Global Warming: Understanding the forecast

GEOL/ENVS 3520-002
I. Feedbacks and coupling between Earth System components
review:

The problem of “man-made” warming and what to do about it is one of the most complex and serious issues facing society.

This course attempts to provide a analytical understanding of the changing Earth based on a systems approach for use in deciphering the complex and uncertain forecast...
the Earth System

a system of connected parts that work together dynamically
i.e., all parts are connected and affect the others
what are the parts of the system?
and humans are clearly now an important part of the interconnected system.....
what about the climate system?

there is nothing here we can take away and still describe fully the important interactions w/in the climate system
today’s goals

a focus on interactions

• a working knowledge of the systems approach to the study of Earth and climate science

• an ability to recognize and use the concept of feedback (negative and positive)

• an ability to recognize and use the concept of equilibrium (stable and unstable)

• an understanding of the relationship between forcing, feedback and equilibrium
couplings
(1-way interactions)

• positive coupling
  – something *increases* (decreases) *causing* something else to *increase* (decrease)

In the example above, you are the blanket temperature is high (low), so your body temperature is high (low)- i.e. *a positive coupling*…

source: Kump et al. “The Earth System”
**couplings**
*(1-way interactions)*

- **negative coupling**
  - something *increases* (decreases) *causing* something else to *decrease* (increase)

In the example above, you are too hot (cold) so you turn down (up) the blanket temperature - *i.e. a negative coupling*…

*source: Kump et al. “The Earth System”*
feedbacks
(interaction in both directions)

more complicated, but more interesting

some simple examples.........
negative feedback
(w/ simple Hi/Low thermostat)

based on simple RULE:

sign of feedback = product of signs of couplings

source: Kump et al. “The Earth System”
negative feedback
(w/ simple Hi/Low thermostat)

person A’s body temperature

net(−)

person A’s blanket temperature

what happened?
the system has reached equilibrium
temp. no longer changes (much)
negative feedbacks are stabilizing
**positive feedback**
(thermostats in the wrong hands)

**interactions:**
- 2 positive couplings
- 2 negative couplings

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**Jimmy’s thermostat**
*is controlling Rosalynn’s blanket*  
*and visa versa*

**what happens?**

source: Kump et al. “The Earth System”
positive feedback
(thermostats in the wrong hands)

the positive feedback is destabilizing
(the system is changing at an ever increasing rate)

net (−)

what happened?
• **positive feedback**
  – change in the state *increases the strength* of the influence

• **negative feedback**
  – change in the state *decreases the strength* of the influence

*thus, as we have seen:*

• **positive feedbacks are destabilizing**
• **negative feedbacks are stabilizing**

some examples ......
Clicker question:
(discuss w/ your neighbor)

Having to guess, is the dominant feedback in this system likely to be a) negative, b) destabilizing, c) positive, d) stabilizing, e) both b & c

Extent (millions of square kilometers)

Year

September sea ice extent

source: CU-NSIDC
What is the feedback process depicted here?

Think about this: sea ice is bright and reflects ~90% of the sun's rays, sea water is dark and absorbs ~90% of the sun's rays.

source: A. Gore’s “AlT”
What is the feedback process depicted here?

Think about this: sea ice is bright and reflects ~90% of the sun's rays, sea water is dark and absorbs ~90% of the sun's rays.

source: A. Gore’s “AIT”
pos. feedback involving sea ice

Temperature → "reflectivity" → Sea ice cover

Note the product of all couplings is positive.
another feedback involving sea ice?

consider the Arctic in winter- which is colder the ocean or the air above?

given the chance which way will the heat move?

what might keep it from moving?
Arctic Ocean sea smoke
Sea ice - heat flux feedback

- Lower temperature
- More sea ice
- Lower O-A heat flux
- Lower temperature

- Higher temperature
- Less sea ice
- Greater O-A heat flux
- Higher temperature

You could say sea-ice acts like an insulating blanket.
in-class exercise:

Earth’s average temperature is determined in part by the amount of CO$_2$ in the atmosphere, by way of the enhanced greenhouse effect. The atmospheric CO$_2$ content may in turn be affected by the photosynthetic activity of plants, which converts CO$_2$ into plant tissue. The components of the system—atmospheric CO$_2$ content, global temperature, and photosynthesis rate—are intimately connected. By increasing the global rate of photosynthesis, plants would tend to lower the atmospheric CO$_2$ level. In doing so, however, the plants would tend to cool the Earth. This cooling might tend to reduce photosynthetic activity in plants.

