Mon Oct 13

Announcements:

- HW 1 in; HW 2 out (due: Thurs Oct 23)

This week:

- Chap 2 and the science of systems

Today:

- System basics
- Earth surface temperature as an indicator of climate change
- System diagrams: couplings, feedback loops

upcoming talks

MONDAY 13 October:

12:30 ATG 310c

Dr. Roy Darwin, Economist, U.S. Department of Agriculture
"Simulating Global Climate Change in Economic Models"

3:30 ATG 310c

Dr. Kunihiko Kodera, Meteorological Research Institute, Japan
"AO/NAO, ENSO, and their relationship with solar activity"

TUESDAY 14 October

12:30 ATG 310c, Weather discussion

FRIDAY 17 October:

12:30 ATG 310c

Dr. Kevin E. Trenberth
NCAR Climate & Global Dynamics Division
"Problems with climate observations; need for an Earth Information System"

but first...

What is it that every child spends much time making, yet no one can ever see when it is made?

noise

I have cities with no houses, forests without trees, rivers without water. What am I?

A map

System essentials - 1

system: “*an entity composed of diverse but interrelated parts that function as a complex whole*” *(p. 20)*

examples: human body, nation, ecosystem, planet, computer, internet, car, traffic

Characteristics of systems:

- multiple components
- components are somehow coupled to each other
- ***energy and/or matter flows through***

System essentials - 2

Critical to understanding almost any system is to understand how it handles (or processes) the energy and/or matter flowing through it.

at equilibrium

$$F_{IN} = F_{OUT}$$

where F = flow or flux

examples:

planet/temperature (F is flow of energy)
body/weight (F is flow of food and water)

Earth as a coupled system

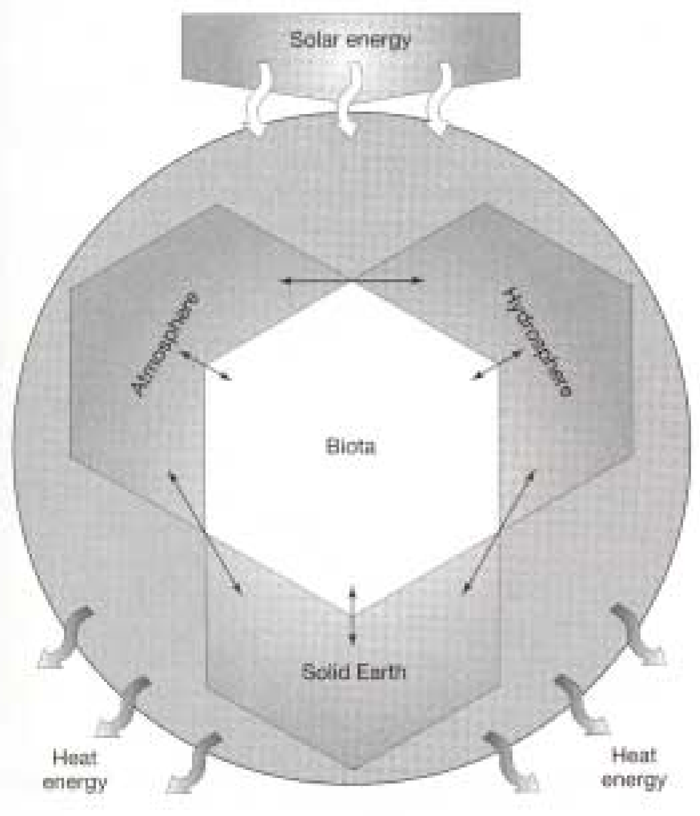


FIGURE 1-1

Schematic diagram of the Earth system, showing interactions among its four components. (From R.W. Christopherson, *Geosystems: An Introduction to Physical Geography*, 3/e, 1997. Reprinted by permission of Prentice Hall, Upper Saddle River, N.J.)

System essentials - 3

component: *any individual part of a system that can be conceptually separated and described in terms of its state, its behavior, and its influence on other components*

note: quite arbitrary; choice based on what makes sense – what helps us diagnose and understand the system

examples for a planet: atmosphere, surface, biosphere

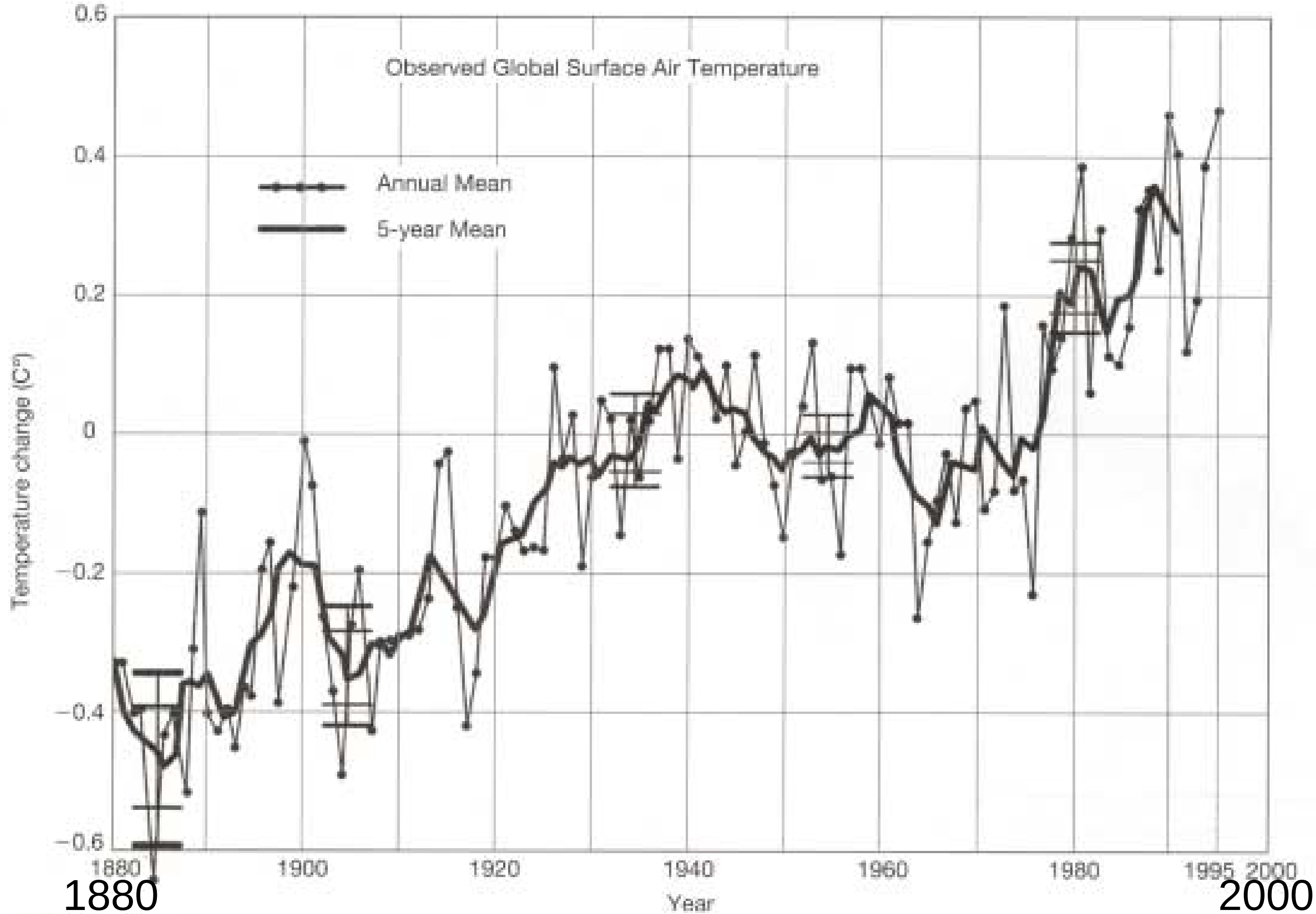
State of a system: *"the set of important attributes that characterize the system at a particular time" (p. 20)*

note: we can also speak of the state of a component

examples: atmosphere: CO_2 content
surface: temperature
biosphere: number of daisies

GAAST -1

Observed changes in the Earth's surface temperature over the past 120 years



GAAST - in class activity -1

The main evidence that global warming is really happening is that the earth's surface temperature has increased over the past century. Exactly what is meant by the phrase "the earth's surface temperature"? That is, how is this quantity defined and how is it measured?

<u>Key point:</u> global-average and annual-average

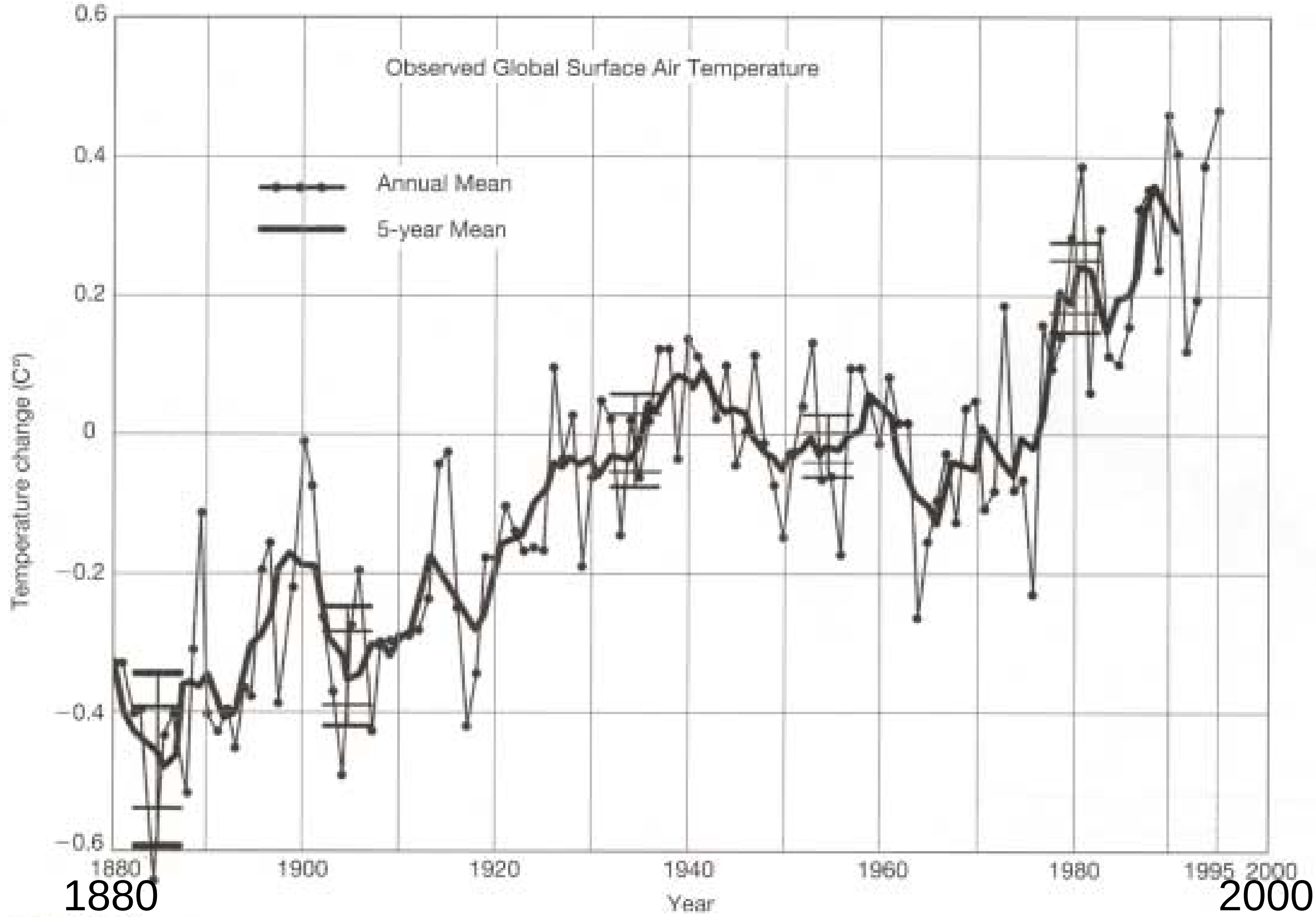
Why is this quantity used as an indicator of climate change? (scientific reasons, practical reasons)

<u>Key points:</u>

- indicates a property of the entire planet (e.g. responds to planetary energy balance)
- living things are very sensitive to temperature
- people and most life is at the surface
- determined very accurately because random errors cancel out with millions of measurements

GAAST -2

Global- annual-average surface temperature (GAAST)
observed changes over the past 120 years



GAAST - in class activity -2

Average surface temperature is the best SINGLE indicator we have of the state of the Earth's climate. But the earth's "climate" is much much more than the average surface temperature!

