Climate

- Chap. 2

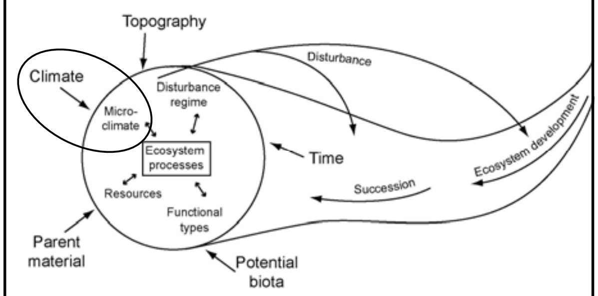
Introduction

I. Forces that drive climate and their global patterns
   A. Solar Input – Earth's energy budget
   B. Seasonal cycles
   C. Atmospheric circulation
   D. Oceanic circulation
   E. Landform effects
   F. Vegetation feedbacks

II. Variability in climate
   A. Seasonally (see I.B.)
   B. Yearly – El Niño Southern Oscillation (ENSO)
   C. Millenial
   D. Human impacts

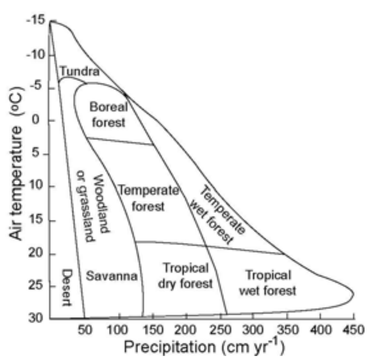
Powerpoint modified from Harte & Hungate (http://www2.for.nau.edu/courses/hart/for479/notes.htm)
and Chapin (http://www.faculty.uaf.edu/fffsc/)

Climate is the state factor that most strongly governs the global pattern of ecosystem structure and processes



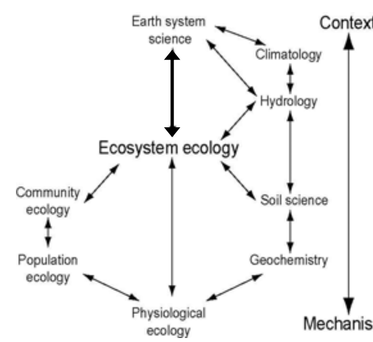
1.3

Climate gives rise to predictable types of ecosystems



2.21

Climate is a key mechanism by which ecosystems interact with the total Earth System



1.2

Observation: predictable patterns of ecosystem distribution across Earth

Why are there rainforests in the tropics?
Why are there bands of desert at ~30° N & S?

Observation: predictable patterns of ecosystem distribution across Earth

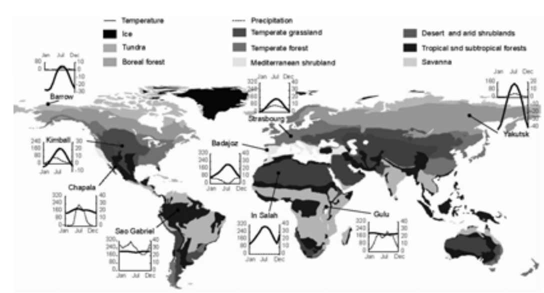


Plate 1

Major goals in this lecture

Answer these questions:

I. - What are the forces that drive climate?
- Are there predictable patterns of climate across the globe?

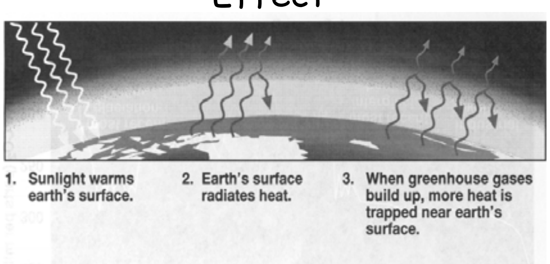
II. Why and how does climate vary through time?
- Seasonally
- Annually
- Millenial scales
- Human effects

I. What are the forces that drive climate?
What are the global patterns?

A. Solar radiation - Earth's energy budget

- Question: What is the greenhouse effect? Is this a recent phenomenon?

