Agronomy 406
World Climates

April 3, 2018

Causes of natural climate changes (finish).

Schedule is being adjusted. No change to due dates.

Bring IPCC Fifth Assessment Report Summary for Policymakers to class on Thursday and next Tuesday (linked from course schedule). Either printed or electronic copy is OK.

Semester project topics

You can modify the focus of your semester project (fact sheet and poster), for example if your original topic was too broad.

You **must** email any changes in your topic and title to me by this Thursday, April 5 and get my written (email) approval.

You are encouraged to discuss your changes with me but any discussion **must be confirmed by email.**

Variations in earth-sun geometry: Milankovich cycles

Three cycles relating to the shape of Earth's orbit or rotation on its axis:

Obliquity

- Tilt of earth's axis relative to its plane of orbit.

Eccentricity

- Deviation of earth's orbit from a perfect circle.

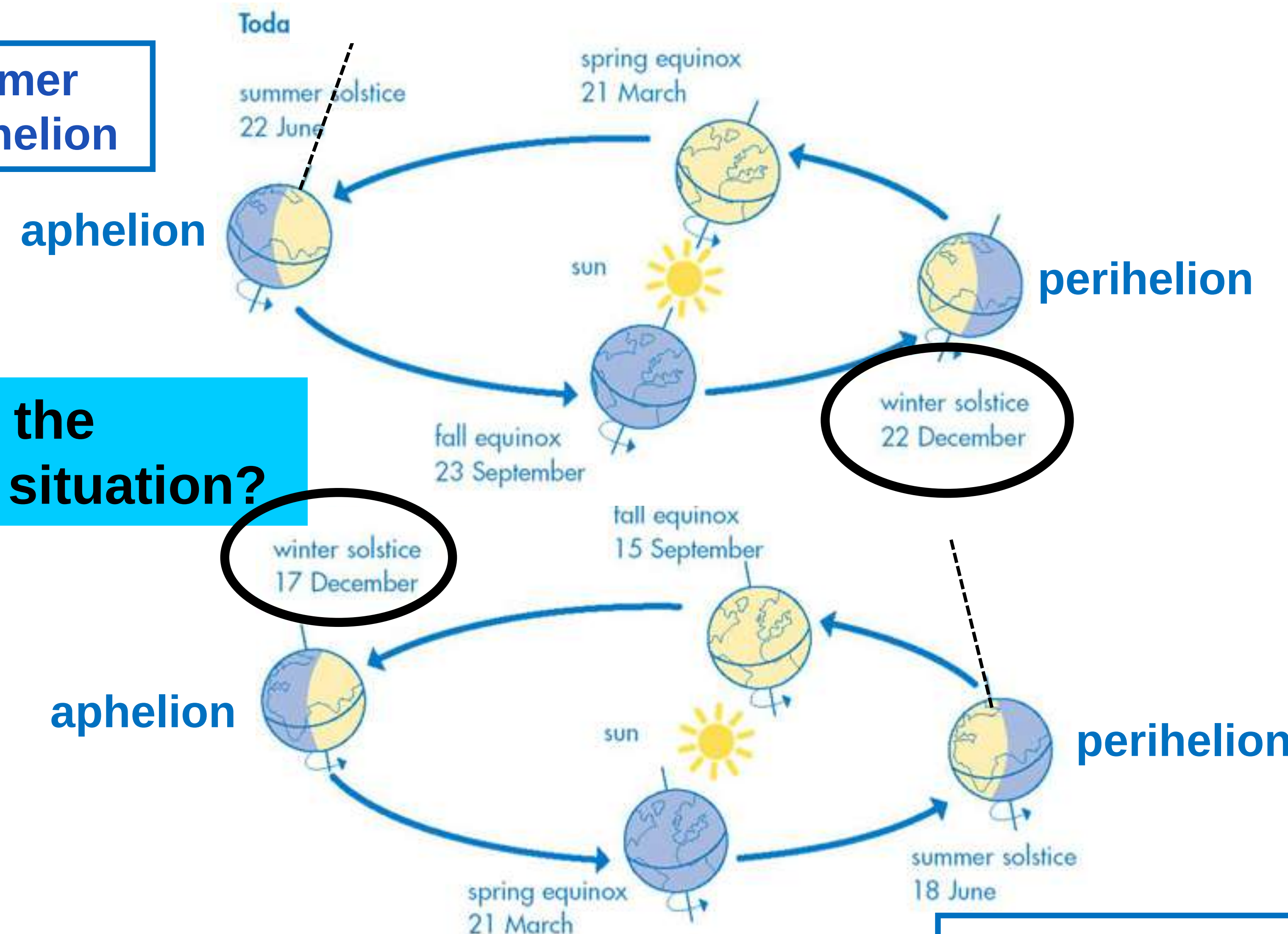
Precession

- Change in direction that the axis points.

Combining precession and eccentricity

NH summer near aphelion

What is the current situation?



NH summer near perihelion

Team question

Assume: Onset of glaciation occurs when summertime insolation in the **sub-polar latitudes of the Northern Hemisphere** (~60ºN) is too low to melt all the ice and snow that formed in the previous winter.

This allows snow cover to carry over to the next year and gradually accumulate over time.

