Lecture 3

- Global Sulfur, Nitrogen, Carbon Cycles
- Short-term vs. Long-term carbon cycle
- CO_2 & Temperature: Last 100,000+ years

METR 113/ENVS 113

Spring Semester 2011

March 1, 2011

Suggested Reading

(Books on Course Reserve)

- Turco “Earth Under Siege”, Chapter 10 (very good chapter!)
- Hensen “Rough Guide to Climate Change”, check chapters and index yourself for relevant sections
- Any other stuff referenced in slides to follow …

Background

Air Pollution "Sources" vs. "Sinks"

- **Source (S+)**: Process that puts pollutants into the atmosphere
- **Sink (S-)**: Process that removes pollutants from atmosphere

Global air pollution concentrations increase (decrease) when global pollution input from sources is greater (less than) global pollution removal due to sinks.

i.e.

S+ > S- … pollution concentration increases
S+ < S- … pollution concentration decreases
S+ = S- … pollution concentration is constant ("steady state")

Question: What does increase in CO_2 concentration in the atmosphere therefore mean in terms of the above?

Will look at global balance of three key substances with increased anthropogenic industrial emissions …

- **Sulfur**
  - Emitted mostly as SO_2
  - Also some H_2S (hydrogen sulfide), other stuff …
- **Nitrogen**
  - Emitted mostly as NO & NO_2 (i.e. "NO_x")
  - $NO_x = NO + NO_2 + NO_3$ Very small emissions …
  - Also NH_3 (ammonia), other stuff …
- **Carbon**
  - Emitted mostly as CO_2
  - Also some CH_4 (methane), other stuff …

Post-industrial trend in anthropogenic sulfur emissions

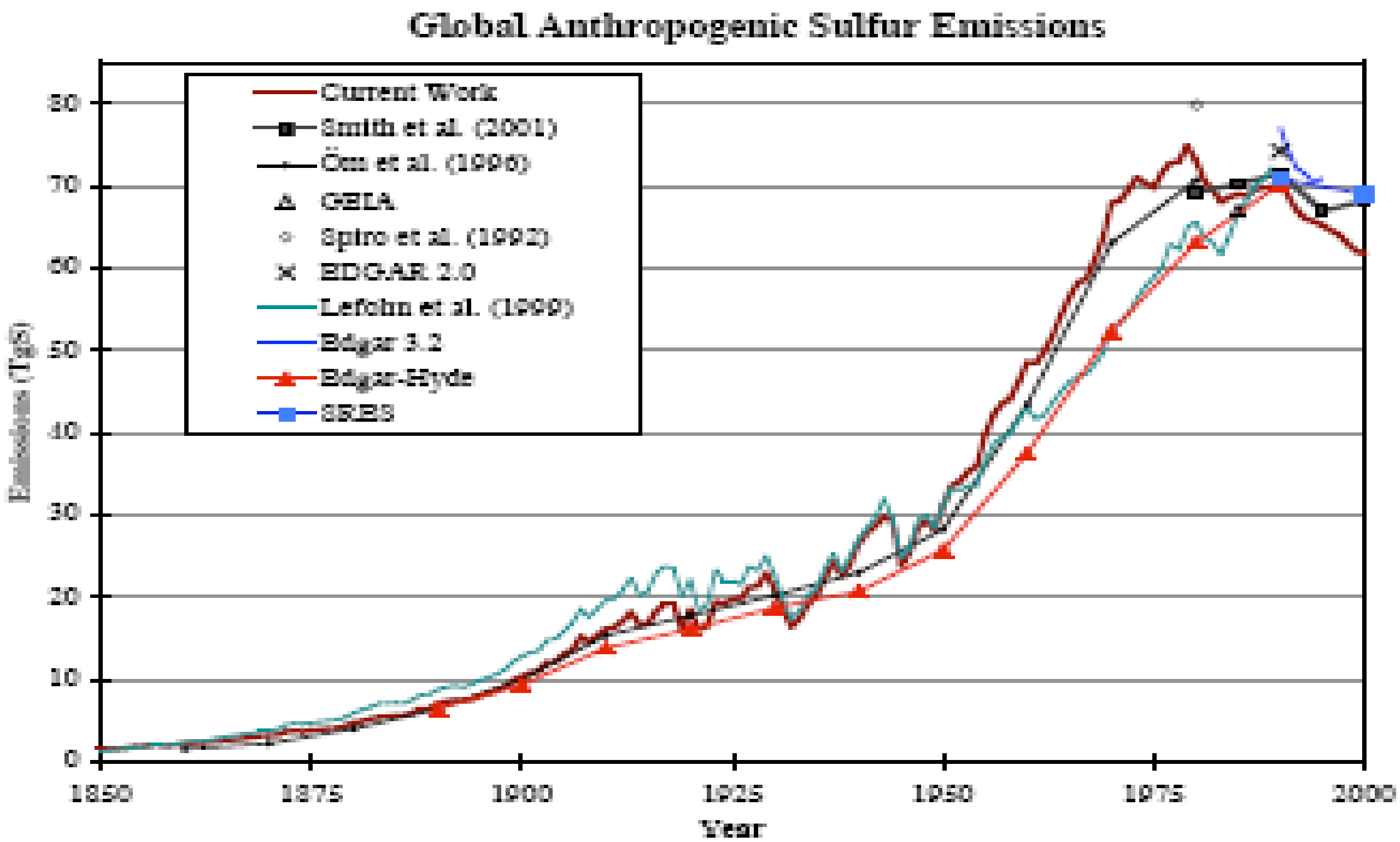
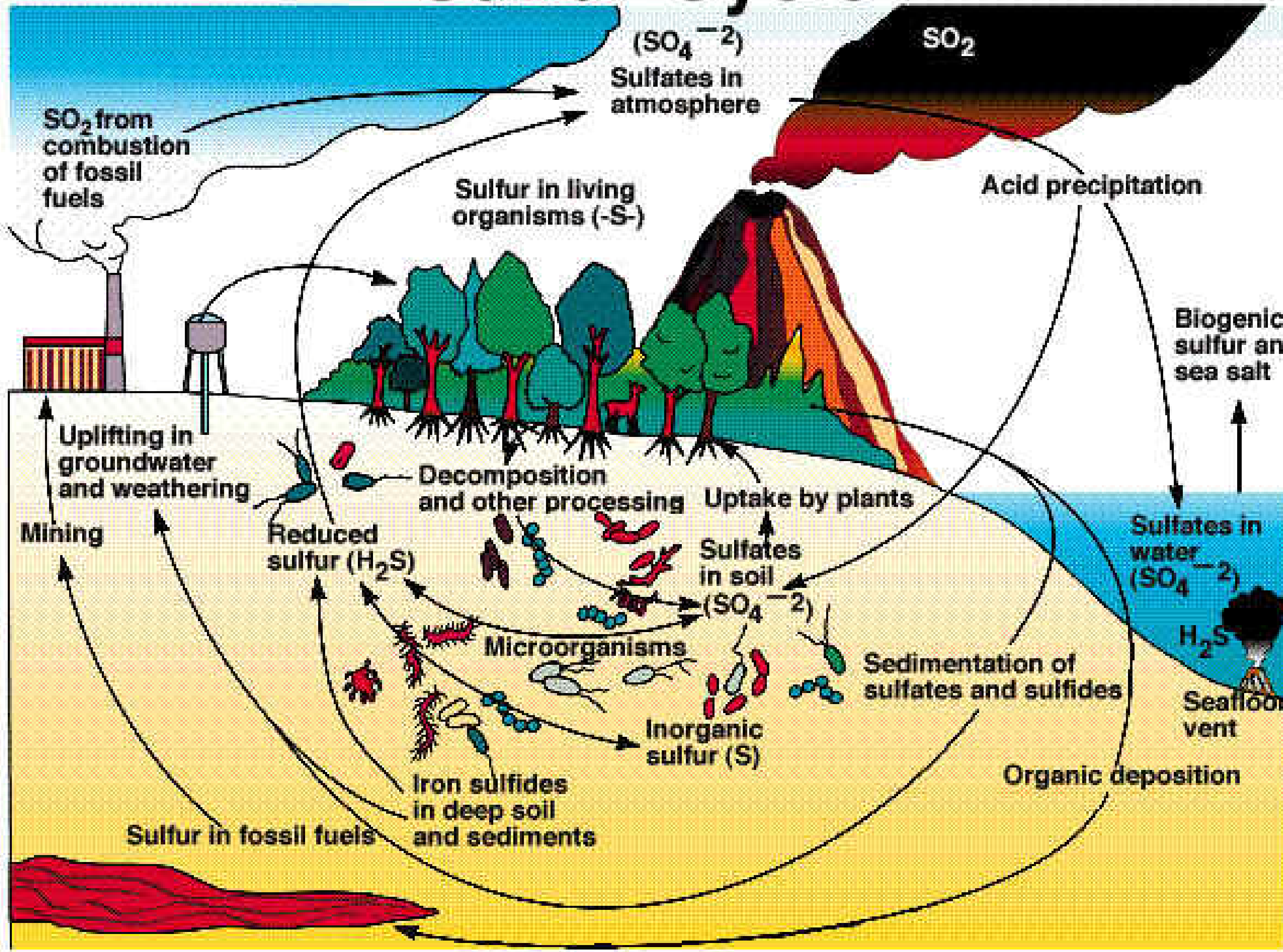
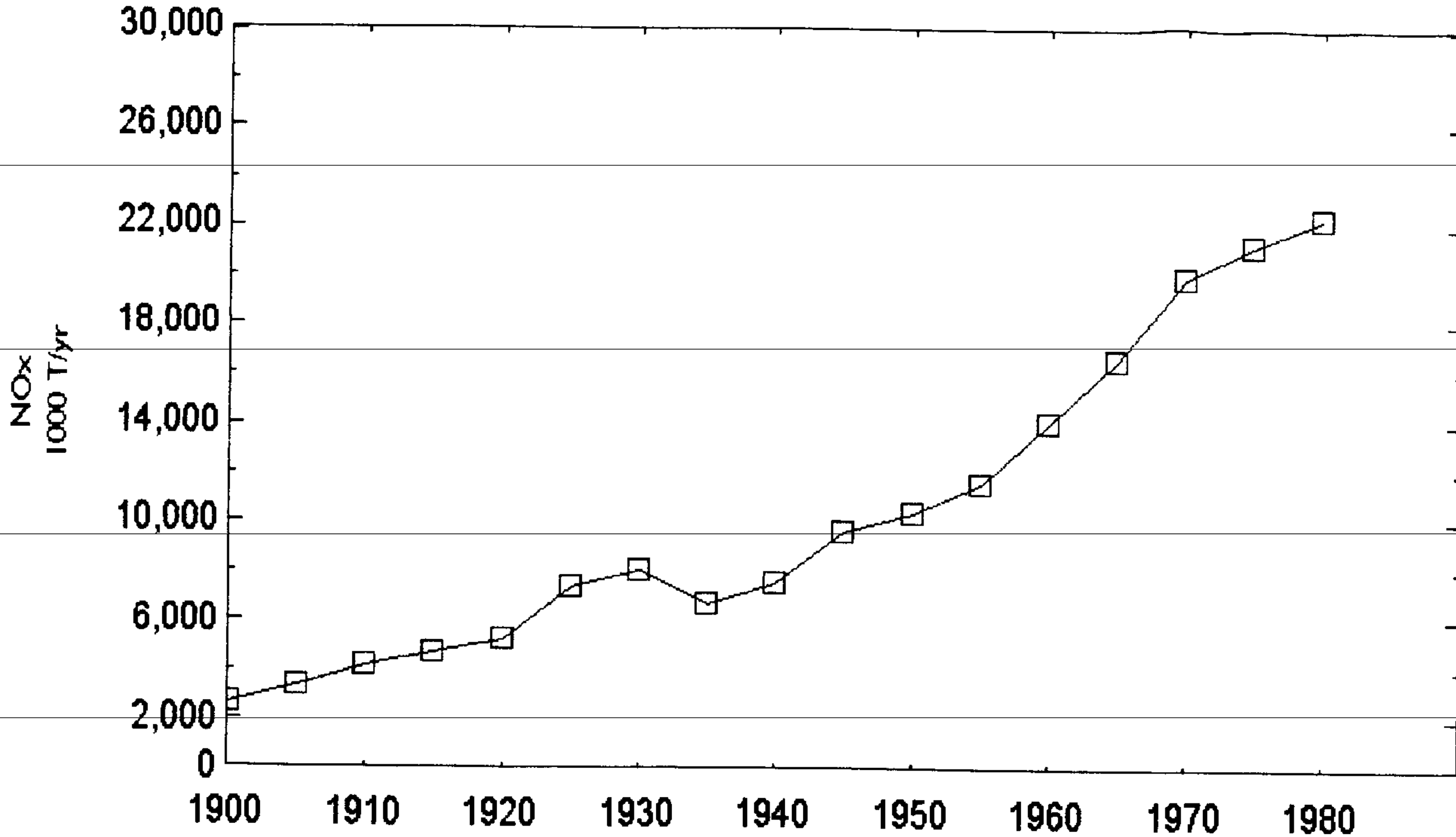


