Feedback Analyses using Radiative Kernels in Support of the CLARREO Science Definition Team

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Outline

- **Background**:
  - Concept of “radiative kernels”.
- **Current activities**:
  - Climate feedback OSSE.
  - Changes in radiation budget from HIRS.
- **Future plans**

Climate Feedbacks: Kernel Method

$$\Delta T_s = \frac{G}{\lambda}$$

G = radiative forcing
R = net radiation at TOA
λ= climate sensitivity parameter
(rate of radiative damping)

$$\lambda = \frac{\delta R}{\delta T}\frac{dT}{dT_s} + \frac{\delta R}{\delta W}\frac{dW}{dT_s} + \frac{\delta R}{\delta C}\frac{dC}{dT_s} + \frac{\delta R}{\delta \alpha}\frac{d\alpha}{dT_s}$$

Temperature Feedback | Water Vapor Feedback | Cloud Feedback | Sfc Albedo FeedbacK

Climate Feedback = $\delta R/\delta X$ X dX/dT_s

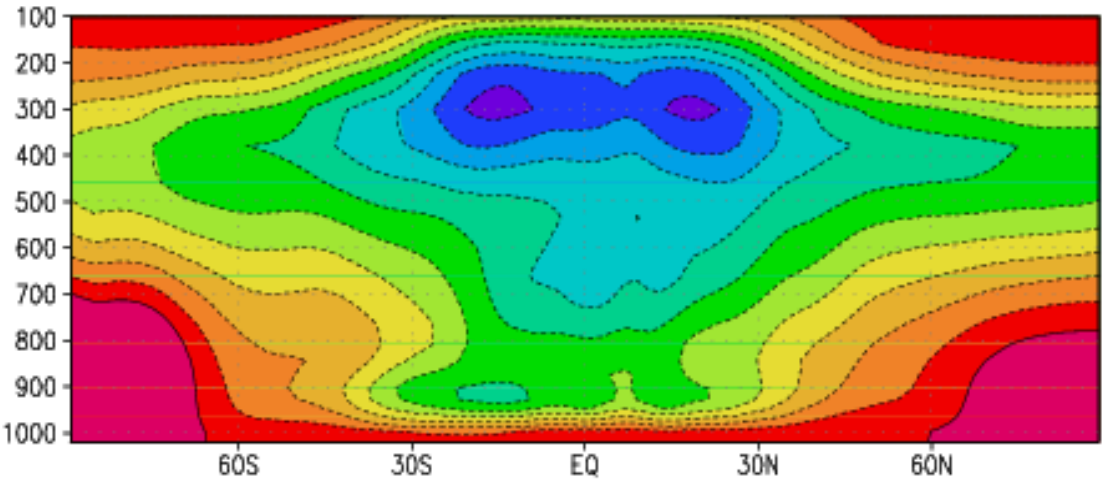
Radiative Transfer | Climate Response

Water Vapor Kernel (zonal, annual mean)

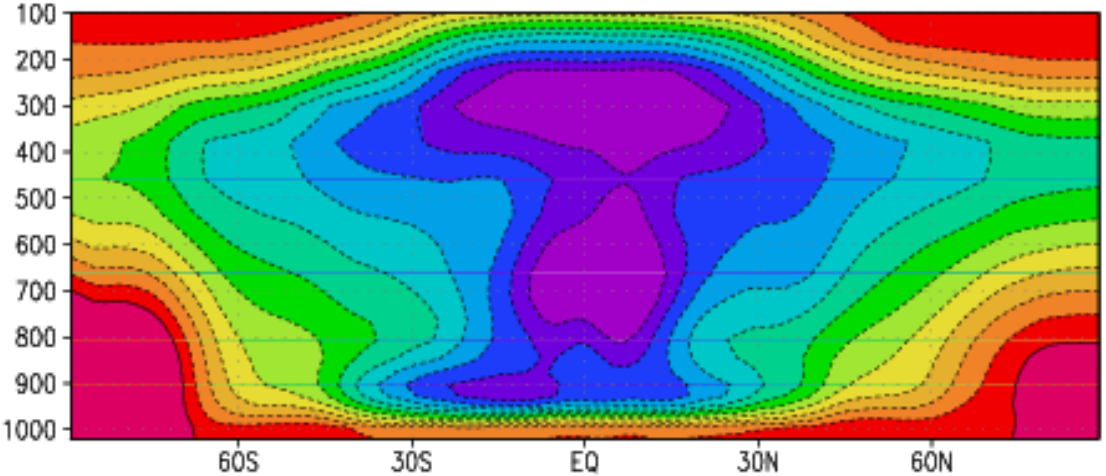
Change in OLR due to constant RH increase in WV

Clouds mask effect of water vapor in lower levels

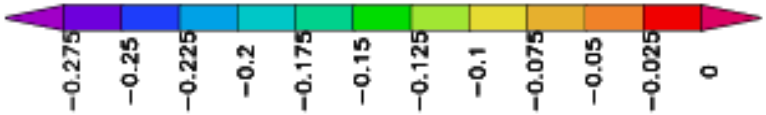
Largest feedback comes from upper troposphere because that is where the fractional change in water vapor is greatest.



Total Sky



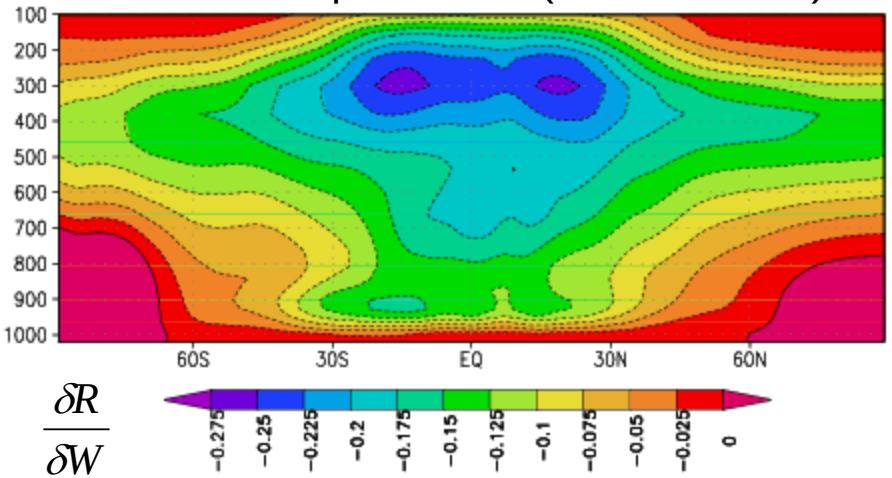
Clear Sky



$W/m^2/K/100$ mb

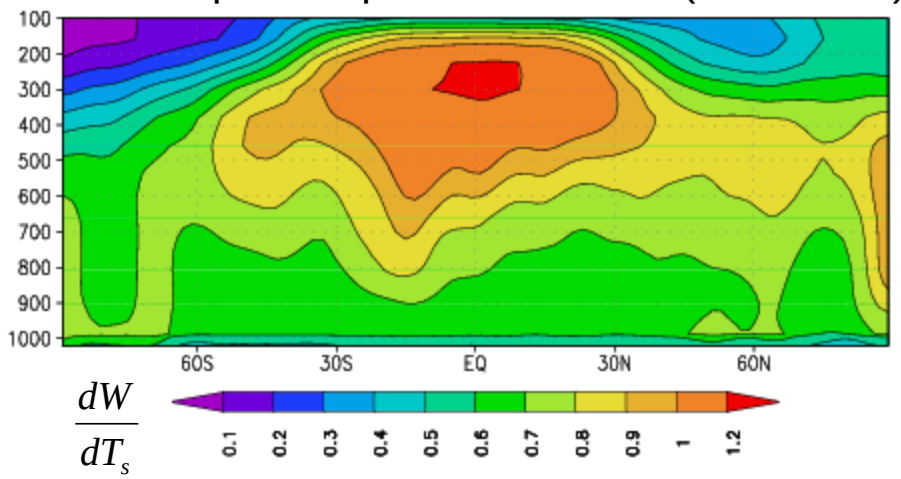
Water Vapor Feedback using Kernels

Water Vapor Kernel (from RT code)



