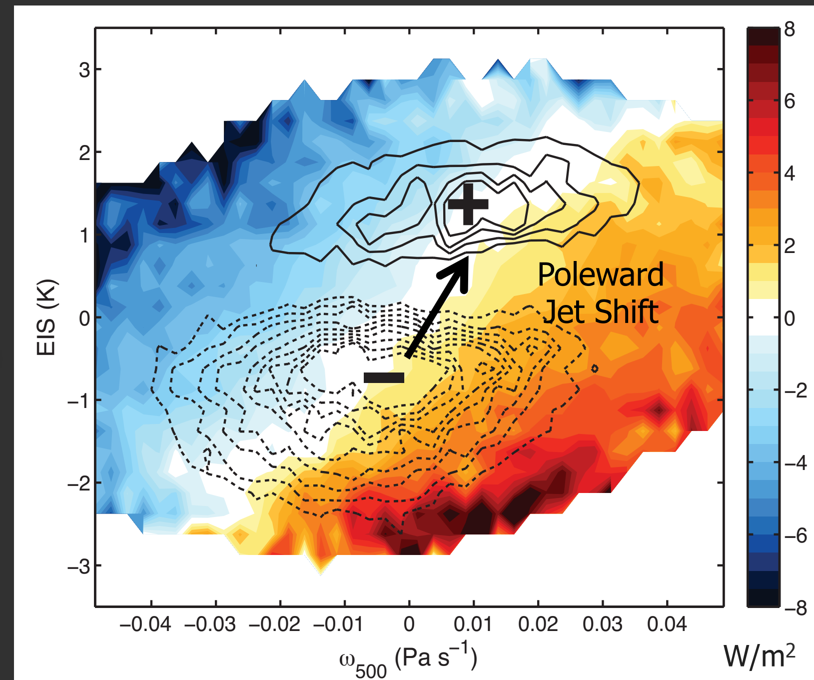


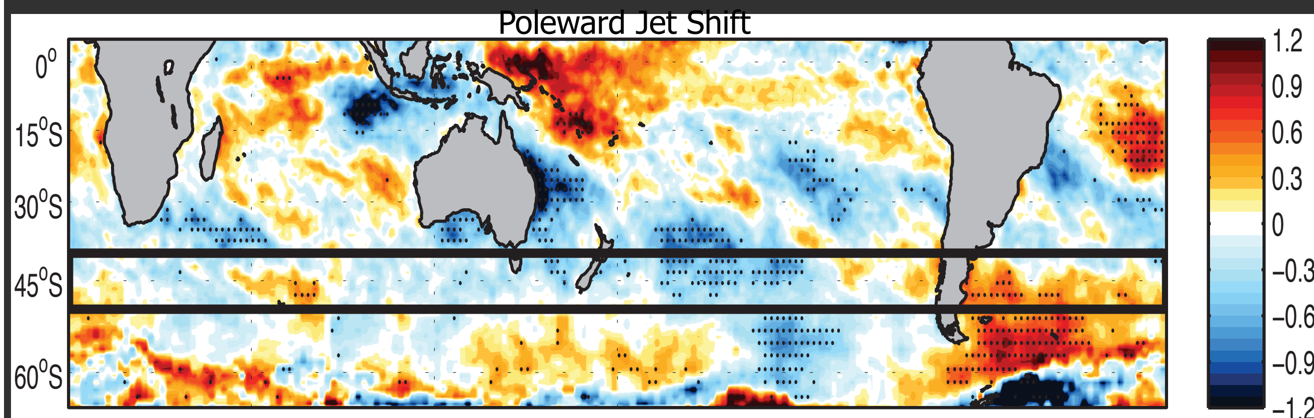
Low clouds increase with increasing strength of boundary layer inversion. (Wood and Bretherton 2006)

Grise and Medeiros (2016)

Poleward Jet Shift: Cloud Controlling Factors





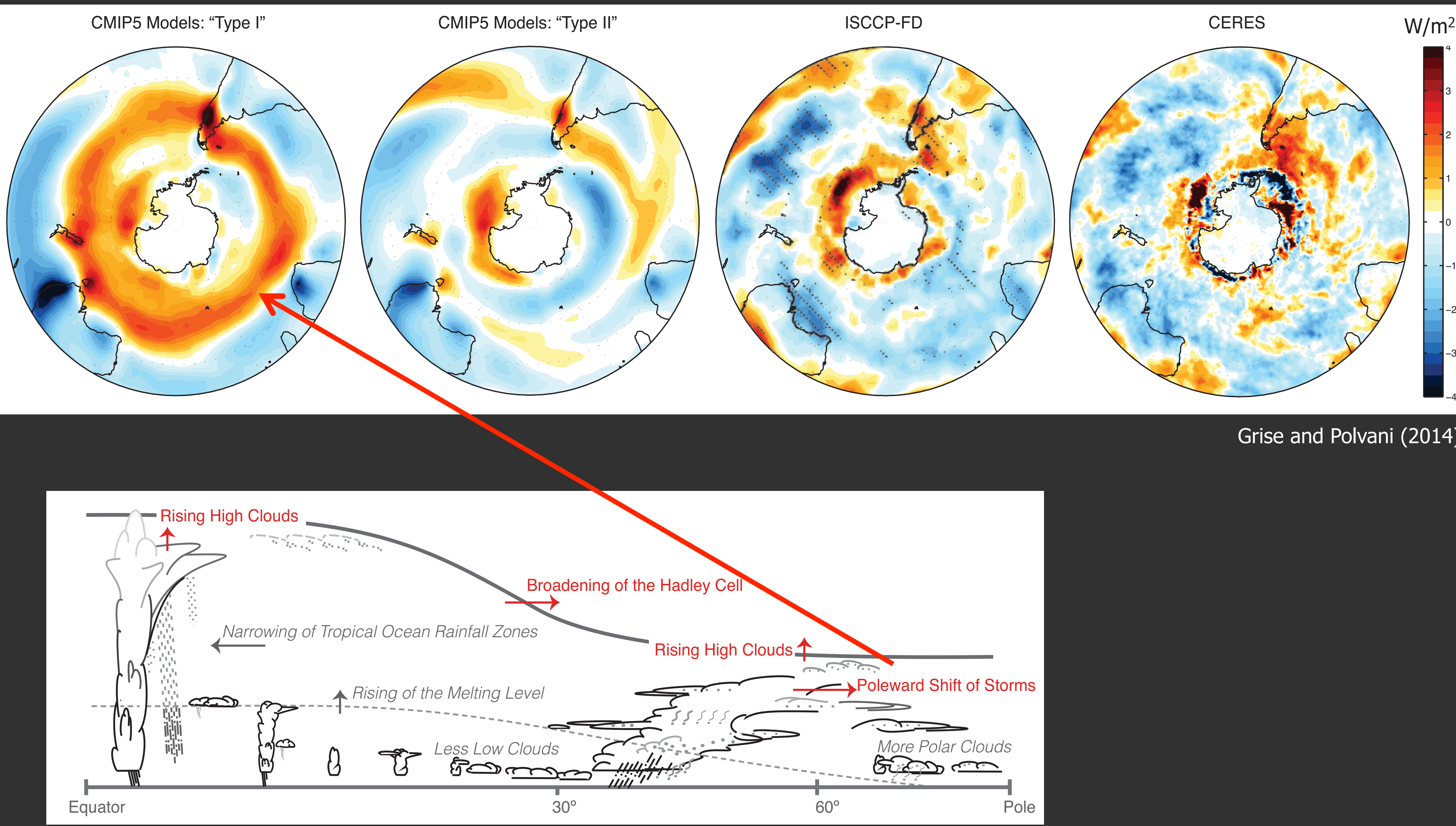


Shortwave cloud-radiative effects depend on both vertical velocity and EIS anomalies. (see also Myers and Norris 2013)

Grise and Medeiros (2016)

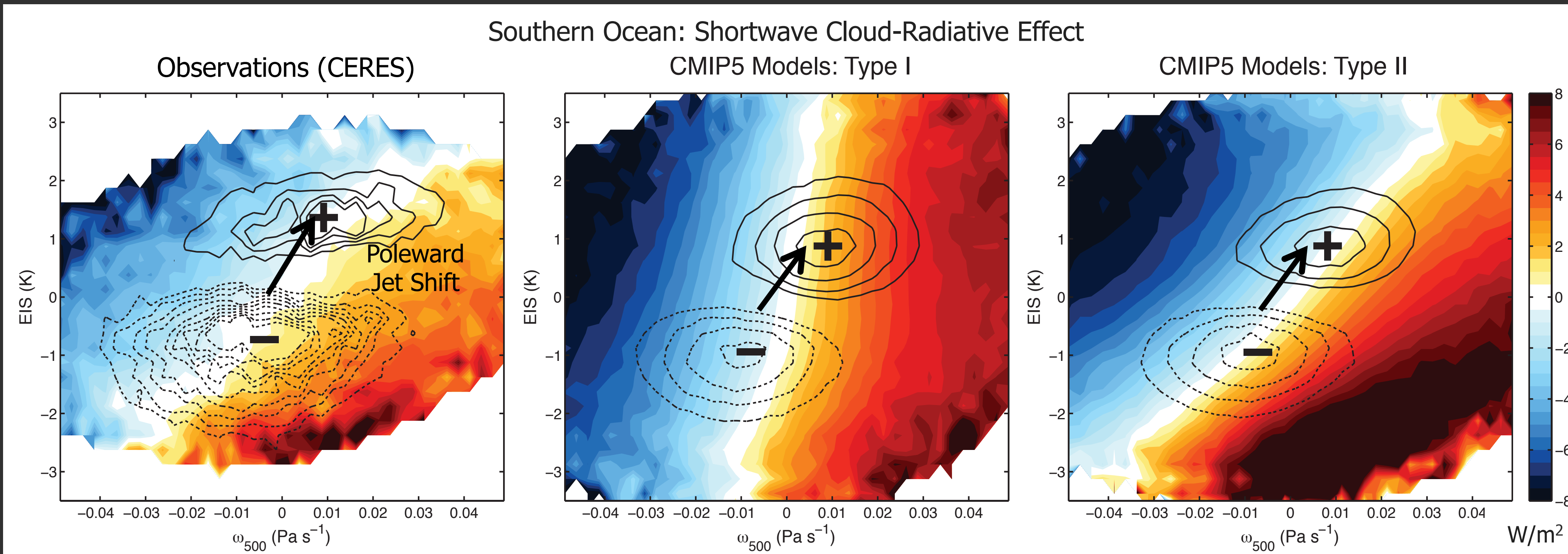
Poleward Jet Shift: Model Biases

Shortwave Cloud-Radiative Effect Anomalies
1° Poleward Jet Shift (Interannual Variability)



Grise and Polvani (2014)

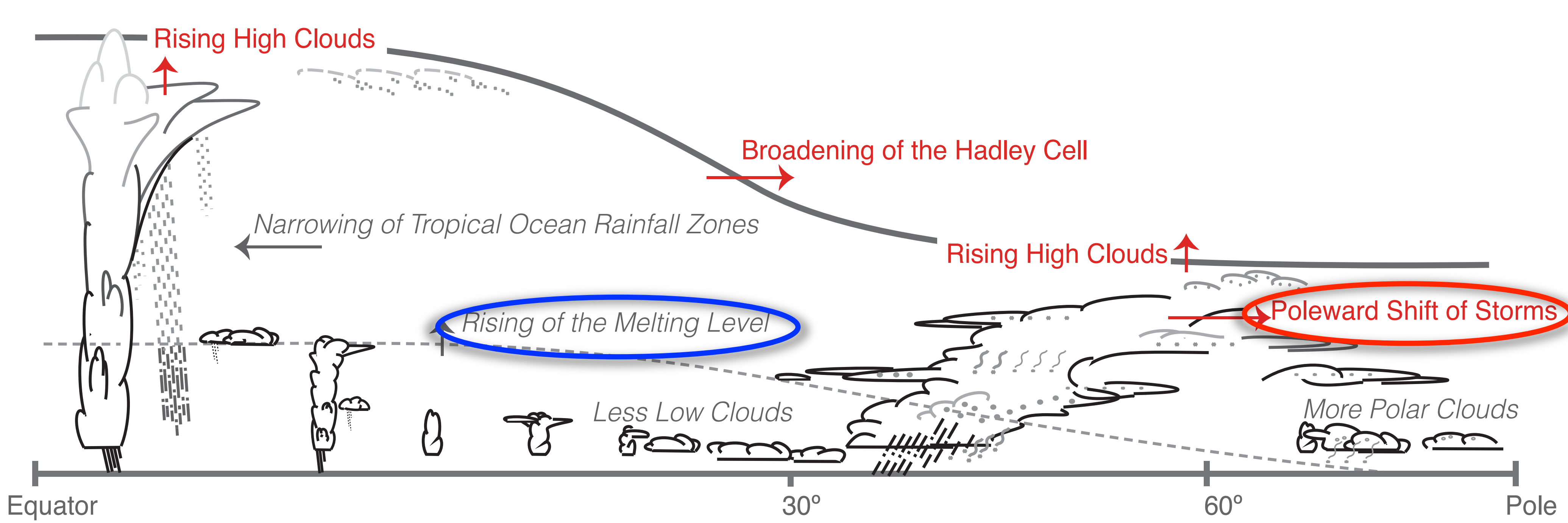
Poleward Jet Shift: Model Biases



Grise and Medeiros (2016)

Biases in type I models arise from an underestimation of the sensitivity of model cloud-radiative effects to the strength of the boundary layer temperature inversion (EIS).

