Understanding Feedback Processes

Outline

• Definitions

• Magnitudes and uncertainties

• Geographic distributions and priorities

• Observational requirements
Climate Feedbacks

• Climate sensitivity is the equilibrium change in global mean surface temperature ($\Delta T$) that results from a specified radiative forcing ($\Delta Q$).

• The sensitivity is a function of the feedback factors ($\lambda$).

$$\Delta T = \frac{\Delta Q}{(\lambda_{Planck} + \lambda_{wv} + \lambda_{cloud} + \lambda_{albedo})}$$
Climate Feedbacks

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- The sensitivity is a function of the feedback factors (\(\lambda\)).

\[
\Delta T = \frac{\Delta Q}{\lambda_{Planck} + \lambda_{wv} + \lambda_{cloud} + \lambda_{albedo}}
\]

\[
\begin{align*}
\lambda_{Planck} & = 3.6 \\
\lambda_{wv} & = -1.6 \\
\lambda_{cloud} & = -0.4 \\
\lambda_{albedo} & = -0.3
\end{align*}
\]

Radiative Forcing: 4 W/m\(^2\) = 3 K

Planck (temperature + lapse rate)
Water Vapor (mixing ratio)
Clouds (cloud amount, water path, particle size)
Albedo (snow, ice)
Range of Model Feedbacks

Colman (2003)
Range of Model Feedbacks

Colman (2003)
The Importance of Water Vapor Feedback

![Graph showing the impact of water vapor feedback on global warming. The graph illustrates the increase in global warming (ΔT °C) as water vapor feedback increases, with different feedback scenarios indicated by blue and yellow regions. The current model range is highlighted, showing a potential increase of 4.5 °C at 1.6 W/m²/K.]
Distribution of Water Vapor Feedback

**Vertical Contributions**
- Boundary Layer: (~10%)
- Upper Trop: (~70%)

**Latitudinal Contributions**
- Tropics: (~65%)
- Mid-Lat: (~30%)
- Polar: (~5%)
Water Vapor Feedback

Fractional Change in Water Vapor Concentration: GFDL GCM (SRES A1B)
Water Vapor Trends

Global Mean 6.7 micron $T_b$

- HIRS (0.01 K/decade)
- GFDL GCM (0.04 K/decade)
- GFDL GCM (no moistening 0.24 K/decade)

GCM
No Moistening

HIRS

6.7 µm Brightness Temperature Anomaly (K)
Cloud Feedback

Summer 2002

IPCC TAR Models

2xCO₂ Sensitivity (K)

GFDL AM2–ML (2xCO₂ - CTRL)

Change in Low Cloud Amount (%/K)

NCAR CAM2 (Year70 @1%CO₂/yr - CTRL)

Change in Low Cloud Amount (K/K)
Cloud Feedback

Fall 2003

2xCO₂ Sensitivity (K)

GFACL

NCAR

Change in Low Cloud Amount (%/K)

GFACL AM2p12o-ML (2xCO₂ - CTRL)

NCAR CAM2x-ML (2xCO₂ - CTRL)
Cloud Feedback

**ENSO**
- **GFSL AM2p9**
  - Change in Low Cloud Amount (%)

**2x CO2**
- **GFSL AM2-ML (2xCO₂ - CTRL)**
  - Change in Low Cloud Amount (%/K)

**NCAR CAM2**
- Change in Low Cloud Amount (%)

**GFDL:** Strong positive low cloud feedback.

**NCAR:** Weak negative low cloud feedback.
Response to Transient Forcings

Eruption of Mt. Pinatubo
June 1991
Cloud and Radiation Trends

Verification requires redundancy

Wielicki et al. (2002)
Priorities

- Free tropospheric temperature
- Tropical upper tropospheric water vapor (1%/dec, ΔZ=0.5 km)
- Low cloud cover (0.5%/dec, ΔZ=0.5 km)
- TOA radiative fluxes
- Redundancy

- Climate OSSE to guide system design and requirements
Extra Slides
Calculation of Feedbacks: Control

- sfc albedo
- temperature
- mixing ratio
- clouds
- CO₂

Radiation Model

SW at tropopause

LW at tropopause
Calculation of Feedbacks: Perturbation

Radiation Model

- sfc albedo
- temperature
- mixing ratio
- clouds
- CO₂

ΔSW at tropopause

ΔLW at tropopause
Colman (2003)  
PRP Method

Cess et al. (1996)  
ΔCRF Method

CFMIP contribution from each feedback class

S^L+ stronger conv (purple)  S^N L+ higher cirrus (d. red)  S^+ L+ higher weaker cirrus (red)  (clear-sky albedo feedback)

LW CRF response
SW CRF response

S^L N stronger low (blue)  S^N L N neutral (white)  S^+ L N weaker low (orange)  Global Mean

S^L - stronger low (d. blue)  S^N L - weaker cirrus (green)  S^+ L - weaker conv (yellow)

Mark Webb
Observable Radiative Damping Rates

Interannual

Seasonal

Regional
Cloud Changes in a Warmer Climate

AM2p5 – AM2p9: Increased tropical high cloud amount.

AM2p10: Reduced tropical high cloud amount. This weakens LW feedback and changes sign of SW feedback in model.