On the basis of this discussion, draw a systems diagram of the photosynthesis rate - CO$_2$ - temperature system.

(and get ready for a related clicker question next!)
clicker question:

On the basis of your diagram, the photosynthesis rate - CO₂ - temperature system constitutes:

a) a positive feedback which would decrease the strength of the original influence

b) a positive feedback which would increase the strength of the original influence

c) a negative feedback which would decrease the strength of the original influence

d) a negative feedback which would increase the strength of the original influence

e) can’t tell from the information given
plausible diagram

explain the response of the system to an initial increase or decrease of CO$_2$
in-class exercise:

Observations from experiments in enclosures indicate that an increase in CO$_2$ may lead directly to an increase in photosynthetic activity.

*Draw the systems diagram for the two-way interaction between CO$_2$ and photosynthetic activity.*
clicker question:

On the basis of your diagram, the photosynthesis rate - CO₂ system constitutes:

a) a *positive* feedback which would *decrease* the strength of the original influence

b) a *positive* feedback which would *increase* the strength of the original influence

c) a *negative* feedback which would *decrease* the strength of the original influence

d) a *negative* feedback which would *increase* the strength of the original influence

e) can’t tell from the information given
describe the response the of the system to an initial increase or decrease of CO₂
possible feedbacks involving CO$_2$

both of the feedbacks shown are ________ in sign
types of equilibrium

consider a ball in a valley

what happens to the ball when dis(per)turbed in this imaginary situation?

and that the ball represents the state of some variable (say temperature)

narrower & steeper, less stable
types of equilibrium

consider a ball in a valley

it’s STABLE
(if perturbed it tends to return to equilibrium as result of negative feedbacks)

consider a ball on a peak

it’s UNSTABLE
(e.g. temperature changes continuously as result of positive feedbacks)
types of equilibrium

*consider a ball, now.................., on a peak*

what happens to the ball when dis(per)turbed in this imaginary situation?
types of equilibrium

- consider a ball, now....................., on a peak

it’s UNSTABLE
(if perturbed it will tend to change continuously, as result of positive feedbacks)
forcing
simple forcing w/ negative feedback

• I always push (force) the ball up hill

• What determines the height?

• How hard I push (i.e. strength of forcing) and how hard the ball pushes back (i.e. strength of negative feedback)

teaching slides after Prof. D. Noone (ATOC)
forcing

simple forcing w/ negative feedback

• I always push (force) the ball up hill

• What determines the height?

• How hard I push (i.e. strength of forcing) and how hard the ball pushes back (i.e. strength of negative feedback)

do we have an example of forcing and feedback like this …….
CO₂ system forced by fossil fuel burning

These might help restore the system
CO₂ system forced by fossil fuel burning

except that deforestation offsets any likely benefit (more on that in a later class)
types of equilibrium

each responds differently to forcing

STABLE EQUILIBRIUM
(resistant to change as result of negative feedbacks)

UNSTABLE EQUILIBRIUM
(sensitive to change resulting from positive feedbacks)
consider body temperature

(warm blooded animals require near-constant internal temp.)

what happens if we take a short cold swim?
stability diagram
for body temperature

what might happen if we stay in too long (i.e. Man Overboard!)?

state of system

feedback
forcing or perturbation (what is the difference?)
stability diagram
for body temperature

ALIVE
warm

DEAD
cold

state of system
clicker question:

what is the relative rank of stability for positions on the diagram from most to least: a) X, Y, Z  b) Z, Y, X  c) Z, X, Y  d) Y, X, Z  e) they are all the same
stability diagram for body temperature

ALIVE
warm

threshold

stable equilibria

DEAD
cold
stability of body temperature to forcing

**short swin** - small shock or *perturbation*

“Man Overboard!” - big, long shock or *perturbation*

body temperature stable to small perturbations, but perhaps not to large or long ones
SO…..