Next: Cloud Phase Feedback



IPCC AR5 (Chapter 7)

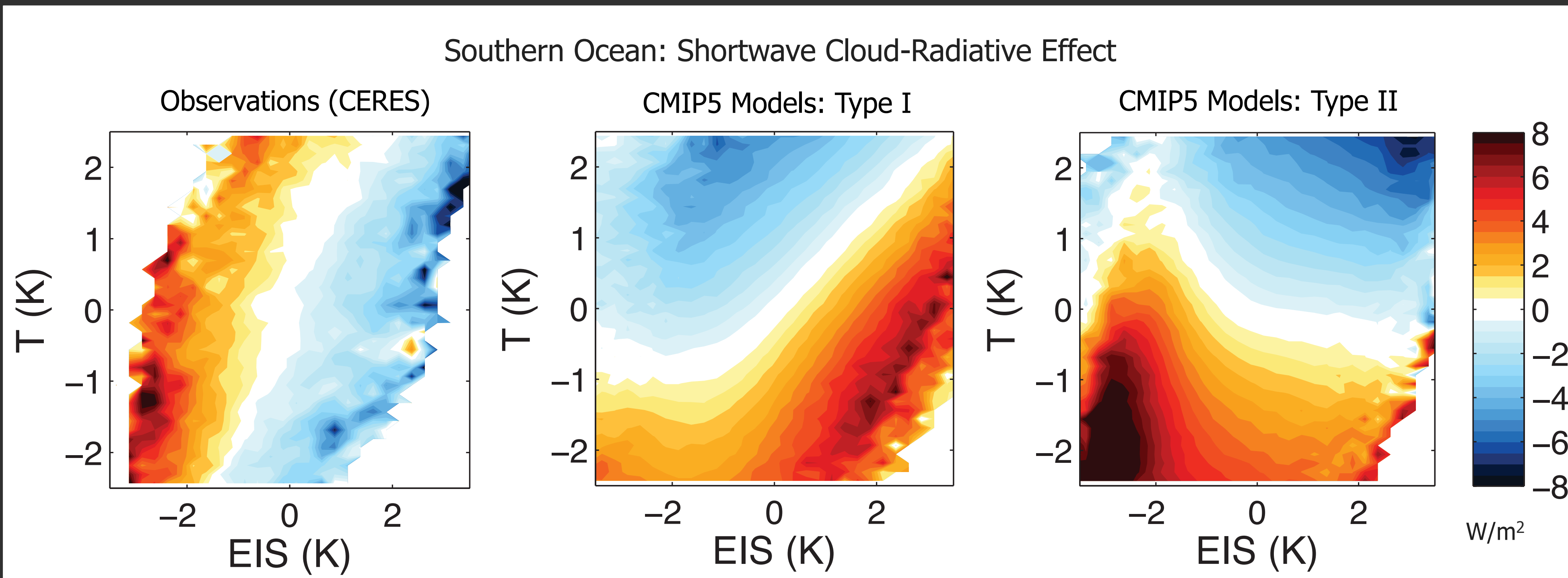
Can we put observational constraints on the dynamic and thermodynamic processes underlying midlatitude cloud feedbacks?

1) Positive cloud feedback with poleward shift of midlatitude jet stream

2) Negative cloud phase feedback at midlatitudes

Cloud Phase Feedback: Controlling Factors

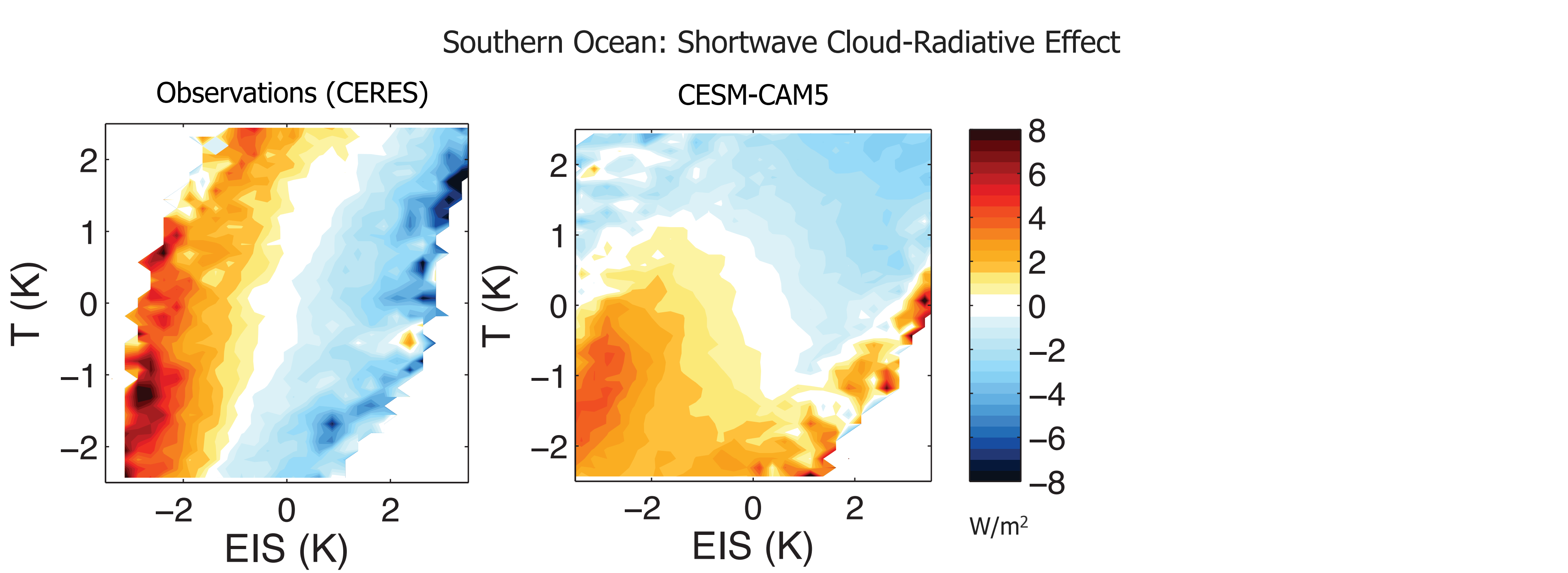
Consider two controlling factors on Southern Ocean shortwave cloud-radiative effects: EIS and temperature (500–850 hPa)



Shortwave cloud-radiative effect variability with temperature is overestimated by CMIP5 models (see also Terai et al. 2016).

Cloud Phase Feedback: Controlling Factors

Consider two controlling factors on Southern Ocean shortwave cloud-radiative effects: EIS and temperature (500–850 hPa)



Cloud Phase Feedback: Controlling Factors

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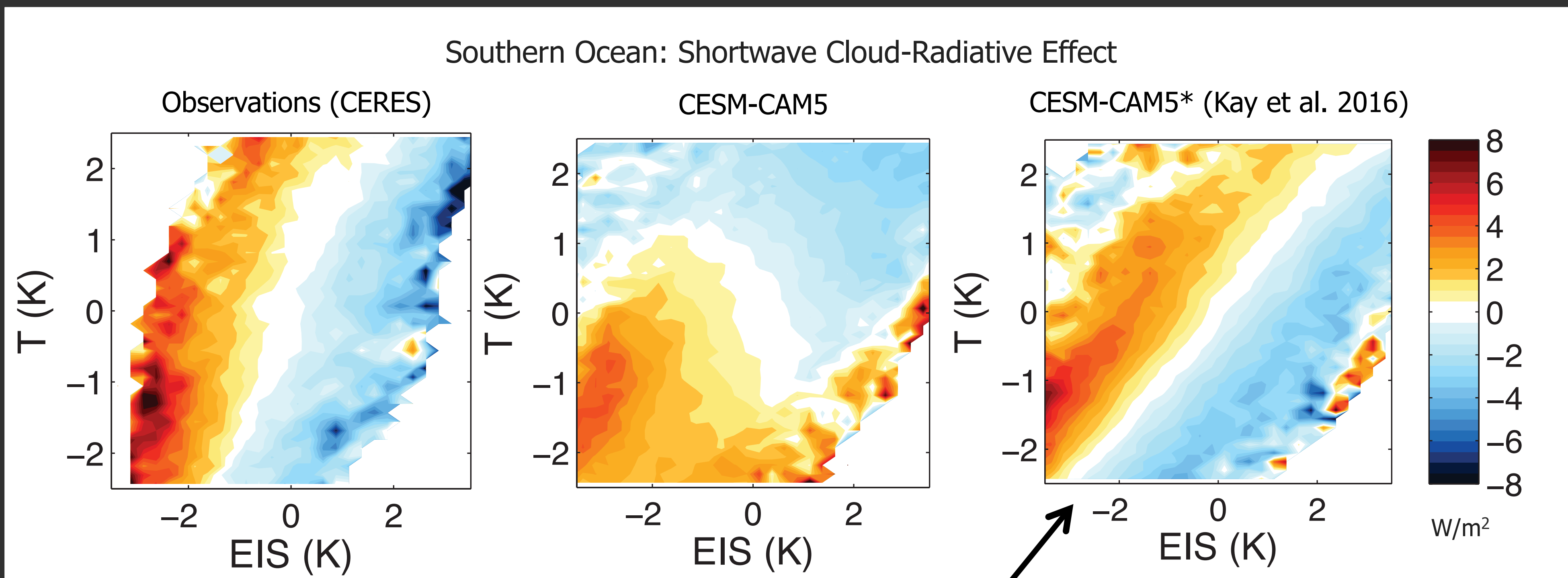


Kay et al. (2016) modified CESM-CAM5, increasing supercooled water at the expense of ice in mixed-phase clouds.

Summary

Can we put observational constraints on the dynamic and thermodynamic processes underlying midlatitude cloud feedbacks?

