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.

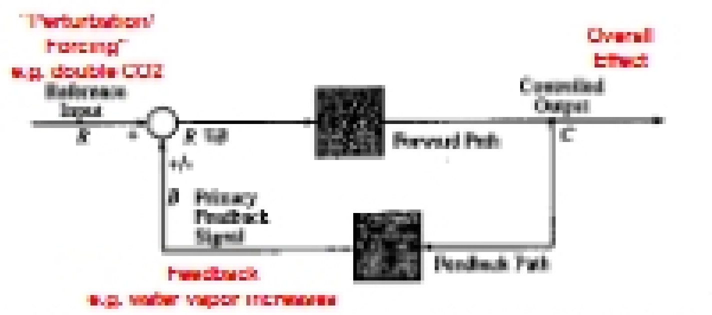
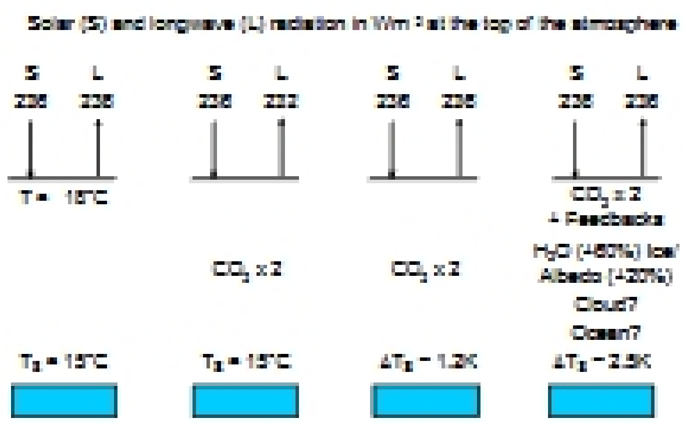


Figure 13.1 Basic block diagram including feedback elements. Negative feedback means that the summing point is a subtractor, i.e., R − B. Positive feedback means that the summing point is an adder, i.e., R + B

The Enhanced Greenhouse Effect



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.

Feedbacks also often involve the following complexities:

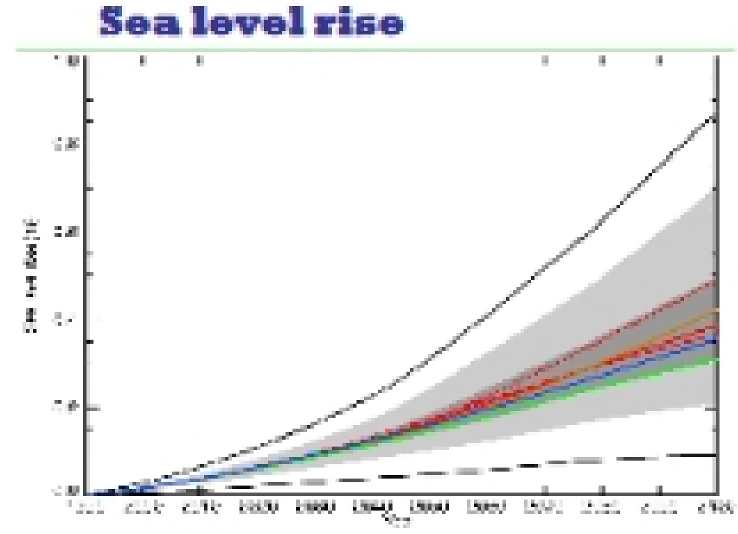
The climate system is not linear. Important "tipping points" or thresholds or instabilities are known to exist.

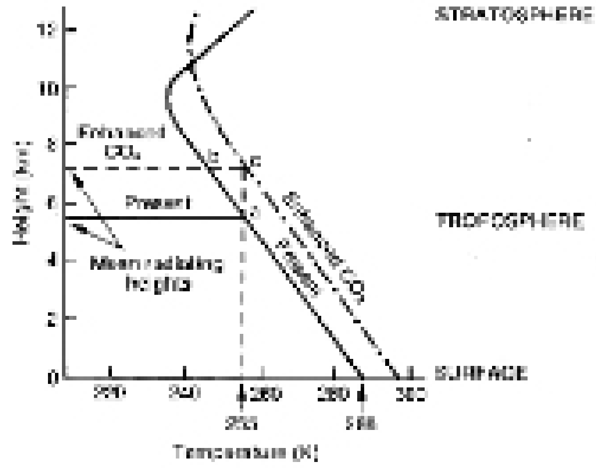
The base state can influence the feedbacks. Example: Snow-albedo feedback depends on snow being present.