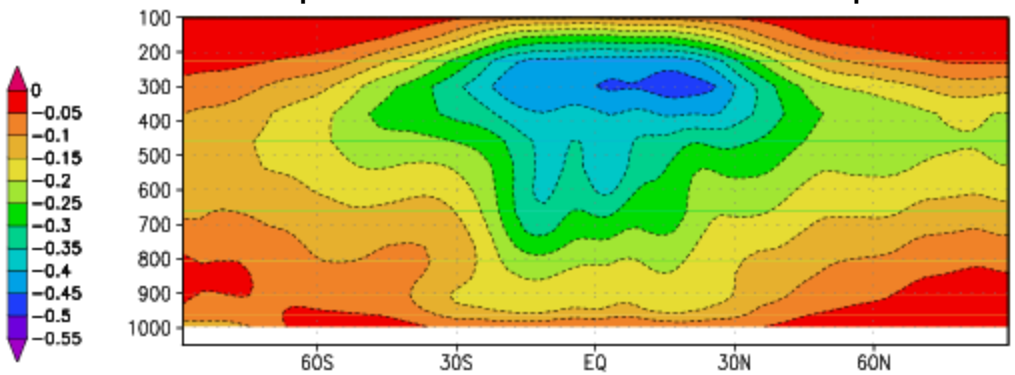
x

Water Vapor Response to 2xCO2 (from GCM)

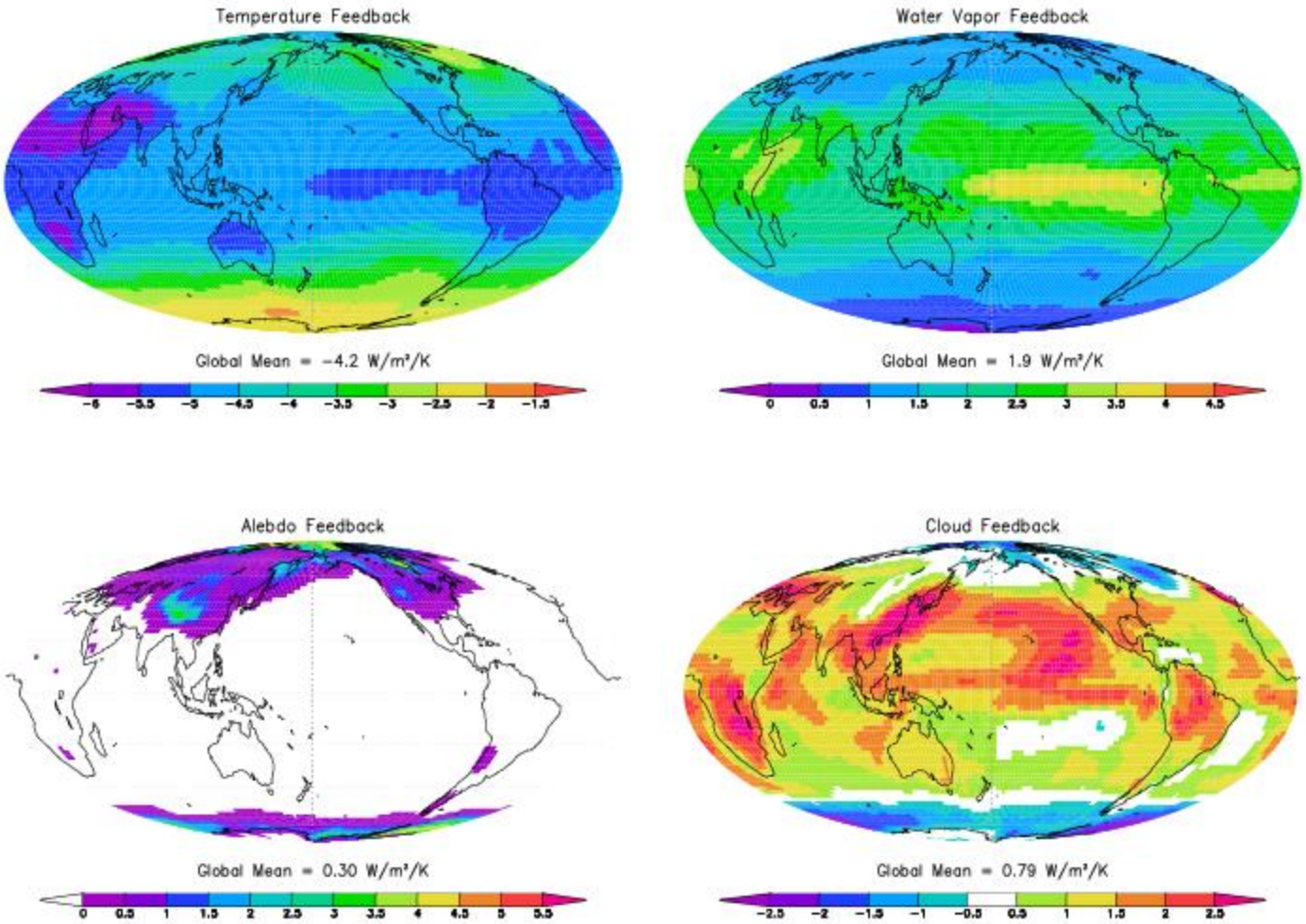


Water Vapor Feedback = Kernel x Response

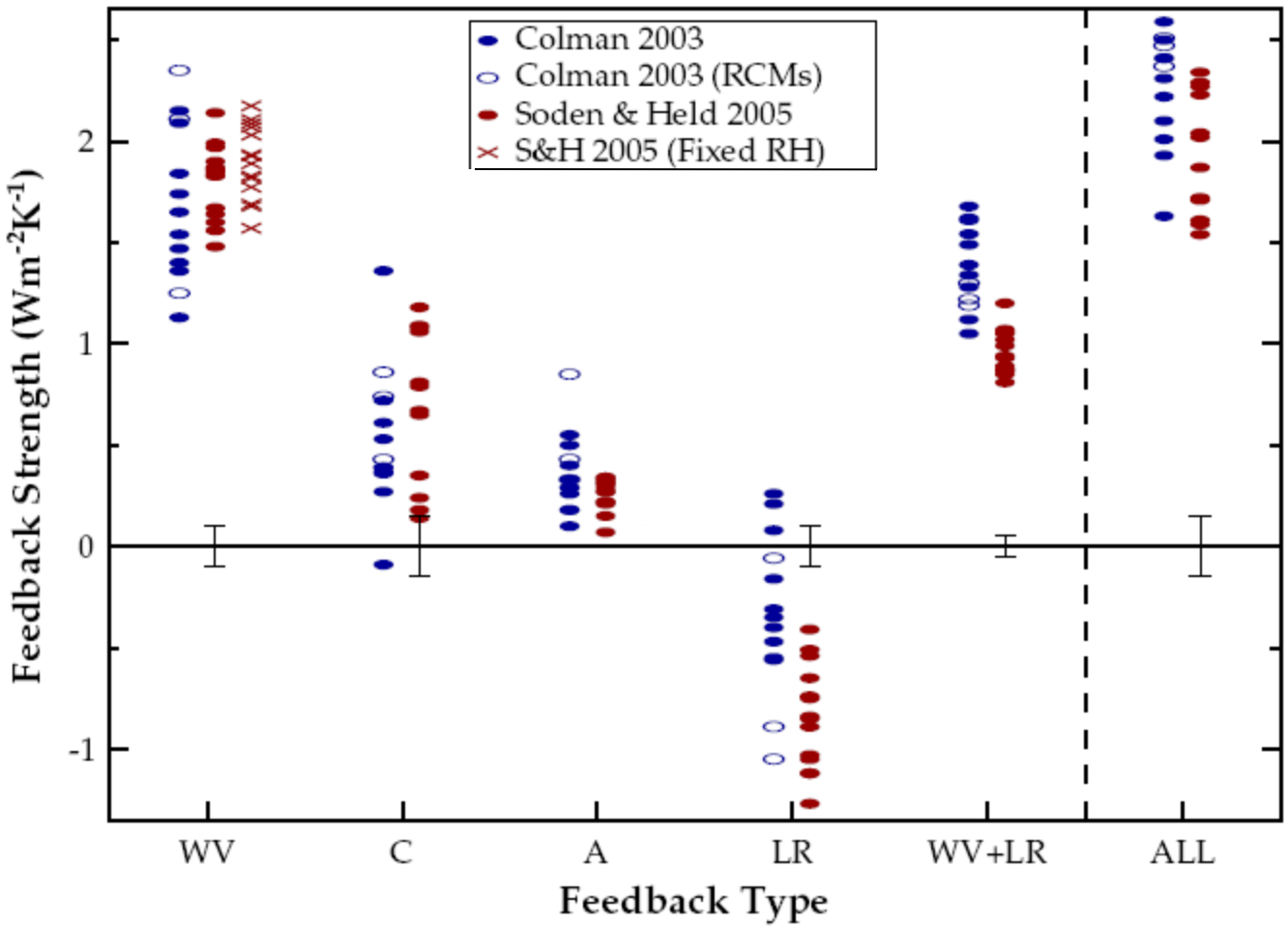
=



Ensemble Mean Feedbacks: IPCC AR4 GCMs



Climate Feedbacks in IPCC Models



Bony et al. 2006

- **Water vapor provides the strongest positive feedback in GCMs.**
- **Water vapor and lapse-rate are strongly correlated.**