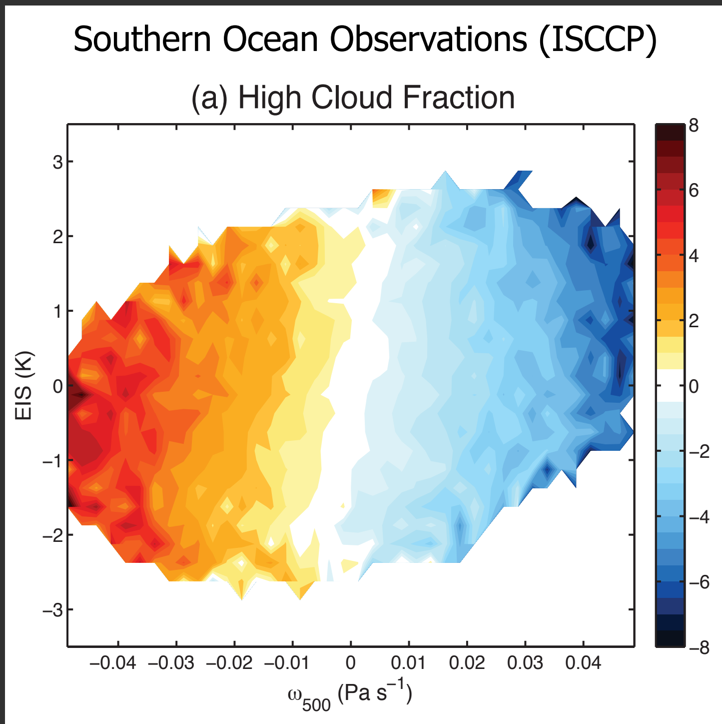
1) Positive cloud feedback with poleward midlatitude jet shift

Likely overestimated as many CMIP5 models underestimate the observed dependence of midlatitude clouds on the strength of the boundary layer temperature inversion (EIS)
(Grise and Medeiros 2016)

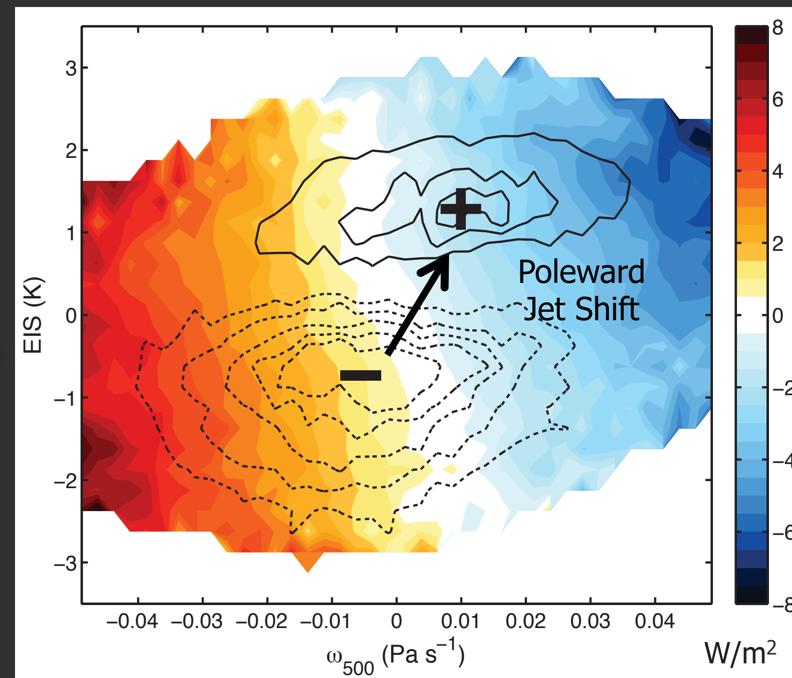
2) Negative cloud phase feedback at midlatitudes

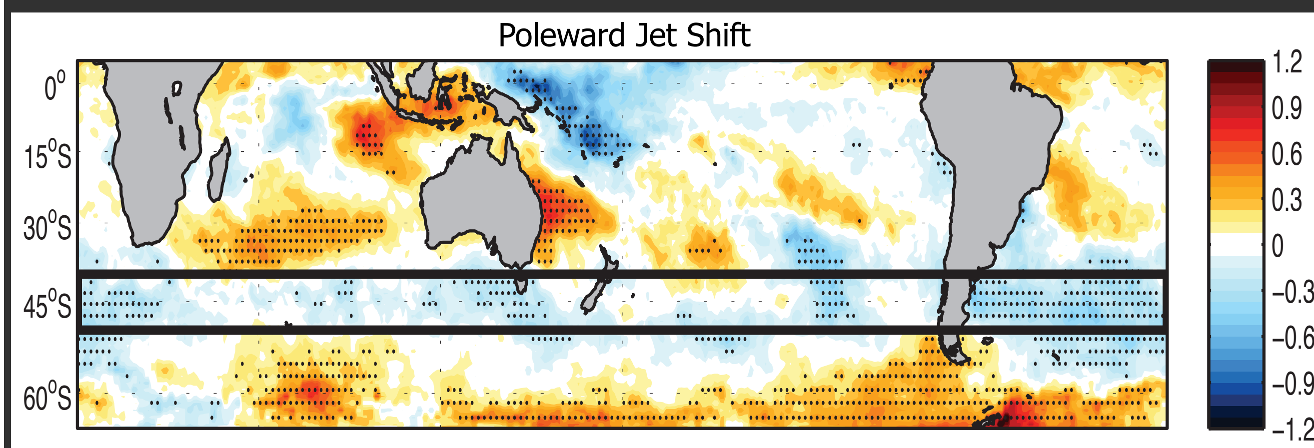
Likely overestimated as CMIP5 models overestimate the observed dependence of midlatitude clouds on temperature variability (see also Terai et al. 2016, Tan et al. 2016, etc.)

Poleward Jet Shift: Cloud Controlling Factors



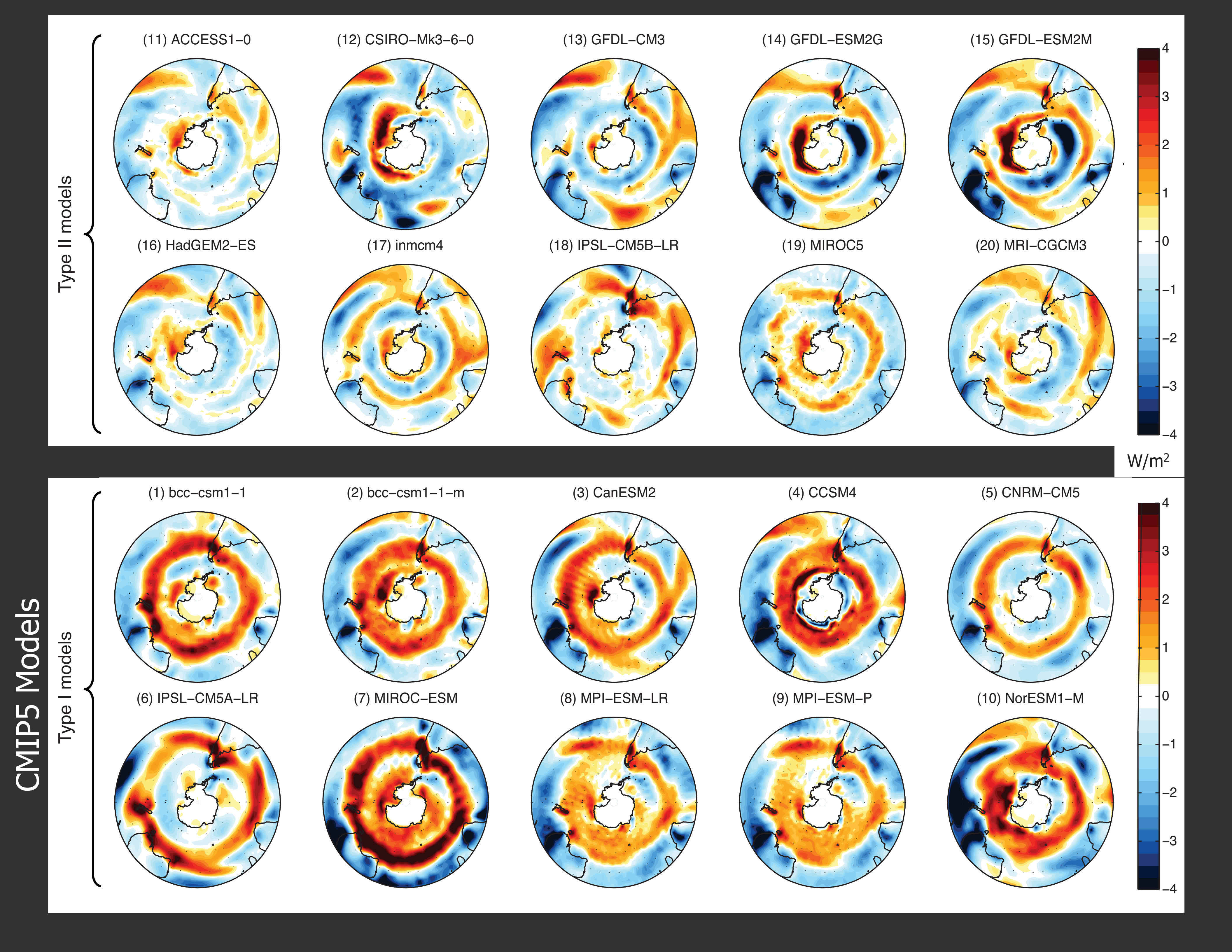
Longwave Cloud-Radiative Effect (CERES)





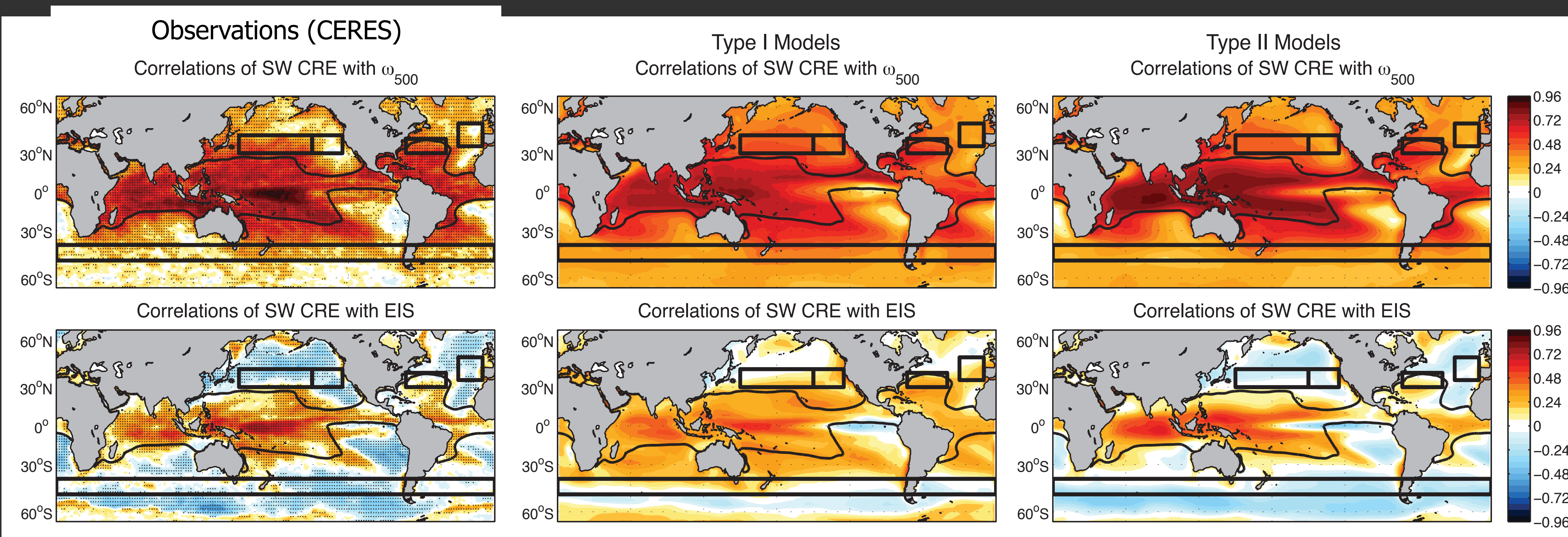
Longwave cloud-radiative effects closely follow vertical motion.