Figure 1–Global sulfur dioxide emissions from this study (thick line) and several other recent estimates (see text). Note that the Lefohn *et al.* estimate does not include all anthropogenic emissions sources. References not shown on the cart are: GEIA (Benkovitz *et al.*1996); EDGAR 2.0 (Olivier *et al* 1996); EDGAR 3.2 (Olivier and Berdowski, 2001); EDGAR-HYDE (Van Aardenne *et al.* 2001); and SRES (Nakicenovic and Swart 2000).

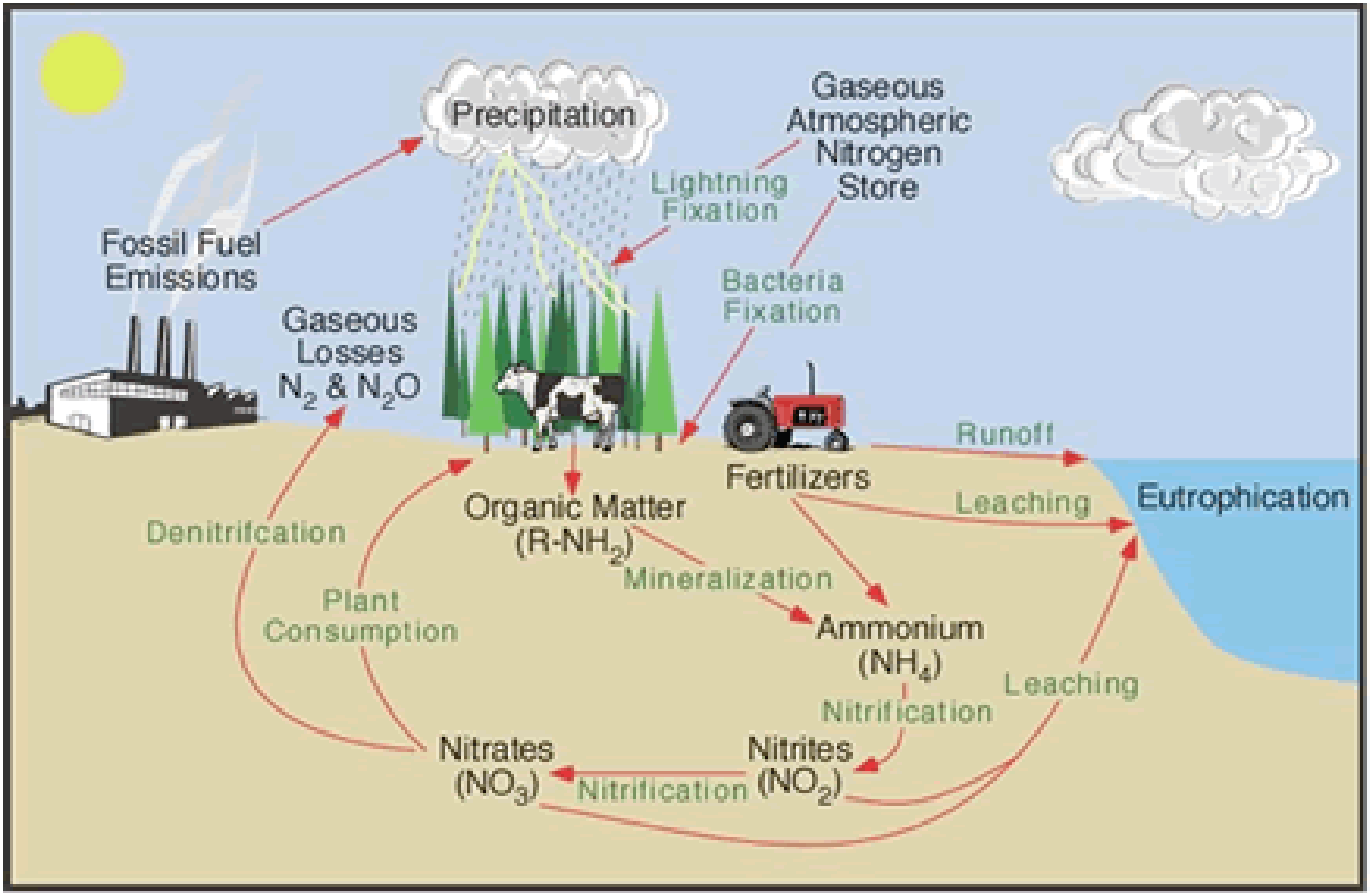
Sulfur Cycle



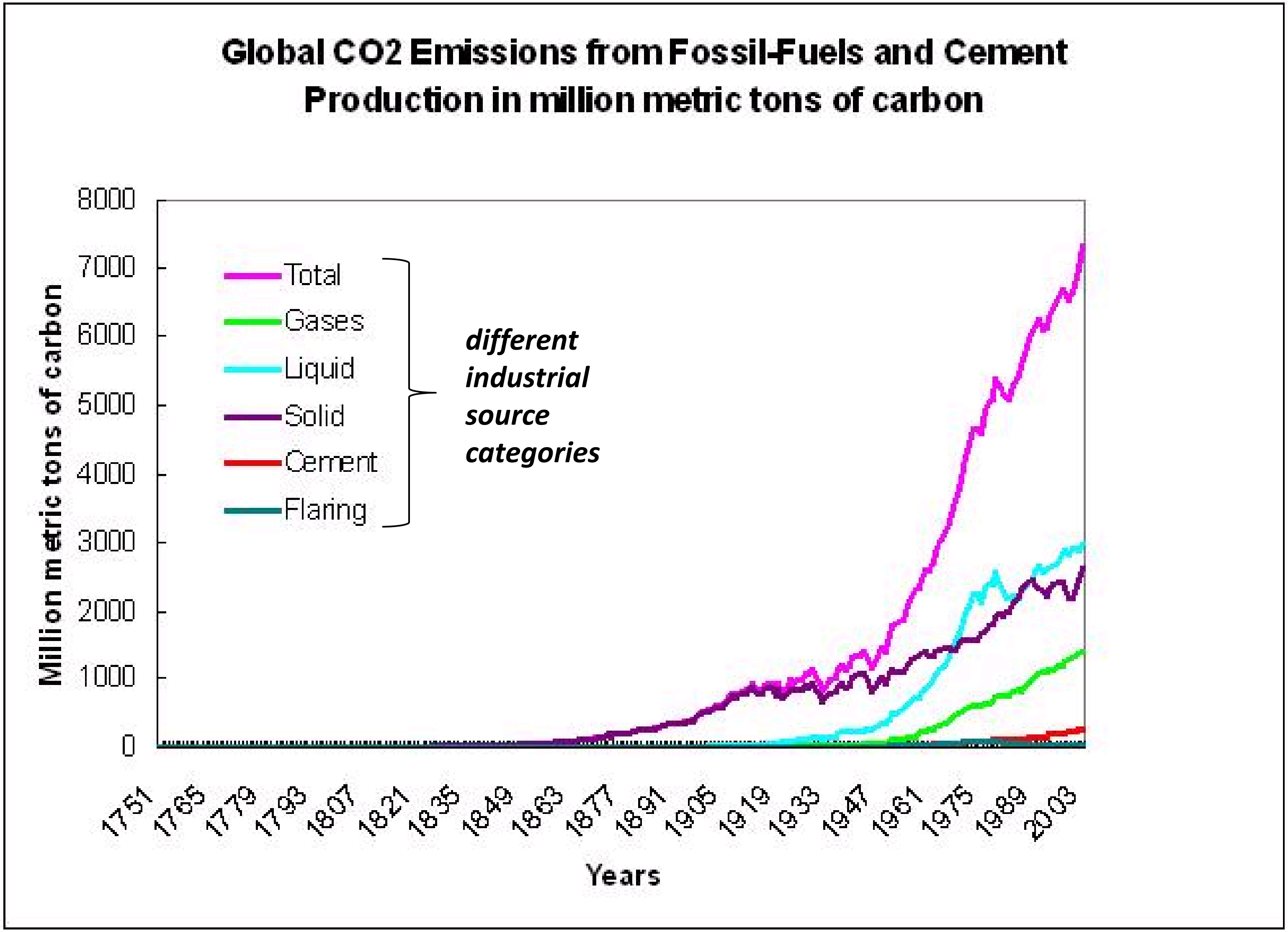
Post-industrial trend in anthropogenic nitrogen oxide emissions (graph below for Eastern U.S., global trend is similar)



Nitrogen Cycle

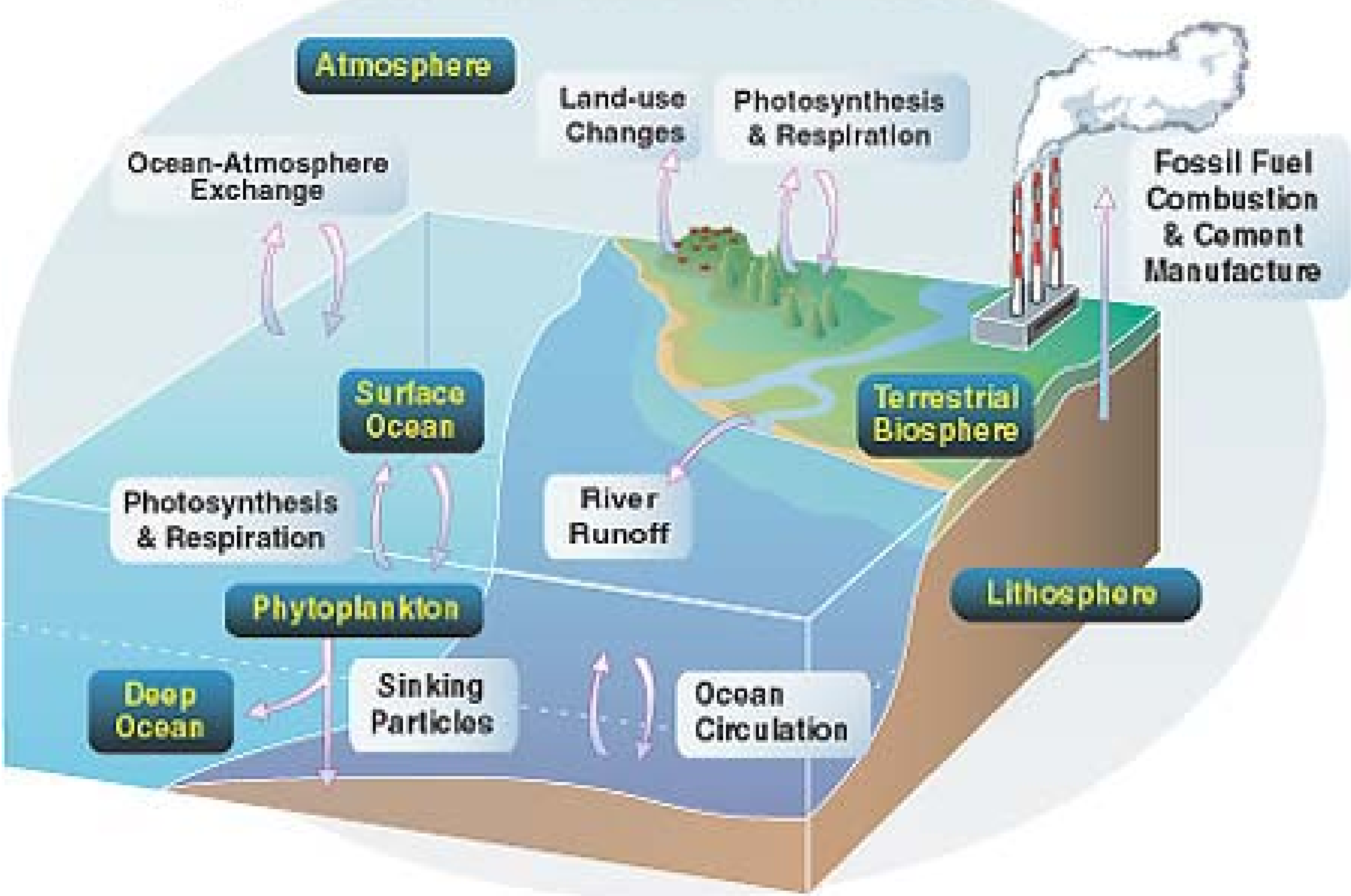