Climate Feedback OSSE

Assuming we had perfect observations, how long of a record would be required to observe climate feedbacks?

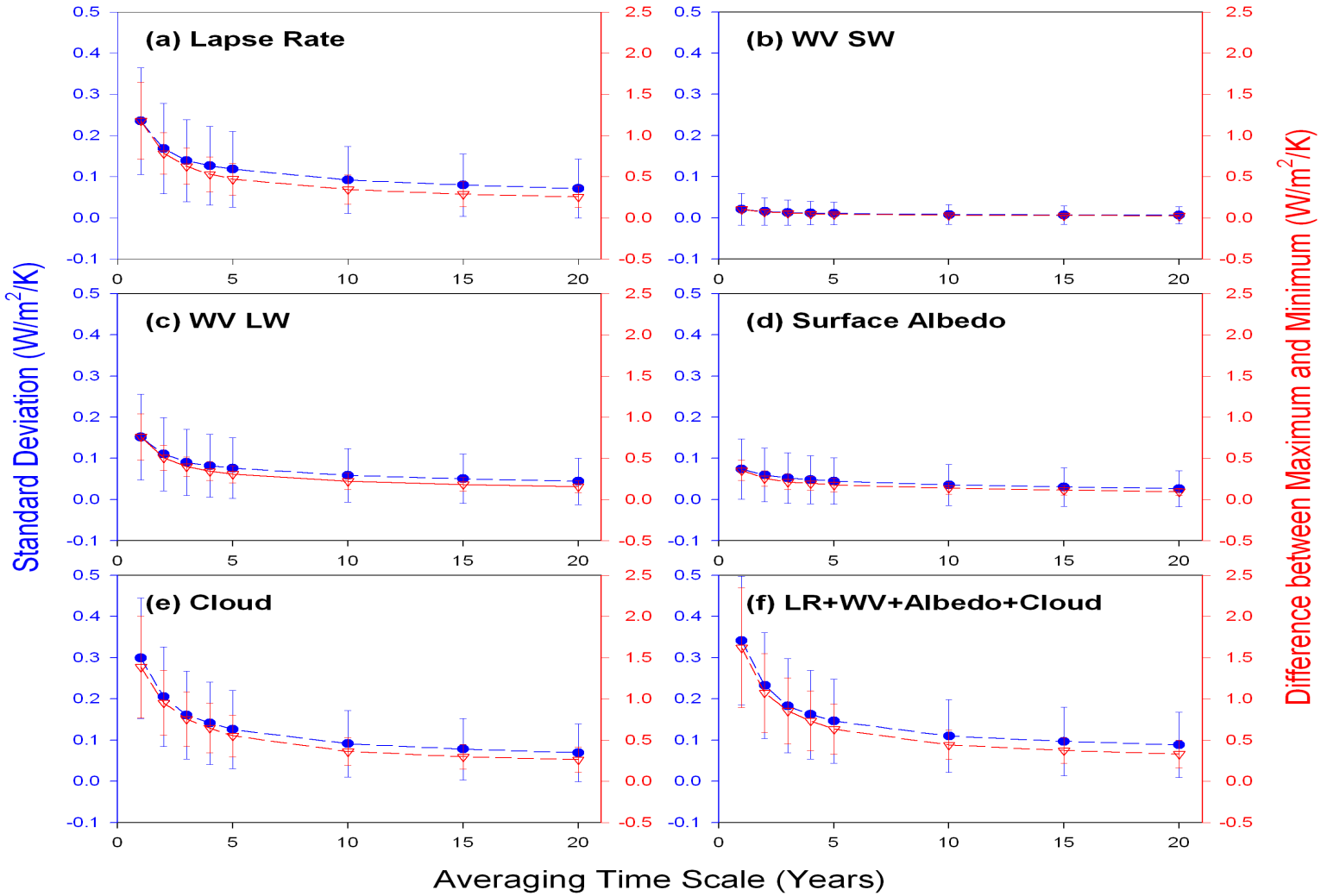
Climate response is determined by differencing 2 climate states A & B:

$$\Delta W = \overline{W}_B - \overline{W}_A$$

How long of record is needed to define the reference climate?
(internal variability)

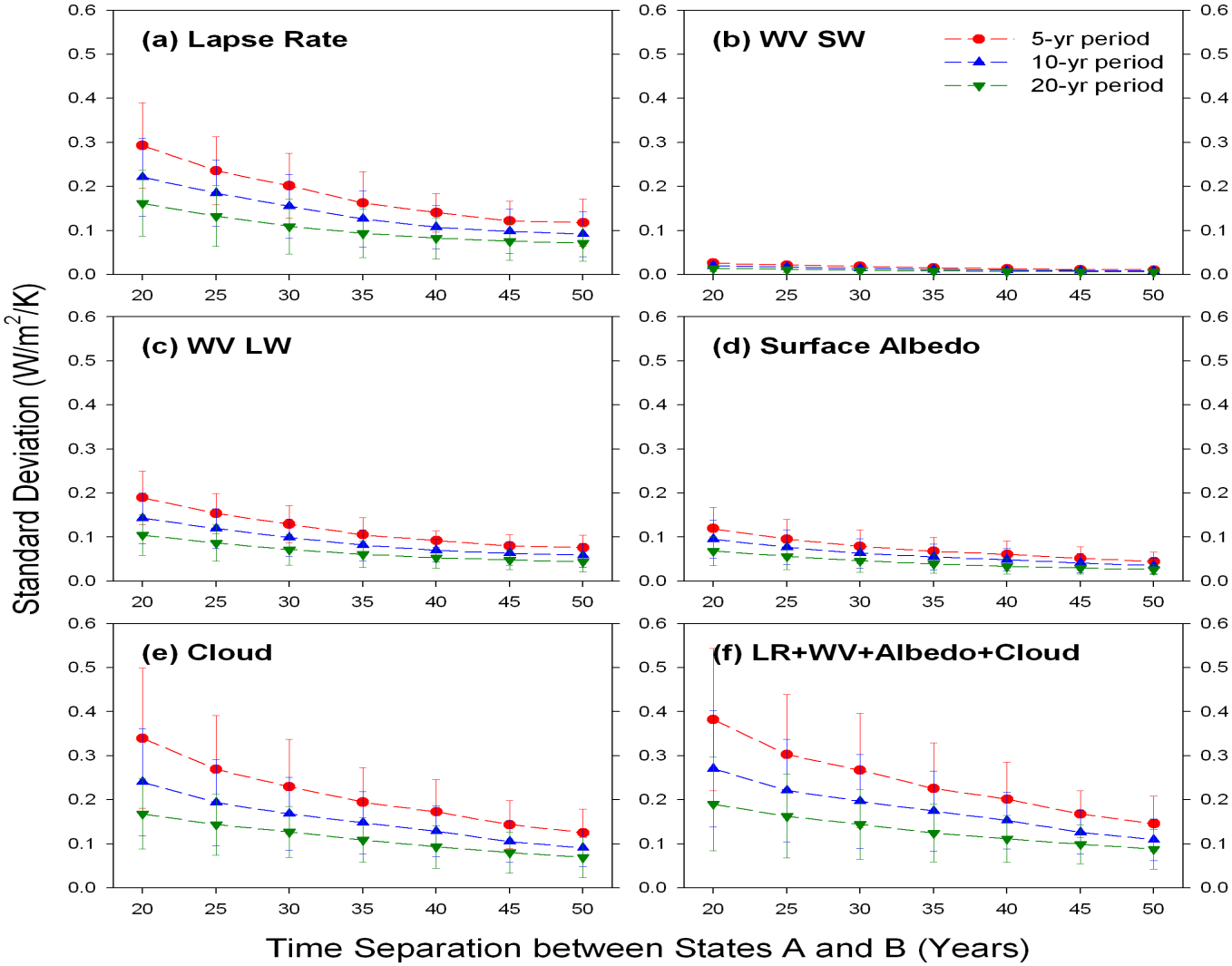
How long of a record is needed to detect a change in climate?
(externally forced change).