Describe two ways that the "climate" could change WITHOUT changing the global-annual-average surface temperature.

- northern hemisphere cools; southern hemisphere warms
- nighttime gets warmer; daytime gets cooler
- changes in precipitation, wind (hurricanes), sea level, etc.

Name three types of businesses/industries that could be affected by climate change. How would each be affected? How might each be able to use climate change predictions (if accurate predictions were available)?

Tues Oct 14

Announcements:

- Darwin talk? Kodera talk?
- Reports (due 31 Oct); Mann article shows format
- GAAST: Recent warming in 1000-year perspective
- read Chap 2 !!!

Today:

- System diagrams, feedback loops
- Jimmy Carter's wild and crazy bedroom
- simple Daisyworld
- graded in-class activity

Wed:

- Daisyworld, albedo, planetary energy balance

Thurs:

- Radiation intro

What did the receptionist say at the incontinence clinic?

Can you hold?

upcoming talks

TUESDAY 14 October

12:30 ATG 310c, Weather discussion

2:30 A-118 Phys./Astronomy Aud. (PAA)
Dr. James F Kasting
Penn State
"Methane Greenhouses on Early Earth"

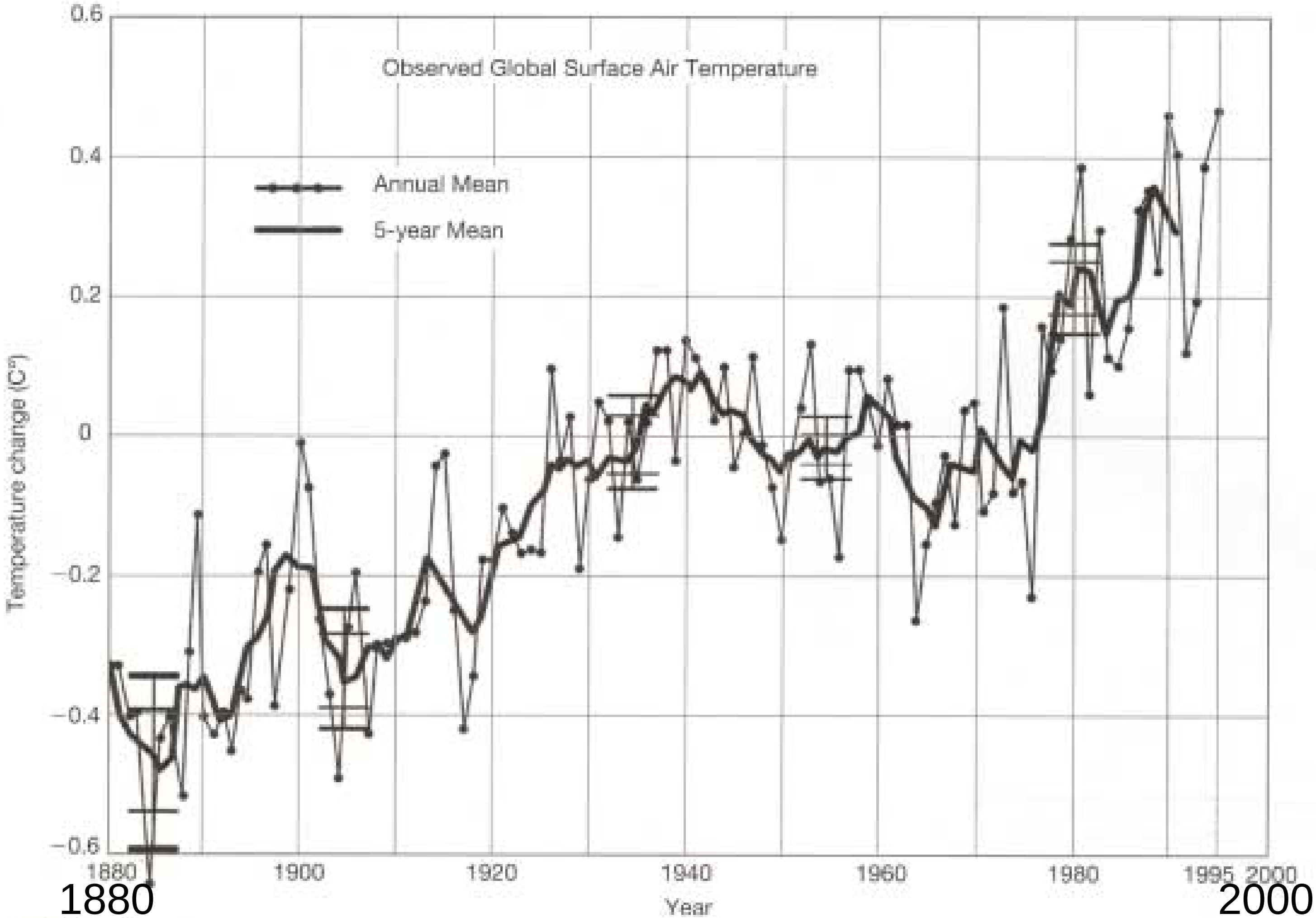
FRIDAY 17 October:

12:30 ATG 310c
Dr. Kevin E. Trenberth
NCAR Climate & Global Dynamics Division
"Problems with climate observations; need for an Earth Information System"

3:30 ATG 64 JHN
Dr. Steve Warren
UW Atmos Sci Dept
"Trends in cloud cover and type over land"

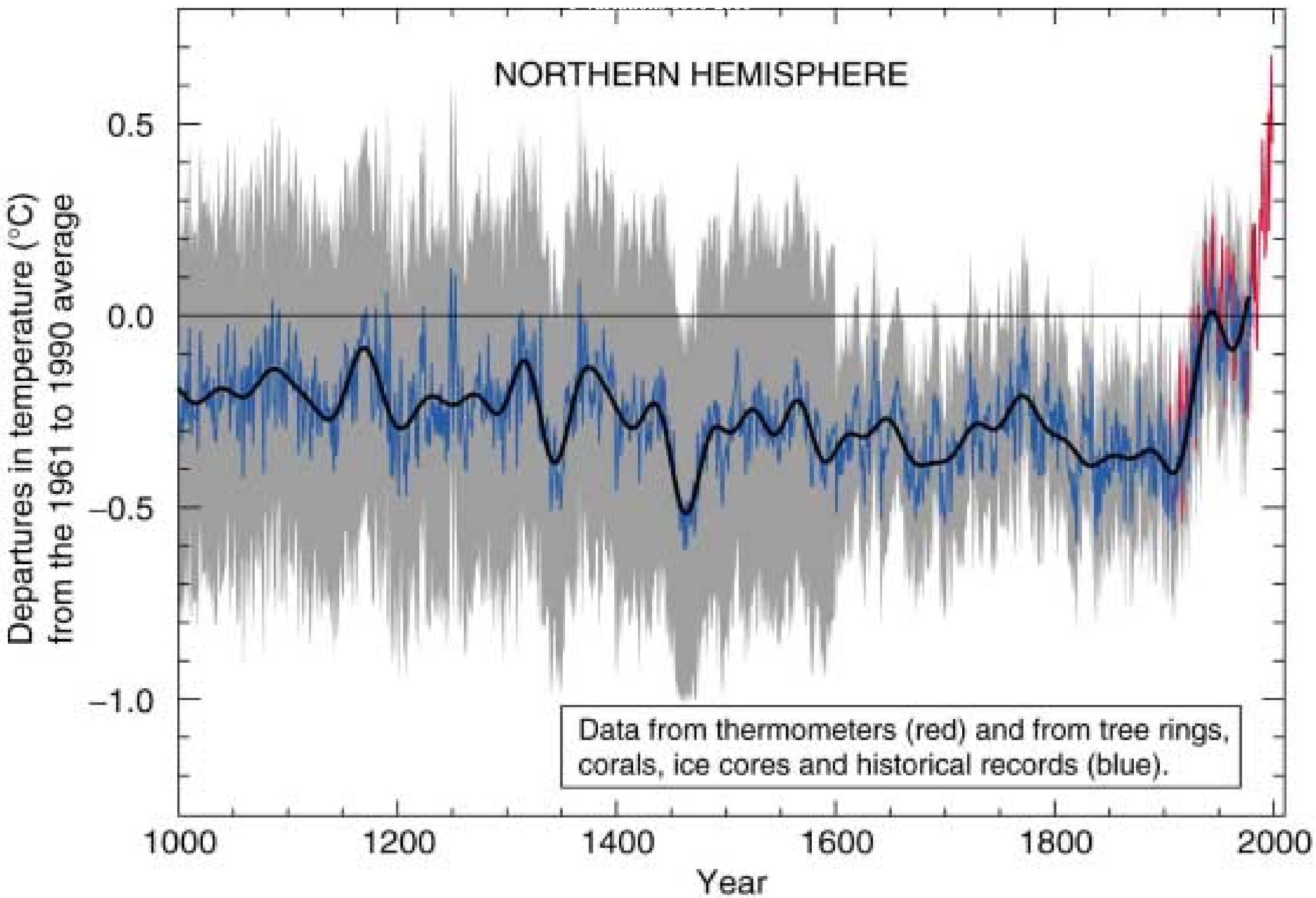
Change in GAAST

Natural or Anthropogenic?
How would we know?



1880 2000

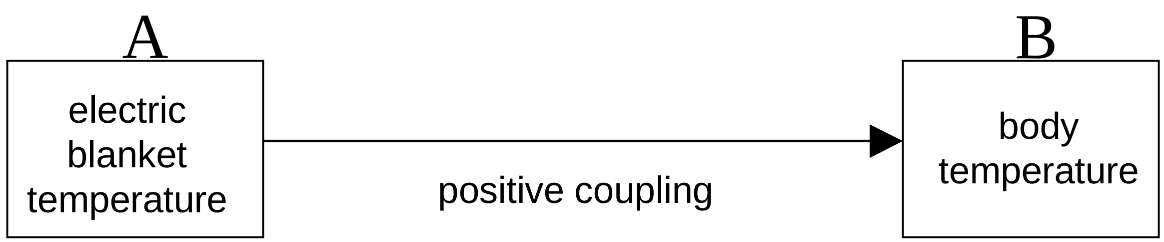
Variations of the Earth's surface temperature for the past 1,000 years



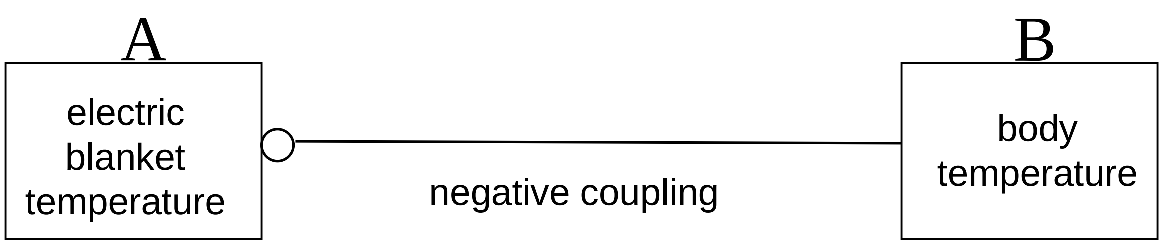
System Essentials - 4

<u>coupling:</u> *how one component affects another – how the state or behavior of one component influences the state or behavior of another component*

example: ocean temperature > evaporation > coastal rainfall



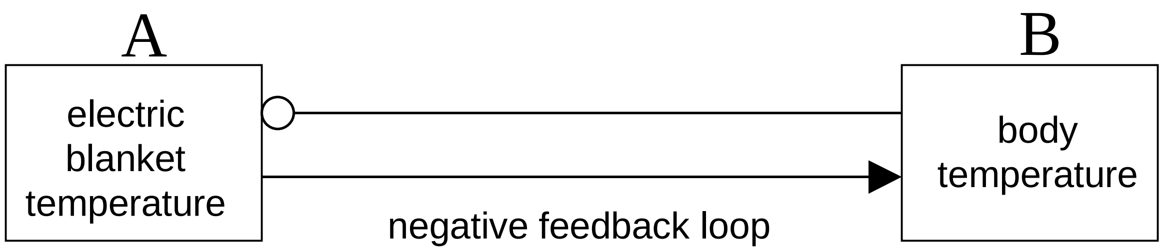
Positive coupling:
if A goes up this causes B to go up