Enhanced Greenhouse Effect



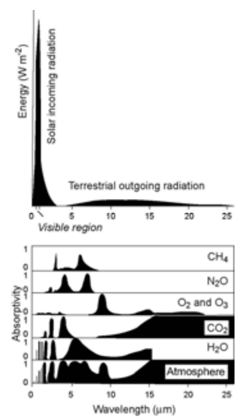
Starr and Taggart 1997

Atmosphere is more transparent to incoming short-wave radiation than to outgoing long-wave radiation

The temperature of a body determines wavelengths of energy emitted

Solar radiation has high energy (shortwave) that readily penetrates the atmosphere

Earth emits low-energy (longwave) radiation that is absorbed by different gases in the atmosphere



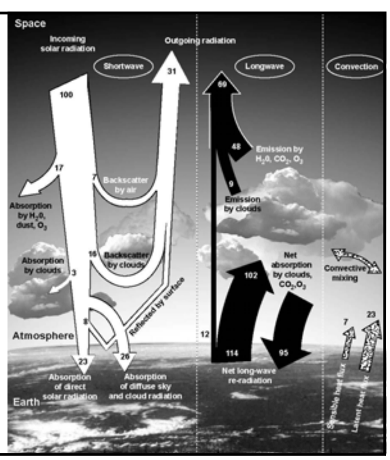
2.1

Energy in = energy out

Half of solar radiation reaches Earth (latent & sensible heat)

The atmosphere is transparent to shortwave but absorbs longwave radiation (greenhouse effect)

The atmosphere is heated from the bottom by longwave radiation and convection



2.2

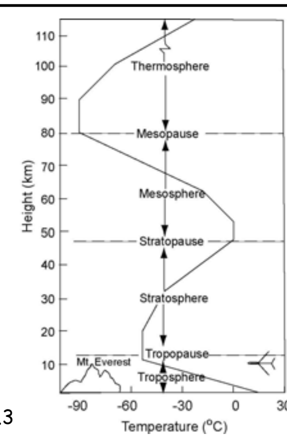
The atmosphere is heated from the bottom

Therefore it is warmest near the bottom, and gets colder with increasing elevation

Except the stratosphere is heated from the top – ozone absorption of incoming UV

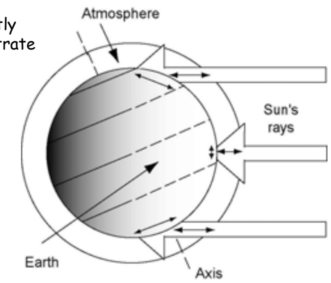
Mesosphere and Thermosphere have little impact on the biosphere.

2.3



Uneven heating of Earth's surface causes predictable latitudinal variation in climate.

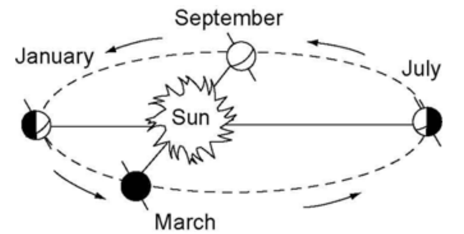
1. Greater heating at equator than poles
2. Why?
   a. sun's rays hit more directly
   b. less atmosphere to penetrate



2.5

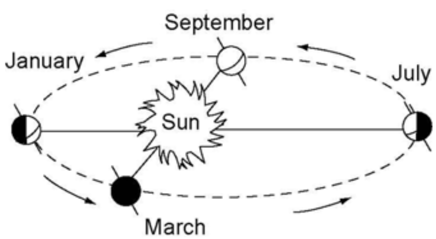
B. Seasonality
What causes seasons?

