An overview of the water vapor and cloud feedbacks: What we know and what we don’t

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\[ \Delta T_i \]

Diagram:
- \( \text{CO}_2 \) increase
- \( \text{T}_s \) increase
\( \Delta T_i \approx 1.2 \text{ K} \)
\[ \Delta T_i + g \Delta T_i \]

- CO\textsubscript{2} increase
- \( T_s \) increase
- Atmospheric humidity increases
\[ \Delta T_i + g \Delta T_i + g^2 \Delta T_i \]
\[ \Delta T_f = \Delta T_i + g\Delta T_i + g^2\Delta T_i + g^3\Delta T_i + g^4\Delta T_i + \ldots \]
\[ \Delta T_f = \Delta T_i + g\Delta T_i + g^2\Delta T_i + g^3\Delta T_i + g^4\Delta T_i + \ldots \]

\[ \Delta T_f = \frac{\Delta T_i}{(1-g)} \]
\[ \Delta T_f = \Delta T_i + g\Delta T_i + g^2\Delta T_i + g^3\Delta T_i + g^4\Delta T_i + \ldots \]

\[ \Delta T_f = \frac{\Delta T_i}{(1 - g)} \approx 2-4 \text{ K} \]
$$\Delta T_f = \frac{\Delta T_i}{(1 - g)}$$

$$g = g_{i-a} + g_{wv} + g_{lr} + g_{cloud} + g_{cc}$$
Soden et al., 2008

Change in globally avg. OLR in response to $\Delta q(\text{lat},\text{p})$

Fig. 2 of Soden et al., 2008
Water vapor feedback is primarily a “tropical” phenomenon

Change in globally avg. OLR in response to $\Delta q(\text{lat}, p)$

Fig. 2 of Soden et al., 2008

1990: “The best understood feedback mechanism is water vapor feedback, and this is intuitively easy to understand.”

1992:

1995:

2001:

2007:
Fig. 7. Schematic illustration of cumulus tower wherein moisture evaporated from the surface and converged into cumulus convection is rained out, leaving dry air to detrain into the environment.
Water vapor in the UT is set by the detrainment temperature in the UT.

**Large-scale control:** Sherwood, Pierrehumbert, Salathe, Dessler, Folkins
Dessler and Minschwaner, 2007
Fig. 8. Schematic illustration of cumulus heating distribution under (solid line) normal conditions, and (dashed line) under conditions of anomalous warming. Warming leads the following effects: 1) cloud tops are raised leading to dryer detrained air; 2) convective intensity increases which leads to the dryer air being pushed down more effectively; and 3) there is an increase in the height at which there is maximum cumulus heating, thus bypassing more infrared absorbers in the atmosphere.
“cloud tops are raised leading to dryer detrained air”
“The best understood feedback mechanism is water vapor feedback, and this is intuitively easy to understand.”

“There is no compelling evidence that water vapor feedback is anything other than positive — although there may be difficulties with upper tropospheric water vapor.”

“Feedback from the redistribution of water vapor remains a substantial source of uncertainty in climate models ... Much of the current debate has been addressing feedback from the tropical upper troposphere ...”
"cloud tops are raised leading to dryer detrained air"
“cloud tops are raised leading to dryer detrained air”
Downward mass flux

\[ M_c = \frac{Q_R}{c_p \left[ \frac{dT}{dz} + \Gamma \right]} \]

Continuity equation for \( q \)

\[ \frac{dM_c}{dz} [q - q^*(T)] = M_c \frac{dq}{dz} \]

Minschwaner and Dessler, *J. Clim.*, 2004
\[ M_c = \frac{Q_R}{c_p \left( \frac{dT}{dz} + \Gamma \right)} \]

\[ \frac{dM_c}{dz} \left[ q - q^*(T) \right] = M_c \frac{dq}{dz} \]

Minschwaner and Dessler, *J. Clim.*, 2004
• As the climate warms ...
  – Detrainment goes up in altitude
  – Temperature of detrainment also goes up
• Water vapor goes up
• These two parameters cannot be independently varied
• Hartmann and Larsen also found this
Observational tests of the water vapor feedback

<table>
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<th>Volcano</th>
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El Niño minus La Niña
% change in specific humidity
AIRS data: D06JF07-D07JF08

Dessler et al. 2008
Verify that the water vapor feedback is strong and positive

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<td>Seasonal cycle</td>
<td>Inamdar and Ramanathan, 1998; Wu et al., 2008</td>
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<td>Soden et al., 2005; Hall and Manabe, 1999</td>
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### Subtle complexity

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<td>Volcano</td>
<td>Forster and Collins: 1.6 W/m²/K</td>
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<tr>
<td>ENSO</td>
<td>Wong and Dessler: AMIP: 2.6 W/m²/K, MERRA: 3.3 W/m²/K, ERA40: 5.0 W/m²/K</td>
</tr>
<tr>
<td>decade-scale warming</td>
<td>Soden and Held (models): 1.8 W/m²/K</td>
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WARNING

• average “constant RH” is nearly true for both ENSO and for long-term warming
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• but the details of the changes are different
WARNING

• average “constant RH” is nearly true for both ENSO and for long-term warming
• but the details of the changes are different
• this leads to quite different feedbacks

• different strategy to verify feedbacks?
The best understood feedback mechanism is water vapor feedback, and this is intuitively easy to understand.

There is no compelling evidence that water vapor feedback is anything other than positive — although there may be difficulties with upper tropospheric water vapor.

Feedback from the redistribution of water vapor remains a substantial source of uncertainty in climate models ... Much of the current debate has been addressing feedback from the tropical upper troposphere ...