Grise and Medeiros (2016)



CMIP5 Models
Type II models
(11) ACCESS1−0
(12) CSIRO−Mk3−6−0
(13) GFDL−CM3
(14) GFDL−ESM2G
(15) GFDL−ESM2M
(16) HadGEM2−ES
(17) inmcm4
(18) IPSL−CM5B−LR
(19) MIROC5
(20) MRI−CGCM3
W/m2
Type I models
(1) bcc−csm1−1
(2) bcc−csm1−1−m
(3) CanESM2
(4) CCSM4
(5) CNRM−CM5
(6) IPSL−CM5A−LR
(7) MIROC−ESM
(8) MPI−ESM−LR
(9) MPI−ESM−P
(10) NorESM1−M
4
3
2
1
0
−1
−2
−3
−4

Understanding the Model Biases

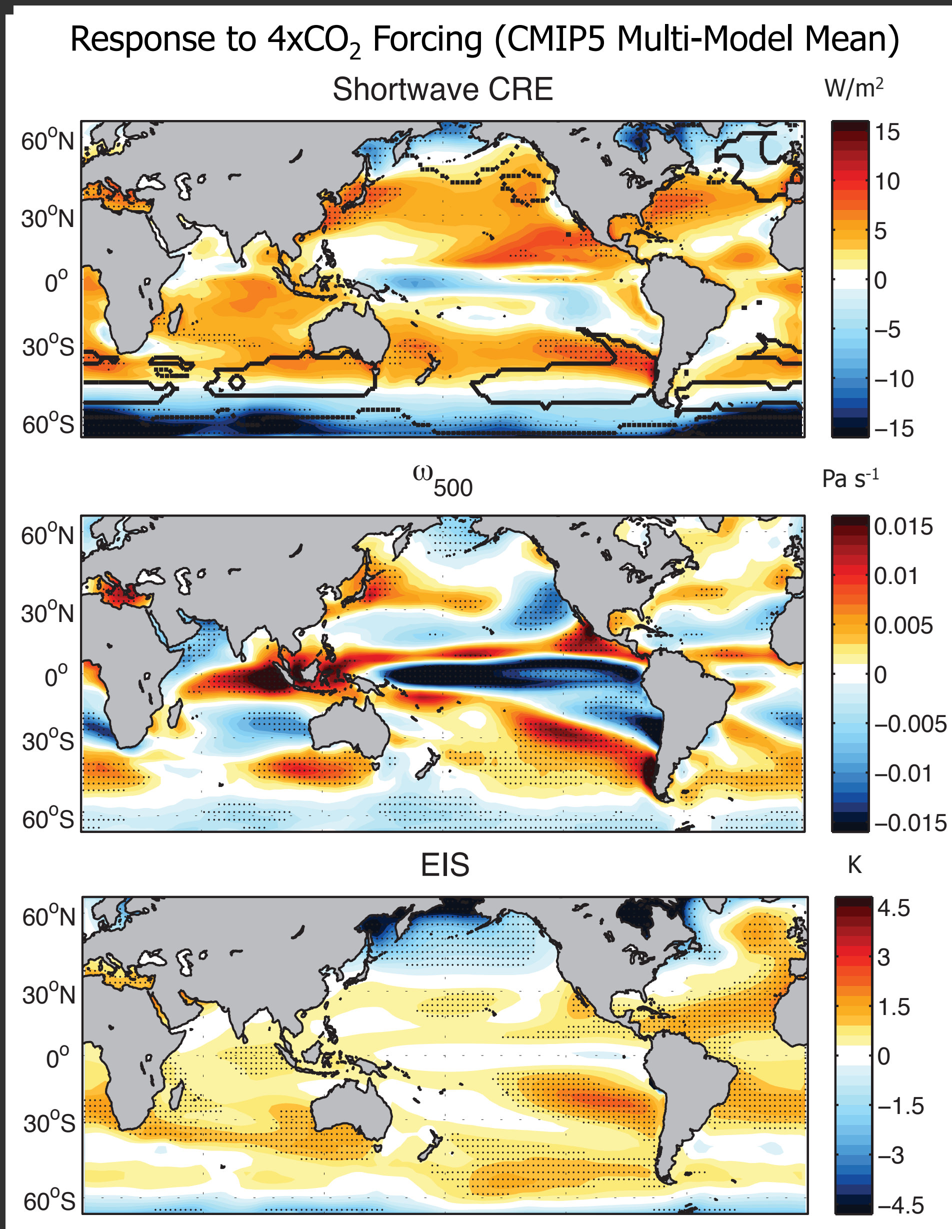


Grise and Medeiros (2016)

Biases in type I models appear related to overdependence of model cloud-radiative effects on vertical motion and underdependence of model cloud-radiative effects on lower tropospheric stability.

Qu et al. (2015) reach similar conclusion for subtropical clouds.

Implications for Climate Feedbacks



Grise and Medeiros (2016)

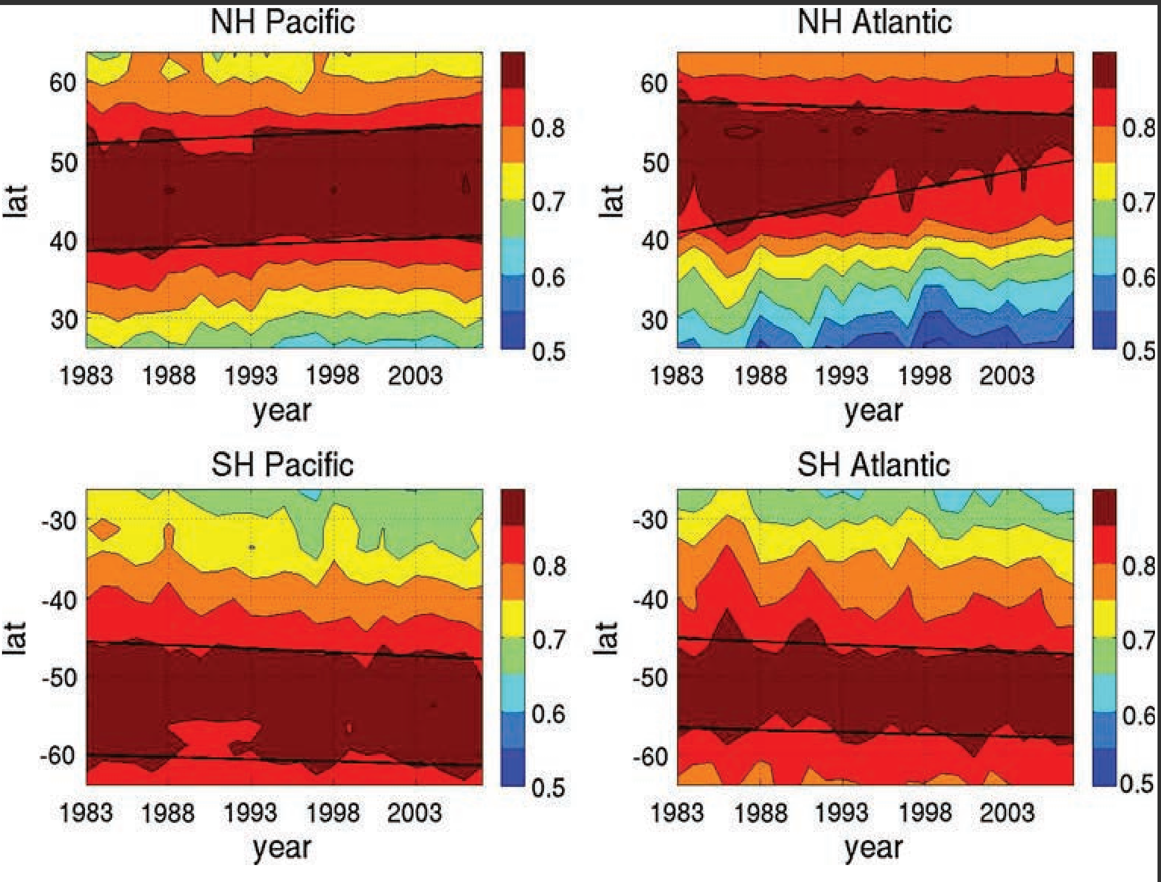
In response to increasing greenhouse gases, many climate models project similarly signed changes in EIS and vertical velocity over mid-latitude oceans.

Should we have lower confidence in dynamically driven cloud feedbacks in type I models in these regions?

Evidence from Observed Trends

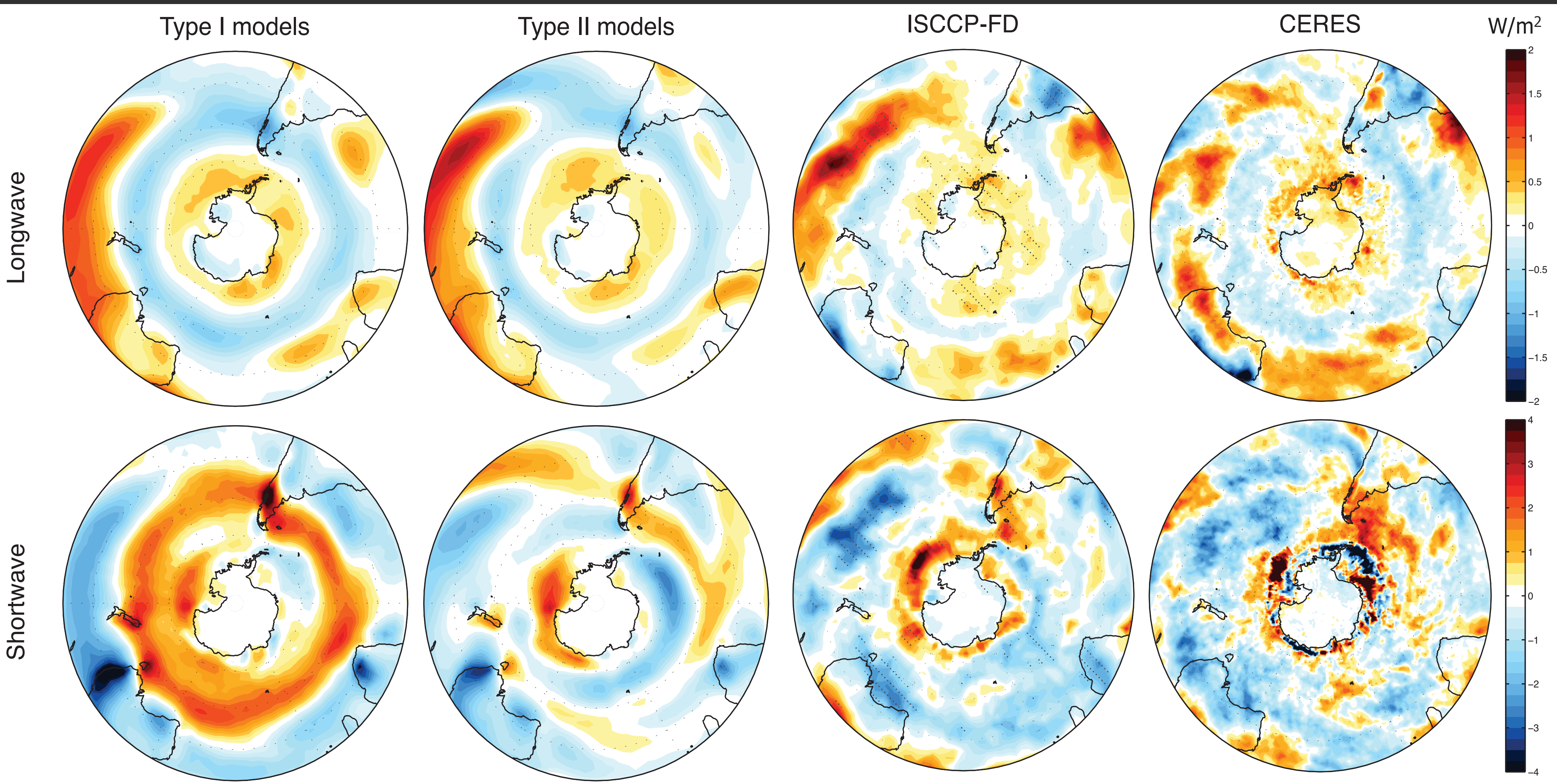
Bender et al. (2012)

Annual-mean Total Cloud Fraction



- ISCCP satellite observations suggest poleward shift in mid-latitude cloud patterns.
  - Reduction in total cloud cover
  - Increase in high cloud cover
  - Positive net radiative effect
- Poleward shift in mid-latitude cloud bands also apparent in surface-based cloud observations (Eastman and Warren 2013).