Negative coupling:
if B goes up this causes A to go down

System Diagram - 1

<u>System diagram:</u> *"allows us to keep track of the various couplings within a system" (p. 20)*



Negative feedback loop >>> STABLE

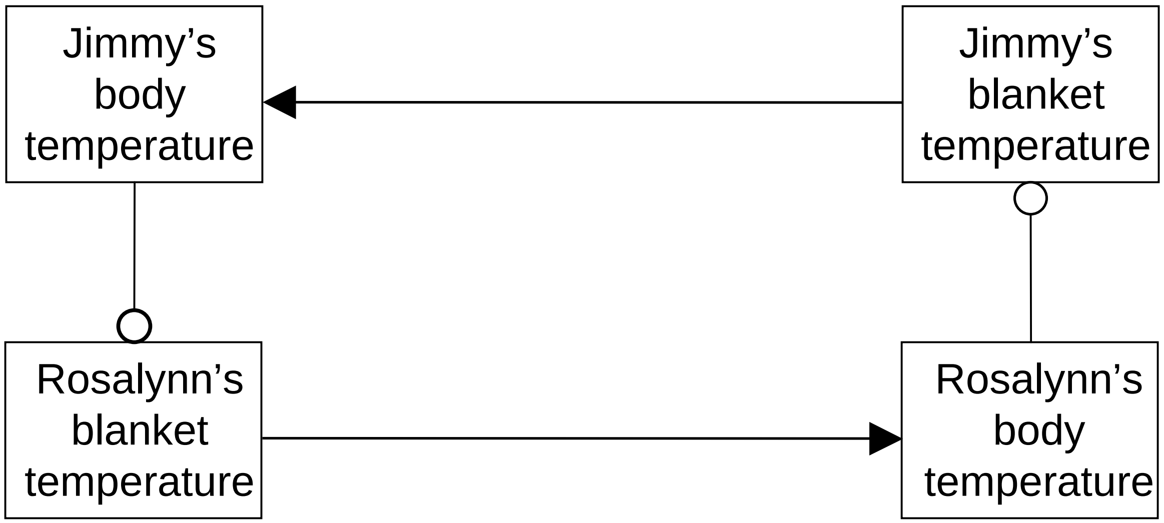
Stable: tends to return to equilibrium when perturbed

Equilibrium: steady state; temperatures are "just right"

System Diagram -2

Feedback loop:

- count up the number of negative couplings
- odd means "negative"
- even or zero means "positive"



Text figure 2-2

A wild and crazy bedroom

Equilibrium

"A state of a system in which forces, influences, reactions, etc balance each other out so that there is no net change"

Static equilibrium: couplings are inactive; system is at rest

Dynamic equilibrium: couplings are active but are in balance

Thermal equilibrium: no net heat exchange

Chemical equilibrium: reaction and its reverse proceed at equal rates

Mechanical equilibrium: not moving, forces balanced such that position is fixed
example: ball-on-curved-surface (Fig 2-3)

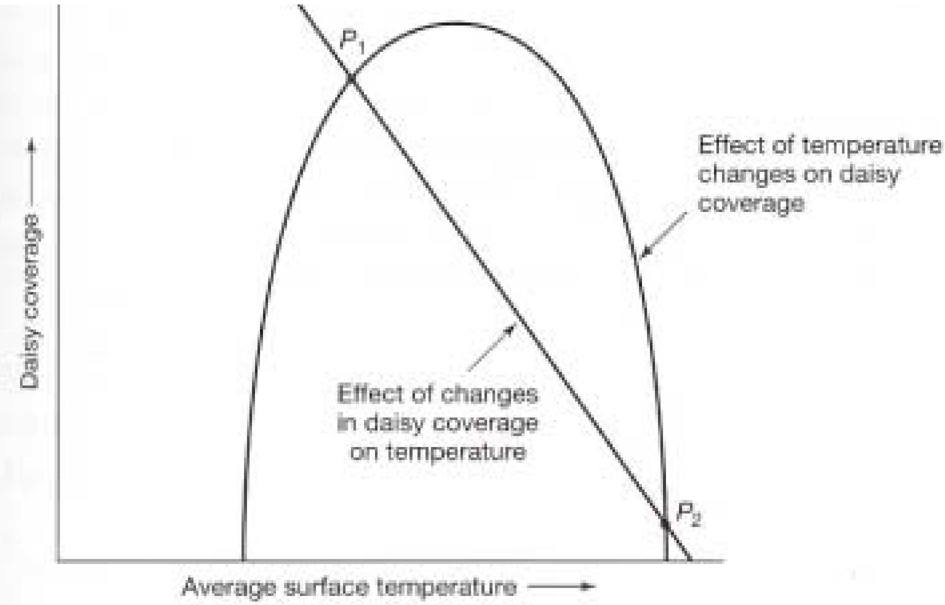
Stable equilibrium: position or state is restored after small perturbation

Unstable equilibrium: small perturbation causes change of position or state

Positive Feedback Table

Jimmy's body temperature	Jimmy's control	Rosallyn's body temperature	Rosallyn's control
70	0	80	0
-2	--	--	--
68	+2	82	-2
66	+4	86	-6
60	+10	96	-16
44 !	**+26**	**122 !**	**-44**

Welcome to Daisyworld



The mutual influences of average surface temperature on white-daisy coverage (the parabola) and white-daisy coverage on surface temperature (the straight line). The intersection points (P_1 and P_2) are the equilibrium states of the system.

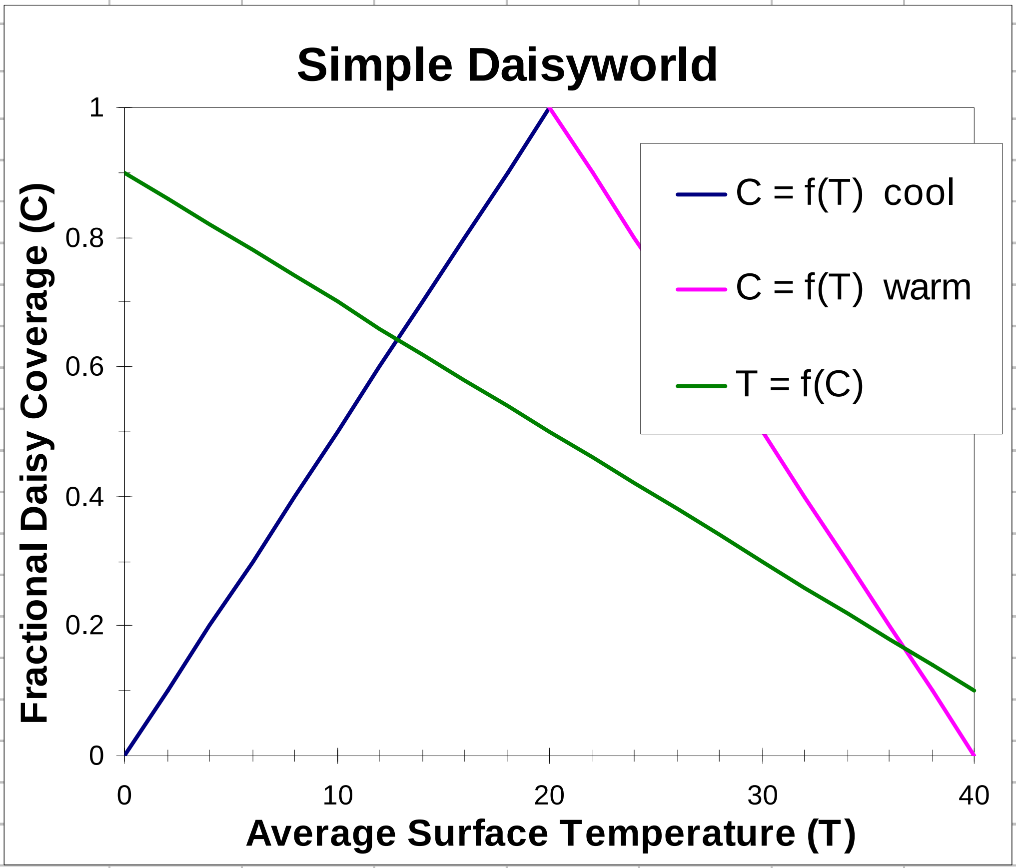
Themes:

- Energy balance
- Planetary albedo
- Self-regulation
- Graphs of two functions

Simple Daisyworld

Effect of Temperature on Daisy Coverage

	cool	warm
T	C=f(T)	C=f(T)
0	0	2
2	0.1	1.9
4	0.2	1.8
6	0.3	1.7
8	0.4	1.6
10	0.5	1.5
12	0.6	1.4
14	0.7	1.3
16	0.8	1.2
18	0.9	1.1
20	1	1
22	1.1	0.9
24	1.2	0.8
26	1.3	0.7
28	1.4	0.6
30	1.5	0.5
32	1.6	0.4
34	1.7	0.3
36	1.8	0.2
38	1.9	0.1
40	2	0



Effect of Daisy Coverage on Temperature

C	T
0.9	0
0.86	2
0.82	4
0.78	6
0.74	8
0.7	10
0.66	12
0.62	14
0.58	16
0.54	18
0.5	20
0.46	22
0.42	24
0.38	26
0.34	28
0.3	30
0.26	32
0.22	34
0.18	36
0.14	38
0.1	40

-- Equilibrium Points -

	T	C
cool	**12.9**	**0.64**
warm	**36.7**	**0.17**

functions and variables

"Daisy coverage (C) is a function of surface temperature (T)"

$$C = f(T)$$

Dependent variable

Independent variable

$$T = f(C)$$

"Surface temperature (T) is a function of daisy coverage (C)"

physical relationships

“Daisy coverage (C) is a function of surface temperature (T)”

$$C = f(T)$$

Life responds to temperature.
There is an optimal temperature for daisy growth.
Daisy coverage increases as you get closer to that optimum.
(and conversely...)

“Surface temperature (T) is a function of daisy coverage (C)”

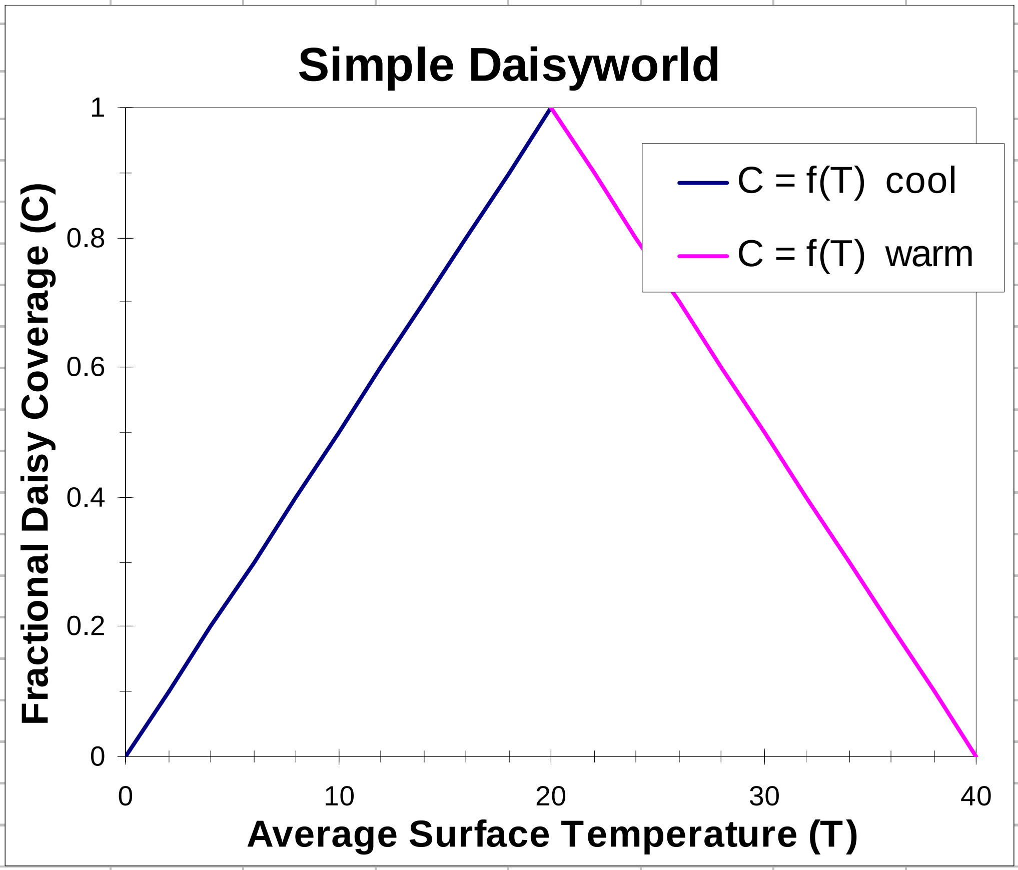
$$T = f(C)$$

Daisies are white, therefore reflect sunlight.
Reflectivity (or "albedo") of planet responds to daisy coverage.
Planetary temperature cools as more sunlight is reflected away.
(and conversely...)

