

unraveling cloud feedbacks

brian medeiros

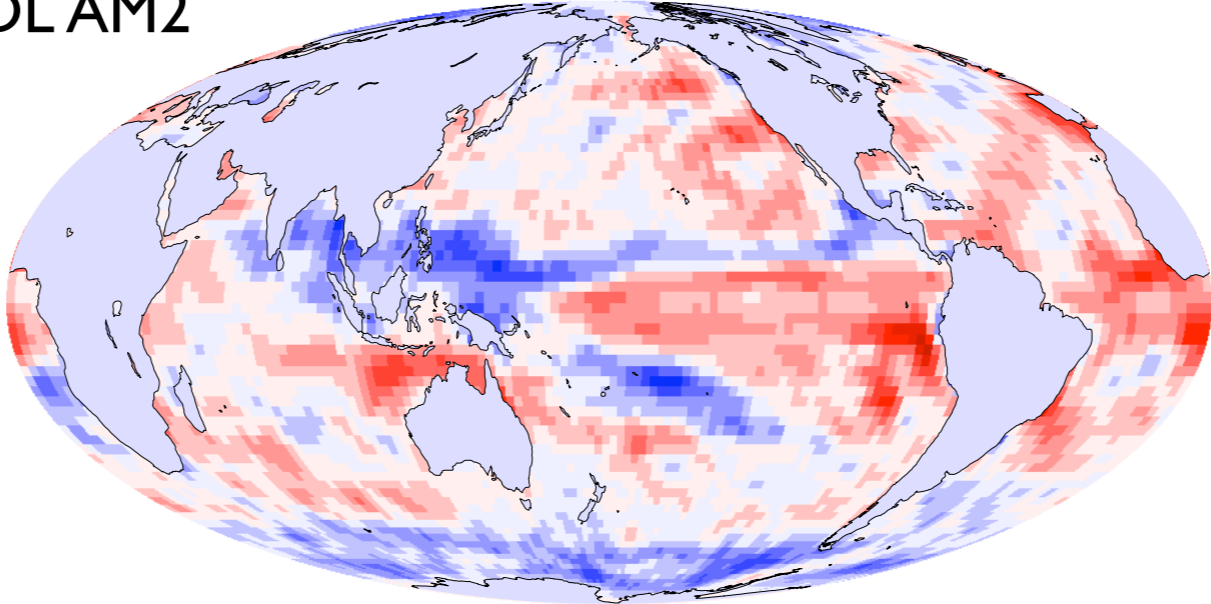
AOS 270, UCLA, 31 may 2006

ABSTRACT:

The response of clouds to climate changes differs widely among general circulation models (GCMs). This disagreement about cloud feedbacks is the largest source of uncertainty in projections of future climate, and has been so for years. Studies of cloud feedbacks are dominated by diagnostic studies of GCMs and simple theoretical models of the tropical circulation. Here I add another diagnostic study comparing two GCMs under a simple climate change, using realistic and simplified aquaplanet configurations. The aquaplanet cloud response is shown to be closely related to the full GCM, and it is suggested that this simple configuration can be used to bridge the gap between climate models and simple theoretical models.

an inconvenient truth

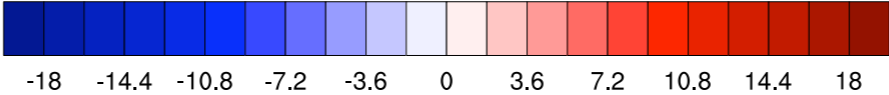
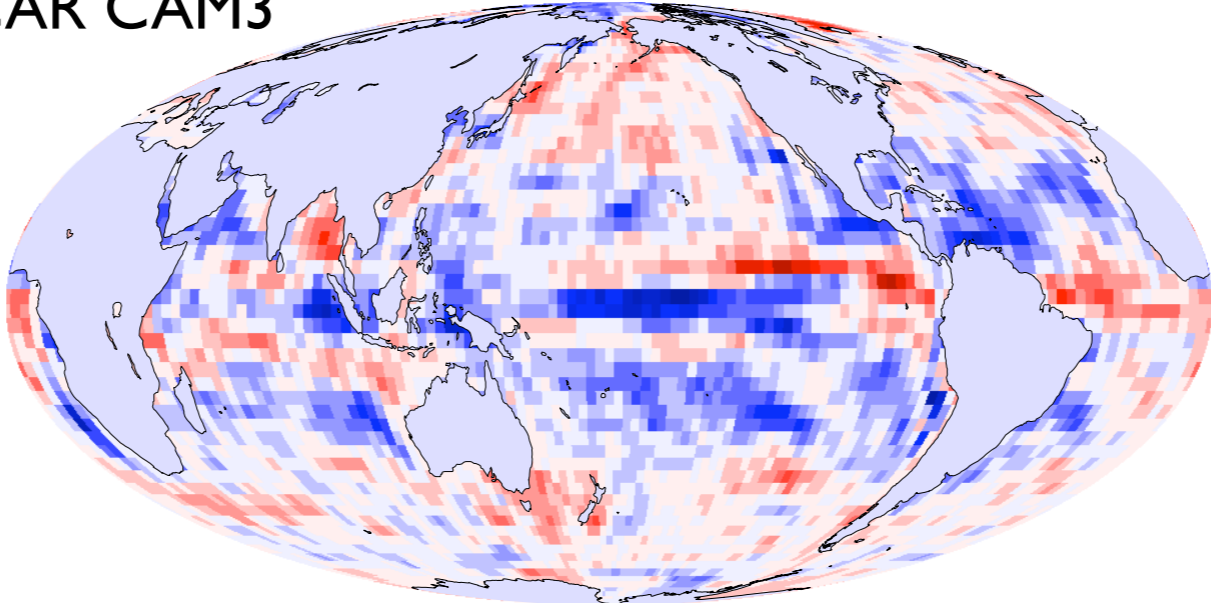
GFDL AM2



MORE WARMING

LESS WARMING

NCAR CAM3



an old story

“It must thus be emphasized that the modeling of clouds is one of the weakest links in the general circulation modeling efforts.”

-- National Research Council, Charney et al. (1979)

IPCC 4th Assessment Report will likely agree...

intro: some definitions

- ▶ **Cess-like experiment:**

Prescribe climate change by perturbing SST by 2 K.

- ▶ **climate forcing:**

$$G = \Delta(\text{netTOA})$$

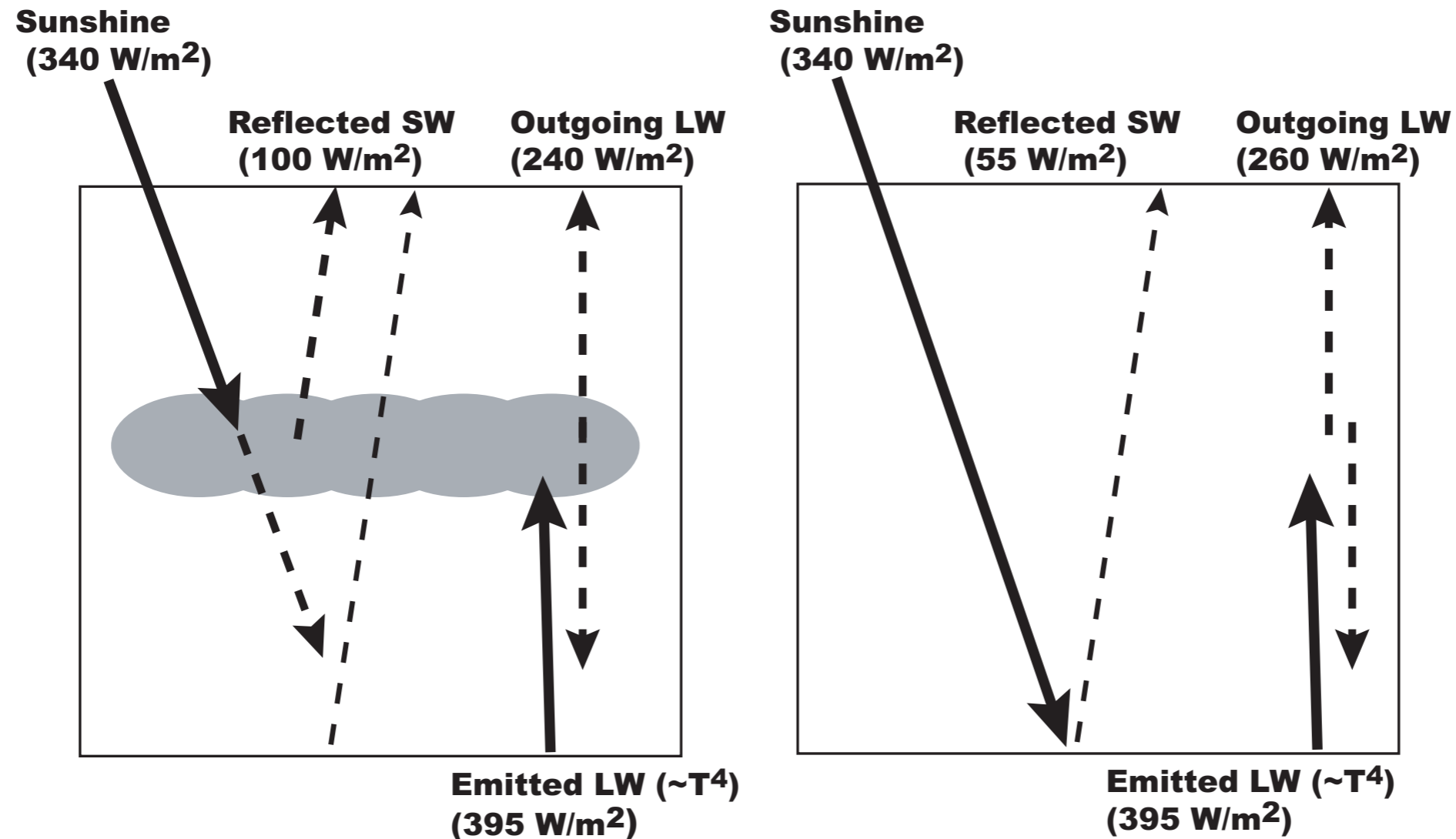
- ▶ **climate sensitivity parameter:**

$$\lambda = \Delta T/G$$

- ▶ **cloud feedback parameter:**

$$\lambda / \lambda_{\text{clr}} = \Delta \text{CRF}/G$$

intro: cloud radiative forcing [CRF]

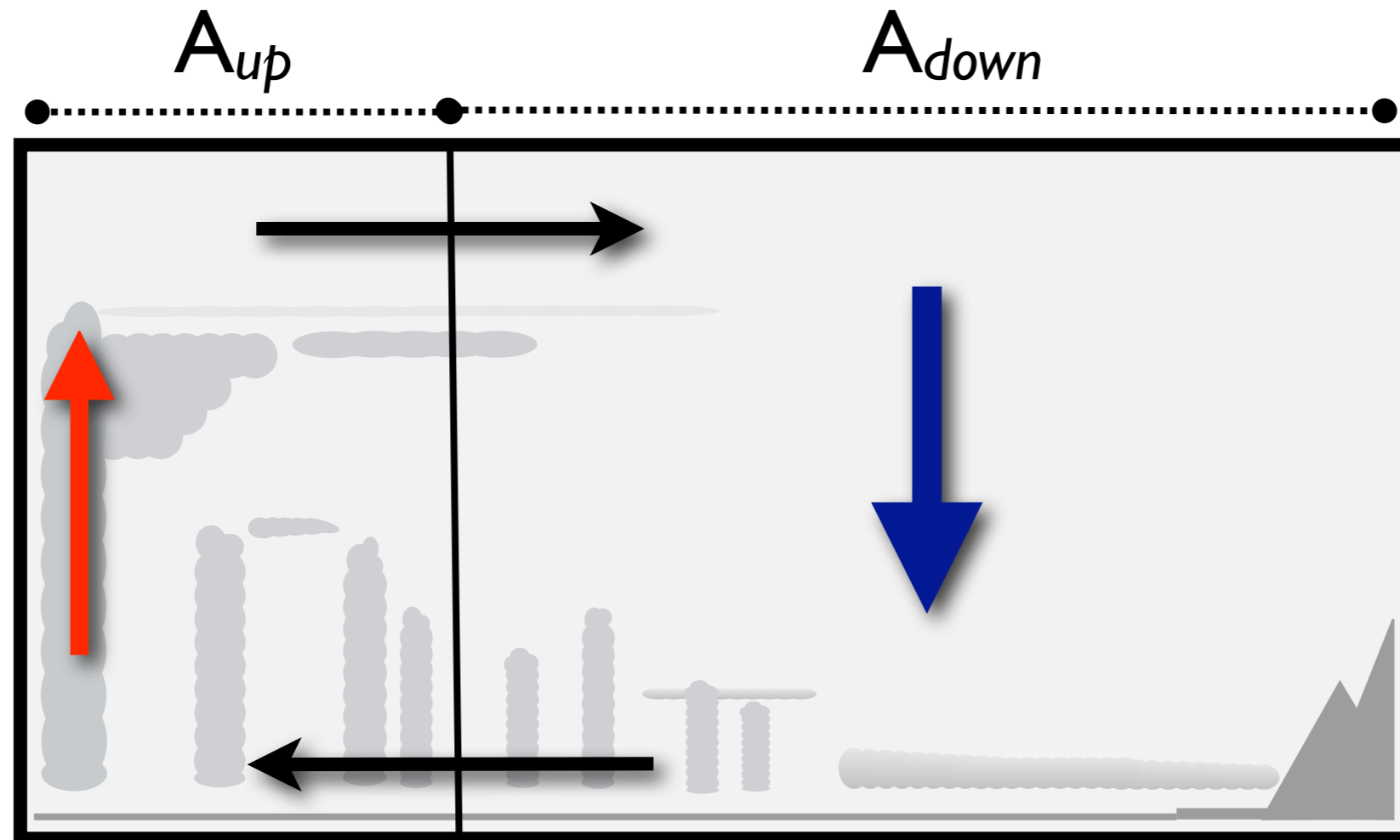


[After Cess et al 1996]

$$\text{CRF(SW)} = 240 - 285 = -45 \text{ W/m}^2$$
$$\text{CRF(LW)} = -240 + 260 = 20 \text{ W/m}^2$$