Time Scale Dependence of Feedbacks: IPCC AR4



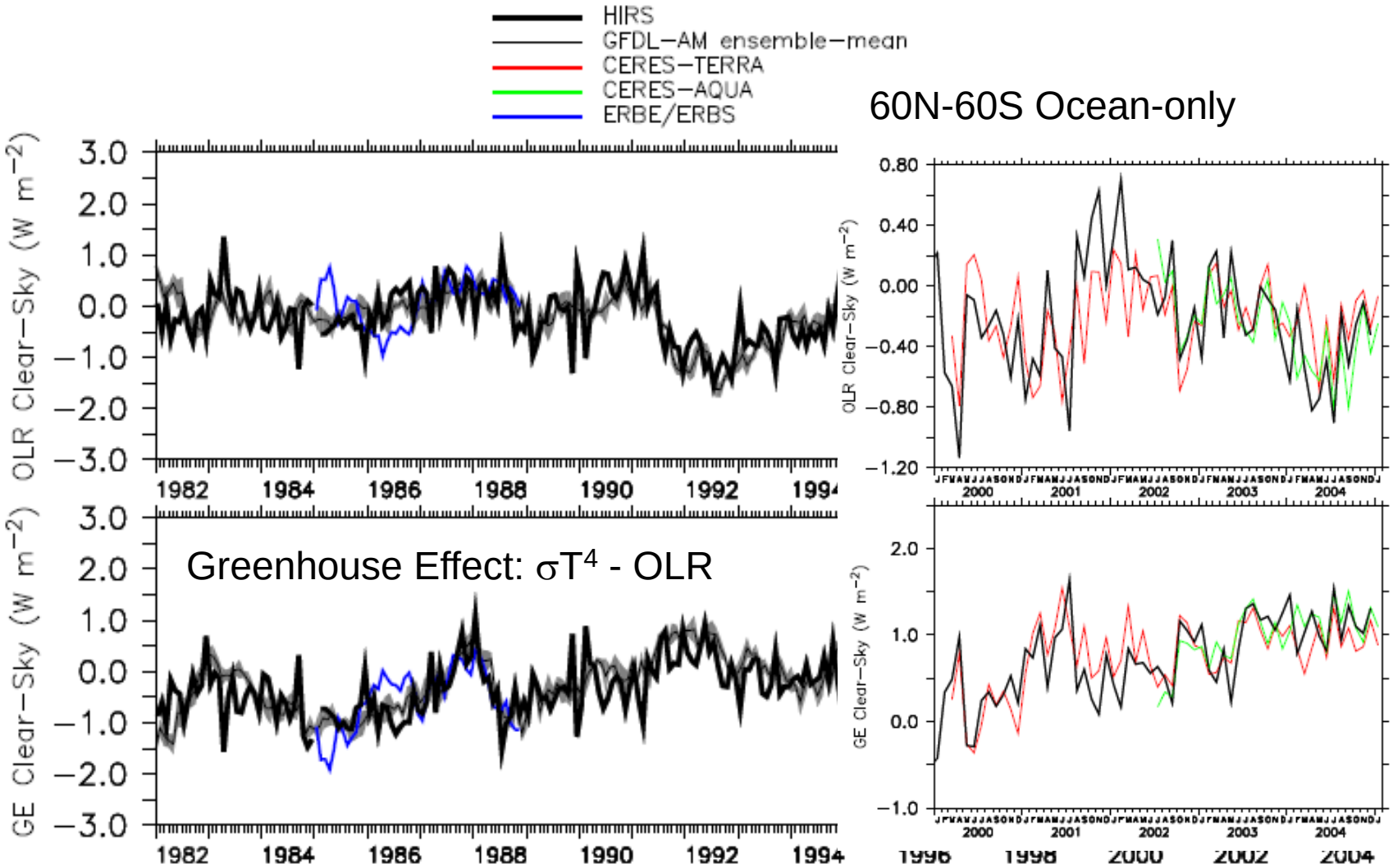
- **Need averaging periods of ~5 years or more**

Time Scale Dependence of Feedbacks: IPCC AR4



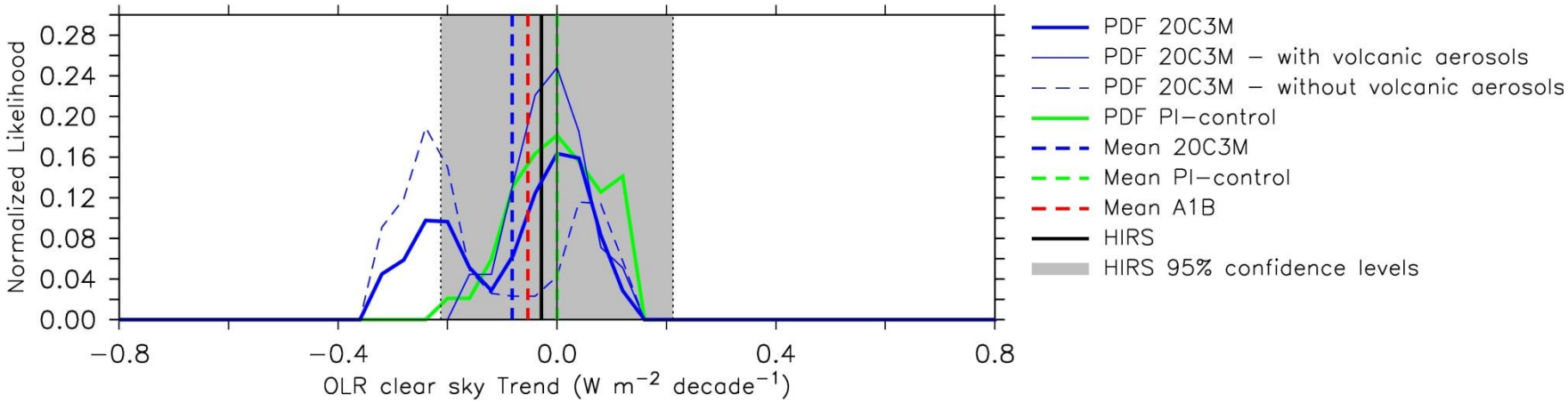
- **Longer averaging periods reduce separation time.**

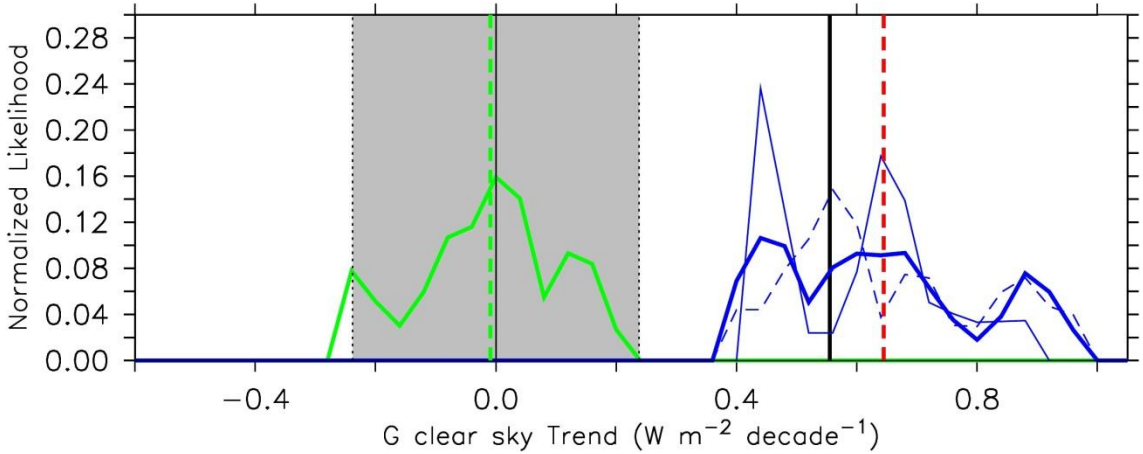
Changes in Earth's Radiation Budget from HIRS



- **Little trend in clear-sky OLR.**
- **Substantial trend in surface emission.**

Changes in Earth's Radiation Budget from HIRS





- **No anthropogenic signal in OLR alone.**
- **Clear anthropogenic signal in GE (OLR + surface emission).**

Future Plans

- Collaborate on feedback OSSEs for CLARREO and related observational missions.

