The carbon cycle
A story of timescales and movement of elements

We already know…

- CO_2 is an important greenhouse gas
- Even though it is a small component of air (386 ppm!) it is important for radiation because it absorbs longwave radiation in the "window" region of the spectrum. (*i.e., increasing CO_2 "closes" the window*)
- $CO_2$was about 280 ppm before the industrial revolution

- Where does CO2 come from?
- Where does it go?
- What are the important parts of the carbon cycle which control the amount of CO2 in the atmosphere?

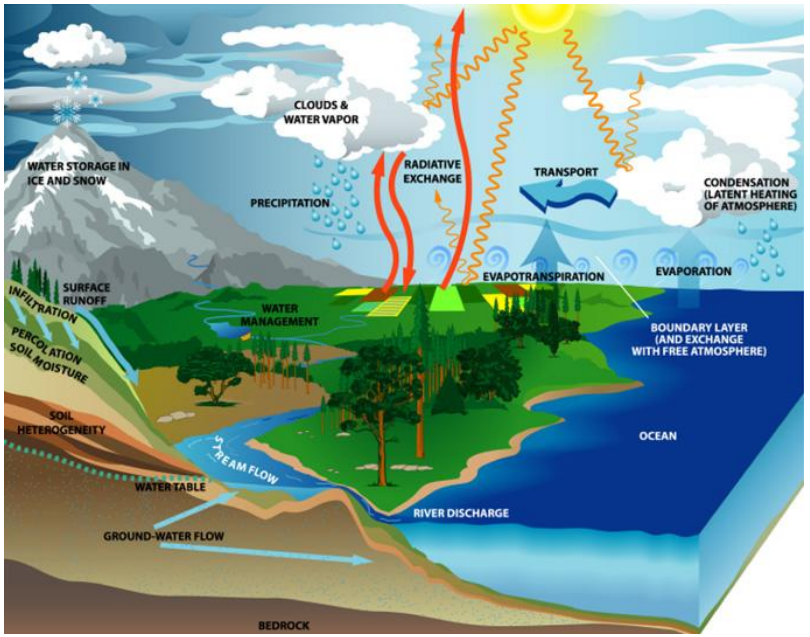
Until humans came along…

a) CO_2 was always lower than present
b) CO_2 was mostly lower than present
c) CO_2 was mostly higher than present
d) CO_2 was always higher than present
e) CO_2 was both lower and higher than present

Circulation of elements

- Earth's circulation system includes atmosphere, ocean, and lithosphere

- Recall water evaporated from the ocean was moved around in the atmosphere, and ultimately recovered after precipitation by river flow



Carbon can move around the Earth system in a similar way.

There are sources, sinks, and storage reservoirs of carbon.

Carbon

Organic carbon

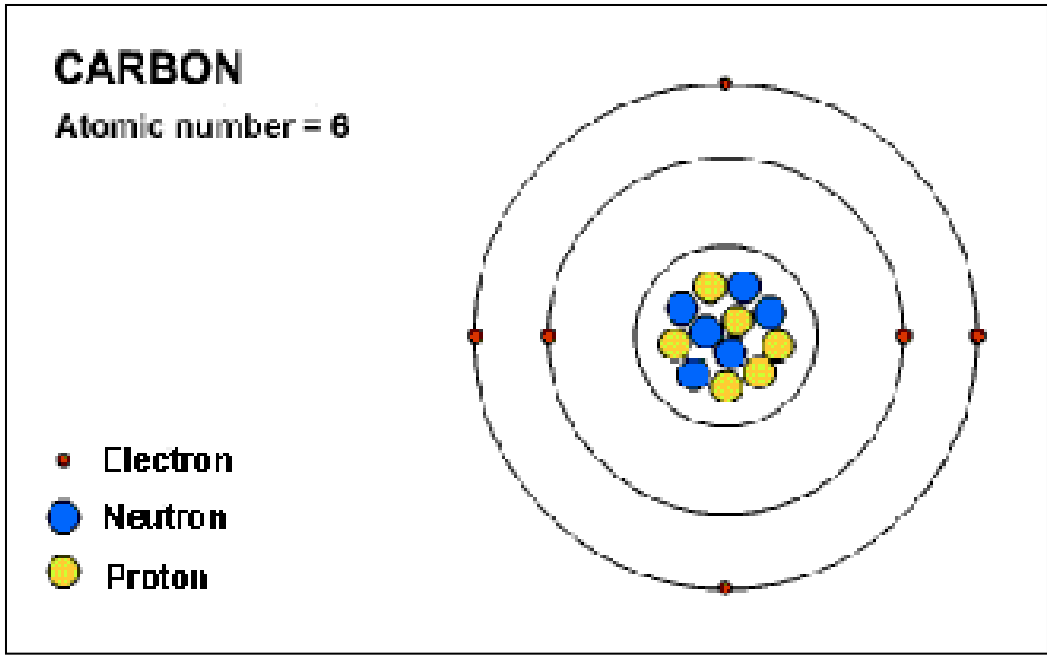
molecules with carbon and hydrogen (e.g., CH4, …). Also oxygen, nitrogen.

