GLOBAL BIOGEOCHEMICAL CYCLES

GEOG/ENST 3331 – Lecture 10

Turco: Chapter 10; Dearden and Mitchell: Chapter 4

Assignment 4

1. Suppose that a layer of air 1000 m thick has conditional stability. A rising parcel of dry air within the layer will be pushed back down.
    1. What does 'conditional stability' tell us about the temperature profile of the layer? What can you say quantitatively about the environmental lapse rate?
    2. How would the stability be affected if the layer passed over a very warm surface?
    3. How would the stability be affected if the layer passed over open water?

Last Lecture

- Weather forecasting
  - Prediction methods
  - Numerical weather prediction
- Long-range forecasting
  - Memory
  - ENSO and NAO

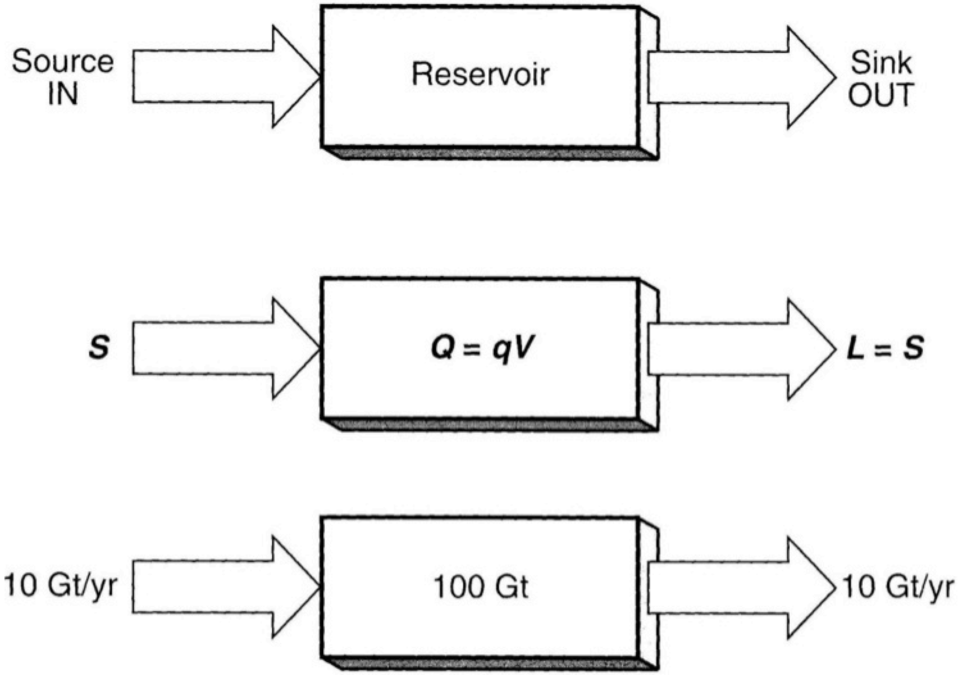
Global biogeochemical cycles

- Objectives
  - Recognize biologically important and abundant chemicals and their associated reservoirs
  - Understand the flows between reservoirs and be able to characterize them as large or small, fast or slow
  - Consider anthropogenic perturbations to these cycles and gain an idea of their implications

Global biogeochemical cycles

- **Reservoirs**
  - **Box models and fluxes**
  - **Sources and sinks**
  - **Residence time**
- Hydrological cycle
- Carbon cycle