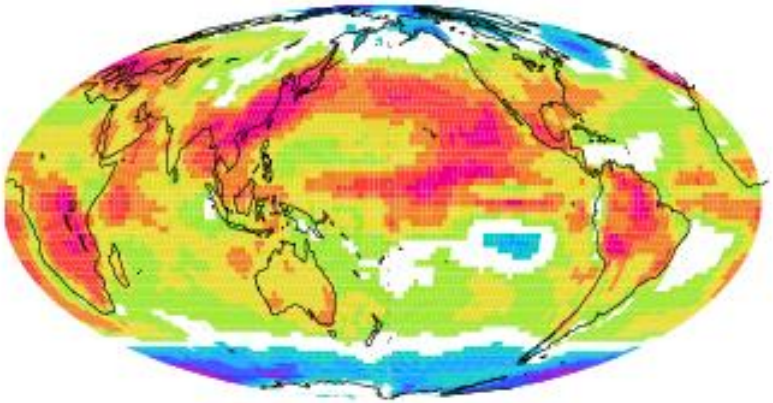
- Collaborate on developing/analyzing spectrally-resolved kernels for feedback and detection/attribution studies.

- Kernel Development:
  - observationally-based kernels
  - kernel intercomparison
  - kernels for surface radiative fluxes
  - kernel analysis of spectral radiative forcings

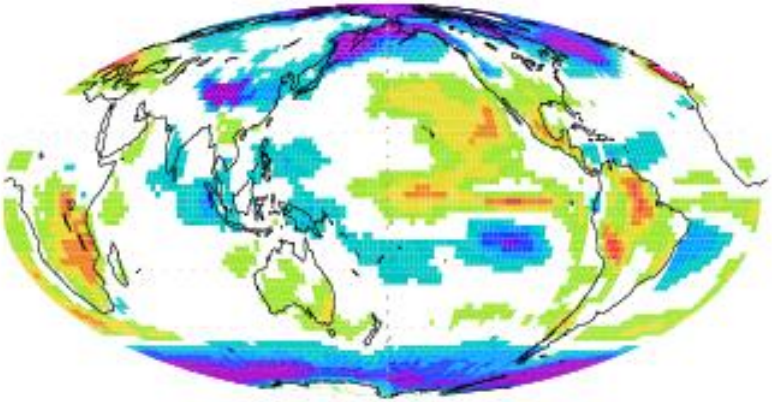
Extra Slides

Cloud Feedback vs Δ Cloud Forcing

Cloud Feedback (0.77 W/m²/K)

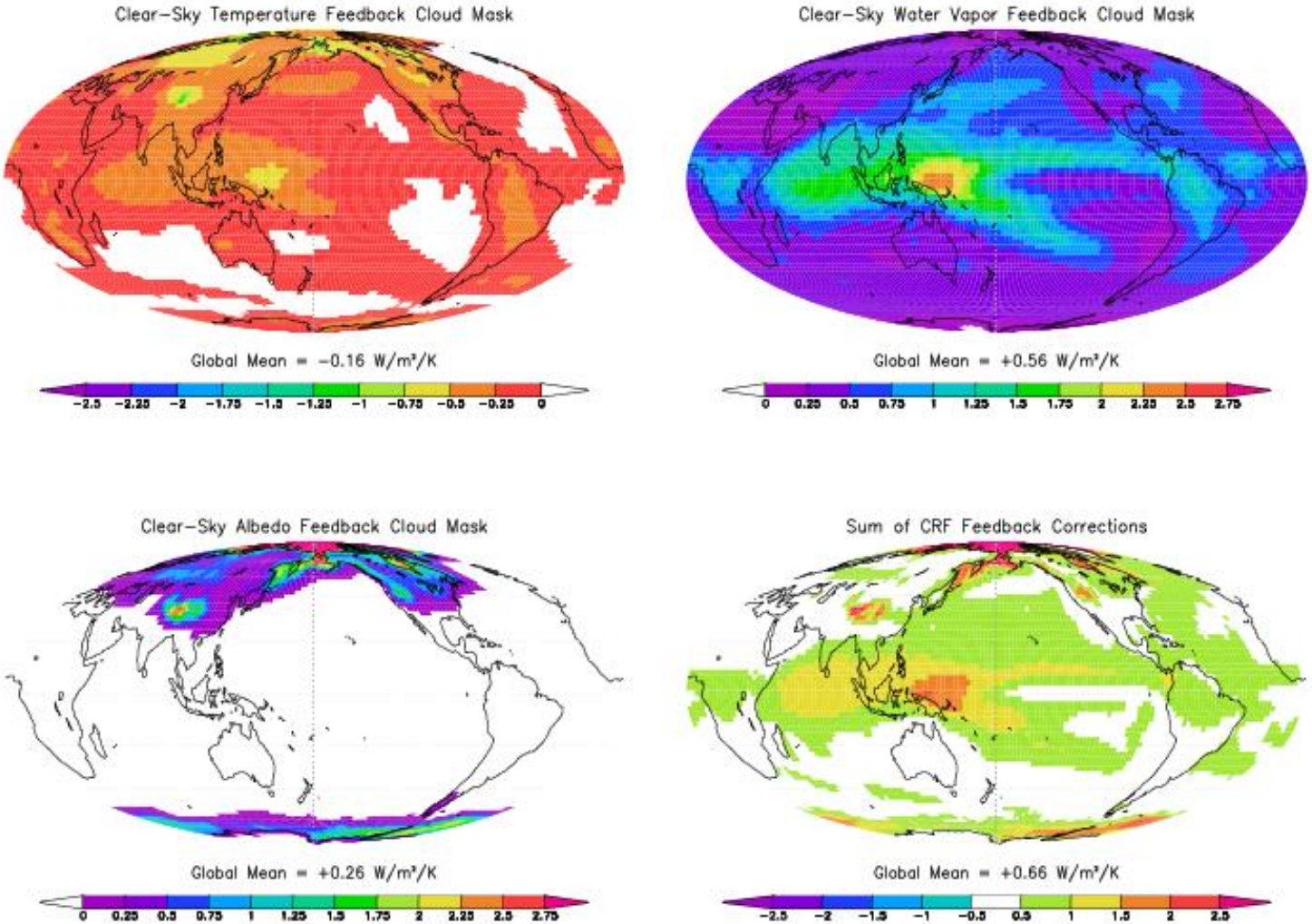


Change in Cloud Forcing (−0.22 W/m²/K)