Associated with life

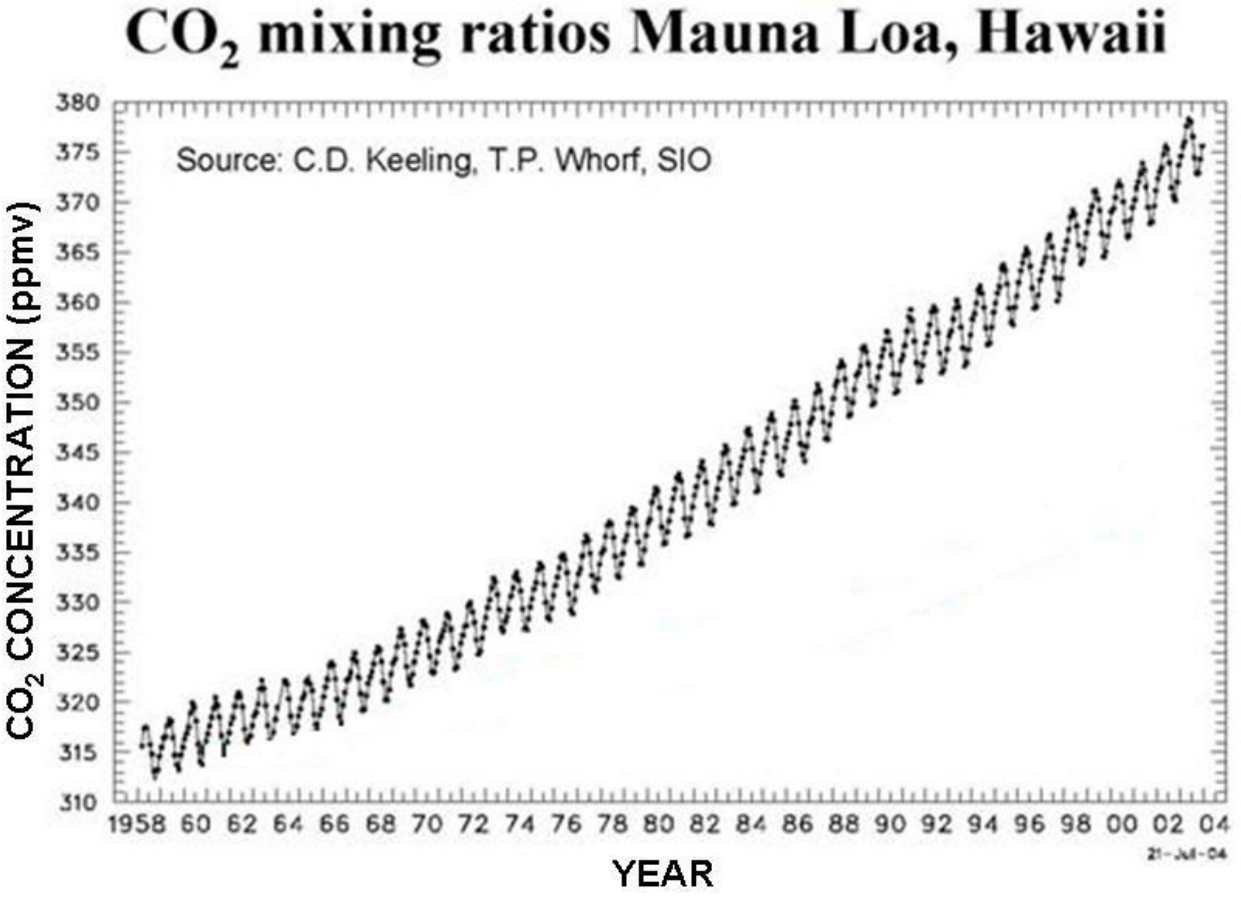
Inorganic carbon

Rocks, graphite, diamonds …. and CO_2

Not associated with life



Increasing carbon dioxide (CO_2)

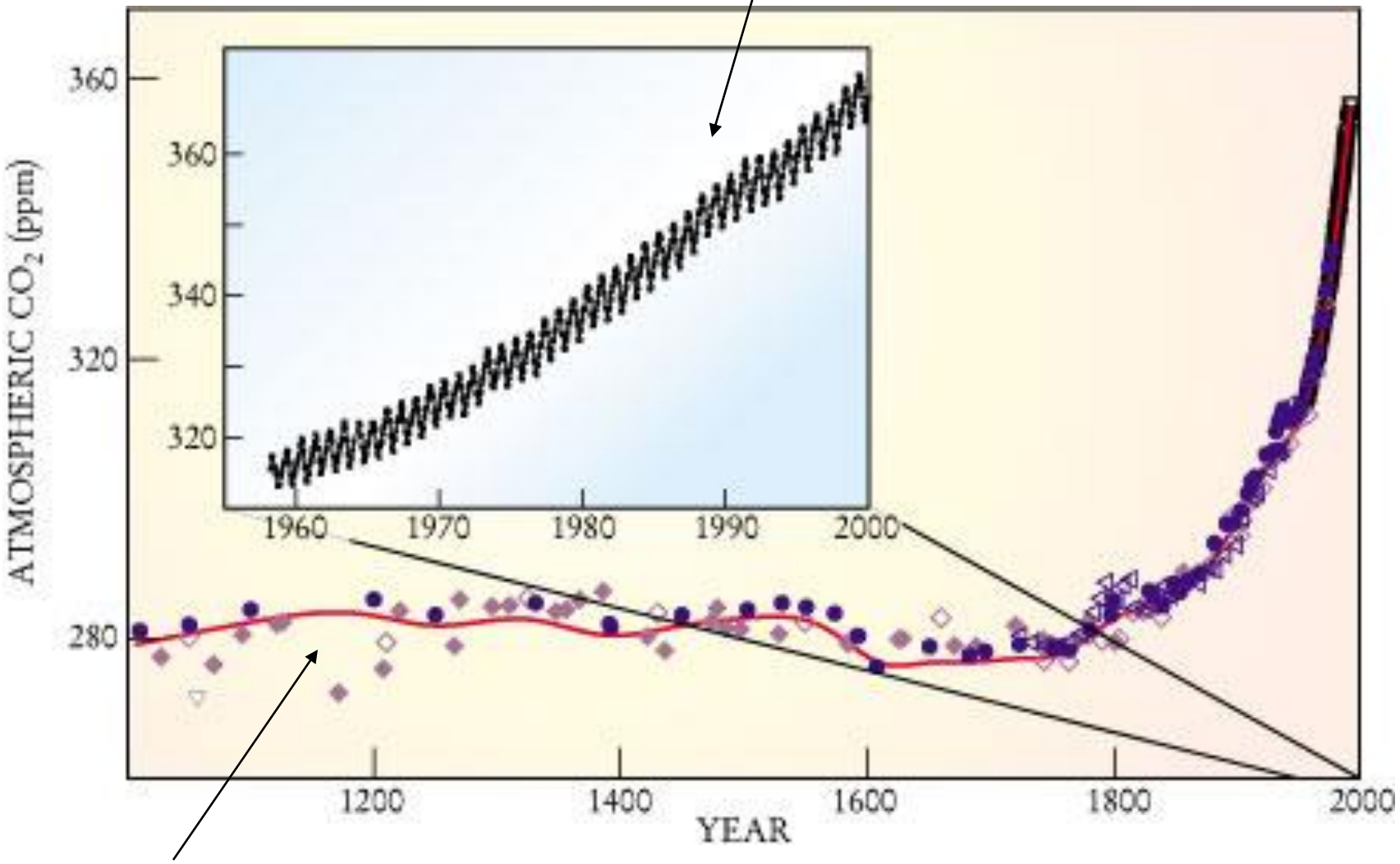


Charles (Dave) Keeling

Where does trend come from?

