Atmosphere, Clouds, and Climate: Energy Flows & Feedback
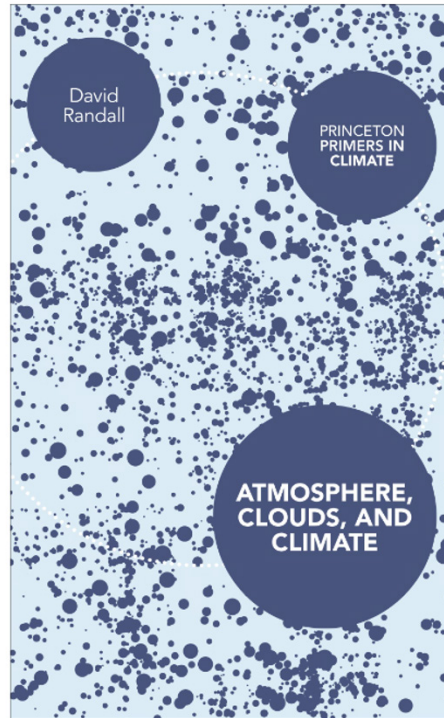
AOSC 680

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Class Web Sites:
http://www2.atmos.umd.edu/~rjs/class/fall2024
https://umd.instructure.com/courses/1367293

Lecture 12

15 October 2024

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Cloud Feedback

Cloud feedbacks are infamous. Their potential importance has been recognized at least since the 1970s (Schneider, 1972; Arakawa, 1975; Charney, 1979). For decades, they have been highlighted as a major source of uncertainty in predictions of future climate change. Why is the problem taking so long to solve?

Although cloud processes are among the most important for climate, they are also among the most difficult to understand and predict. As discussed in Chapter 3, clouds usually form in rising air, which expands and cools until condensation occurs. Cloud processes can be grouped into five categories, all of which are important for the climate system:

Cloud microphysical processes, involving cloud drops, ice crystals, and aerosols, with scales on the order of microns

Cloud dynamical processes associated with the motion of the air in cumulus clouds, with scales on the order of a few kilometers

Cloud radiative processes, involving the flows of both solar and terrestrial radiation through the cloud field

Cloud turbulence processes, which include boundary-layer (near-surface) turbulence, the entrainment of environmental air into the clouds, and the formation of small clouds

Cloud chemical processes, which, among other things, are important for the annual formation of the ozone hole through the destruction of ozone in polar stratospheric clouds

Cloud Feedback

These various processes interact with each other on space scales of a few kilometers and time scales of a few minutes, and they also jointly interact with larger-scale weather systems, up to the size of the Earth itself.

Clouds also couple climate processes together. For example, they cast shadows on the land and ocean, which tend to reduce the surface temperature and evaporation rate.

Each cloud process has the potential to feed back as the climate state evolves due to externally forced variability. As a result, there are many different kinds of cloud feedbacks. Broadly speaking, they occur through changes in cloud amount, cloud top height, and cloud optical properties. In a climate change, there can be many different changes in the geographical patterns and seasonal distributions of both high and low clouds. The net cloud feedback results from the combined effect of these various changes.