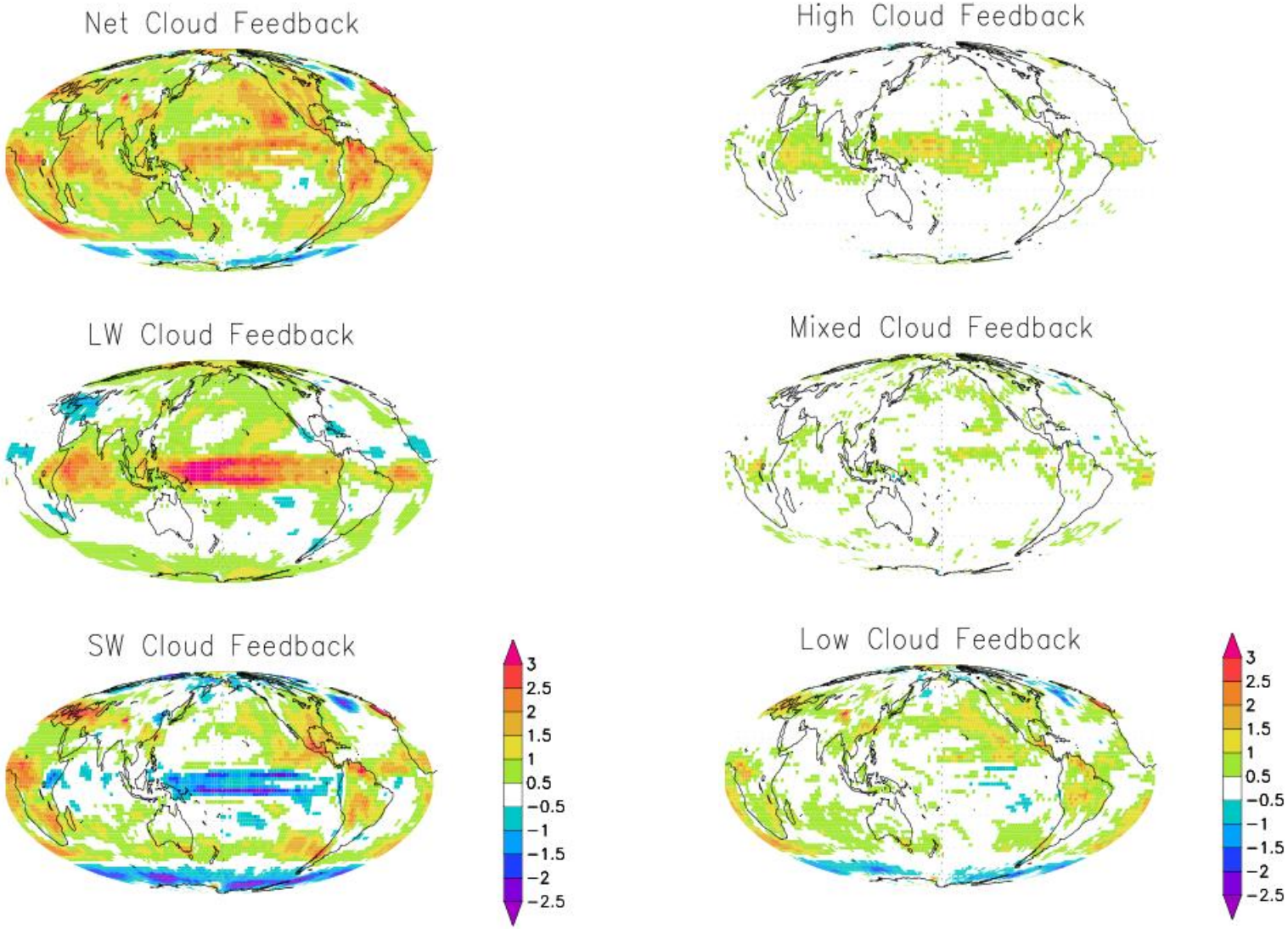


$CRF = R_{clr} - R$

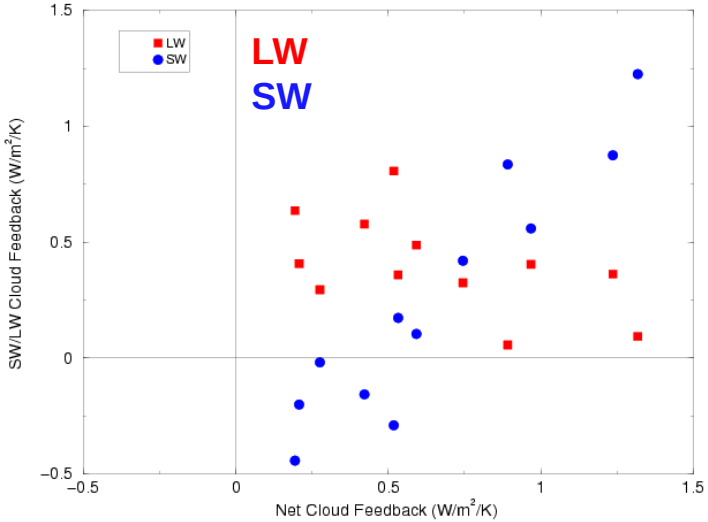
Effects of Non-Cloud Feedbacks on ΔCRF

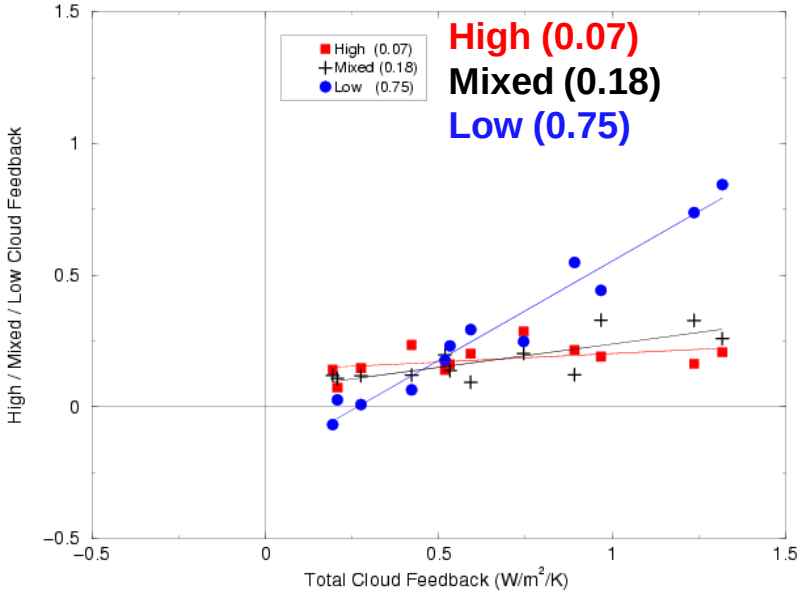


Ensemble Mean Cloud Feedback



Intermodel Spread in Global Mean Cloud Feedback

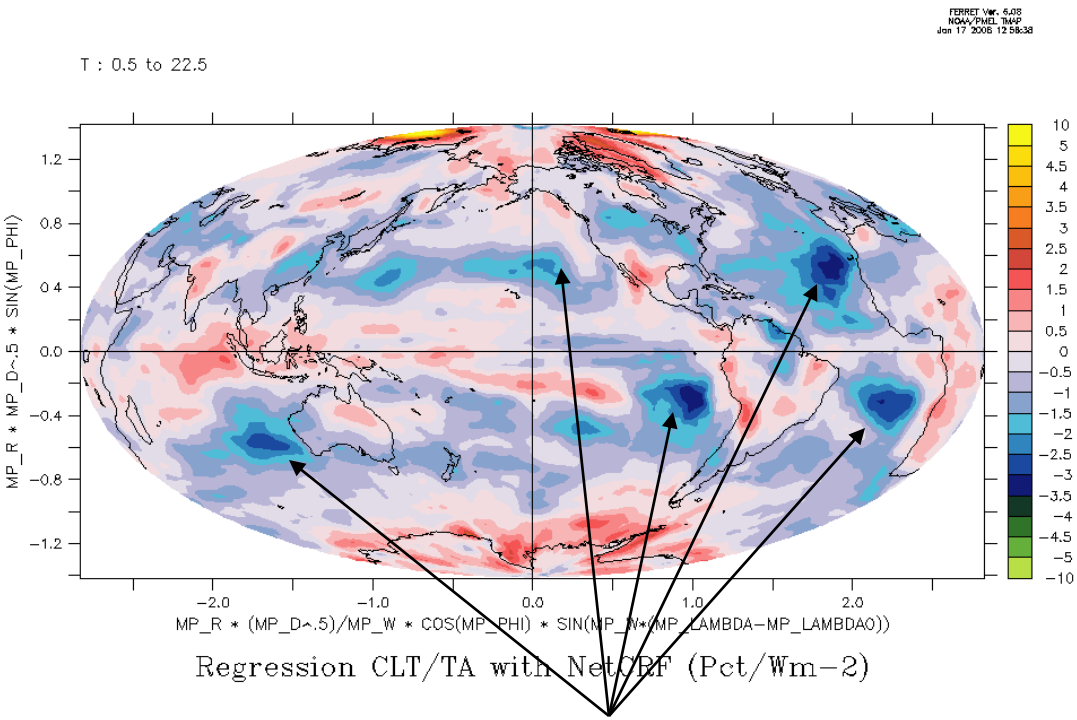




Most spread due to SW cloud feedback

Most spread due to low clouds

Regional contribution to intermodel spread in cloud feedback



Most of intermodel spread arises from stratocumulus regions

Determining Radiative Forcing as a Residual

For Clear-sky Fluxes

$$dR = \left(\frac{\delta R}{\delta T}\frac{dT}{dT_s} + \frac{\delta R}{\delta W}\frac{dW}{dT_s} + \frac{\delta R}{\delta \alpha}\frac{d\alpha}{dT_s}\right)dT_s \quad + G \quad + \ldots$$