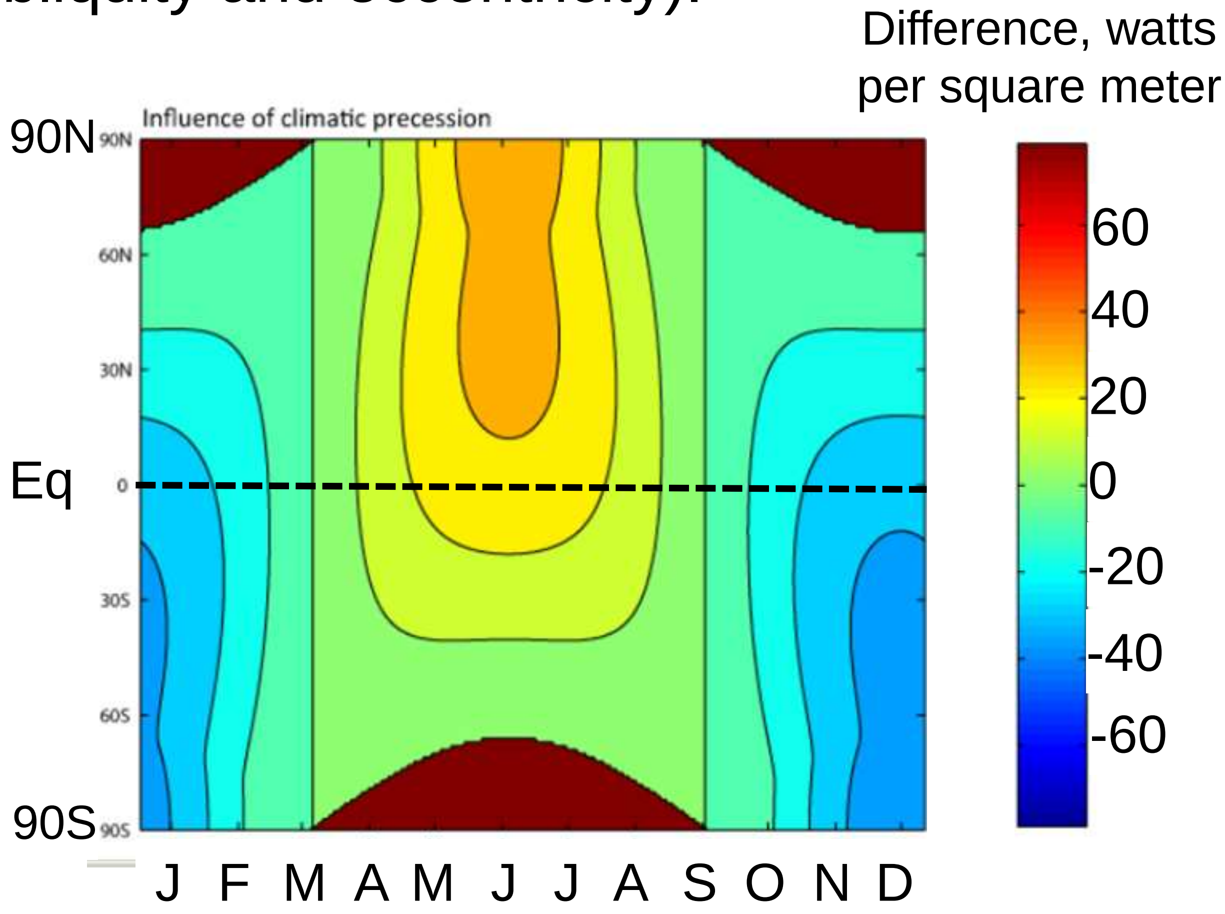
> Assuming this is true, what **combination of eccentricity and precession** would be most conducive to onset of glaciation?

Effect of precession on insolation

NH summer at perihelion versus NH winter at perihelion (with present obliquity and eccentricity).

Notice increases (yellow-red shading) balance decreases (blue shading).

Total sunlight stays the same but we "move sunlight around."



Using the Milankovitch cycles to understand past (and future?) climate

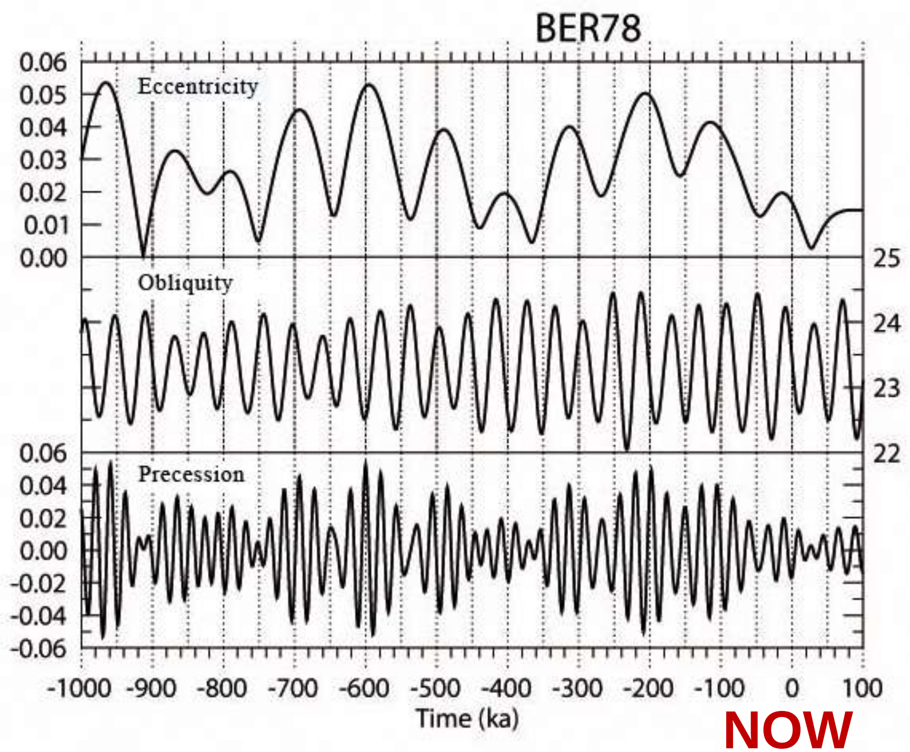
Cycles of eccentricity, obliquity and precession result from gravitational interaction of Earth, sun, moon and planets.

