CLOUD—CLIMATE FEEDBACK(S?)

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What About Model Analyses?
(some examples)

- “Cess” experiment results do not correctly predict model climate sensitivity
- Most model analyses still assume linearly independent effects (might be useful metrics)
- More appropriate model analyses of feedback cannot be verified by observations
- Model analyses cannot inform understanding of real climate feedbacks (but can assist forming hypotheses)
ENERGY AND WATER CYCLE OF CLIMATE

- Clouds
- Radiative Fluxes
- Atmospheric Circulation
- Water Vapor
- Evaporation
- Precipitation
**General Feedback Formulation**

\[ \Delta X_e(t_0 + 2\Delta t) = E X_e(t_0 + 2\Delta t) + \sum_i \frac{\partial X_e(t_0 + 2\Delta t)}{\partial X_i(t_0 + \Delta t)} \cdot \Delta X_i(t_0 + \Delta t) \]

\[ + \sum_i \sum_j \frac{\partial X_e(t_0 + 2\Delta t)}{\partial X_i(t_0 + \Delta t)} \frac{\partial X_i(t_0 + \Delta t)}{\partial X_j(t_0)} \cdot \Delta X_j(t_0) \]

**Classical Formulation**

\[ \Delta X_e(t_0 + 2\Delta t) = E X_e + \sum_i \frac{\partial X_e(t_0 + 2\Delta t)}{\partial X_i(t_0 + \Delta t)} \frac{\partial X_i(t_0 + \Delta t)}{\partial X_d(t_0)} \cdot \Delta X_d(t_0) \]
NECESSARY Assumptions

Forcing is Constant

Sensitivities are Constant

No System Memory

Single-Variable Cause-Effect Relationships
Some Other Common Assumptions

System in Static Equilibrium

Small Perturbations Allow for Linearized Analysis

Small Feedbacks Can be Ignored
Cloud cover feedback
with $\Delta$cloud cover = 0
(hypothetical examples)

$\partial \text{Rad}/\partial C$
is undefined

$\partial C/\partial T$
is zero

Solar zenith angle effect
day $\rightarrow$ night (need diurnal cycle!!)
tropics $\rightarrow$ midlatitudes
summer $\rightarrow$ winter

Surface albedo effect
ocean $\rightarrow$ land
forest $\rightarrow$ snow
041015 Daily Mean LWnet (w/m^2): All sky

The graph shows the daily mean longwave net radiation (LWnet) for all sky conditions. The x-axis represents latitude in degrees, ranging from -90 to 90 degrees. The y-axis represents pressure in hPa, ranging from 1000 to 100 hPa. The LWnet values are indicated by contour lines and color coding, with a color bar on the right side of the graph. The values range from -400 to 400 w/m^2.
041015 Daily Mean LWnet (w/m^2): Clear sky

![Graph showing daily mean LWnet (w/m^2) for clear sky conditions across various latitudes and pressures.](image-url)
041015 Daily Mean LWnet (w/m^2): All sky W/O PW
040715 Daily Mean LWnet (w/m^2): All sky w/ clouds replaced by 040115's
040715 Daily Mean LWnet (w/m^2): All sky w/ PW replaced by 040115's
NEED HOLISTIC OBSERVATIONAL EVALUATION
SOME QUESTIONS

BASIC IDEA is to reduce “dimension of problem” by associating Diabatic Heating with Each Meteorological State.

Should States be classified locally or globally?

Should atmosphere AND ocean be considered?

Will this approach really simplify the problem?
ISCCP PC - TAU histogram pattern and Map in Tropics over 21.5 years

Cluster Analysis + ISCCP D1 data

WS1 : Deep cumulus clouds
WS2 : Anvils clouds
WS3 : Congestus clouds
WS4 : Cirrus clouds
WS5 : Shallow cumulus clouds
WS6 : Stratocumulus clouds

1983 - 2004 time period
Relative Frequency of Occurrence (RFO) in the Tropics

RFO for each weather state -- 15S-15N -- 1983-2004

RFO (%) vs region

WS1, WS2, WS3, WS4, WS5, WS6
Anomaly cross sections in 60E-180E region / 5S-5N latitude band

- **Zonal Wind anomalies**
  - Weak MJO (Index < -1)
  - Strong MJO (Index < -2.2)

- **Omega anomalies**
  - Weak MJO (Index < -1)
  - Strong MJO (Index < -2.2)

- **Specific Humidity anomalies**
  - Weak MJO (Index < -1)
  - Strong MJO (Index < -2.2)
RFO of each cloud regime in 60E-180E region / 5S-5N latitude band

(MJO events in November-April periods from 1983 - 2004)

GPCP Precipitation -- 15S-15N -- 1997-2004

The graph shows the GPCP precipitation over the region from 15S to 15N from 1997 to 2004, with different colors representing different regions or data sets (WS1 to WS6). The y-axis represents precipitation in mm/day, and the x-axis represents different regions spanning from 0E to 330E.
Composite Total Precipitation Anomalies, 60E-180E -- 5S-5N latitude

