Global Warming: Understanding the forecast

GEOL/ENVS 3520-002

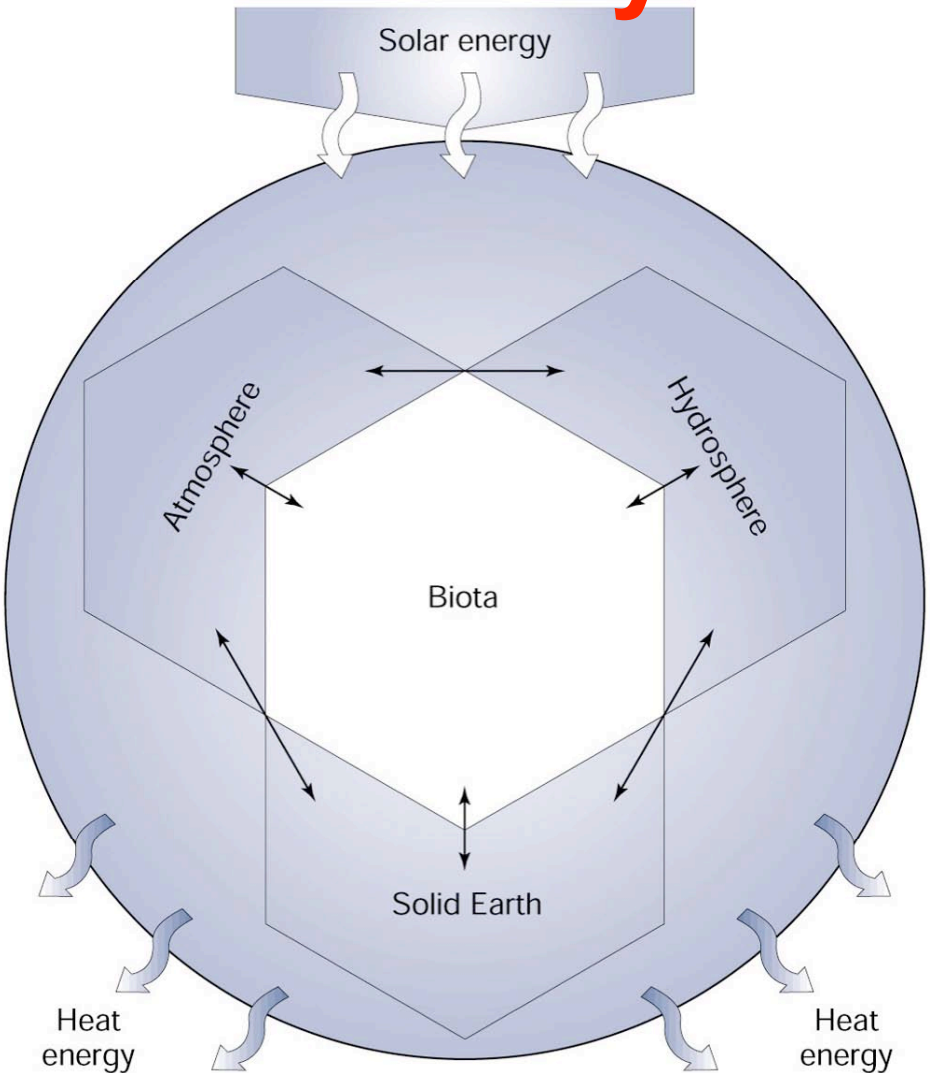
I. Feedbacks and coupling between Earth System components

review:

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

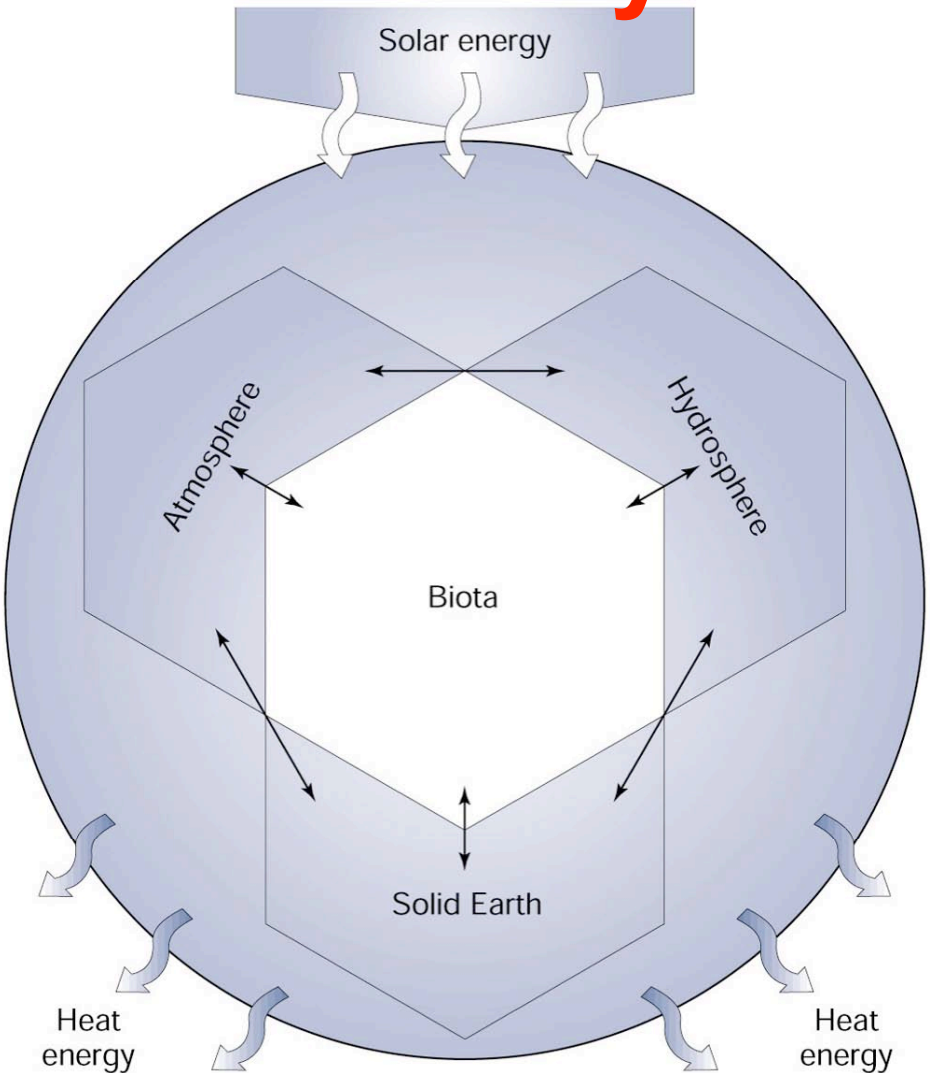
This course attempts to provide a analytical understanding of the changing Earth based on a <u>systems approach</u> for use in deciphering the complex and uncertain forecast…

the Earth System

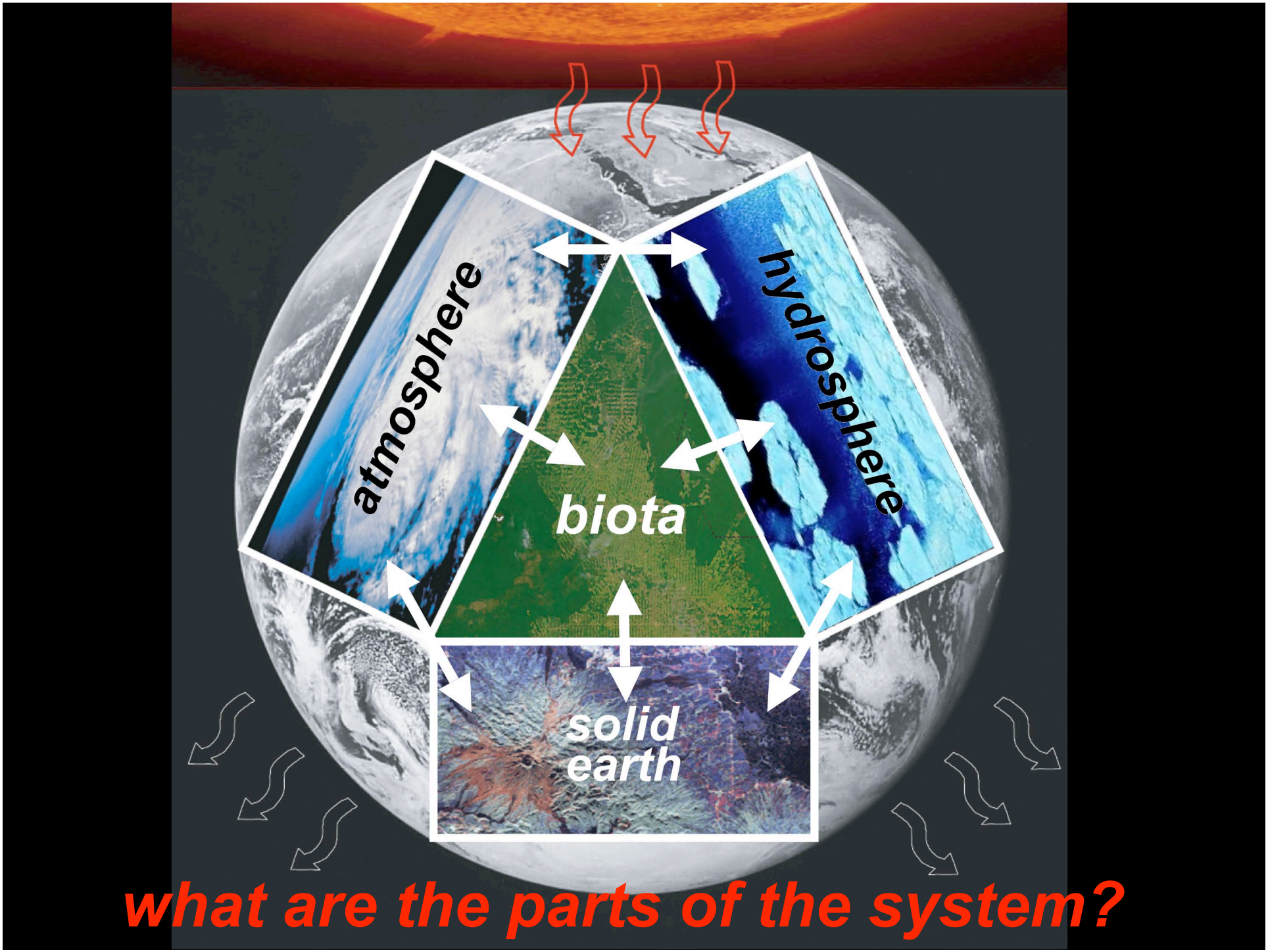


a system of connected parts that work together dynamically

the Earth System



i.e., all parts are connected and affect the others

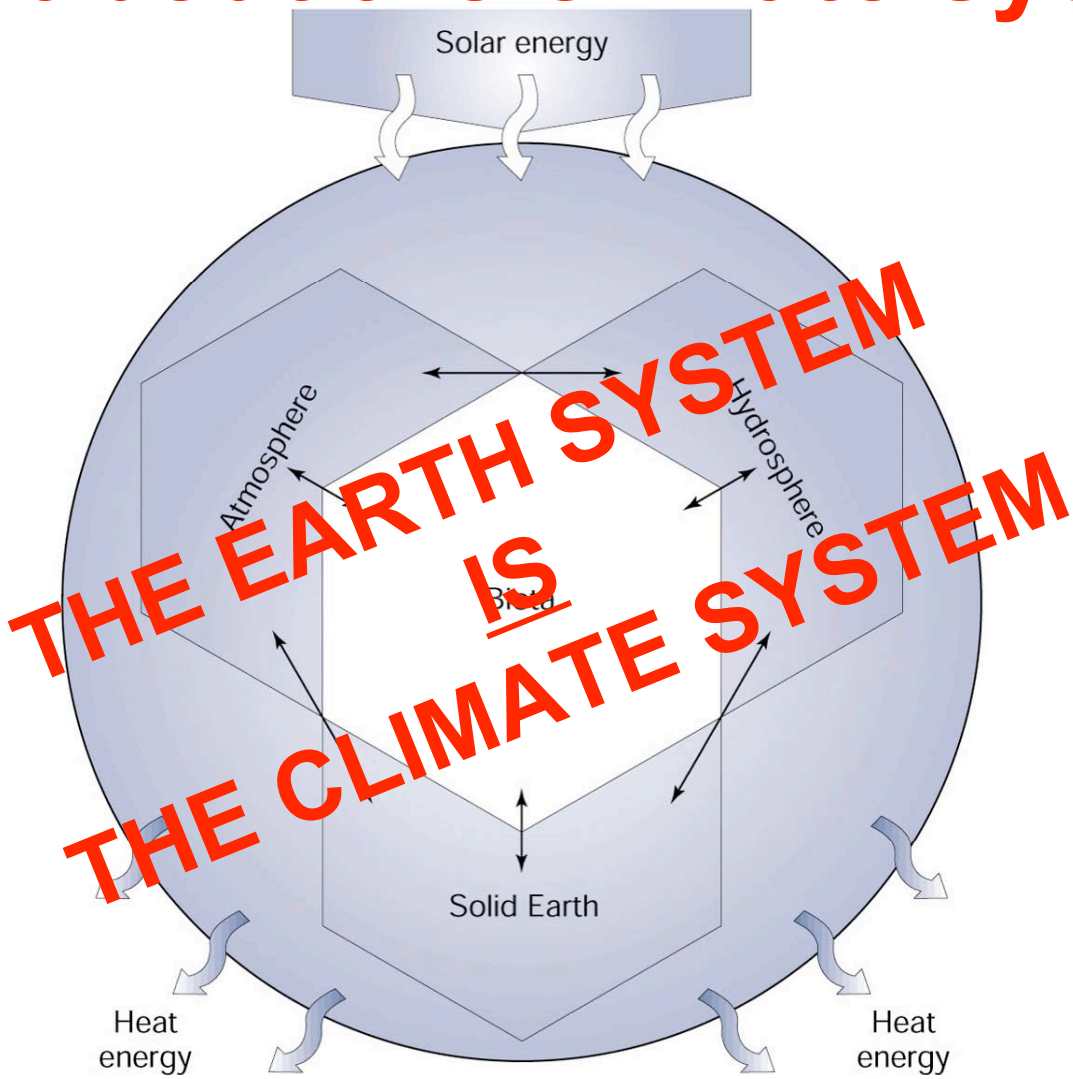


what are the parts of the system?

Earth at night

and humans are clearly now an important part of the interconnected system…..

what about the climate system?