Temperature Feedback | **Water Vapor Feedback** | **Sfc Albedo FeedbacK**

From GCM Output

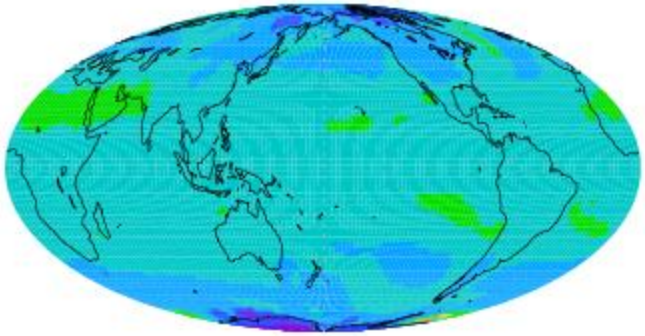
From Kernels

Clear-Sky Radiative Forcing as a Residual

Kernel vs. Direct Radiative Forcing

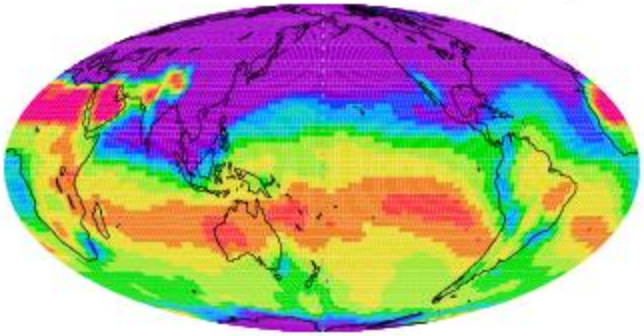
2x CO2

GFDL CM2.0 Kernel (4.20)

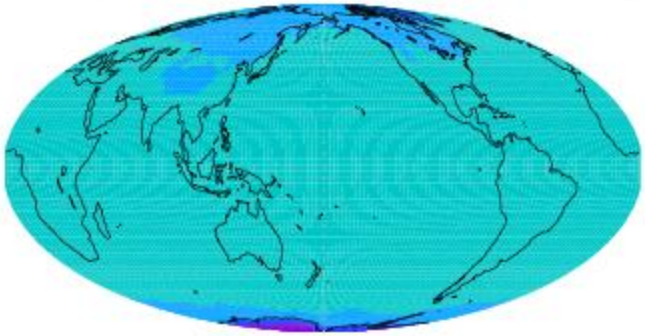


20C3M

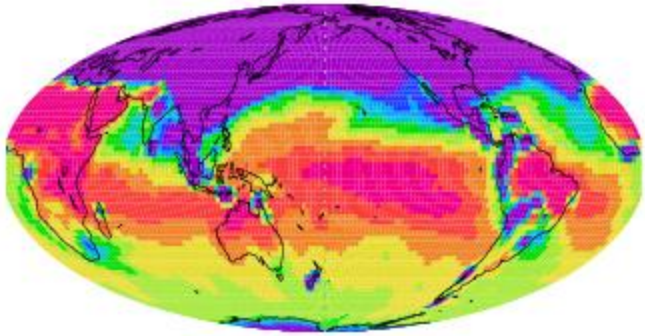
GFDL CM2.0 Kernel (0.76)

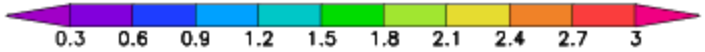


GFDL AM2p12b Instant Tropopause (4.27)

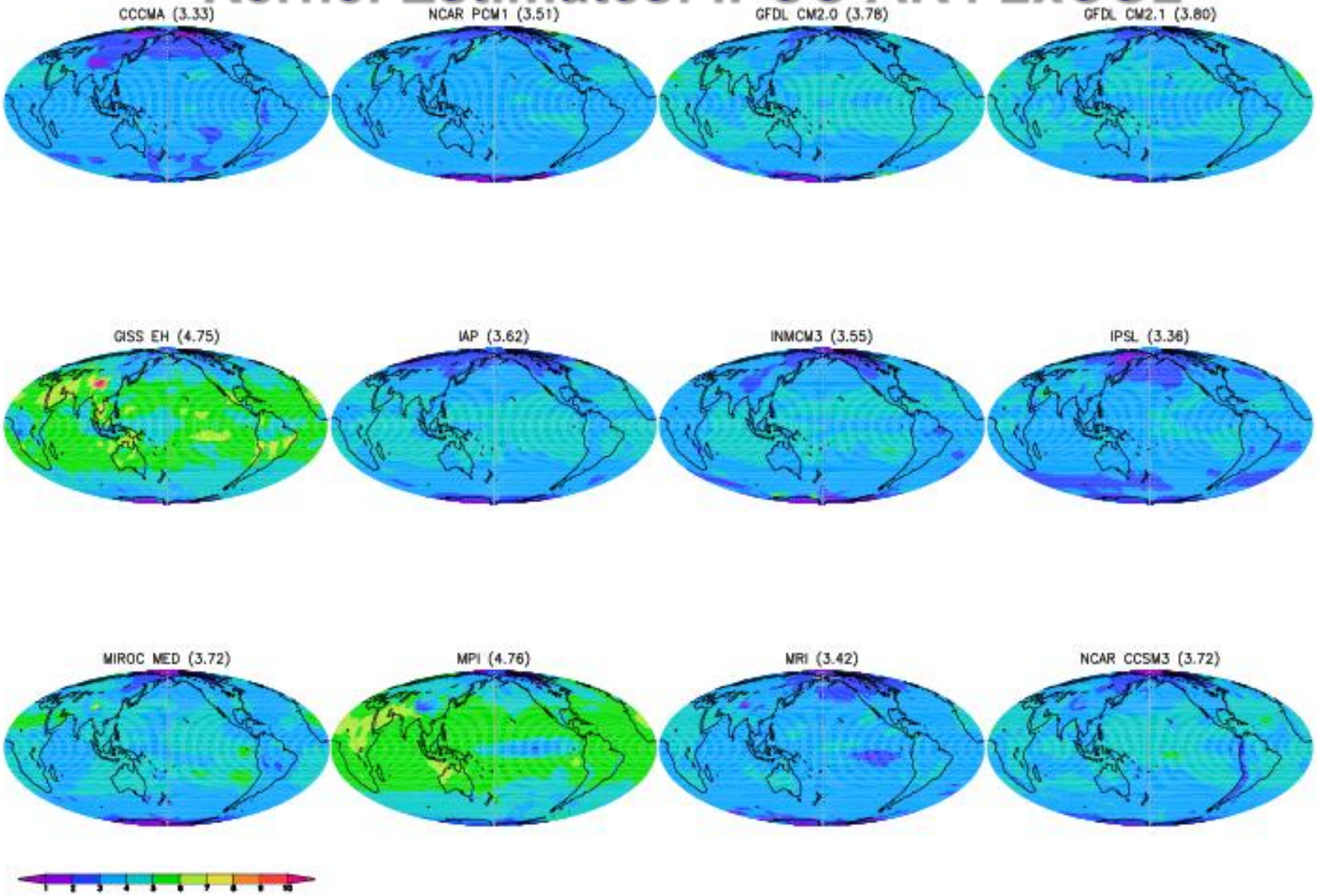


GFDL AM2 Instantaneous Tropopause (0.85)