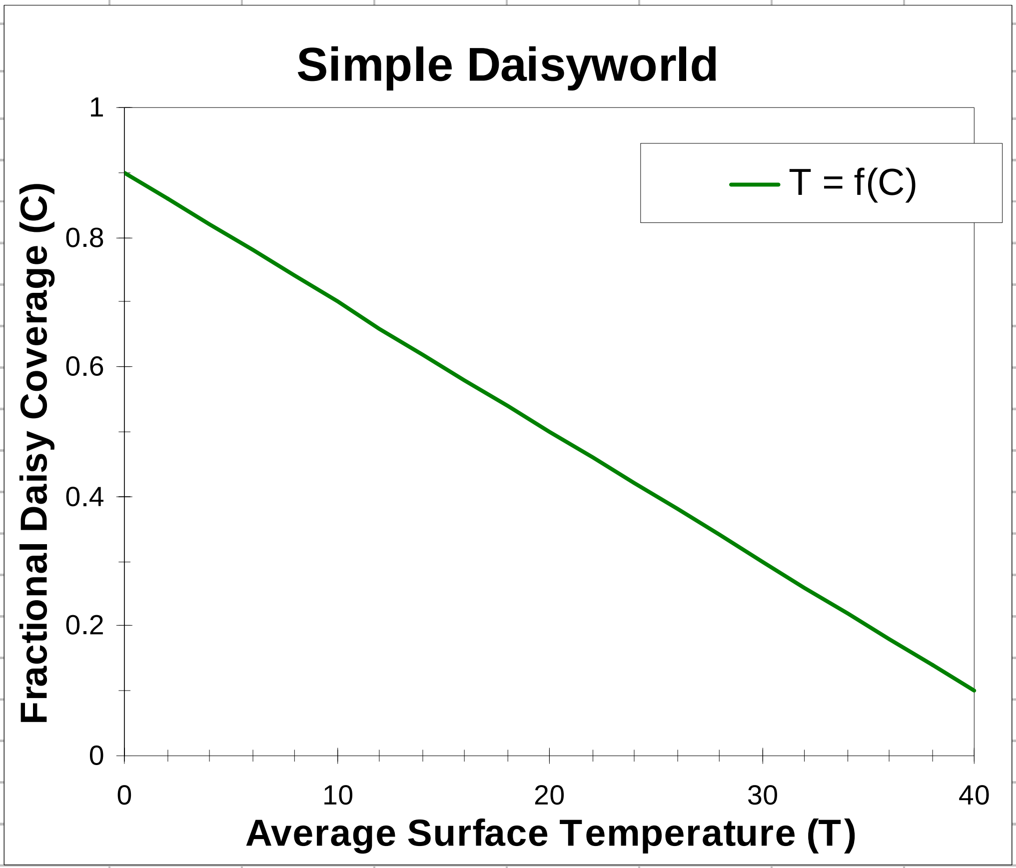
Daisy Coverage as a function of Temperature

Effect of Temperature on Daisy Coverage

	cool	warm
T	C=f(T)	C=f(T)
0	0	2
2	0.1	1.9
4	0.2	1.8
6	0.3	1.7
8	0.4	1.6
10	0.5	1.5
12	0.6	1.4
14	0.7	1.3
16	0.8	1.2
18	0.9	1.1
20	1	1
22	1.1	0.9
24	1.2	0.8
26	1.3	0.7
28	1.4	0.6
30	1.5	0.5
32	1.6	0.4
34	1.7	0.3
36	1.8	0.2
38	1.9	0.1
40	2	0



Temperature as a function of Daisy Coverage



Effect of Daisy Coverage on Temperature

C	T
0.9	0
0.86	2
0.82	4
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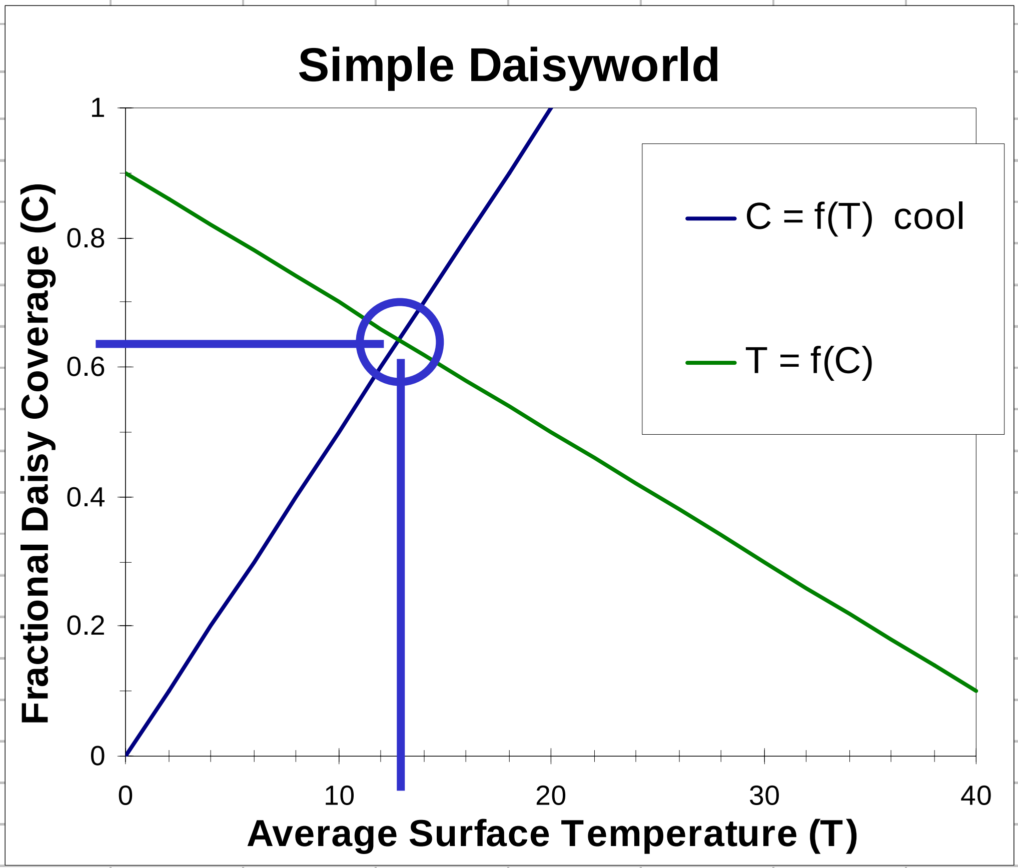
0.74	8
0.7	10
0.66	12
0.62	14
0.58	16
0.54	18
0.5	20
0.46	22
0.42	24
0.38	26
0.34	28
0.3	30
0.26	32
0.22	34
0.18	36
0.14	38
0.1	40

Cool Climate

Effect of Temperature on Daisy Coverage

	cool
T	C=f(T)
0	0
2	0.1
4	0.2
6	0.3
8	0.4
10	0.5
12	0.6
14	0.7
16	0.8
18	0.9
20	1
22	1.1
24	1.2
26	1.3
28	1.4
30	1.5
32	1.6
34	1.7
36	1.8
38	1.9
40	2



-- Equilibrium Points -		
	T	**C**
cool	**12.9**	**0.64**

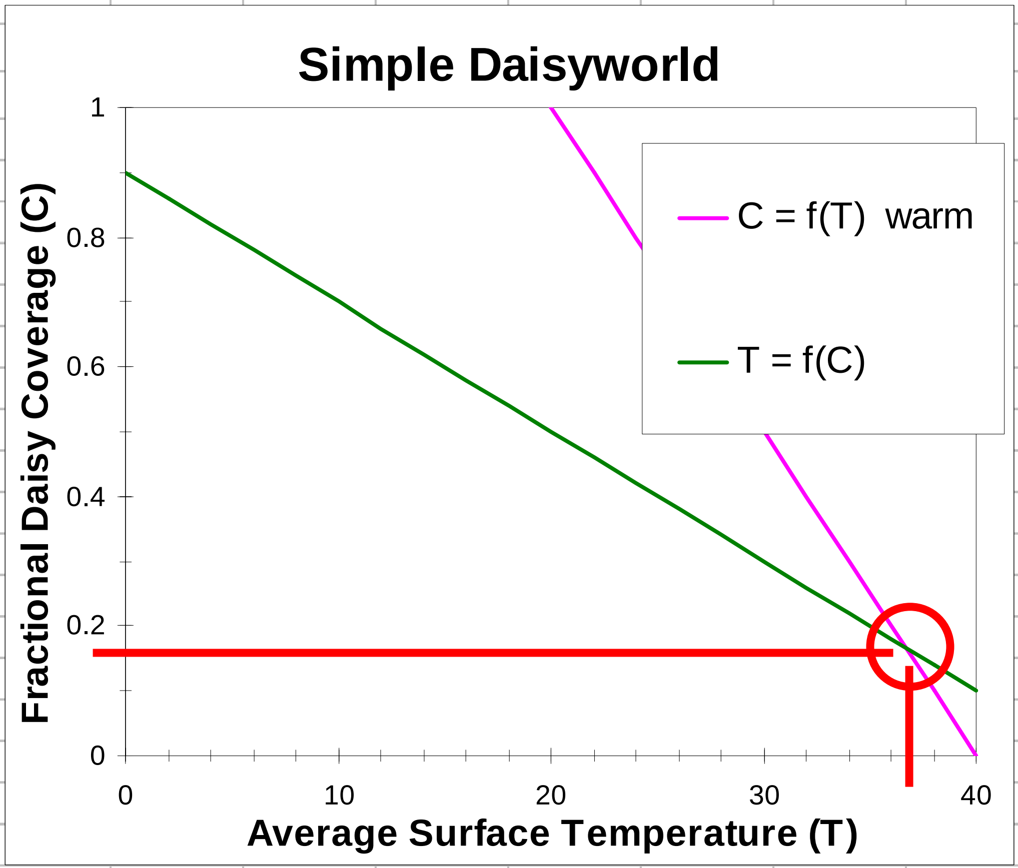
Effect of Daisy Coverage on Temperature

C	T
0.9	0
0.86	2
0.82	4
0.78	6
0.74	8
0.7	10
0.66	12
0.62	14
0.58	16
0.54	18
0.5	20
0.46	22
0.42	24
0.38	26
0.34	28
0.3	30
0.26	32
0.22	34
0.18	36
0.14	38
0.1	40

Warm Climate

Effect of Temperature on Daisy Coverage

T		warm C=f(T)
0		2
2		1.9
4		1.8
6		1.7
8		1.6
10		1.5
12		1.4
14		1.3
16		1.2
18		1.1
20		1
22		0.9
24		0.8
26		0.7
28		0.6
30		0.5
32		0.4
34		0.3
36		0.2
38		0.1
40		0



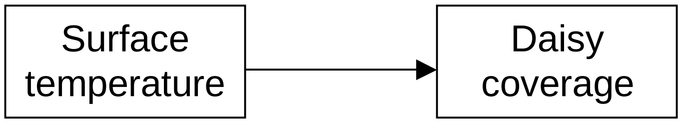
-- Equilibrium Points -		
	T	**C**
warm	**36.7**	**0.17**

