Chapter 13: Feedbacks

- Forcing vs. Feedbacks
  - "W/m2" vs. "K"
  - "instant" vs. "after response"
  - "external agent" vs. "system"
  - "easier to quantify" vs. "decades to detect"
- Three Important Feedbacks
  - Water vapor
  - Clouds
  - Snow and sea ice

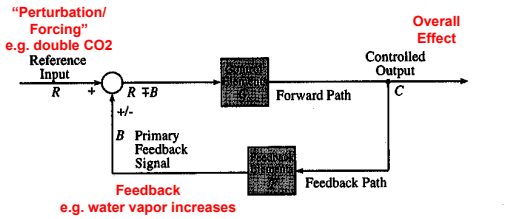
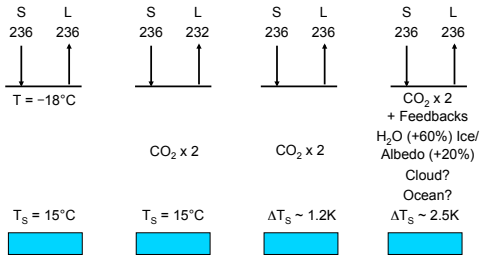


Figure 13.1 Basic block diagram including feedback elements. Negative feedback means that the summing point is a subtractor, i.e., $R - B$. Positive feedback means that the summing point is an adder, i.e., $R + B$.

The Enhanced Greenhouse Effect

Solar (S) and longwave (L) radiation in Wm^{-2} at the top of the atmosphere



What are the forcings?

- Any "external agent" that warms or cools the Earth system relative to a base state, which is typically taken to be "preindustrial" (i.e. 1750).

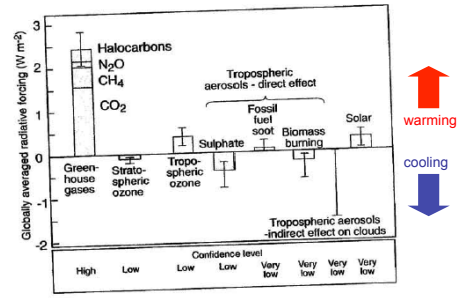
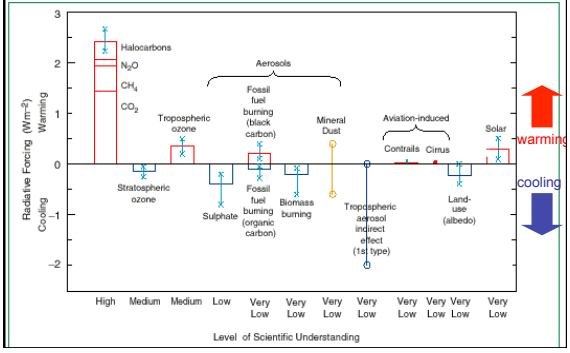
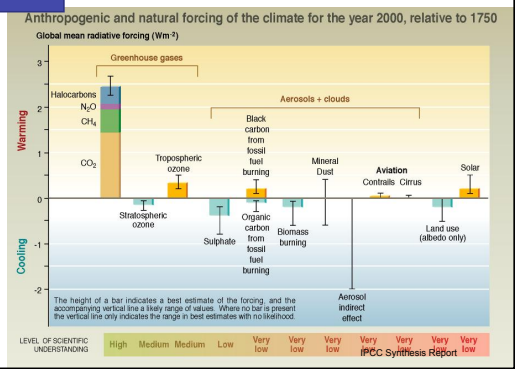


Figure 4.12. Estimate of the globally and annually averaged anthropogenic radiative forcings due to changes in the concentrations of greenhouse gases and aerosols from preindustrial times to 1995 and to natural changes in solar output from 1850. The height of the rectangular bar indicates a midrange estimate of the forcing, and the error bar shows an estimate of the uncertainty range. A subjective confidence that the actual forcing lies within the error bar is indicated by the "confidence level." [From *Climate Change 1995*, Ed. J. T. Houghton et al., Cambridge University Press (1996).]

