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
- \( \lambda \) = climate sensitivity parameter (rate of radiative damping)

\[ \lambda = \frac{\partial R}{\partial T} \frac{dT}{dT_s} + \frac{\partial R}{\partial W} \frac{dW}{dT_s} + \frac{\partial R}{\partial C} \frac{dC}{dT_s} + \frac{\partial R}{\partial \alpha} \frac{d\alpha}{dT_s} \]

- Temperature Feedback
- Water Vapor Feedback
- Cloud Feedback
- Sfc Albedo Feedback

Climate Feedback = \( \frac{\partial R}{\partial X} X \frac{dX}{dT_s} \)

Radiative Transfer

Climate Response
Water Vapor Kernel (zonal, annual mean)

Change in OLR due to constant RH increase in WV

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

Clouds mask effect of water vapor in lower levels

Total Sky

Clear Sky

W/m²/K/100 mb
Water Vapor Feedback using Kernels

Water Vapor Kernel (from RT code)

Water Vapor Response to 2xCO2 (from GCM)

\[ \text{Water Vapor Feedback} = \text{Kernel} \times \text{Response} \]
Ensemble Mean Feedbacks: IPCC AR4 GCMs
• Water vapor provides the strongest positive feedback in GCMs.
• Water vapor and lapse-rate are strongly correlated.
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.

Greenhouse Effect: $\sigma T^4 - \text{OLR}$

60N-60S Ocean-only
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 \( \Delta \) Cloud Forcing

Cloud Feedback \((0.77 \text{ W/m}^2/\text{K})\)

Change in Cloud Forcing \((-0.22 \text{ W/m}^2/\text{K})\)

\(\text{CRF} = R_{\text{clr}} - R\)
Effects of Non-Cloud Feedbacks on $\Delta$CRF
Ensemble Mean Cloud Feedback

Net Cloud Feedback

High Cloud Feedback

LW Cloud Feedback

Mixed Cloud Feedback

SW Cloud Feedback

Low Cloud Feedback

W/m²/K

W/m²/K
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

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

- 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)

GFDL AM2p12b Instant Tropopause (4.27)

20C3M
GFDL CM2.0 Kernel (0.76)

GFDL AM2 Instantaneous Tropopause (0.85)
Kernel Estimates: IPCC AR4 2xCO2
Kernel Estimates: IPCC AR4 A1b

3.2 W/m²

5.5 W/m²

3.8 W/m²

6.0 W/m²
Kernel Estimates: IPCC AR4 20C3M

0.8 W/m²

2.2 W/m²
Satellite-Observed and Model-Simulated Changes in Atmospheric Water Vapor

[Graph showing changes in atmospheric water vapor over time, with highlighted periods for El Niño and La Niña events, and a mention of the Pinatubo eruption.]

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