ATM S 111: Global Warming
Climate Feedbacks

Jennifer Fletcher

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Climate Feedbacks

- Things that might change when the climate gets warmer or colder and in turn change the climate.
  - We'll discuss the following:
    - Water vapor feedback
    - Ice-albedo feedback
    - Cloud feedbacks
- Feedbacks are of critical importance in determining **temperature response** to climate forcings.
  - Positive feedbacks are things that amplify warming *or* cooling.
  - Negative feedbacks reduce (damp) warming or cooling.

Example

- Concrete example: The sun shines less intensely. This is a climate forcing.
- What does this do to global mean temperature?
- How might we expect global ice sheets to respond to this change in temperature?
- How does this response of ice sheets affect Earth's albedo?
- How does this change in albedo in turn affect Earth's temperature?

Climate Sensitivity

- Global warming theory:

$$\Delta T = \lambda \, \Delta F$$

Δ = common symbol indicating the change in a quantity

ΔT = change in temperature (in degrees C)

ΔF = radiative forcing (in W/m^2)

λ = climate sensitivity

λ Tells us how much temperature change we can expect from a given climate forcing.

Climate Sensitivity

- Lots of **positive feedbacks** means a very sensitive climate (large λ)
  - Large change in temperature for even a small forcing

$$\Delta T = \lambda \, \Delta F$$

- Lots of **negative feedbacks** means small λ (λ must always be greater than zero – why?)
- What are the main climate feedbacks?
  - And are they positive or negative?

Water Vapor Feedback

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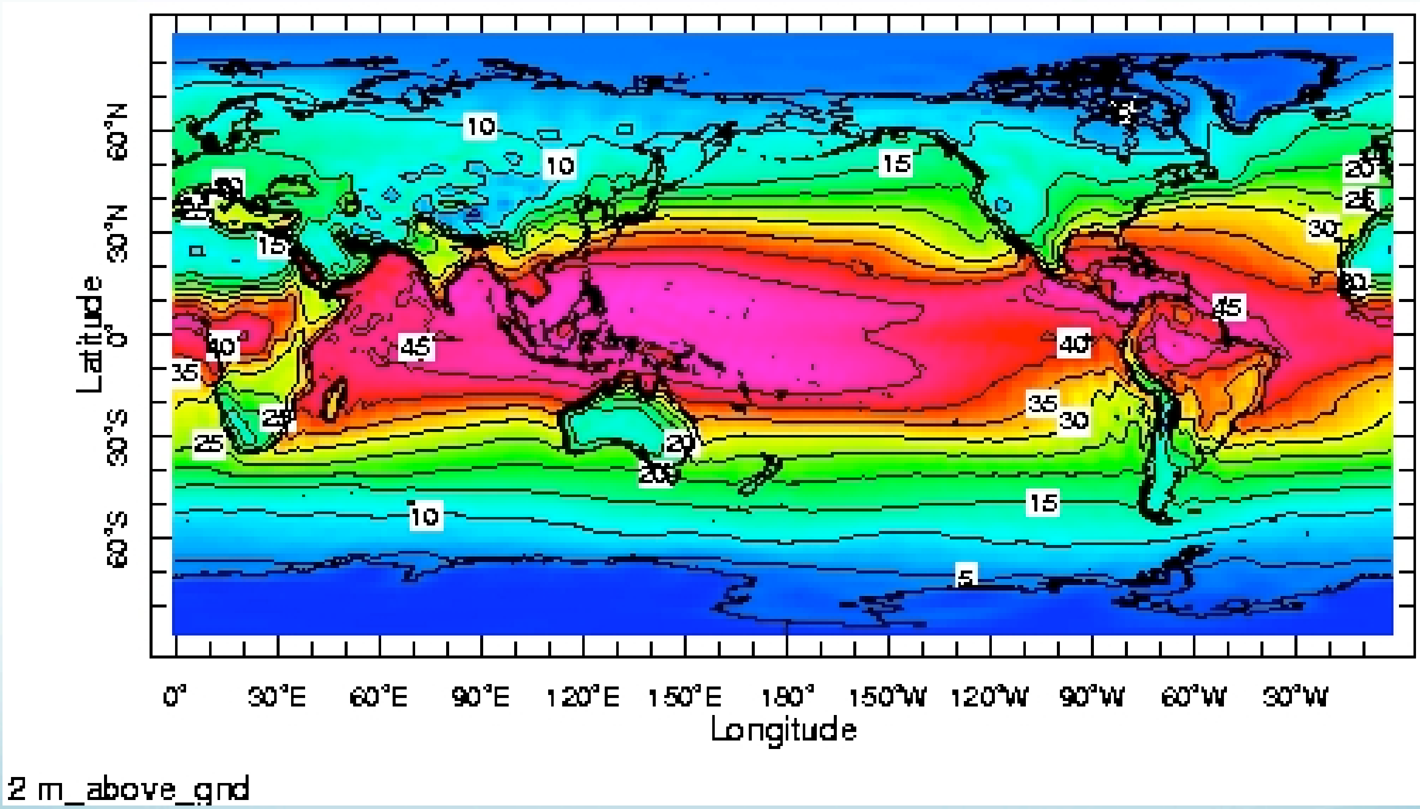
- So why is it not a forcing, like other GHGs, but a feedback?
- Answer: the amount of water vapor in the atmosphere is determined by the climate itself, not by external forces.
- To a large extent, global atmospheric water vapor content just depends on temperature (**warmer air can hold more moisture**).

