Diagnosing Cloud Feedbacks in CMIP5 Models

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Cloud feedback is dominant source of uncertainty in models
Most of cloud change is a “direct” response to CO2 forcing, not “climate” response to surface warming.
Background

Changes in Atmospheric Constituents and in Radiative Forcing

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Climate Feedbacks: Kernel Method

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

<table>
<thead>
<tr>
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<th>Temperature Feedback</th>
<th>Water Vapor Feedback</th>
<th>Cloud Feedback</th>
<th>Sfc Albedo Feedback</th>
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\[ \text{Climate Feedback} = \frac{\delta R}{\delta X} X \frac{dX}{dT_s} \]

Radiative Transfer

Climate Response

Method 1: Finite Differencing

\[ \frac{dX}{dT_s} \]

\[ dX = X_{2000-2020} \]

Assume all change is feedback

FALSE?
Climate Feedbacks: Kernel Method

\[ \lambda = \frac{\delta R}{\delta T} \frac{dT_s}{dT} + \frac{\delta R}{\delta W} \frac{dW_s}{dT} + \frac{\delta R}{\delta C} \frac{dC_s}{dT} + \frac{\delta R}{\delta \alpha} \frac{d\alpha_s}{dT} \]

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

**Method 1: Finite Differencing**

\[ \frac{dX}{dT_s} = \frac{X_{2080-2100} - X_{2000-2020}}{20} \]

Assume all change is feedback

**Method 2: Linear Regression**

\[ \frac{dX}{dT_s} = a + b \cdot T_s \]

Only use component correlated to \( dT_s \)
Climate Feedbacks in IPCC AR5 Models

1%CO2

• Very similar to AR4:
  Water vapor +lapse-rate uncertainty is small.
  Cloud feedback is uncertain, but not negative.
• Method 1 and Method 2 are nearly identical.
Climate Forcing in IPCC AR5 Models

Radiative Forcing
1%CO2 Experiment

Global Mean $dT_s$
1%CO2 Experiment

Clear-sky Radiative Forcing (W/m²)

Global Mean Surface Temperature Anomaly (K)

Time Sequence of Decadal Climate State

Elapsed Time (years)
Climate Forcing in IPCC AR5 Models

Radiative Forcing

1%CO2 Experiment

Time Sequence of Decadal Climate State

Clear-sky Radiative Forcing (W/m$^2$)

Radiative Forcing

Abrupt 4XCO2 Experiment

Time Sequence of Decadal Climate State

Clear-sky Radiative Forcing (W/m$^2$)
Climate Feedbacks in IPCC AR5 Models

Abrupt 4XCO2

- No evidence of a significant indirect forcing from CO₂.
- Climate feedbacks are robust across CO₂ scenarios.
Cloud Feedbacks in IPCC AR5 Models

(a) 1% CO2

(b) 4X CO2

Cloud Feedback (Method 1) Finite Differencing

Cloud Feedback (Method 2) Regression
Cloud Feedbacks in IPCC AR5 Models

(a) 1% CO2

(b) Cloud Feedback (Method 1)
Finite Differencing

(c) Historical

(d) Cloud Feedback (Method 1)
Finite Differencing
Cloud Feedbacks in IPCC AR5 Models

Differencing

Regression

Cloud Feedback: 1% CO2

Cloud Feedback: Historical
Cloud Feedbacks in IPCC AR5 Models

(a) 1%CO2

(b) Abrupt 4xCO2

(c) Historical

(d) RCP2.6

(e) RCP4.5

(f) RCP8.5
Ensemble Mean Feedbacks: IPCC AR5
Historical

Temperature Feedback

Water Vapor Feedback

Albedo Feedback

Cloud Feedback
**Ensemble Mean Cloud Feedback: IPCC AR5 Historical**

- **Surface Temperature**
  - Positive Cloud Feedback
    - 9 GCMs
  - Negative Cloud Feedback
    - 11 GCMs

- **Cloud Feedback**
  - Positive Cloud Feedback
    - 9 GCMs
  - Negative Cloud Feedback
    - 11 GCMs
Local contribution to intermodel spread in cloud feedback: AR4

- Most of intermodel spread arises from low stratocumulus/cumululus regions

Soden and Vecchi (2011)
Local contribution to intermodel spread in cloud feedback: AR5

- Low subtropical clouds still uncertain.
- Large contribution from equatorial Pacific.
No evidence for the indirect forcing of clouds by CO$_2$, but there is evidence for a strong indirect negative forcing by aerosols in historical runs.

Feedbacks in AR5 (CMIP5) models are very similar to those simulated in AR4 (CMIP3) era models … but still no simple answer for why low cloud feedback is positive.

Equatorial Pacific convective clouds and low marine subtropical clouds are biggest contributors to spread.
Extra Slides
• Some models indicate a negative cloud feedback ...

• Cloud feedback differs between Method 1 (difference) & Method 2 (regression)