We can solve for these interactions to find the strengths of the cycles and change of insolation over time.

eccentricity

obliquity

precession
(interaction of precession with eccentricity)

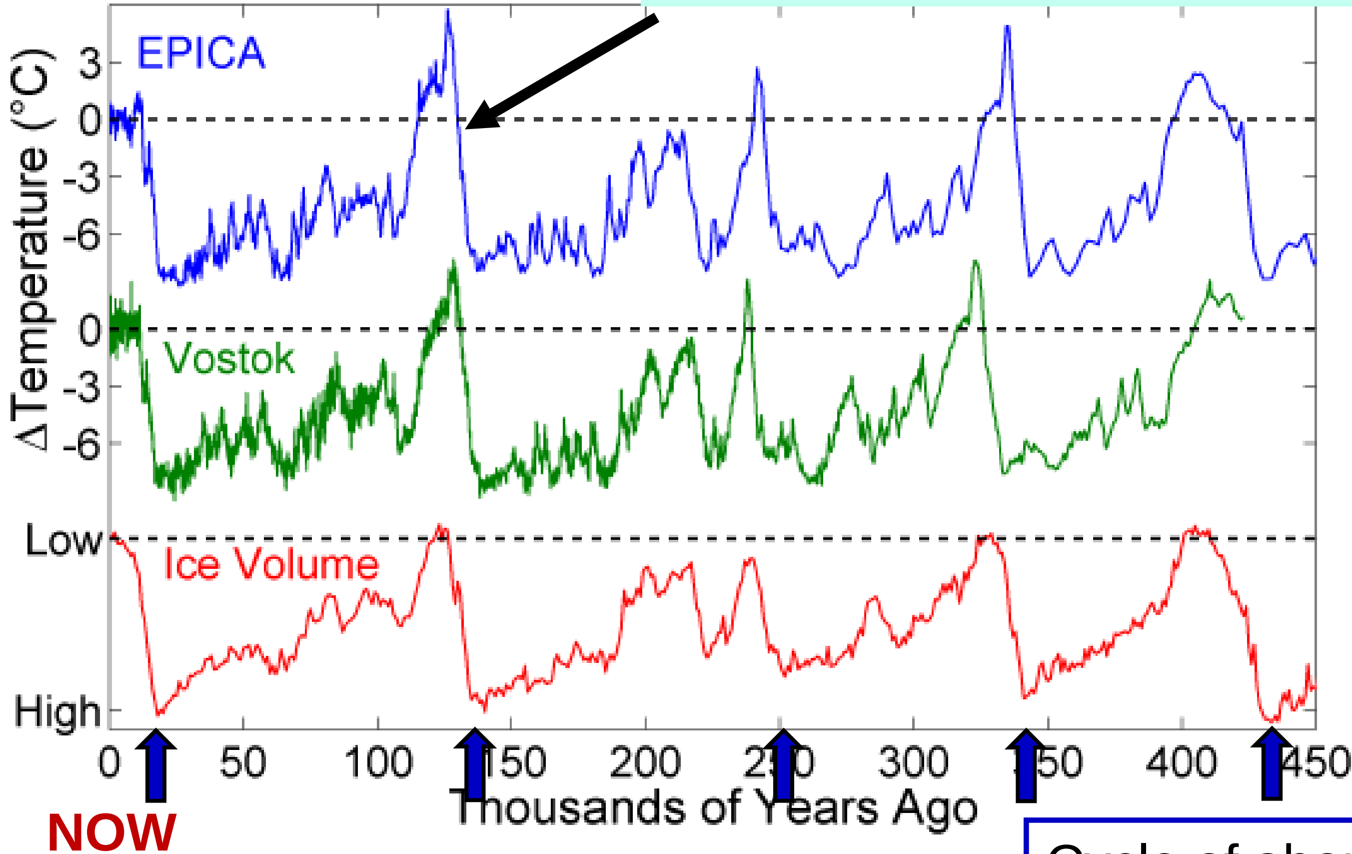


Notice **the strength of each cycle varies**.

Based on Berger (1978, Quat. Res.). See also Williams (1994, Astron. J.)

Temperature inferences from two Antarctic ice cores and ice volume estimate from benthic foraminifera

notice rapid exit from glacial periods



Cycle of about 100,000 yr. **Probably** related to eccentricity.

figure by Robert Rohde, from Global Warming Art

A puzzle

Earth-sun geometry changes slowly, with cycles of 23,000-100,000 years.

But exits from ice ages are much more rapid (about 5,000 years).

What speeds things up?