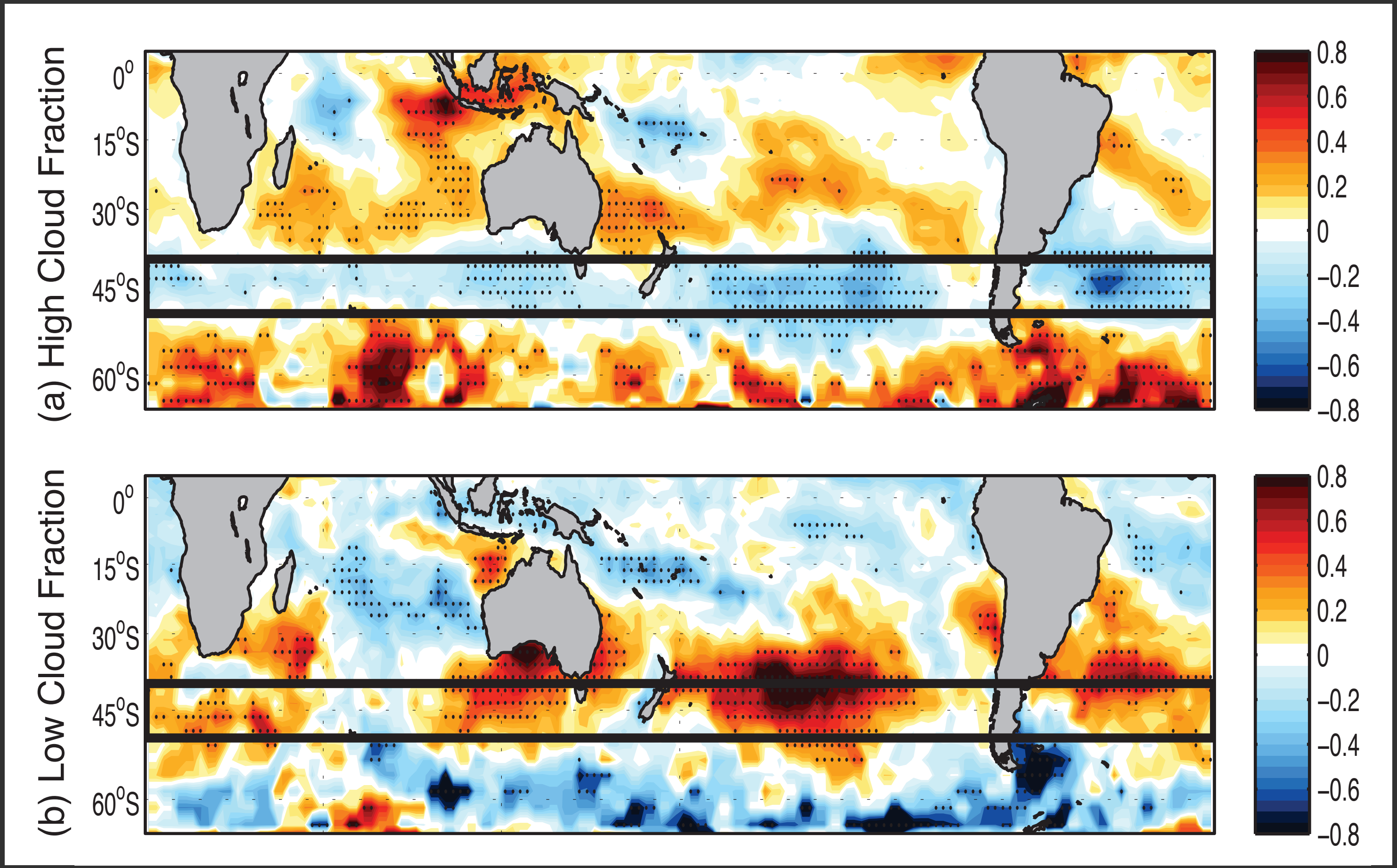
CMIP5 Models — Satellite Observations

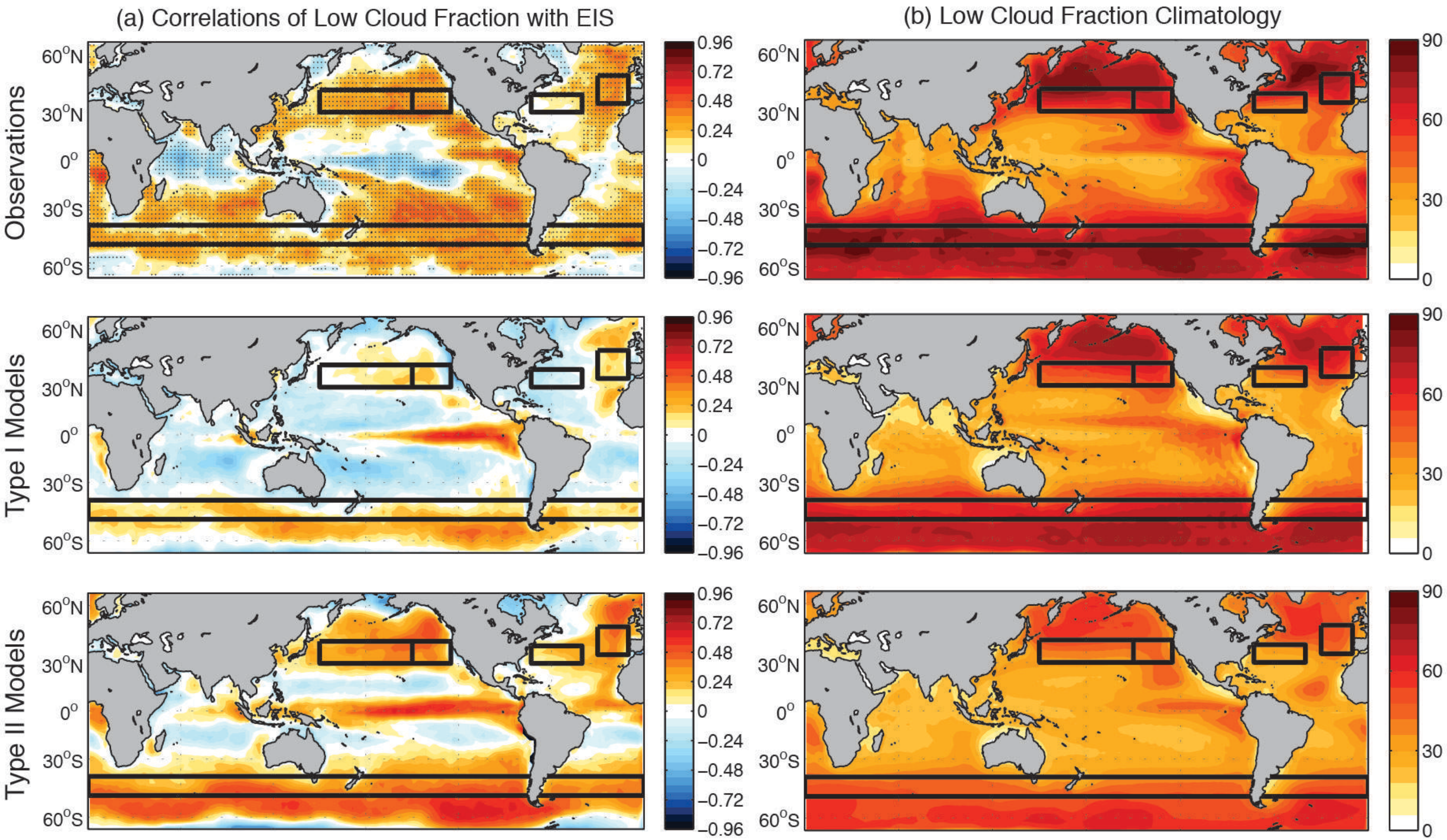


Cloud-Radiative Effect Anomalies Associated with 1° Poleward Jet Shift

Cloud Anomalies

1° Poleward Jet Shift (Observed Variability)



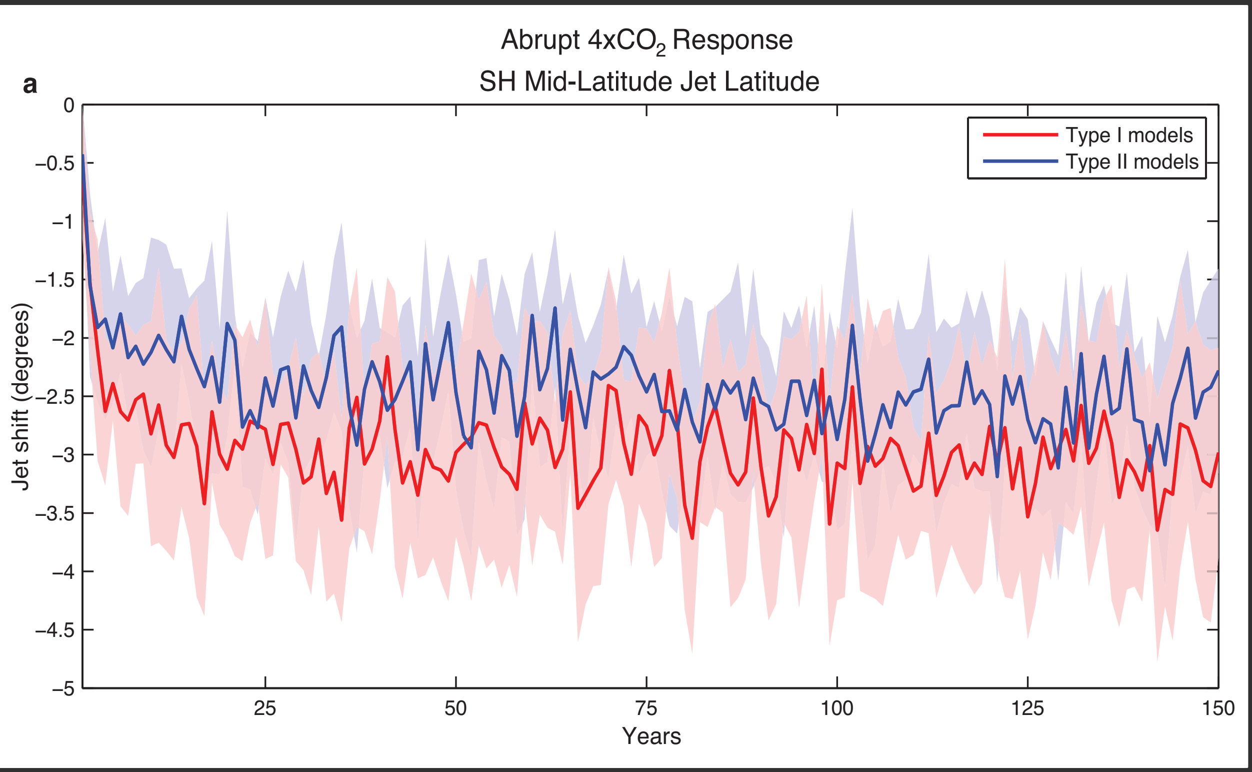


(a) Correlations of Low Cloud Fraction with EIS
(b) Low Cloud Fraction Climatology
Observations
Type I Models
Type II Models
60°N
30°N
0°
30°S
60°S
0.96
0.72
0.48
0.24
0
−0.24
−0.48
−0.72
−0.96
90
60
30
0

Implications for Climate Change

Idealized Experiment: Abrupt Quadrupling of CO_2

1) Jet shifts rapidly poleward in both classes of CMIP5 models.