~~Earth's distance from the sun varies throughout the year~~



2.20

Tilt!
Because of the tilt of Earth's axis, the amount of radiation received by Northern and Southern Hemispheres varies through the year
- angle of incidence and day length



2.20

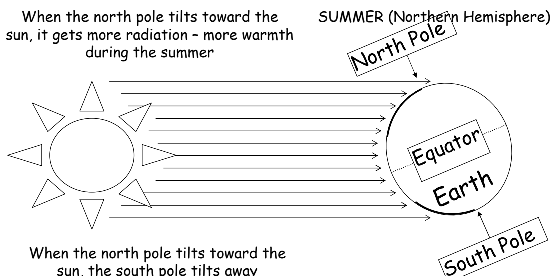
Look at this light projected onto the globe.

Earth's Seasons

Tilt of the Earth's axis towards or away from the sun creates the seasons

When the north pole tilts toward the sun, it gets more radiation – more warmth during the summer

SUMMER (Northern Hemisphere)



When the north pole tilts toward the sun, the south pole tilts away
So when it's summer in the north, it's winter in the south

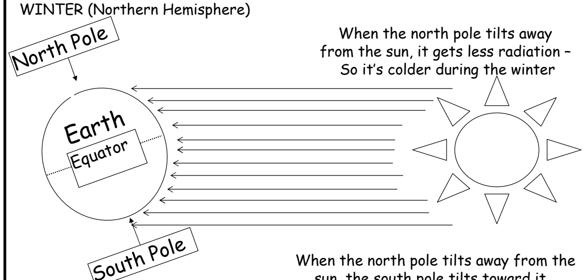
WINTER (Southern Hemisphere)

Earth's Seasons

Tilt of the Earth's axis towards or away from the sun creates the seasons

WINTER (Northern Hemisphere)

When the north pole tilts away from the sun, it gets less radiation – So it's colder during the winter

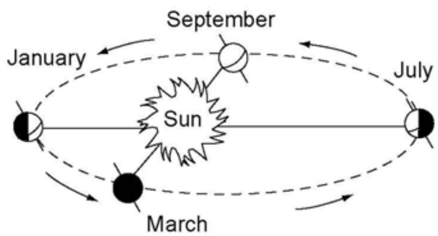


SUMMER (Southern Hemisphere)

When the north pole tilts away from the sun, the south pole tilts toward it…
When it's winter in the north, it's summer in the south

Common geographic boundaries relate directly to Earth's tilt

Tropics: Capricorn (S) & Cancer(N)
Arctic, Antarctic circles



2.20

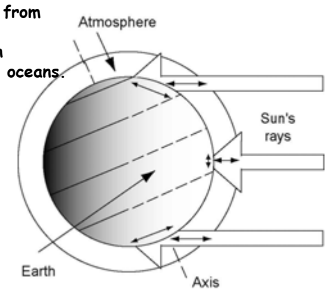
C. Atmospheric circulation
Questions
1. **Why are there rainforests in the tropics and deserts at ~30°N and S?**
2. **What drives the major wind patterns?**
   (e.g., Doldrums, Tradewinds, Westerlies)

C. Atmospheric circulation - Uneven heating of Earth's surface causes atmospheric circulation

Greater heating at equator than poles

Therefore
1. **Net transfer of energy from Equator to poles.**
2. **Transfer occurs through circulation of atmosphere and oceans.**