IPCC AR5 "downgraded" warming forecast by CMIP5 models

Lecture 8

Chapter 11 of IPCC (2013) suggested *CMIP5 GCMs warm too quickly* compared to observations, resulting in "likely range" (red trapezoid) for rise in GMST relative to pre-industrial baseline (ΔT) being considerably less than actual archived ΔT from the CMIP5 GCM runs
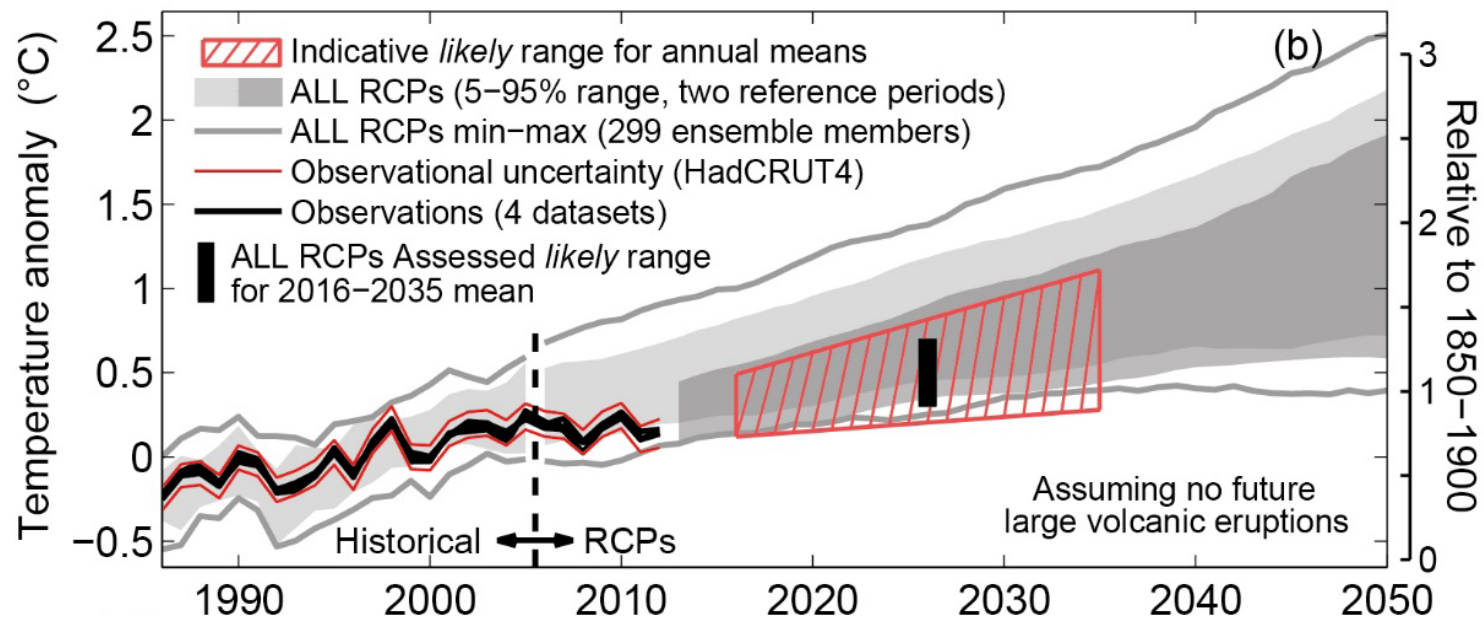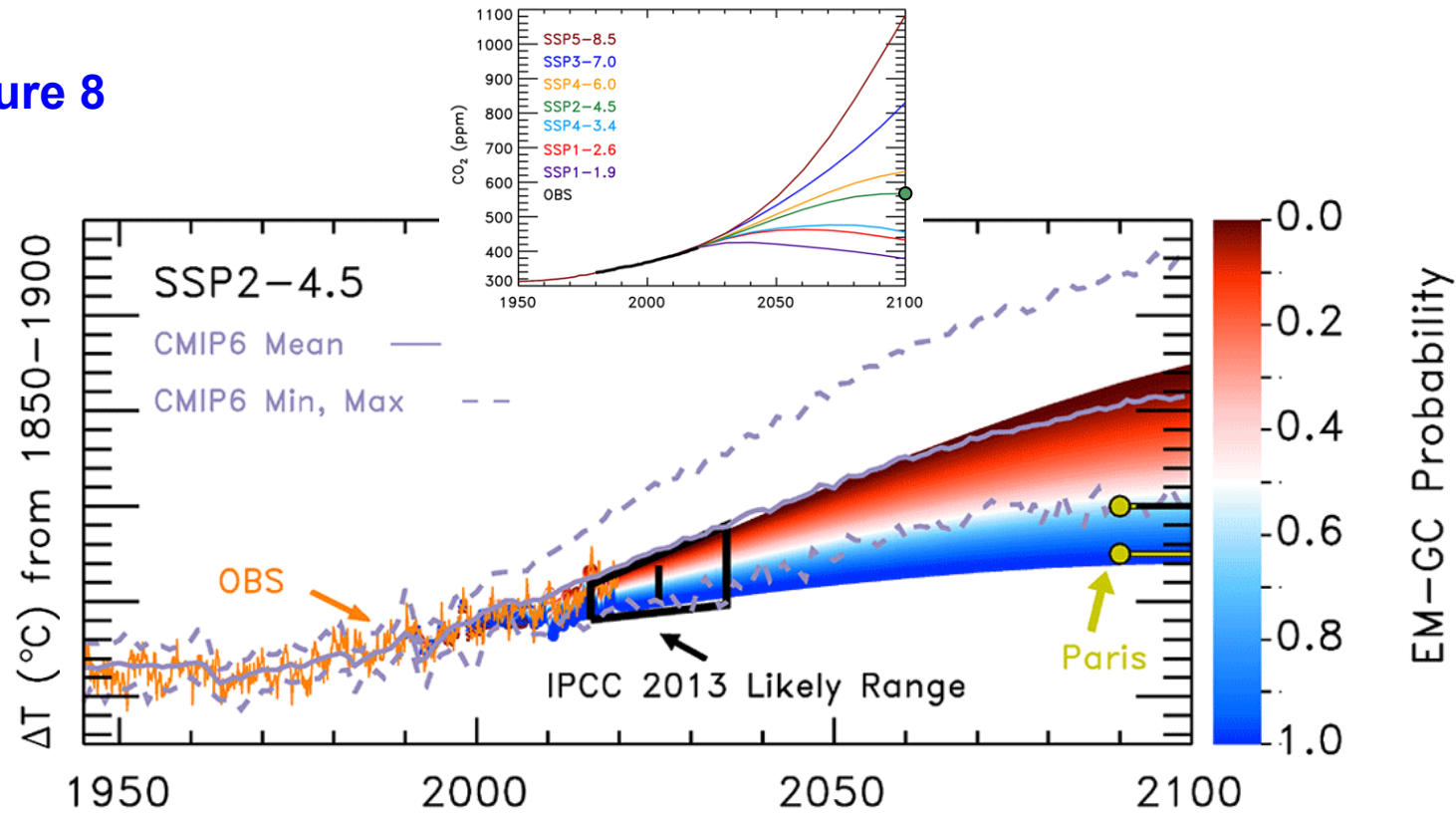