Post-industrial trend in anthropogenic carbon dioxide emissions



The Global Carbon Cycle

A network of interrelated processes that transport carbon between different reservoirs on Earth.

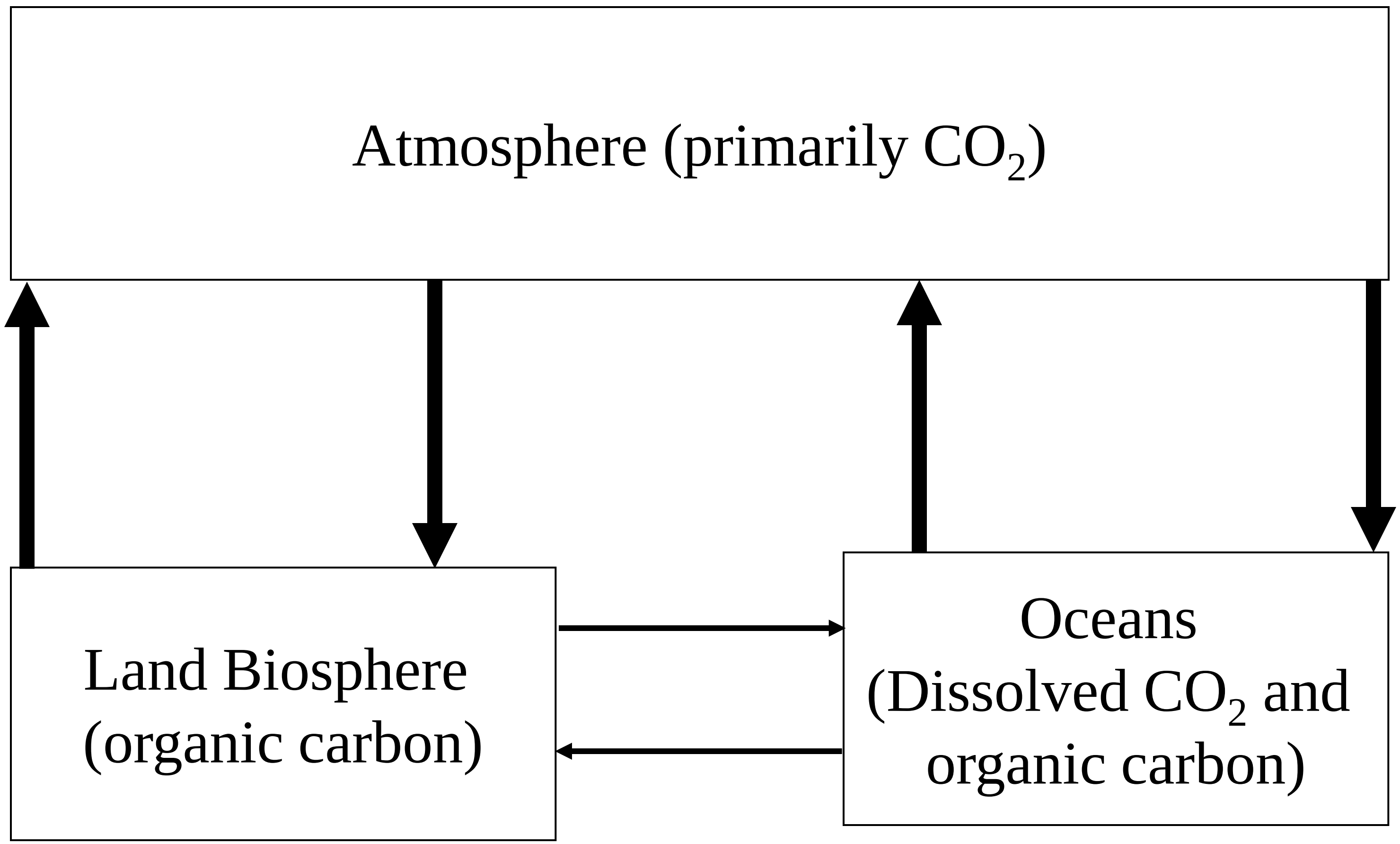


Short Term* Carbon Cycle:
Processes Involved With Earth to Atmosphere Exchange

- Photosynthesis (natural sink, removes carbon from atmosphere)
- Respiration (natural source, puts carbon into atmosphere)
- Biogenic Decay (natural source, puts carbon in …)
- Wildfires (natural source, puts carbon in …)
- Oceanic uptake by phytoplankton (natural sink removes carbon …)
- Oceanic uptake by absorption (natural sink removes carbon …)
- Anthropogenic Emissions (anthropogenic source, puts carbon in …)