THE EARTH SYSTEM
IS
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

<u>a focus on interactions</u>

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

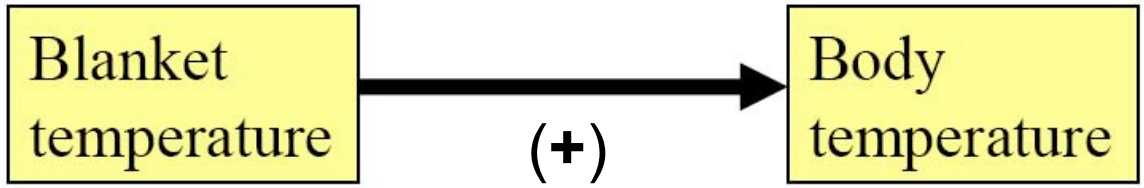
- an ability to recognize and use the concept of ***feedback*** (*negative and positive*)

- 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)

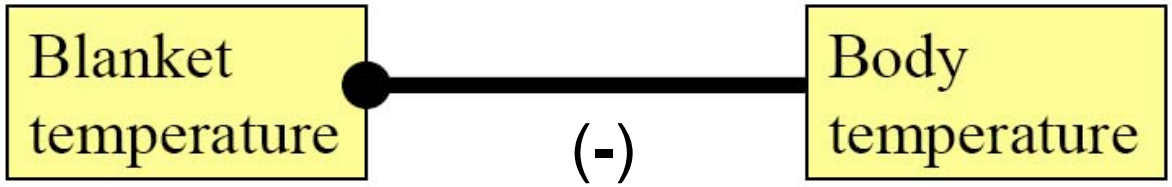


In the example above, you are the blanket temperature is high (low), so your body temperature is high (low)- *i.e. a positive coupling…*

source: Kump et al. “The Earth System”

couplings
(1-way interactions)

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

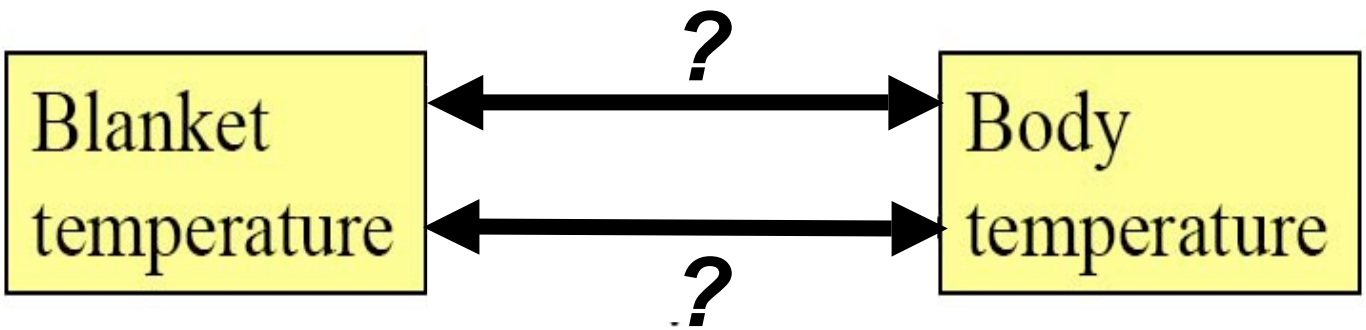


In the example above, you are too hot (cold) so you turn down (up) the blanket temperature- *i.e. a negative coupling…*

source: Kump et al. “The Earth System”

feedbacks

(interaction in both directions)

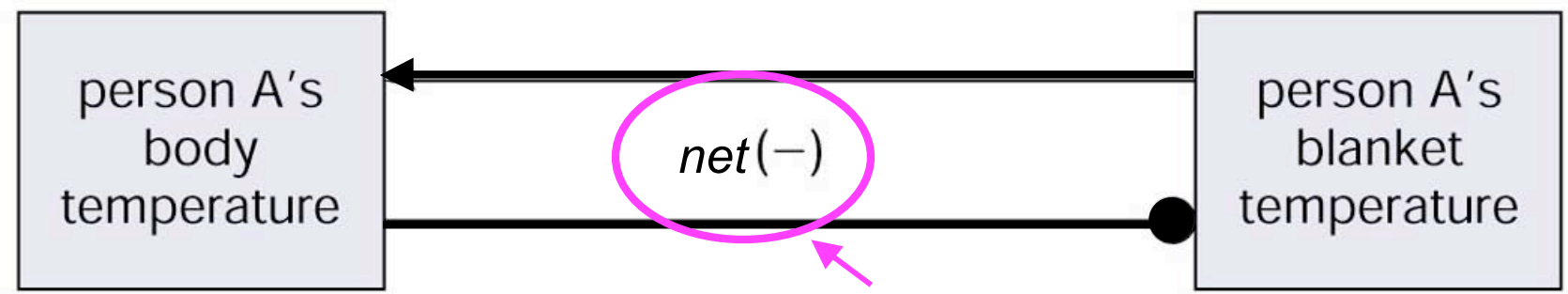


more complicated, but more interesting

some simple examples…….

negative feedback

(w/ simple Hi/Low thermostat)

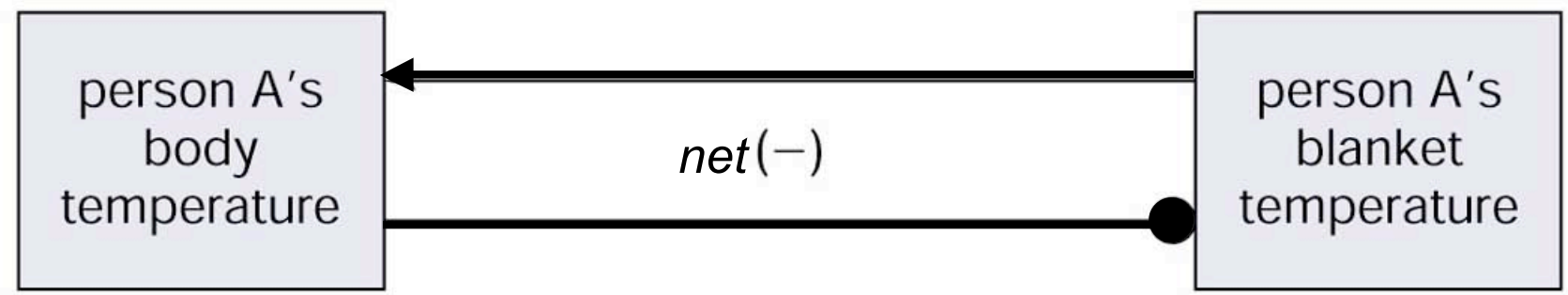


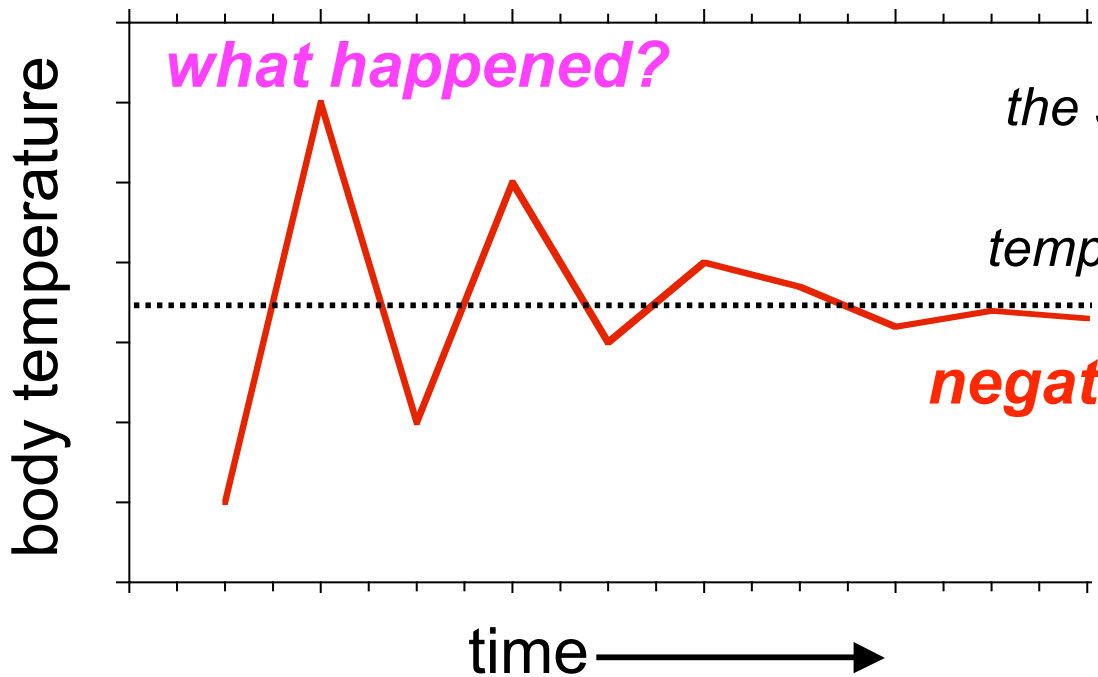
based on simple RULE:
sign of feedback =
product of signs of couplings

source: Kump et al. "The Earth System"

negative feedback

(w/ simple Hi/Low thermostat)





the system has reached

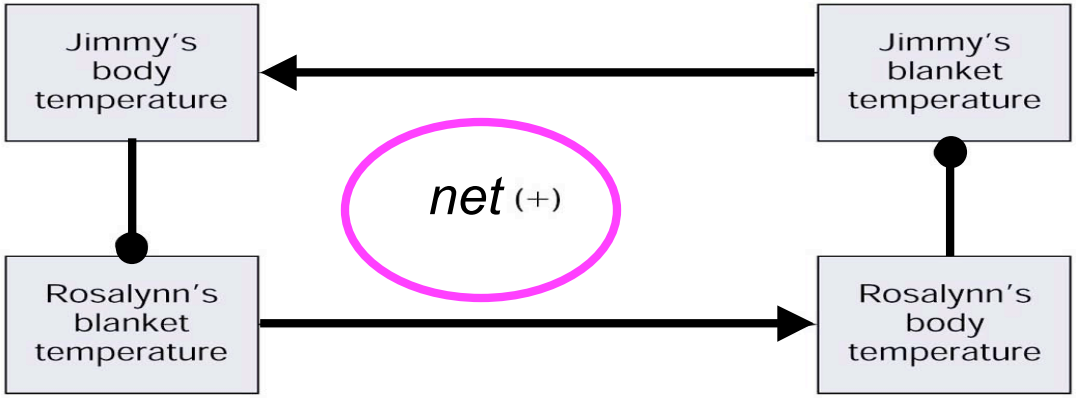
equilibrium

temp. no longer changes (much)

negative feedbacks are stabilizing

positive feedback

(thermostats in the wrong hands)



interactions:
2 positive
&
2 negative
couplings

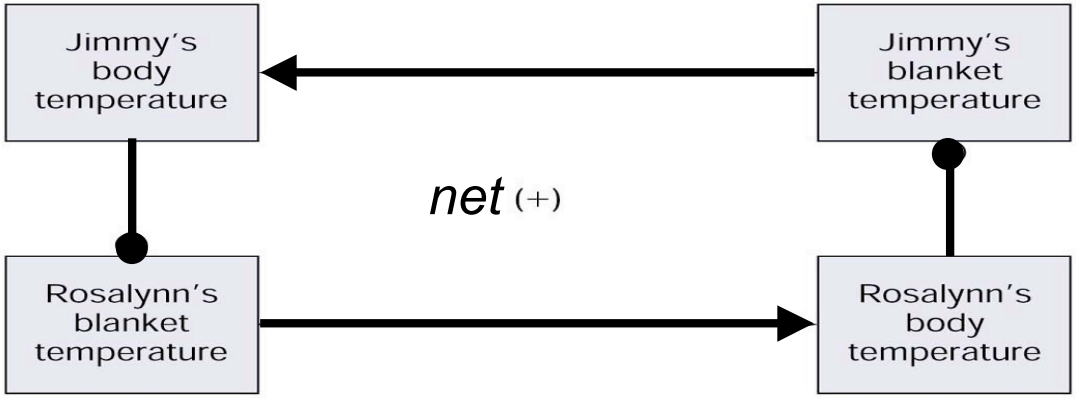
Jimmy's thermostat
is controlling Rosalynn's blanket
and visa versa

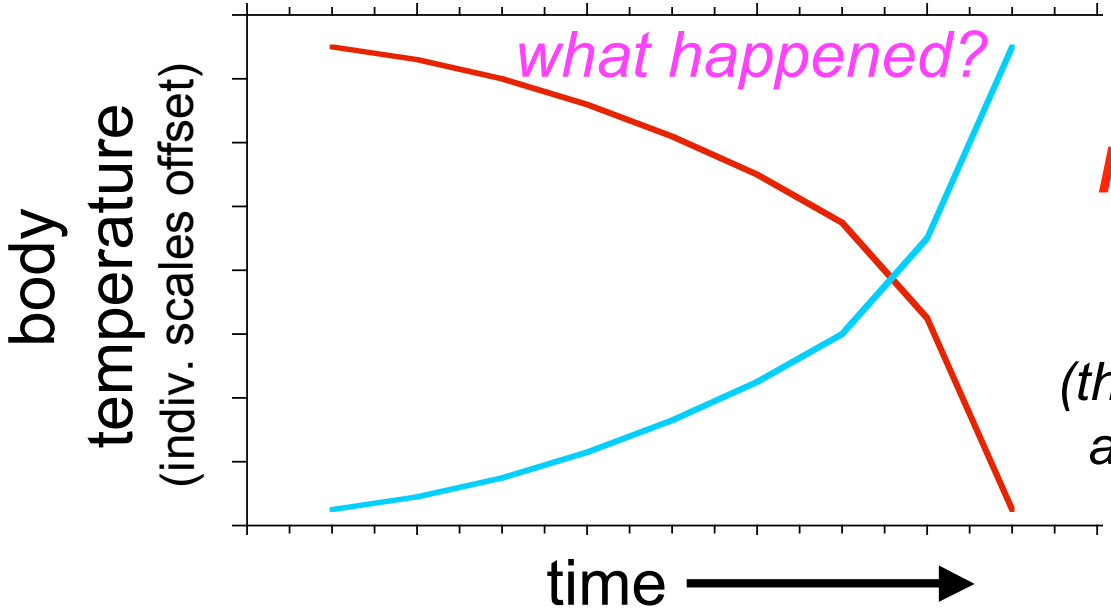
what happens?

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)

- ***positive feedback***
  - change in the state ***increases the strength*** of the influence
- ***negative feedback***
  - change in the state ***decreases the strength*** of the influence

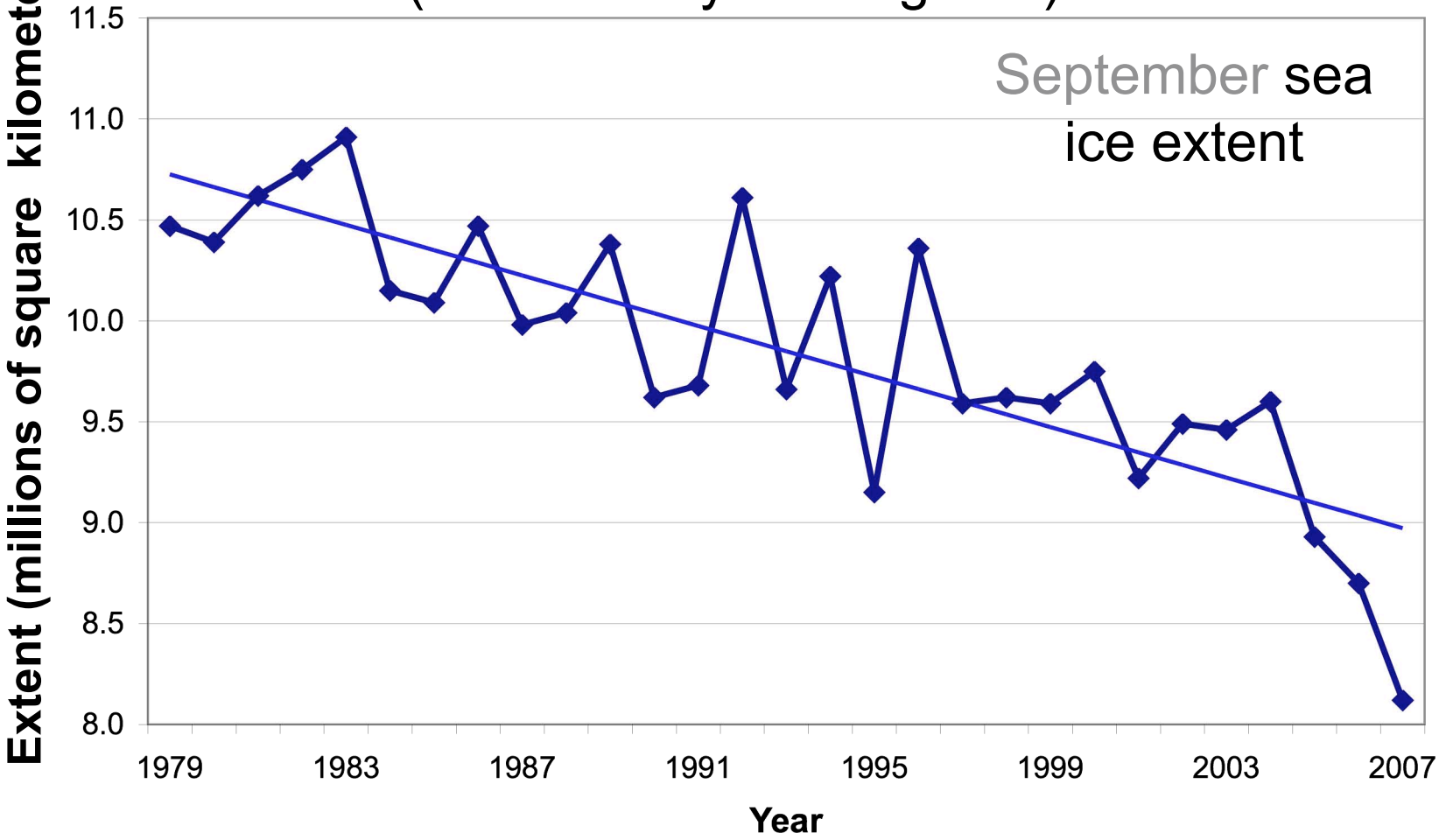
thus, as we have seen:

- ***positive feedbacks are <u>destabilizing</u>***
- ***negative feedbacks are <u>stabilizing</u>***

some examples .....

