Climate Dynamics (PCC 587): Feedbacks

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Cloud Feedbacks?

- If low clouds disappear w/ global warming, cloud feedback would be positive
- If instead low clouds increase => negative feedback
- High clouds may change too…
- Next, let's discuss *forcings* vs *feedbacks*

Forcings vs Feedbacks

- Forcings:
  - Things that change climate directly
    - CO_2, methane, solar, aerosols, etc
- Feedbacks:
  - Things that respond to a change in temperature
    - Water vapor
    - Lapse rate
    - Ice coverage (sea and land)
    - Clouds
  - These would presumably respond similarly to any forcing
    - In a *per degree warming* manner

Radiative Forcing

- Remember we can calculate radiative transfer very accurately
- *Radiative forcing*: a useful method of quantifying climate forcing of different agents
  - Keep temperatures the same, instantaneously change forcing, and calculate effect on radiation
  - Ex 1: if solar radiation was decreased by 2 W/m2
    - Radiative forcing would be -2 W/m2
  - Ex 2: if CO_2 was instantly doubled, OLR decreases by 4 W/m2
    - Radiative forcing is 4 W/m2

Radiative Forcing and Temperature Response

- Temperatures must respond to a radiative forcing
  - Positive radiative forcing → temperatures must increase
  - This will then reduce the radiative imbalance
- How much temperature response depends on feedbacks though
  - Radiative forcing is defined so it doesn't depend on feedbacks

Feedbacks

- For instance, say lots of ice was on the verge of melting
  - Then any small warming would be strongly amplified
- On the other hand, say the lapse rate feedback could act strongly (warming the upper troposphere really quickly)
  - Then the surface temperature might only need to increase a tiny bit to respond to the forcing

Feedbacks

- Remember:
  - A positive temperature change is always required to balance a positive forcing
    - Could be very small though if there are many strong negative feedbacks
  - If there are many strong positive feedbacks, system could spiral out of control
    - "Runaway greenhouse effect": Earth keeps getting hotter & hotter until all the oceans evaporate
    - Not going to happen on Earth, but happened on Venus?

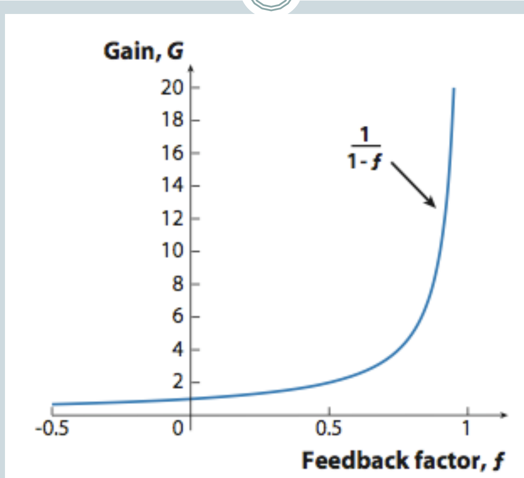
Climate Sensitivity

- Climate sensitivity:
  - The total temperature change required to reach equilibrium with the forcing
  - Depends on feedbacks! (unlike radiative forcing)
  - Refers to equilibrium state
    - Real climate change is transient: we'll discuss this later

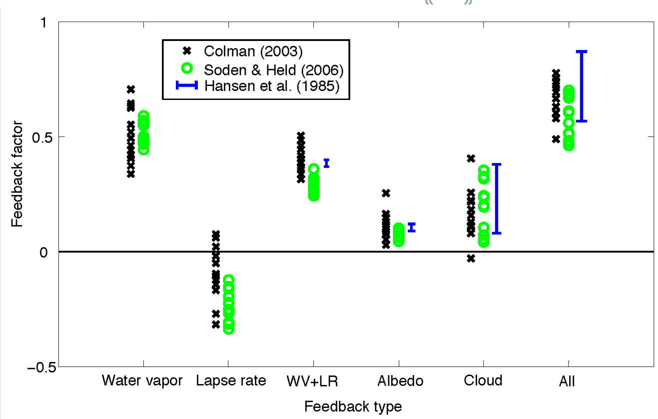
Climate Sensitivity and Feedbacks

- How does each feedback affect radiation
  - E.g., how much decrease in OLR per unit increase in humidity
- And how fast does a temperature rise cause the quantity to increase
  - E.g., water vapor content increases 7%/K
- Derivations on the board…

Feedback Factor vs Gain



Feedback Factors for Global Warming



Individual feedbacks uncorrelated among models, so can be simply combined:

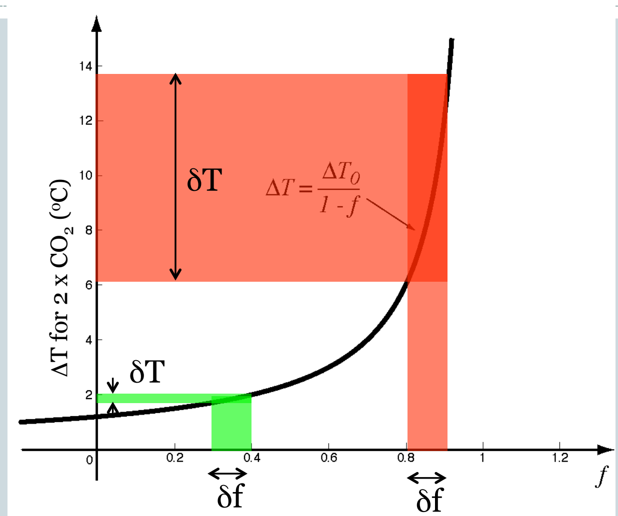
Soden & Held (2006):
$\bar{f} = 0.62; \sigma_f = 0.13$

Colman (2003):
$\bar{f} = 0.70; \sigma_f = 0.14$

Clouds have largest uncertainty by far (when water vapor and lapse rate are combined)

Cloud LW forcing is expected to be slightly positive (depth of high clouds to increase)

Uncertainty in Sensitivity



Can show:

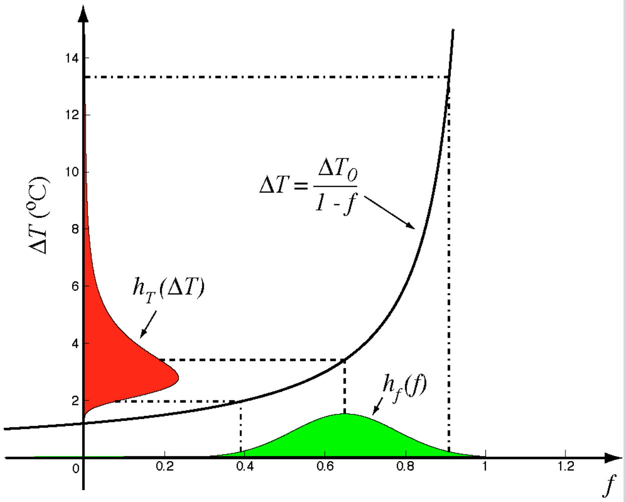
$\Delta T = G \cdot \Delta T_0$

$\delta T \sim G^2 \cdot \Delta T_0 \cdot \delta \bar{f}$

Uncertainty is higher when gain is higher

- Uncertainty in climate sensitivity strongly dependent on the gain.

Distributions of Sensitivity



for:

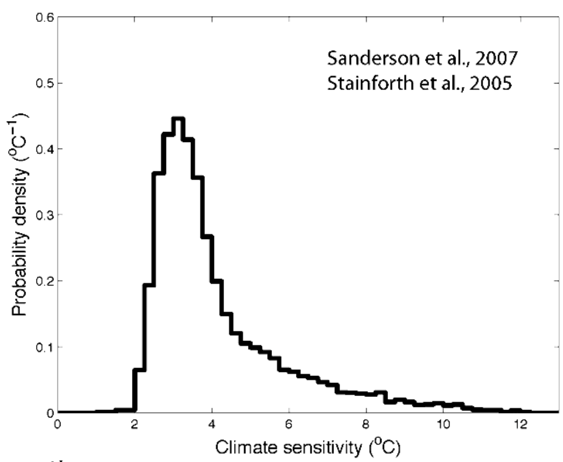
$\bar{f} = 0.65$

$\sigma_f = 0.14$

- Skewed tail of high climate sensitivity is inevitable!

Climate sensitivity: an envelope of uncertainty

climateprediction.net 250,000+ integrations, 36,000,000+ yrs model time(!);



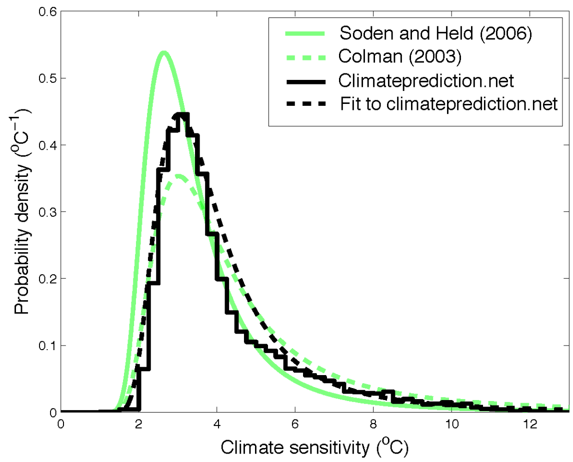
Eq^{m}. response of global, annual mean sfc. T to 2 x CO_2.

6,000 model runs, perturbed physics

Slab ocean, Q-flux 12 model params. varied

- Two questions:
  1. What governs the shape of this distribution?
  2. How does uncertainty in physical processes translate into uncertainty in climate sensitivity?

Climate sensitivity: GCMs



- GCMs produce climate sensitivity consistent with the compounding effect of essentially-linear feedbacks.

Time Dependence

- What if there's time dependent forcing?
  - We'll show on the board that stronger feedbacks → slower response