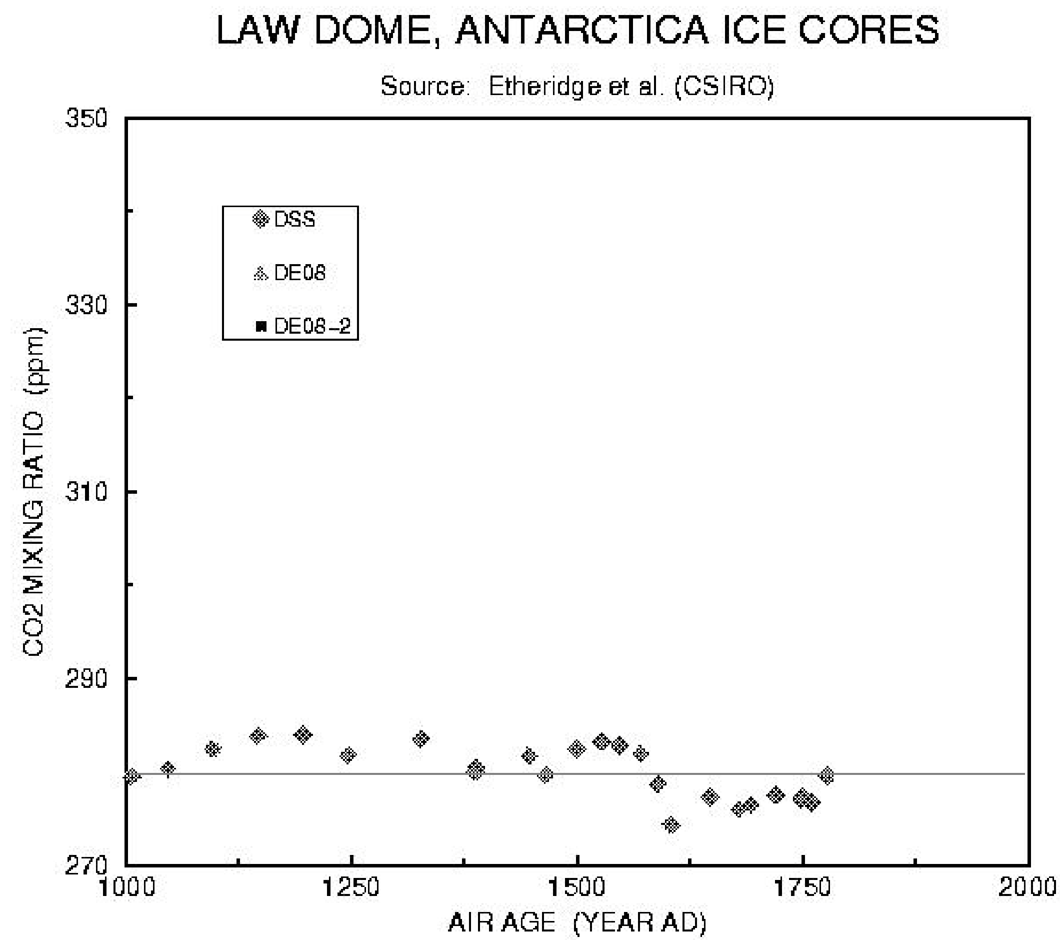
* By "short-term", we mean processes that cycle carbon through earth system on roughly annual/decadal time scales.

The Short-Term Carbon Cycle

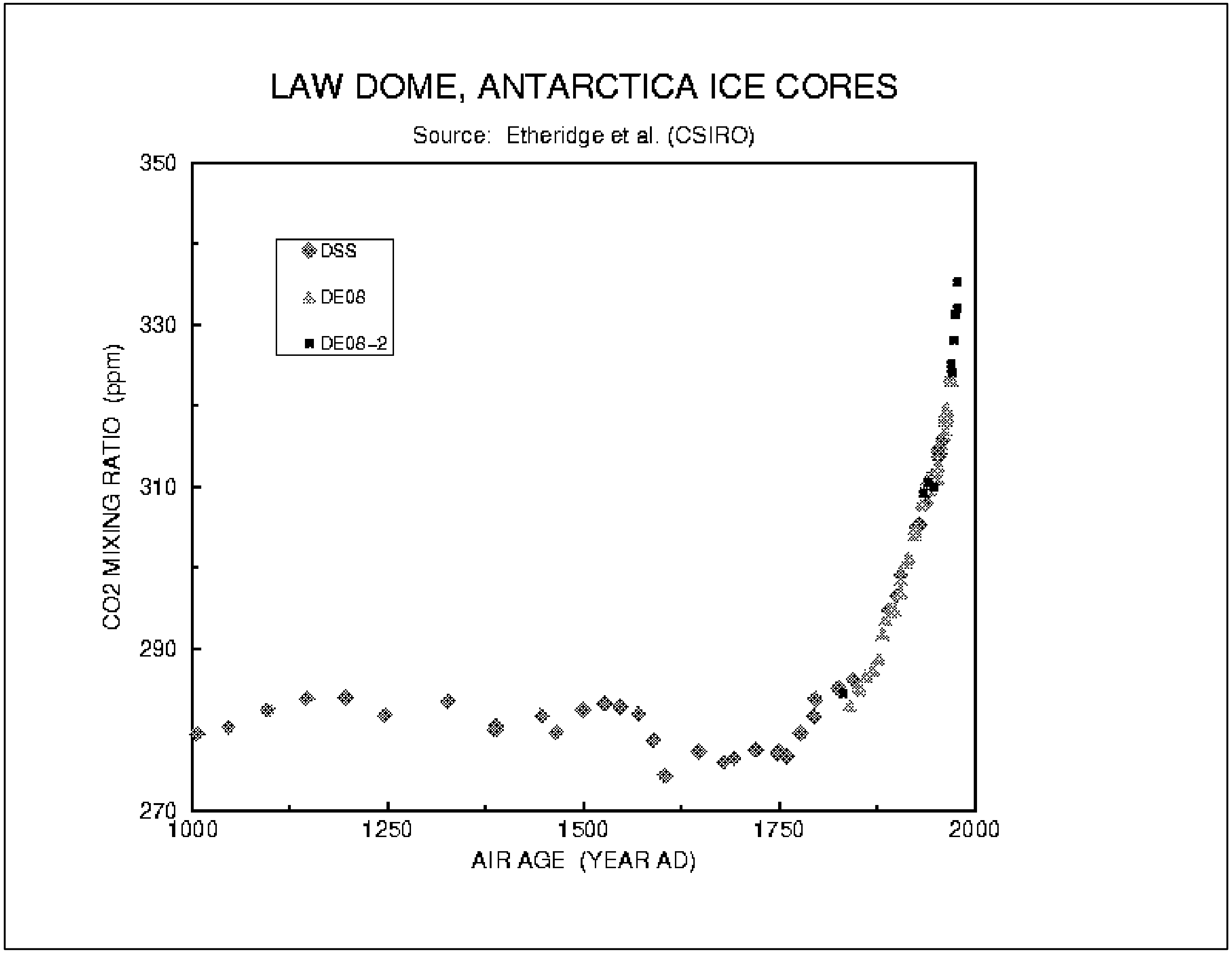


1000 AD – 1800 AD

- Pre-Industrial era
- Small fluctuations around 280 ppm
- Short-term carbon sources and sinks roughly in balance