Effect of Daisy Coverage on Temperature

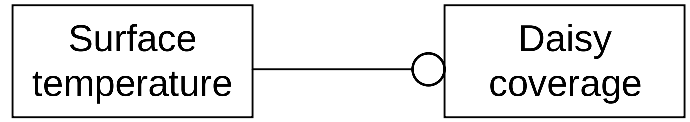
C	T
0.9	0
0.86	2
0.82	4
0.78	6
0.74	8
0.7	10
0.66	12
0.62	14
0.58	16
0.54	18
0.5	20
0.46	22
0.42	24
0.38	26
0.34	28
0.3	30
0.26	32
0.22	34
0.18	36
0.14	38
0.1	40

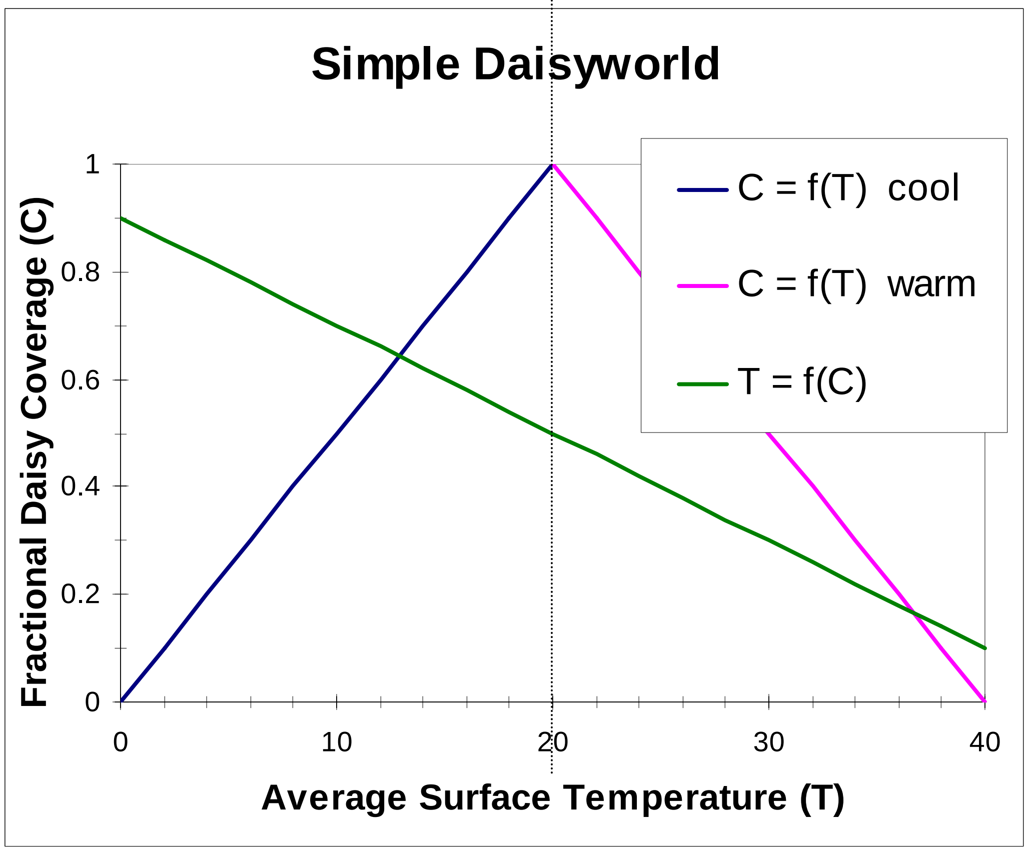
In-class activity

Cool Climate Regime



Warm Climate Regime





These figures show only the couplings from temperature to daisy coverage. Draw the complete system diagram for both the cool and warm climates – that is, add in the coupling from daisy coverage to surface temperature. Which climate is stable? How can you tell?

Wed Oct 15

Announcements:

- Lecture schedule subject to change
  - > Thurs, Oct 30, guest lecture on history of global warming science

Today:

- debrief yesterday's in-class activity
- forcing (vs perturbation)
- albedo and planetary energy balance
- planetary climate regulation (Daisyworld)

Thurs:

- Radiation intro

Friday:

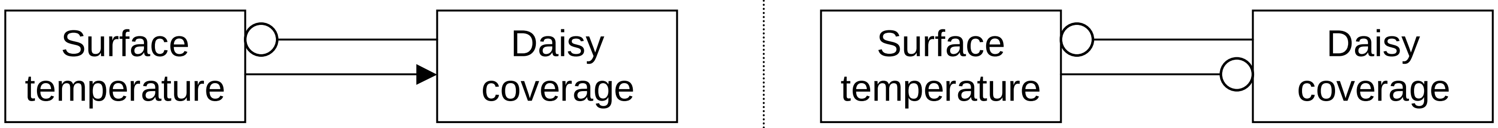
- Review/questions
- Temperature measurement lab

To know the future: A quiet dinner conversation...

Yesterday's In-class activity

Cool Climate Regime

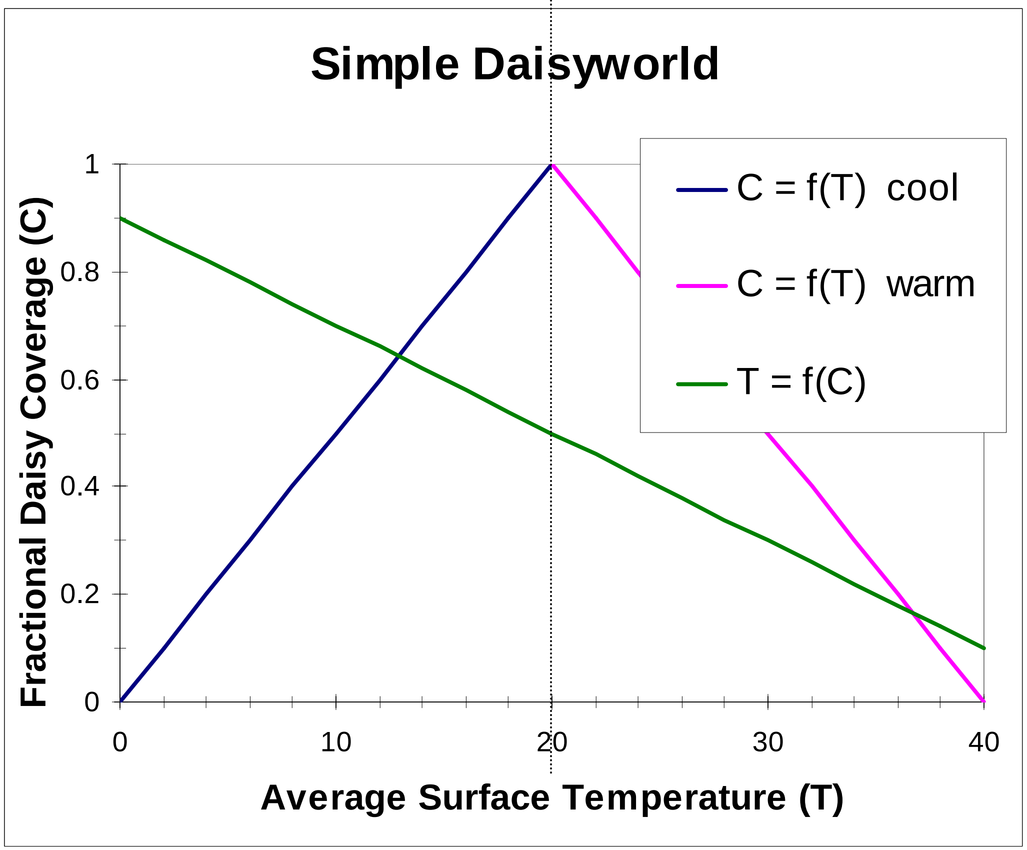
Warm Climate Regime



1 negative coupling (odd)

negative feedback loop

STABLE



2 negative couplings (even)

positive feedback loop

UNSTABLE

These figures show only the couplings from temperature to daisy coverage. Draw the complete system diagram for both the cool and warm climates – that is, add in the coupling from daisy coverage to surface temperature. Which climate is stable? How can you tell?

Forcing

Forcing: sustained disturbance of a system

example:
Climate Forcing: sustained change in planetary energy balance

Perturbation vs Forcing

- Both are imposed changes on the system.
- "perturbation": temporary, random, usually small
- "forcing": persistent, systematic, or large

Examples…

- gust of wind on someone walking (tightrope walker)
- Carter bedroom: rise and fall of room temp vs nighttime cooling
- solar fluctuations vs long-term increase in solar luminosity
- greenhouse gas forcing vs volcanic eruption (see next...)

Forcing vs Perturbation

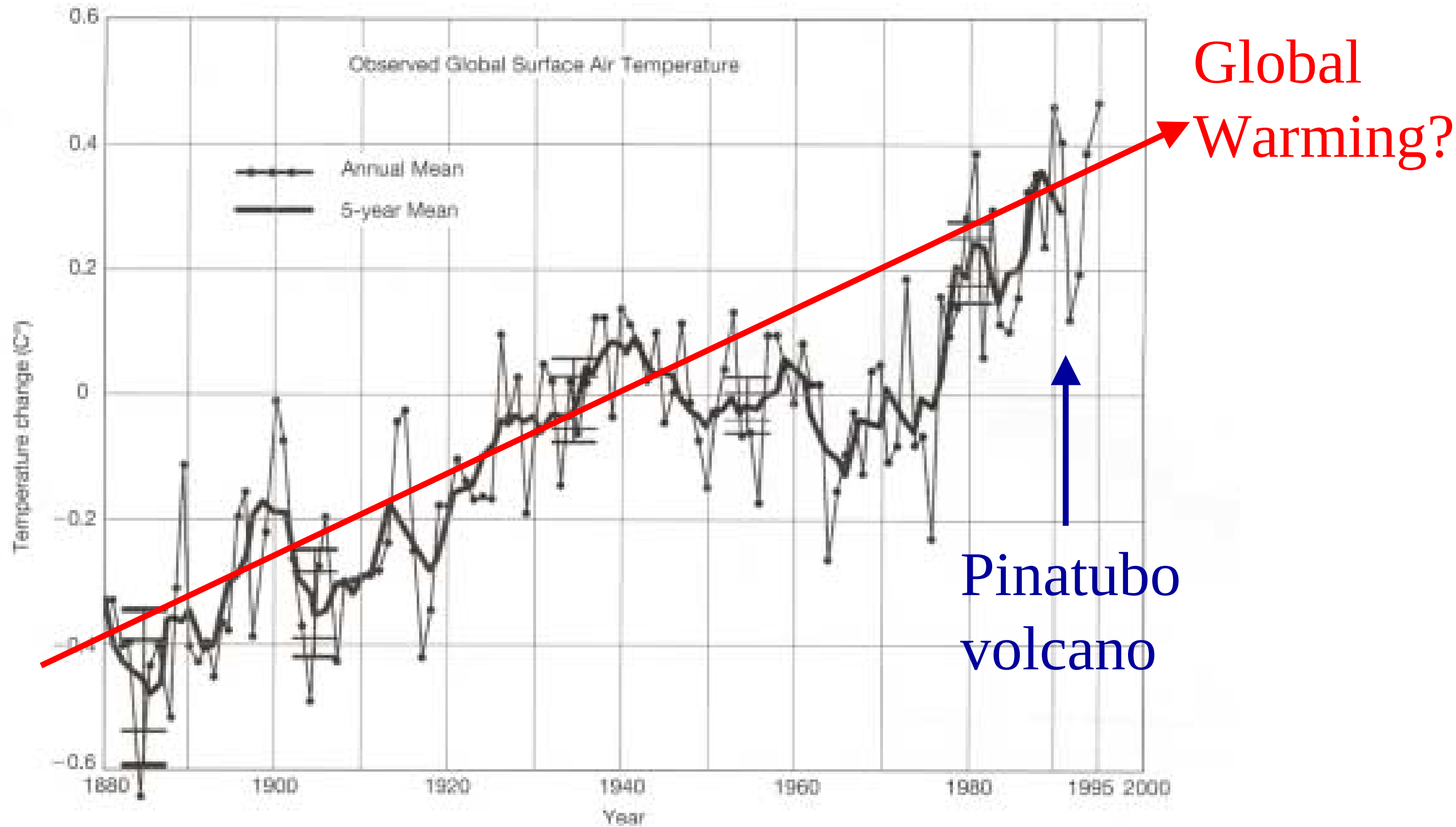


FIGURE 2-4

The globally averaged temperature history from 1950 to 1996, showing the 0.5°C (1°F) cooling associated with the eruption of Mt. Pinatubo in 1991. Anomalies are defined as deviations from the 1951–1980 mean. (From R.W. Christopherson, *Geosystems: An Introduction to Physical Geography*, 3/e, 1997. Reprinted by permission of Prentice Hall, Upper Saddle River, N.J.)