... the balance of evidence favours a positive clear-sky water vapour feedback of a magnitude comparable to that found in simulations.

New observational and modelling evidence strongly supports a combined water vapour-lapse rate feedback of a strength comparable to that found in [GCMs].
Lapse-rate feedback
If the UT warms too much:
1) too much water, leads to too much trapping of IR
2) too much IR emission to space
These (at least partially) cancel
Soden and Held, 2006
(corrected figure)

FIG. 1
Corrected version of Fig. 1 of Soden and Held, 2006

Cloud: 0.14-1.18
\[ \Delta T = \frac{\Delta T_0}{1 - f} \]
\[ \Delta T = \frac{\Delta T_0}{1 - f} \]

\[ f = f_{i-a} + f_{wv} + f_{lr} + f_{clouds} \]

From Baker and Roe, CERES STM presentation
Corrected version of Fig. 1 of Soden and Held, 2006

Cloud: 0.14-1.18
Fig. 2. Equilibrium temperature change associated with the Planck response and the various feedbacks, computed for 12 CMIP3/AR4 AOGCMs for a $2 \times CO_2$ forcing of reference (3.71 W m$^{-2}$). The GCMs are sorted according to $\Delta T^e$. 
Cloud radiative forcing
Cloud radiative forcing

CRF = all-sky fluxes - clear-sky fluxes
Cloud radiative forcing

$\text{CRF} = -25 \text{ W/m}^2$

cool climate by $25 \text{ W/m}^2$
clouds cool more
clouds cool less
the “cloud feedback” is the change in CRF as the climate varies
Does the Earth Have an Adaptive Infrared Iris?

Richard S. Lindzen, Ming-Dah Chou, and Arthur Y. Hou

ABSTRACT

Observations and analyses of water vapor and clouds in the Tropics over the past decade show that the boundary between regions of high and low free-tropospheric relative humidity is sharp, and that upper-level cirrus and high free-tropospheric relative humidity tend to coincide. Most current studies of atmospheric climate feedbacks have focused on such quantities as clear sky humidity, average humidity, or differences between regions of high and low humidity, but the data suggest that another possible feedback might consist of changes in the relative areas of high and low humidity.
Cloud and radiation budget changes associated with tropical intraseasonal oscillations

Roy W. Spencer,† William D. Braswell,† John R. Christy,† and Justin Hnilo²

Received 15 February 2007; revised 30 March 2007; accepted 16 July 2007; published 9 August 2007.

[1] We explore the daily evolution of tropical intraseasonal oscillations in satellite-observed tropospheric temperature, precipitation, radiative fluxes, and cloud properties. The warm/rainy phase of a compositing average of fifteen oscillations is accompanied by a net reduction in radiative input into the ocean-atmosphere system, with longwave heating anomalies transitioning to longwave cooling during the rainy phase. The increase in longwave cooling is traced to decreasing coverage by ice clouds, potentially supporting Lindzen’s “infrared iris” hypothesis of climate stabilization. These observations should be considered in the testing of cloud parameterizations in climate models, which remain sources of substantial uncertainty in global warming prediction. Citation: Spencer, R. W., W. D. Braswell, J. R. Christy, and J. Hnilo (2007), Cloud and radiation budget changes associated with tropical intraseasonal oscillations, Geophys. Res. Lett., 34, L15707, doi:10.1029/2007GL029698.

2. Data and Analysis Method

Measuring CRF

Day one

Day two
Measuring CRF

Day one

Day two

Longwave CRF can also be measured by AIRS (Susskind + Molnar data)
How to measure cloud feedback

• Select your climate variation
• Measure variation in cloud radiative forcing
  – e.g., CRF(El Nino)-CRF(La Nina)
  – \((\text{CRF}_{\text{LW}}+\text{CRF}_{\text{SW}})_1-(\text{CRF}_{\text{LW}}+\text{CRF}_{\text{SW}})_2 \approx 1 \text{ W/m}^2\)
  – other terms \(\approx \pm 100 \text{ W/m}^2\)
• Regress vs. surface T variations
Figure 4. The sum of SW and LW cloud radiative forcings (CRF) versus tropospheric temperature for the 15-ISO composite, which represents about 30% of the six-year data record.

Spencer et al., 2008
How to measure cloud feedback

• Select your climate variation
• Measure variation in cloud radiative forcing over the climate variation
• Regress vs. Ts
• Adjust for changes in q, T (Soden et al., 2004)
Soden et al., 2008
How to measure cloud feedback

• Select your climate variation
• Measure variation in cloud radiative forcing over the climate variation
• Regress vs. Ts
• Adjust for changes in q, T (Soden et al., 2004)
• For a global average, this is quite hard
Summarize cloud feedback

• Main source of uncertainty in climate predictions
• If the mainstream view of climate change is wrong, this is where it will go wrong
• Lots of analysis of models, but little analysis of observations
• Observational analysis of cloud feedback in response to short-term climate fluctuations
Summarize water vapor feedback

- Overall, this feedback is strongly positive for all climate variations
- As the climate warms, tropical UT detrainment temperature increases
- No credible theory for negative feedback
- WV+LR feedback is better constrained
- to do: Better theoretical and (to the extent possible) observational work on how the feedback varies for different variations
- to do: More analysis on how UT humidity is regulated
Feedback

\[ \lambda = \sum_{x,y,z} \frac{\partial R}{\partial q(x,y,z)} \frac{\Delta q(x,y,z)}{\Delta T_s} \]

Use pre-computed kernels from Soden et al., 2008

Measured change between climate states