Here's how it works…



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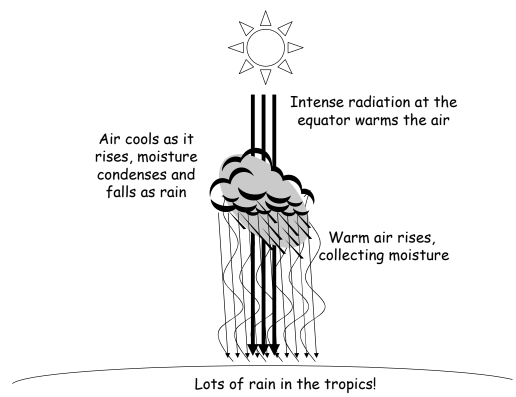
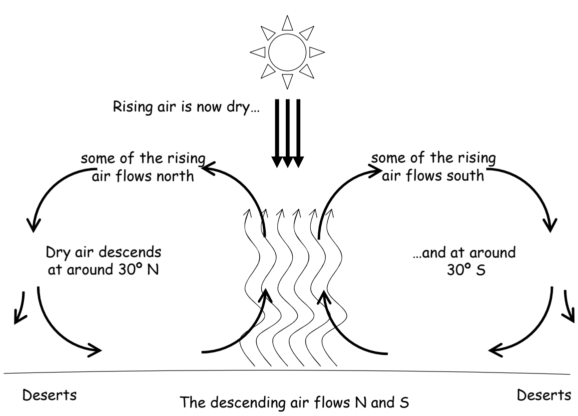
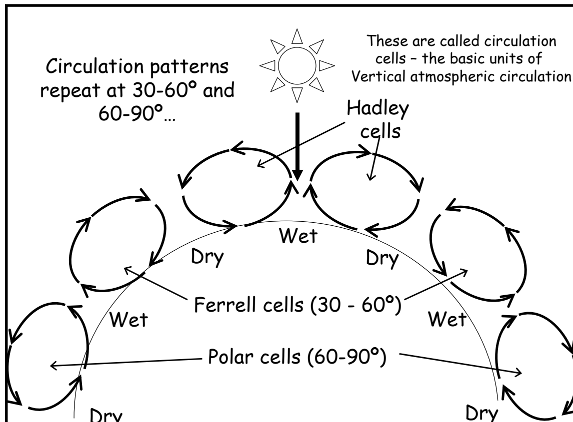




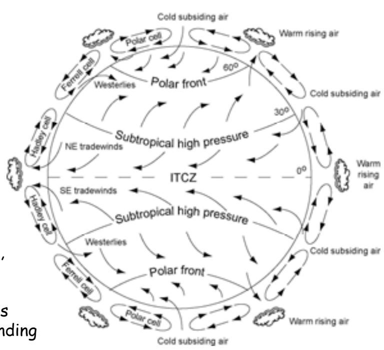


Air rises and falls in Hadley, Ferrel, and Polar cells (vertical circulation)

Circulation cells explain global distribution of **rainfall**

Earth's rotation determines **wind direction** (horizontal circulation, Coriolis force)

ITCZ and cell locations **shift seasonally** depending on location of maximal heating of Earth's surface



2.6

These general circulation patterns are modified by the distribution of oceans and continents.

High heat capacity of water and ocean currents buffer ocean temperatures

Land temperatures fluctuate more, especially in higher latitudes

These differences in surface energy balance influence air movements, and create prevailing winds

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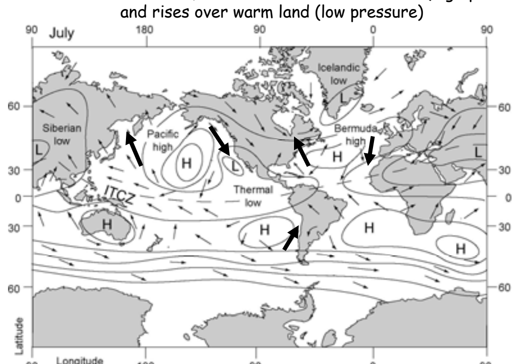
In summer at 60 ° N & S, air descends over cold ocean (high pressure) and rises over warm land (low pressure)



2.7b

Cool equator-ward flow of air on W coast of continents
Warm poleward flow of air on E coasts of continents

Observation: predictable patterns of ecosystem distribution across Earth

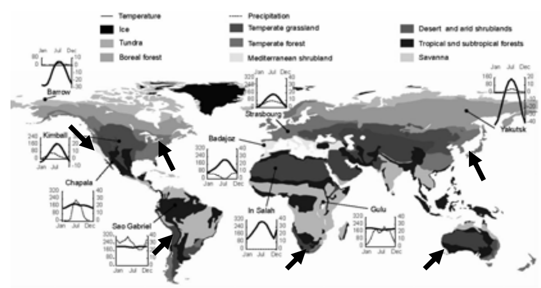


Plate 1

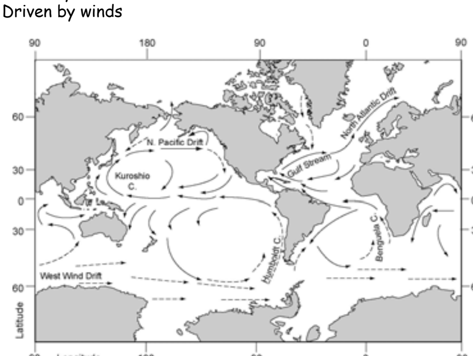
D. Ocean currents

Questions:

1. Why is San Francisco so cold?
2. Why is London so warm?

D. Surface ocean currents are similar to wind patterns:

1. Driven by Coriolis forces
2. Driven by winds



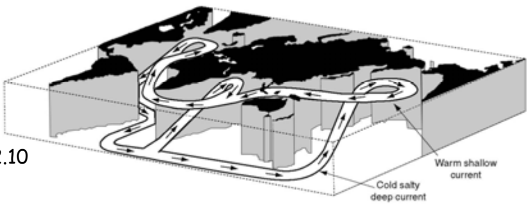
2.9

Warm currents – solid, Cold currents - dashed

Deep ocean currents are driven by cooling, freezing of pole-bound water (thermohaline circulation).

– Deepwater formation occurs at high latitudes (near Greenland and Antarctic)

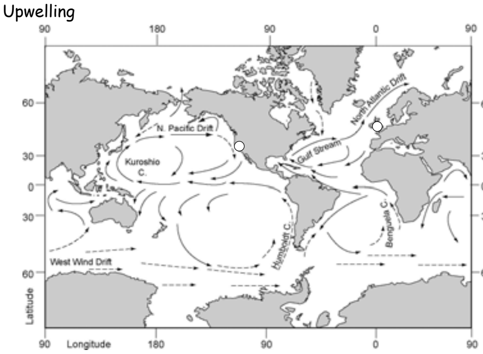
- Upwelling at lower latitudes, western continental margins due to Coriolis effect.



2.10

Ocean currents move 40% of “excess heat” from equator to poles (60% of heat transport is carried by atmosphere through storms that move along pressure gradients).

Oceans affect terrestrial climate by
1. High heat capacity of water
2. Currents
3. Upwelling

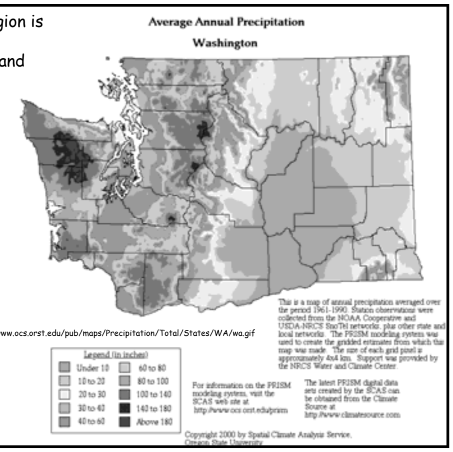


2.9

E. Landform effects on climate

Mountain effects
- Orographic precipitation
- Rain shadow
- Effects of aspect
- Air drainage (inversion, arising due to topography, where cold air settles in valleys, for example)

Climate of any region is predictable from topography, wind and ocean currents

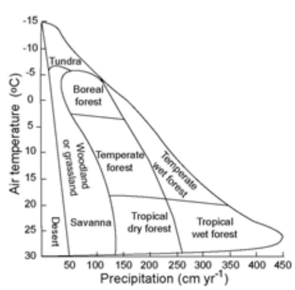


http://www.ocs.orst.edu/pub/maps/Precipitation/Total/States/WA/wa.gif

F. Vegetation effects on climate

Climate effects on vegetation

In space (global distribution)…



2.21

Vegetation effects on climate

Vegetation can affect components of surface energy balance

$$Rt - r(a) = \lambda E + C + G$$

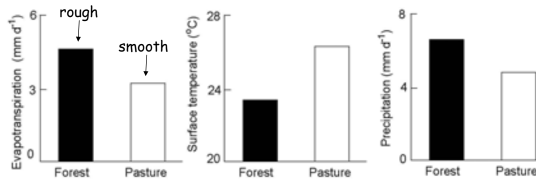
1. *Rt* is total solar radiation reaching Earth
2. *r* is reflected radiation, a function of albedo (a)
3. λE is latent heat transfer, driven by evapotranspiration
4. *C* is convective heat transfer (sometimes called sensible heat flux)
5. *G* is storage

