Observational evidence for positive low-cloud feedback and constraints on climate sensitivity

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What did we learn from observations?

Slight positive SW cloud feedback

Strong uncertainty

Strong disagreement across models

Correlation SW cloud feedback versus $T_s$ (global)

Strong regional discrepancy

Positive feedback over subtropical regions

Is it possible to constrain cloud feedback based on observed variations?

Dessler et. al 10, Science

Focus on low-clouds

Low-clouds are present over subtropical regions (eastern parts of oceans)
Drier than the tropical mean

Lower quartile of RH deviation from tropical-ocean averaged RH
Focus on low-clouds

Unique Low-Cloud fraction (Calipso/CloudSat)

Cloud fraction (%)

Latitude

Cloud fraction (%)

RH anomaly (%)

drier lower quartile

ERA-Interim

Frequency of occurrence

Longitude

Frequency of occurrence

Latitude

Latitude
Temporal evolution of dry region

Two observed dataset

ISCCP-FD (1983-2009)

\[ \alpha_{SW} = \frac{SW_{\uparrow}^{tot}}{SW_{\downarrow}^{tot}} = \frac{SWCRE}{SW_{\downarrow}^{tot}} + \frac{SW_{\uparrow}^{clear}}{SW_{\downarrow}^{tot}} \]

Earth SW albedo:

Variabilities at high and low frequencies

ERSST

\( \alpha_{cloud} \)

\( \alpha_{clear} \)

Cloud feedback

Dominated by volcanoes
Spectral decomposition

1. Seasonal variability

1-yr bandpass filter with 12-order Chebyshev polynomial

Bandpass filter

Very strong correlation \((R=-0.97)\)

Observed cloud albedo is related SST change
Spectral decomposition

1. Seasonal variability
   1-yr bandpass filter with 12-order Chebyshev polynomial

2. Deseasonal variability
   1-yr high/low pass filter with 12-order Chebyshev polynomial

Robust negative slope (positive feedback)
Slope albedo vs SST

SWCRE vs SW cloud feedback

-0.16 W/m²/K

200 stationary bootstrapping slopes for uncertainty

positive feedback

negative feedback

correlation coefficients of slopes

0.54 0.95 0.47

where are CMIP5 models?

δα_c/δSST (%/K)

δSWCRE/δSST (W/m²/K)
Slope albedo vs SST

29 CMIP5 models
separation by high and low ECS
cloud feedback is abrupt4xCO2-piControl

$\delta \alpha_c / \delta \text{SST} (\%/K)$

$\delta \text{SWCRE} / \delta \text{SST} (\text{W/m}^2/\text{K})$

- intra
- season
- inter
- future

0.54
0.95
0.47
Slope albedo vs SST

29 CMIP5 models
separation by high and low ECS
cloud change is based on historical

Models have difficulties to represent high-frequency variabilities (MJO?)
Slope albedo vs SST

High ECS models have better slope and correlation coefficients.
Slope albedo vs SST

Can we constrain model ECS by observed variabilities?

High ECS models have better slopes and correlation coefficients.
CMIP5 ECS range is [2.1, 4.6] K, with a max probability of 3.6 K
$\alpha_c$ change Future (%/K)

$R = -0.72$

$ECS$ (K)

PDF

$ECS$ estimate
Interannual variability explains a significant part of the spread of ECS.

\[ R = -0.67 \]
ECS estimate

CERES observations give a slope of -0.9 %/K

Inferred ECS gives a 90% confidence interval of [3.3, 4.3] K (based 200*200 samples)

Too strong influence of lowest sensitivity models (by their impact on the slope)
Too weak influence of some realistic models

Using Bayesian Model Averaging
CERES observations give a slope of -0.9 %/K

\[ w_i = \frac{P(\alpha_{obs} \mid M_i)}{\sum_k P(\alpha_{obs} \mid M_k)} \]

Proba of the model given the obs

\[ P(\text{ECS} \mid \alpha_{obs}) = \sum_k w_k P(\text{ECS} \mid M_k) \]

Proba of ECS given the obs

Strengthen the weight of realistic models

R = -0.67
**ECS estimate**

CERES observations give a slope of -0.9 %/K

BMA methodology gives a 90% confidence interval of [2.4, 4.9], with a max probability of 3.9K

Likelihood function

\[ w_i = \frac{P(\alpha_{obs} | M_i)}{\sum_k P(\alpha_{obs} | M_k)} \]

Proba of ECS given the obs

\[ P(ECS | \alpha_{obs}) = \sum_k w_k P(ECS | M_k) \]

Strengthen the weight of realistic models

\[ R = -0.67 \]
Conclusions

Robust positive low-cloud feedback across temporal variability

Seasonal variability of cloud albedo change is related to surface warming misrepresentation by CMIP5 models and possible constrain to improve models

Spread of ECS by CMIP5 models is 2.1-4.5K with a most probable value of 3.3K

ECS lower bounds increases from 2.1K to 2.4 K
Most probable ECS value is higher (3.9K)

Need process-oriented analysis of observed low-cloud change (especially by their vertical development)