Positive feedbacks can cause an initial change to rapidly intensify. Examples:

- CO_2 feedback
- Ice-albedo feedback

Feedback

"Feedback" happens when different processes (call them A and B) affect each other:

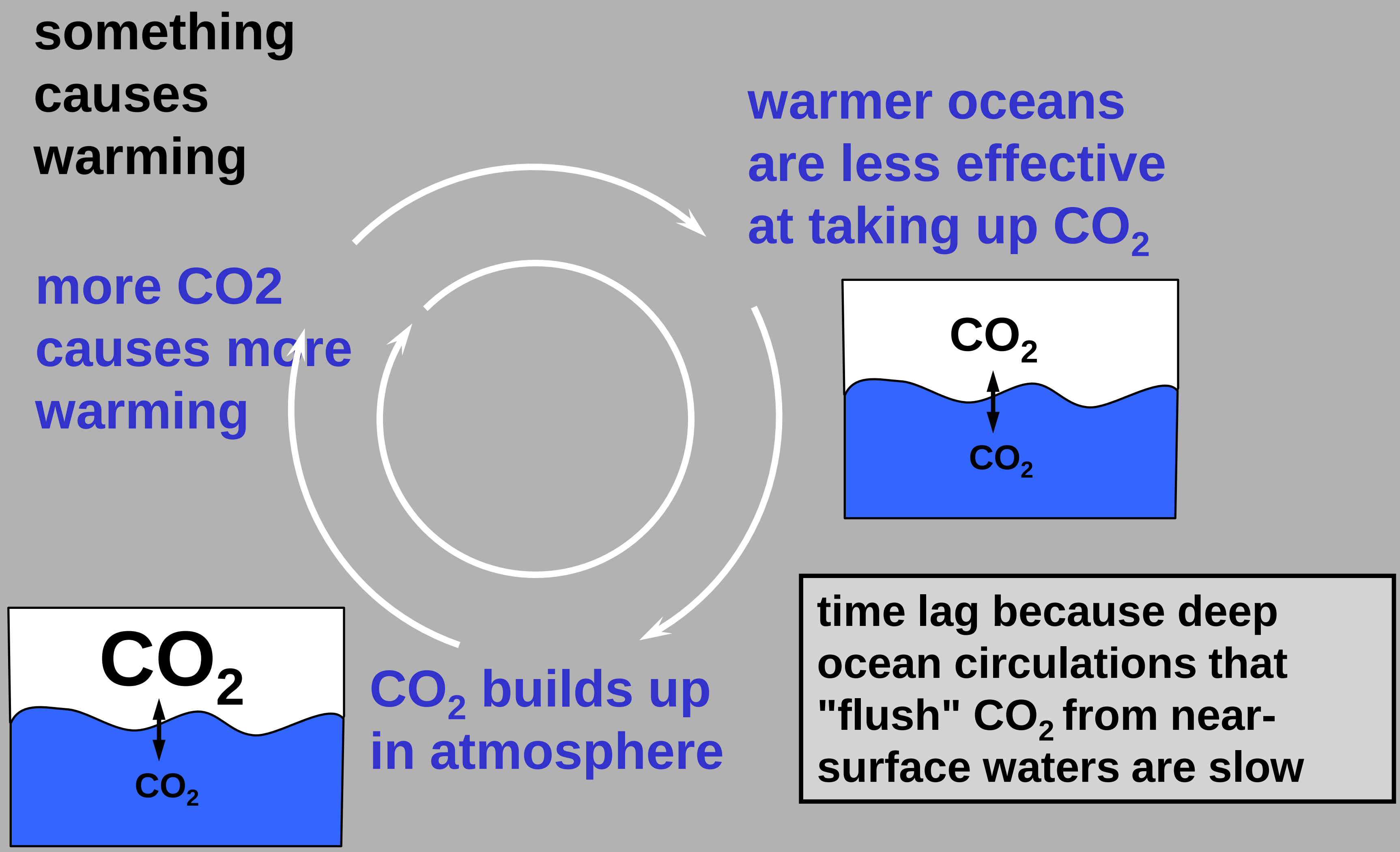
- A causes B
- But B also causes A

Like feedback with a microphone:

- The microphone (A) picks up sound from the speakers (B).
- The speakers (B) amplify sound from the microphone (A).
- The microphone then picks up the louder sound.

Once a feedback "loop" begins, changes build on themselves and can grow quickly.

One type of carbon dioxide feedback



Cause and effect:
What do you think?

So: does increased CO_2 cause warming, or does warming cause increased CO_2?

Cause and effect: What do you think?

So: does increased CO_2 cause warming, or does warming cause increased CO_2?

Answer: Yes.