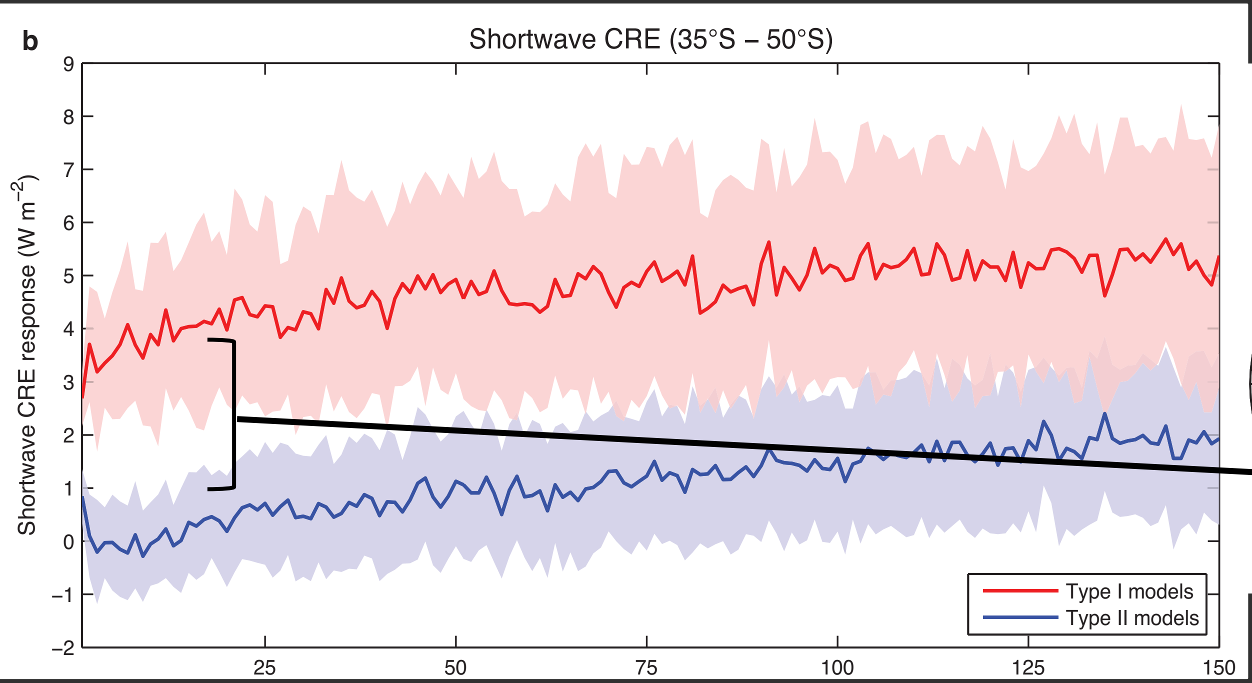
Grise and Polvani (2014, J. Climate)

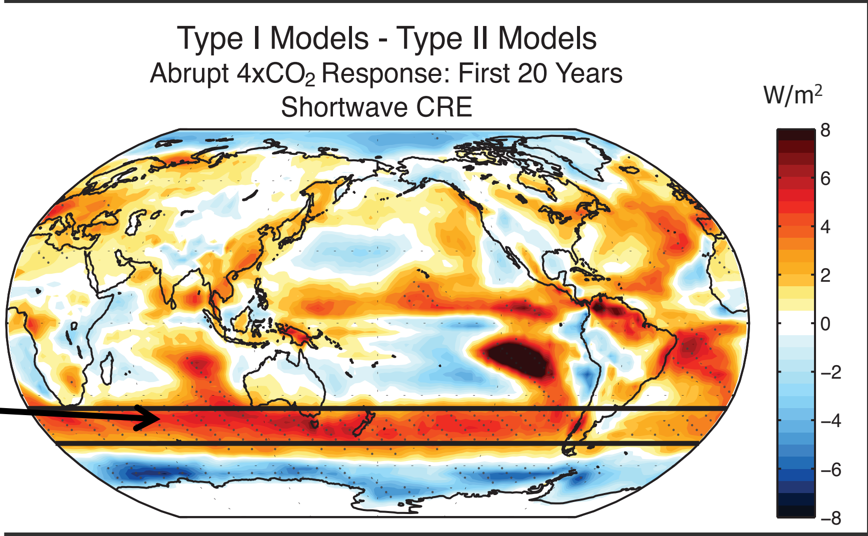
Implications for Climate Change

Idealized Experiment: Abrupt Quadrupling of CO_2

1) Jet shifts rapidly poleward in both classes of CMIP5 models.

2) Rapid reduction in reflection of shortwave radiation by clouds in Type I models only



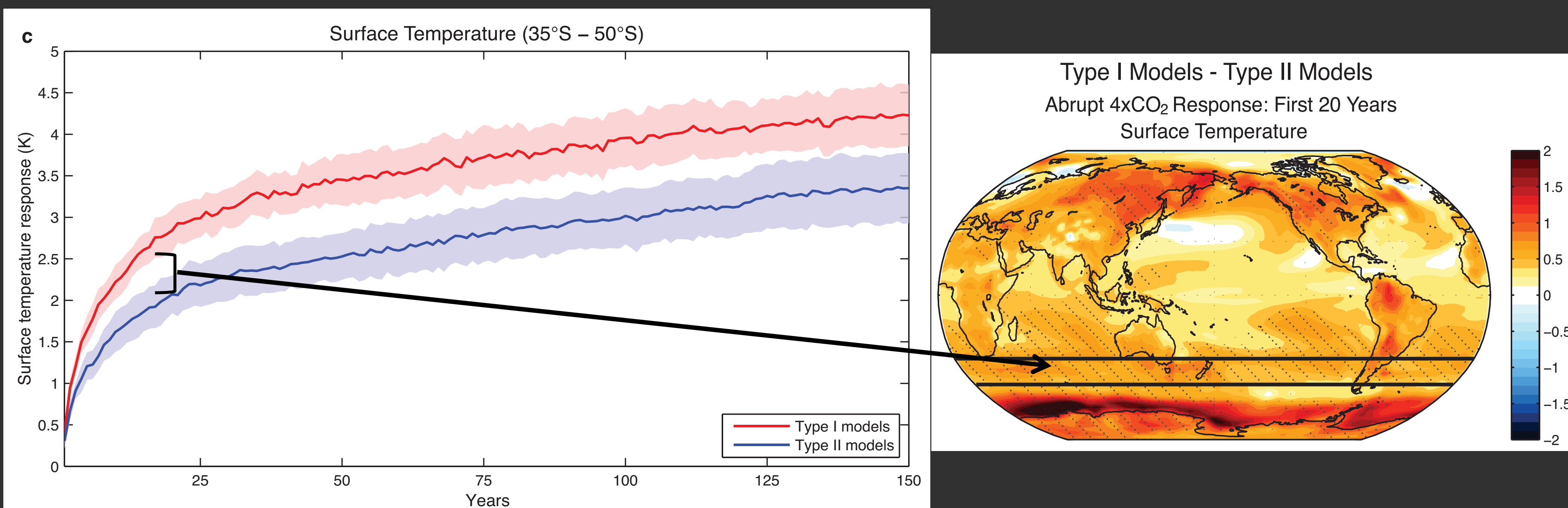


Grise and Polvani (2014, J. Climate)

Implications for Climate Change

Idealized Experiment: Abrupt Quadrupling of CO_2

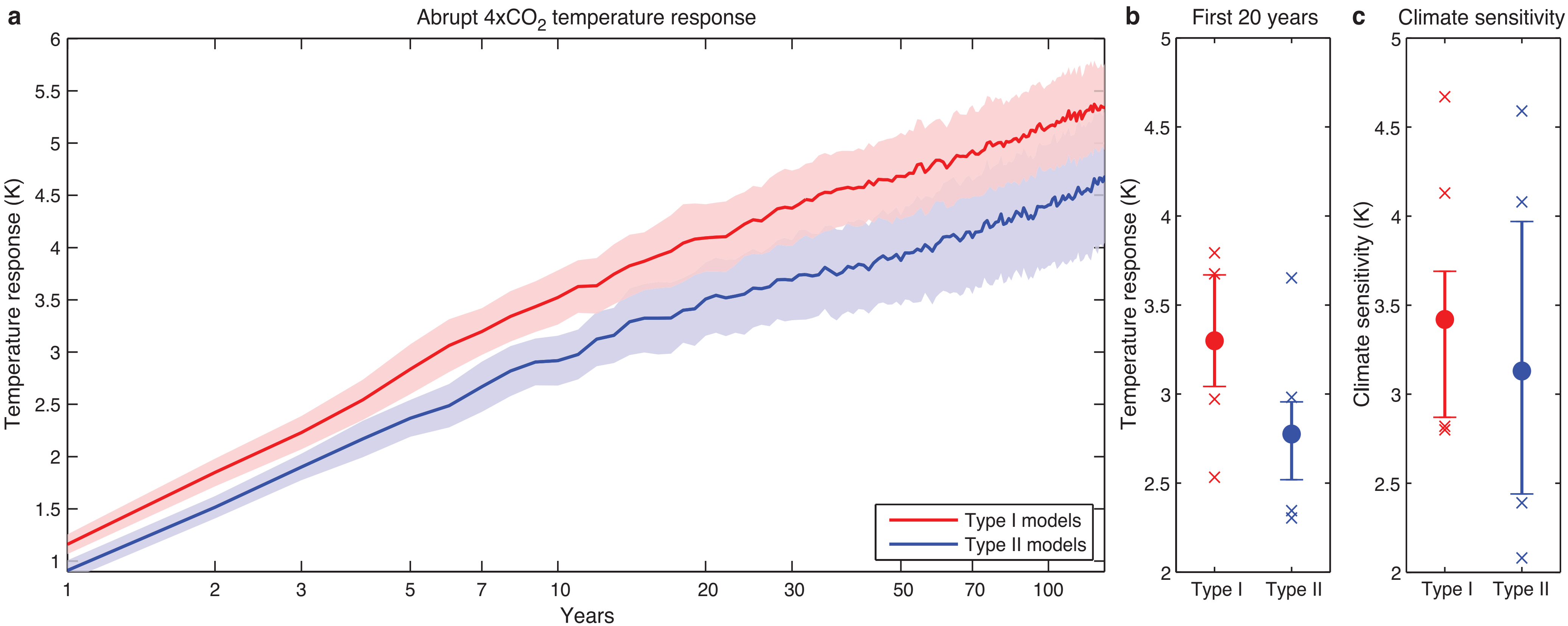
1) Jet shifts rapidly poleward in both classes of CMIP5 models.
2) Rapid reduction in reflection of shortwave radiation by clouds in Type I models only
3) Excess initial warming in SH in Type I models



Grise and Polvani (2014, J. Climate)

Implications for Climate Change

Idealized Experiment: Abrupt Quadrupling of CO_2

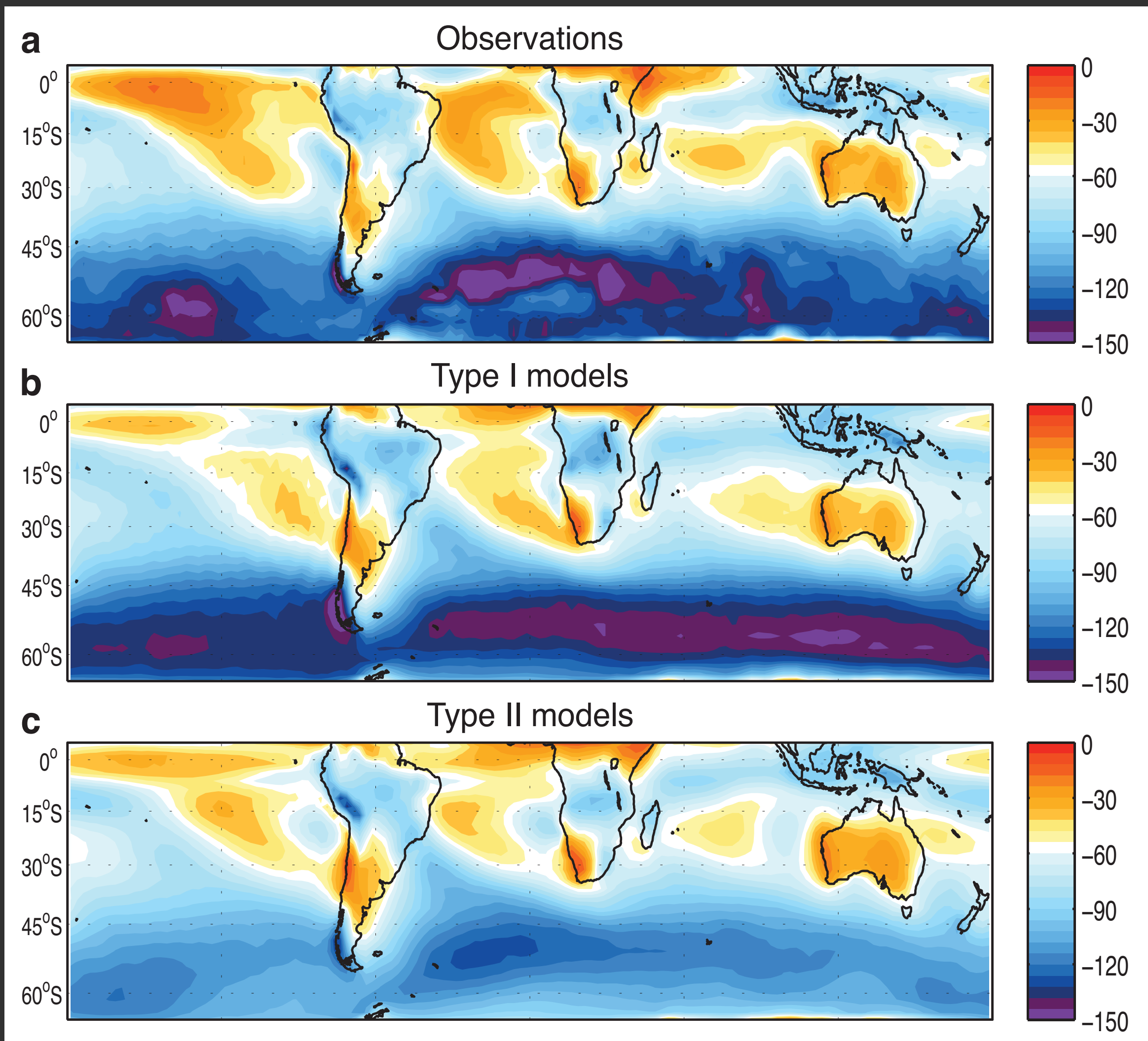


Grise and Polvani (2014, J. Climate)