Surface Water Vapor Content

- Surface water vapor content

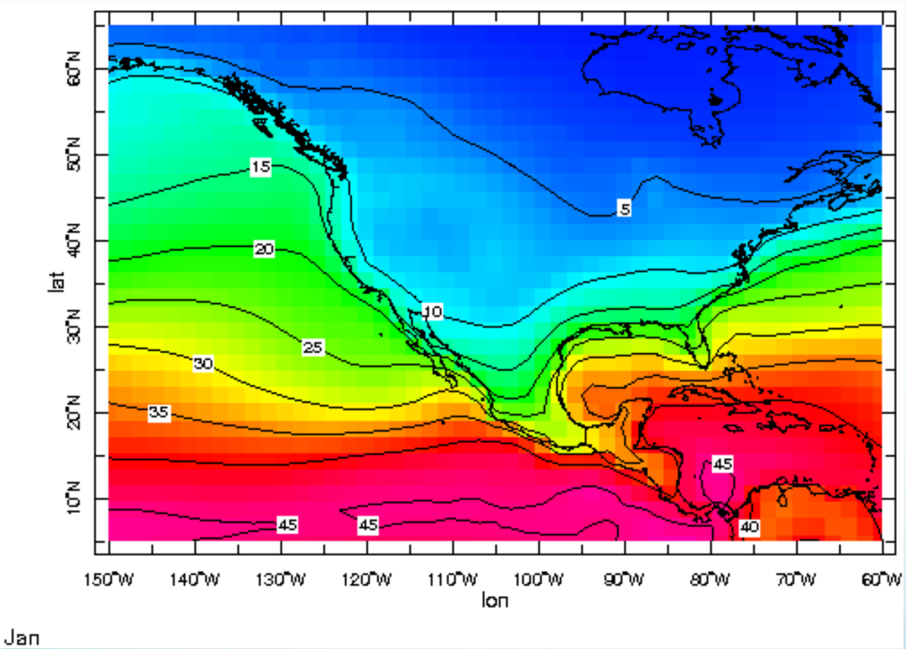


Source: NCEP Reanalysis

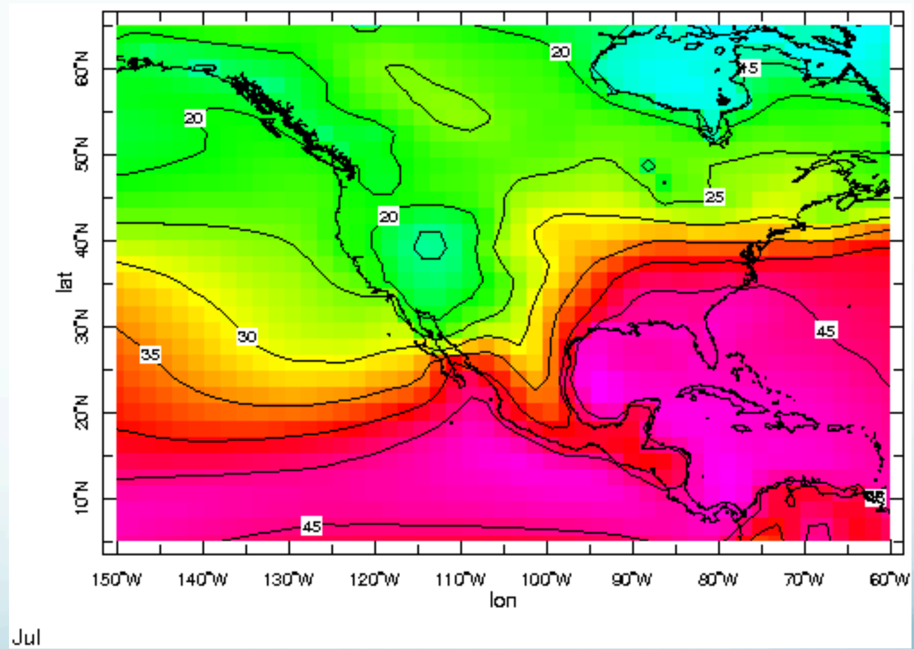
Most water vapor is in the tropics where it's hot