See "CO2 as a Feedback and Forcing in the Climate System" by Zeke Hausfather, Yale Forum on Climate Change and the Media.

https://www.yaleclimateconnections.org/2007/10/common-climate-misconceptions-co2-as-a-feedback-and-forcing-in-the-climate-system/

Getting out of ice ages

CO_2 as a feedback has two effects on the exit from ice ages:

warming $\Rightarrow$ more CO_2 $\Rightarrow$ more warming $\Rightarrow$ more CO_2

warming $\Rightarrow$ more CO_2

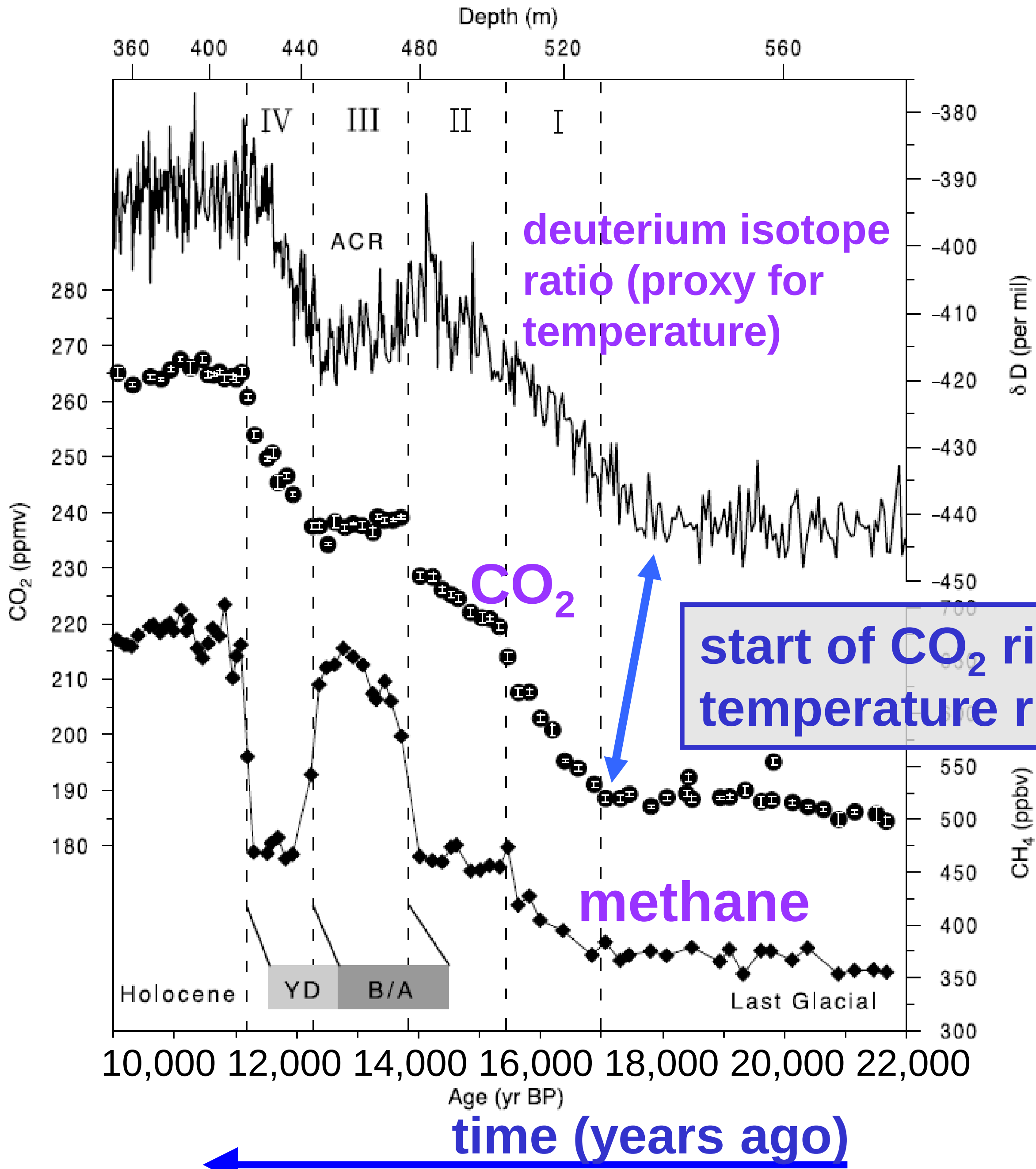
$\Rightarrow$ CO_2 **spreads over the Earth**

$\Rightarrow$ warms the **whole Earth**, not just the region that was originally warmed.

CO_2 has a long atmospheric lifetime (100++ years) which is more than enough time for it to spread over the whole Earth (takes about 3 years).

Increased methane (another greenhouse gas) also plays a role.

Data from Vostok ice core (Antarctica) during the exit from the Last Glacial Maximum