intro: understanding tropical clouds

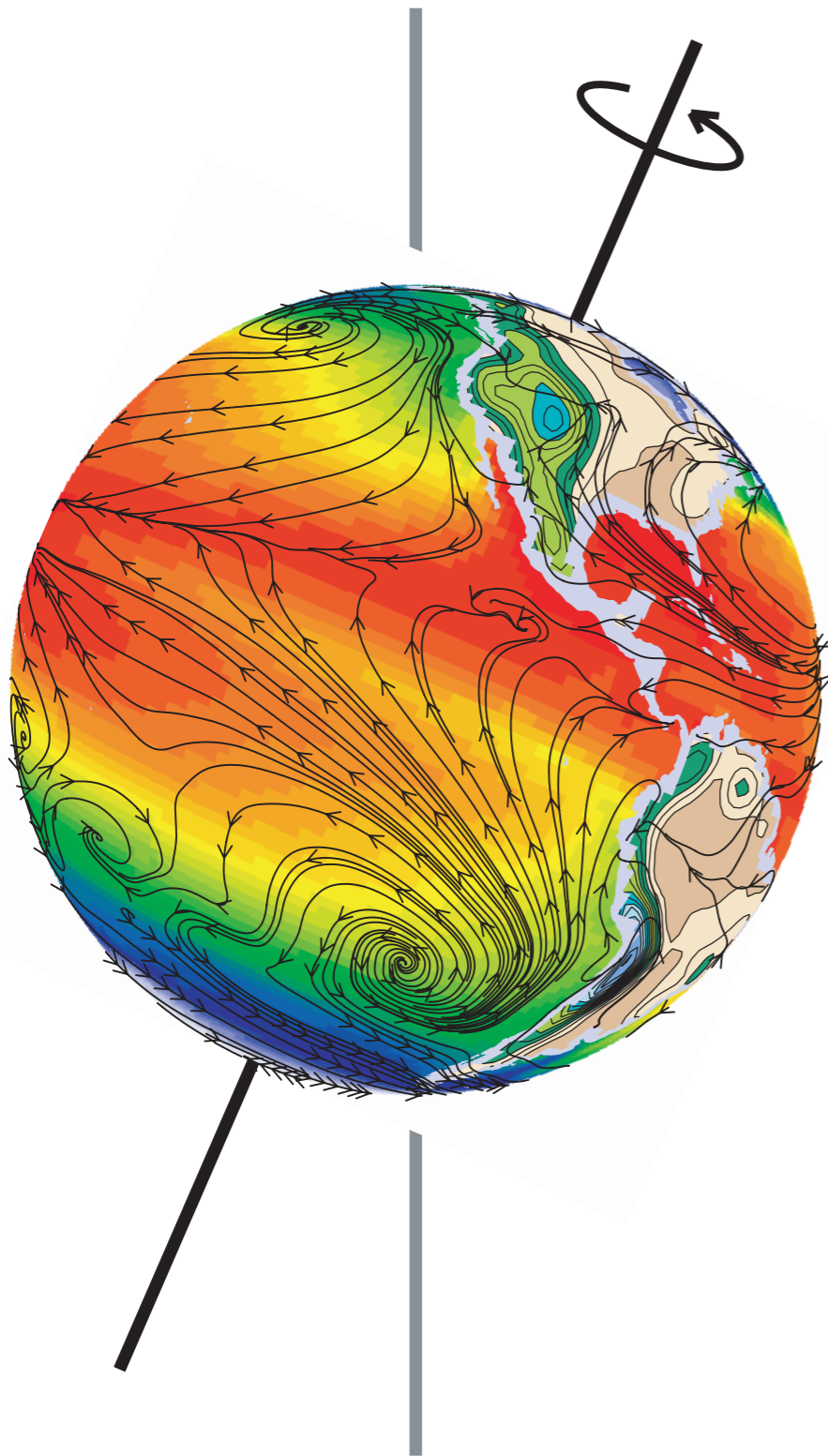


Pierrehumbert (1995)
Miller (1997)
Larson + Hartmann (1999)

intro: the idea

Is an aquaplanet a good predictor of GCM climate sensitivity and cloud feedbacks?

aquaplanet: construction



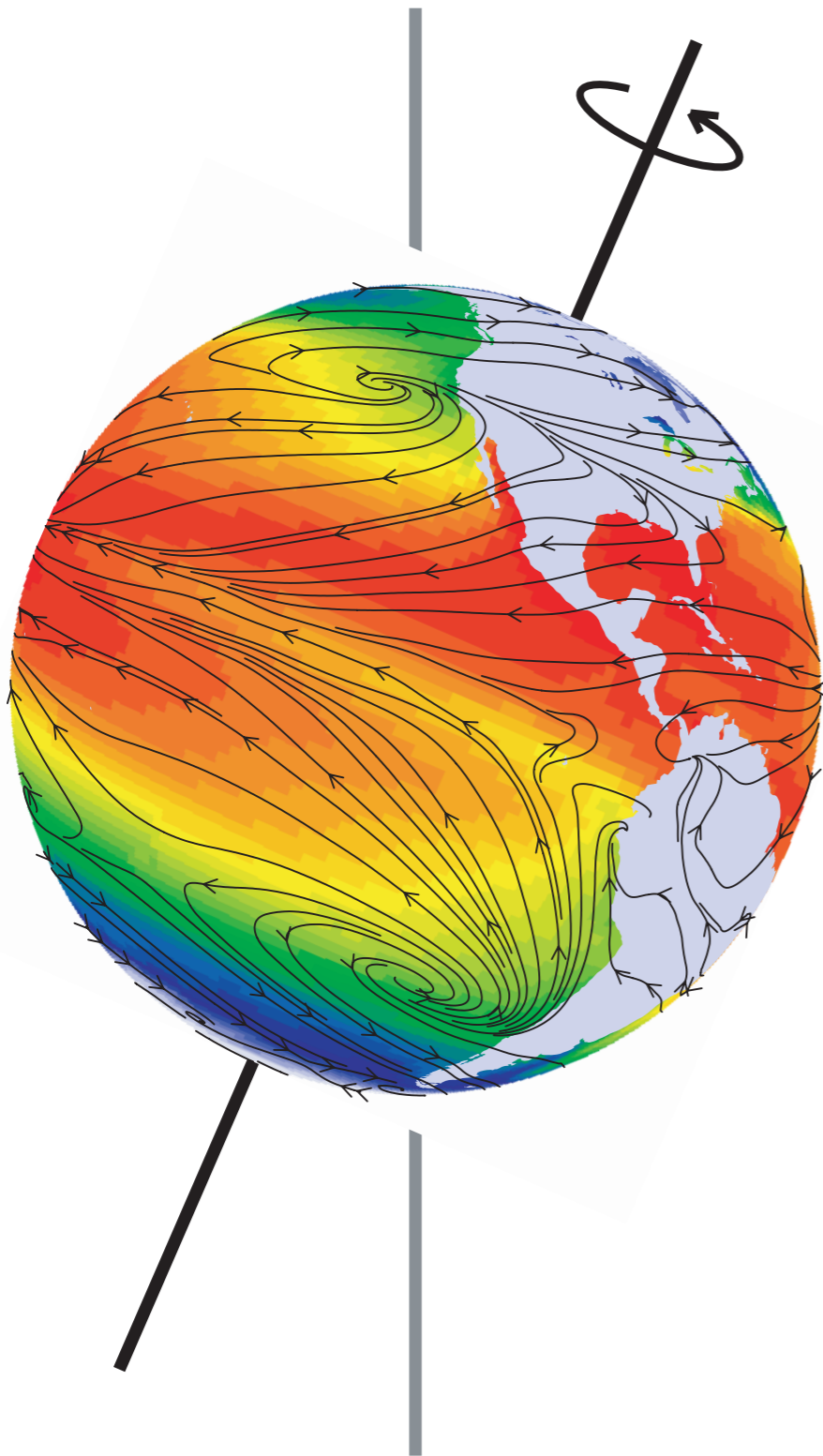
complex topography

asymmetric SST

seasonal variation

(sea-ice, land-ice, etc)

aquaplanet: construction



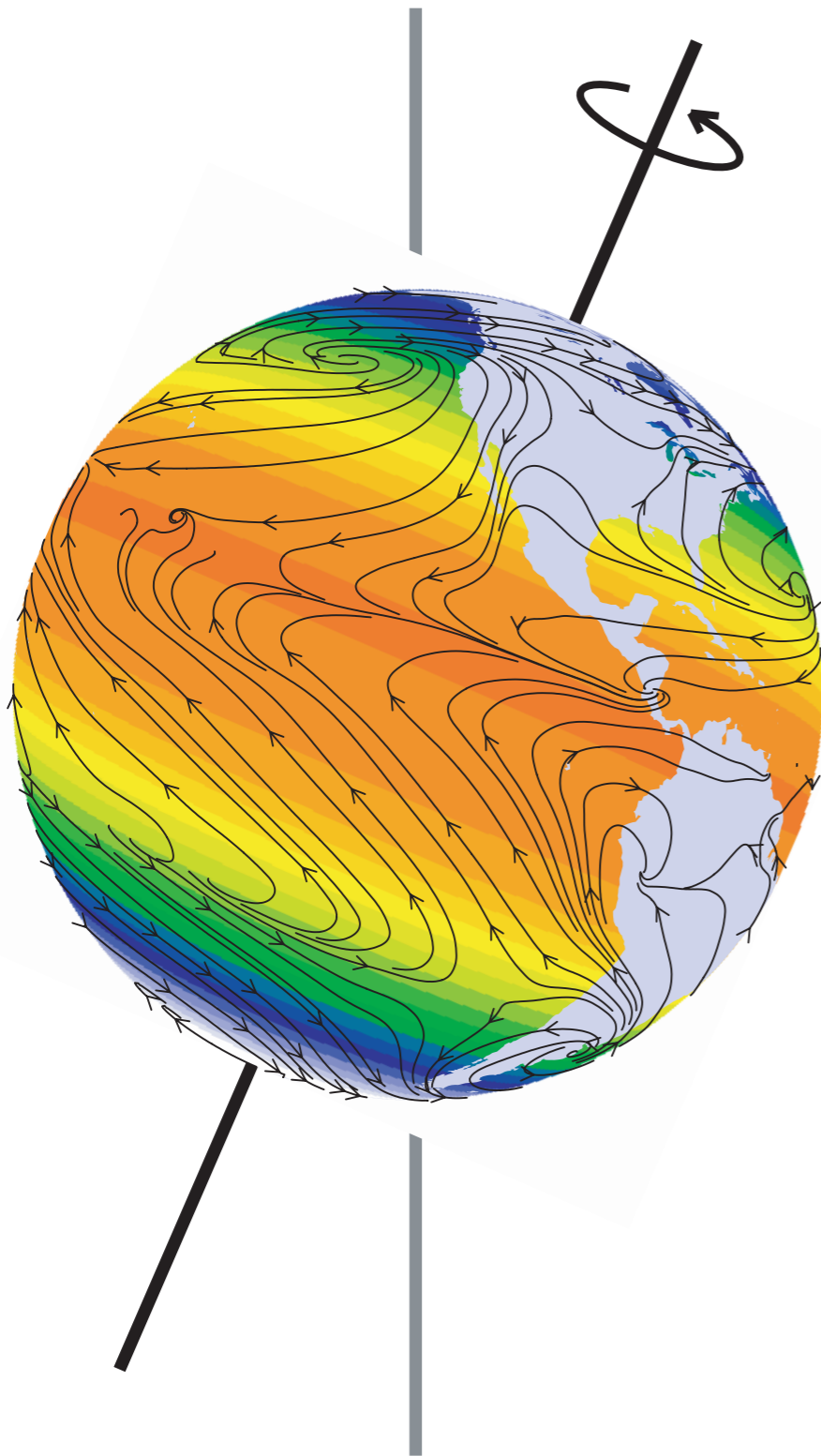
~~complex topography~~

asymmetric SST

seasonal variation

(sea-ice, land-ice, etc)

aquaplanet: construction



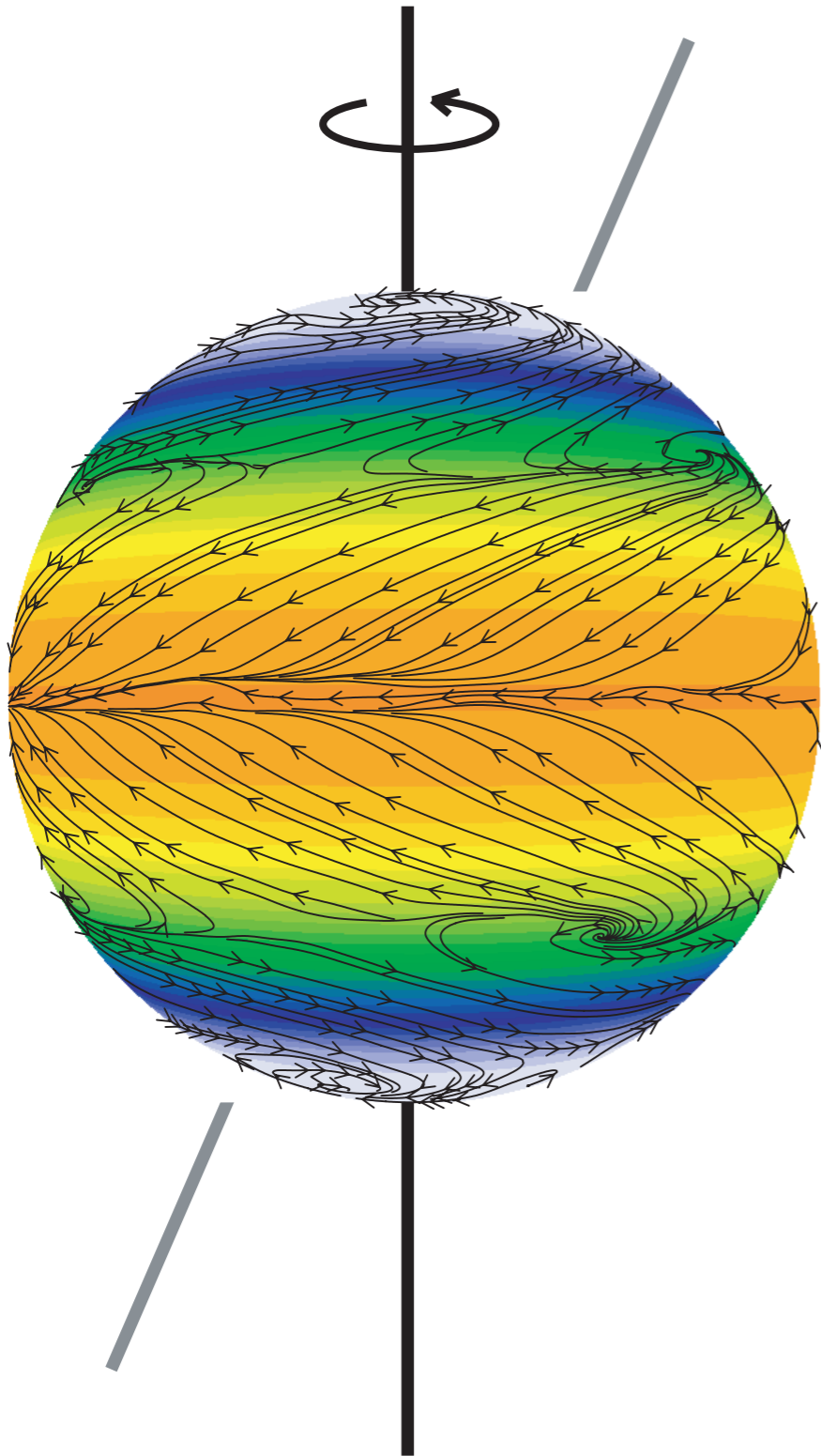
~~complex topography~~

~~asymmetric SST~~

seasonal variation

(sea-ice, land-ice, etc)