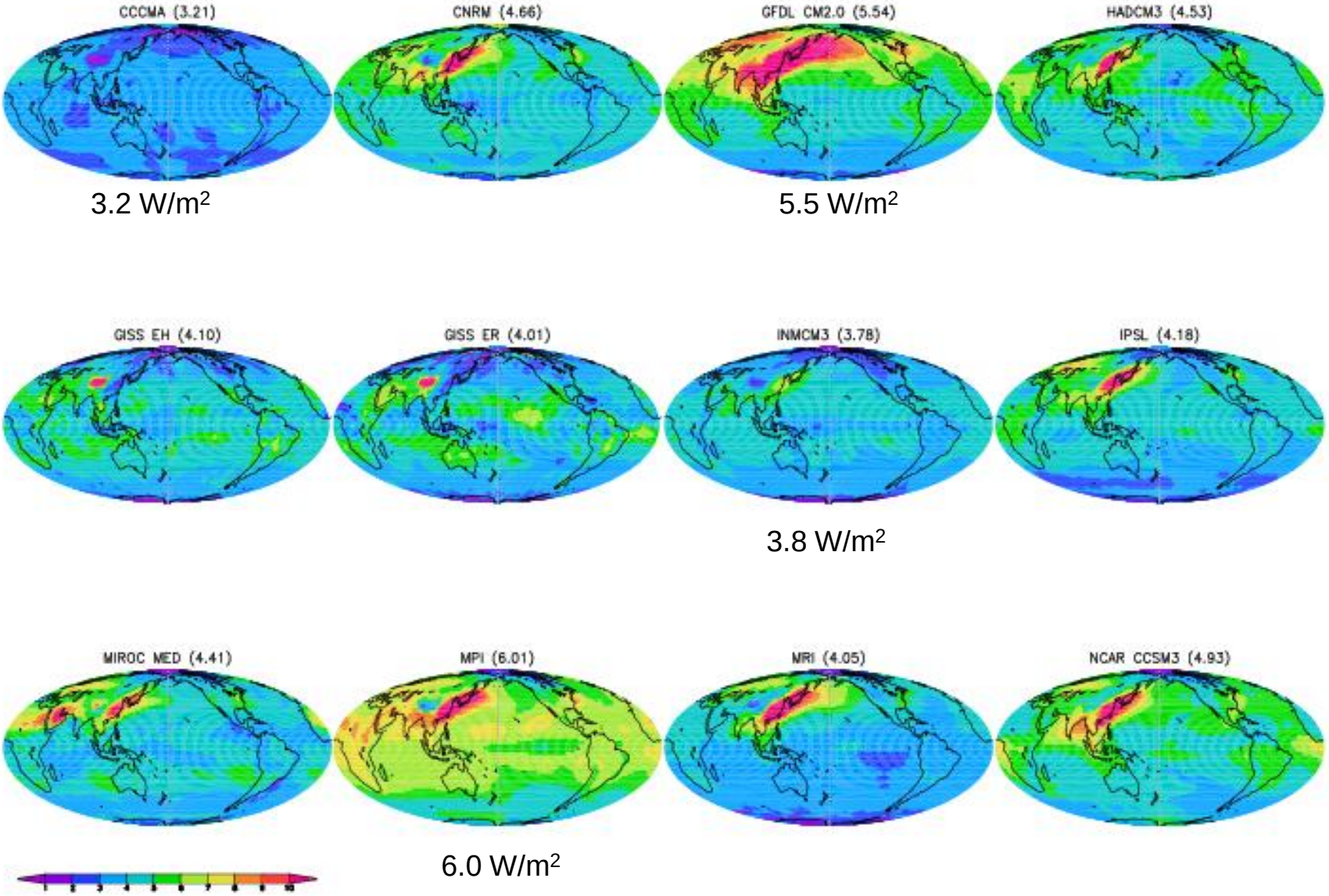




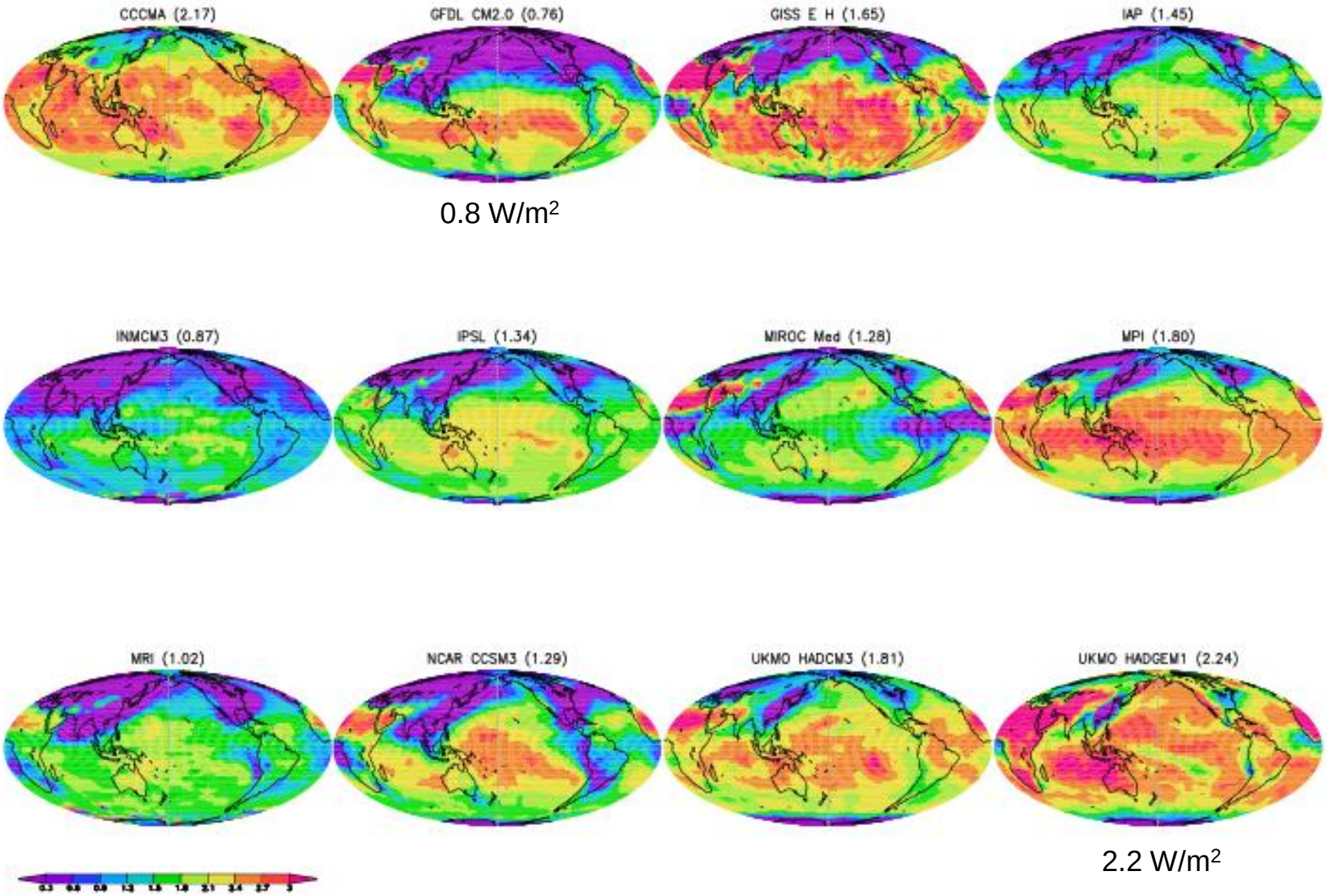
Kernel Estimates: IPCC AR4 2xCO2



Kernel Estimates: IPCC AR4 A1b



Kernel Estimates: IPCC AR4 20C3M



0.8 W/m^2

2.2 W/m^2

Satellite-Observed and Model-Simulated Changes in Atmospheric Water Vapor