Clicker question:

(discuss w/ your neighbor)



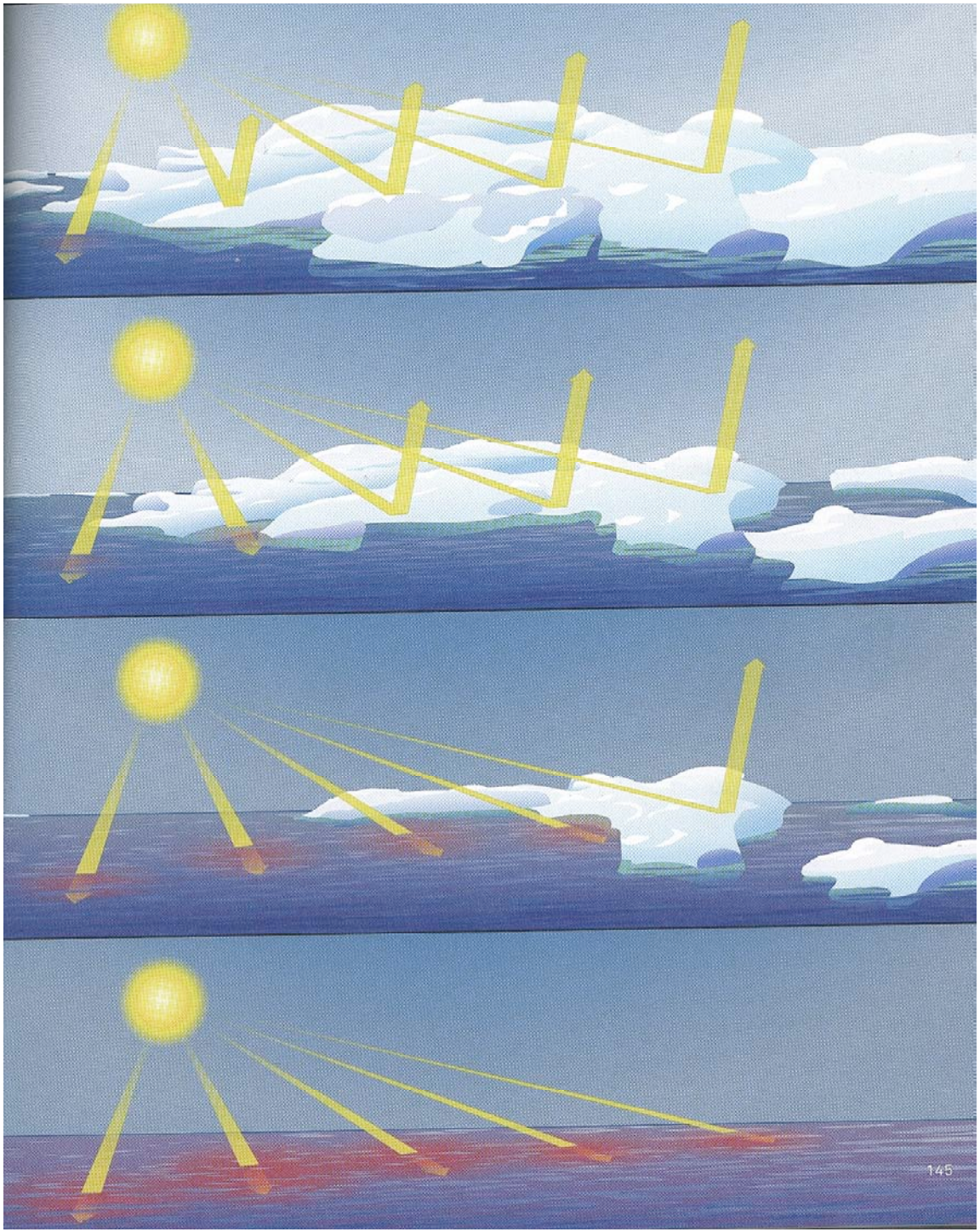
Having to guess, is the dominant feedback in this system likely to be *a*) negative, *b*) destabilizing, *c*) positive, *d*) stabilizing, <u>*e*) both *b* & *c*</u>

source: CU-NSIDC

What is the feedback process depicted here ?

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

source: A. Gore's "AIT"



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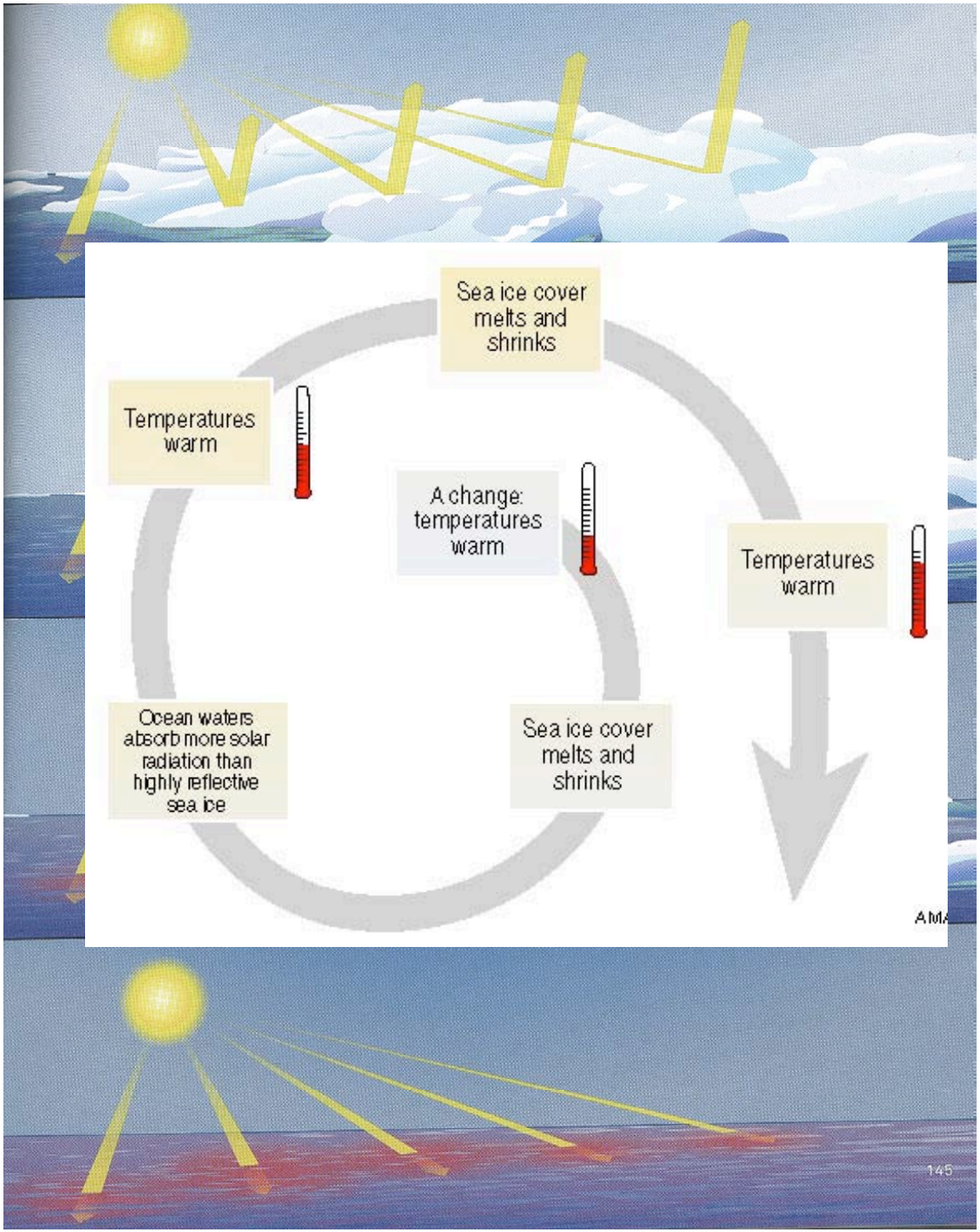
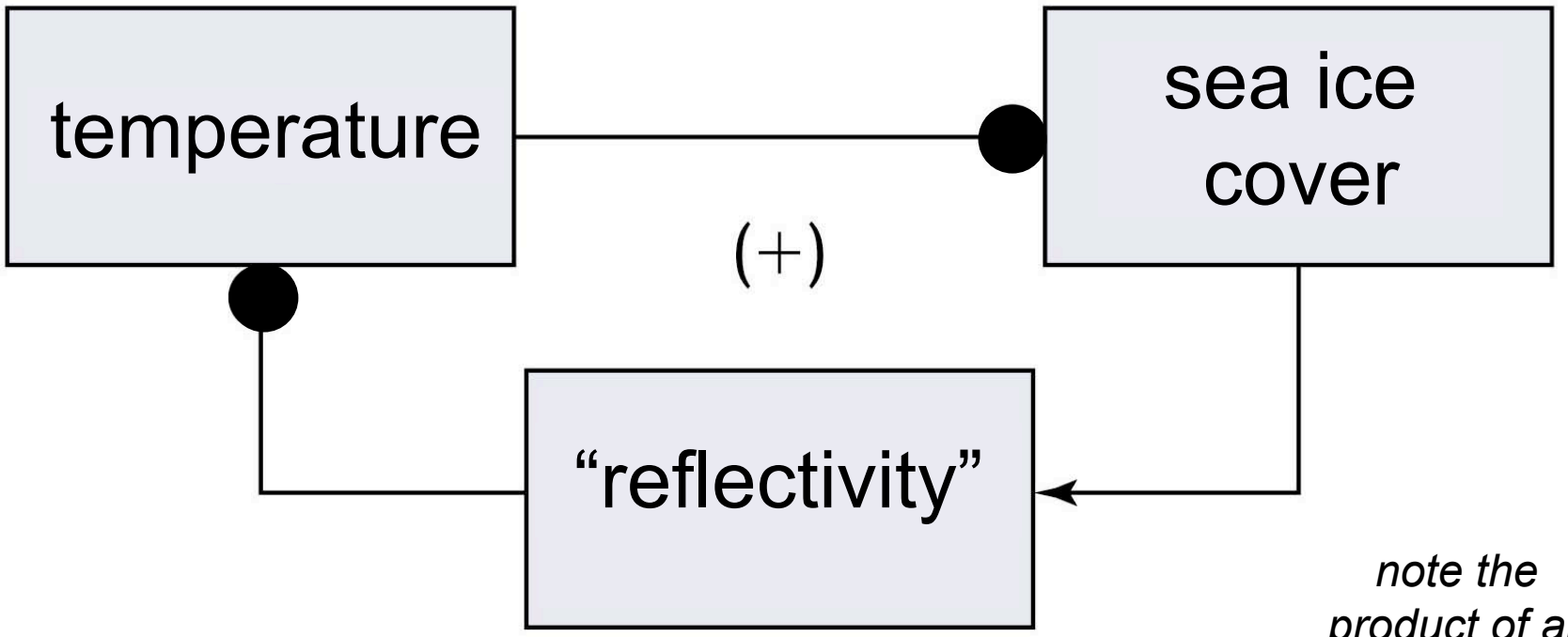


source: A. Gore's "AIT"

pos. feedback involving sea ice



note the product of all couplings is positive

another feedback involving sea ice?

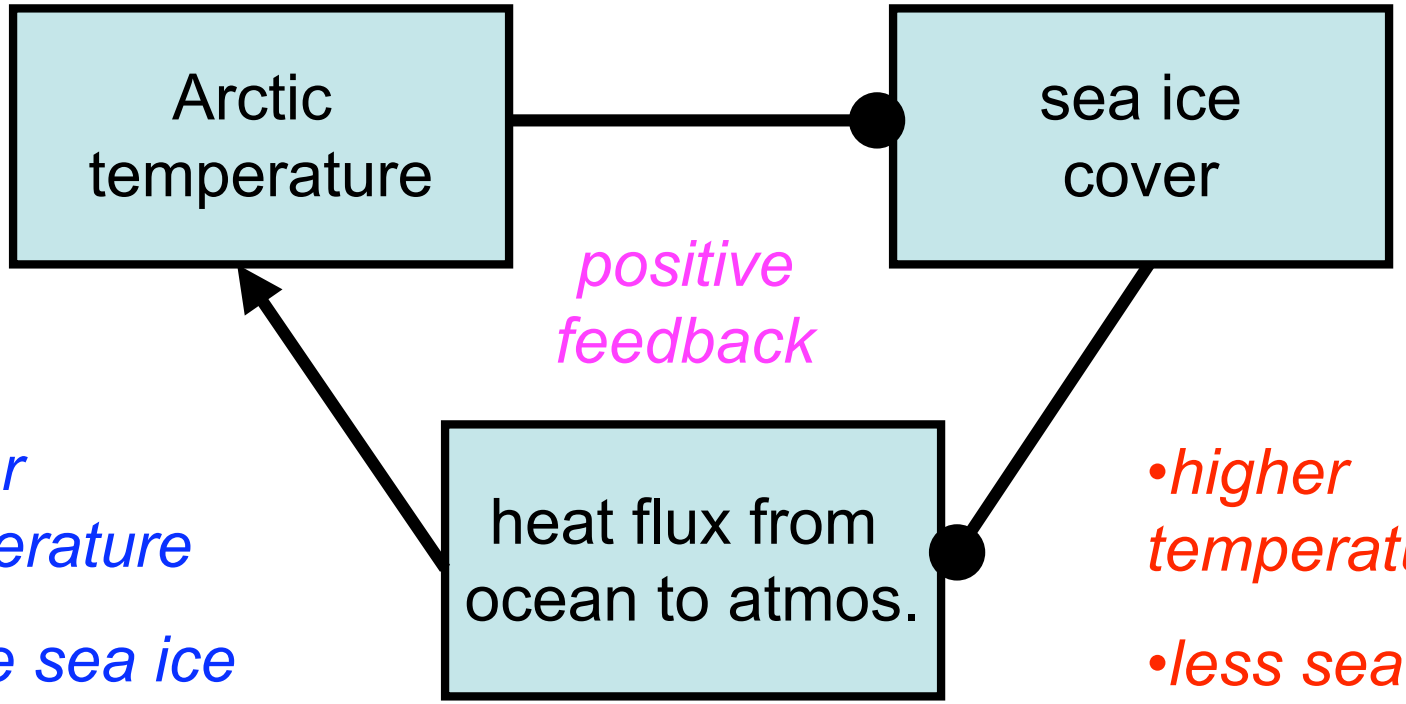
consider the Arctic in winter- which is colder the ocean or the air above?

