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. 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 CO2, is not always best.

Sea level rise

Steady rise in sea level over recent decades.
Causes particular problems when storms come during high tide.

NCAR Climate Model (PCM)
Global Temperature and Precipitation Changes

| Control run: Annual mean (thin lines) and 30 year means |
| Sea level rise (thicker lines) |
| Stabilization of Carbon Dioxide concentrations (STA) |

Sea level rise graph:

Seattle
San Francisco
San Diego
Greenland: up to 7 meters of sea level

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

Overpeck et al., Science, 2006

The Enhanced Greenhouse Effect

Solar (S) and longwave (L) radiation in Wm⁻² at the top of the atmosphere

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T = -18°C

CO₂ x 2

ΔT₂ = 1.2K

ΔT₃ = 2.5K

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

Increase CO₂ → Increase Temperature → Increase Water Vapor → Increase CO₂

Water Vapor Feedback Loop

+3°C ~ +20% H₂O

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.
Model Estimates of Cloud Radiative Forcing with CO₂ Doubling

Effect of cloud feedback formulation on climate prediction

- Feedback scheme
- Global Av Temp change, C for doubled CO₂
  - RH
  - CW
  - CWRP
  - after Senior & Mitchell, Hadley Centre

Evolution of Climate Sensitivity in AM2


This classic paper showed that the same climate model can produce different sensitivities 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.
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.

Land areas are projected to warm more than the oceans with the greatest warming at high latitudes

Annual mean temperature change, 2071 to 2100 relative to 1990: Global Average in 2085 = 3.1°C
Global mean surface air temperature anomalies from 1,000 year control simulations with three different climate models— Hadley, GFDL, and Hamburg— compared to the recent instrumental record. No model control simulation shows a trend in surface air temperature as large as the observed trend. If internal variability is correct in these models, the recent warming is likely not due to variability produced within the climate system alone.

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

John Tyndall (1820–1893)

Investigated radiant (infrared) heat in 1859. Was first to measure absorptive powers of gases such as H2O, CO2, O3 and hydrocarbons (all greenhouse gases).

Demonstrated that H2O, CO2, O3 are some of the best absorbers of infrared radiation.

Svante Arrhenius (1859–1927), Swedish physical chemist

Said rising atmospheric CO2 due to human industry.

Predicted doubling CO2 would increase average global temperature by ~5°C.