Climate Feedbacks from ERBE Data

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Outline

1 Introduction
   - Climate Sensitivity and Climate Feedback

2 How to Understand Climate Change Feedback Processes
   - The Concept of Forcing, Feedback and Climate Sensitivity
   - Three Ways to Study Climate Feedbacks

3 Constraint from the Instrumental Period
   - The Instrumental Period
   - Lindzen and Choi, 2009
   - Trenberth et al., 2010

4 Discussion
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Climate Sensitivity and Climate Feedback

- The global mean surface air temperature change in response to a doubling of the atmospheric $CO_2$ concentration after the system has reached a new steady state, commonly referred to as **climate sensitivity**.

- Processes in the climate system that can either **amplify** or **dampen** the climate response to an external perturbation are referred to as **climate feedbacks**.
Introduction

How to Understand Climate Change Feedback Processes

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Earth’s Global Energy Balance.

A linearized Earth’s Global Energy Balance is

\[ \Delta Q = \Delta F - \lambda \Delta T \]

where \( \Delta Q \) is the net energy radiation at the top of atmosphere (TOA) into the earth, \( \Delta F \) is the net forcing, \( \lambda \Delta T \) is the change in net radiation due to a temperature change \( \Delta T \).
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Comprehensive Global Climate Models

Observed and simulated evolution of September sea-ice extent in the Arctic.

(Julien Boé et al., 2009)
Palaeoclimatic Evidence

Proxy-based reconstructions of Northern Hemisphere surface temperature variations over the past millennium.

(Mann et al., 2008)
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Constraint from the Instrumental Period

- Many recent estimates of the equilibrium climate sensitivity are based on climate change that has been observed over the instrumental period.
- On the determination of climate feedbacks from ERBE data (Lindzen and Choi, 2009).
- Relationships between tropical sea surface temperature and top-of-atmosphere radiation (Trenberth et al., 2010).
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Model and Data

- Region: the entire tropics (20S - 20N).
- Models: 11 models from Atmospheric Model Intercomparison Project (AMIP) for IPCC-AR4. GFDL-CM2.1 (Geophysical Fluid Dynamics Laboratory Coupled Model, version 2.1).
- Data set: Earth Radiation Budget Experiment (ERBE) composed of ERBS satellite (1984), NOAA-9 satellite (1985) and NOAA-10 satellite (1986).
Variables: outgoing radiation fluxes consisting of outgoing longwave radiation (OLR) and reflected shortwave radiation (RSW) from ERBE; sea surface temperature (SST) from NCEP.

For the entire tropics, regression is performed between the net outgoing radiation fluxes with the sea surface temperature anomalies (SSTA).

The feedback factor \( f = 0.25 \cdot \frac{\Delta F_{\text{lux}}}{\Delta S_{\text{ST}}} \) is calculated based on a linearized earth global energy budget.

\[ \Delta T = \frac{\Delta T_0}{1 - f} \]

where \( \Delta T \) is feedback response and \( \Delta T_0 \) is nonfeedback response.
Monthly SST Anomalies, and TOA OLR Anomalies from ERBE (red) and GFDL-CM2.1 (black) for 20S - 20N, The major SST intervals for which $\Delta$SST exceeds 0.2 K are indicated by red and blue colors.
Monthly SST Anomalies, and TOA RSW Anomalies from ERBE (blue) and GFDL-CM2.1 (black) for 20S - 20N, The major SST intervals for which $\Delta$SST exceeds 0.2 K are indicated by red and blue colors.
Net $\Delta$Flux Against $\Delta$SST

Scatterplots of net $\Delta$Flux against $\Delta$SST for ERBE and GFDL-CM2.1. Plots for $\Delta$SST exceeds 0.1 K are displayed.
ERBE-observed and AMIP-simulated ratios of total (LW + SW) radiative flux changes to temperature changes ($\Delta$Flux/$\Delta$SST) with respect to the equilibrium climate sensitivity. The solid curves are theoretical estimate of climate sensitivity for total feedback.
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Time Period Endpoint Issues

LC09 did not provide an objective criterion for selecting these endpoints.

Warming (red) and cooling (blue) intervals of HadISST tropical SST (20N-20S) used by LC09 (solid circles) and an alternative selection proposed here derived from an objective approach (open circles).
Linearly regressed slope ($m$) and associated correlation ($r$) of the relationship between SST and net TOA flux using approaches that shift the endpoints of intervals by 1 month or less from LC09 result (dotted red).
Air Sea Interaction Issues

- The dominant interannual variations in TOA radiative fluxes in the tropics occur with ENSO.
- In the tropical Pacific during large El Niño events the anomalous divergence of the atmospheric energy transports exceeds $50\, W \cdot m^{-2}$ over broad regions for several months, and this energy does not come from net radiation.
- The global nature of ENSO is thus known to include a substantial dispersion of energy beyond the tropics, and clouds and convection fail to achieve a local equilibrium with the surface.
- LC09 treats the tropical atmosphere as a closed and deterministic system in which variations in clouds are driven solely by SST.
Models Prescribed with Incomplete Forcings Issues

Figure: Eruption of Mount Pinatubo in 1991. Courtesy of NASA.

Greenhouse gases, aerosols, the sun and volcanoes changed the radiative fluxes, which need to be taken into account.
Why Is Climate Sensitivity So Unpredictable?

(Cox and Stephenson, 2007)
Thank you!
Positive Feedback

A system exhibiting **positive feedback** responds to perturbation acts to **amplify** the magnitude of a perturbation.

(Credit: Figure courtesy of the National Academies, 2008.)
Negative feedback occurs when the output of a system acts to dampen changes to the input of the system.

(Credit: Figure courtesy of the National Academies, 2008.)
Climate Feedbacks

- A change in **clouds** radiative effect in response to a global temperature change may produce a substantial feedback on the earth’s temperature.
- The increase of **water vapor** with temperature will oppose the increase in radiative cooling due to increasing temperature.
- **Cryosphere** reflects part of the incoming shortwave radiation to space.
- The temperature **lapse rate** in the troposphere affects the atmospheric emission of longwave radiation to space.
Radiative Forcing, Feedbacks and Climate Sensitivity

(Knutti and Hegerl, 2008)