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.....*

you could say sea-ice acts like an insulating blanket

- *higher temperature*
- *less sea ice*
- *greater O-A heat flux*
- *higher temperature.....*

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 photo-synthesis 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 - CO_2 - temperature system constitutes:

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

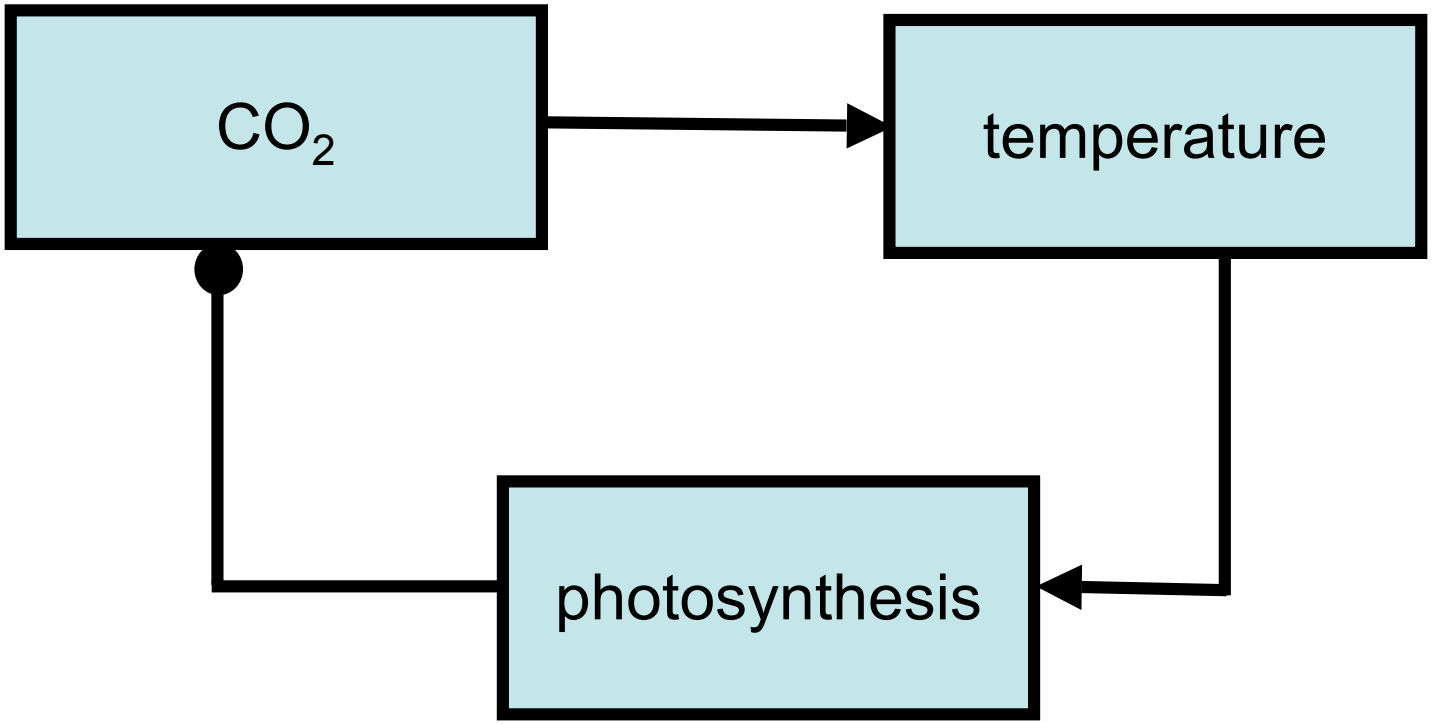
b) a *positive* feedback which would *increase* the strength of the original influence

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 the 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 - CO_2 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

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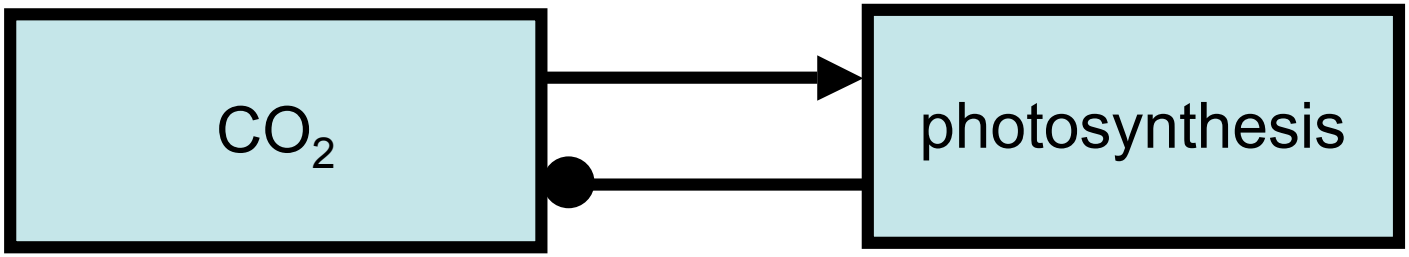
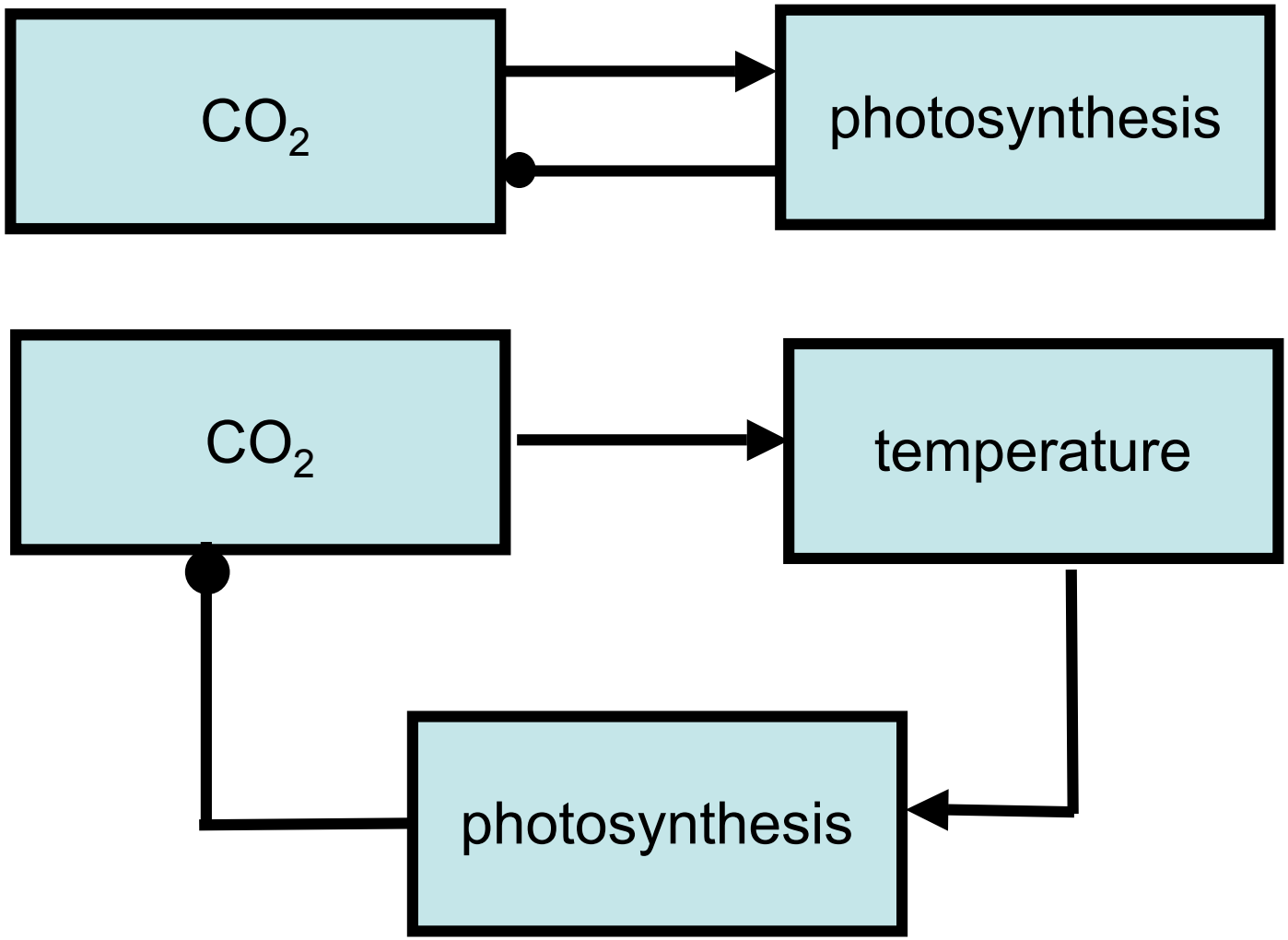
e) can't tell from the information given

plausible diagram



describe the response the of the system to an initial increase or decrease of CO_2

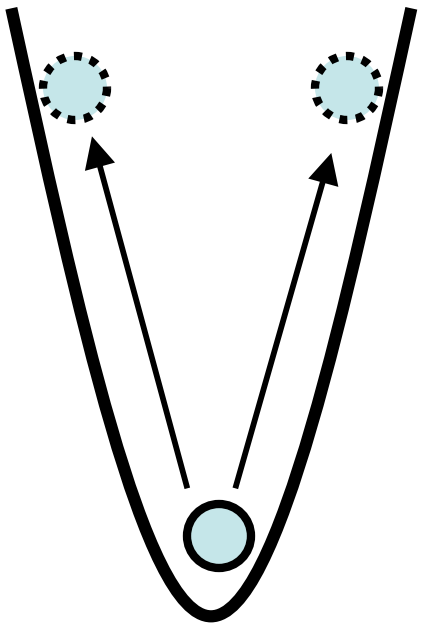
possible feedbacks involving CO_2



both of the feedbacks shown are _____ in sign

types of equilibrium

consider a ball in a valley

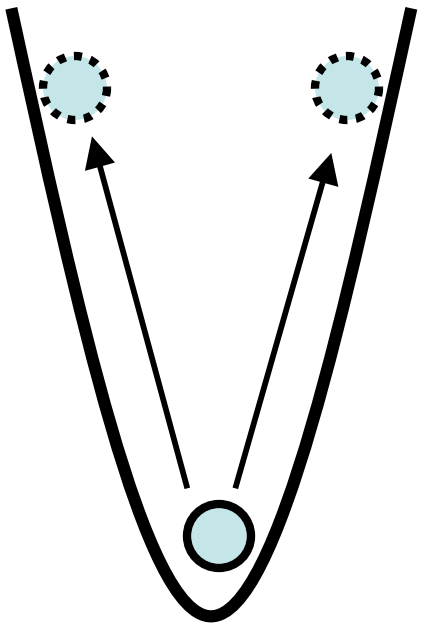


and that the ball represents the state of some variable (say temperature)

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

types of equilibrium

consider a ball in a valley

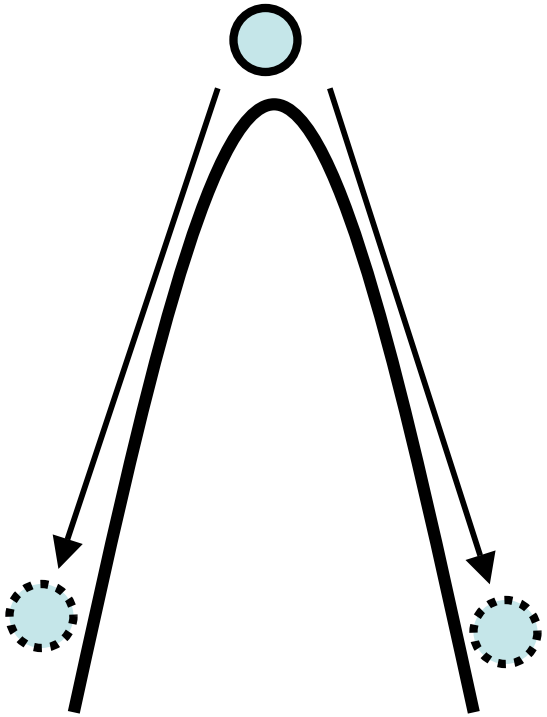


it's STABLE

(if perturbed it tends to return to equilibrium as *result of negative feedbacks*)

types of equilibrium

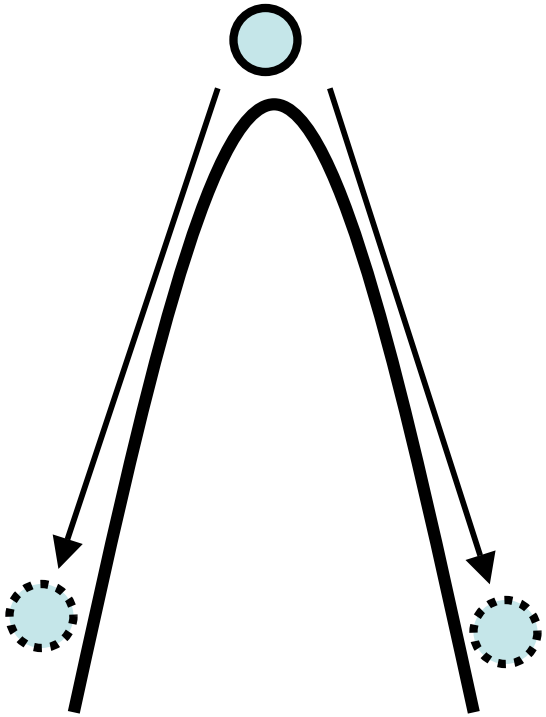
consider a ball, now……., on a peak



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

types of equilibrium

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

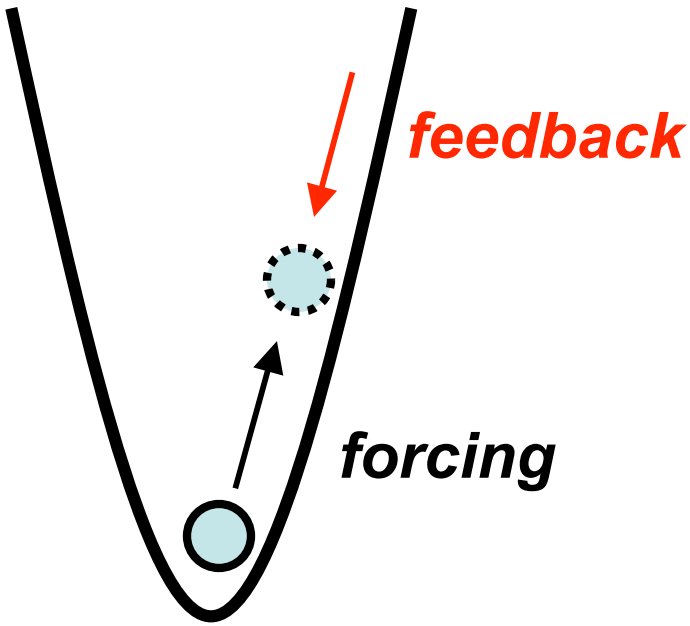


it's UNSTABLE

(if perturbed it will tend to change continuously, as *result of positive feedbacks)*

forcing

simple forcing w/ negative feedback

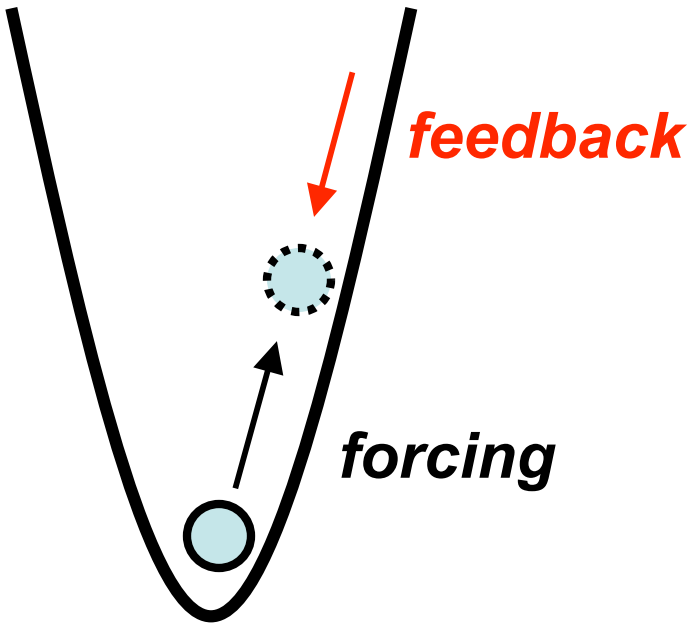


- *I always push (force) the ball up hill*
- ***What determines the height?***
- *How hard I push (i.e.* ***strength of forcing****) and how hard the ball pushes back (i.e. strength of* ***negative feedback****)*