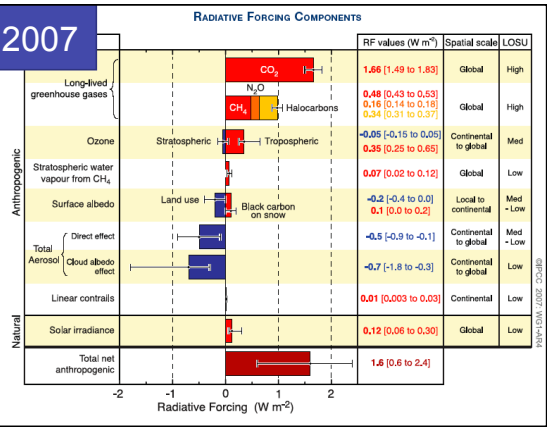
1995



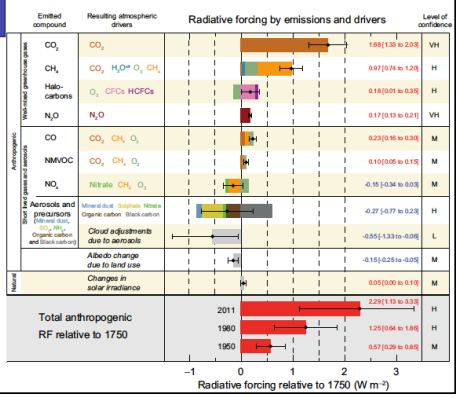
2000



2007



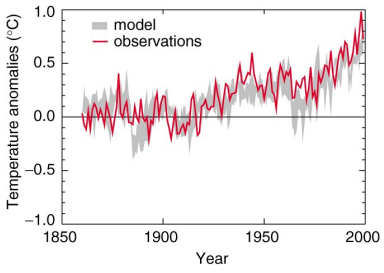
2013



Why doesn't net forcing tell us temperature change?

- Because feedbacks will dampen or enhance these initial changes.

Simulated annual global mean surface temperatures



IPCC statements on Detection

- "The balance of evidence suggests a discernible human influence on global climate" ***1995 Report***
- "There is new and stronger evidence that most of the warming observed over the last 50 years is attributable to human activities" ***2001 Report***
- "A global assessment of data since 1970 has shown it is likely that anthropogenic warming has had a discernible influence on many physical and biological systems." ***2007 Report***

What are the feedbacks?

- Any "external agent" that warms or cools the Earth system relative to a base state, which is typically taken to be "preindustrial" (i.e. 1750).

Feedbacks also often involve the following complexities:

The climate system is not linear. Important "tipping points" or thresholds or instabilities are known to exist.

The base state can influence the feedbacks. Example: Snow-albedo feedback depends on snow being present.

A global average can be misleading. Feedbacks may be locally important but less important in the global mean.

Climate sensitivity depends strongly on feedbacks, and the usual way of defining it, as a surface temperature change in response to doubling CO_2, is not always best.

Climate Feedbacks - A Study Guide to Chapter 13

This topic is extremely important and is central to modern research on climate, especially anthropogenic climate change. It is no exaggeration to say that understanding feedbacks in the climate system is a major challenge to science, and indeed to humanity.

However, the Chapter 13 formalism (from control theory) can obscure rather than illuminate key issues.

The chapter emphasizes 3 especially important feedbacks (but there are many others).

Section 13.3 Water Vapor Feedback

Section 13.4 Cloud-radiation Feedback

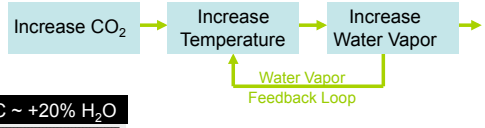
Section 13.5 Snow/Ice-albedo Feedback

One complexity is that these feedbacks (and others) can and do interact with one another. The partial derivatives in the control theory formalism are an idealization that cannot be observed in the "real world" -- rarely does only one variable vary.