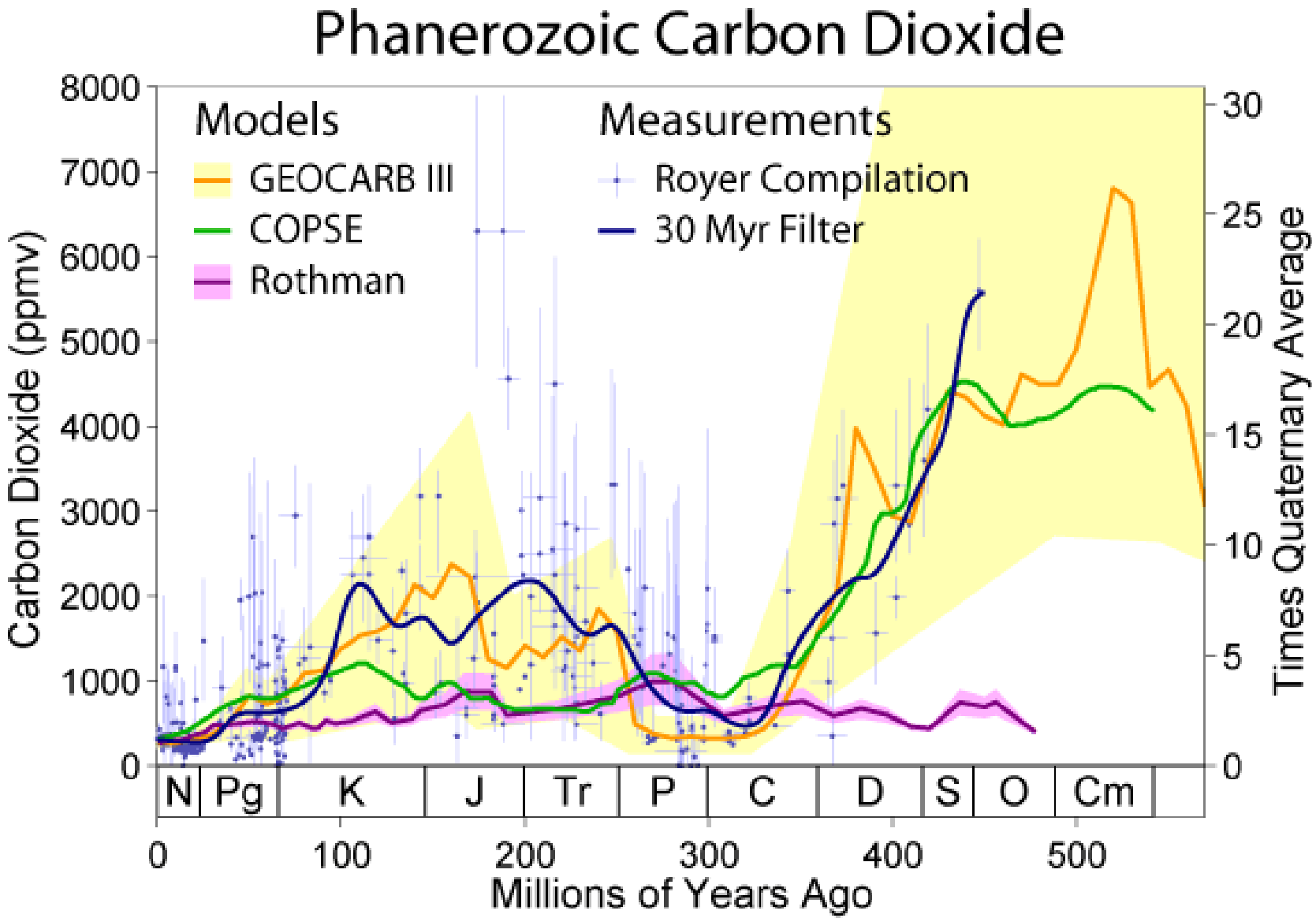
Why is the line wiggly?

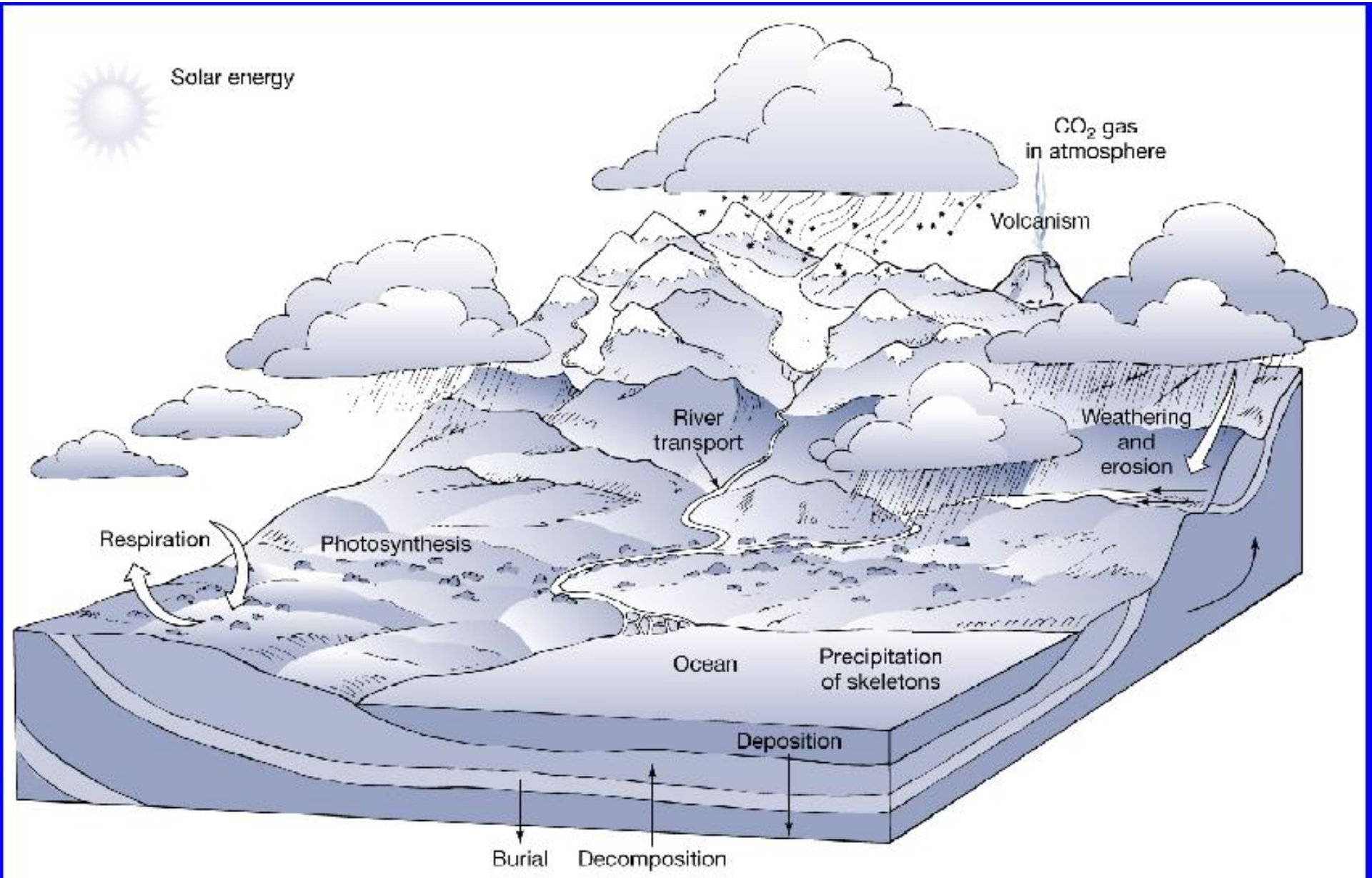
Air samples (now at CMDL)