teaching slides after Prof. D. Noone (ATOC)

forcing

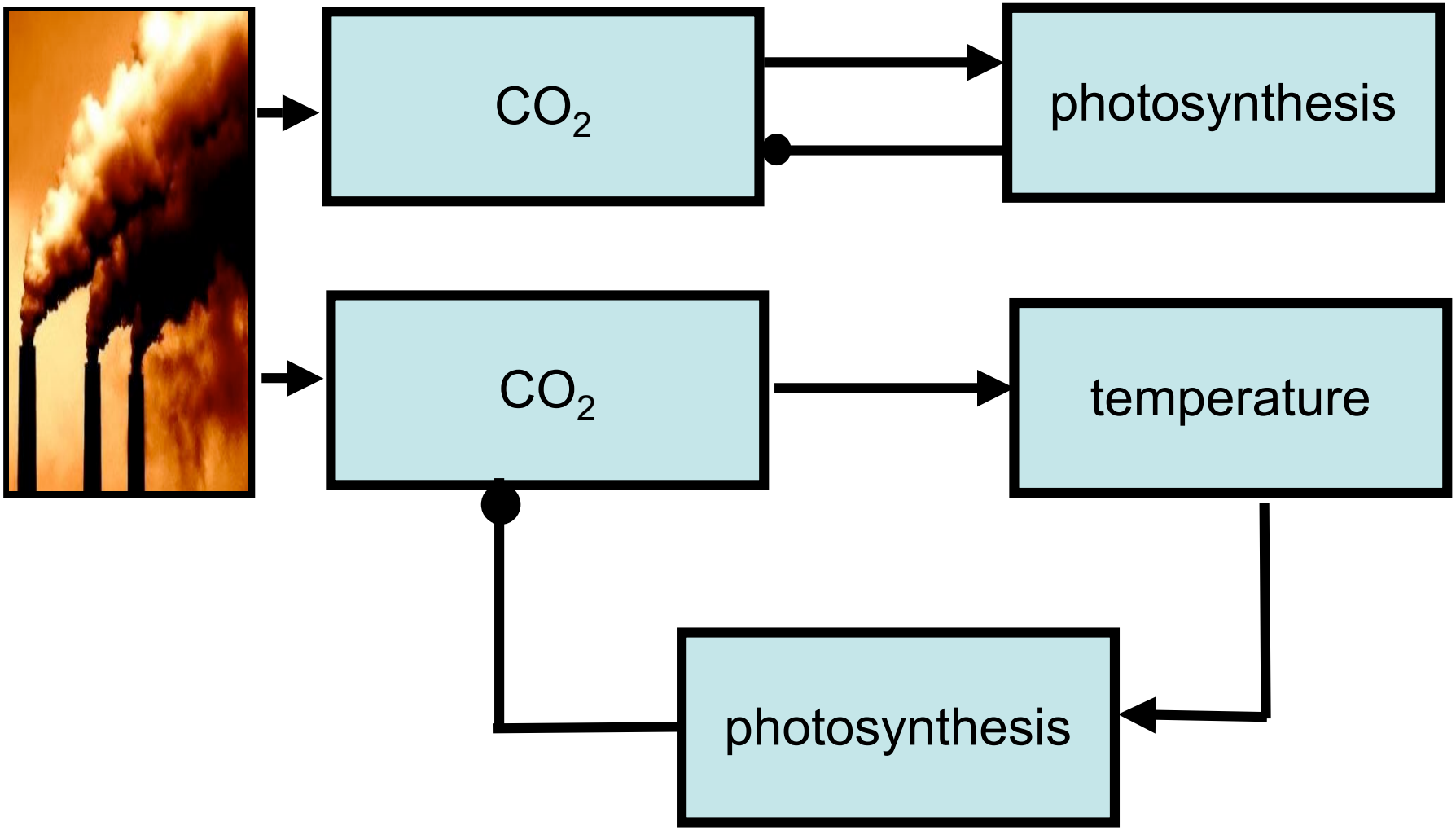
simple forcing w/ negative feedback



- *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 ……..

CO_2 system forced by fossil fuel burning



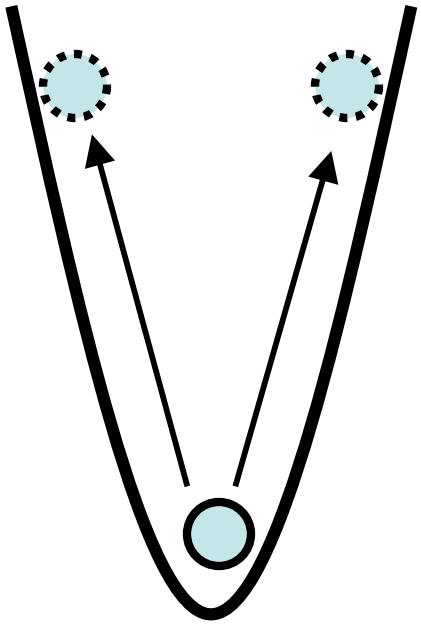
these might help restore the system

CO_2 system forced by fossil fuel burning

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

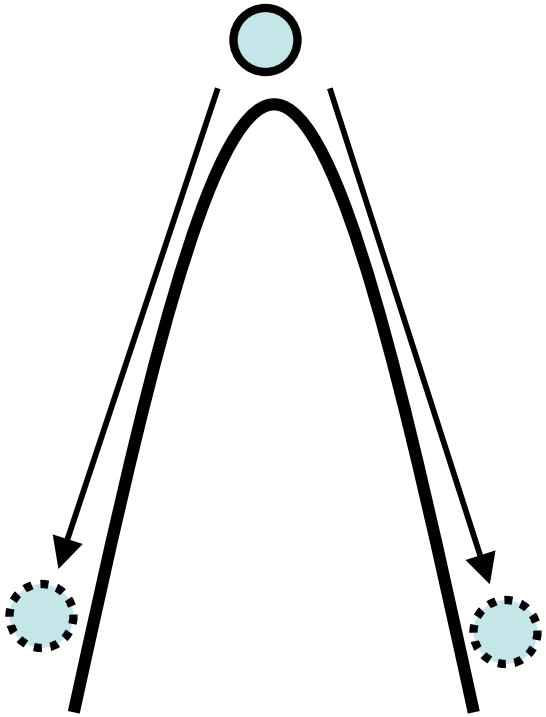
types of equilibrium

each responds differently to forcing



STABLE EQUILIBRIUM

(resistant to change as result of negative feedbacks)



UNSTABLE EQUILIBRIUM

(sensitive to change resulting from positive feedbacks)

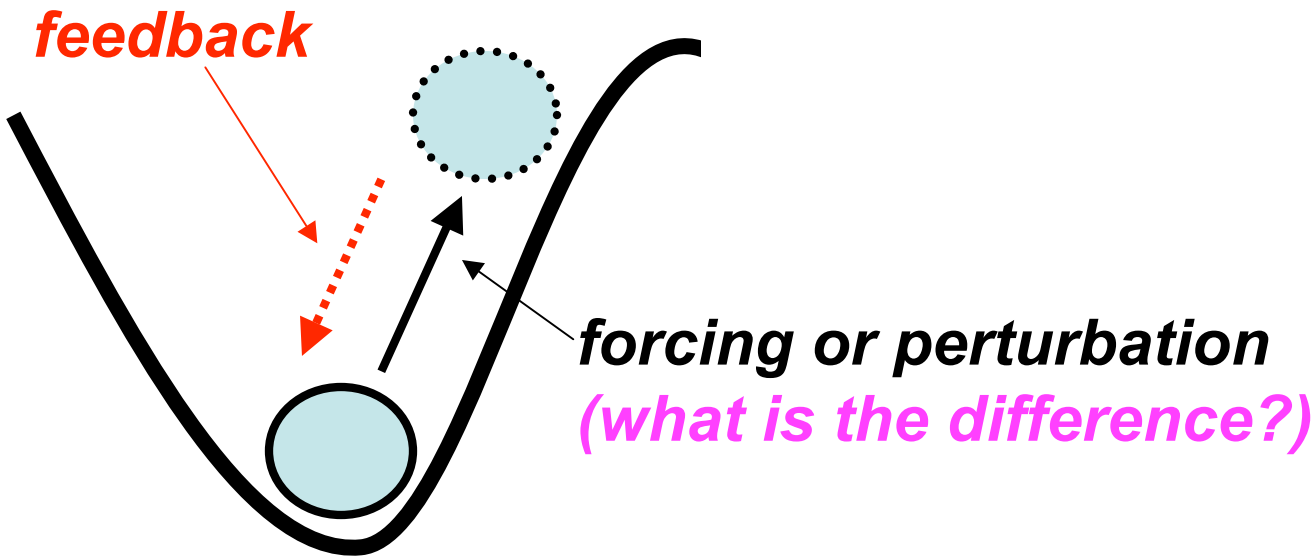
consider body temperature

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

what happens if we take a short cold swim?

stability diagram

for body temperature

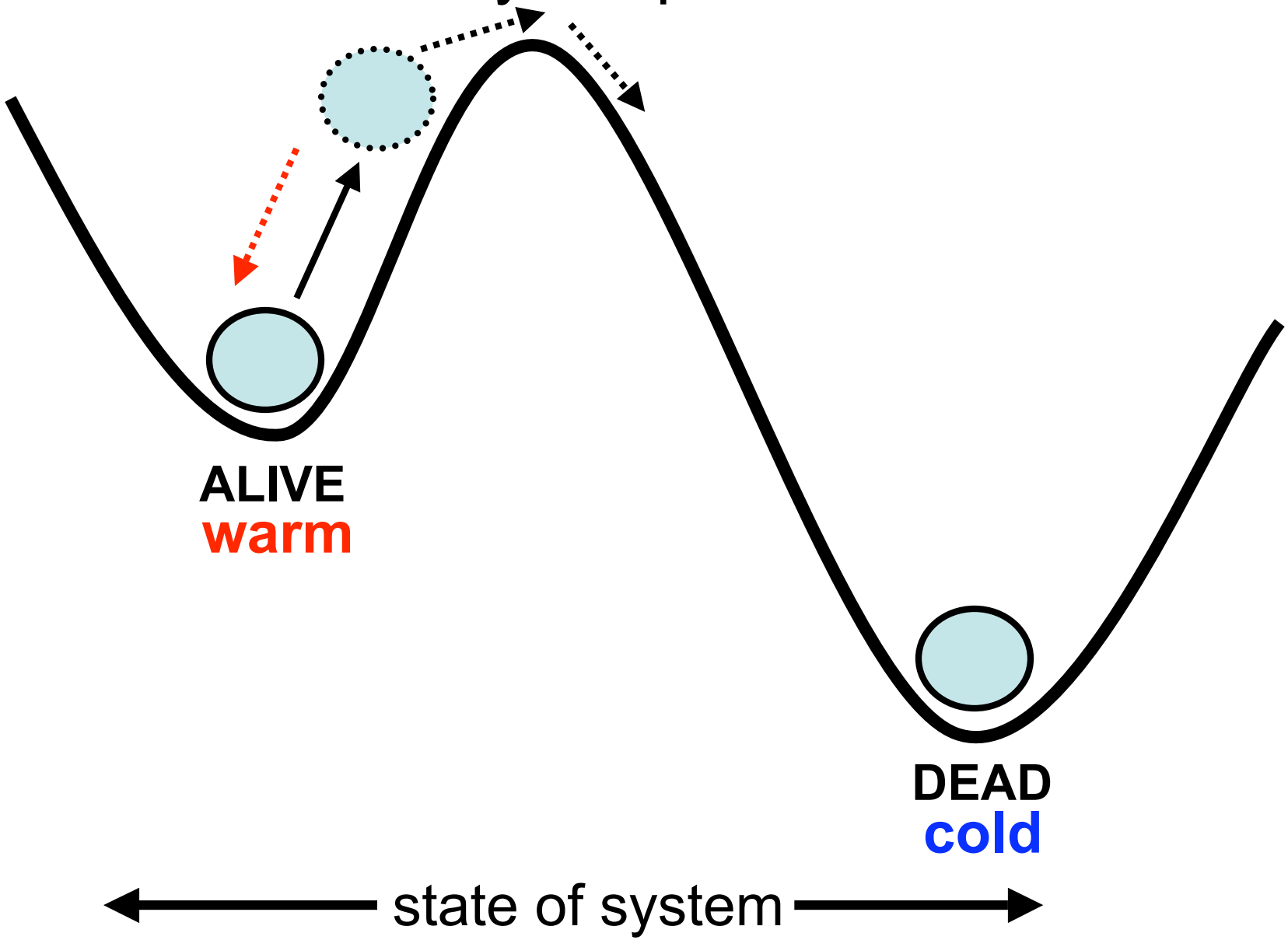


what might happen if we stay in too long (i.e. Man Overboard!)?