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.

Sea level rise





The Development of Climate models, Past, Present and Future

Section 13.3 Water Vapor Feedback

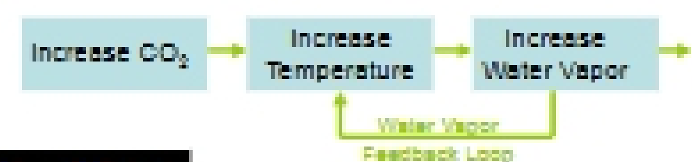
Key points:

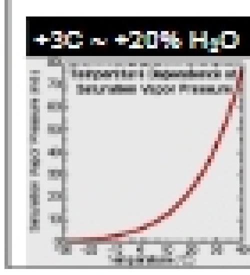
This is a strongly positive feedback, nearly doubling the effect of carbon dioxide alone.

Relative humidity seems to be approximately constant under climate change (p. 359).

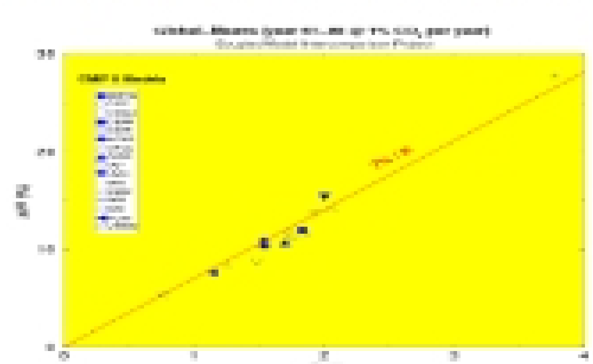
Relatively dry regions, such as the upper troposphere and polar regions, are especially sensitive (p. 362).

Natural Feedbacks within the Climate System:Water Vapor Feedback



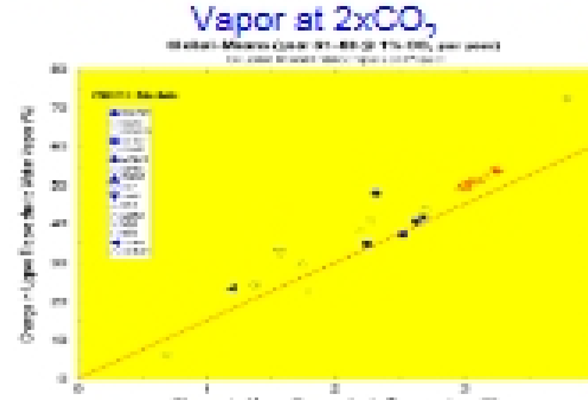


Change in Global Water Vapor at $2xCO_2$



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.

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

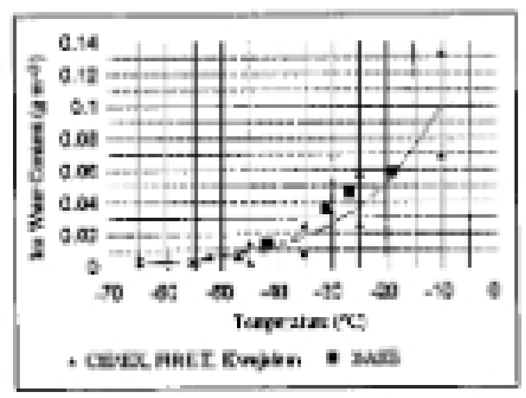
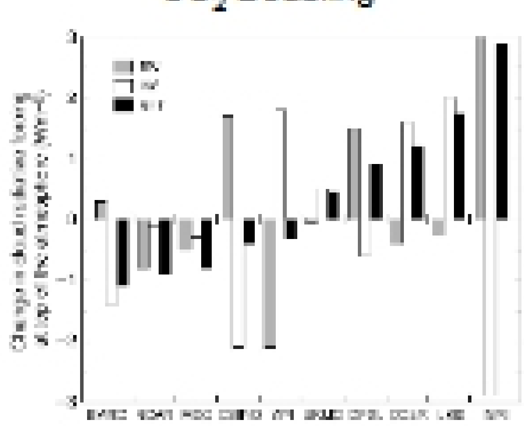


Figure 13.7 Observed relationship between in situ ice water content and cloud temperature, obtained from research aircraft flights during CEPEX (tropics), FIRE II (mid-latitudes), and BASE (Arctic).

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*