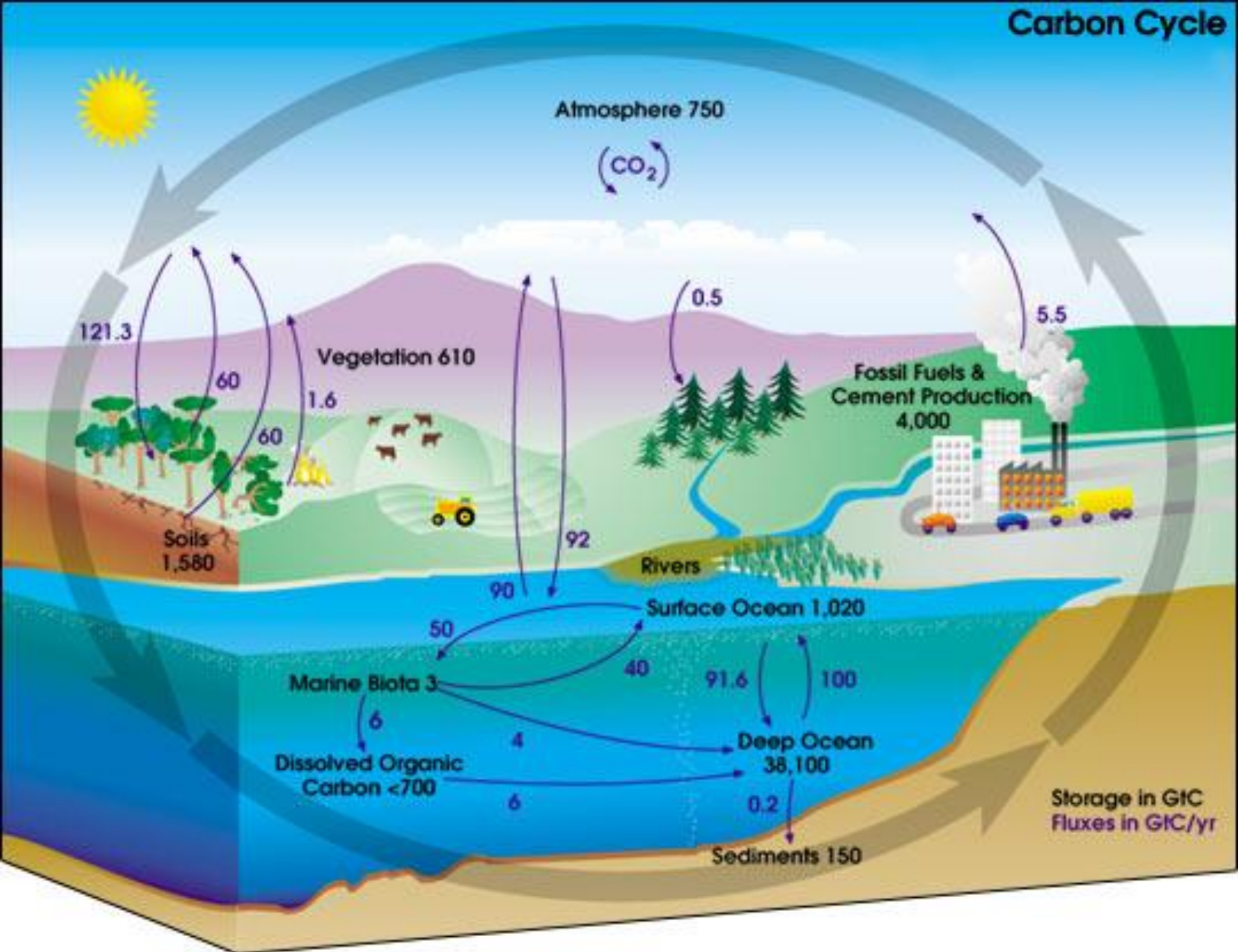


Antarctic ice core

Changes in atmospheric CO_2






Carbon Cycle
Atmosphere 750
(CO_2)
121.3
60
60
1.6
Vegetation 610
0.5
5.5
Fossil Fuels &
Cement Production
4,000
Soils
1,580
92
90
Rivers
Surface Ocean 1,020
50
40
Marine Biota 3
91.6
100
6
4
Deep Ocean
38,100
Dissolved Organic
Carbon <700
6
0.2
Sediments 150
Storage in GtC
Fluxes in GtC/yr

What is the residence time in the atmosphere if the annual photosynthesis flux is 60 Pg/year, and the atmosphere holds 600 Pg of carbon?

a) Less than 1 year
b) 1 year
c) 10 years
d) 100 years
e) 1000 years

Which of the following would be most likely to influence year to year variations in atmosphere $CO_{2?}$

a) Atmospheric circulation
b) Oceanic circulation
c) Changes in land vegetation
d) Changes in subduction
e) Variations in use of fossil fuels