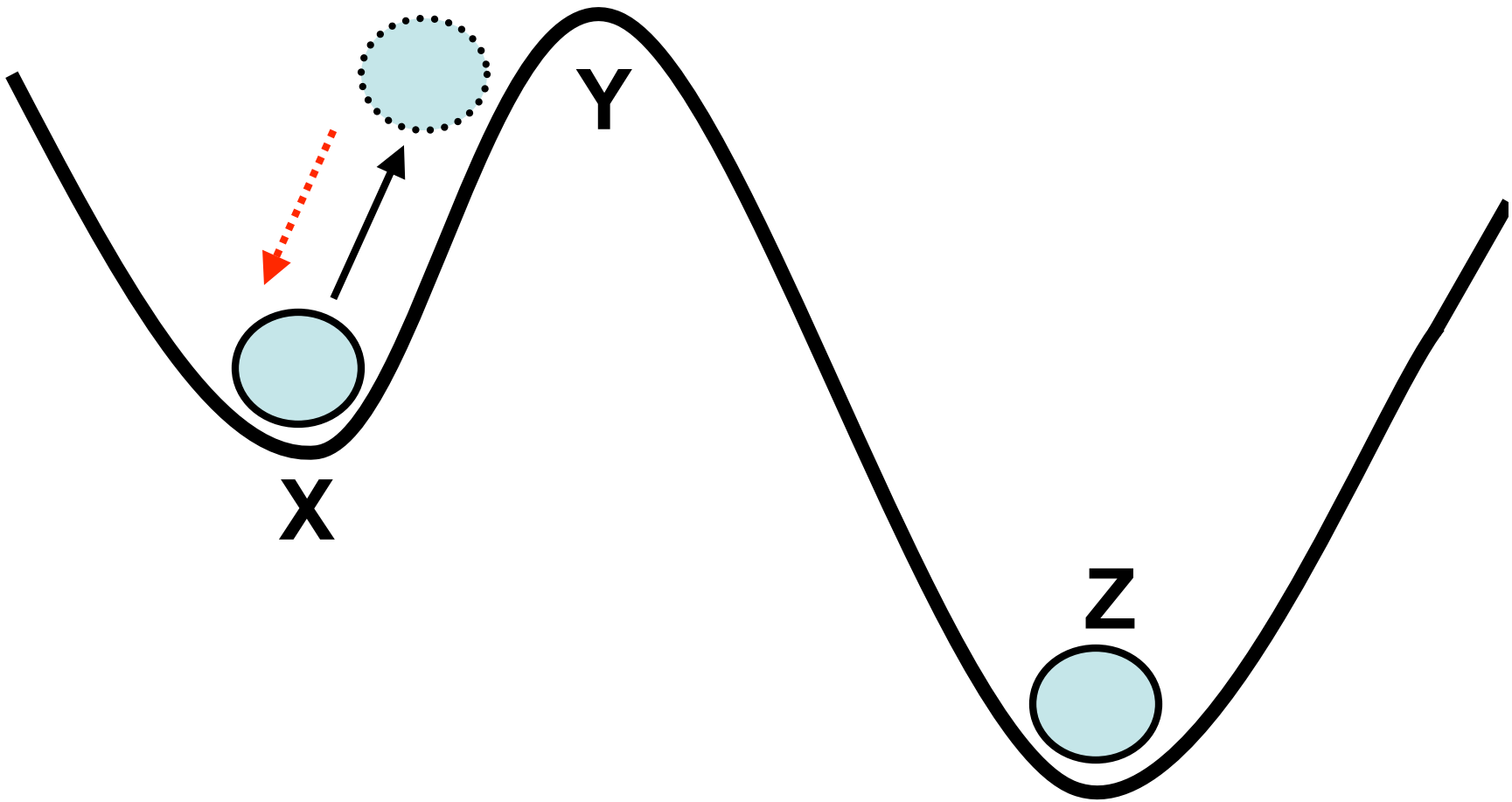
← state of system →

stability diagram

for body temperature

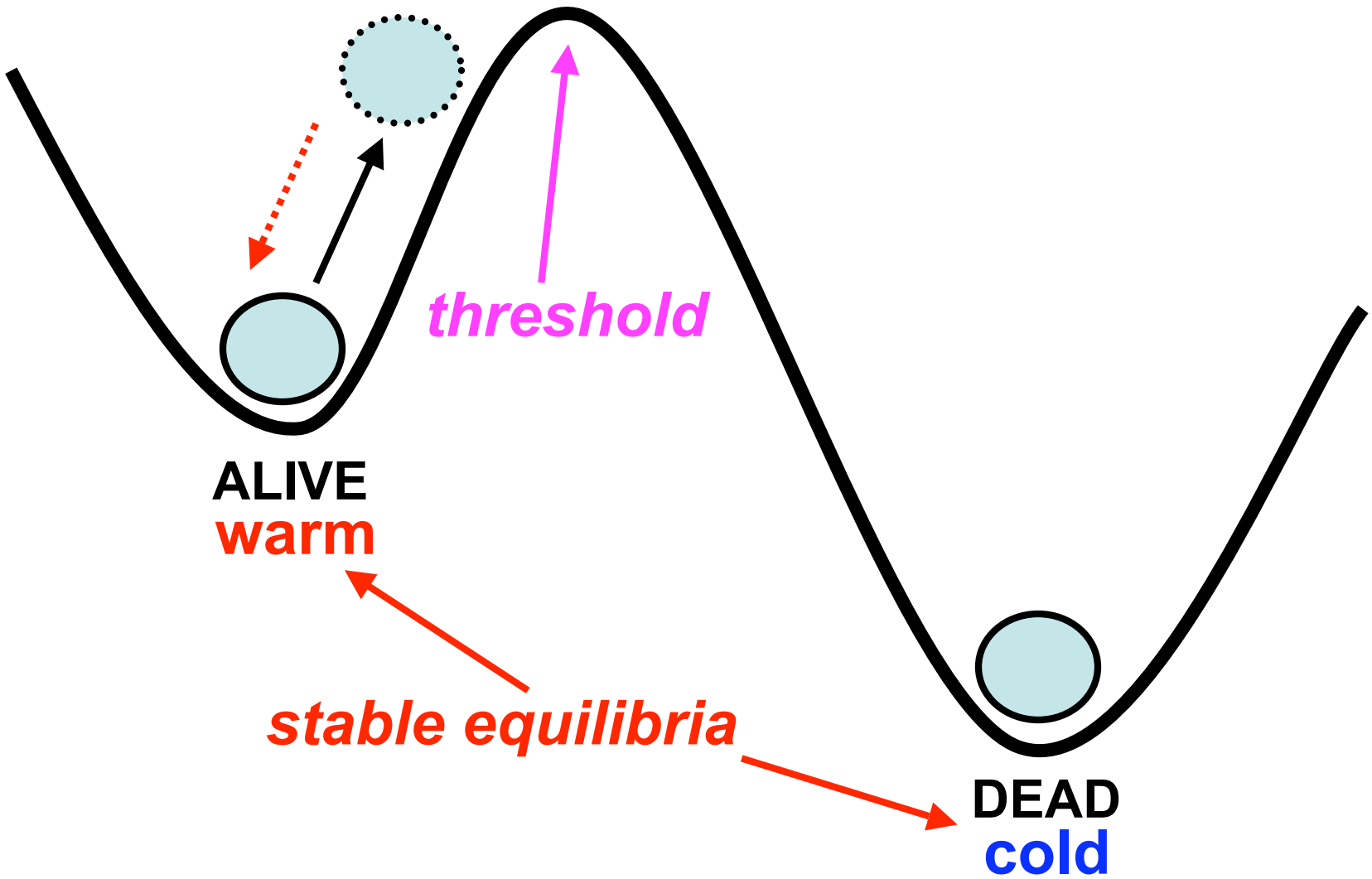


clicker question:

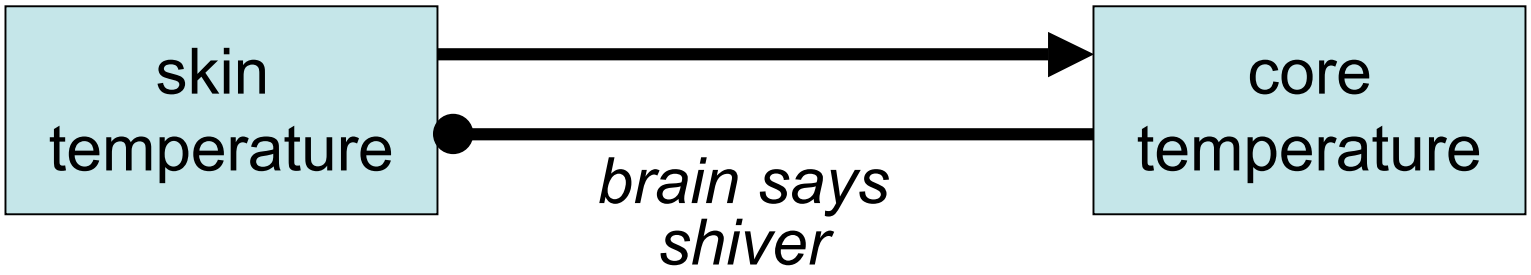


what is the relative rank of stability for positions on the diagram from most to least: ***a) X, Y, Z b) Z, Y, X <u>c) Z, X, Y</u> d) Y, X, Z e) they are all the same***

stability diagram
for body temperature



stability of body temperature to forcing



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

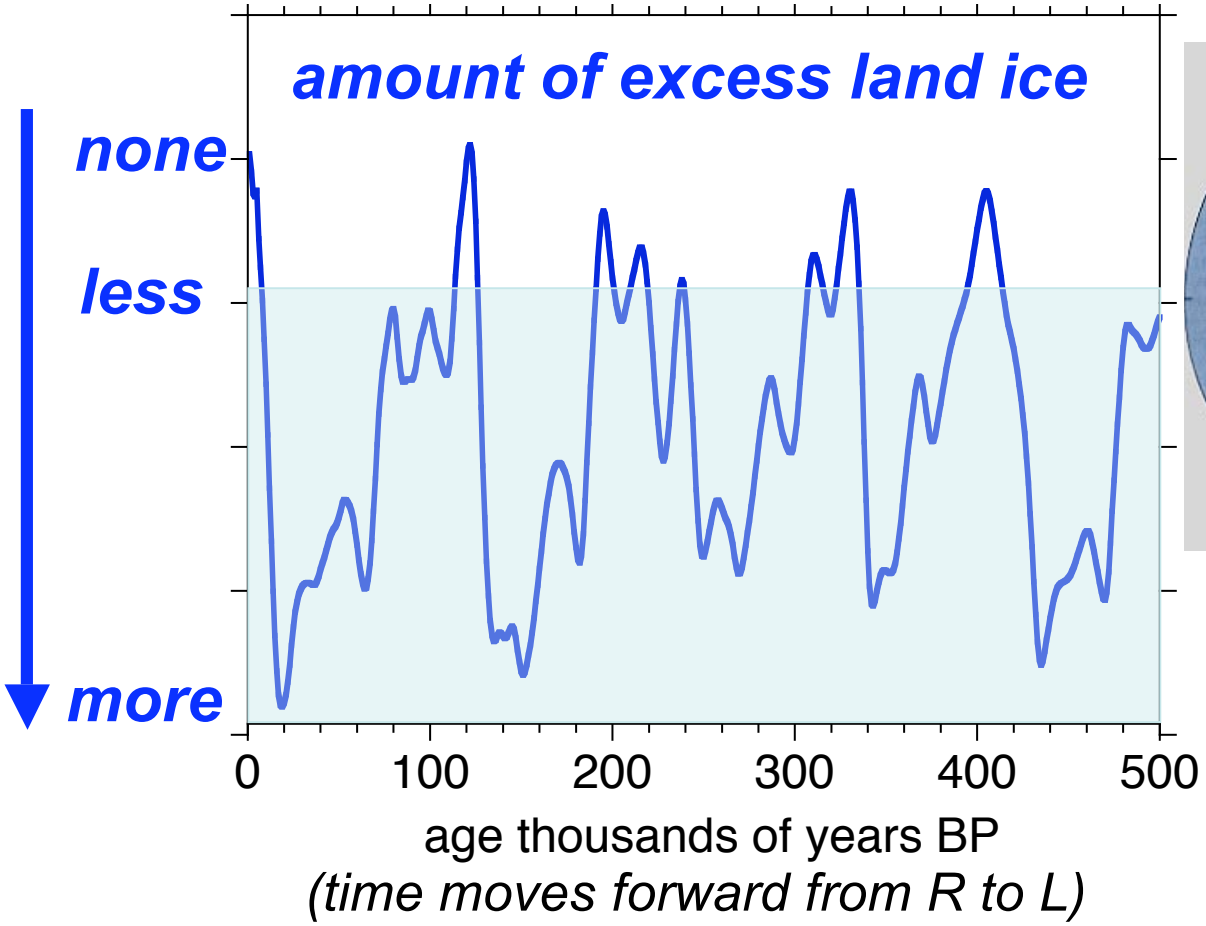
"Man Overboard!" *- big, long shock or* ***perturbation***

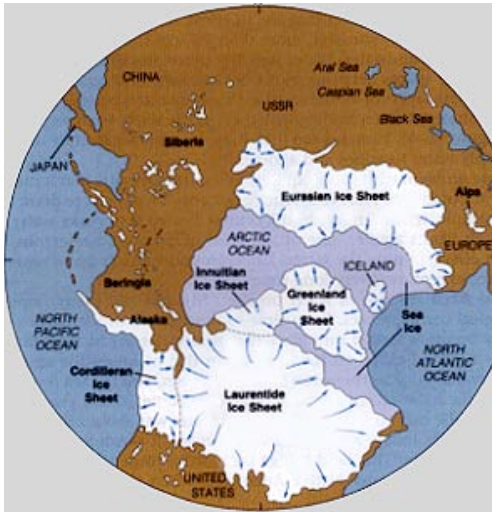
body temperature stable to small perturbations, but perhaps not to large or long ones

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

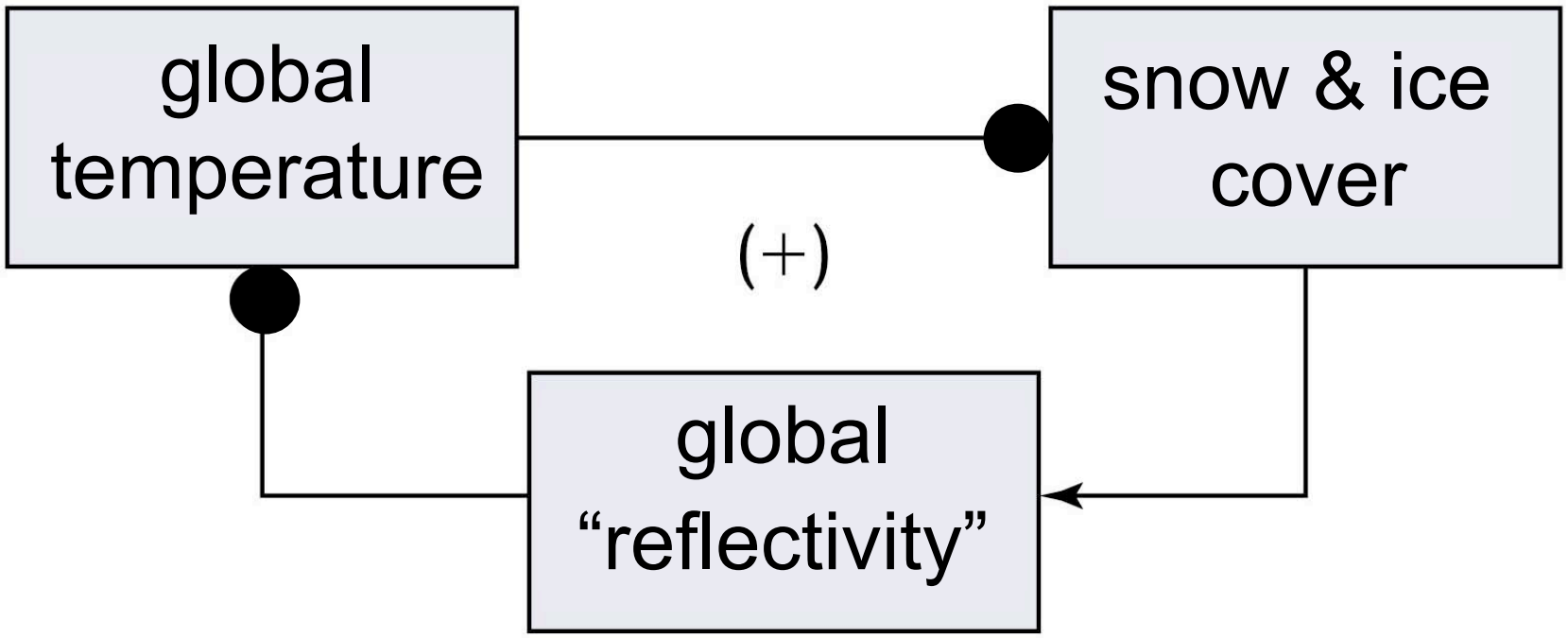




periodic changes in amount of sunlight reaching Arctic in summer influence amount of ice on land, but notice that there is excess ice more than 80% of the time

- ***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



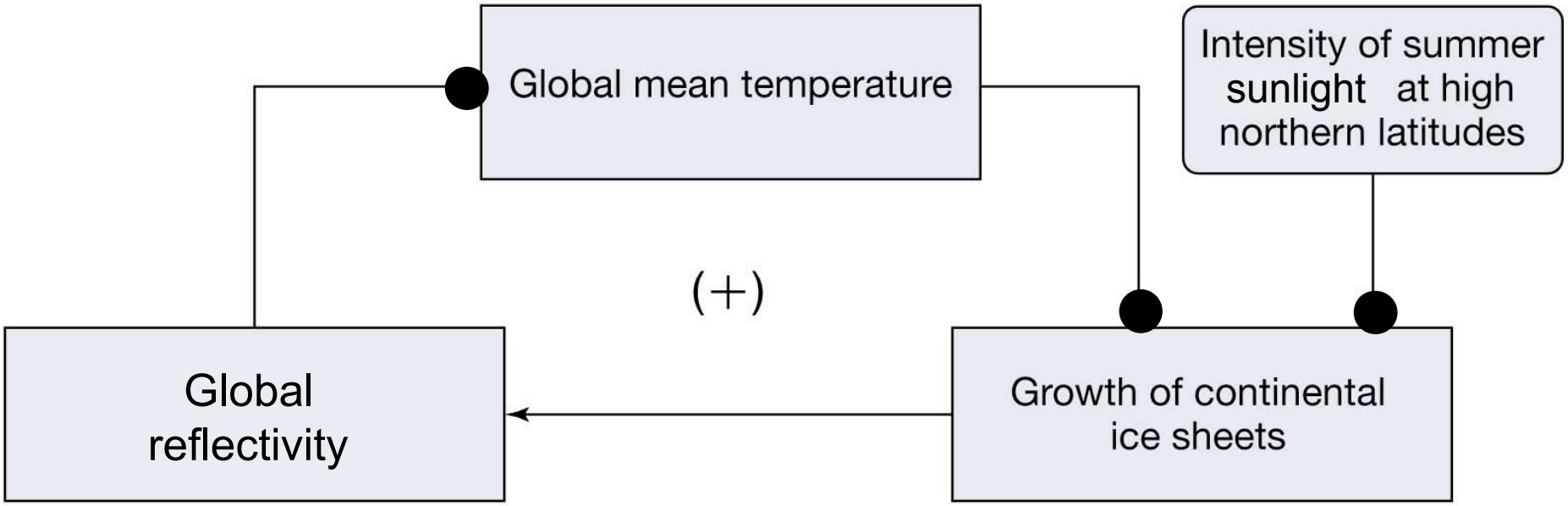
this can "jump start" an Ice Age and help to maintain excess ice on land

after: Kump et al. "The Earth System"

example: Scandinavia

inception of continental glaciation in plateau areas when conditions permitted snow to linger year ‘round