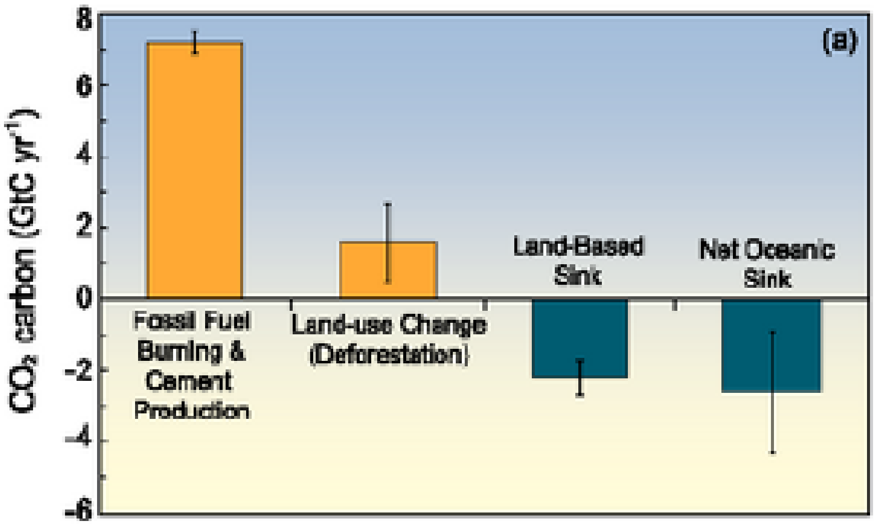


CO_2: 1000 – 1980



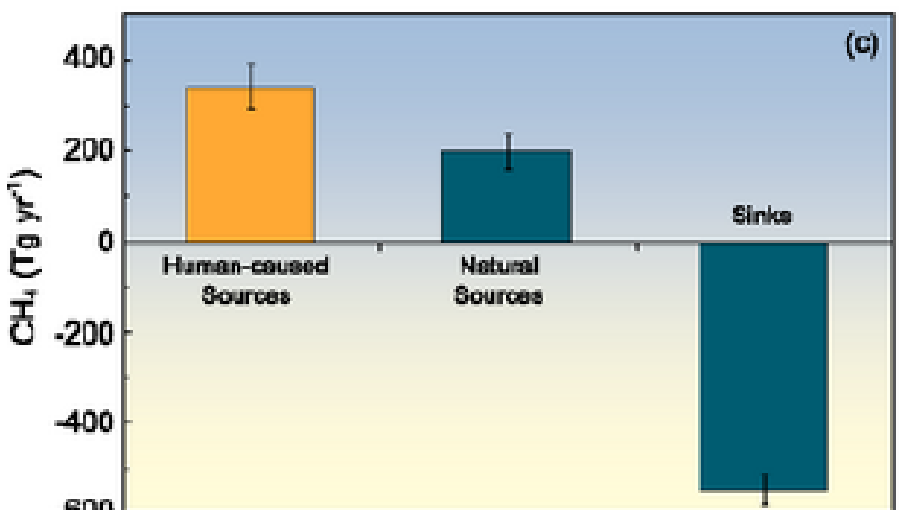
Large increase after 1800 indicates imbalance in short-term source/sink processes in atmosphere. Note that current-day level is around 390 ppm, rather than around 340 ppm (where data on above graph stops, around year 1980).

Current-Day Annual Budget: Carbon to/from Atmosphere



CO_2

- Most recent understanding.
- Note that S+ > S-

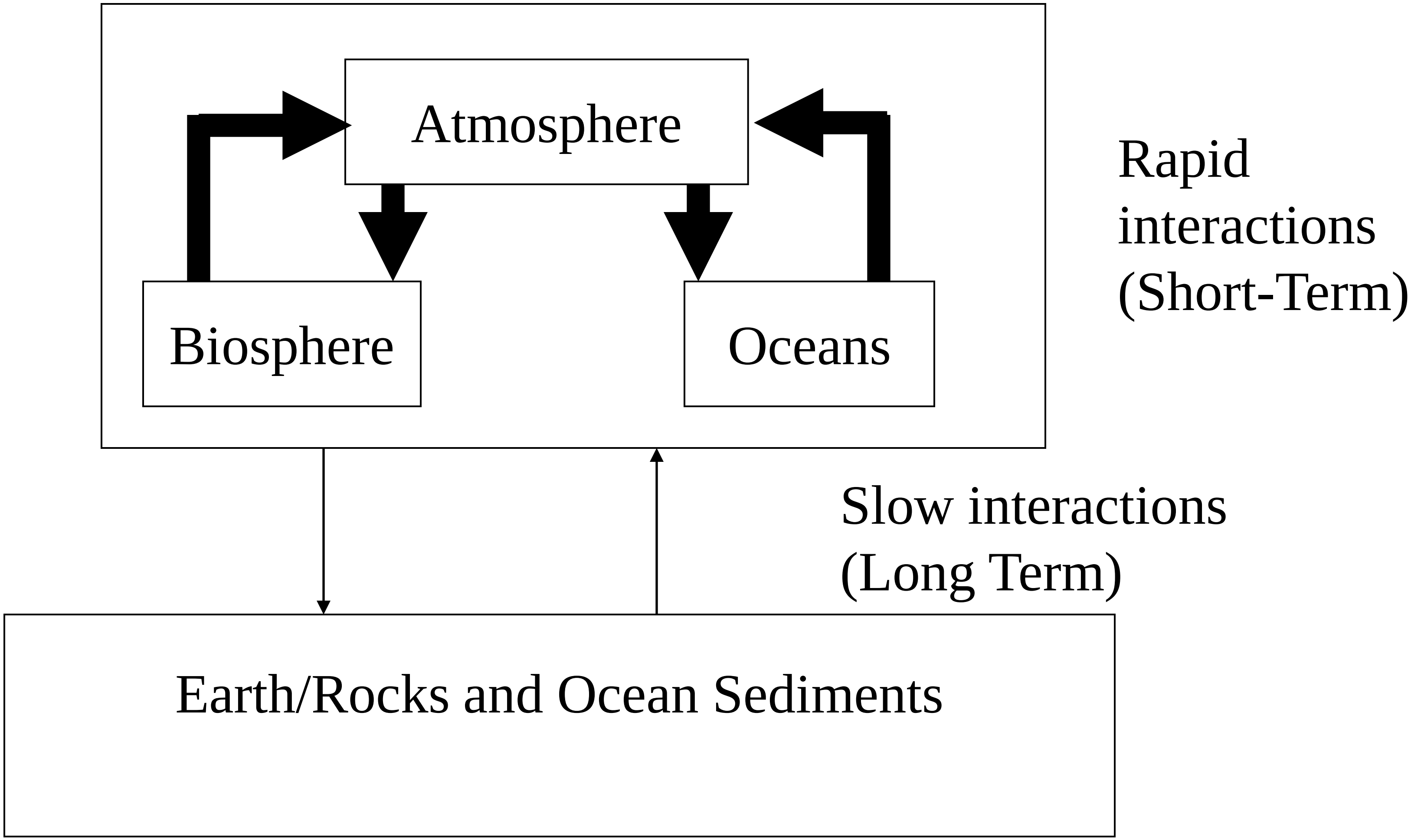


CH_4

- Most recent understanding.
- Note that S+ ≈ S-
- Confirm from Lecture 2 plot that concentration of CH_4 in recent years has not increased much

http://www.ipcc.ch/publications_and_data/ar4/wg1/en/faq-7-1.html

Short-Term vs. Long-Term Carbon Cycles



Long Term Carbon Cycle

- Carbon is slowly and continuously being transported around earth system on long (geologic) time scales …
  - Between atmosphere/ocean/biosphere
  - And the Earth's crust (rocks like limestone)

- The main components to the long term carbon cycle:
  - Chemical weathering (or called: "silicate to carbonate conversion process")
  - Volcanism/Subduction
  - Some other processes … (not discussed here)