Albedo definition

Light (electromagnetic energy) impinging on a surface can either be absorbed, reflected, or transmitted.

[for a planetary surface, we can forget transmission]

the albedo (A) of a surface is the fraction of total, incoming light energy (E) that is reflected:

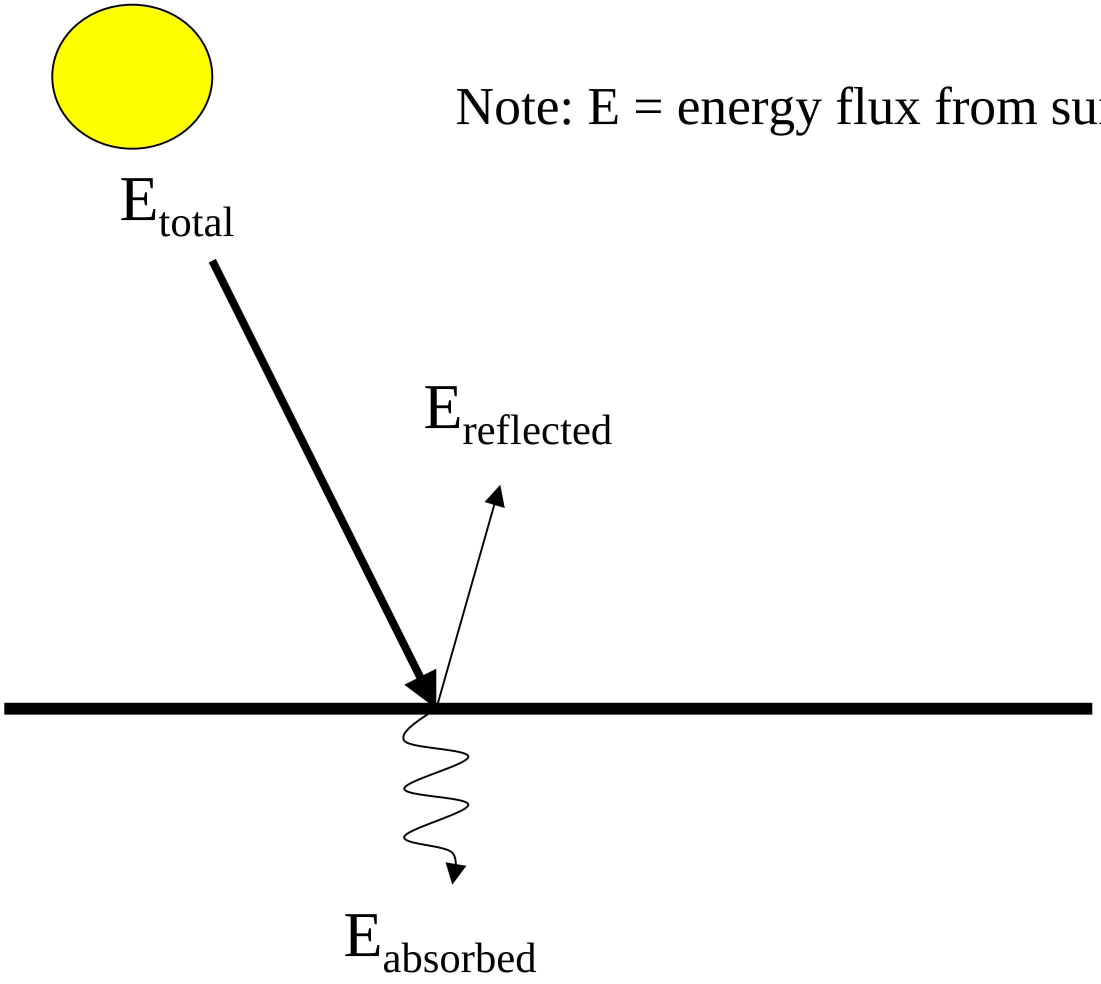
$$A = \frac{E_{reflected}}{E_{total}}$$

also, equivalently, the fraction of light that is absorbed is given by:

$$(1 - A) = \frac{E_{absorbed}}{E_{total}}$$

Albedo definition

Note: E = energy flux from sun (W/m^2)



Albedo calculation

Total flux of light energy: $E_{total} = 100\ W/m^2$

	Albedo of surface, A	Energy absorbed, $E_{absorbed}$ (W/m2)	
ocean, black asphalt	0.07	93 W/m^2	Example?
snow, white paint	0.8	20 W/m^2	Example?

See Table 2-1 for more examples

Albedo and Planetary Energy Balance

Energy balance equation for a planet:

$E_{IN} = E_{OUT}$ where E is a flux of energy (W/m^2)

The energy coming in is simply the portion of incoming solar energy that is not reflected away:

$E_{IN} = E_{SUN} * (1-A)$

where A is the planetary albedo

A is a critical climate parameter

What controls A on Earth?

Daisyworld Temperature Control

$$T = f(E_{absorbed})$$

$$E_{absorbed} = E_{sun} * (1 - A)$$

varies with steadily brightening sun -

a forcing

varies with daisy coverage

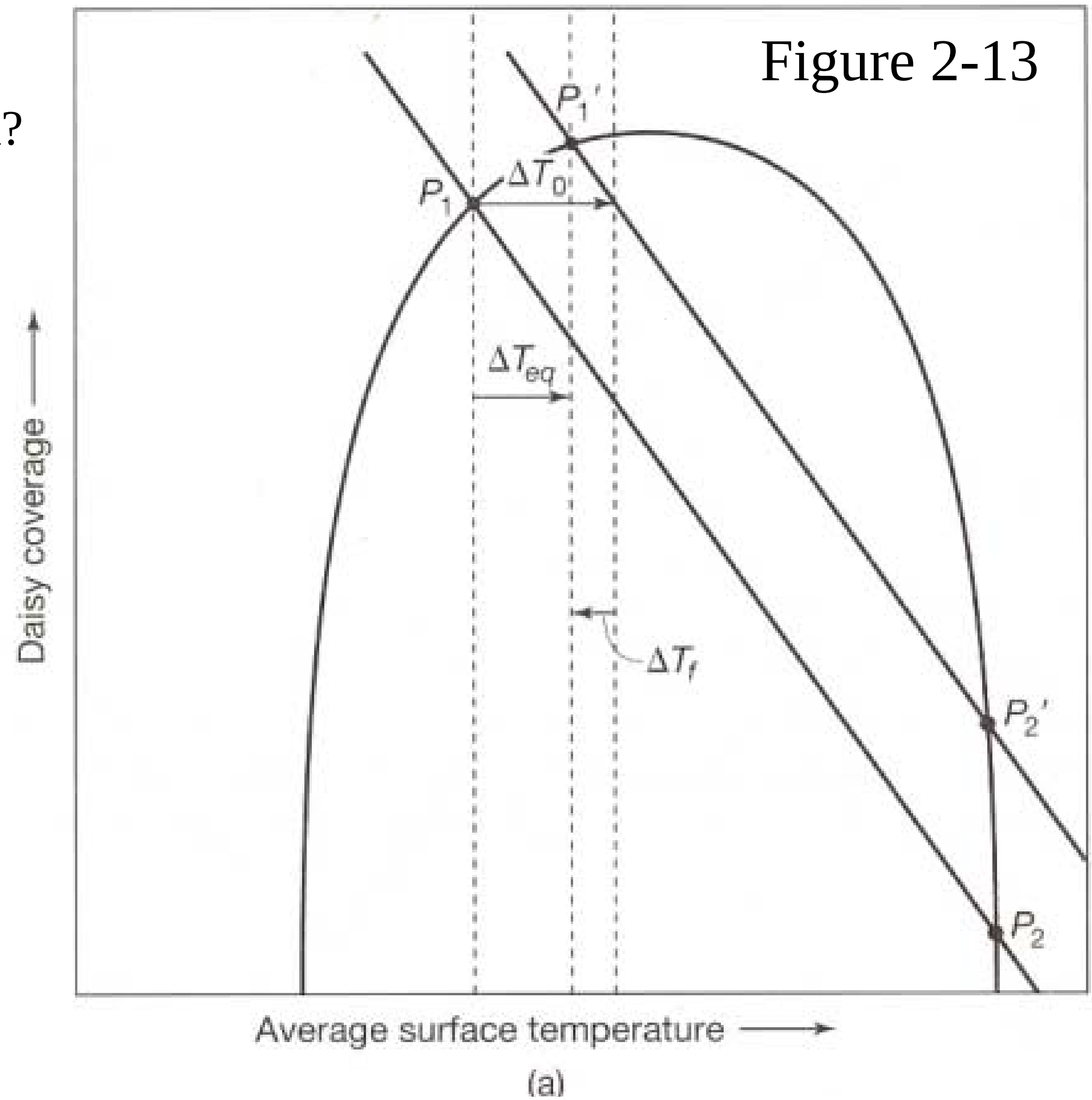
Response to Forcing for a System with Feedbacks

1. Which diagonal line represents the warmer sun?

2. Feedback factor:

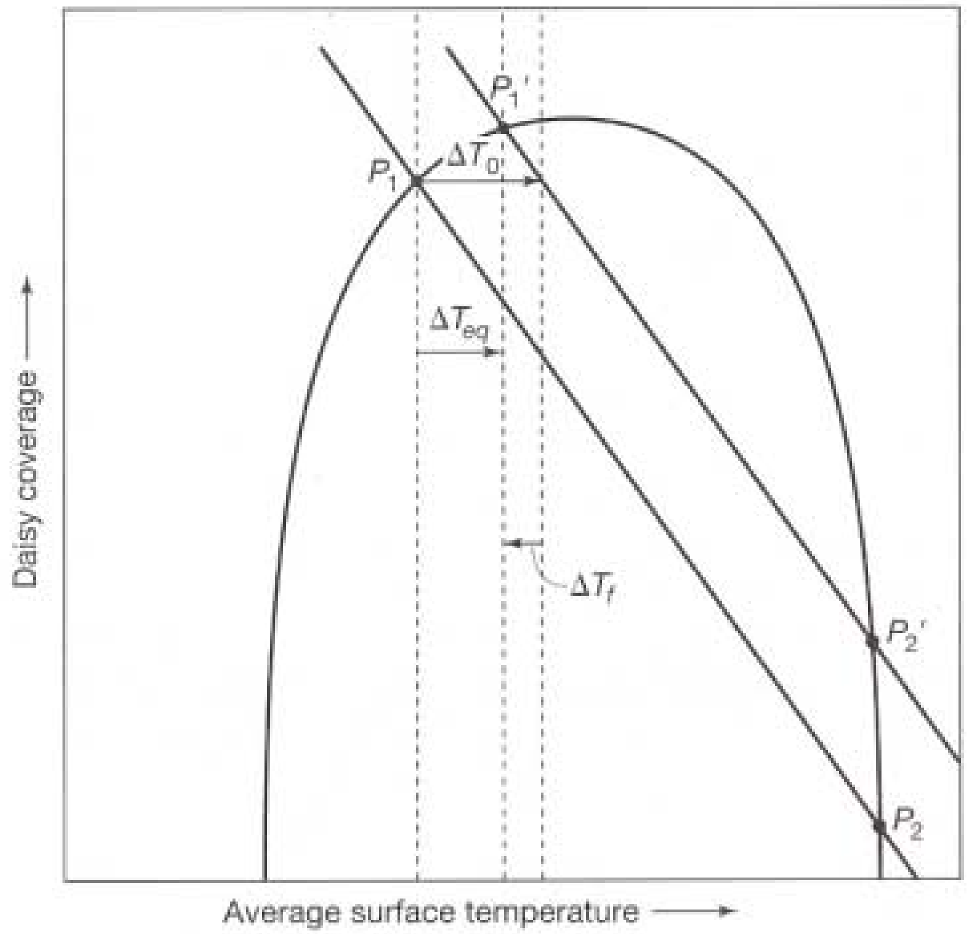
$$f = \frac{\Delta T_{eq}}{\Delta T_0}$$

3. Is the feedback factor larger or or smaller than one?



Stability

Is the warmer-sun case more or less stable?