aquaplanet: construction



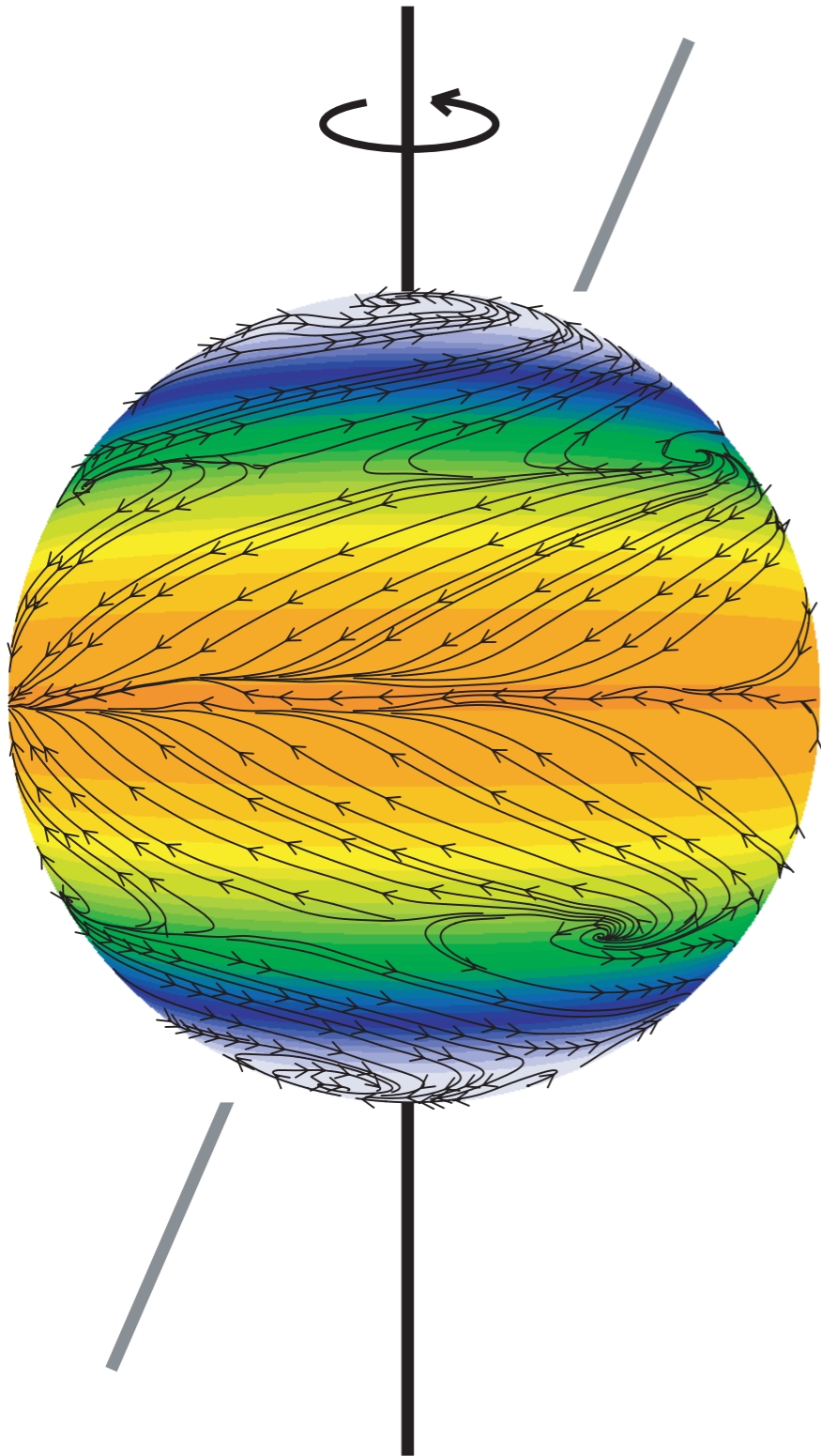
~~complex topography~~

~~asymmetric SST~~

~~seasonal variation~~

~~(sea-ice, land-ice, etc)~~

aquaplanet: construction



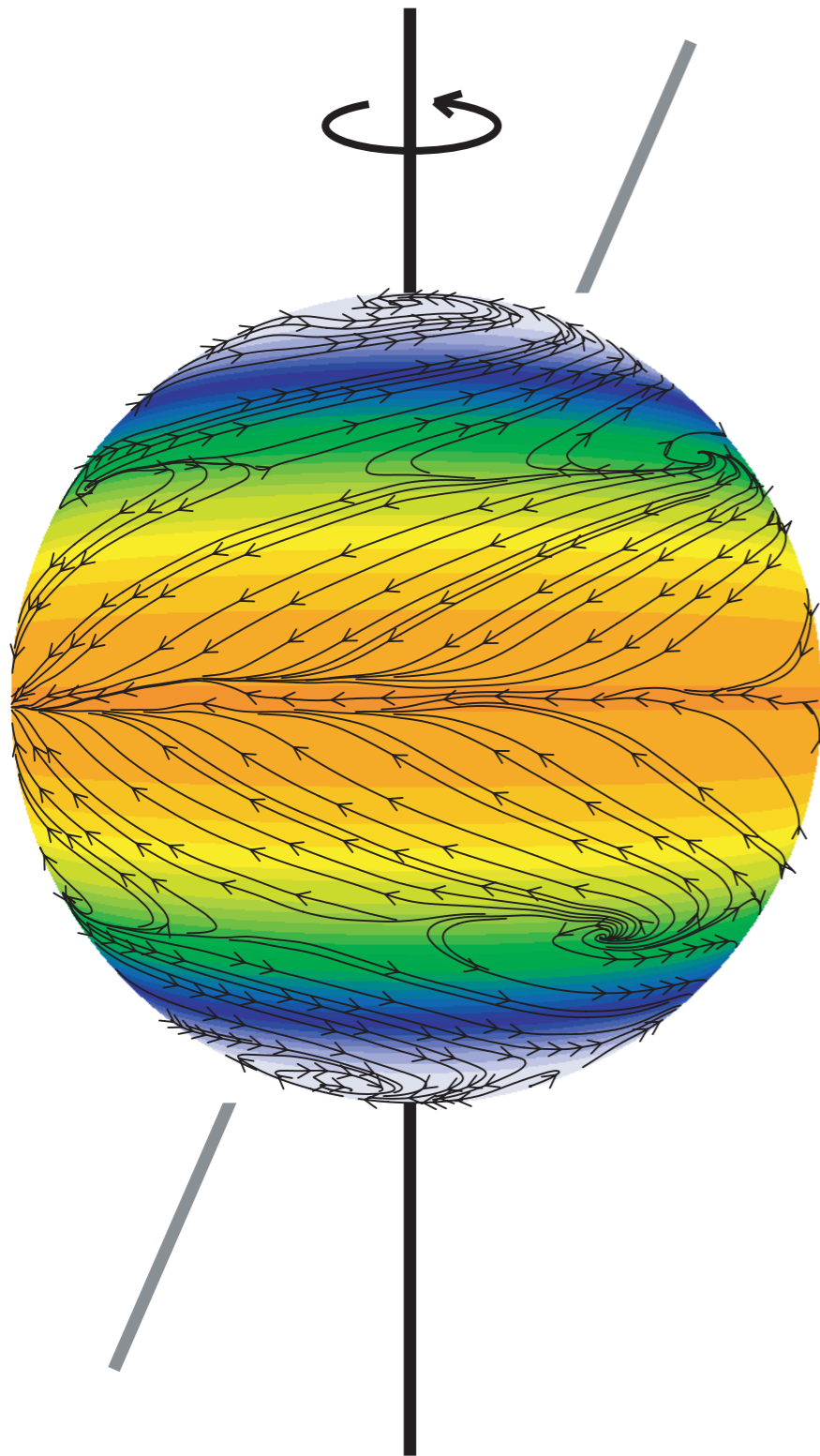
diurnal variation

full atmospheric dynamics

full GCM physics

- radiation, convection, liquid, precip...
- and of course clouds

aquaplanet: literature



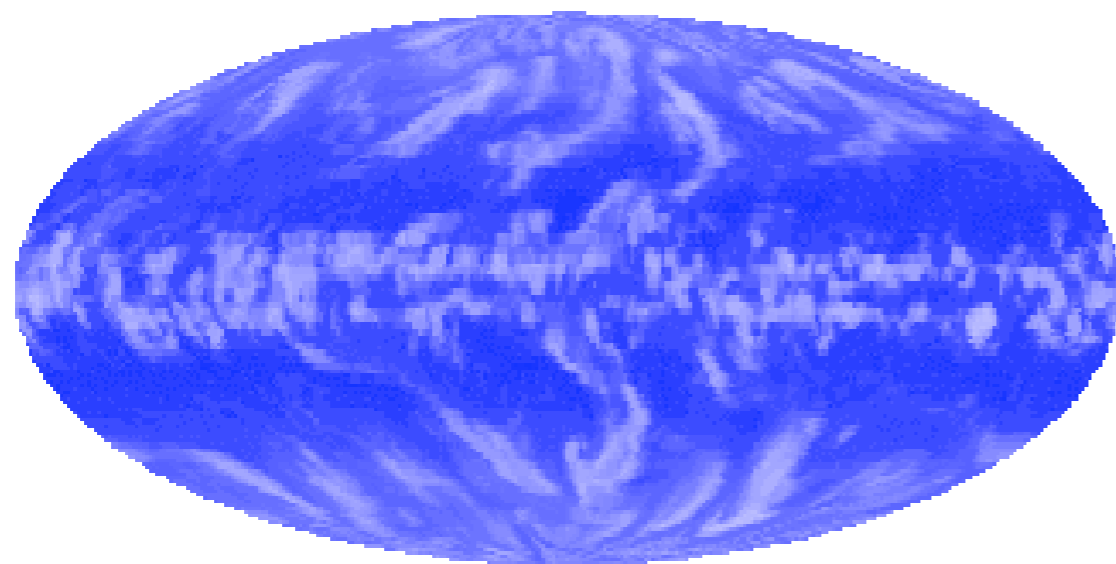
some past efforts

- ▶ sumi + hayashi (1986)
- ▶ neelin et al (1987)
- ▶ lau et al (1988)
- ▶ randall et al (1989)
- ▶ hess et al. (1993)
- ▶ kirtman + schneider (2000)
- ▶ chao (and others) (1998,200x)
- ▶ neale + hoskins (2000,2001)
- ▶ williamson + olson (2003)
- ▶ barsugli et al (2004)
- ▶ miura et al (2004)
- ▶ alexeev + langen (2004/5)
- ▶ kuang et al (2005, DARE/RAVE)

We expand the use of this simple setting by applying it to the problem of climate sensitivity and cloud feedback.

aquaplanet: weather

Outgoing Longwave Radiation [W m^{-2}]



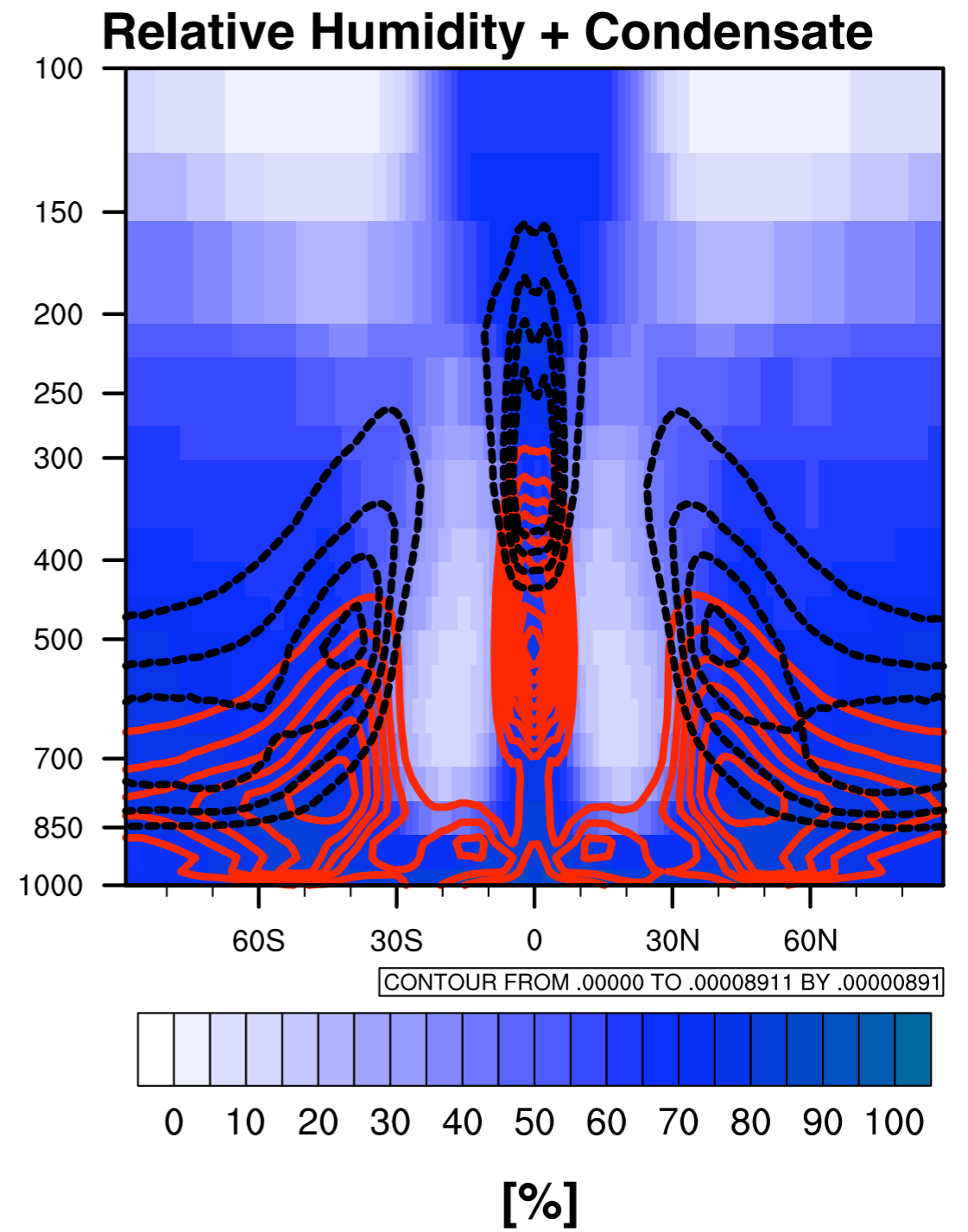
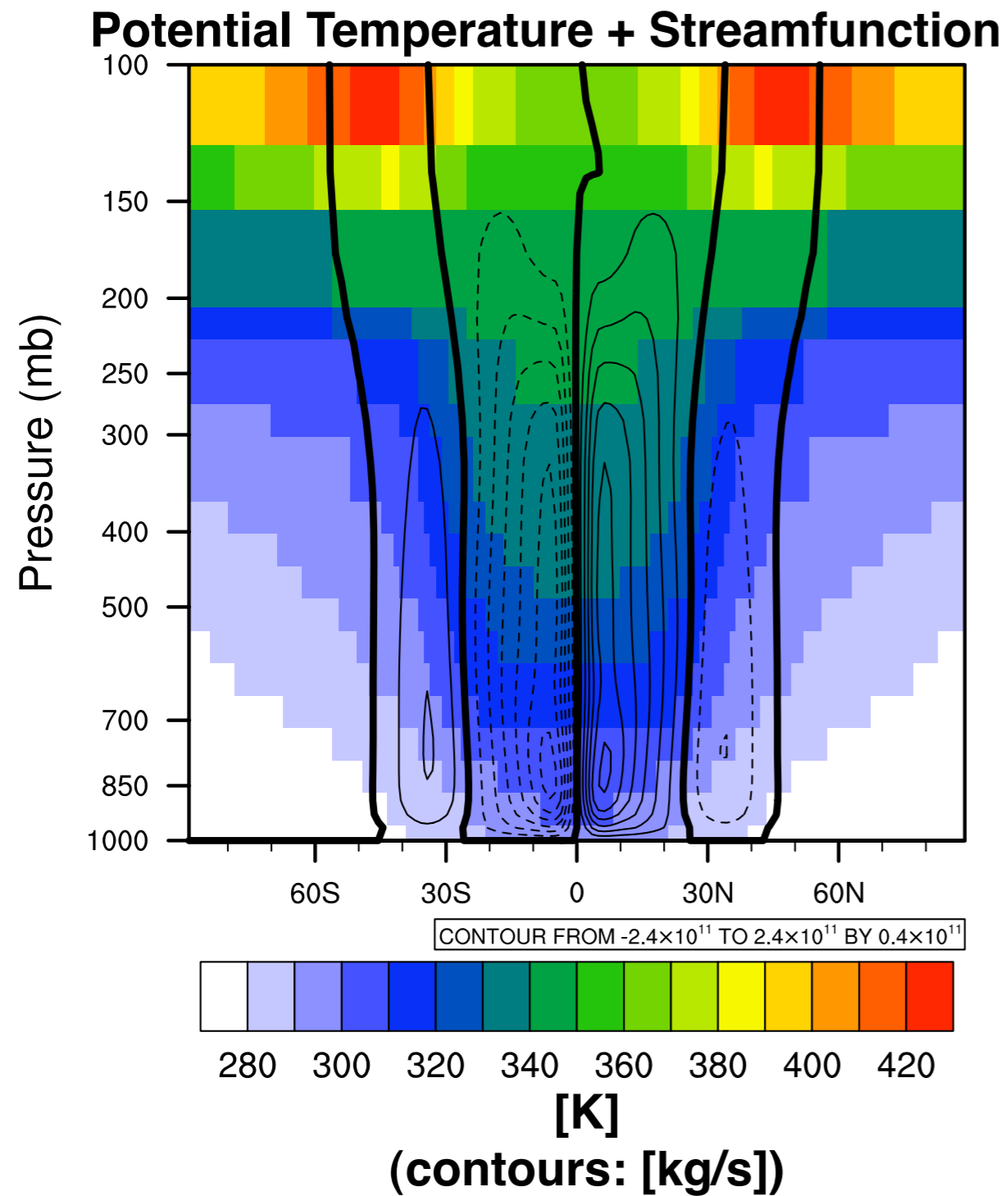
— 30°N
— 10°N