Fluxes and reservoirs

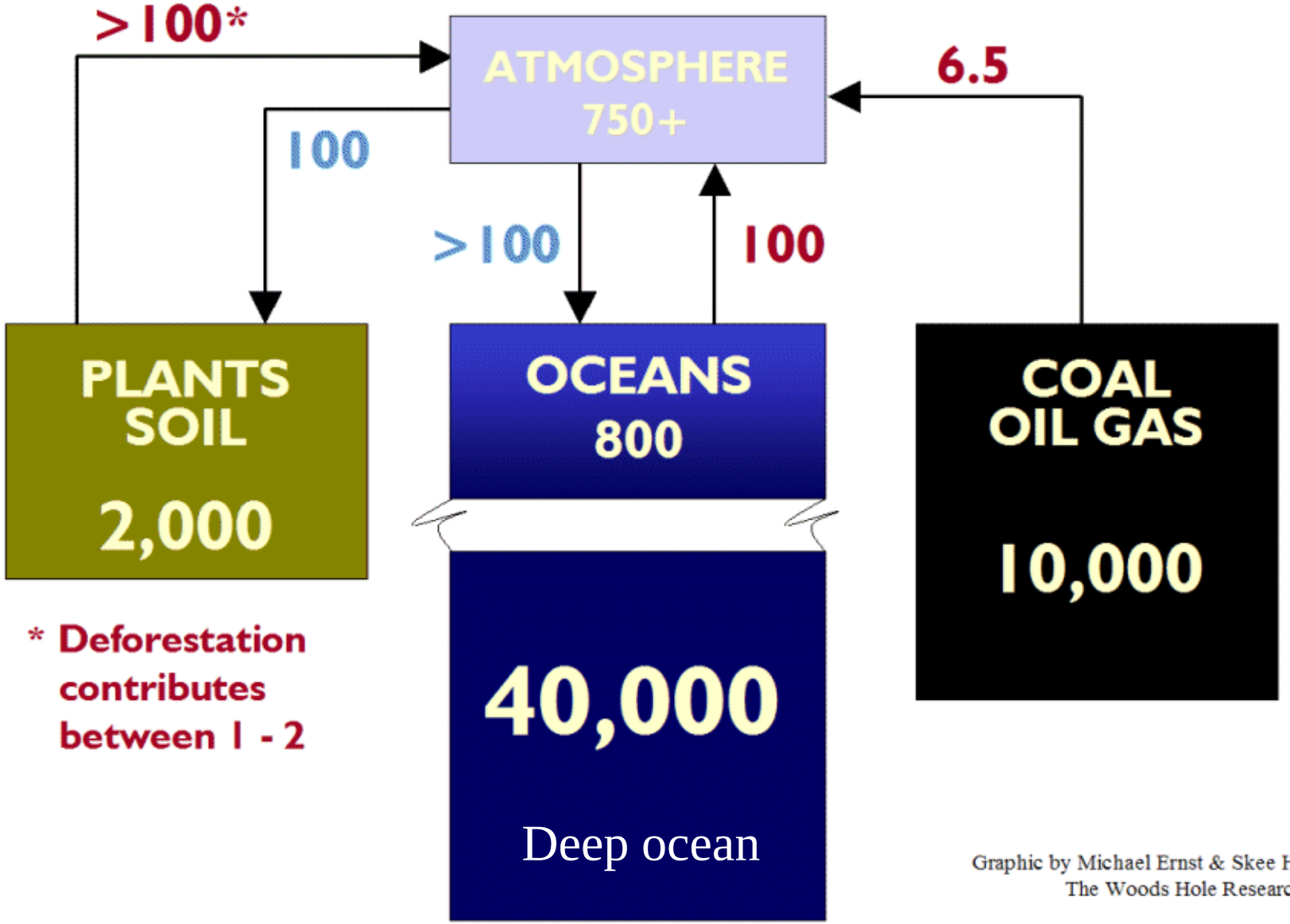
- We have talked about flux (*units of "stuff", e.g., $J/m^2/s = W/m^2$*)
- Reservoir is just the size of the store (*Just how big is David's jar of M&Ms?)*

- For carbon cycle, use Peta grams (Pg) (10^{15} grams)
- And fluxes, typically quoted as Pg/year
- 1 Pg is the same as a Gt (gigaton)

Global Flows of Carbon

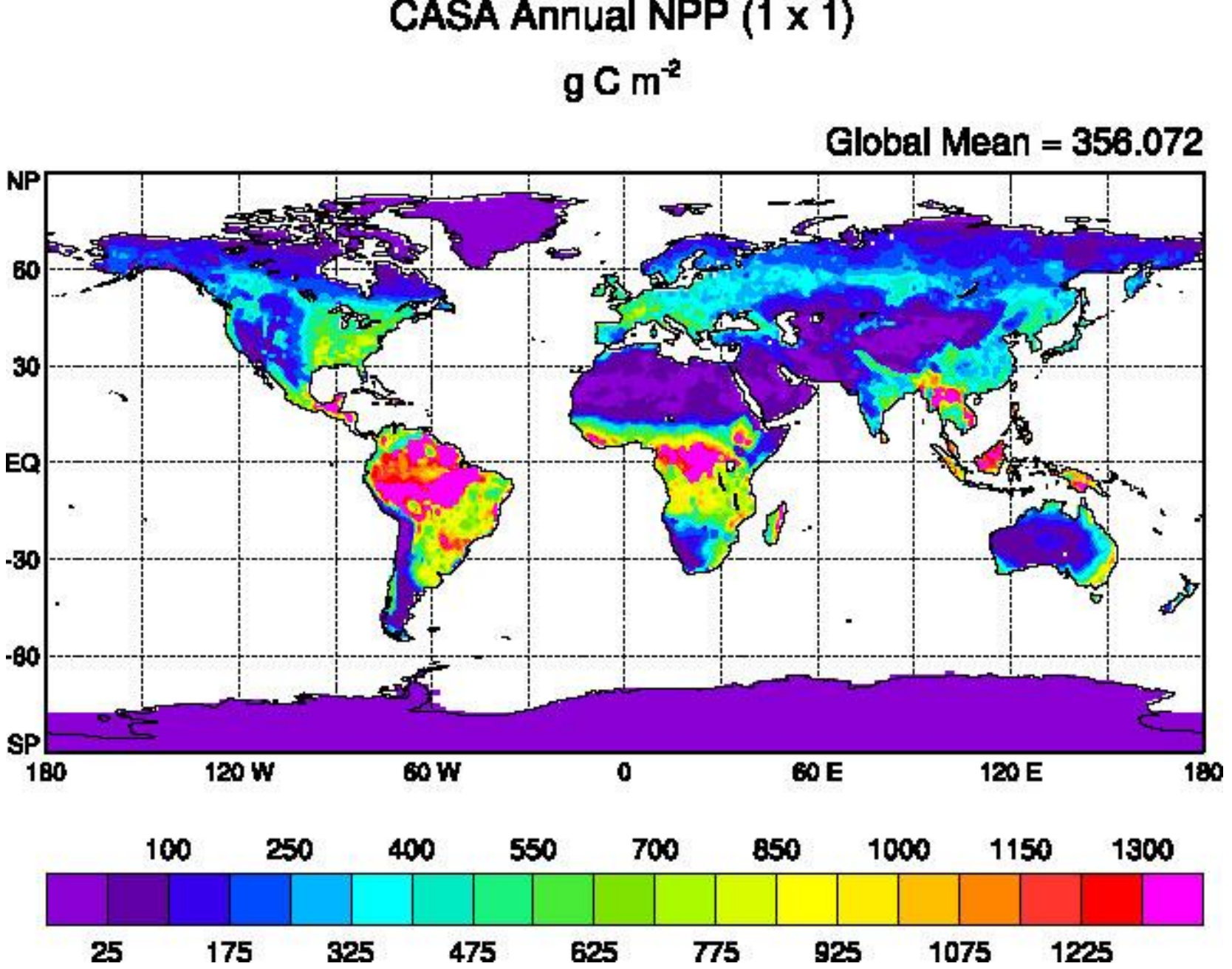
(Petagrams of Carbon/Year)