Water Vapor Content

- Winters are much drier than summers
  - Simply because cold temperatures means small water vapor content



January surface water vapor content



July surface water vapor content

Water Vapor Feedback

- Basic idea:
  - A warmer climate means a higher water vapor climate
    - 20% more humid climate with 3^{o} C temperature increase
    - Because water vapor is a greenhouse gas, this humidity will further increase the temperature.
- As with all feedbacks, water vapor doesn't care what the forcing is that caused the warming
  - Any kind of warming will result in an increase in water vapor content

Water Vapor Feedback

- A warmer climate means a higher water vapor climate
- Essentially no arguments out there that water vapor should act as a negative feedback
  - Some reasonable skeptics argue that the feedback might be weak
    - Arguments focus on how upper atmospheric water vapor might change
  - Observations show evidence for a **strong positive feedback**
    - Water vapor increases/decreases right along with global temperatures

Water Vapor Feedback

- Question: if the net climate forcing were negative (say, because the effect of aerosols was much greater than the effect of greenhouse gases), and we were facing global *cooling* instead of global warming, what effect would the water vapor *feedback* have?
  - A. It would have a warming effect because water vapor is a greenhouse gas and so it will damp the global cooling.
  - B. It would have a cooling effect because it's a positive feedback, which always amplifies a change, no matter what direction the change is in.

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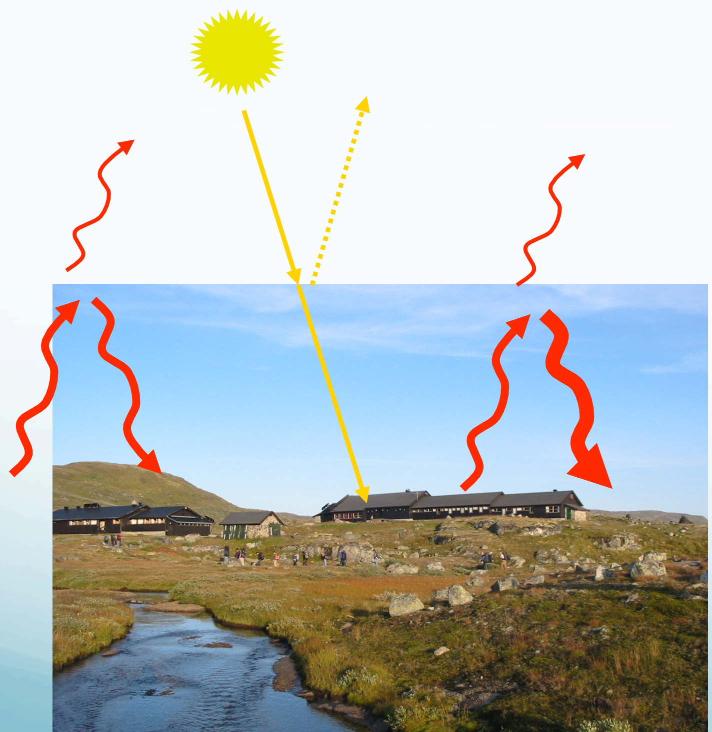
Answer: B. If aerosols caused global cooling, the amount of water vapor in the atmosphere would *decrease* because colder air holds less moisture. This would amplify global cooling, since there would be less of this important greenhouse gas.