Vegetation can alter albedo

- Leaf color
  - Land-use change:
    - Grazing, exposes soil, increases albedo, reducing net radiation, decreasing latent heat flux (less evapotrans)
    - Over large enough scales, such changes can alter regional precipitation
    - Similar phenomenon for deforestation

Tree migration into tundra
- Tundra is snow-covered in winter, very high albedo
- With warming, trees could advance, decreasing winter albedo dramatically
- Potentially, creates a positive feedback to warming

Vegetation change effects on climate in the Amazon Basin



2.11

Rough canopies promote turbulence, increasing air exchange and evapotranspiration (λE)

Smooth canopies have large boundary layers, impeding transfer of water vapor, decreasing latent heat flux (λE), increasing sensible heat flux (C) and storage (G)

Bottom-line: conversion of forest to pasture leads to lower rainfall.

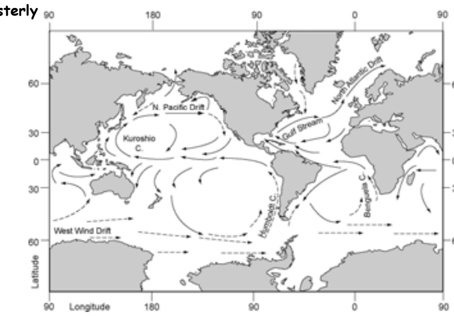
II. Changes in climate

A. Seasonal (see I.B.)
B. Yearly (interannual)
C. Millenial scales
D. Human impacts

- Is global warming for real?
- How do we know that it isn't just a natural fluctuation in temperature?
- What are some of the forces that lead to natural climate variability?

II.B. Interannual Variation – El Niño Southern Oscillation

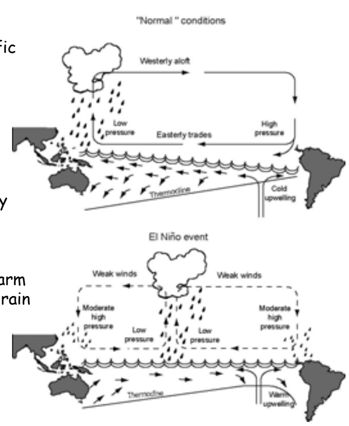
- The Pacific Ocean strongly influences the global climate system because it is the largest ocean basin
- Normal ocean current and wind direction in central Pacific is easterly



2.9

ENSO events result from weakening of tropical Pacific atmospheric and oceanic circulation

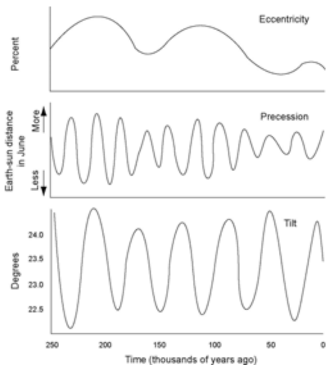
Climatic connections carry these climate effects throughout the globe (e.g., El Niño creates warm winters in AK and lots of rain in Calif)



2.19

II. C. Millenial scale variation

Changes in orbit cause long-term variations in solar input to Earth



Shape of orbit (100,000 yrs)

Wobble of tilt (23,000 yrs)

Angle of tilt (41,000 yrs)

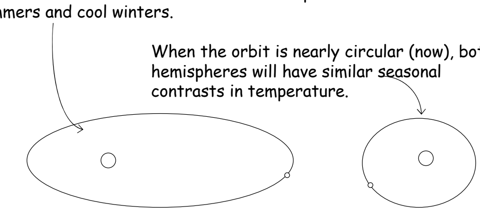
2.14

Eccentricity:

The Earth's orbit around the sun is an ellipse. The shape of the elliptical orbit, which is measured by its eccentricity, varies through time.
The eccentricity affects the difference in the amounts of radiation the Earth's surface receives at aphelion and at perihelion.