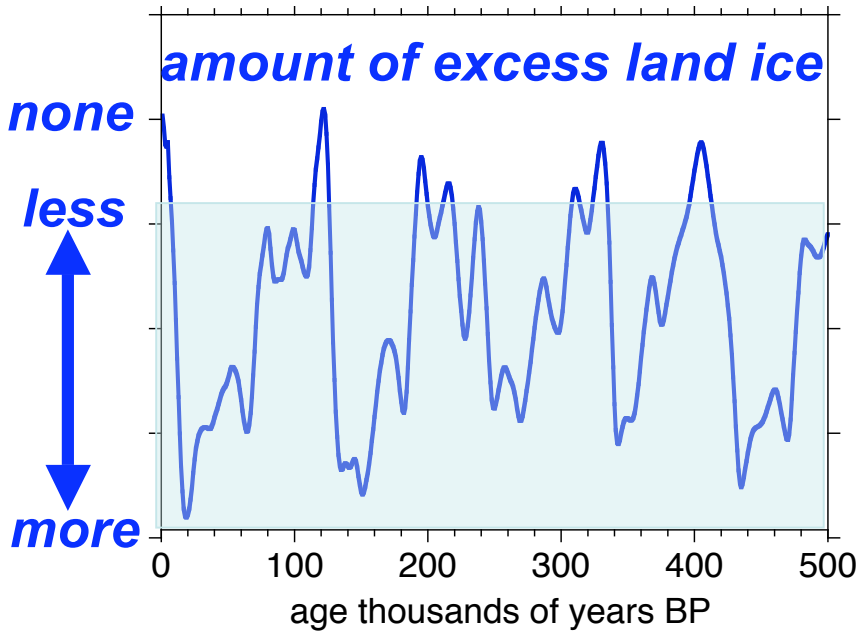
a more complete feedback diagram might look like this:

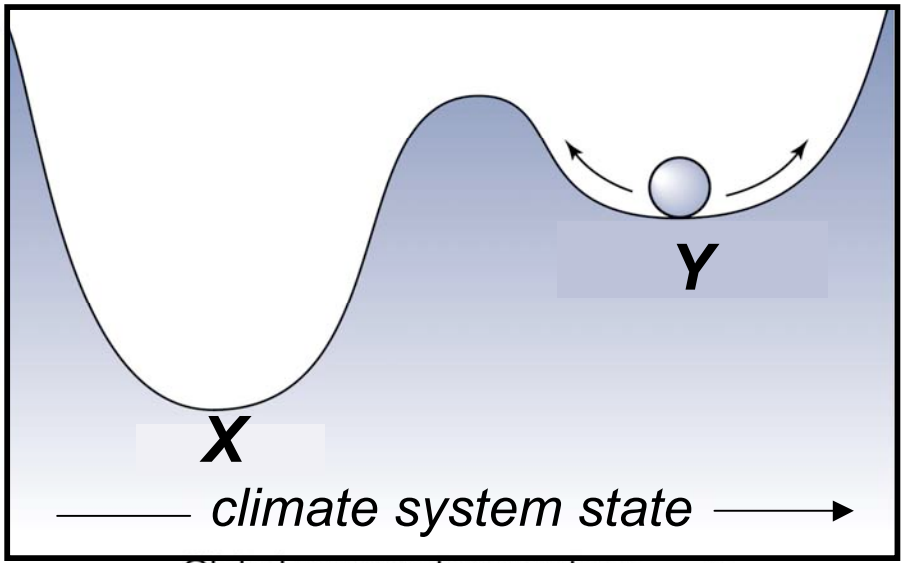


what is the "forcing" in this example?

Answer: intensity of summer sunlight

clicker question:





In the Ice Age stability diagram on the right,

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

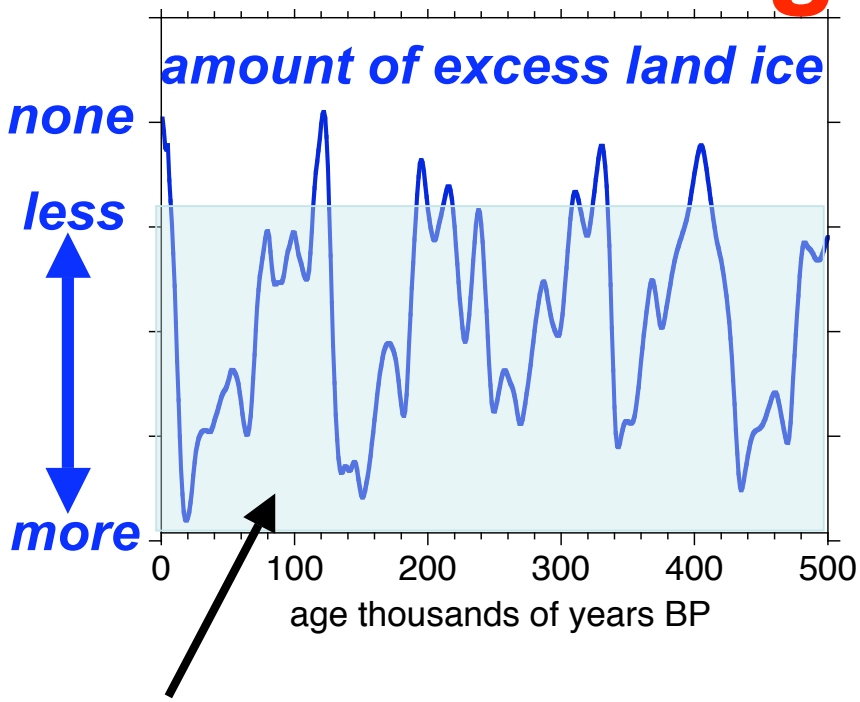
b) point Y represents the cold state with more ice,

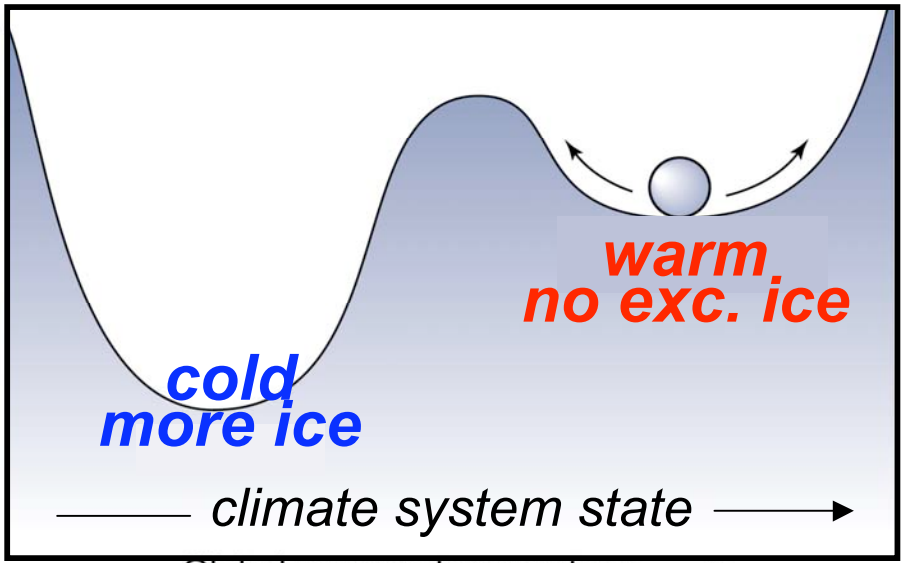
c) the curved arrows represent forcing such as Arctic sunlight