adapted from Monnin et al. 2001, *Science* 291, 112-114

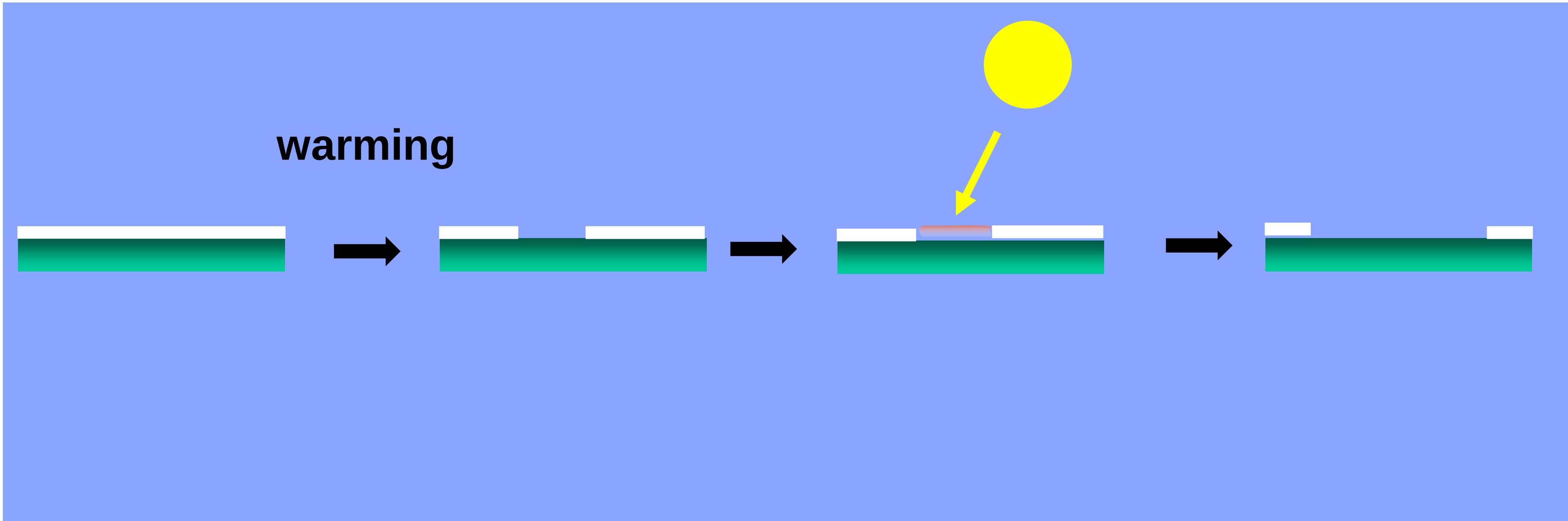
Ice-albedo feedback

Another feedback process involves melting ice:

initial warming ⇒ ice melts

⇒ lower albedo ⇒ more sunlight absorbed

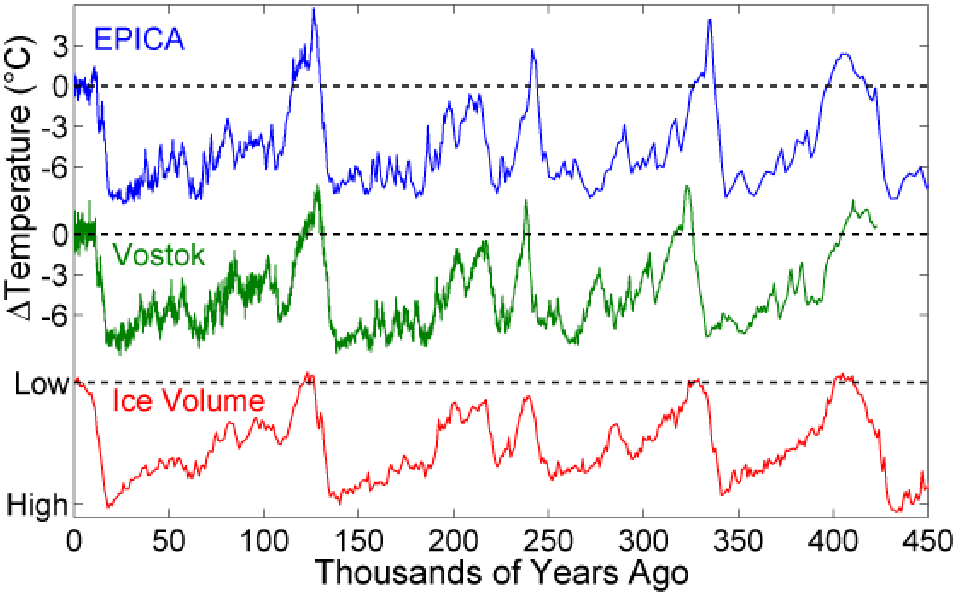
⇒ more warming ⇒ more ice melts...



Getting out of ice ages

Changes in orbital parameters (eccentricity, obliquity, precession) start the exit from glacial to interglacial periods.

Feedback processes then speed up the warming.



Long term changes in solar output

Energy radiated by the sun has gradually increased since formation of the Earth. This is a property of **main sequence** stars:

Luminosity increases about 0.7% every 100 million years.

"Faint Young Sun paradox" mentioned in the Alley video: Solar radiation was about 30% lower in Earth's early history, yet liquid water existed.

Leading hypothesis is higher concentration of CO_2 in the early atmosphere.