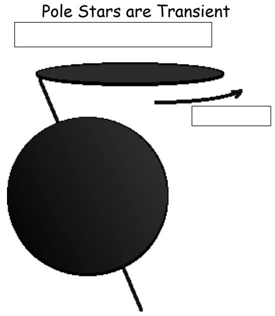
When the orbit is highly elliptical, one hemisphere will have hot summers and cold winters; the other hemisphere will have warm summers and cool winters.

When the orbit is nearly circular (now), both hemispheres will have similar seasonal contrasts in temperature.



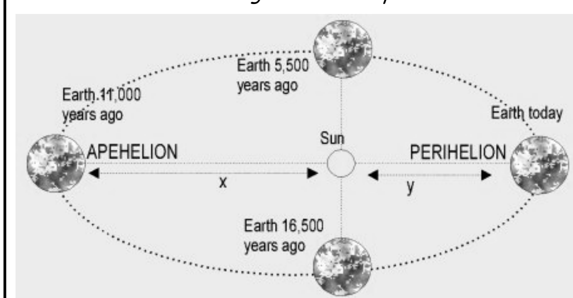
Rotation axis executes a slow precession with a period of 23,000 years (see following figure)

Pole Stars are Transient



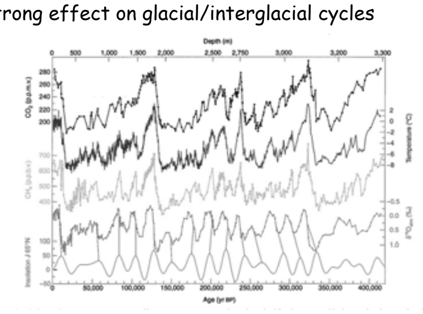
Wobble in the tilt

Precession: Present and past orbital locations of the Earth during the N Hemisphere winter



Milankovitch cycles

- The interactive effects of Earth's orbital variation on timing and distribution of total solar input.
- Strong effect on glacial/interglacial cycles



http://en.wikipedia.org/wiki/Image:Vostok_420ky_4curves_insolation.jpg

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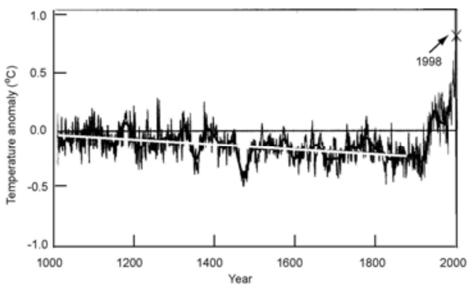
D. Human effects

- Global warming

Earth's climate is now warmer than at any time in the last 1000 years



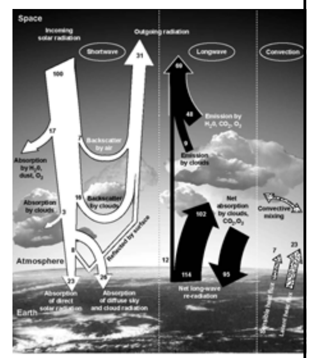
2.16

How can the atmosphere warm?