<u>d) both a) and c) are correct</u>

e) both b) and c) are correct

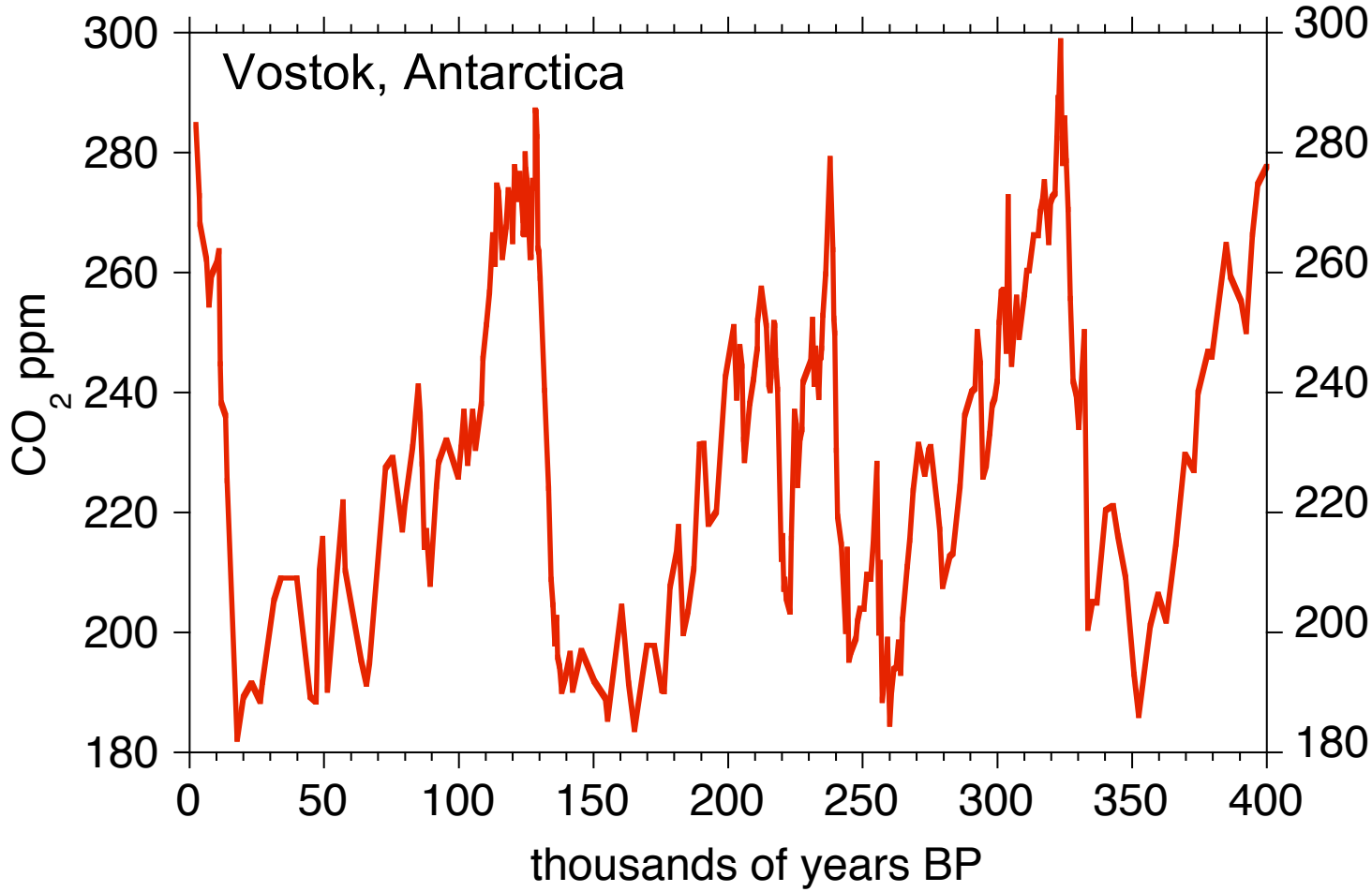
Ice Age example





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)……

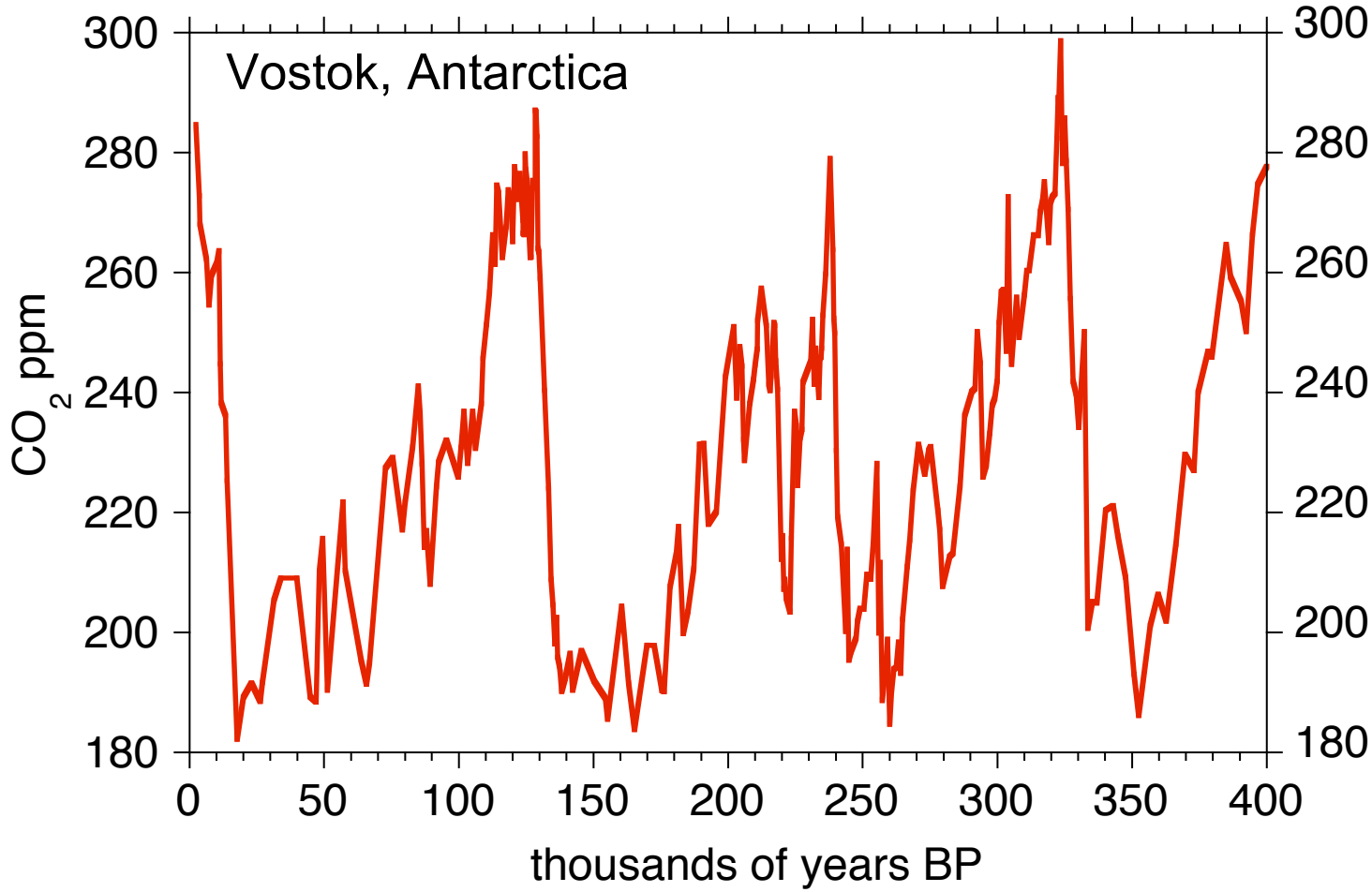
natural CO_2 variations



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

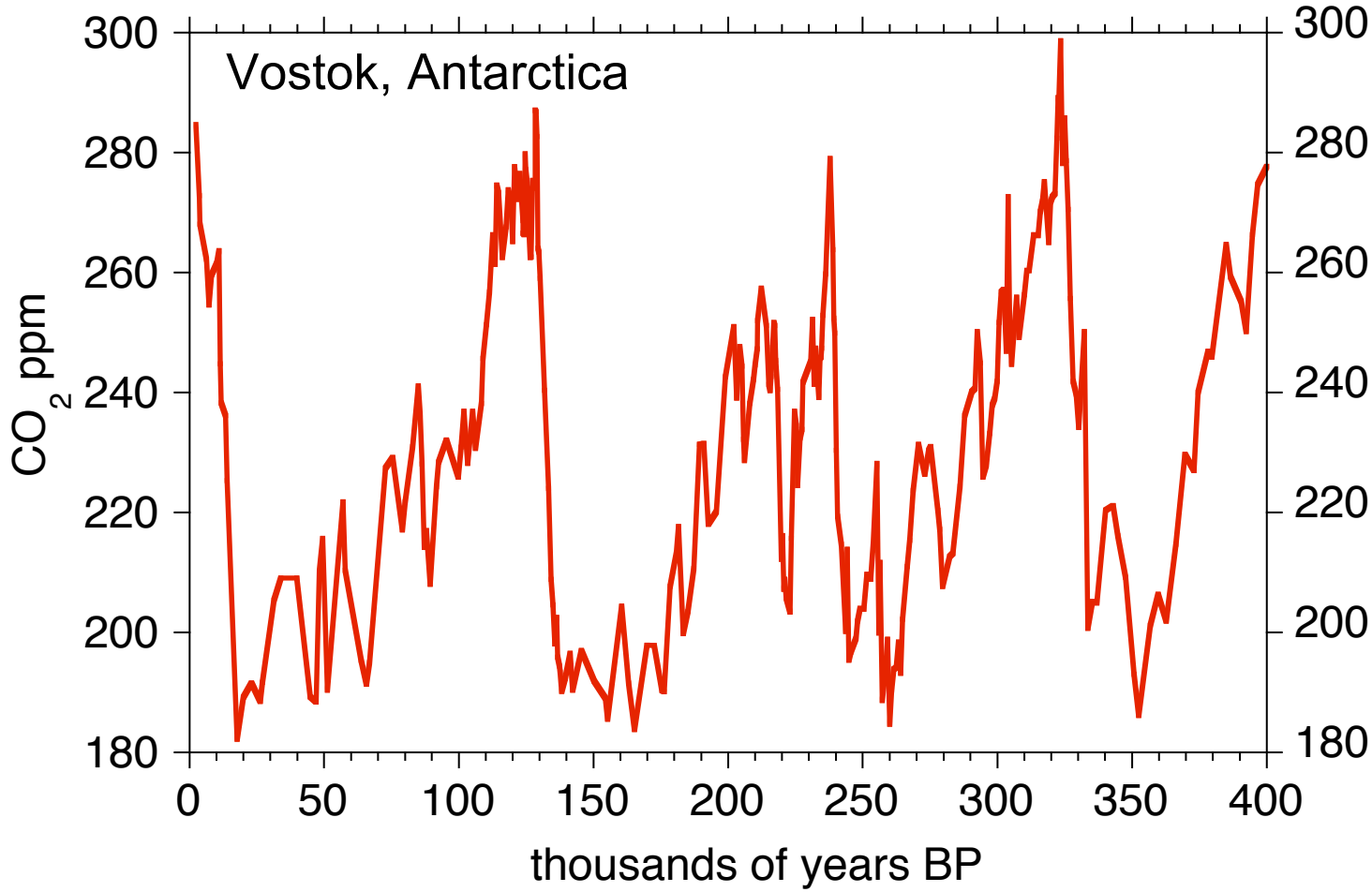
clicker question:



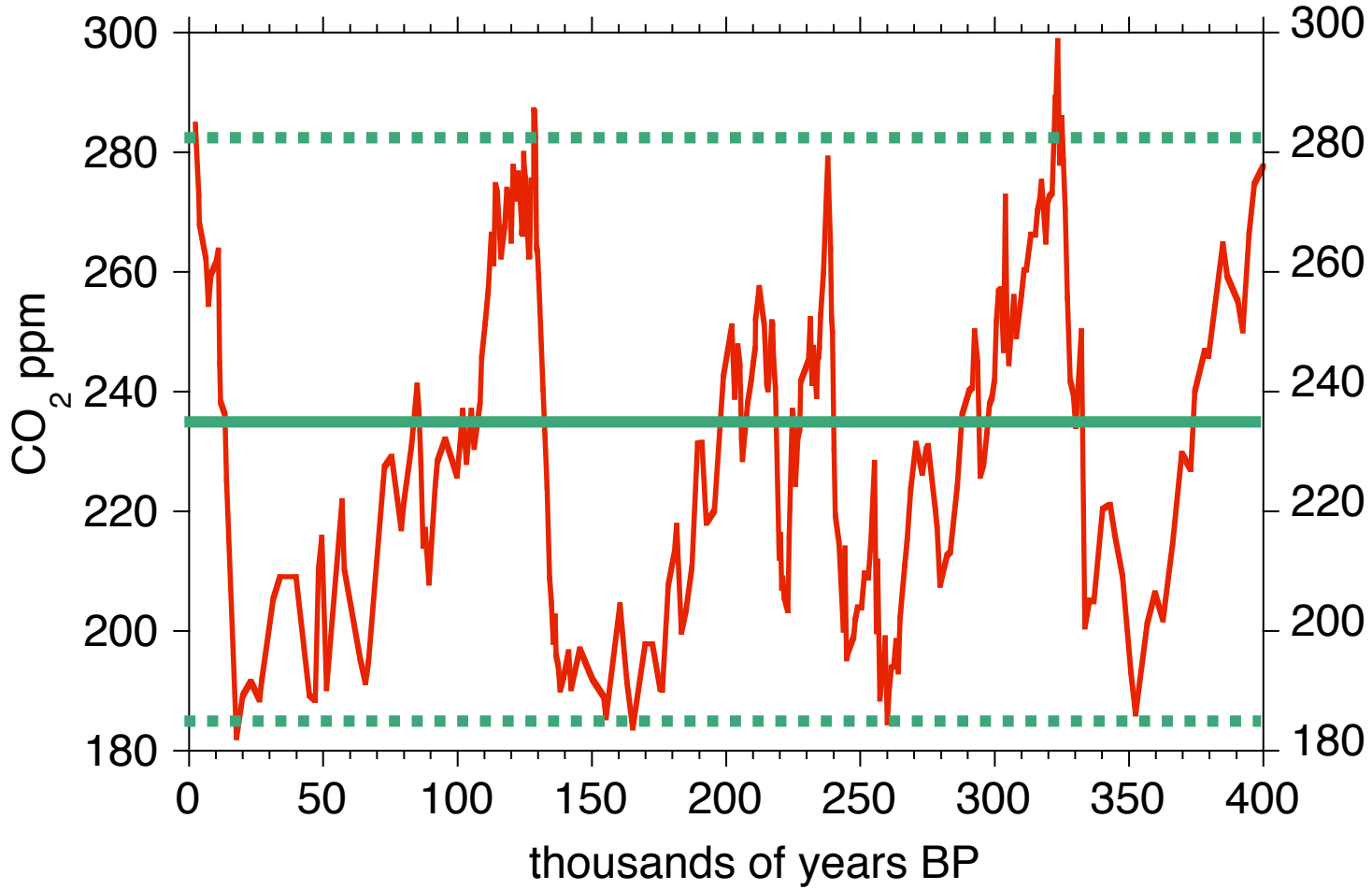
Is the dominant feedback in this system:

a) positive, *b*) negative, *c*) stabilizing, <u>*d*) both *b* & *c*</u>,
e) there is no feedback

discussion:

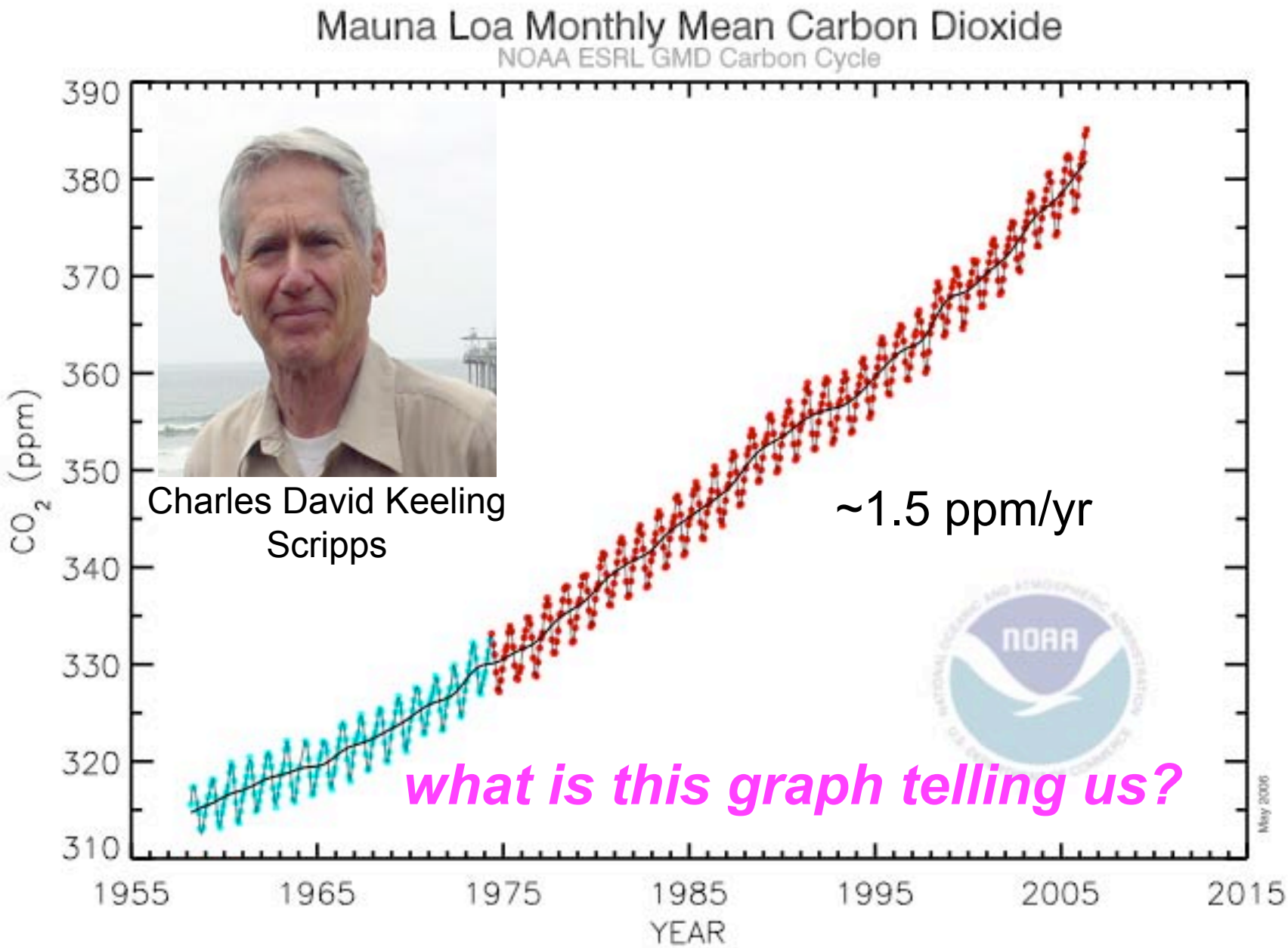


does the system ever get too far out of whack?

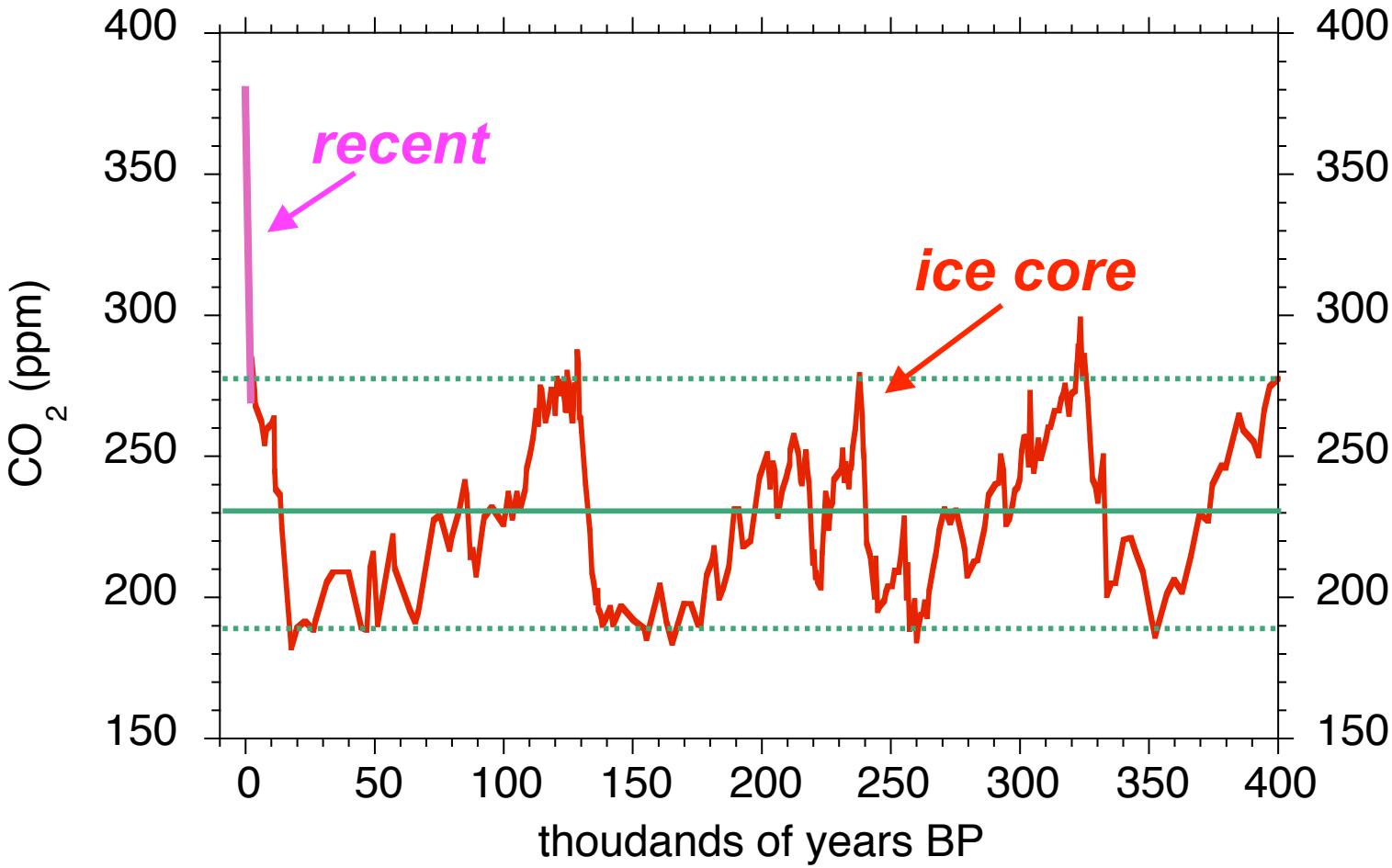


does the system have bounds?
a middle?

recent CO_2 variations



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).

Thanks to Jennifer Stempien, SEI Scholar