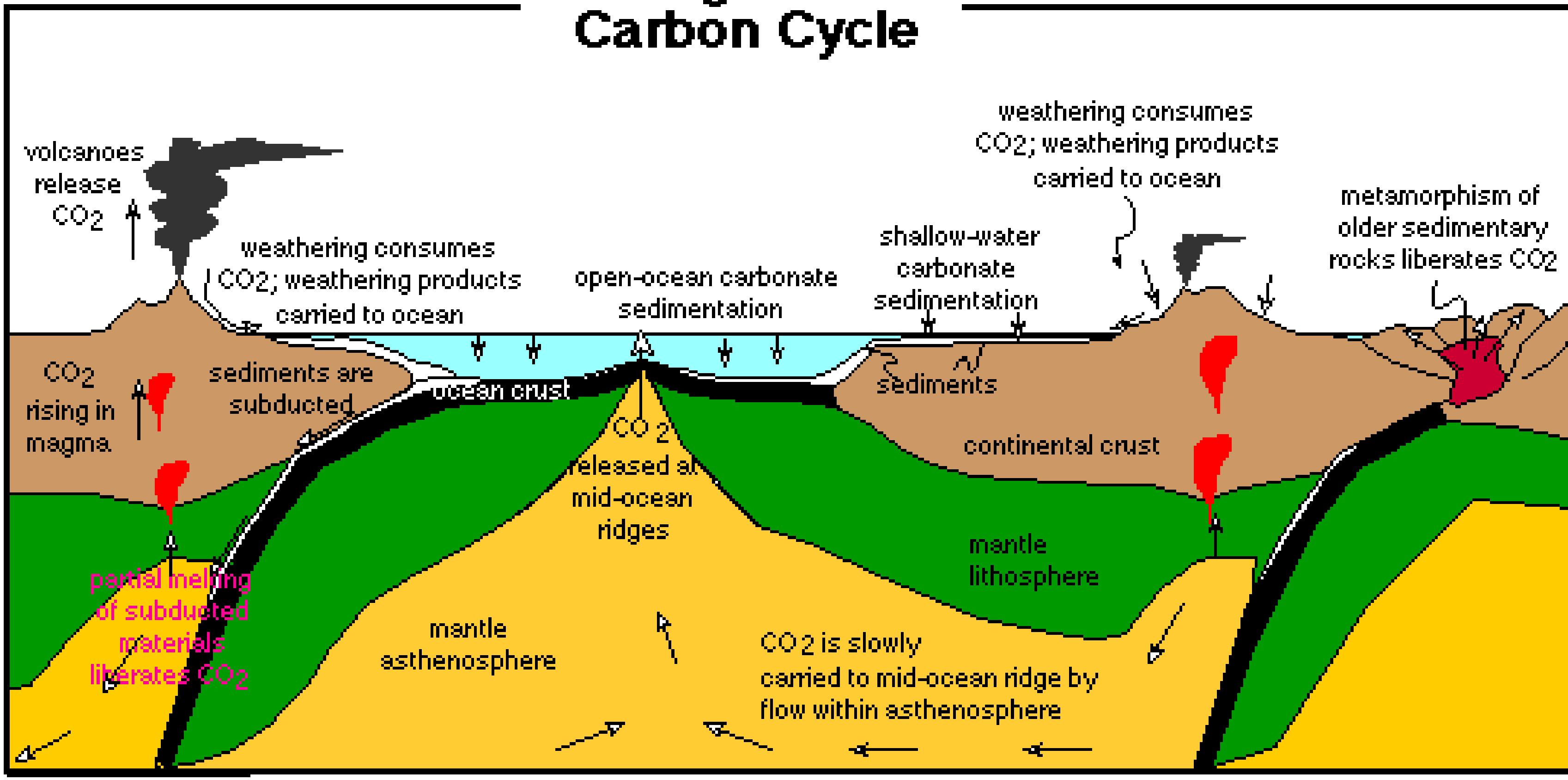
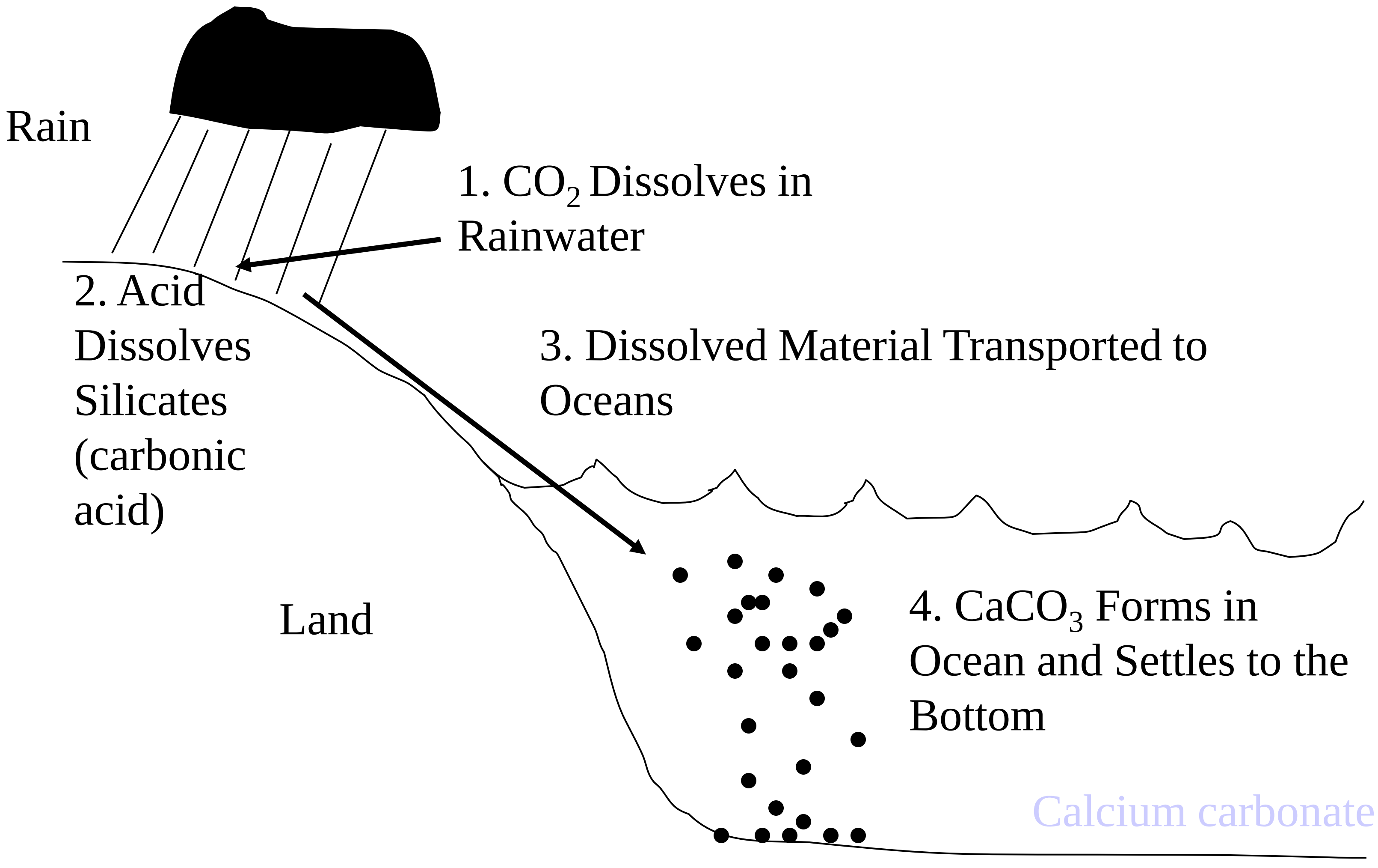


Figure 7.3.1 Schematic representation of the long-term global carbon cycle showing the flows (hollow arrows) of carbon that are important on timescales of more than 100 Kyr. Carbon is added to the atmosphere through metamorphic degassing and volcanic activity on land and at mid-ocean ridges. Atmospheric carbon is used in the weathering of silicate minerals in a temperature-sensitive dissolution process; the products of this weathering are carried by rivers to the oceans. Carbonate sedimentation exracts carbon from the oceans and ties it up in the form of limestones. Pelagic limestones deposited in the deep ocean can be subducted and melted. Limestones deposited on continental crust are recycled much more slowly — if they are exposed and weathered, their remains may end up as pelagic carbonates; if they get caught up in a continental collision, they can be metamorphosed, liberating their CO_2.

Silicate-to-Carbonate Conversion



Silicates

- Compounds containing silicon and oxygen
- Example: calcium silicate, $CaSiO_3$

Granite (A *Silicate* Rock)

Limestone Quarry (Calcium Carbonate, $CaCO_3$)

Volcanic Eruption

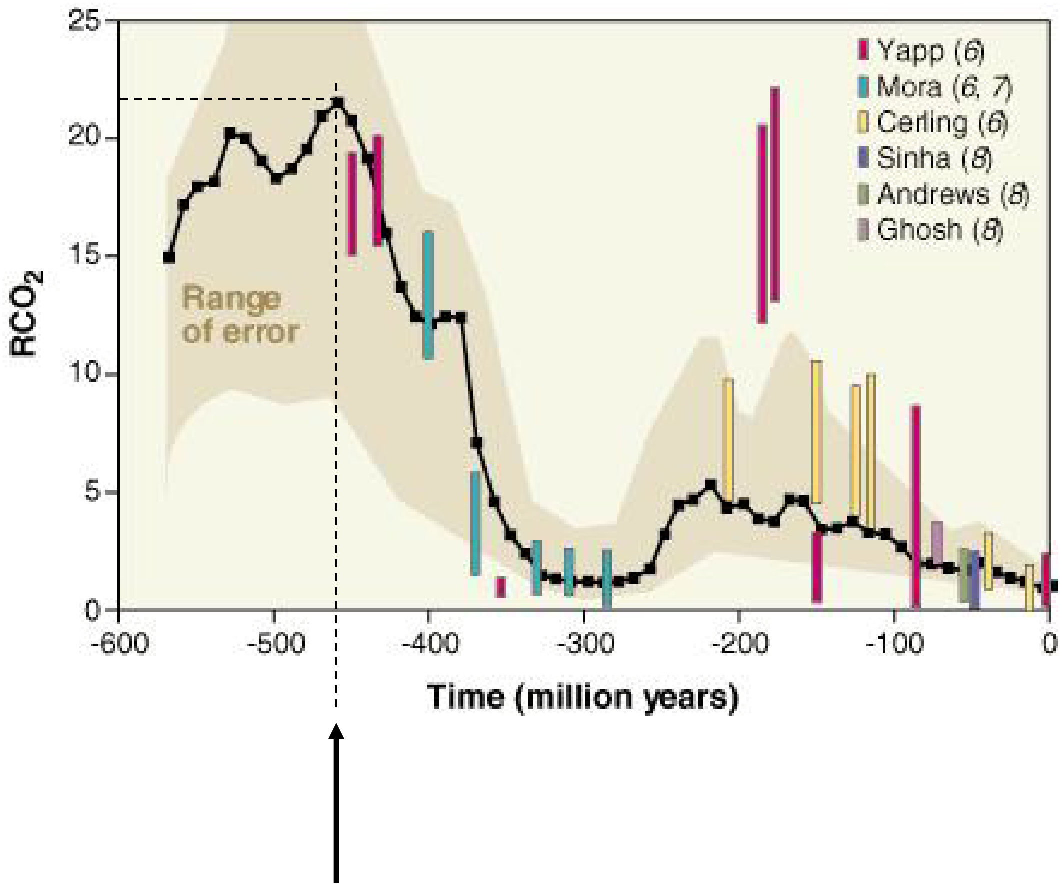
Geologic periods exist in past when there were much larger frequency of volcanic activity than today. Those periods appear to correspond to periods of relatively large CO_2 into the atmosphere compared to times with lower frequency of volcanism.