The Woods Hole Research Center



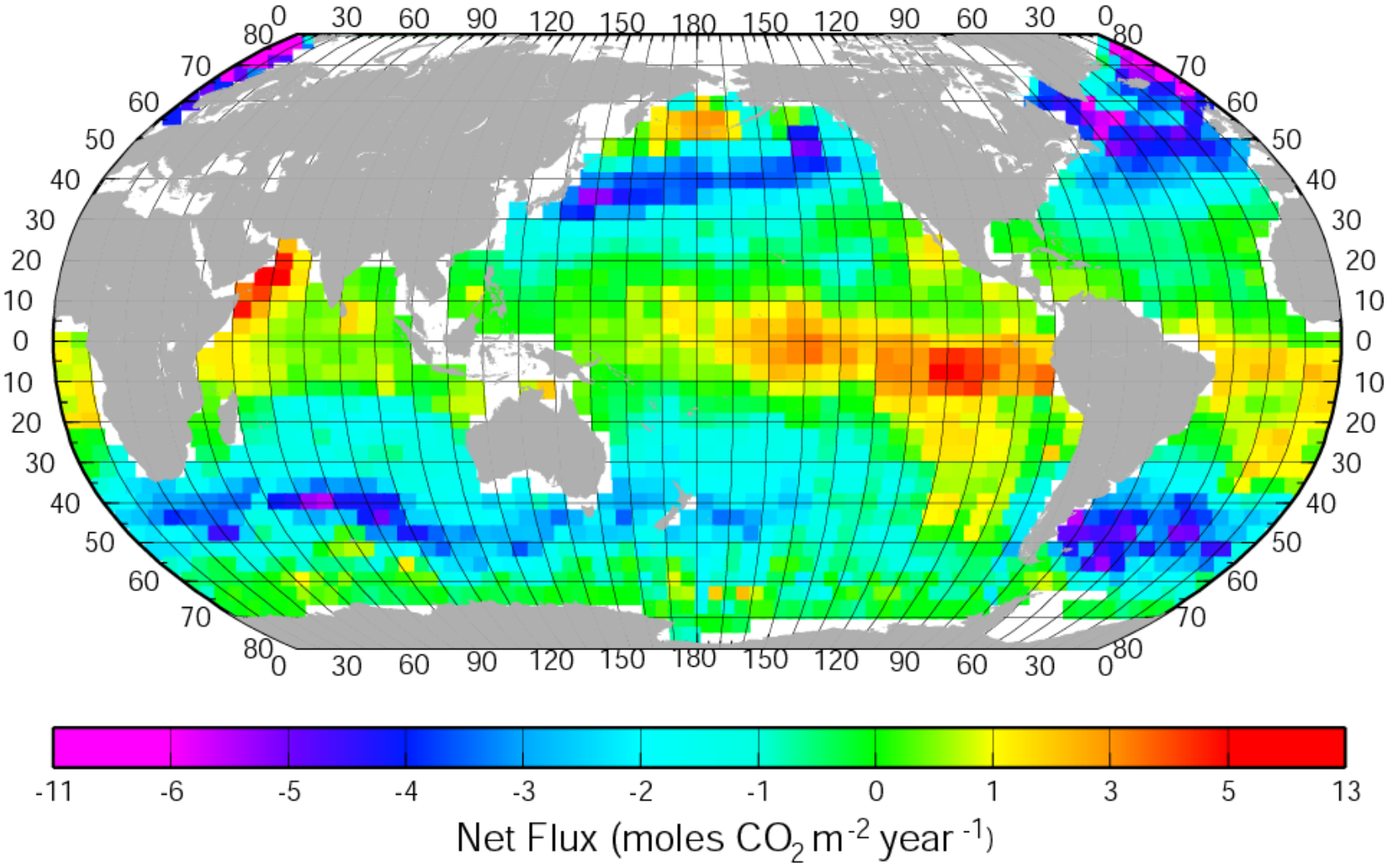
* Deforestation contributes between 1 - 2