Shorter term changes in solar output

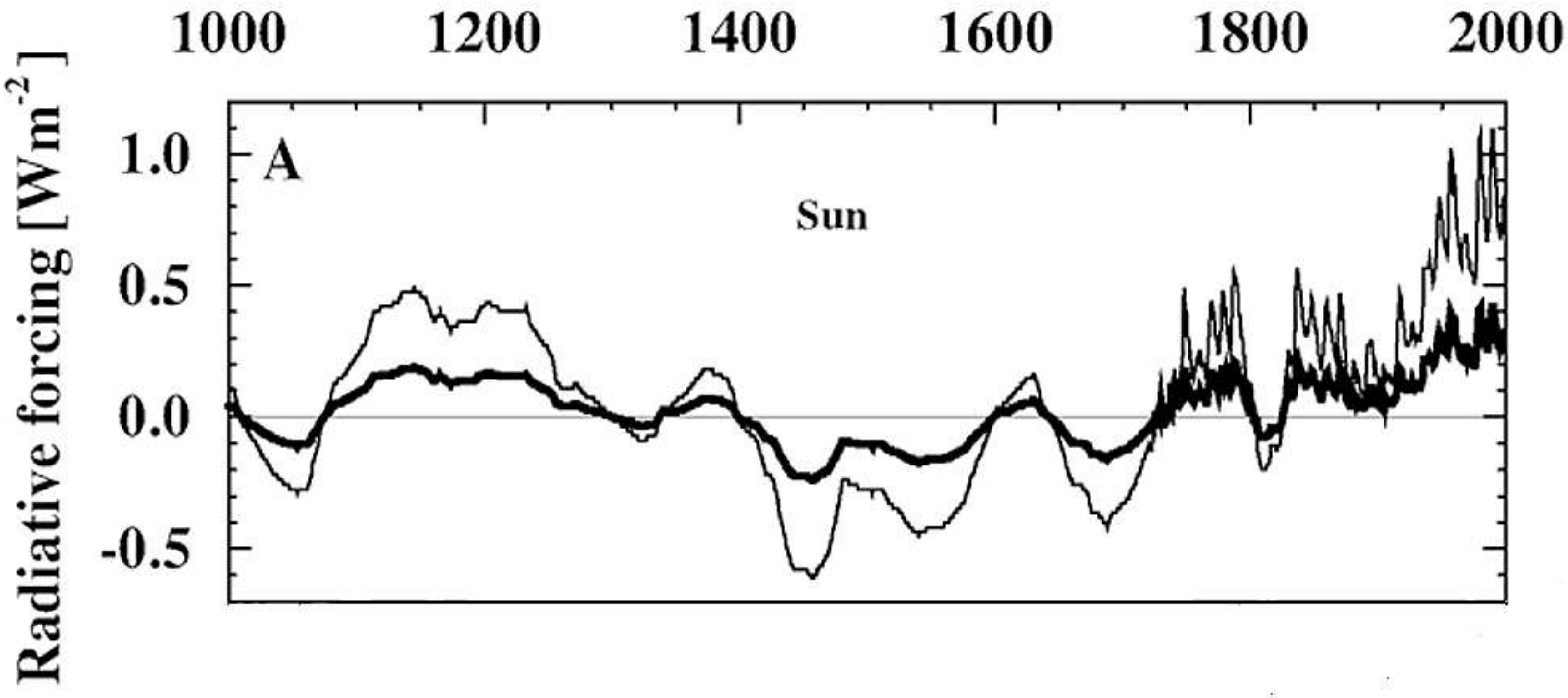
Solar radiation fluctuates slightly (about 0.1%, or 1 W m^{-2}) over the 11-year sunspot cycle.

Effect is very small but can be detected, especially in the upper atmosphere.

Less regular fluctuations in solar output also have occurred over historical times (also about 1 W m^{-2}).

Too small to produce significant climate changes unless some as yet unknown **feedback process** amplifies the change.

Two reconstructions of solar radiation over the past 1000 years



from Gerber et al. (2003), *Climate Dynamics* 20, 281-299.

Energy balance

Remember our simple energy balance model for the Earth:

$$E_{out} \quad = \quad E_{in}$$

Putting in definitions of E_{out} and E_{in} gives

$$(4\pi R^2) \text{ x } (\sigma T_e^4) = S_0 \text{ x } (\pi R^2) \text{ x } (1-\alpha_p)$$

which we solved for T_e to get

$$\mathbf{T_e = [S_F\ (1 - \alpha_p) / 4\sigma]^{1/4}}$$

Class problem

Using the solution for temperature from our global energy balance model,

$$T_e = [S_F (1 - \alpha_p) / 4\sigma]^{1/4}$$

we inserted values of

$S_F = 1361$ W m^{-2}

$\alpha_p = 0.30$

$\sigma = 5.67\times10^{-8}$ W m^{-2} K^{-4}

which gave $T_e = 254.58$ K

Class problem

1. (Odd numbered teams): Suppose ice cover declined so that albedo of Earth decreased to $\boldsymbol{\alpha_p = 0.29}$. What would be the **change** in mean Earth temperature?

2. (Even numbered teams): The solar constant (S_F) may have been as much as **1.5 W m^{-2} lower** at some times in the past 2000 years. What would have been the corresponding **change** in mean Earth temperature compared to present?

Volcanoes

Volcanos have both long-term and short-term effects on climate.

Long term: Effects on CO_2 concentration.

Usual time scale of ~500,000+ years.

Discussed in the Alley video.