Ice-Albedo Feedback

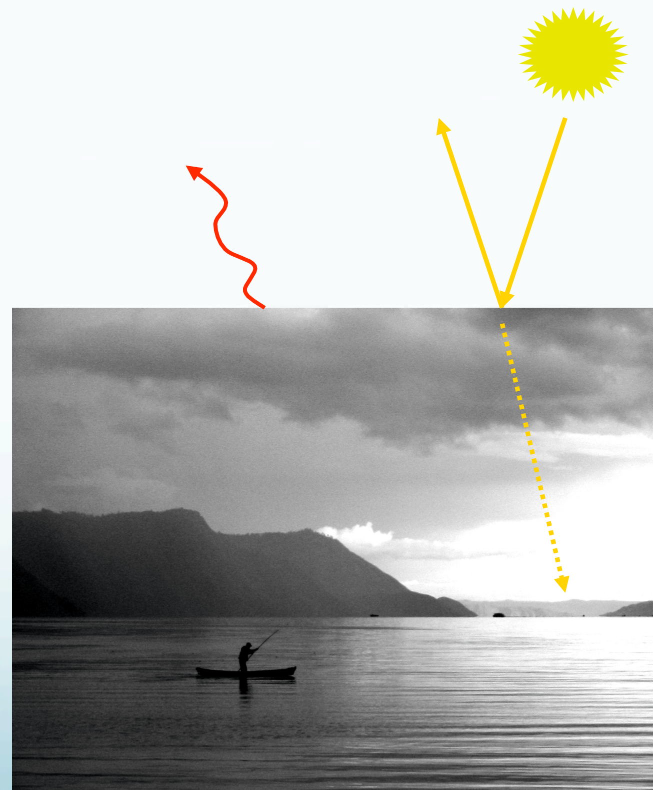
- Warming → ice melting → dark open ocean visible → more warming
- Similar feedback is present for snow (revealing darker land surfaces below)

Cloud Feedbacks

- Cloud feedbacks are much more uncertain
  - Partially because clouds have both an albedo effect and a greenhouse effect



High (thin) Clouds Warm



Low (thick) Clouds Cool

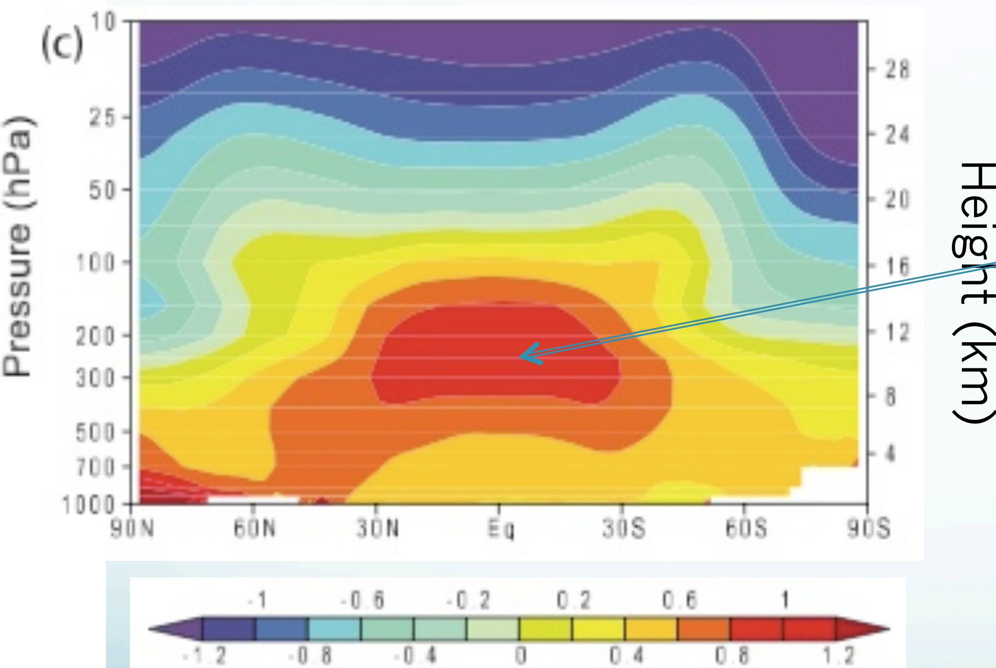
Cloud Feedbacks

- Cloud feedbacks lead to the largest uncertainty in global warming forecasts
  - More low clouds could lead to less warming than predicted
  - However, roughly equally likely, less low clouds could lead to significantly more warming…

- Currently, almost all climate models predict a **positive** cloud feedback.
- Uncertainty: a reason not to act or to act quickly?

Lapse Rate Feedback

- Main **negative** feedback: “lapse rate feedback”



“Lapse rate” = how much the atmosphere cools as you go up in altitude.

