Lecture 11

- Finish with Daisyworld and go to the real world
- Introductory material for the "greenhouse effect"
- This week we will cover Chapter 3 of the textbook
- Homework #2: due next Monday

'Goldilocks' and the 3 planets

Too hot	Ah, just right!	Too cold
(460°C)	(15°C)	(-55°C)

Forcing vs. Perturbation

Forcing: sustained disturbance of a system

e.g.,Climate Forcing: sustained change in planetary energy balance

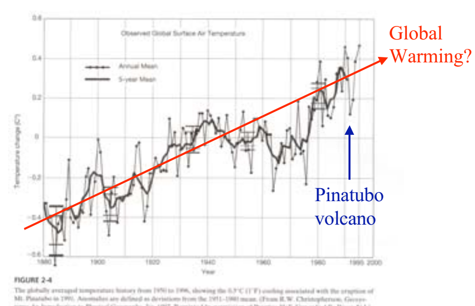
Perturbation vs Forcing
Both are imposed changes on the system.

perturbation: temporary, usually small
forcing: persistent, often large

Examples…

- gust of wind on Philippe Petit, famous tightrope walker
- solar fluctuations vs long-term increase in solar luminosity
- greenhouse gas forcing vs volcanic eruption (see next...)

Forcing vs Perturbation



Albedo definition

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

[for a planetary surface, we can forget transmission]

Albedo (A) = the fraction of total incoming light energy flux (F) that is reflected:

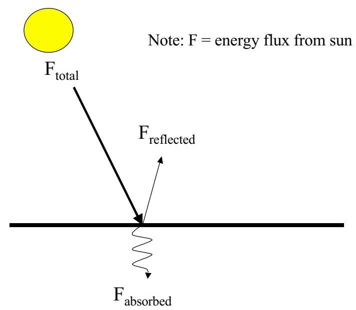
$$A = \frac{F_{reflected}}{F_{total}}$$

Thus, the fraction of light that is absorbed is given by (1-A)

Forest albedo = 0.05-0.10
Snow albedo = 0.80-0.85

Albedo definition

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



Albedo calculation

Total flux of light energy: F_{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:

$F_{IN} = F_{OUT}$ where F is the energy flux (W/m^2)

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

$F_{IN} = F_{SUN} * (1\text{-}A)$

where A is the planetary albedo

A is a critical climate parameter

What controls A on Earth?

Daisyworld Temperature Control

T = a function of $F_{absorbed}$

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

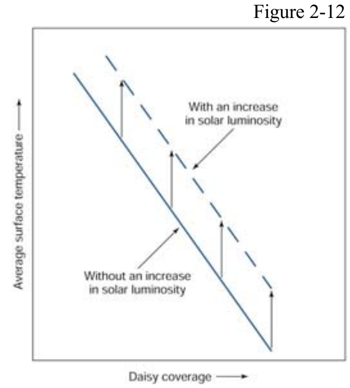
varies with steadily brightening sun - a forcing

varies with daisy coverage

Response to Forcing for a System with Feedbacks

For a particular value of daisy coverage, the temperature is higher with more solar forcing

Figure 2-12



Response to Forcing for a System with Feedbacks

1. Which diagonal line represents the warmer sun?

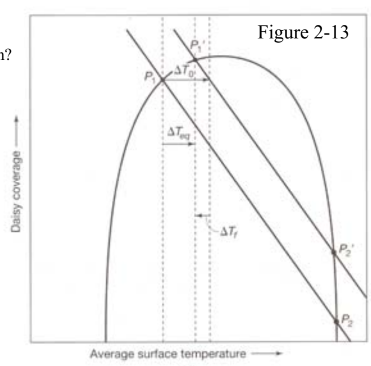
We get a shift of the stable equilibrium state
- more daisies
- hotter

2. Feedback factor, *f*:

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

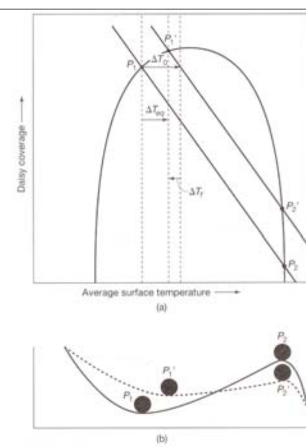
3. Is the feedback factor larger or or smaller than one?

Figure 2-13



Stability

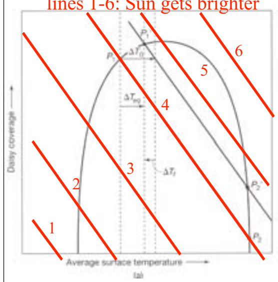
Is the warmer-sun case more or less stable?

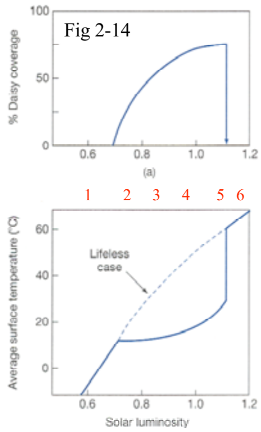


Planetary Regulation

Explanation of Figure 2-14

lines 1-6: Sun gets brighter





Debriefing the Daisyworld experience

1. **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 is a component of the climate system
   - self-regulating climate without "intelligence"
   - self-regulation is imperfect (e.g. has limits)
   - negative feedbacks counter external forcings

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" *J. Theoretical Biology* **166**

   … and more

Where now?

delve into a bit more nitty gritty
physics of "electromagnetic radiation"

Goal: to calculate temperature of Earth from radiation balance

Why?

1. Demonstrate and quantify the Greenhouse Effect

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