- ▶ **double ITCZ**
- ▶ **subtropical low clouds**
- ▶ **midlatitude storms**



high clouds ← → low clouds

aquaplanet: climate



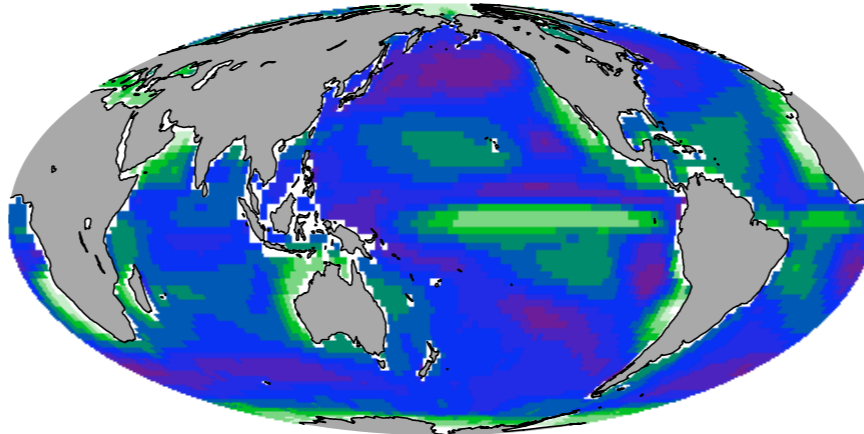
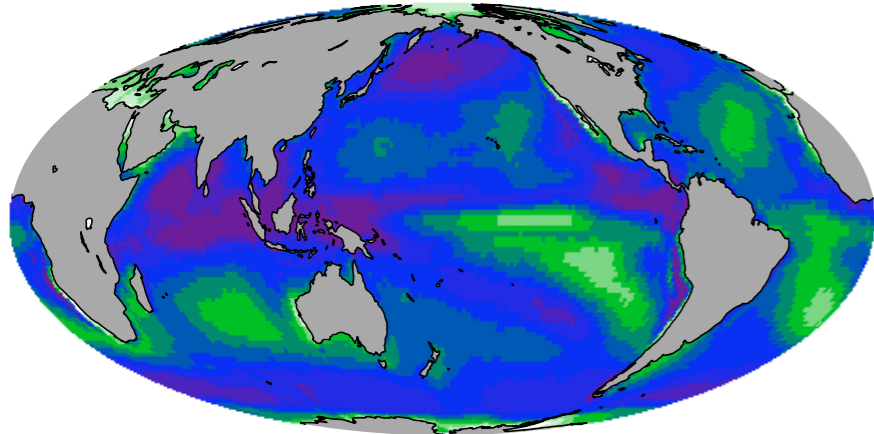
test: simulated CRF

Cloud Radiative Forcing

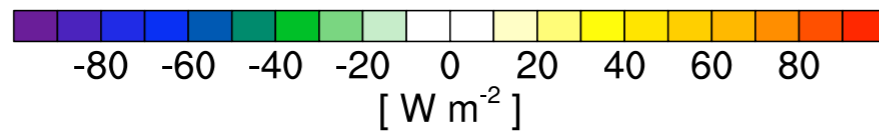
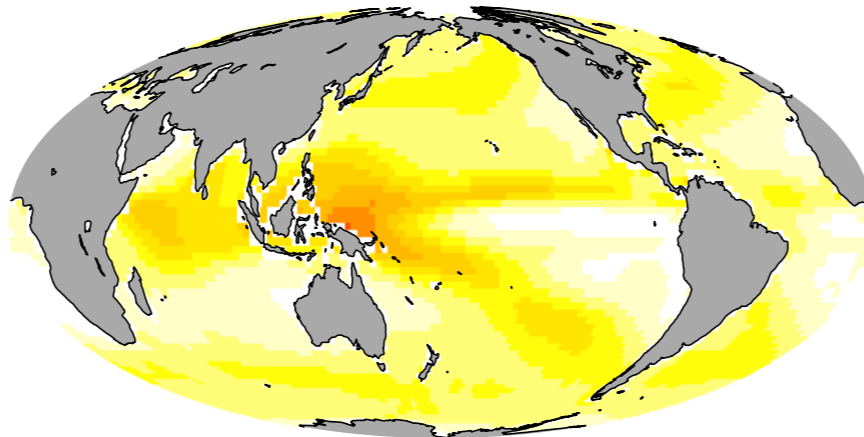
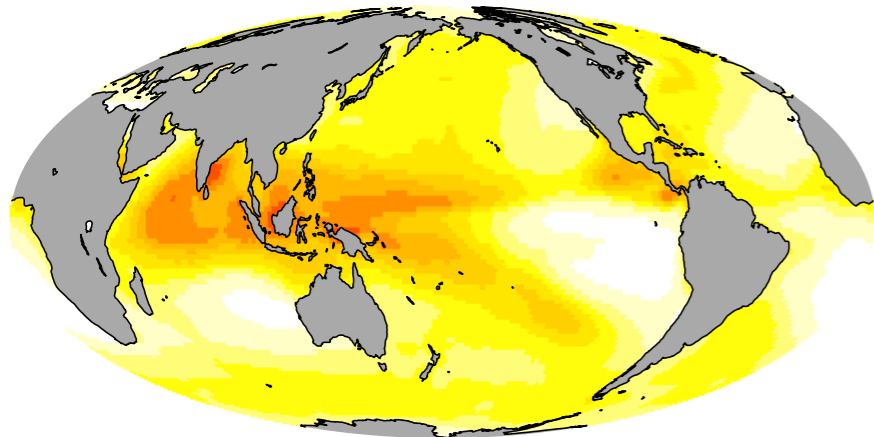
Shortwave

NCAR CAM3

GFDL AM2



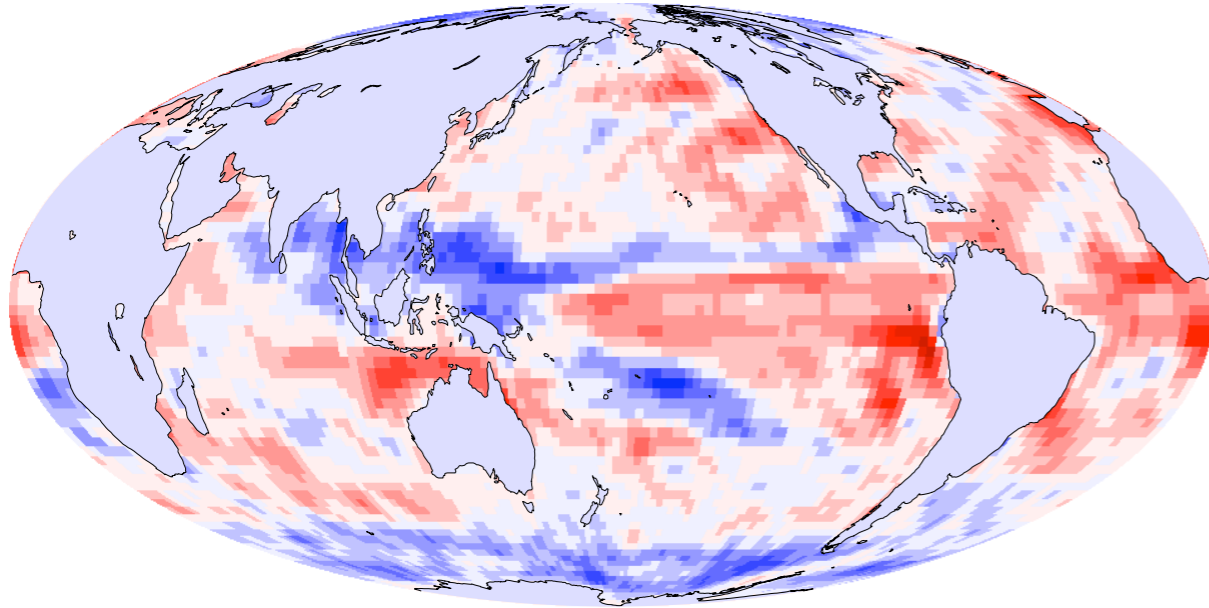
Longwave



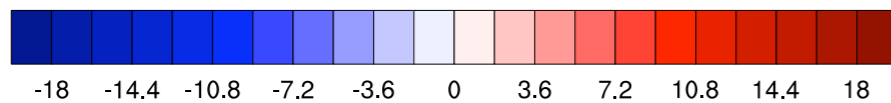
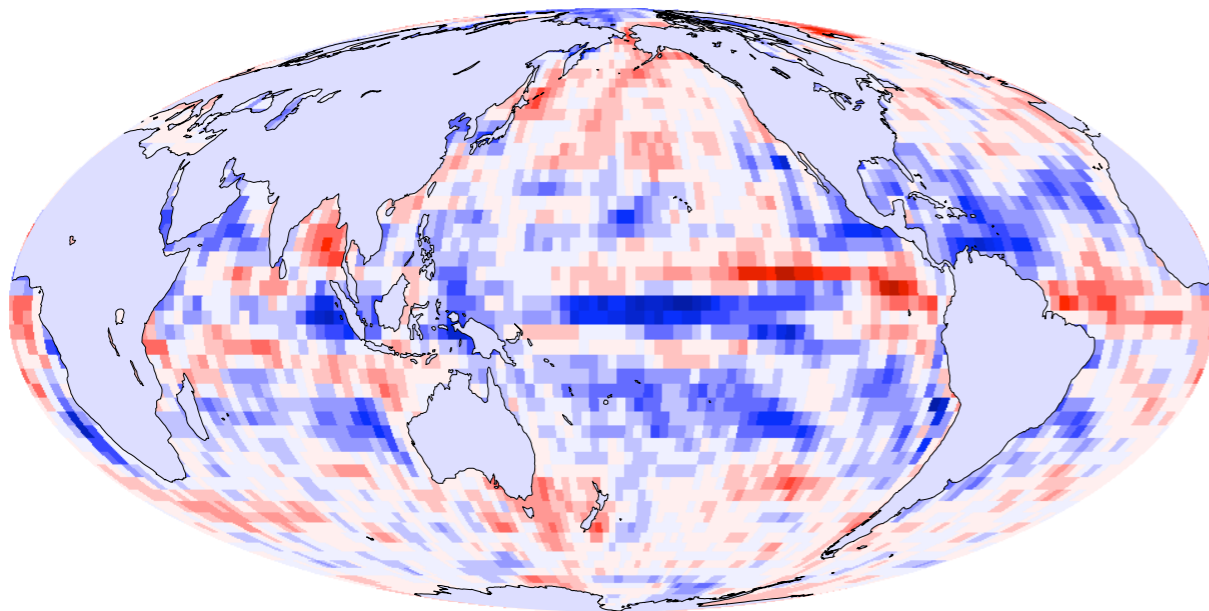
- ▶ 2 GCMs have “similar” CRF
- ▶ high clouds: LW vs. SW
- ▶ low clouds: SW
- ▶ What about climate change?

test: Δ CRF

GFDL AM2



NCAR CAM3



Cess-like experiment

- ▶ SST+2 globally

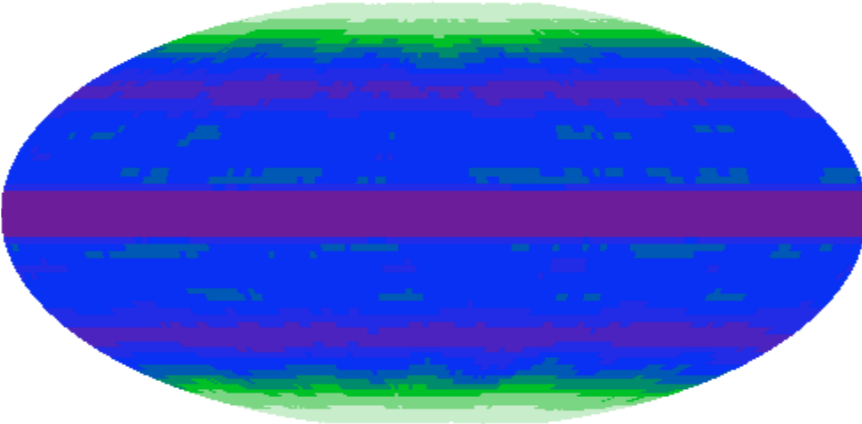
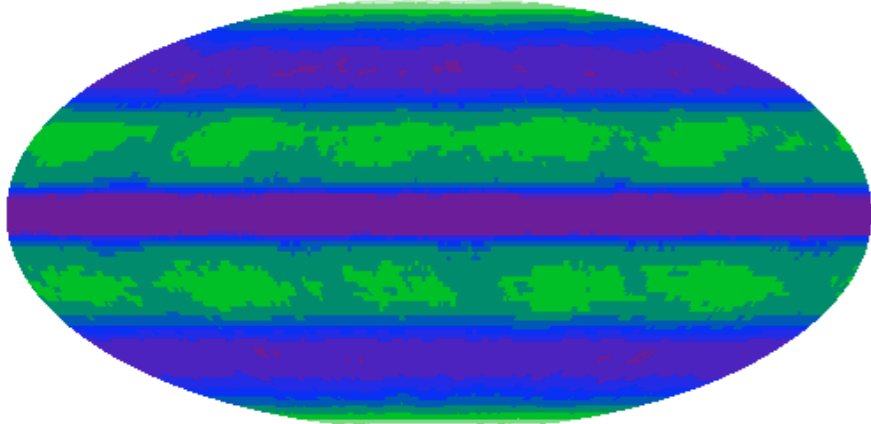
test: aquaplanet CRF