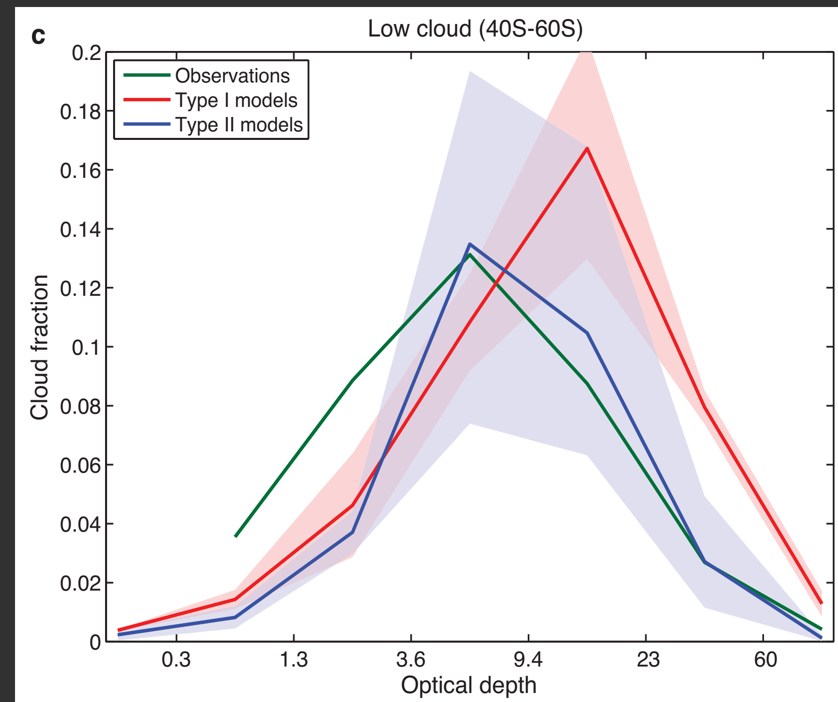
Nearly instantaneous global warming response is significantly larger in the type I models.

Why do the models behave so differently?

Shortwave Cloud-Radiative Effect Climatology



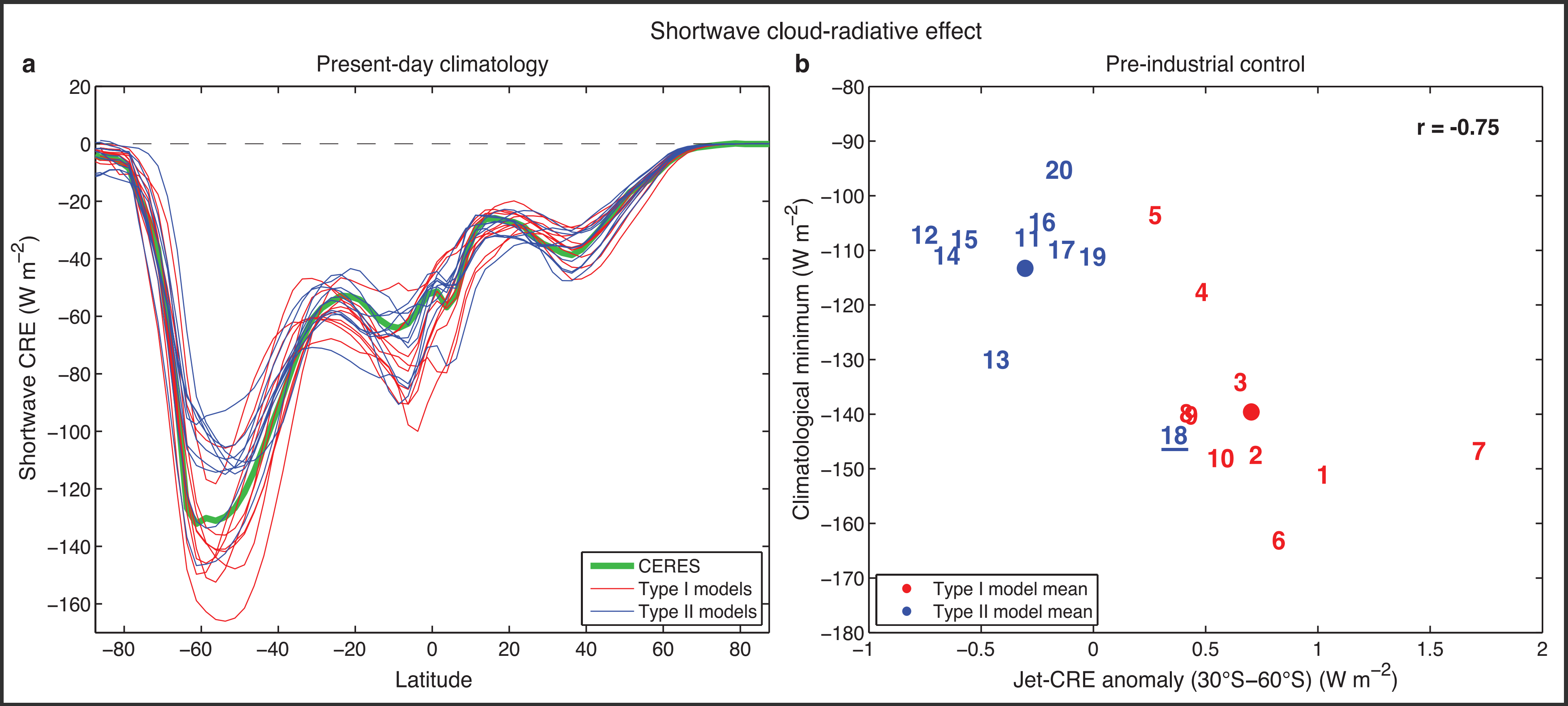
Cloud Fraction Climatology



Grise and Polvani (submitted)

- <u>Type I models:</u> Bright, zonally symmetric Southern Ocean clouds
- <u>Type II models:</u> Less bright, more zonally asymmetric clouds

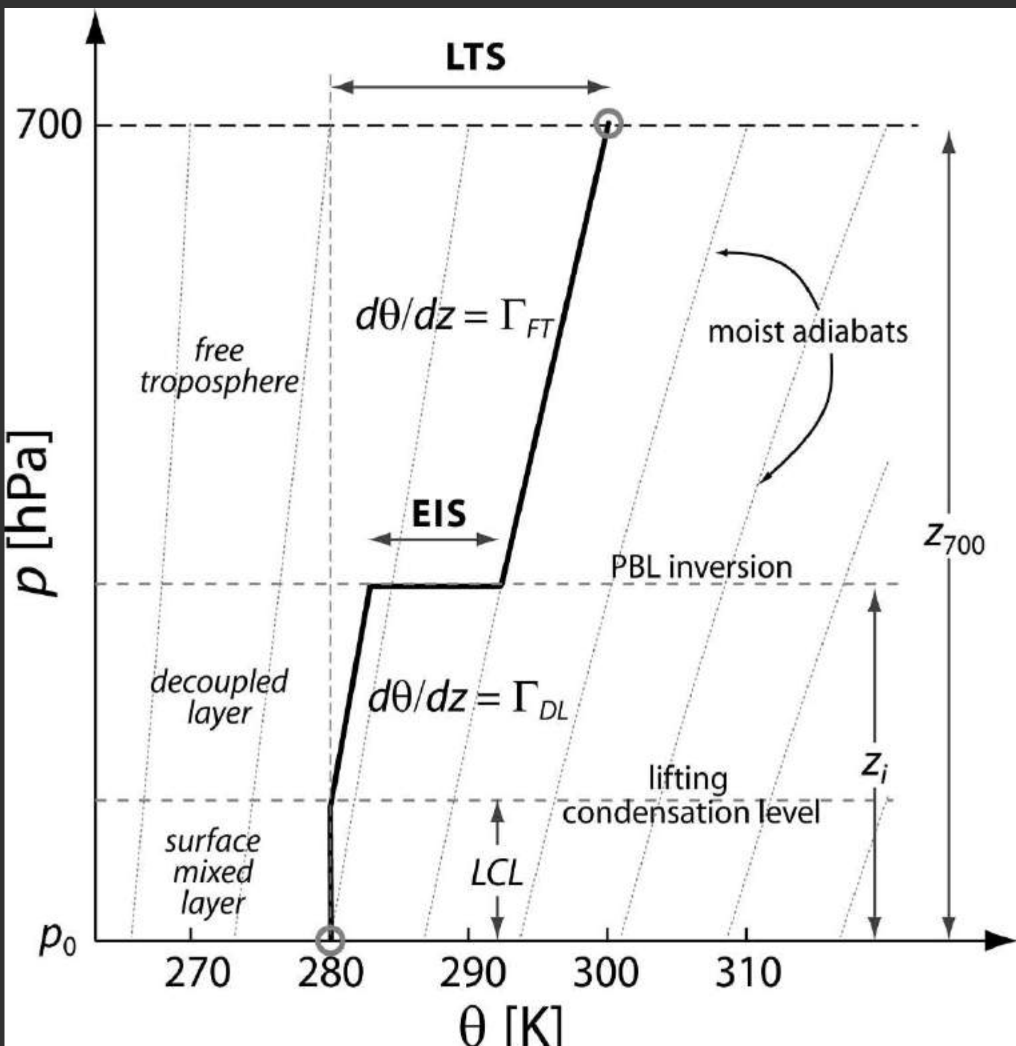
CMIP5 CRE Zonal Mean Climatology



Estimated Inversion Strength (EIS)

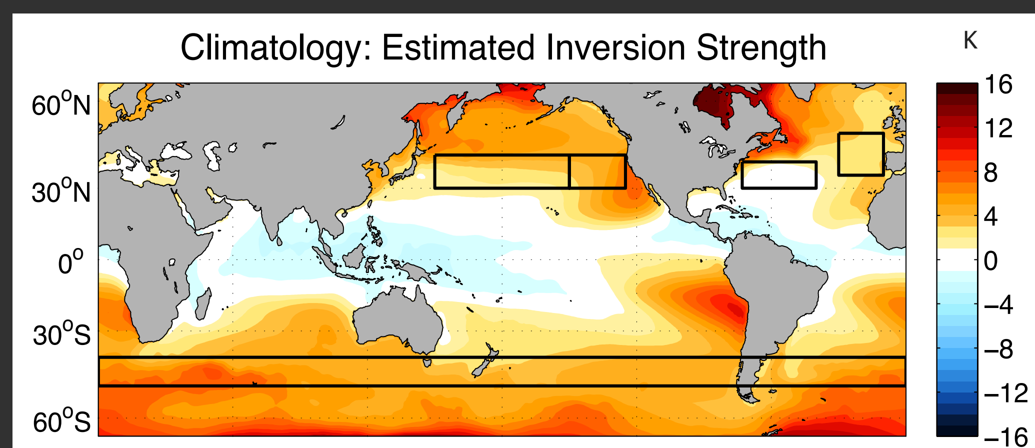
Wood and Bretherton (2006)