Mt. Pinatubo (June 15, 1991)

CO_2 Values: Geologic Time Scales

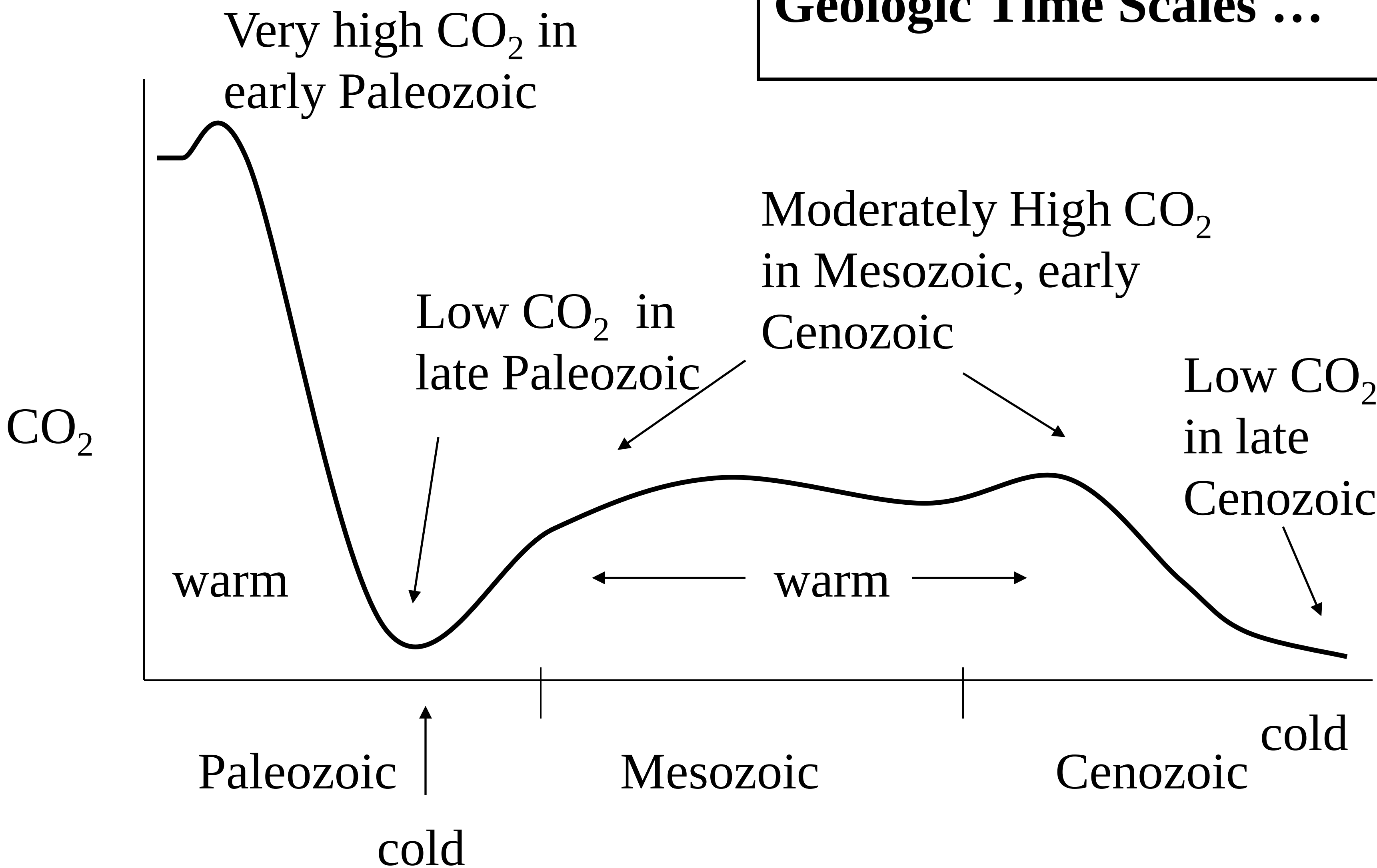
RCO_2 is the ratio of CO_2 at the given time to current CO_2 levels

450 mya. CO_2 levels ~20 times current



Origin of land plants ~ 450 million years ago (mya.)

CO_2 and Temperature over Geologic Time Scales …



Carbon Budget: Natural Processes

- Very little change in carbon concentrations in atmosphere on short time scales due to natural processes alone.
  - Indicates that natural short term source/sink processes roughly balance.
  - Key processes are photosynthesis/respiration & oceanic absorption.

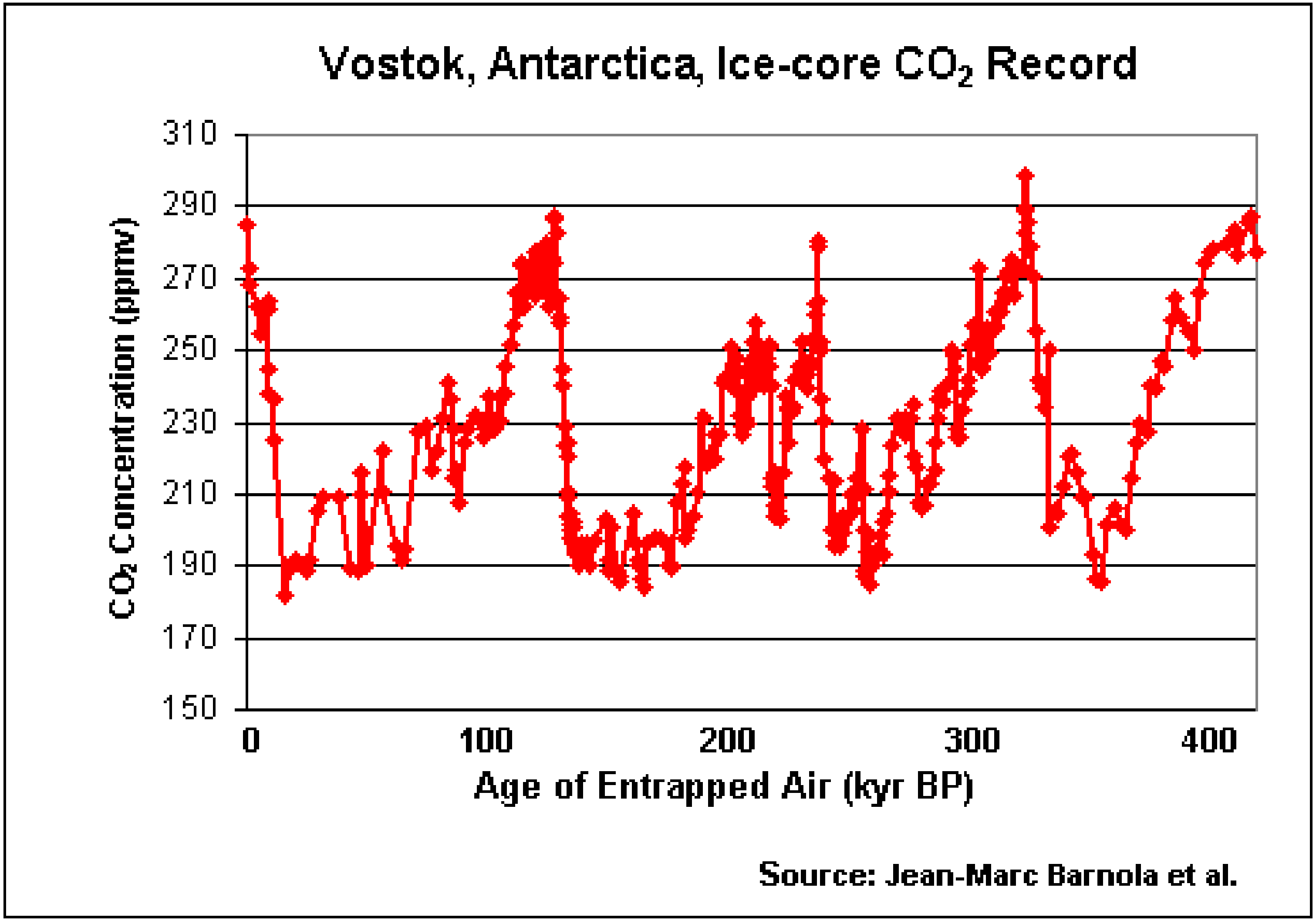
- Appreciable changes are seen on long, geologic time scales.
  - Indicates imbalances on geologic time scales among long term processes
  - Key processes are volcanism and uptake by earth (also called “weathering”)
  - Weathering involves calcium to carbonate conversions.