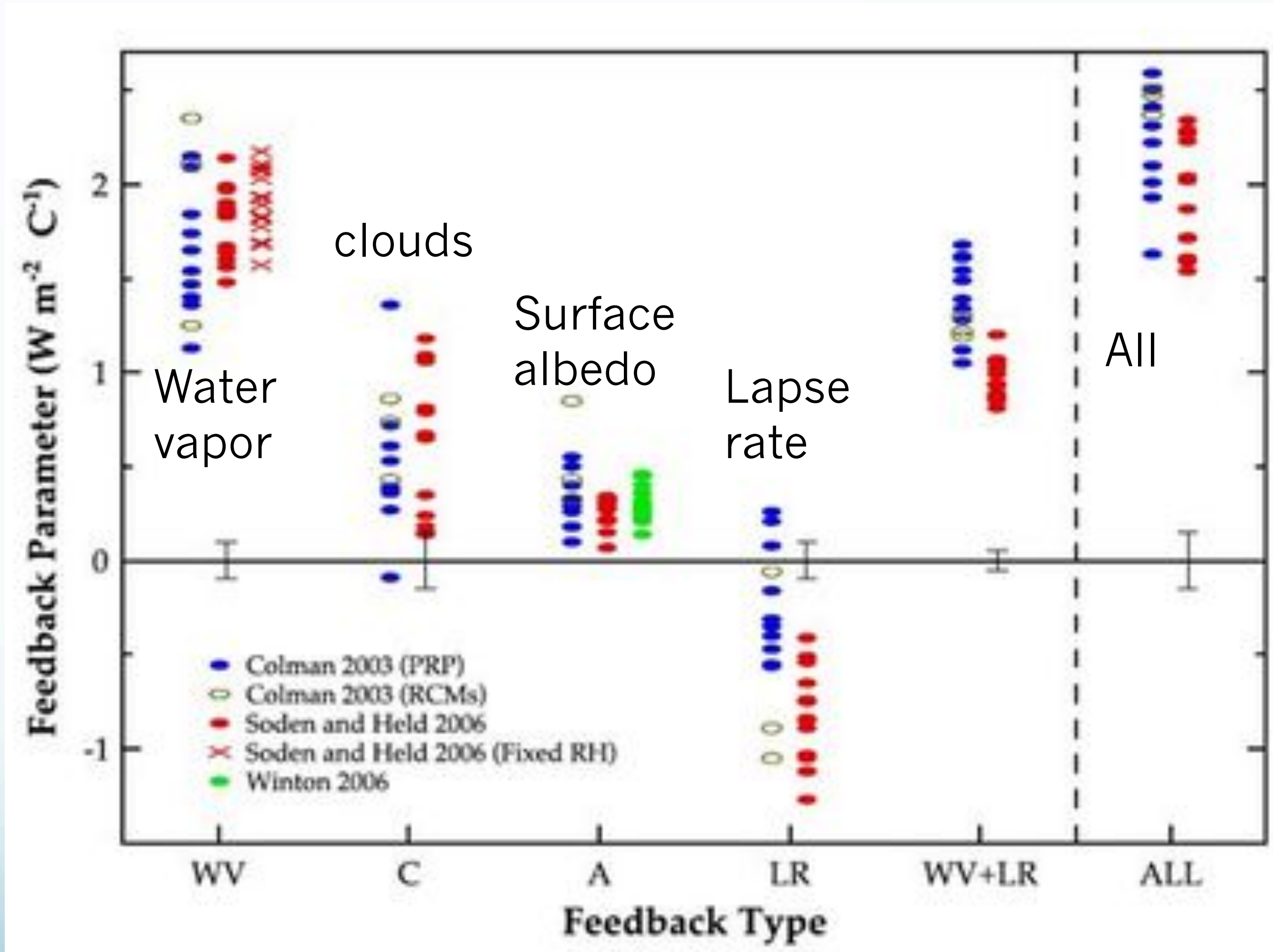
Upper atmosphere warms faster than lower atmosphere in climate models

This is where longwave radiation to space comes from

Funny skeptic argument: upper atmosphere wasn’t warming as fast as expected (resolved by Celeste Johanson and Qiang Fu and at UW): If it had been true, this would have meant we’d expect **more** warming!

Summary of Feedbacks

- This represents the extra radiation the climate system receives due to a specific feedback per degree C of global warming.
- Different colors represent different studies, and different circles represent different climate models.