Fig 11.25b, IPCC (2013)

Probabilistic Forecast of _Human-Induced Rise in GMST_ for model trained on data acquired until end of 2019 and future GHG levels from SSP2-4.5

Lecture 8

If GHGs follow SSP2-4.5, **2%** chance rise GMST stays below **1.5°C** and **33%** chance stays below **2.0°C**

> **EM-GC: University of Maryland Empirical Model of Global Climate**
> ∆T: rise in GMST (Global Mean Surface Temperature) relative to pre-industrial
> **CRU: Climate Research Unit, Easy Anglia, UK: Premier source of data for ∆T**

McBride _et al_., 2021: https://esd.copernicus.org/articles/12/545/2021

Recent Attempt to Evaluate the "Hot Models"

Evaluating Climate Models' Cloud Feedbacks Against Expert Judgment

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JGR Atmospheres

Plain Language Summary Climate models strongly disagree with each other regarding how much warming will occur in response to increased greenhouse gases in the atmosphere. This is mainly because they disagree on the response of clouds to warming—a process known as the cloud feedback that can amplify or dampen warming initially caused by carbon dioxide. In this study, we compare many models' cloud feedbacks to those that have been determined by a recent expert assessment of the literature. We find that the models whose cloud feedbacks most strongly disagree with expert assessment tend to have more extreme cloud feedbacks and hence warm too much or too little in response to carbon dioxide. The models with total cloud feedbacks that are too large do not have a single massive feedback component but rather several components that are larger than in other models. Models that simulate current-climate clouds that look more like those in nature also simulate stronger amplifying cloud feedbacks, but doing a better job at simulating current-climate clouds does not, in general, guarantee a better simulation of cloud feedbacks.