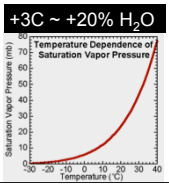
Section 13.3 Water Vapor Feedback

- **Key points:**
- **This is a strongly positive feedback, nearly doubling the effect of carbon dioxide alone.**
- **Relative humidity seems to be approximately constant under climate change (p. 359).**
- **Relatively dry regions, such as the upper troposphere and polar regions, are especially sensitive (p. 362).**

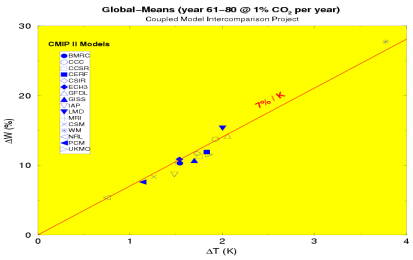
Natural Feedbacks within the Climate System:Water Vapor Feedback



+3C ~ +20% H_2O

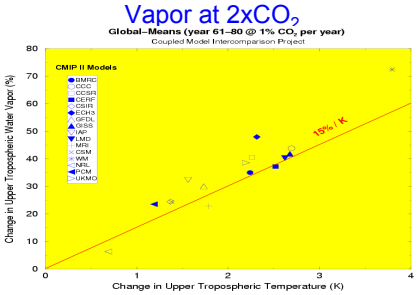


Change in Global Water Vapor at 2xCO$_2$



All models predict total column water vapor to increase at 7% /K

Change in Upper Tropospheric Water Vapor at 2xCO$_2$



All models predict upper trop water vapor to increase at ~15% /K

Section 13.4 Cloud-radiation Feedback

Key points:

- Clouds affect both shortwave (low clouds) and longwave (high clouds). Present climate has cloud cooling dominating cloud warming (pp. 368-369).
- Many different mechanisms, including those involving aerosol-cloud interactions, may be important, but the sign and magnitude of cloud feedbacks is still largely unknown (p. 374). Clouds have big effects in models

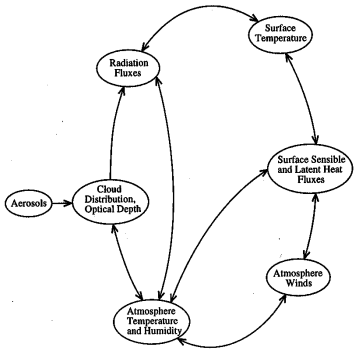


Figure 13.6 Signal flow graph illustrating the cloud-radiation feedback. Feedback loops may be positive or negative, depending on the atmospheric state and the horizontal scale under consideration. (After Curry *et al.*, 1996.)

Table 13.1. Estimates of the mean annual, globally averaged cloud-radiative effect (W m^{-2}) at the top of the atmosphere derived from satellite observations and general circulation models.

Basis	Investigation	CF^{LW}	CF^{SW}	CF^{net}
Satellite	Ramanathan *et al.* (1989)	31	–48	–17
Satellite,	Ardanuy *et al.* (1991)	24	–51	–27
Models	Cess and Potter (1987)	23 to 55	–45 to –75	–2 to –34

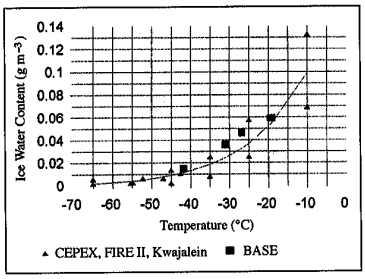
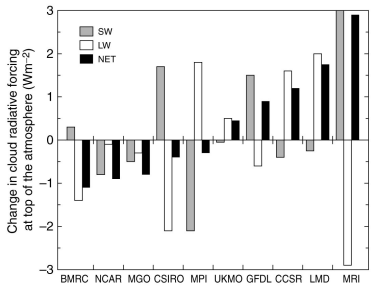


Figure 13.7 Observed relationship between cirrus ice water content and cloud temperature, obtained from research aircraft flights during CEPEX (tropics), FIRE II (mid-latitudes), and BASE (Arctic). (Courtesy of J. Intrieri.)

Model Estimates of Cloud Radiative Forcing with CO_2 Doubling



Effect of cloud feedback formulation on climate prediction

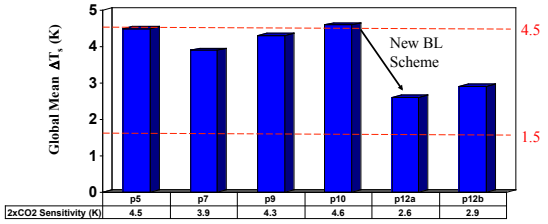
• Feedback scheme change,C	Global Av Temp for doubled CO2
–RH	5.3
–CW	2.8
–CWRP	1.9

– ***after Senior & Mitchell, Hadley Centre***

Senior, C. A., and J. F. B. Mitchell, 1993: Carbon Dioxide and Climate: The Impact of Cloud Parameterization. *Journal of Climate*, **6**, 393-418.