Box models



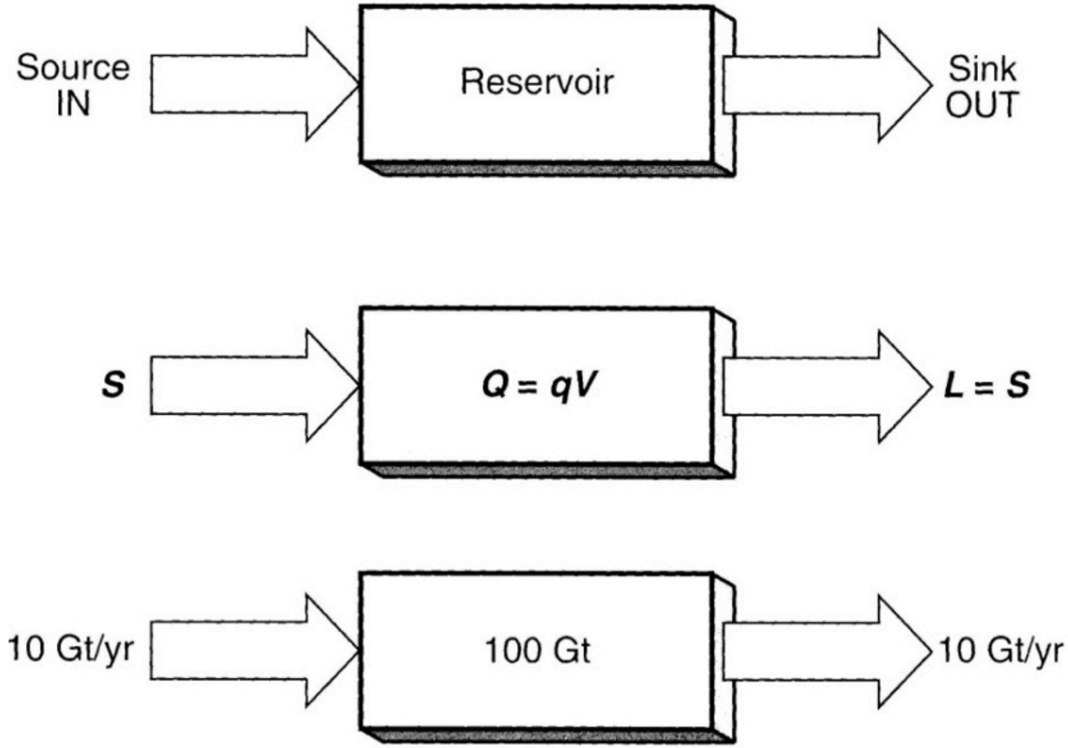
Turco: Figure 10.2

- Q ~ total mass
- S ~ source
- L ~ sink
- Mass balance
  - $\Delta Q = S - L$
- Steady state
  - $L = S$, $\Delta Q = 0$