ECS: Equilibrium Climate Sensitivity

Key Points

- Models with smallest feedback errors have moderate total cloud feedbacks and ECS

- Models with large positive total cloud feedbacks have several systematically high-biased feedback components

- Better simulation of mean-state cloud properties leads to stronger but not necessarily better cloud feedbacks

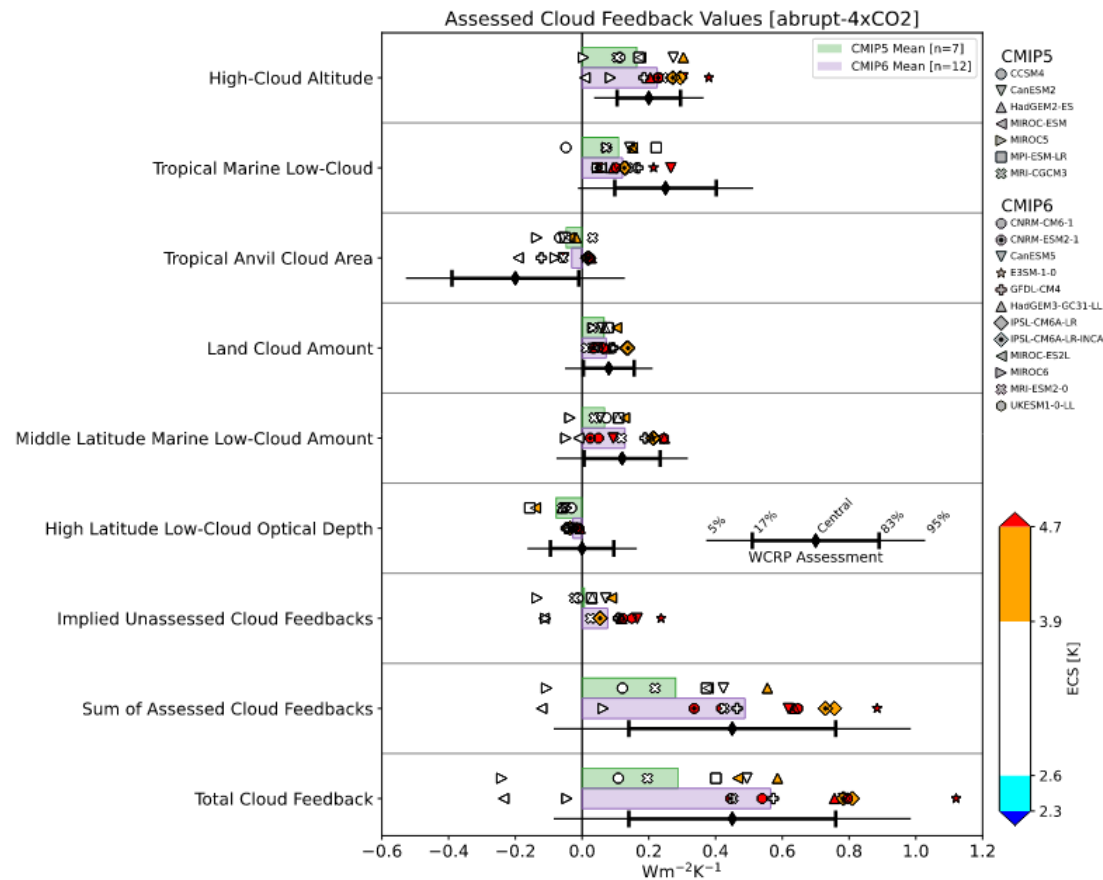https://agupubs.onlinelibrary.wiley.com/doi/epdf/10.1029/2021JD035198

Figure 1. Cloud feedback components estimated from climate model simulations and as assessed in Sherwood et al. (2020). For each component, the individual model values are indicated with symbols, the multimodel means are indicated with green (CMIP5) and purple (CMIP6) bars, and the expert-assessed *likely* and *very likely* confidence intervals are indicated with black errorbars. Model symbols are color-coded by ECS with color boundaries corresponding to the edges of the *likely* and *very likely* ranges of the Baseline posterior PDF of ECS from Sherwood et al. (2020). Identical figures highlighting each individual model are provided in Figures S4–S22 in Supporting Information S1.