Cloud Radiative Forcing

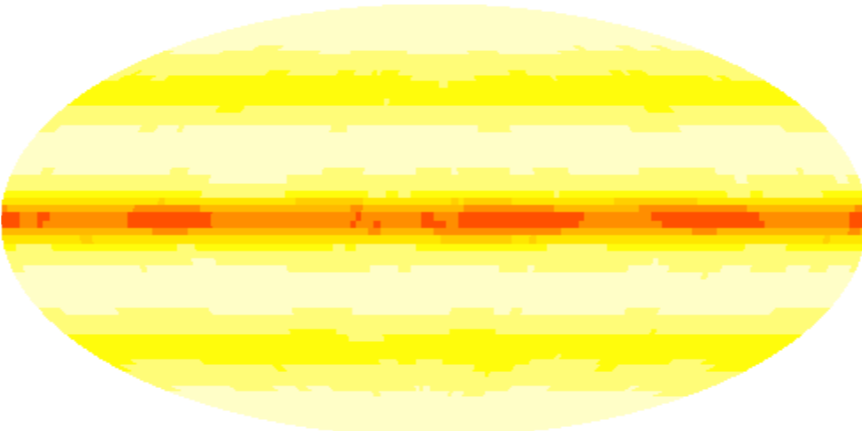
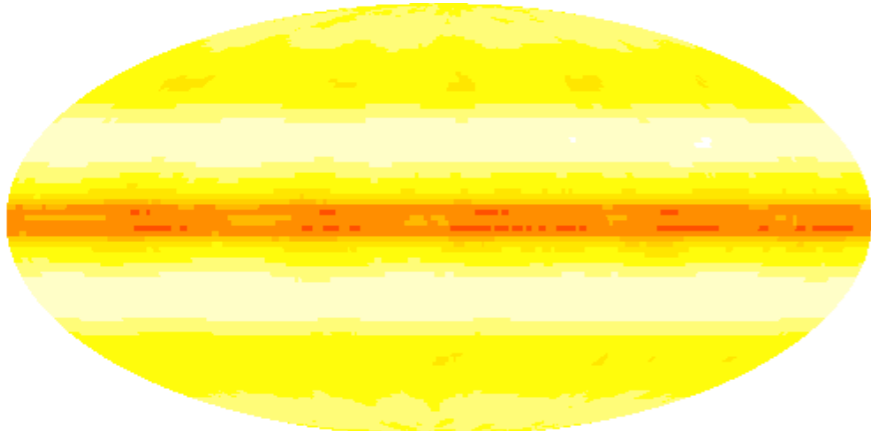
Shortwave

NCAR CAM3

GFDL AM2



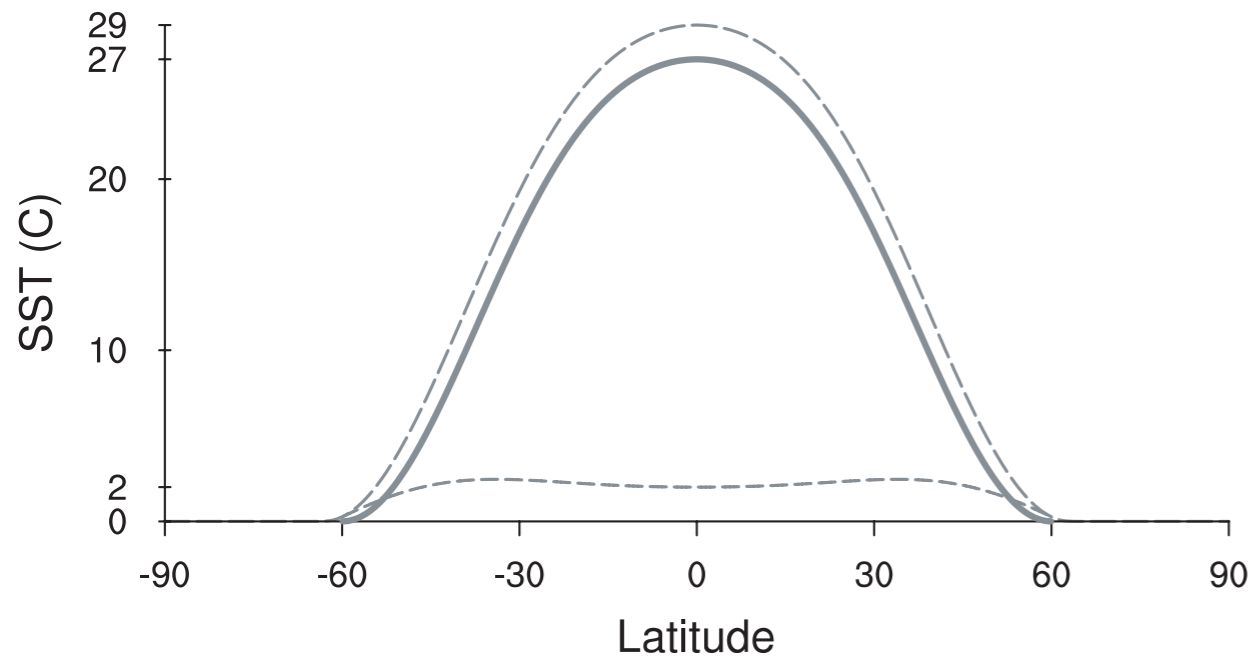
Longwave



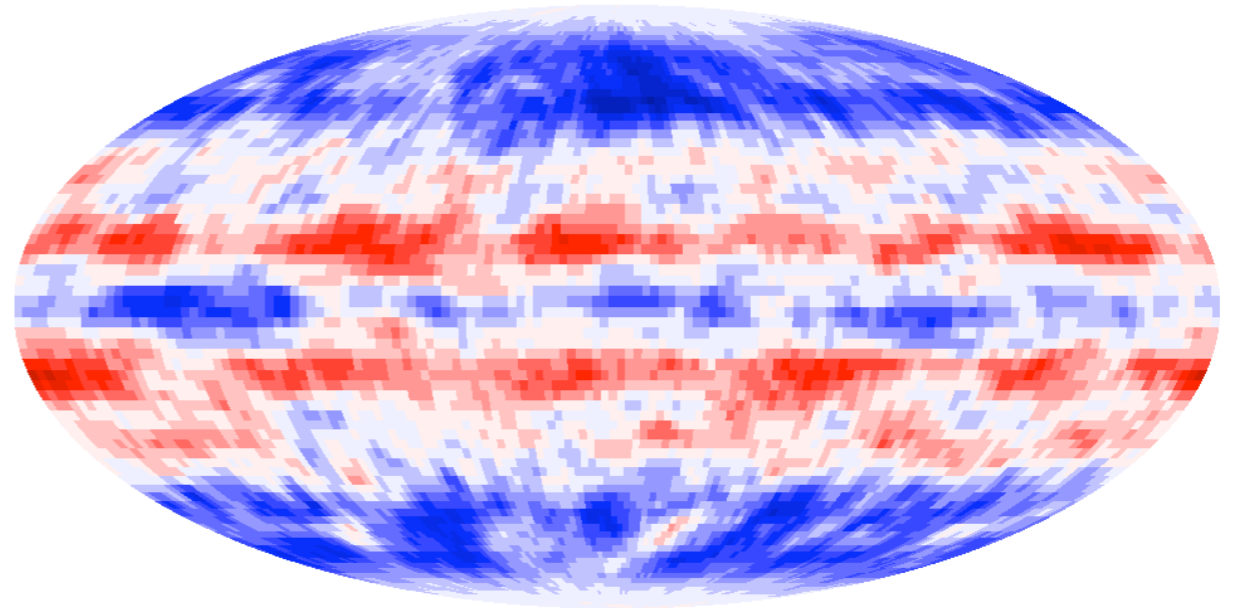
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- ▶ low clouds: SW
- ▶ What about climate change?

test: Δ CRF

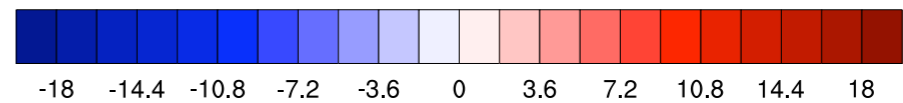
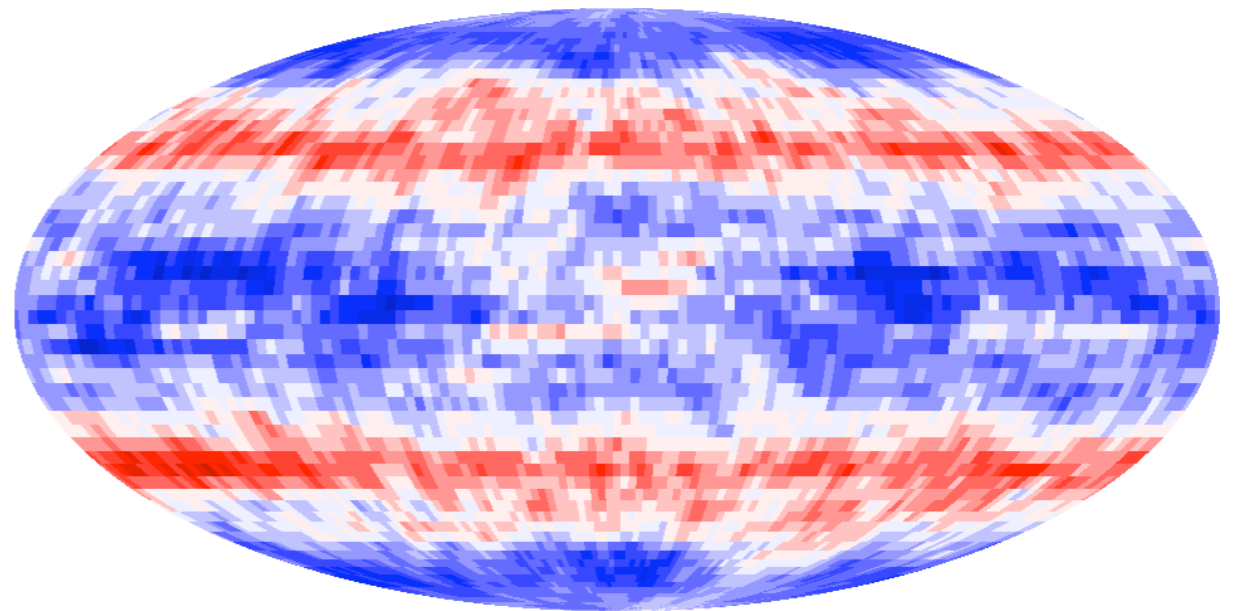
Cess-like experiment



GFDL AM2



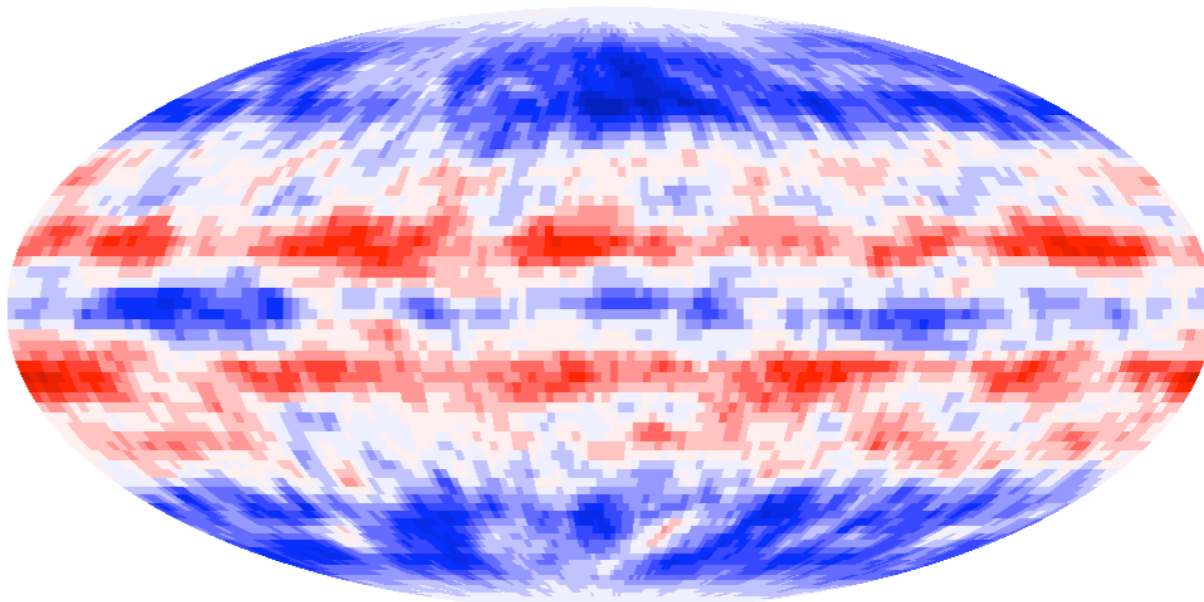
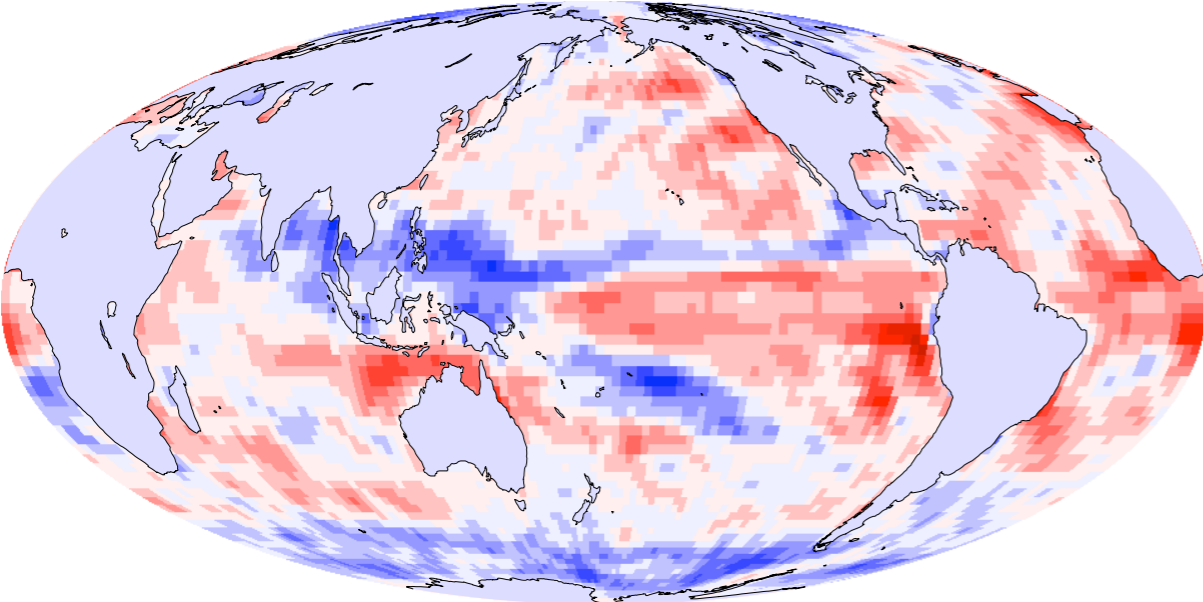
NCAR CAM3