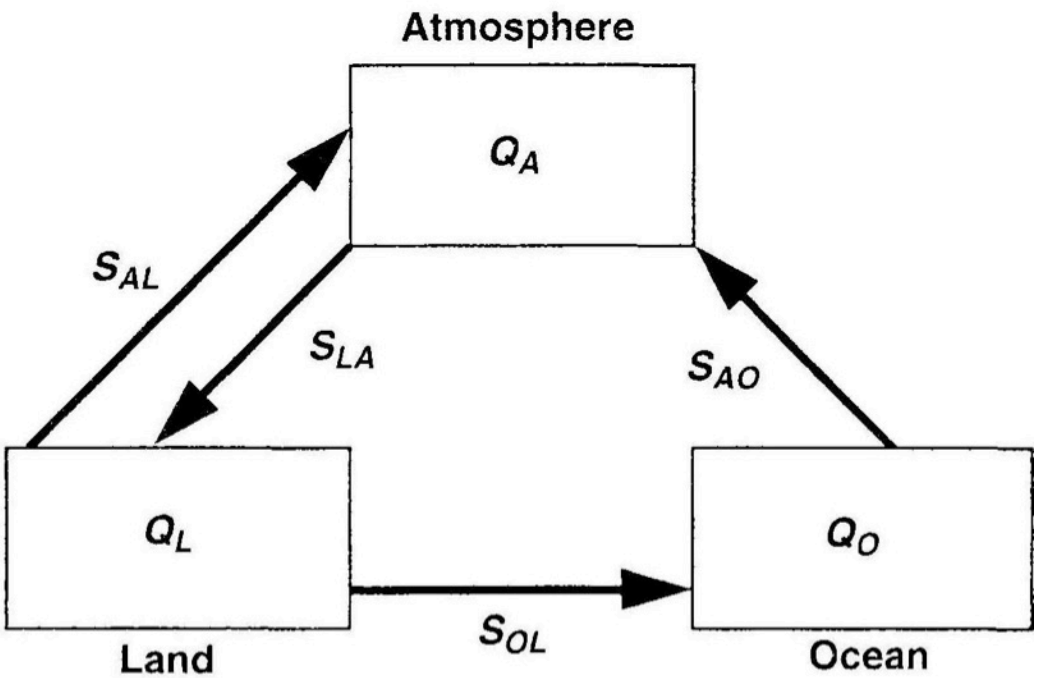
Residence time

- Residence time of the substance in a reservoir:

$$\tau = \frac{Q}{L}$$



Multiple reservoirs

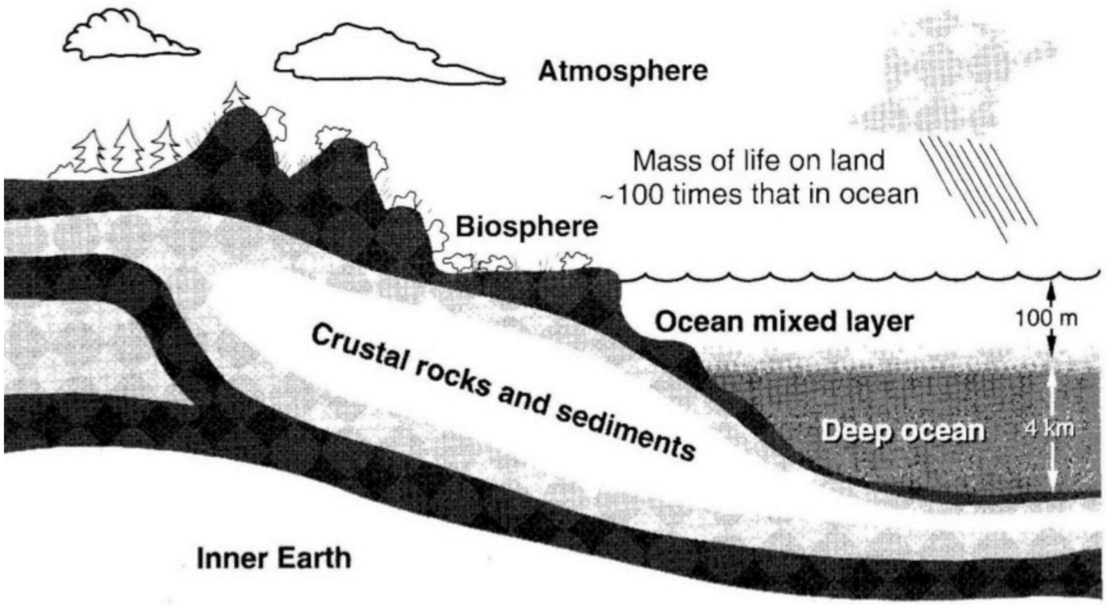


Example

- Closed system
  - Extend mass balance
  - Every flux is a source and a sink

Reservoirs

- Atmosphere
- Hydrosphere
  - Mixed layer
  - Deep ocean
- Lithosphere
  - Crust and upper mantle
  - Sediments
- Biosphere
- Cryosphere