Graphic by Michael Ernst & Skee Houghton
The Woods Hole Research Center

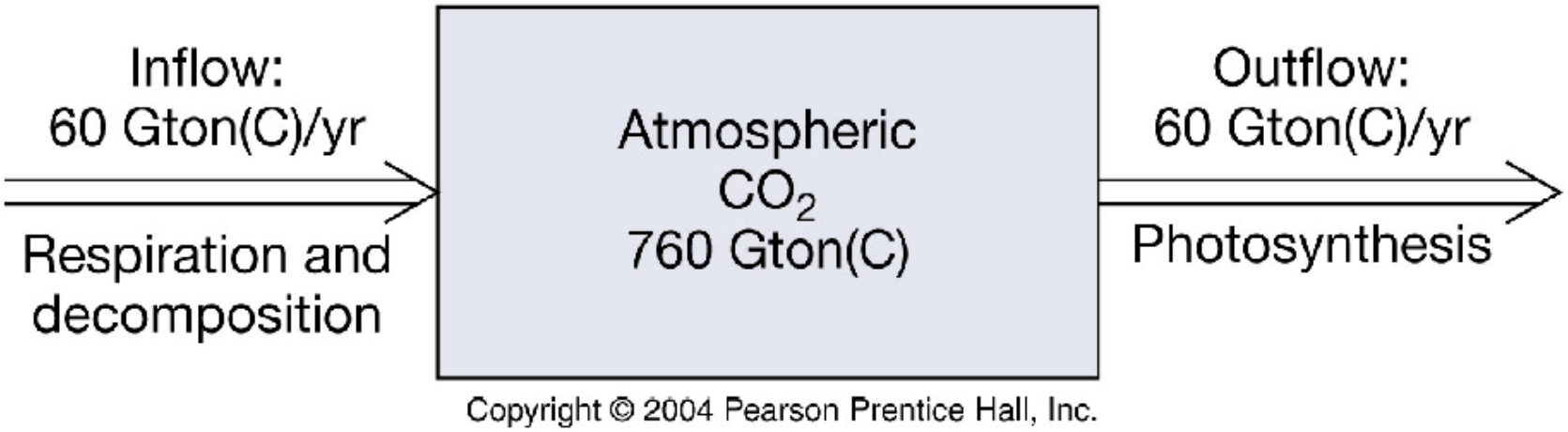


Net primary production: Carbon taken up by growing plants

Net CO_2 Flux from Takahashi et al., 2002

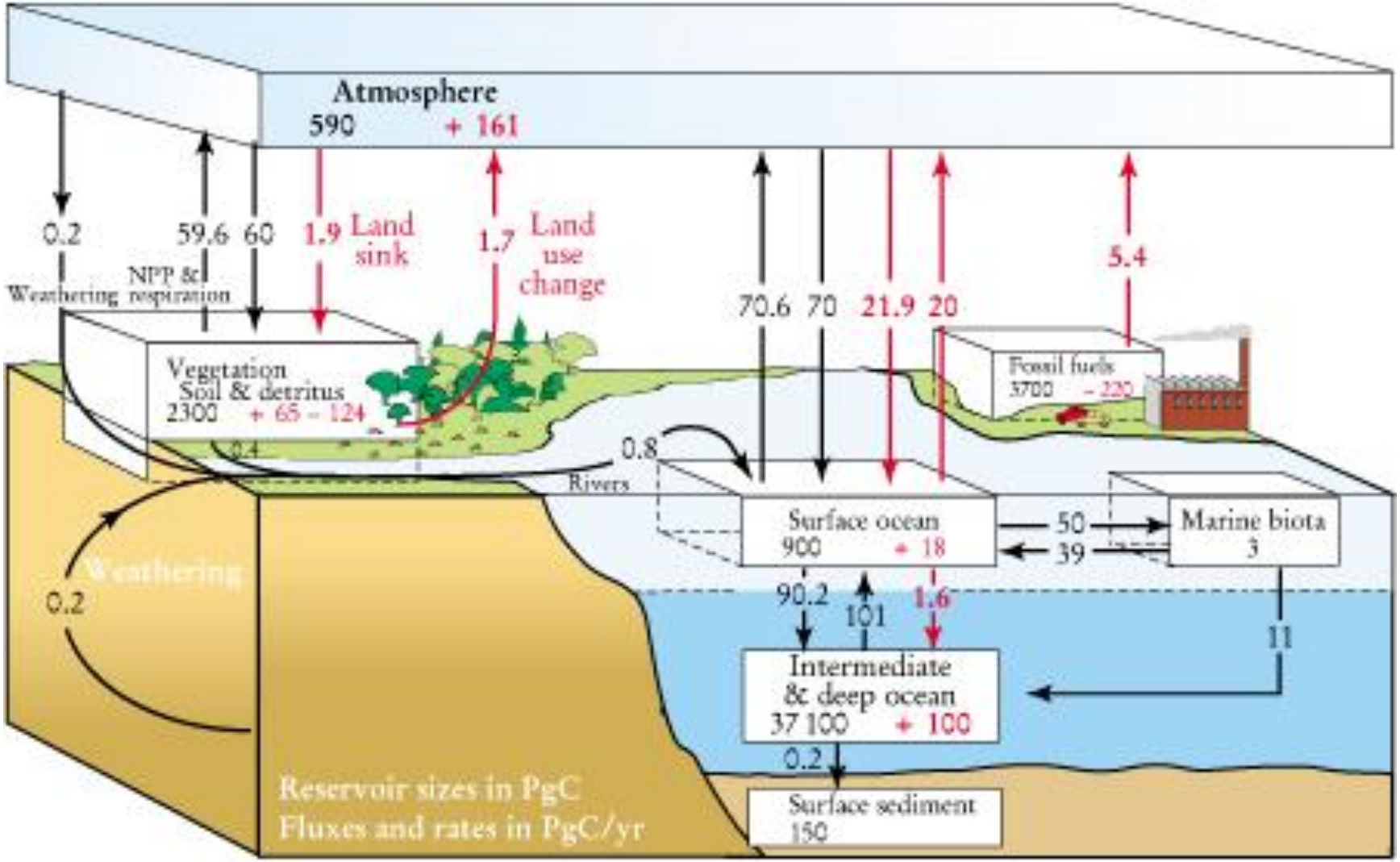


Time scales



- Big flux, small reservoir = short time
- Big flux, big reservoir = normal time
- Small flux, small reservoir = normal time
- Small flux, big reservoir = long time

Time scale is how long it takes for flux to refill the reservoir.



Time scale ~ reservoir / flux.

E.g., Land: (2300 PgC) / (60 PgC/year) = 39 years.

Final answer

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Final answer

Which of the following would be most likely to influence year to year variations in atmosphere $CO_{2?}$