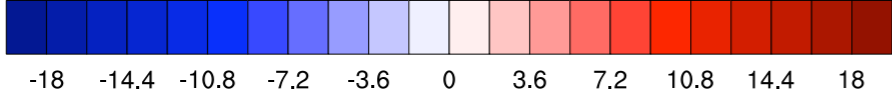
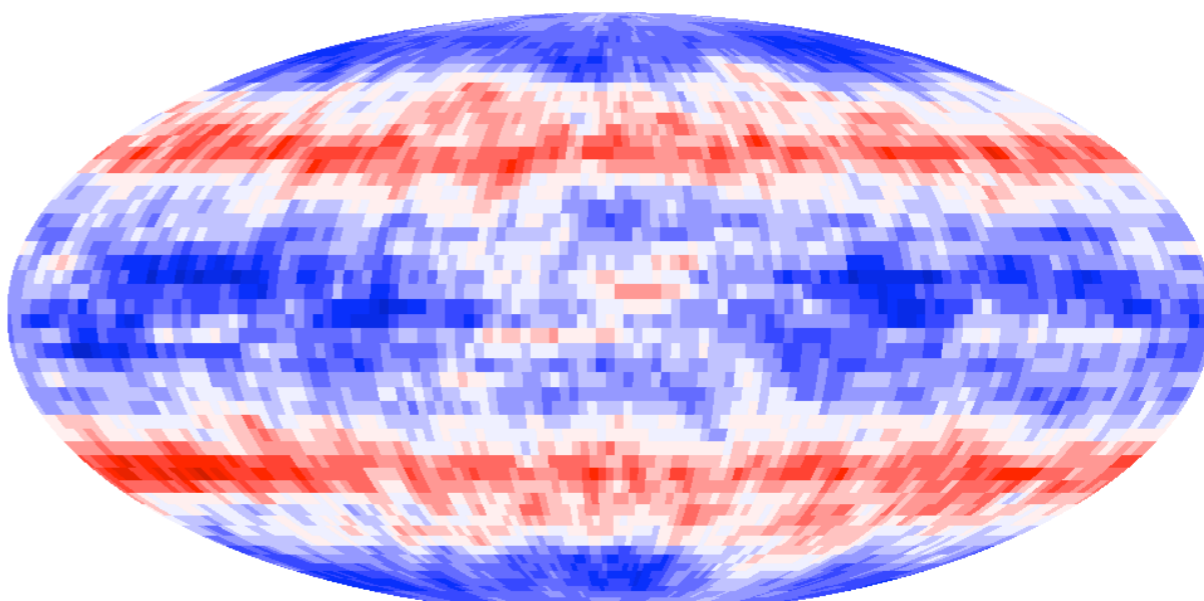
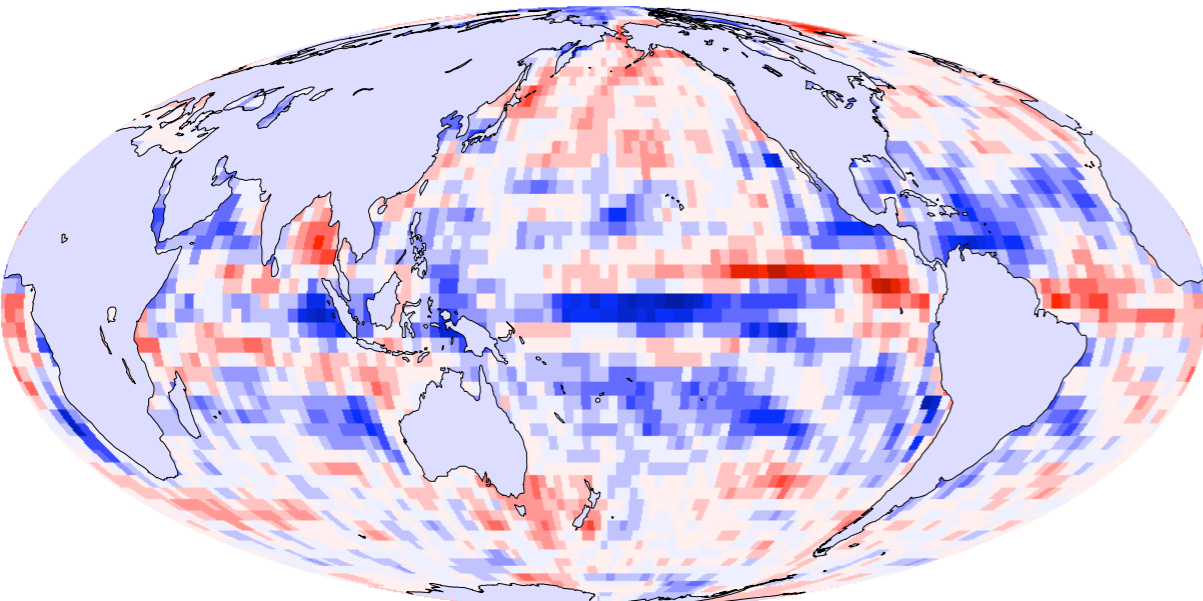
Neale + Hoskins (2000/1)

test: compare

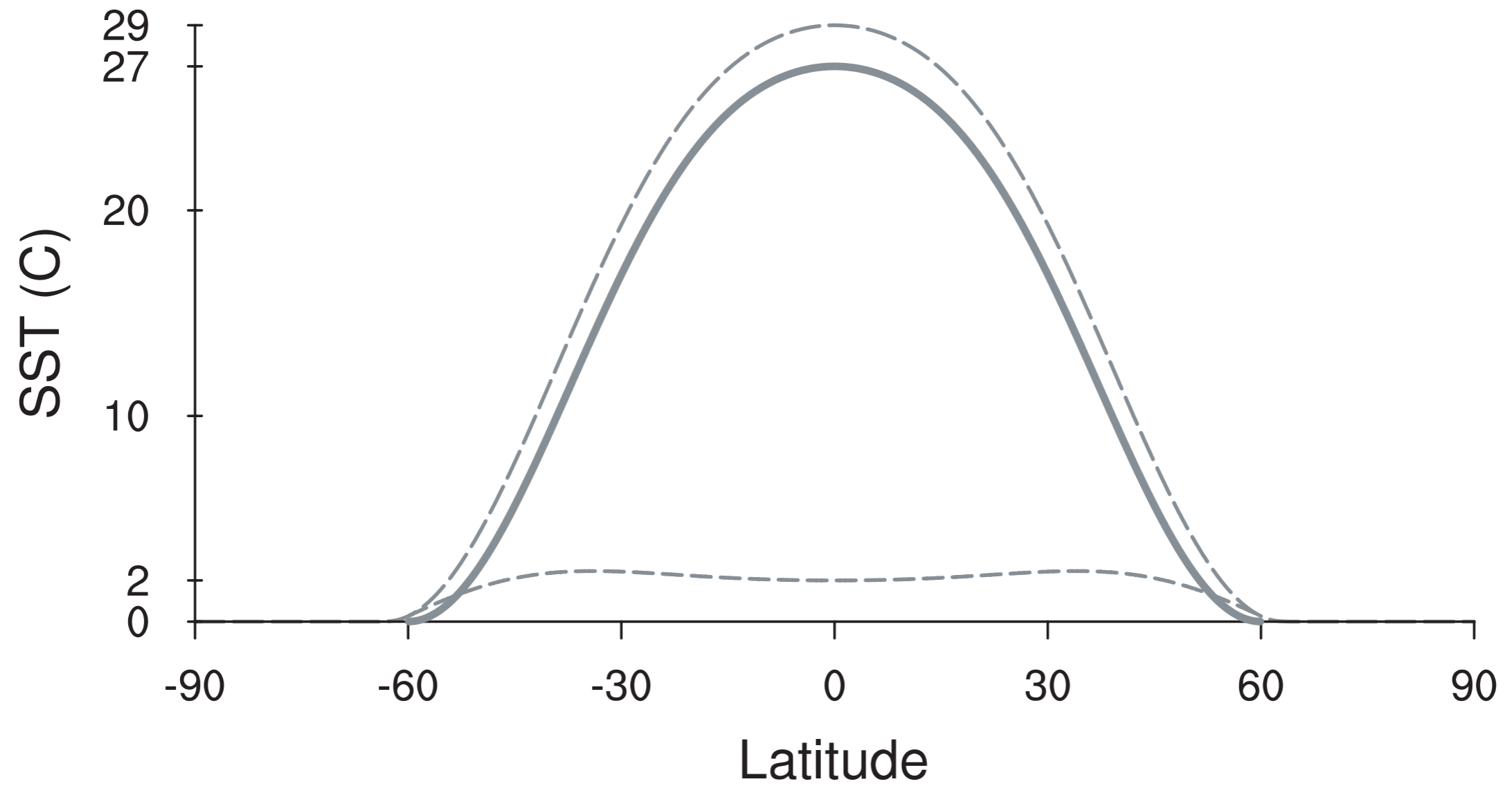
GFDL AM2



NCAR CAM3



lucky?

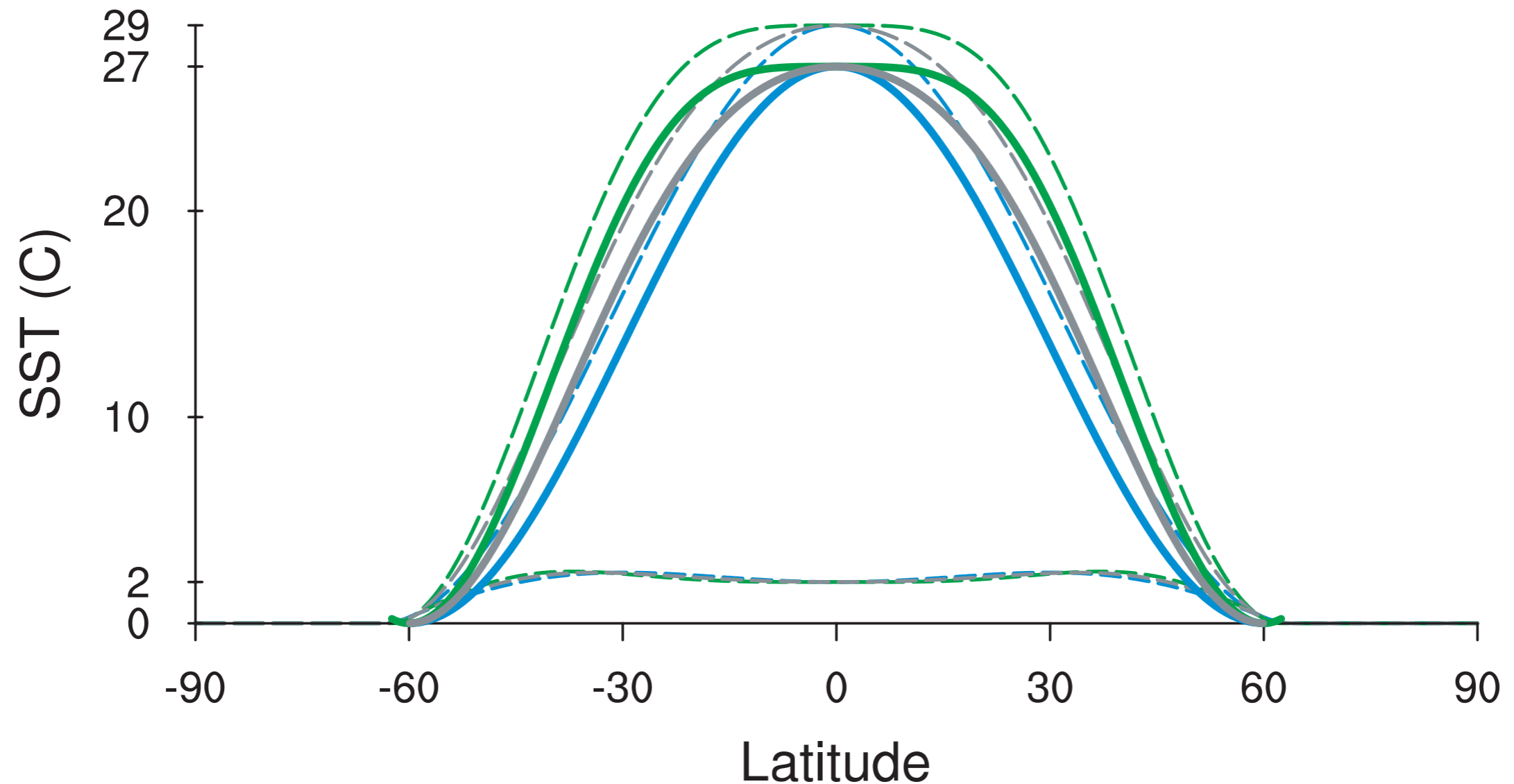


lucky?

Compare NCAR CAM3 and GFDL AM2

Use NCAR CAM3 twice (T85, T42)