This classic paper showed that the same climate model can produce different sensitivites to carbon dioxide, varying by a factor of three in terms of global average warming, depending on the treatment of clouds and cloud-radiation interactions.

Evolution of Climate Sensitivity in AM2



Large change in sensitivity occurred between AM2p10 and AM2p12a due to the introduction of a new boundary layer parameterization, which modifies the response of low-level clouds to warming

Connecting this course to current research…Parameterizations

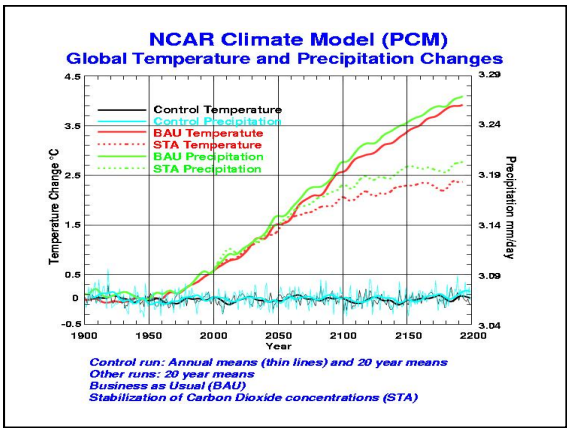
Start from two sections of Curry & Webster:

- Parameterization of Cloud Microphysical Processes (Section 8.6), pages 241 - 244. Understand the ideas behind the equations on page 242 and note the remarks on page 244.
- Cloud-radiation Feedback (Section 13.4), especially the last 2 paragraphs of Section 13.4.1 on pages 368, 369, and the last paragraph of Section 13.4 on page 374.

Section 13.5 Snow/Ice-albedo Feedback

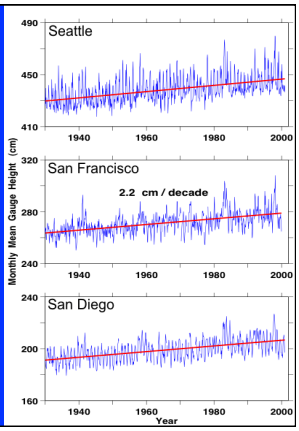
Key points:

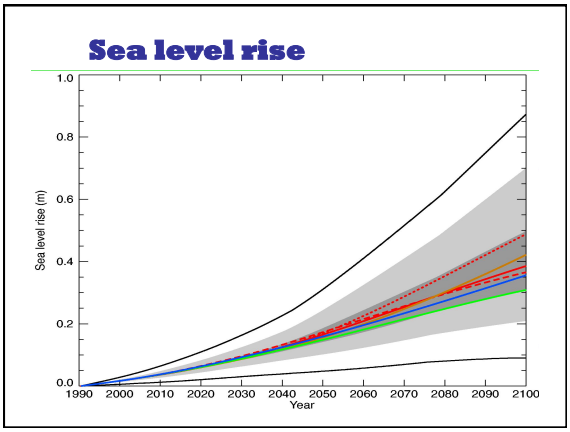
- **This feedback is large and positive in high northern latitudes.**
- **Observations show that this effect is occurring now.**
- **Melting ice on land has another large effect, unrelated to albedo: it causes sea level to rise.**



Steady rise in sea level over recent decades.

Causes particular problems when *storms* come during *high tide*





Greenland: up to 7 meters of sea level

"Ice sheets have contributed meters above modern sea level in response to modest warming [~3ºC, or 5ºF]… a threshold triggering many meters of sea-level rise could be crossed well before the end of the century."

Overpeck et al., *Science*, 2006

Review and Final

- Review Session: Friday 12/6
  - 12:30 pm here
- Final Exam: Thursday 12/12
  - 11:30 am here

Quiz Ch. 12-13

Answer briefly and clearly, with appropriate equations or diagrams.

1. What is the source of energy for the atmospheric heat engine?
2. Name the equator-to-pole transport of air.
3. Why is there an "atmospheric window" in longwave emissions?
4. Is a thermostat a positive or negative feedback?
5. Is water vapor a positive or negative feedback?
6. Is sea ice a positive or negative feedback?
7. What kind of feedback are clouds?