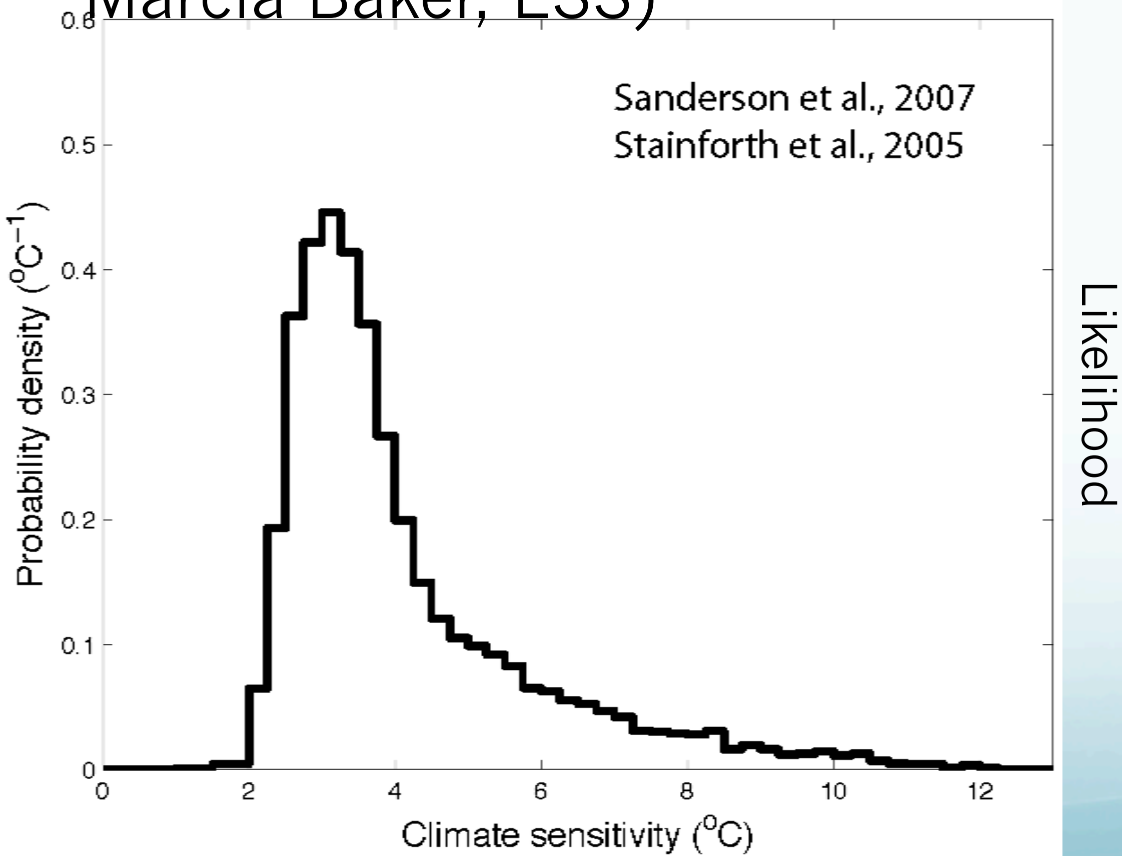


Feedbacks and Climate Sensitivity

- Climate models say that expected warming is approximately **double** that expected with no feedbacks
  - Warming response to doubling CO_2 (we'll likely get to this around 2050) with no feedbacks is around 1.5° C
  - Models predict 3° C average response to warming
- There's some uncertainty in the feedbacks though
  - And it's hard to rule out **high sensitivity** climates

Uncertainty in Feedbacks

Since positive feedbacks combine, high sensitivity climates are hard to rule out (work of Gerard Roe and Marcia Baker, ESS)



From 6,000 simulations randomly changing model parameters

Very high temperature changes (e.g., 8° C) are unlikely, but hard to rule out (on the other hand, small temperature changes like 1° C are essentially impossible)

Summary

- Feedbacks:
  - Water vapor feedback is positive
  - Ice-albedo feedback is positive
  - Lapse rate feedback is negative
  - Cloud feedback is another key uncertainty

- Because of positive feedbacks, it is possible, though unlikely, that the climate may be very sensitive to radiative forcing. This can be quantified as large λ in the equation below:

$$\Delta T = \lambda \, \Delta F$$

Next

- Spend more time on feedbacks and/or radiation? Review them more?
- Move on to global warming impacts: draughts?
- (Will talk about who's responsible later in the quarter).