4 configurations × 2 runs (control & SST+2) × 3 GCMs = 24 simulations



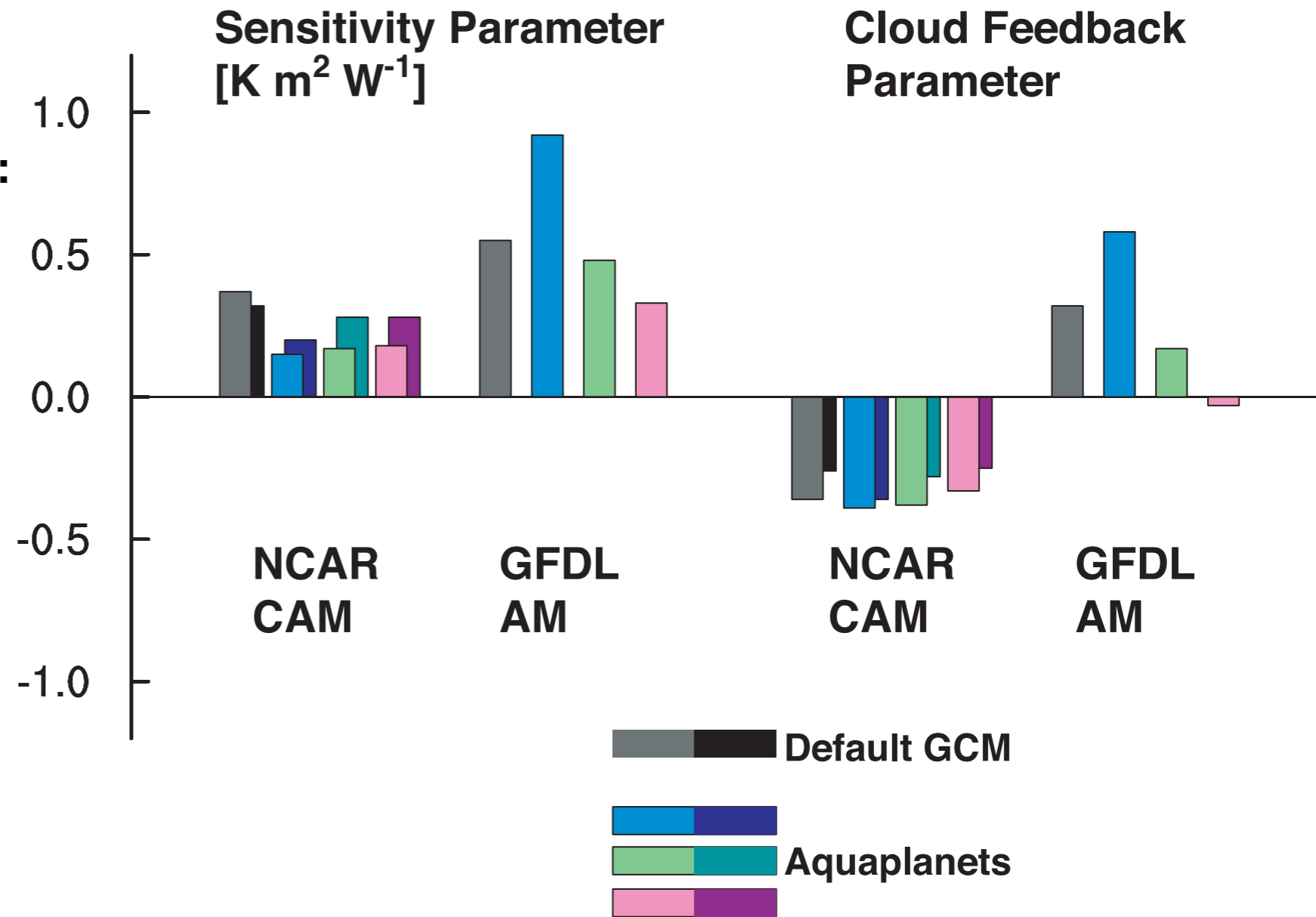
tropical climate sensitivity

- ▶ **climate sensitivity parameter:**

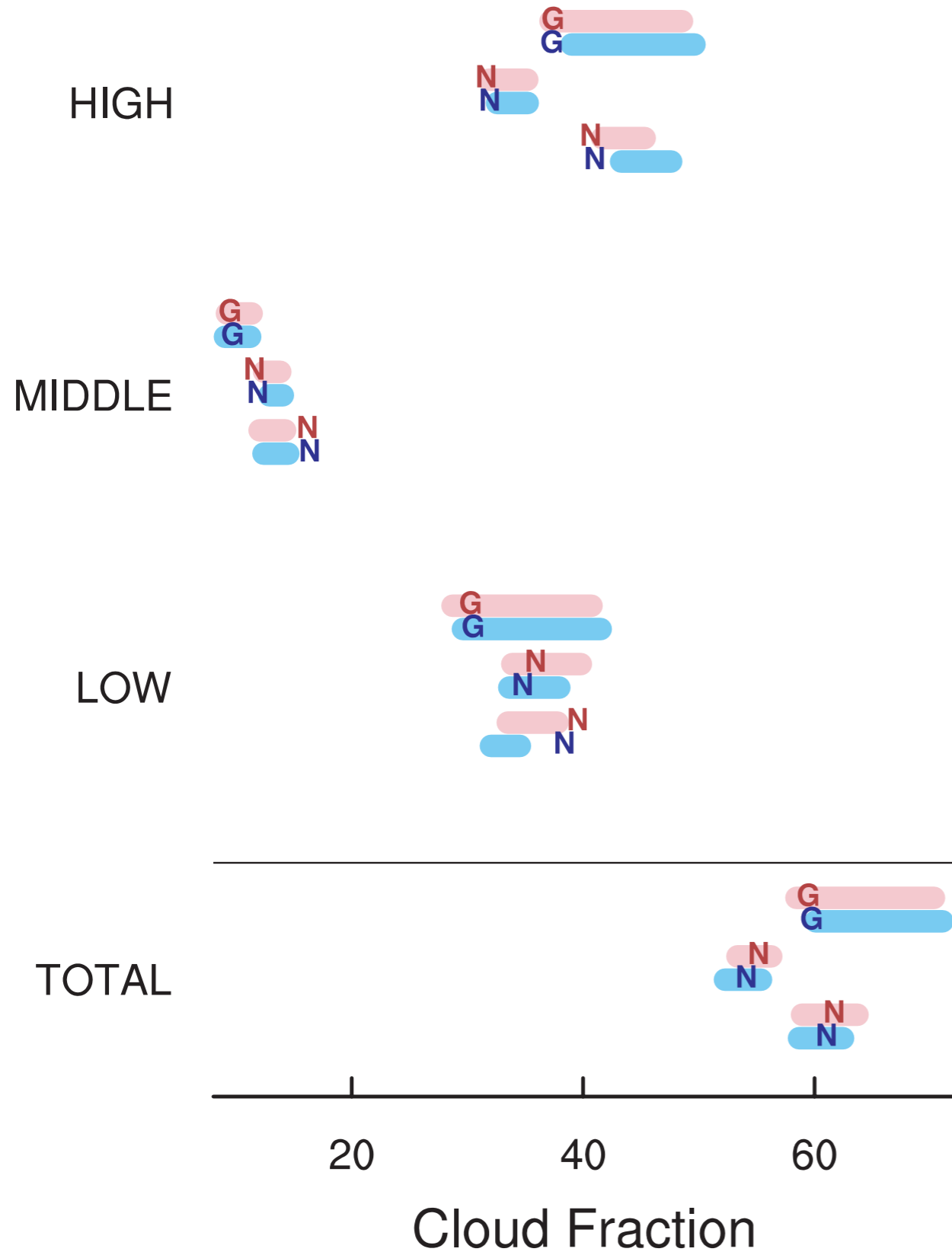
$$\lambda = \Delta T / G$$

- ▶ **cloud feedback parameter:**

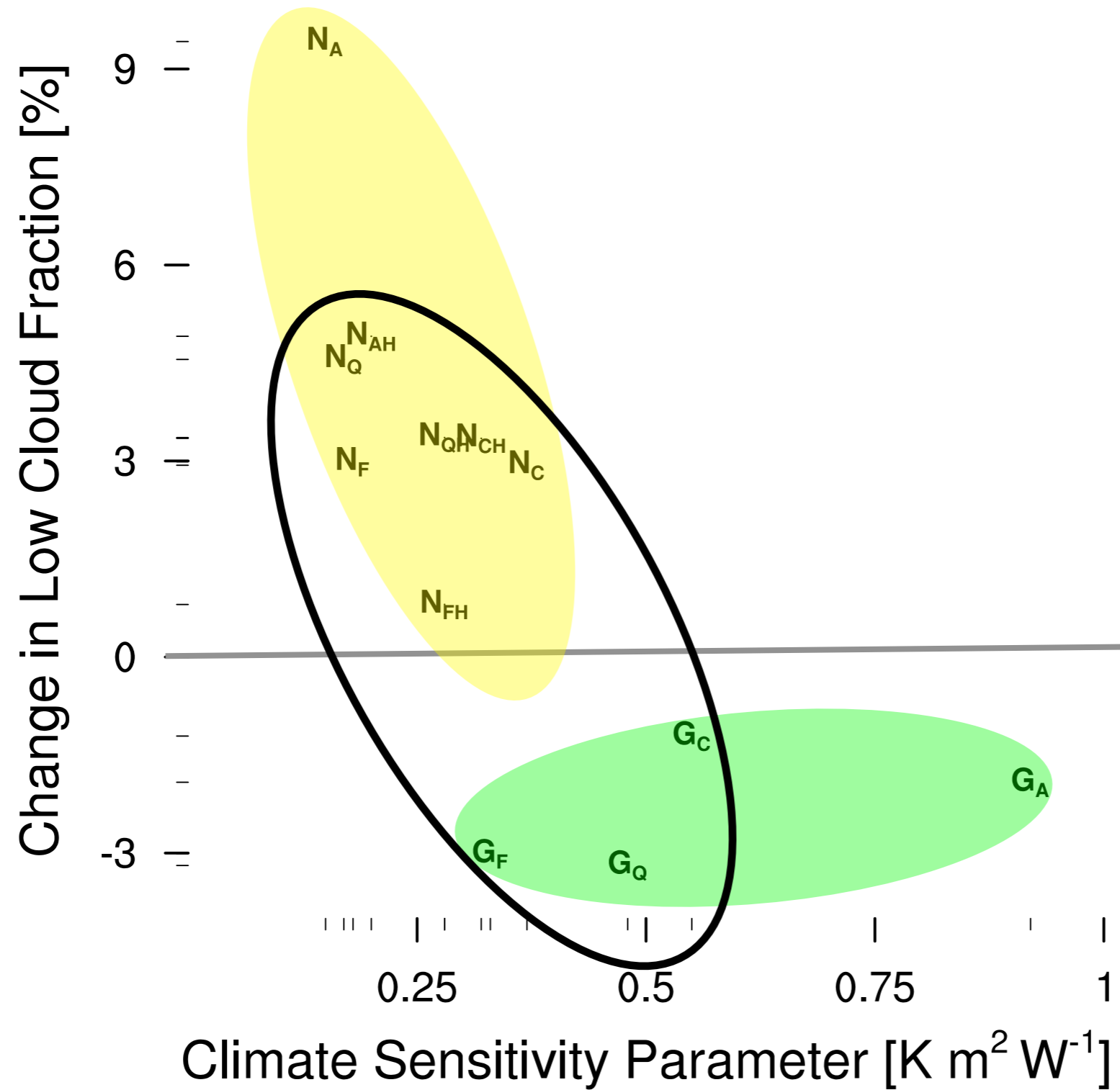
$$\lambda / \lambda_{\text{clr}} = \Delta \text{CRF} / G$$



which clouds?



it might be low clouds



double check: dynamical regimes

mean change in CRF

$$\overline{\delta c} = \int_{-\infty}^{\infty} P_{\omega} \delta C_{\omega} d\omega + \int_{-\infty}^{\infty} C_{\omega} \delta P_{\omega} d\omega + \int_{-\infty}^{\infty} \delta C_{\omega} \delta P_{\omega} d\omega$$

change in CRF

change in circulation

both change

choose a “dynamic” variable
(vertical motion)

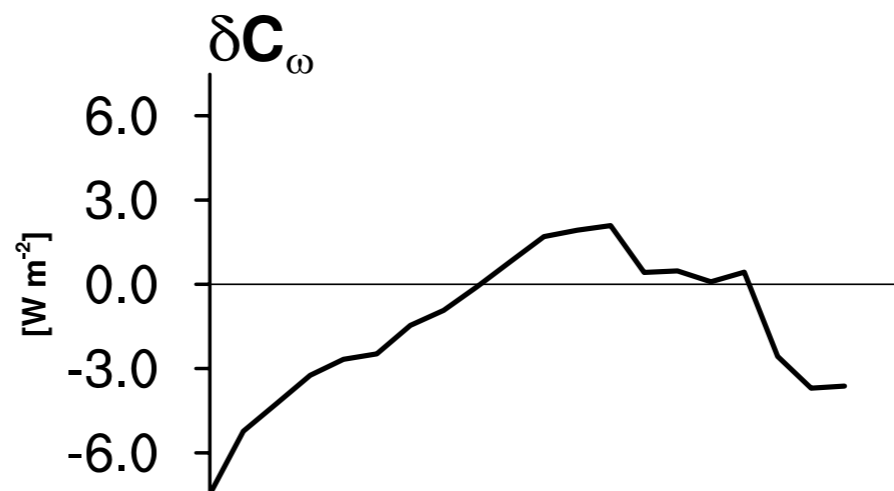
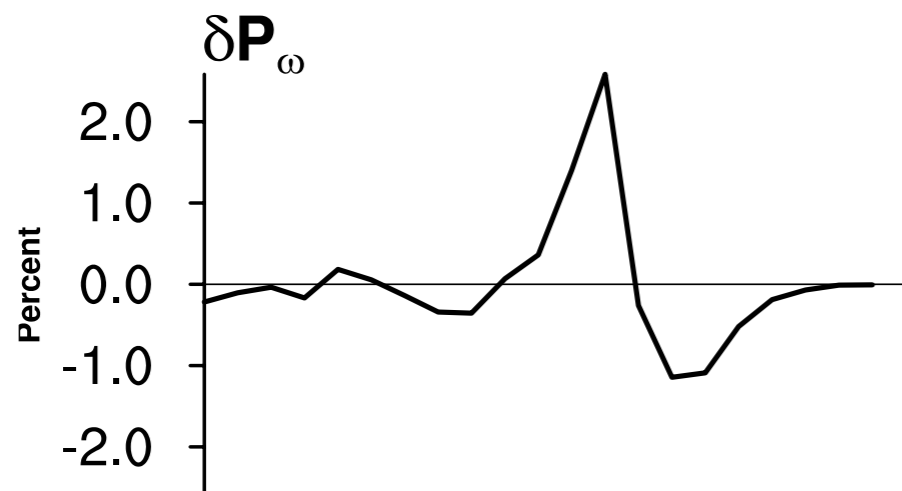
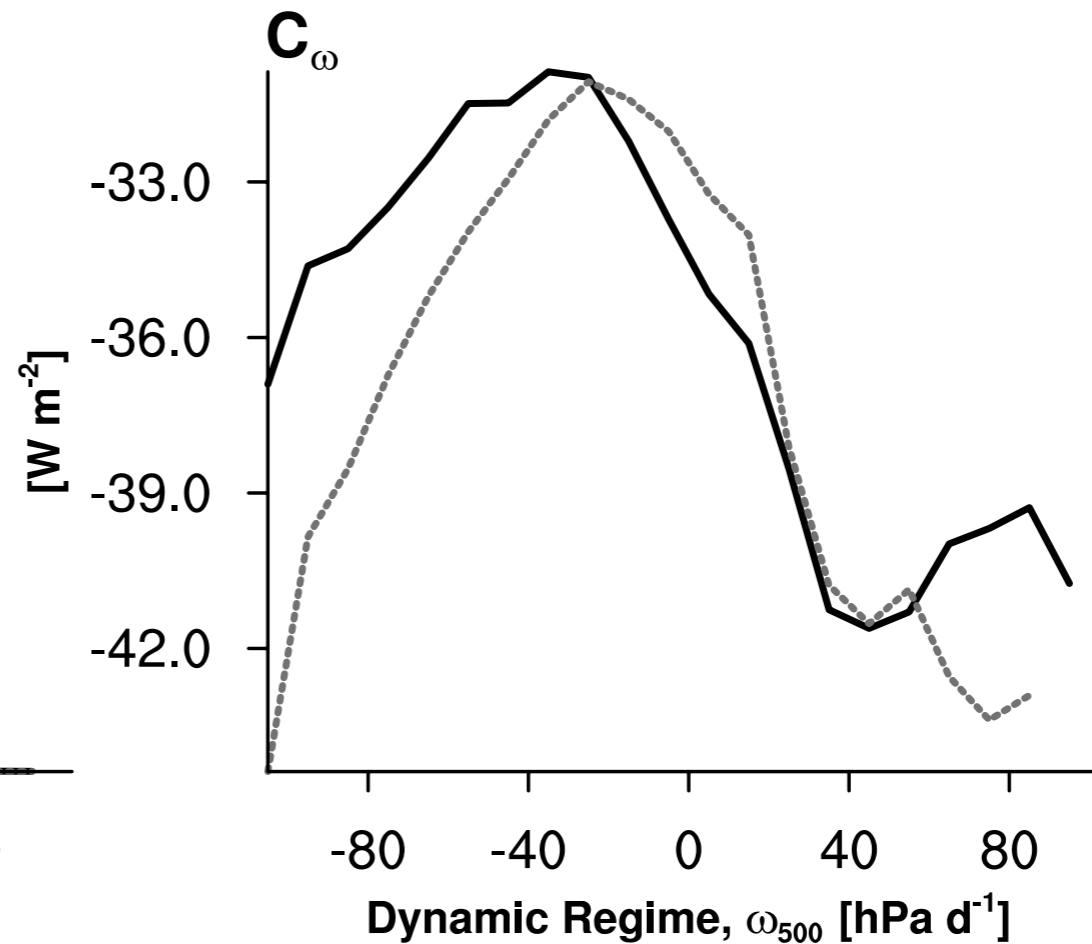
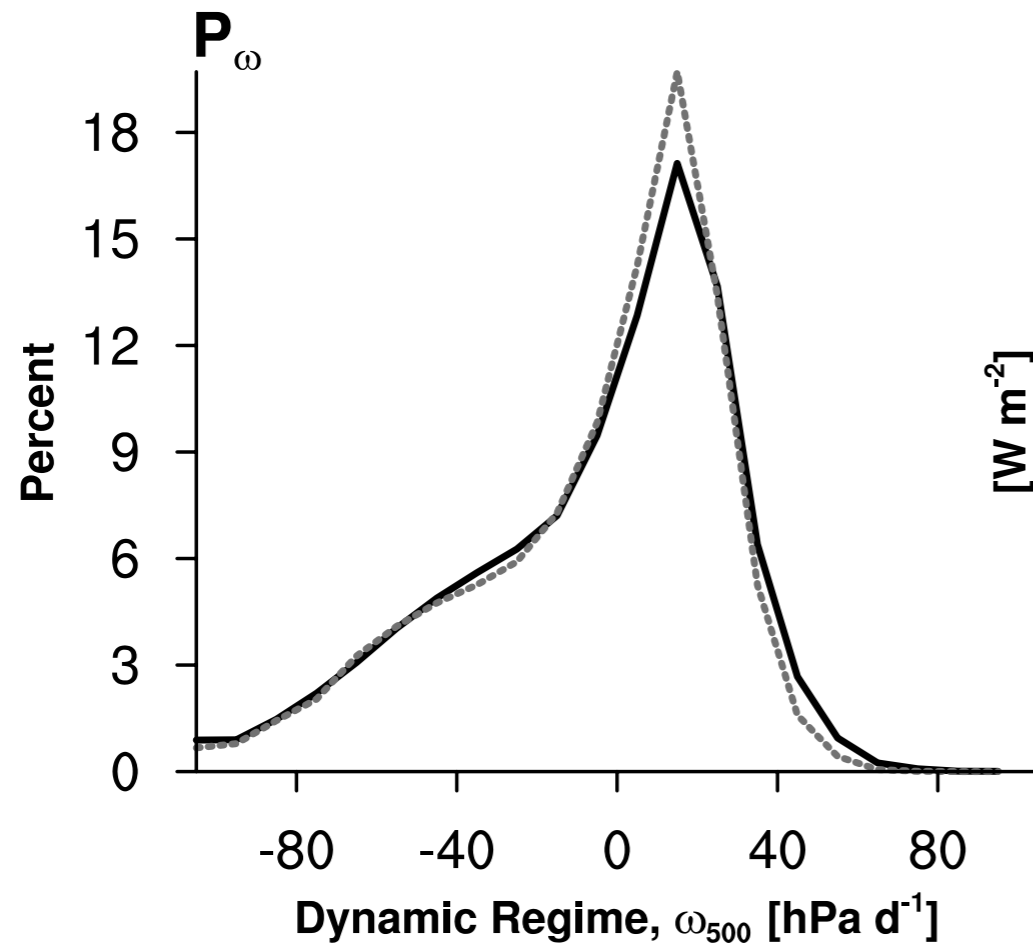
choose a “cloud variable” (CRF)