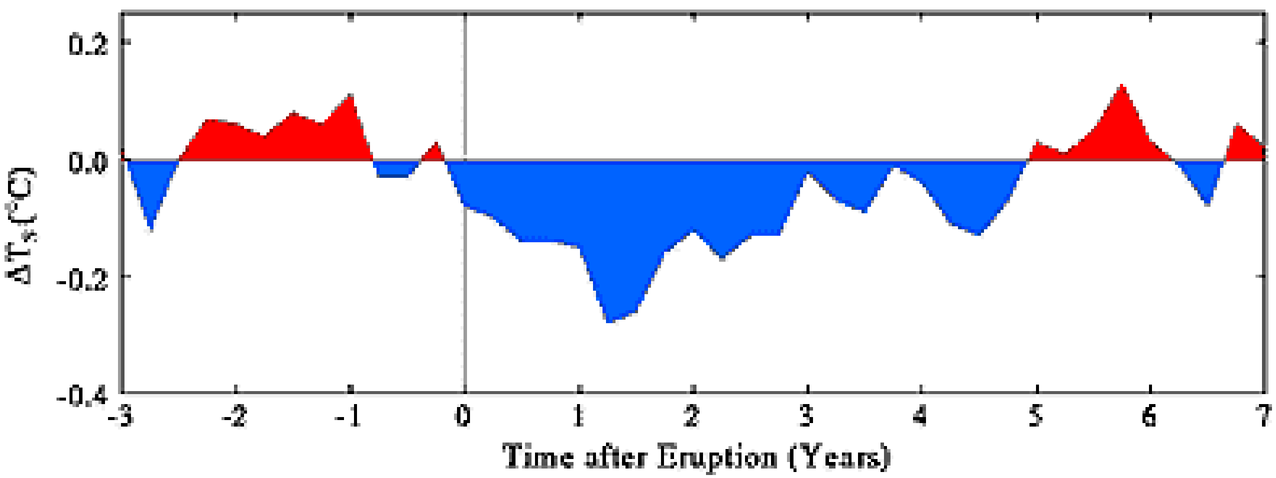
Short term:

Major eruptions can have dramatic effects on climate.

Effects seldom last more than a few years.

Intensity and duration of climate effect depends on how much material is put into the **stratosphere.** (Why not the troposphere?)

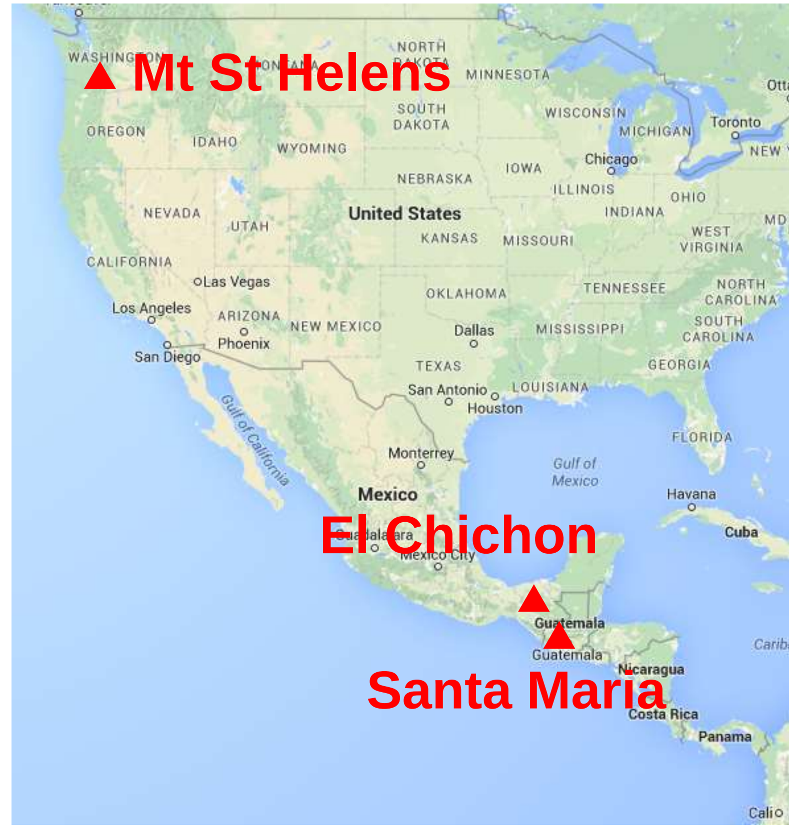
Composite trend of global surface temperature anomalies following the strongest volcanic eruptions since 1880



Composite temperature anomalies following eruptions of Krakatau (1883), Santa Maria (1902), Agung (1963), El Chichon (1982) and Pinatubo (1991).

source: http://www.giss.nasa.gov/research/briefs/hansen_02/

Locations of major volcanic eruptions since 1800



Quantifying eruptions

Probably most common is **Volcanic Explosivity Index.** Depends on:

volume of material ejected.

height to which the material is ejected.

Applied only to explosive eruptions.

Volcanic Explosivity Index

VEI	Description	Plume Height	Volume	How often	Example
0	non-explosive	< 100 m	1000s m3	daily	Kilauea
1	gentle	100-1000 m	10,000s m3	daily	Stromboli
2	explosive	1-5 km	1,000,000s m3	weekly	Galeras, 1992
3	severe	3-15 km	10,000,000s m3	yearly	Ruiz, 1985
4	cataclysmic	10-25 km	100,000,000s m3	10's years	Galunggung, 1982
5	paroxysmal	> 25 km	1 km3	100's years	St. Helens, 1981
6	colossal	> 25 km	10s km3	100's years	Krakatau, 1883
7	super-colossal	> 25 km	100s km3	1000's years	Tambora, 1815
8	mega-colossal	> 25 km	1,000s km3	10,000's years	Yellowstone, 2 Ma

A long-term stabilizer of climate: The CO_2 – rock weathering "thermostat"

Basic ideas:

Over long times **volcanoes add large amounts of CO_2** to the atmosphere.

CO_2 is removed from by **weathering of rocks**: CO_2 reacts with rock material and the dissolved products are carried to sea.

Both processes **usually** are slow (~500,000+ years for a significant climate effect).

Removal of CO_2 by rock weathering is **temperature dependent:** warm climates have more precipitation, which causes more weathering.