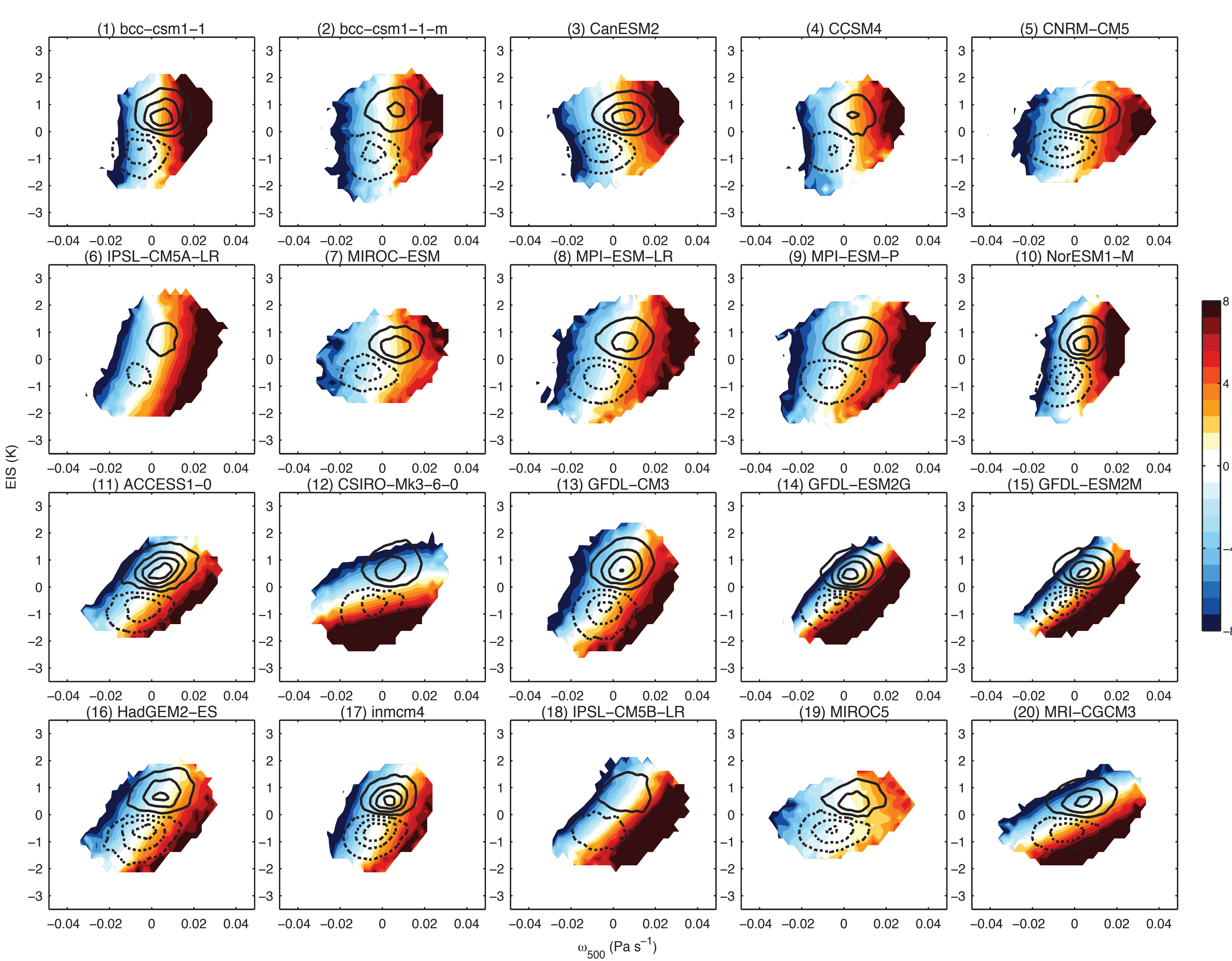
- $EIS = \theta_{700\ hPa} - \theta_{sfc} - \Gamma_{moist\ (850\ hPa)} (z_{700hPa} - z_{LCL})$



$\Delta\theta = \theta_{700\ hPa} - \theta_{sfc} - \Gamma_{FT} (z_{700} - z_i) - \Gamma_{DL} (z_i - LCL)$

$\Delta\theta = \theta_{700\ hPa} - \theta_{sfc} - \Gamma_{FT}\, z_{700} + \Gamma_{DL}\, LCL$




(1) bcc–csm1–1
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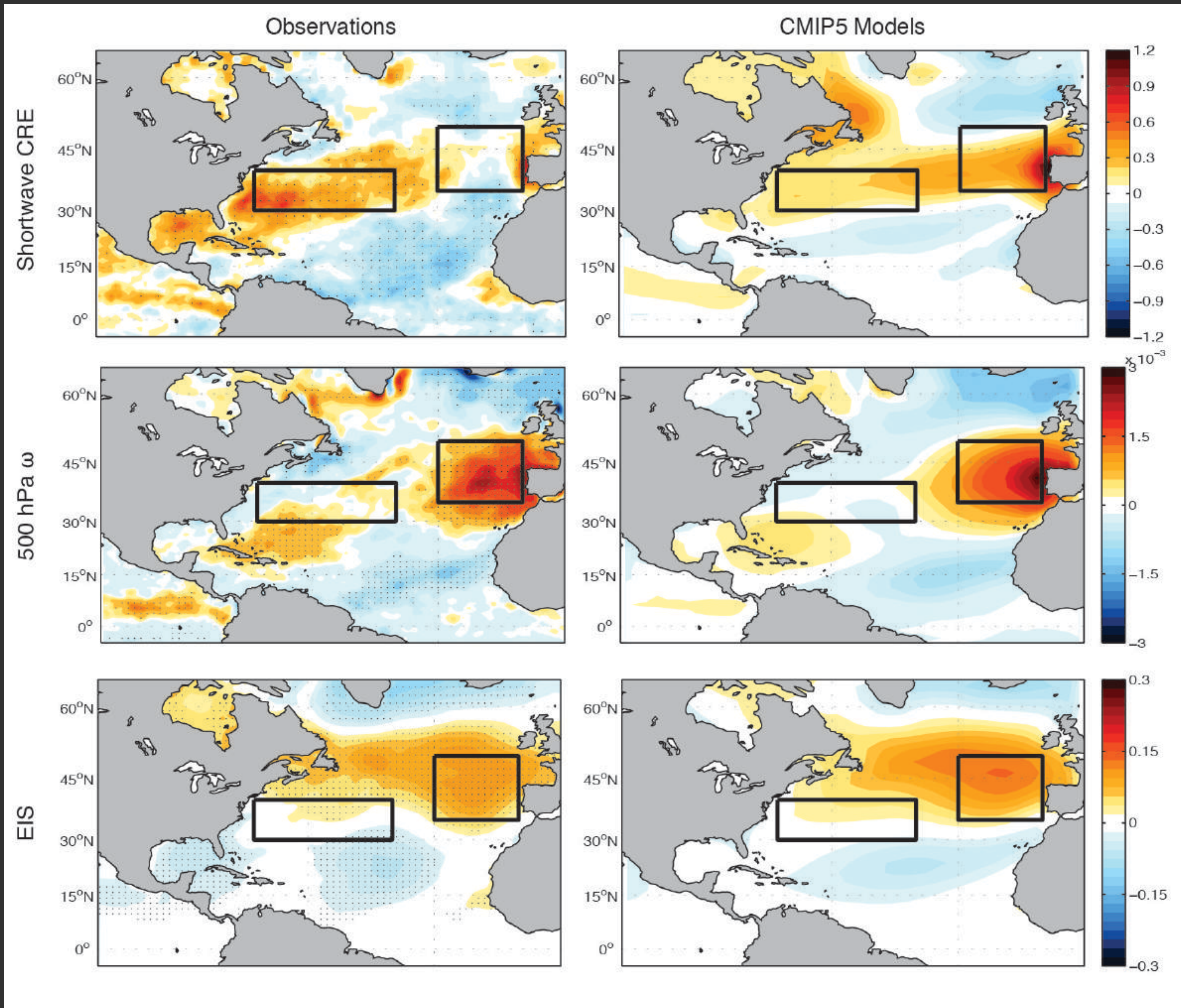
(13) GFDL–CM3
(14) GFDL–ESM2G
(15) GFDL–ESM2M
(16) HadGEM2–ES
(17) inmcm4
(18) IPSL–CM5B–LR
(19) MIROC5
(20) MRI–CGCM3
EIS (K)
ω_{500} (Pa s^{-1})
8
4
0
−4
−8

What about the Northern Hemisphere?



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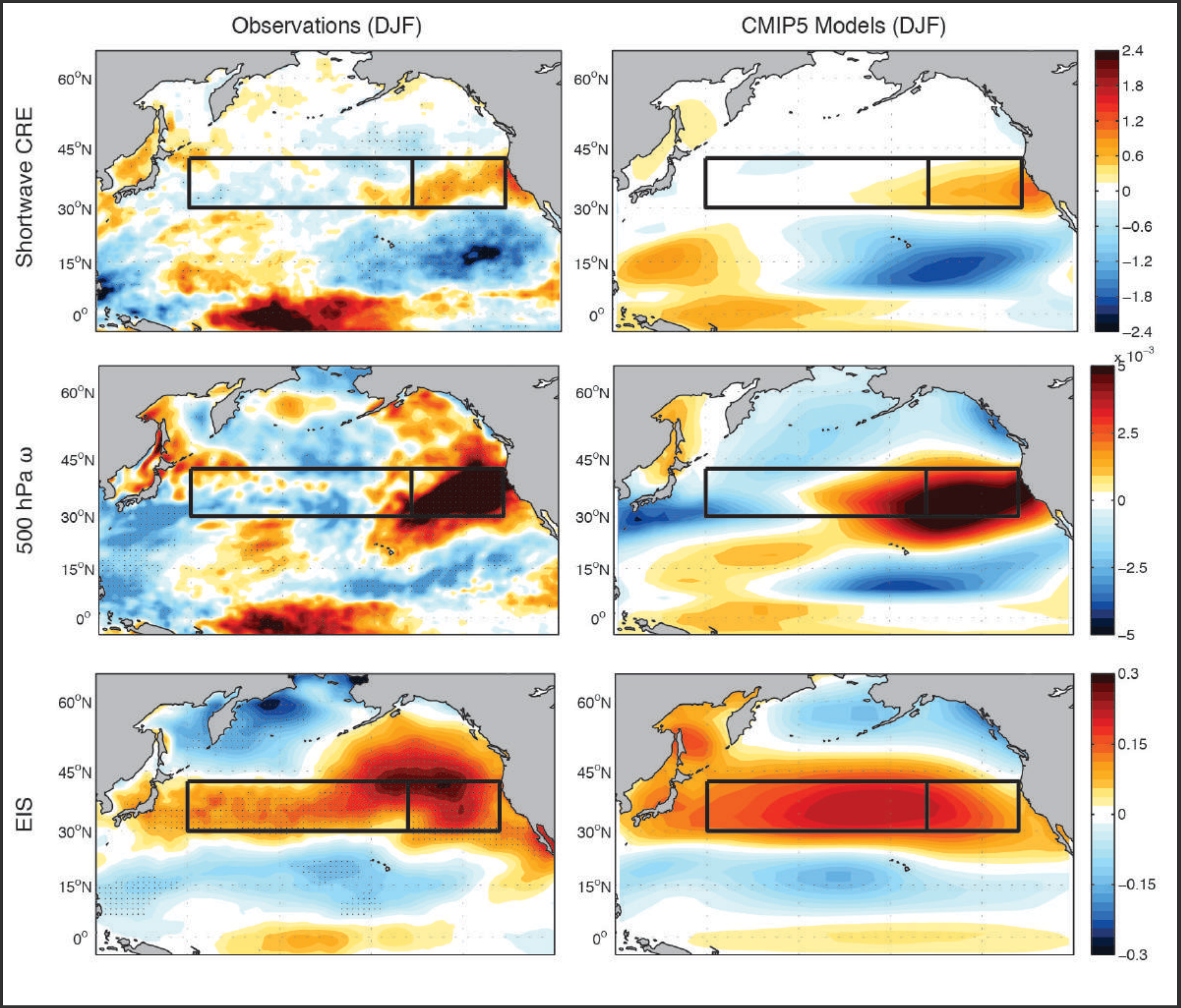

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