CO2 & Temperature Cycles

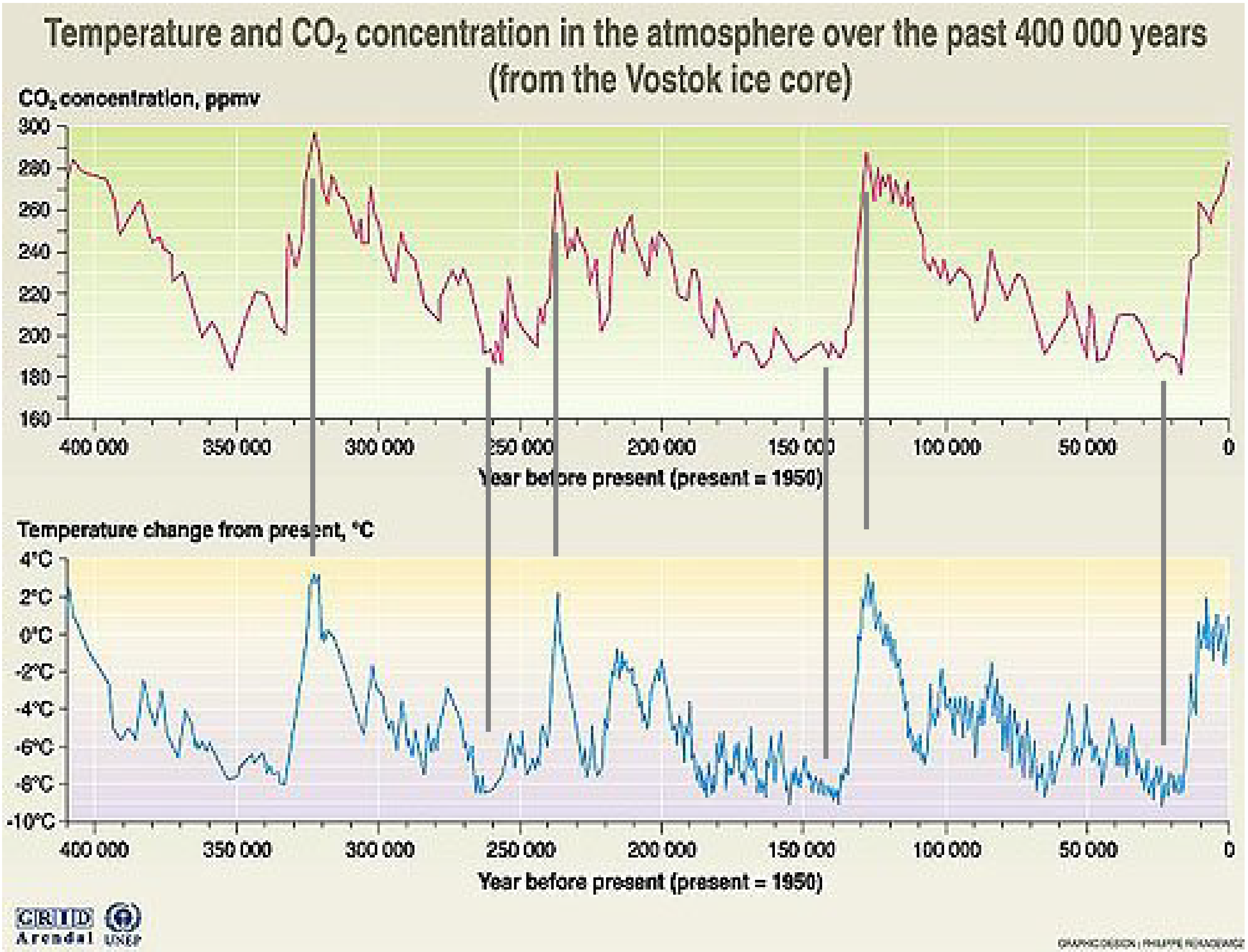
(Interglacial Periods of Pleistocene Era)

Pleistocene Era – 1 million to 10,000 years ago. Periods of glacial advance equator-ward (interglacial maximums) and retreat pole-ward (interglacial minimums). Periods of interglacial maximums are called “ice ages”. Most recent “ice age” ended 10,000 years ago. Currently in a period of interglacial minimum.

Vostok Ice-Core Data



Ice-Core Data: Temperature and CO_2

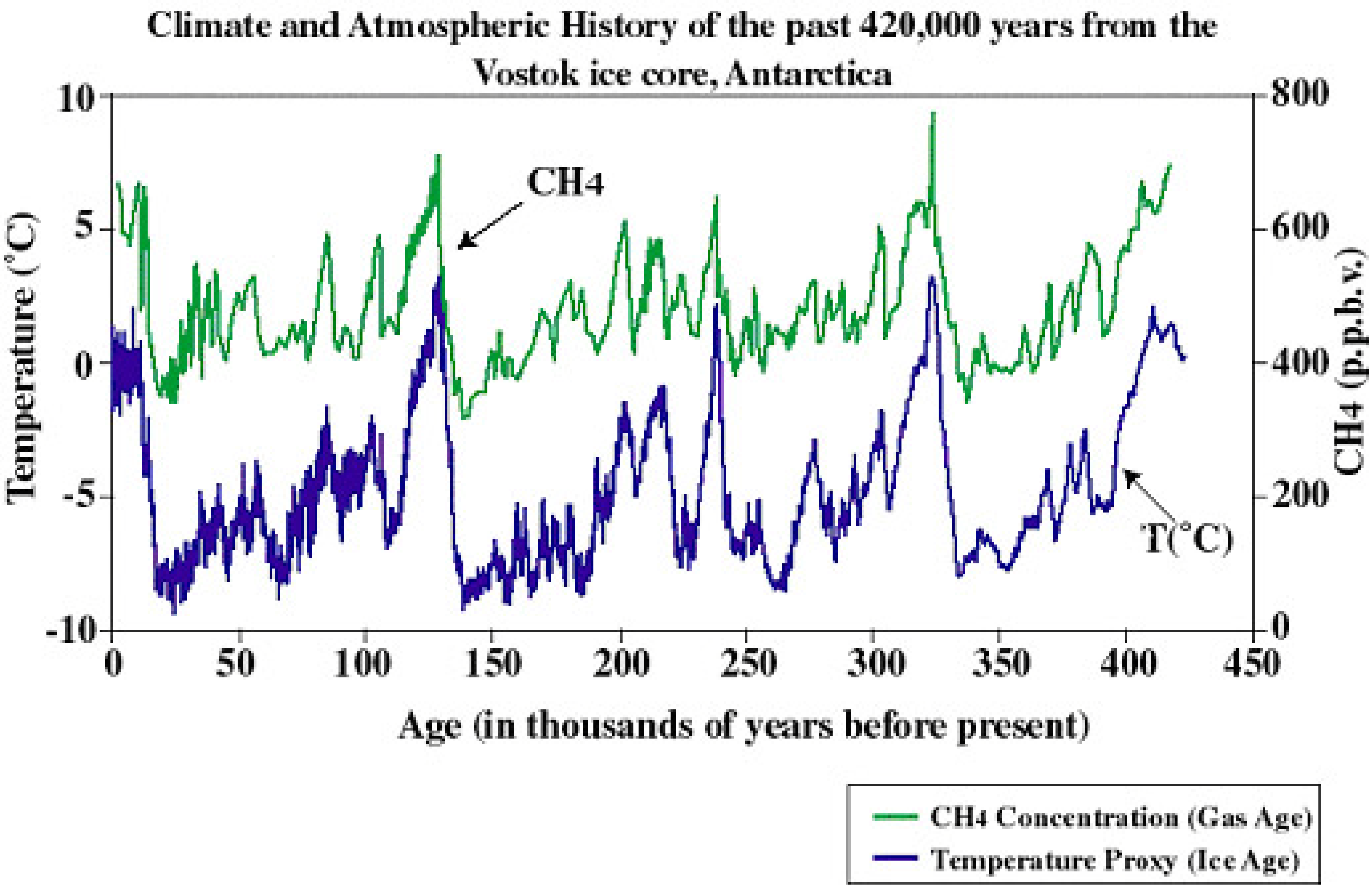


Source: J.R. Petit, J. Jouzel, et al. Climate and atmospheric history of the past 420 000 years from the Vostok ice core in Antarctica, Nature 399 (3June), pp 429-436, 1999.

CO_2

Temp

Ice-Core Data: Temp and CH_4



CO2 Changes During Pleistocene Era …

- CO_2 concentrations
  - Warmest Times: 280 – 300 ppm
  - Coldest Times (Ice Ages): around 200 ppm
- CO_2 concentrations never exceeded 300 ppm.
- Change of ~ 100 ppm from maximum to minimum took tens of thousands of years to occur.
- Current day CO_2 rise of ~ 100 ppm (280 ppm to 390 ppm) took only 100 years (!).

March 10 Exam Questions

- Some of the questions on following slides will appear on exam exactly as stated.
- Other questions on exam may be a slight variation of those on following slides.

This process is part of the **long-term** carbon cycle *and* it **removes carbon** from the atmosphere:

a) photosynthesis
b) volcanic eruptions
c) silicate-to-carbonate conversion
d) decay of dead plants

During the last roughly 1000 years prior to the industrial era, carbon dioxide concentrations were fairly steady at ______ parts-per-million The lack of substantial variation in concentrations is best explained as follows: _____.

a) 280; rates of CO_2 uptake by photosynthesis and of emissions by respiration tend to be balanced.
b) 280; rates of CO_2 uptake by silicate-carbonate conversion and of emissions by volcanic eruptions tend to be balanced.
c) 350; rates of CO_2 uptake by photosynthesis and of emissions by respiration tend to be balanced.
d) 350; rates of CO_2 uptake by silicate-carbonate conversion and of emissions by volcanic eruptions tend to be balanced.

Ecological Footprint

(Question below will be part of a broader short-answer question on the topic of Ecological Footprint, following from your work on the Ecological Footprint ‘homework’)

Q: What is the difference between direct and indirect carbon emissions? What would be some examples of “direct” and “indirect” carbon emissions associated with your personal ecological footprint?

The following gases are important greenhouse gases in the atmosphere.

a) water vapor, carbon dioxide, methane
b) carbon dioxide, oxygen, nitrogen
c) infrared, ultraviolet, solar
d) ozone, carbon dioxide, carbon monoxide

Which of the following is an accurate description the earth’s greenhouse effect?

a) Greenhouse gases absorb sunlight and emit this to the surface, thereby raising the earth’s temperature.
b) Greenhouse gases reflect radiation emitted by the surface back to the surface, thereby raising the earth’s temperature.
c) Greenhouse gases absorb radiation emitted by the surface and emit some of this back to the surface, thereby raising the earth’s temperature.
d) Greenhouse gases absorb radiation emitted by the earth and reflect this back to the surface, thereby raising the earth’s temperature.

Which of the following is an accurate statement regarding ozone in the earth's atmosphere?

a) Ozone in the stratosphere reflects ultraviolet radiation back to space, thereby protecting surface life from the harmful effects of ultraviolet radiation.
b) Ozone in the troposphere reflects ultraviolet radiation back to space, thereby protecting surface life from the harmful effects of ultraviolet radiation.
c) Ozone in the stratosphere absorbs ultraviolet radiation, thereby protecting surface life from the harmful effects of ultraviolet radiation.
d) Ozone in the troposphere absorbs ultraviolet radiation, thereby protecting surface life from the harmful effects of ultraviolet radiation.