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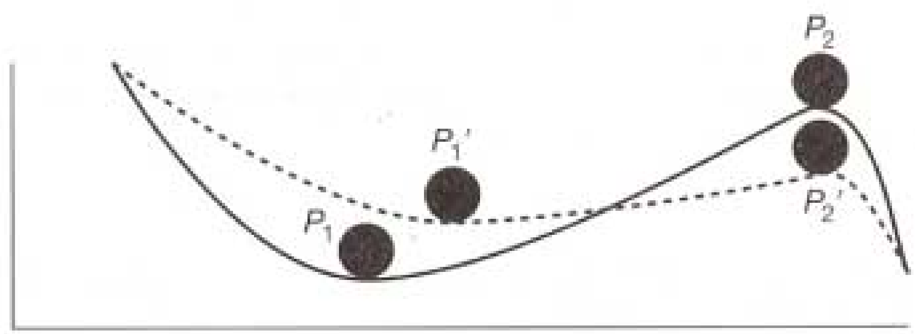


(b)

Planetary Regulation

Explanation of Figure 2-14

(and preparation for HW prob. 2)

lines 1-6: Sun gets brighter

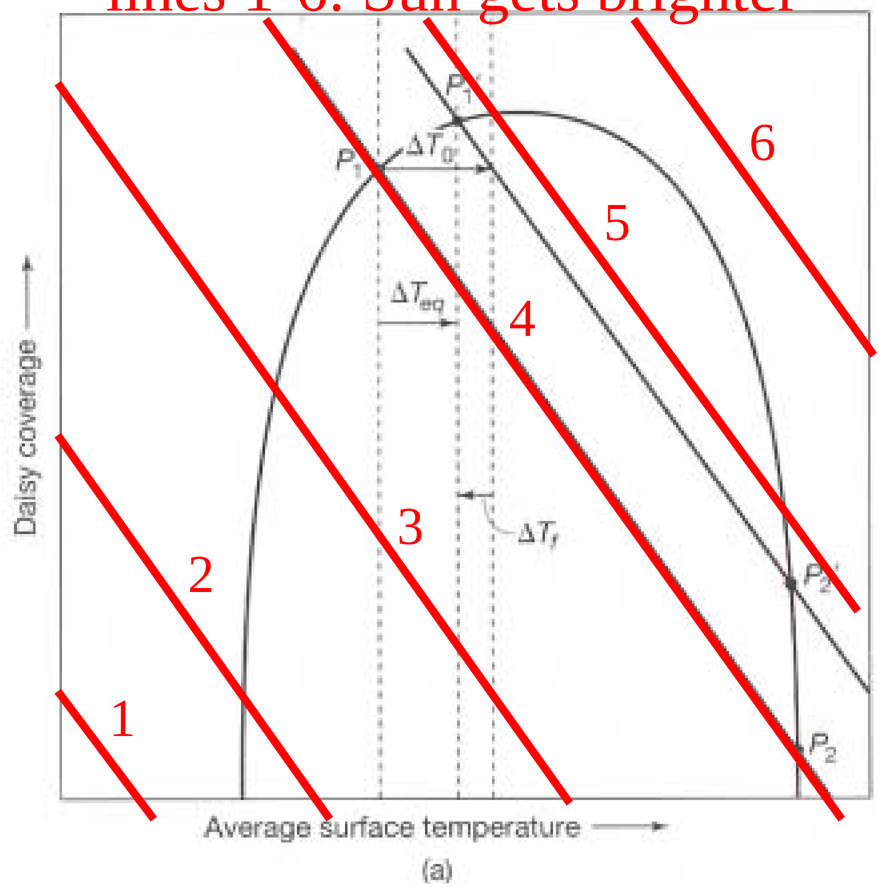
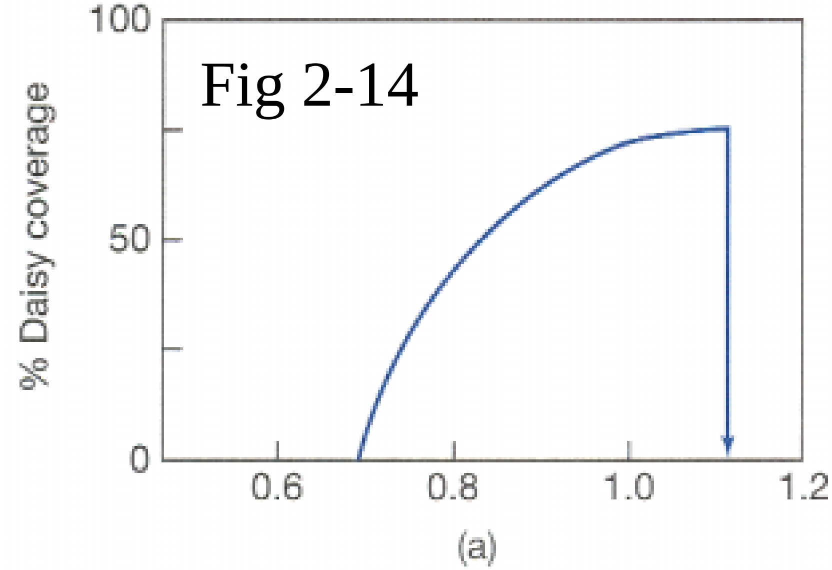
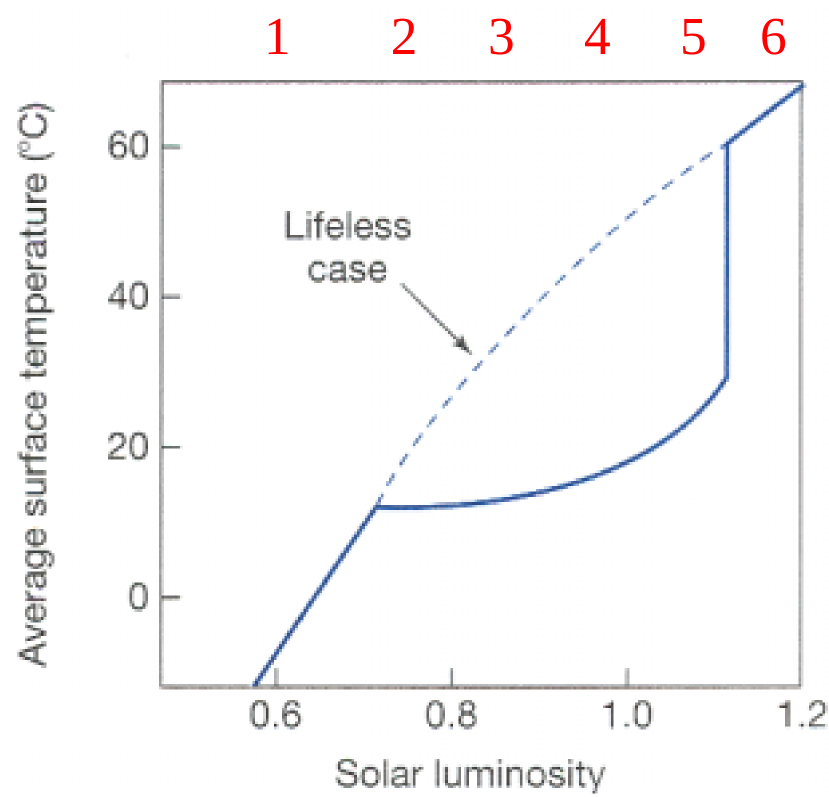


Fig 2-14





Thurs Oct 16

Announcements:

- HW#2, mistake in text regarding extra-credit (see web announcements)
  equation for parabola: $y = o - c(a-x)^2$
  o, c, and a are all constants you need to figure out
  o is the maximum value of y; a is the value of x when y is max
- I need Yellow Personal Information Sheets from 10 of 80 students

Today:

- debrief Daisyworld
- begin RADIATION (and Chap 3)

Friday:

- Review/questions
- Albedo and Temperature fun and games

NEXT WEEK: the Greenhouse Effect

A pleasant breakfast...

upcoming talks

FRIDAY 17 October:

12:30 ATG 310c

Dr. Kevin E. Trenberth
NCAR Climate & Global Dynamics Division
"Problems with climate observations; need for an Earth Information System"

3:30 ATG 64 JHN

Dr. Steve Warren
UW Atmos Sci Dept
"Trends in cloud cover and type over land"

Debriefing the Daisyworld experience

1. Introduction to many core concepts in climate science:
   - planetary albedo, planetary energy balance
   - climate forcing and system response
   - positive and negative feedbacks, feedback factor
   - stable and unstable equilibria

2. Lessons:
   - biota are a component of the climate system
   - self-regulating climate without "intelligence"
   - self-regulation is imperfect (e.g. has limits)

3. By the way, Daisyworld is real science…

Watson, A. J. and J. E. Lovelock (1983). "Biological homeostasis of the global environment: the parable of Daisyworld." Tellus **35B**: 284-289.

Saunders, P. T. (1994). "Evolution without natural selection: Further implications of the Daisyworld parable"

… and many more

Where now?

delve into nitty gritty: “electromagnetic radiation”

- hardest part for non-scientists? (perhaps the most foreign)

Begin Chap 3 (p. 34-42:

Goal is to calculate radiation balance

Why?

1. Demonstrate and quantify the Greenhouse effect

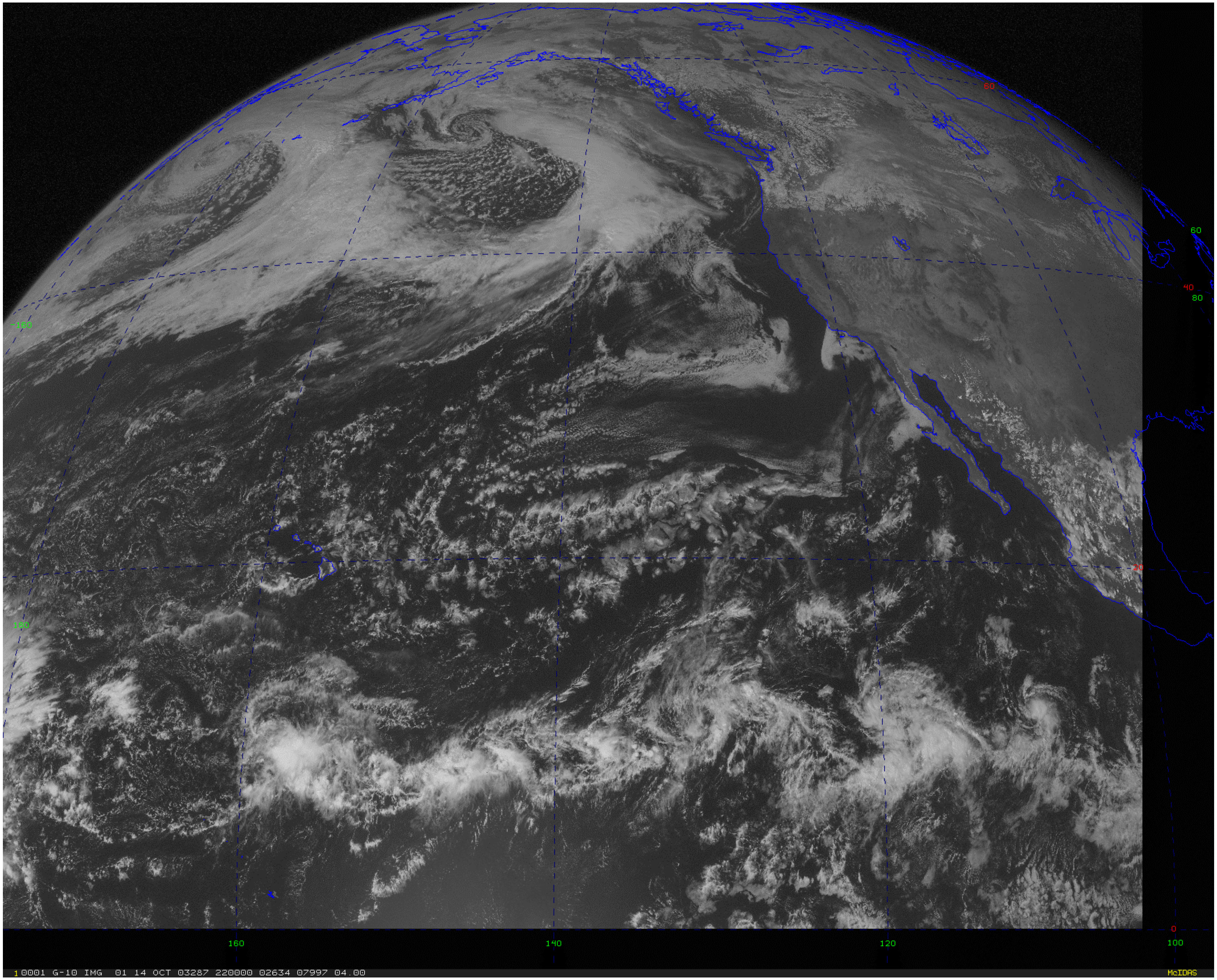
2. Basis for understanding how Earth might respond to changed greenhouse gas concentration