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Final answer

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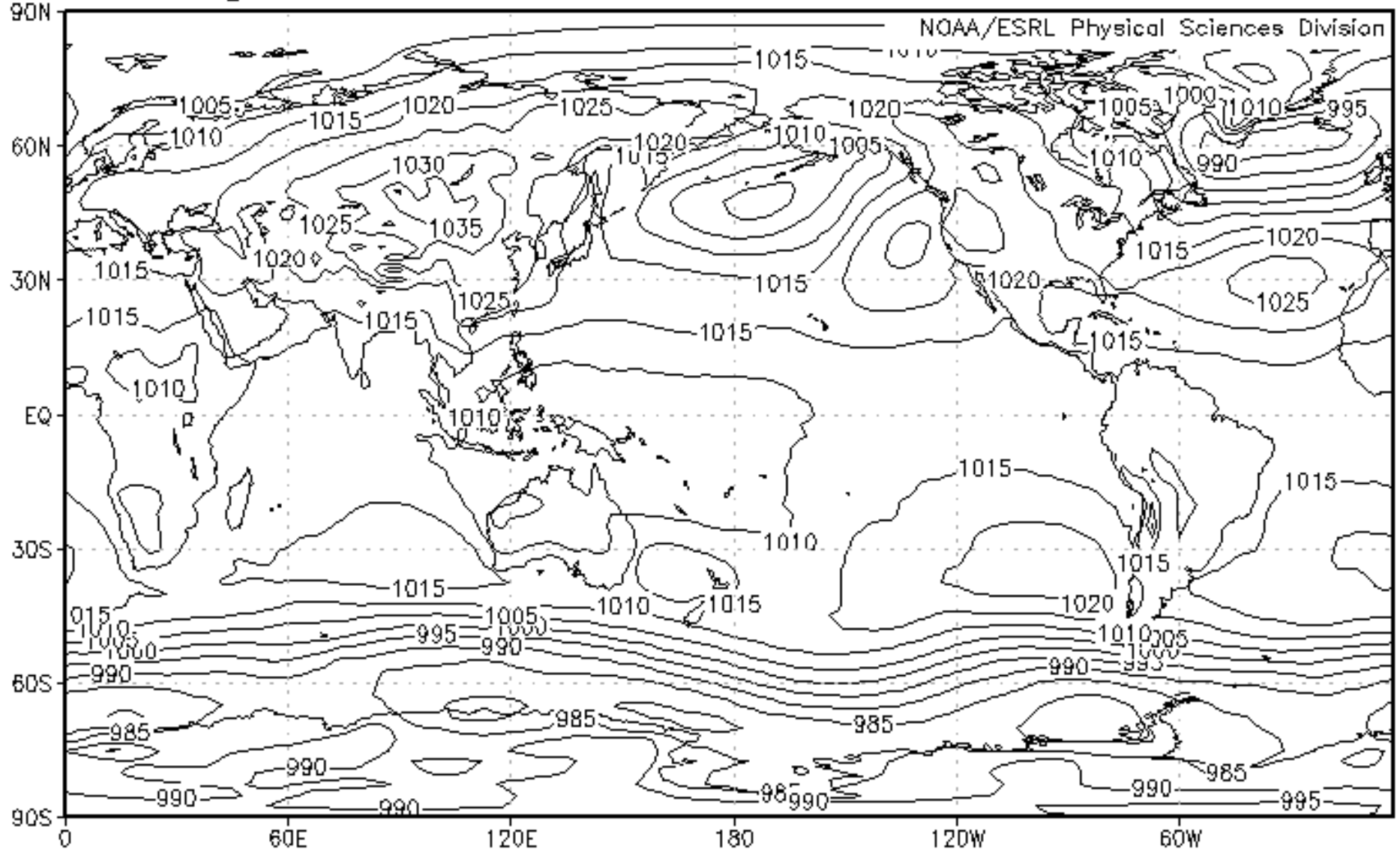
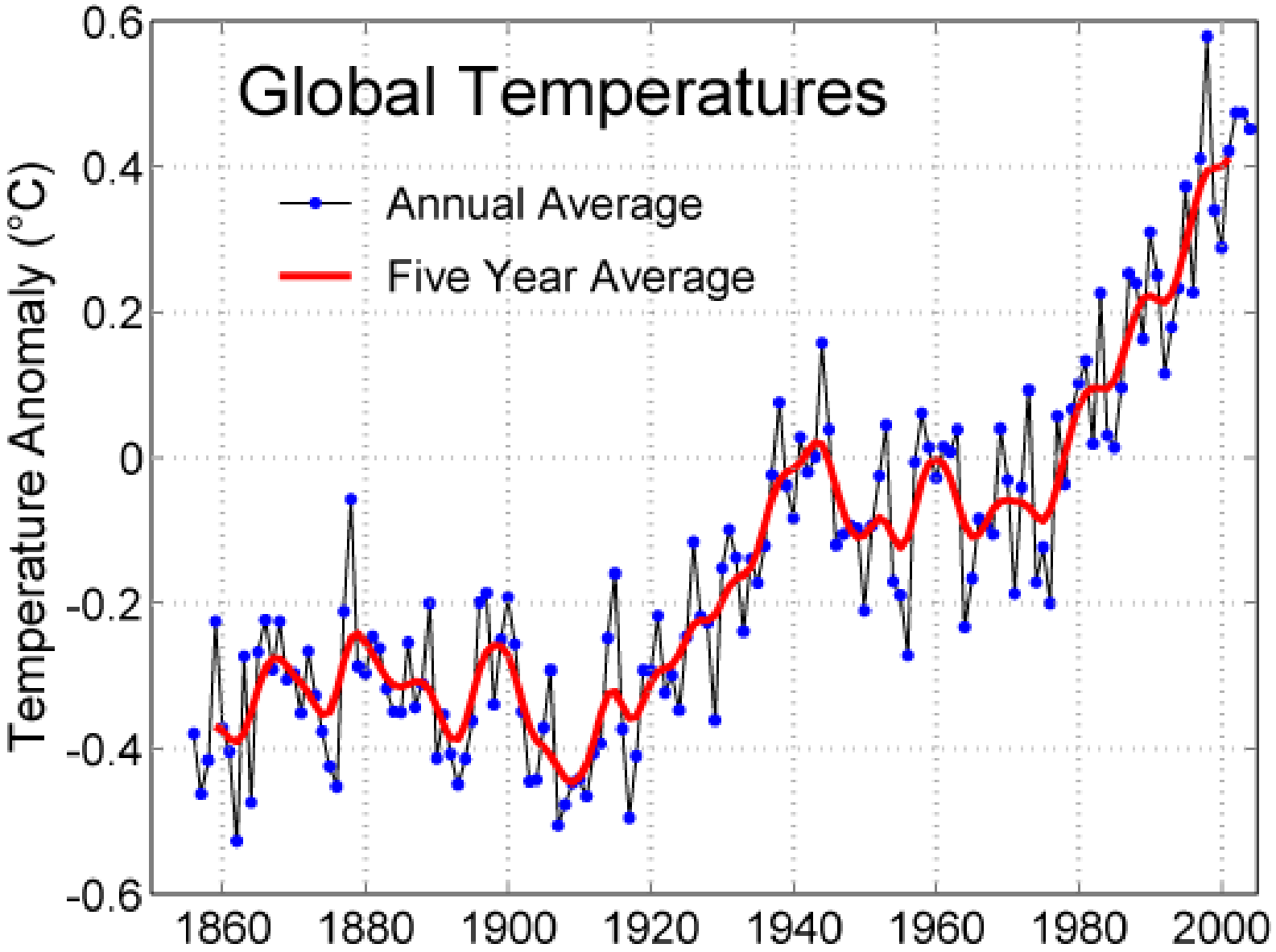
Key points

- Carbon cycle includes atmosphere, ocean, biosphere and lithosphere, but ***each has different time scales***
- Time scales depend on size of flux, and size of reservoirs
- Terrestrial biosphere responsible for seasonal variations in CO_2 as plant grow and drop leaves each year
- Other reservoirs must be responsible for longer time scale changes in CO_2
- Suspect a key role for the ocean… we'll see in future lectures
- Human activity and **burning of fossil fuels** connects the very long time scale of the lithosphere with the short time scale change in the atmosphere. ***This has consequences.***

Midterm

Mean slp millibars




Global Temperatures
Annual Average
Five Year Average
Temperature Anomaly (°C)
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
1860
1880
1900
1920
1940
1960
1980
2000