https://agupubs.onlinelibrary.wiley.com/doi/epdf/10.1029/2021JD035198

Another Recent Attempt to Evaluate the "Hot Models"

Comparison of Proxy-Shortwave Cloud Albedo from SBUV Observations with CMIP6 Models

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SIGNIFICANCE STATEMENT: Equilibrium climate sensitivity is a measure of the rise in global temperature over hundreds of years after a doubling of atmospheric CO_2 concentration. Current state-of-the-art climate models forecast a wide range of equilibrium climate sensitivities (1.5°–6°C), due mainly to how clouds, aerosols, and sea surface temperatures are simulated within these models. Using data from NASA and NOAA satellite instruments from 1980 to 2013, we first construct a dataset that describes how much sunlight has been reflected by clouds over the 34 years and then we compare this data record to output from 47 climate models. Based on these comparisons, we conclude the best estimate of equilibrium climate sensitivity is about 3.5°C, with an uncertainty range of 2.7°–5.1°C.
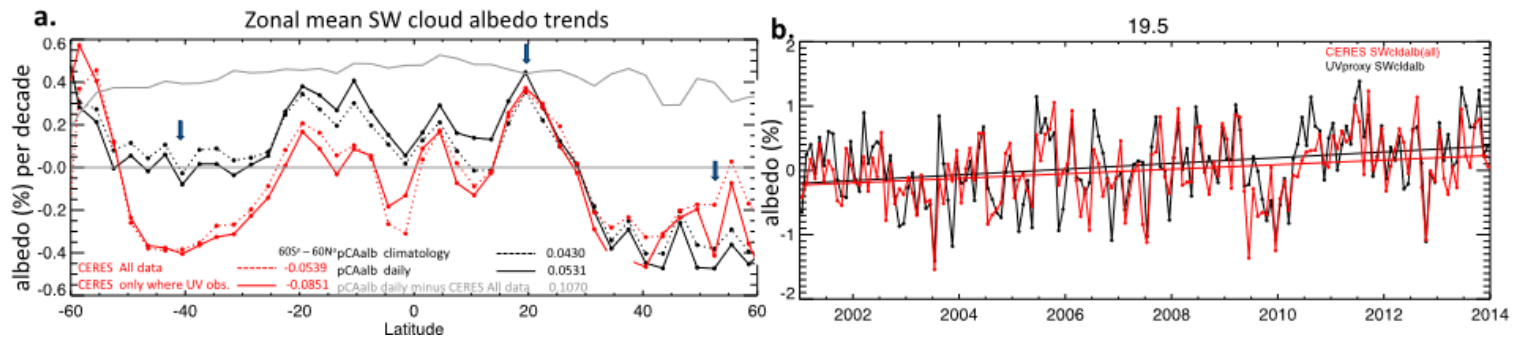

FIG. 4. Comparison of zonal mean pCAalb with CERES SYN1deg SW cloud albedo (%). (a) Latitudinal variability of trends per decade from 2001 to 2014. Trends of pCAalb (black) along with trends using all CERES data (red dashed) and trends using only CERES data where UV observations are available (red solid) are shown. pCAalb is determined using time-dependent daily cloud particle phase information (solid) or a monthly climatology (dashed). Cosine-latitude weighted trends over 60°S–60°N are shown in the legend. The light gray line is the correlation between the monthly means of pCAalb and the CERES albedo. (b)–(d) Time series of albedos with time-averaged mean removed at select latitudes: 19.5°N, 40.5°S, and 52.5°N.

https://journals.ametsoc.org/view/journals/clim/37/11/JCLI-D-23-0170.1.xml

What To Do About The "Hot Models"

CLIMATE MODELS: CHOICE MATTERS

The IPCC's Sixth Assessment Report (AR6) assessed dozens of computer models to project global temperature change (four scenarios shown). Some of these projections were 'too hot' when compared with other lines of evidence for climate warming in response to carbon dioxideemissions[8]. Researchers using all these models without the AR6 statistical adjustments could end up overestimating future temperature change.

- – Mean of all models
- — Limited range of models, no 'too hot' ones*
- — Best estimate of warming as assessed in AR6