(MJO events in November-April periods from 1997 - 2004)

Total precipitation anomalies (60E–180E)

1997–2004 Nov–Apr Period

\[
<P_{\text{weak}}>=6.75 \\
<P_{\text{strong}}>=7.94
\]
Composite total radiative net flux anomalies, 60E-180E -- 5S-5N latitude

(MJO events in November-April periods from 1997 - 2004)
Composite Total Zonal Wind $U^2$ (m$^2$/s$^2$) Cross Sections in Tropics

(MJO events in November-April periods from 1983 - 2004)

Weak MJO

Strong MJO
WHAT DO WE NEED?

More Advanced Observational Analysis Methods

Data available:
- about 10 years of weather-scale variations of atmospheric diabatic heating over oceans
- 30 years of atmospheric state and dynamics
- basic ocean state and circulation

Data coming:
- about 20 years of global weather-scale variations of atmospheric diabatic heating with vertical structure
- more detailed ocean circulation variations

Data needed: more information about water partitioning on land and more detail about ocean variations

**Shortwave net flux**

**Longwave net flux**

**Net flux at TOA**

**Net flux in ATM**
NORTHWARD ENERGY TRANSPORTS BY
THE ATMOSPHERE-EARTH SYSTEM, ATMOSPHERE AND OCEANS
FIG. 16. Qualitative indication of cloud-radiative effects on the zonal annual mean northward total energy transports (PW) by the atmosphere (solid line) and the ocean (dashed line) given by the differences in the inferred transports using total radiative fluxes (cloudy plus clear) and clear-sky radiative fluxes. The changes in the transports shown result from adding clouds, all other factors being held constant.
Annual Mean Generation of APE

Sign of $G_E$ Confirms Lorenz estimate and Contradicts Peixoto & Oort
Even this result is still only qualitative and does NOT indicate feedback on Climate Change.
Figure 21. Annual, zonal mean surface net radiative heating for full sky and clear sky from FC and surface evaporative cooling (shown with positive sign) from Peixoto and Oort [1989] in W/m².
Figure 25. Annual, zonal mean atmospheric net radiative cooling for full sky and clear sky from FC and atmospheric heating by precipitation (shown with negative sign) from Peixoto and Oort [1989] in W/m².
How Do You Know Where You Are?
Time-Dependence of Sensitivities
Approximate Model

[Graphs showing time series data for X(t), Y(t), and Z(t)]
Zonal Seasonal Mean Pressure-Latitude Cross-Sections of Cloud Frequency of Occurrence

Land DJF

Ocean DJF

Land JJA

Ocean JJA
Cloud Effects on Radiation Profiles

85-89 Annual Net Cloud Effect/Forcing profile (W/m²): LW (top left), Total (top right), and SW (bottom).
Composite of Diabatic Heating of Atmosphere with Cyclone Strength

ALL - Full-sky LW net flux at TOA
WEAK 30N-65N NCEP JJA SLP TEST

ALL - Full-sky LW net flux at TOA
MID 30N-65N NCEP JJA SLP TEST

ALL - Full-sky LW net flux at TOA
STRONG 30N-65N NCEP JJA SLP TEST

ALL - GPCP PRECIP
WEAK 30-60N NCEP JJA SLP ANOM

ALL - GPCP PRECIP
MID 30-60N NCEP JJA SLP ANOM

ALL - GPCP PRECIP
STRONG 30-60N NCEP JJA SLP ANOM
ISCCP-FD Minus ERBE Annual Mean Clear-Sky TOA LW↑ (W/m²) for 85-88

Water Vapor Profile Effects
ISCCP-FD Minus ERBE Annual Mean Full-Sky TOA SW↑ (W/m²) for 85-88

Notice Curvature
ISCCP-FD Minus ERBE Annual Mean Full-Sky TOA LW↑ (W/m²) for 85-88
FIG. 1. Schematic illustrating different assumptions about variations of optical media used to model radiative transfer through cloudy atmospheres: (a) horizontally homogeneous layers with properties that vary only in the vertical, (b) horizontally and vertically inhomogeneous layer, (c) horizontally and vertically inhomogeneous layer that is statistically homogeneous in the horizontal direction.
\[ G = \frac{\partial X_e}{\partial X_d} \quad \text{and} \quad H = \frac{\partial X_i}{\partial X_d} \]
First Determination of $G_z$ and $G_E$ from Observations

- Cooling of Winter Poles
- Latent Heating
- Winter Storms
- Summer Monsoons
Zonal Cross-sections of Cloud Effect

85-89 Annual Net Cloud Effect/Forcing profile (W/m²): LW (top left), Total (top right), and SW (bottom).