Radiation Primer - 1

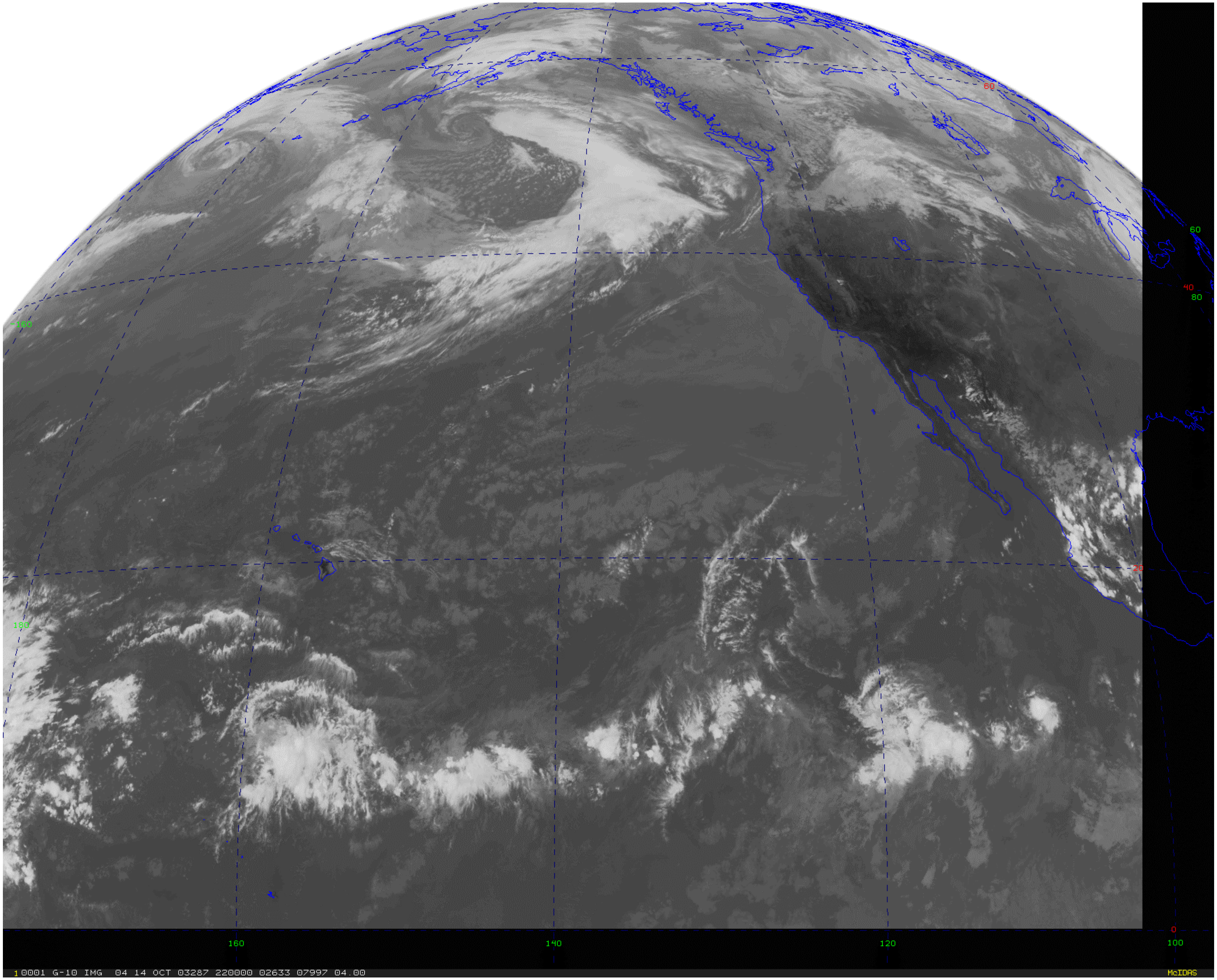
1. Electromagnetic radiation:
    - propagates through space
    - speed?
    - has a characteristic wavelength,
        for now just two types:
            SW: shortwave (mostly visible)
            LW: longwave

SW and LW can be illustrated by "visible" and "infrared" satellite images

Visible satellite image: Oct 14, 2003 at 2pm PST



Infrared satellite image: Oct 14, 2003 at 2pm PST



Radiation Primer - 2

2. Radiation and matter interact in 4 ways:

- Radiation encountering matter can be:
  - (i) absorbed
  - (ii) transmitted
  - (iii) reflected (or scattered)

- All matter emits radiation
  - (iv) emission by matter

"everything emits" can be illustrated by an IR thermometer (later)

Radiation Primer - 3

3a. Absorption of radiation causes matter to warm up (or gain heat)

corollary (converse)???

3b. Emission of radiation causes matter to cool down (or lose heat)

albedo demonstration...

Radiation Primer - 4

4. Temperature of matter is crucial because both the wavelength and the total energy of radiation emitted by matter depend upon its temperature.

4a. Hotter matter emits shorter wavelengths [Wein's Law]

- SUN: "SW" [ultraviolet (UV), visible, near-infrared (IR)]
- Earth: "LW" [infrared (IR)]

ground, ocean, atmosphere, clouds, etc
also, moon and other planets

4b. Hotter objects emit more total energy. [Stefan-Boltzmann Law]

Radiation Primer: S-B Law

4a. Hotter matter emits shorter wavelengths [Wein's Law]
4b. Hotter objects emit more total energy.

Stephan-Boltzmann Law: $E = \sigma T^4$

Put 4a and 4b together:

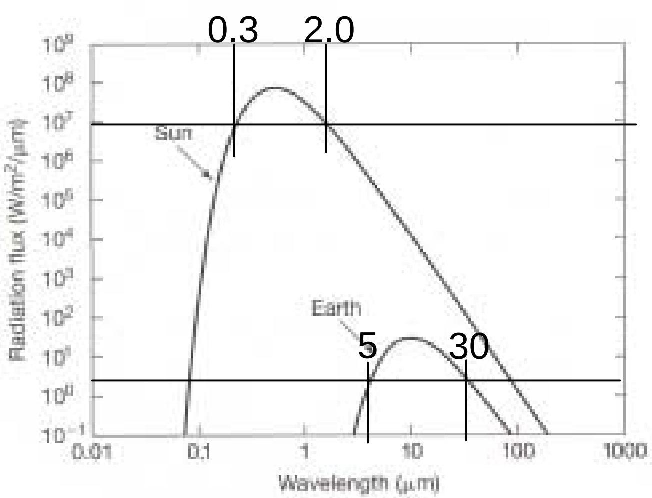


FIGURE 3-8
Blackbody emission curves for the Sun and Earth. The Sun emits more energy at all wavelengths.

Notes:
- log-log scales
- Sun emits more and at shorter wavelengths
- Sun emits some, but very very little at LW

Planetary Energy Balance

Energy balance equation (E is energy flux, W/m^2)…

$$E_{OUT} = E_{IN}$$

energy emitted by Earth — energy absorbed by Earth

“Energy Balance Theory of Climate Change”

if $E_{OUT} < E_{IN}$

then $T_{surface}$ will go up until balance is restored

Energy budget of planet is a bit more complicated.
(See figure...)

Planetary Energy Budget (fig)

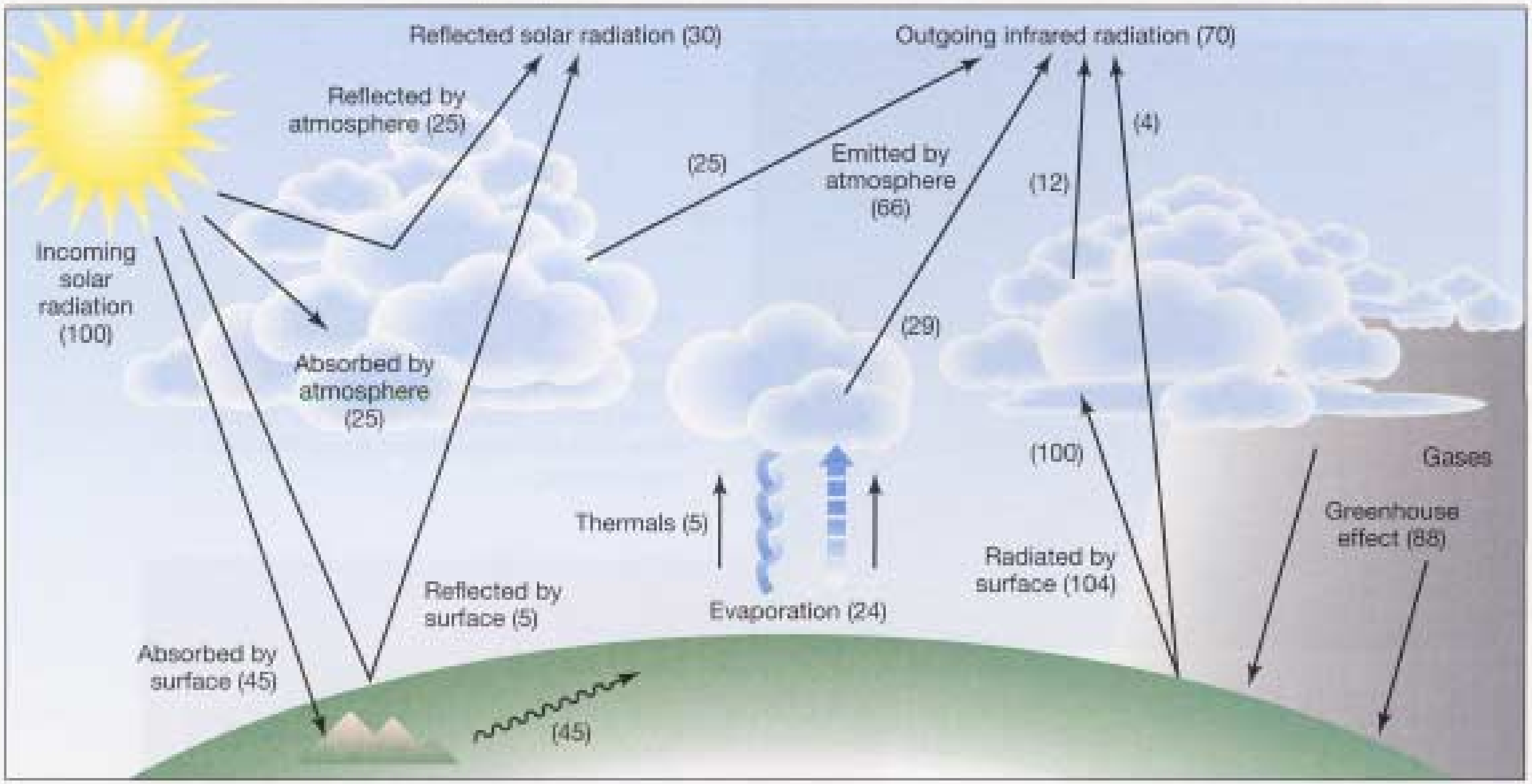


FIGURE 3-19

Earth's globally averaged atmospheric energy budget. All fluxes are normalized relative to 100 arbitrary units of incident radiation.