1. Increased solar input

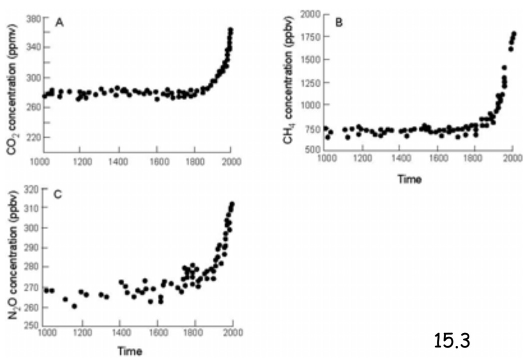
2. Less reflected shortwave, less sulfate aerosols, darker surface of Earth (land-cover change)

3. More absorbed longwave more "greenhouse gases"



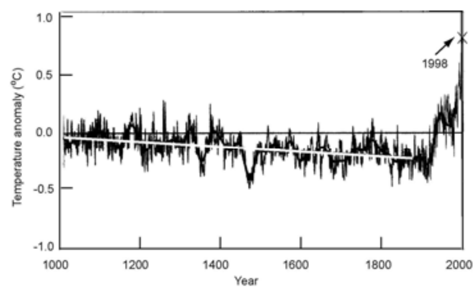
2.2

Most major greenhouse gases are increasing in atmospheric concentrations



15.3

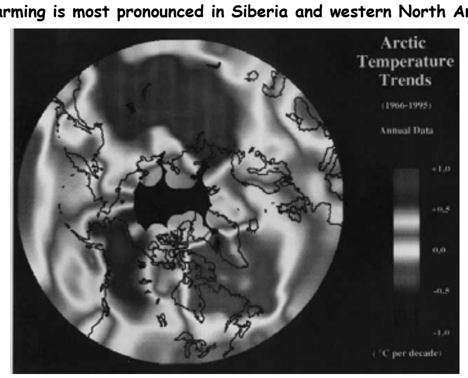
Earth's climate is now warmer than at any time in the last 1000 years
1. increased solar input (small warming effect)
2. Increased sulfate aerosols reflects radiation (small cooling effect)
3. Increased greenhouse gas concentrations (large warming effect)
4. Land-cover change creates a darker surface (large warming effect)



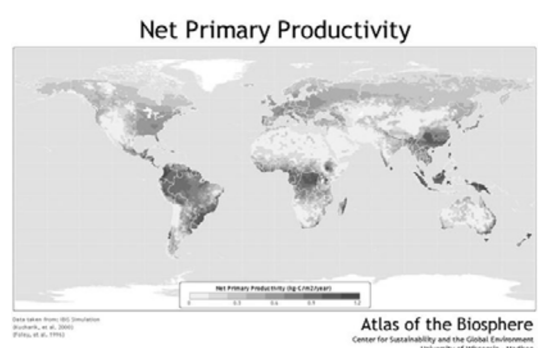
2.16

Climate is warming most rapidly at high latitudes

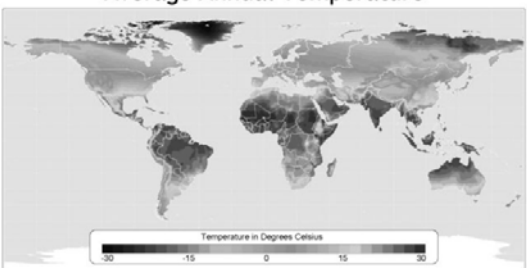
This warming is most pronounced in Siberia and western North America



Summary: Functioning of ecosystems varies predictably with climate



Average Annual Temperature



Data taken from: CRU 0.5 Degree Dataset (New, et al.)

Atlas of the Biosphere
Center for Sustainability and the Global Environment
University of Wisconsin - Madison

Annual Total Precipitation

Atlas of the Biosphere
Center for Sustainability and the Global Environment
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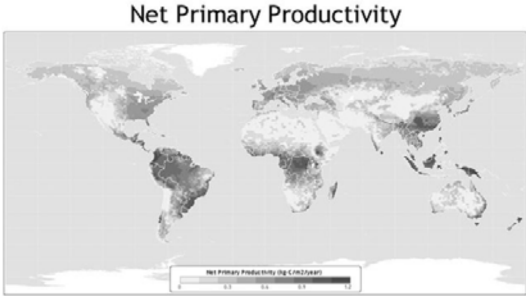
Combination of temperature and precipitation

Net Primary Productivity



Data taken from: IBIS Simulation
(Kucharik, et al. 2000)
(Foley, et al. 1996)

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