• **negative feedbacks are stabilizing**

• *this helps maintain stability in the Earth System, to an extent, but…..*

• **thresholds exist and can be exceeded**

• **what then?**
Ice Age example

Periodic changes in amount of sunlight reaching Arctic in summer influence amount of ice on land, but notice that there is excess ice more than 80% of the time.
• what feedback, akin to one the sea-ice feedbacks we have discussed, might act to maintain excess ice on land?
pos. feedback involving global snow and ice cover

global temperature

snow & ice cover

(+) 

global “reflectivity”

this can “jump start” an Ice Age and help to maintain excess ice on land

after: Kump et al. “The Earth System”
example: Scandinavia

inception of continental glaciation in plateau areas when conditions permitted snow to linger year ‘round
A more complete feedback diagram might look like this:

- Global reflectivity
- Global mean temperature
- Growth of continental ice sheets
- Intensity of summer sunlight at high northern latitudes

What is the “forcing” in this example?

Answer: intensity of summer sunlight
In the Ice Age stability diagram on the right,

a) point X represents the cold state with more ice,

b) point Y represents the cold state with more ice,

c) the curved arrows represent forcing such as Arctic sunlight

d) both a) and c) are correct

e) both b) and c) are correct
Notice that the Ice Age doesn’t stay cold “forever” (consider the last 8,000 years or so). Thus the “ice-reflectivity” feedback must not be strong enough to control the system entirely. Other feedbacks must have acted to produce periodic warmings, also possibly in response to changes in sunlight. This reminds us of the complexity of the climate system (which scientists are still seeking to understand)……
natural CO$_2$ variations

Vostok, Antarctica

number of CO$_2$ molecules for every million molecules of air in Antarctic ice

time moves forward from R to L in thousands of years
Is the dominant feedback in this system:

a) positive, b) negative, c) stabilizing, d) both b & c,
e) there is no feedback
does the system ever get too far out of whack?
does the system have bounds? a middle?
recent CO$_2$ variations

what is this graph telling us?

Charles David Keeling
Scripps

~1.5 ppm/yr
CO$_2$ in the past and present

The system is no longer bounded at natural limits. Population and economic growth have changed the rules. What will happen? Which way will feedbacks push the system?
remember:

• we need to try to understand the feedbacks in the Earth System in order to assess future outcomes

• next lecture we begin the study of Earth’s energy budget with Radiation

• Reading: Ch. 2

• other resources: Kump, Casting & Crane, “The Earth System” Pearson Prentice Hall (2004), Ch. 2.
must-know terms

- positive coupling
- negative coupling
- positive feedback
- negative feedback
- stable equilibrium
- unstable equilibrium
- forcing
- perturbation
- carbon dioxide
key concepts

- the Earth is a system of dynamic linkages between parts, each part affecting the others

- negative feedbacks decrease the strength of interaction between components and promote stable, equilibrium conditions (i.e. the state no longer changes, much….)

- positive feedbacks increase the strength of interaction between components and are generally destabilizing
learning objectives

Know the difference between *negative* and *positive feedback* and be able to use the concept of feedback to predict what will happen to a system if the strength of a variable changes.

Explain how a system of only positive feedback works and contrast with a negative feedback system.

Describe the difference between *stable* and *unstable equilibrium*.

Explain the association between feedback (negative and positive) and equilibrium (stable and unstable).

Describe a system’s response to forcing in terms of feedback and state of equilibrium.

Explain how feedback loops can either diminish or increase the effects of forcing (disturbances).

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