composite CRF by vertical motion -
these are regimes

Bony et al (1997, 2004, 2006)
Williams et al (2003)
Wyant et al (2006)

double check: dynamical regimes

$$\overline{\delta c} = \int_{-\infty}^{\infty} P_{\omega} \delta C_{\omega} d\omega + \int_{-\infty}^{\infty} C_{\omega} \delta P_{\omega} d\omega + \int_{-\infty}^{\infty} \delta C_{\omega} \delta P_{\omega} d\omega$$



double check: dynamical regimes

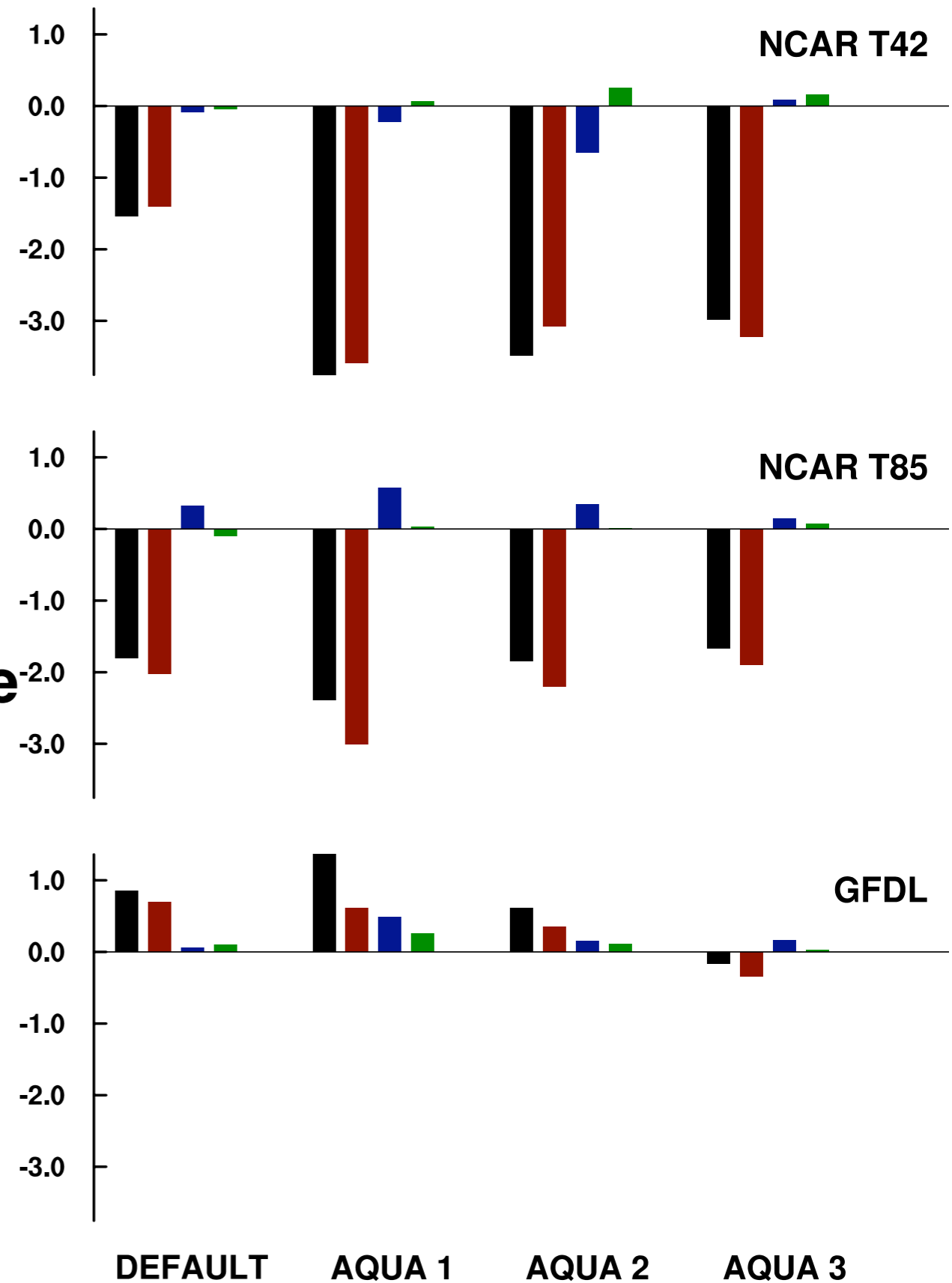
mean change in CRF

$$\overline{\delta c} = \int_{-\infty}^{\infty} P_{\omega} \delta C_{\omega} d\omega + \int_{-\infty}^{\infty} C_{\omega} \delta P_{\omega} d\omega + \int_{-\infty}^{\infty} \delta C_{\omega} \delta P_{\omega} d\omega$$

change in CRF

change in circulation

both change



outro: where are we?

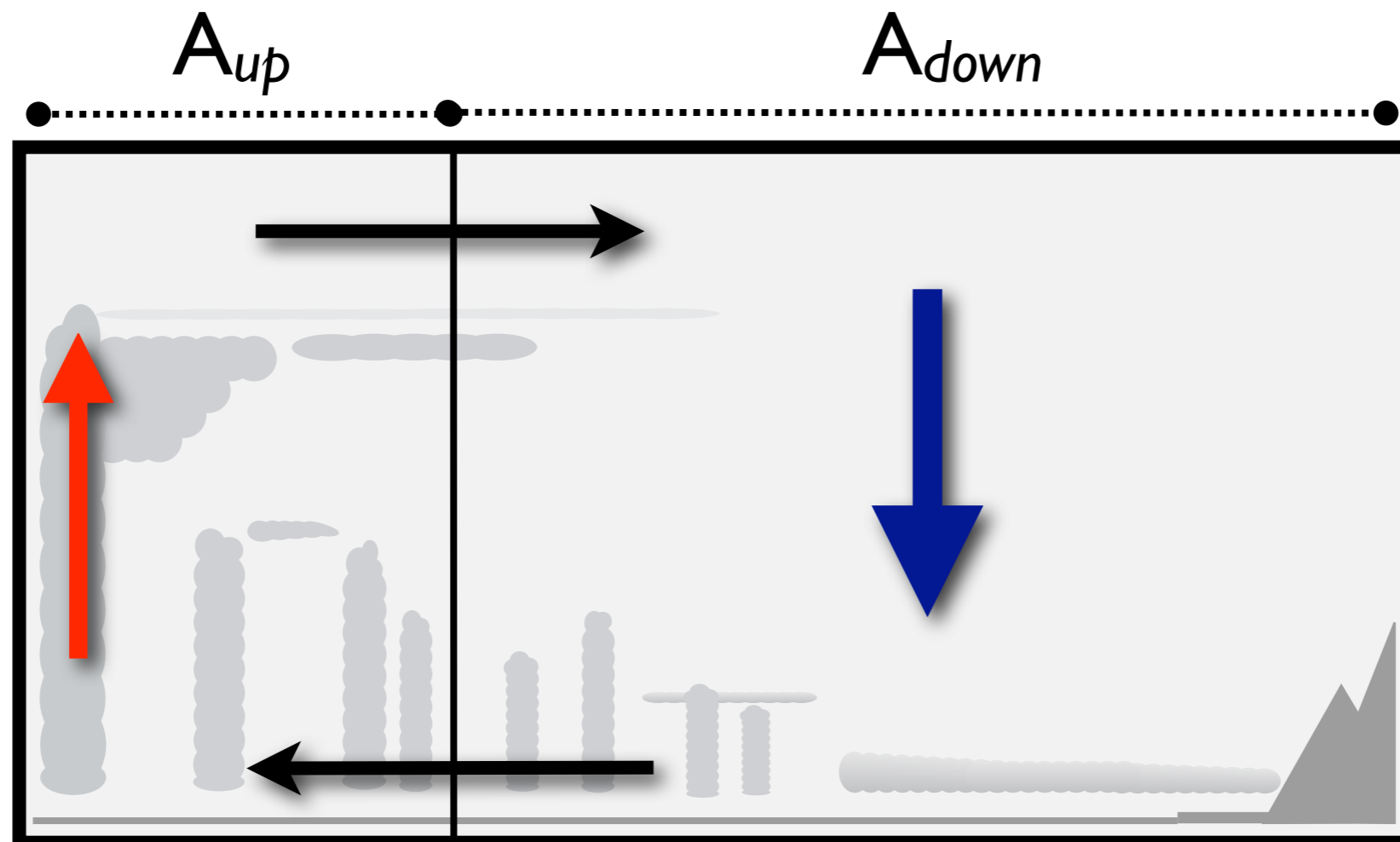
climate sensitivity tied to low-level tropical clouds

effects not strongly related to details of circulation

- implies differences in parameterized physics

the aquaplanet framework reduces the complexity

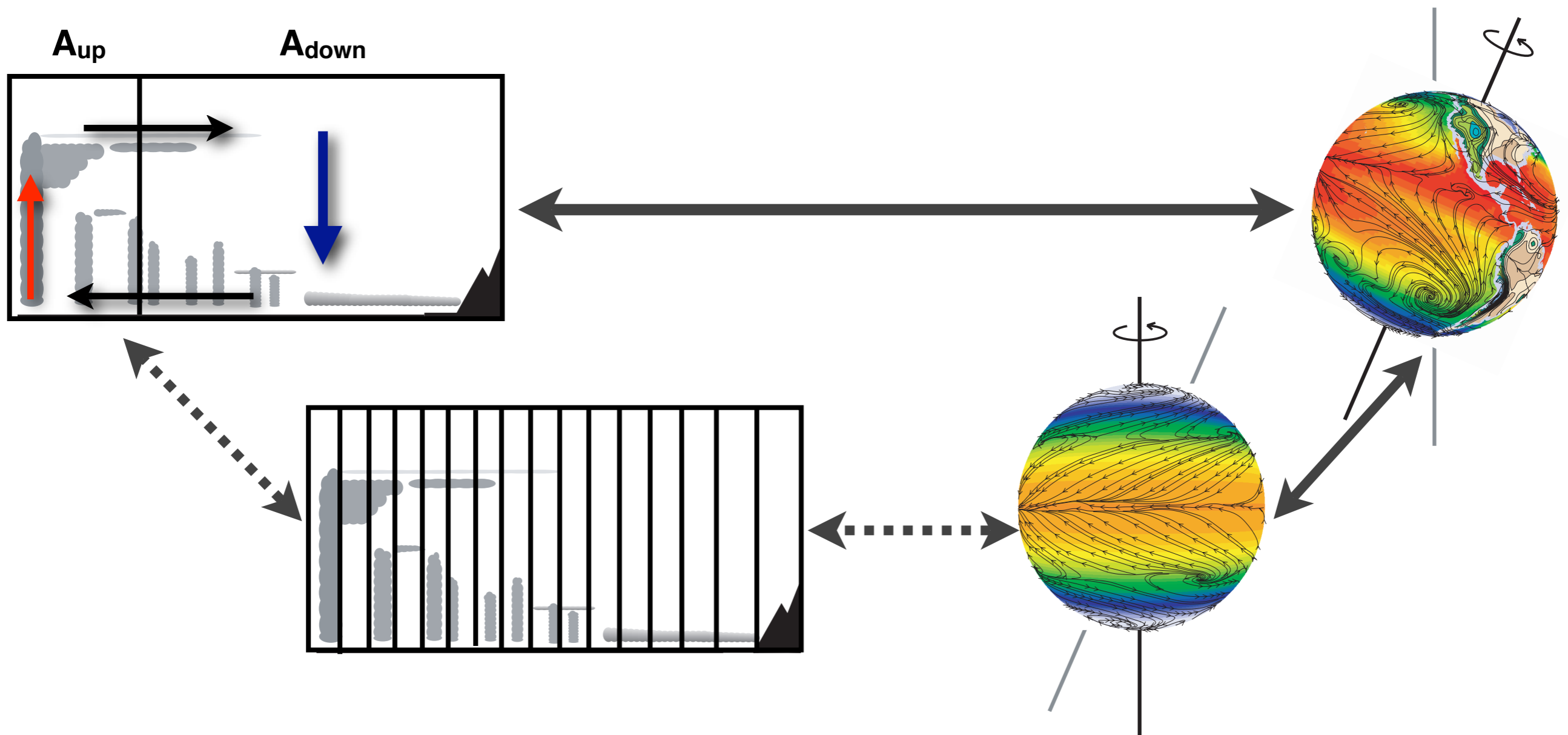
- lends itself to idealized studies with single-column models



outro: where are we going?

coupled single columns form a simple tropical model

- bridge gap between simple 2-column theories and climate models



thanks

Within the collection of possible planetary atmospheres, one which is devoid of irregularities occupies a more central and fundamental position than one with any specific arrangement of irregularities. --Lorenz (1967)