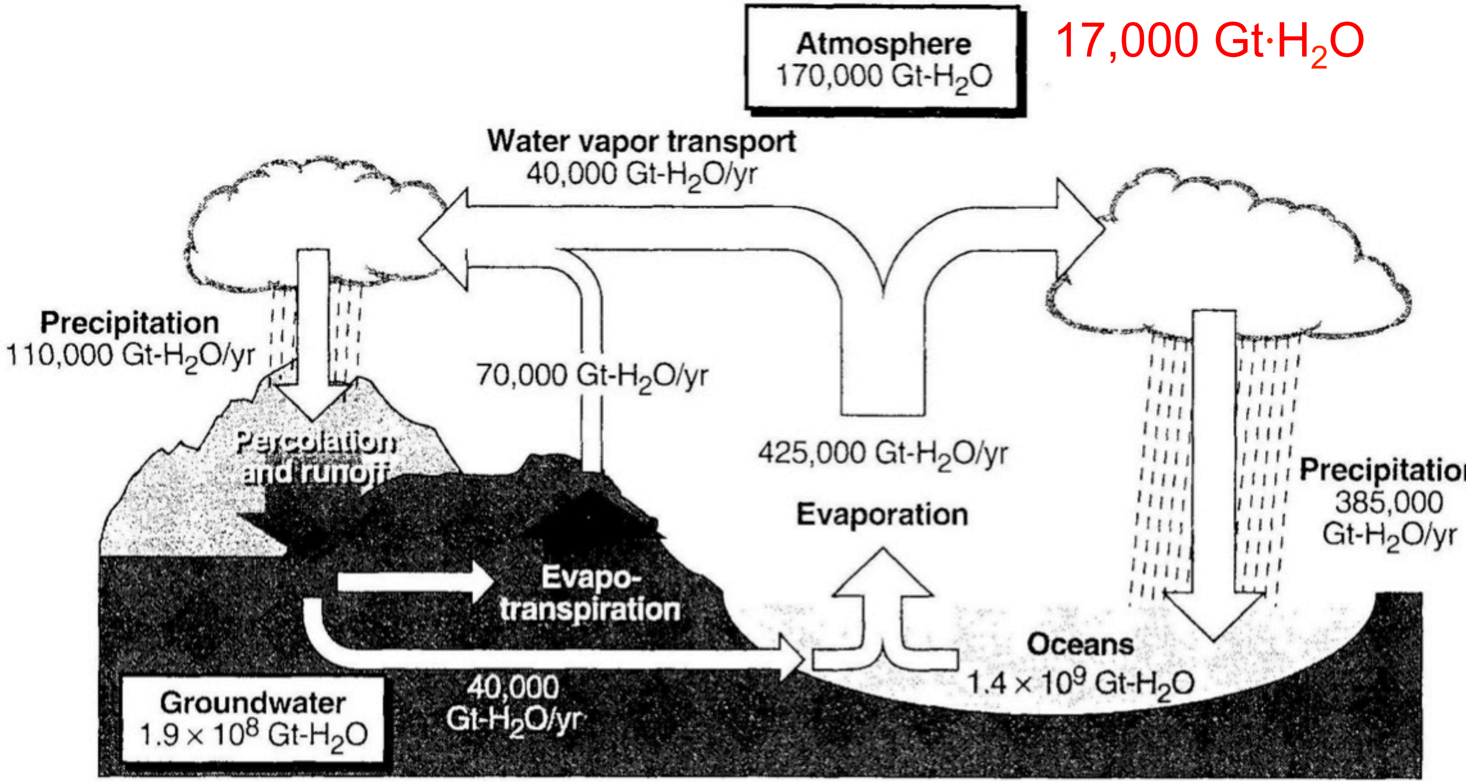
Turco: Figure 10.1

Hydrological cycle

‘Groundwater’ includes water in lakes, soil and ice sheets

Turco: Figure 10.15

$17{,}000\ Gt \cdot H_2O$



$4.9 \times 10^7\ Gt \cdot H_2O$

Importance

- Redistribution to the land
  - Liquid sinks in and flows downhill
  - Important to biosphere
- Desalinization
- Mobilizing Contaminants
  - Universal solvent
  - Precipitation washes out atmosphere
  - Runoff leaches compounds from rocks/soil

Human impacts

- Consumption
  - Freshwater for drinking
  - Cooking
  - Transportation
  - Hydroelectricity

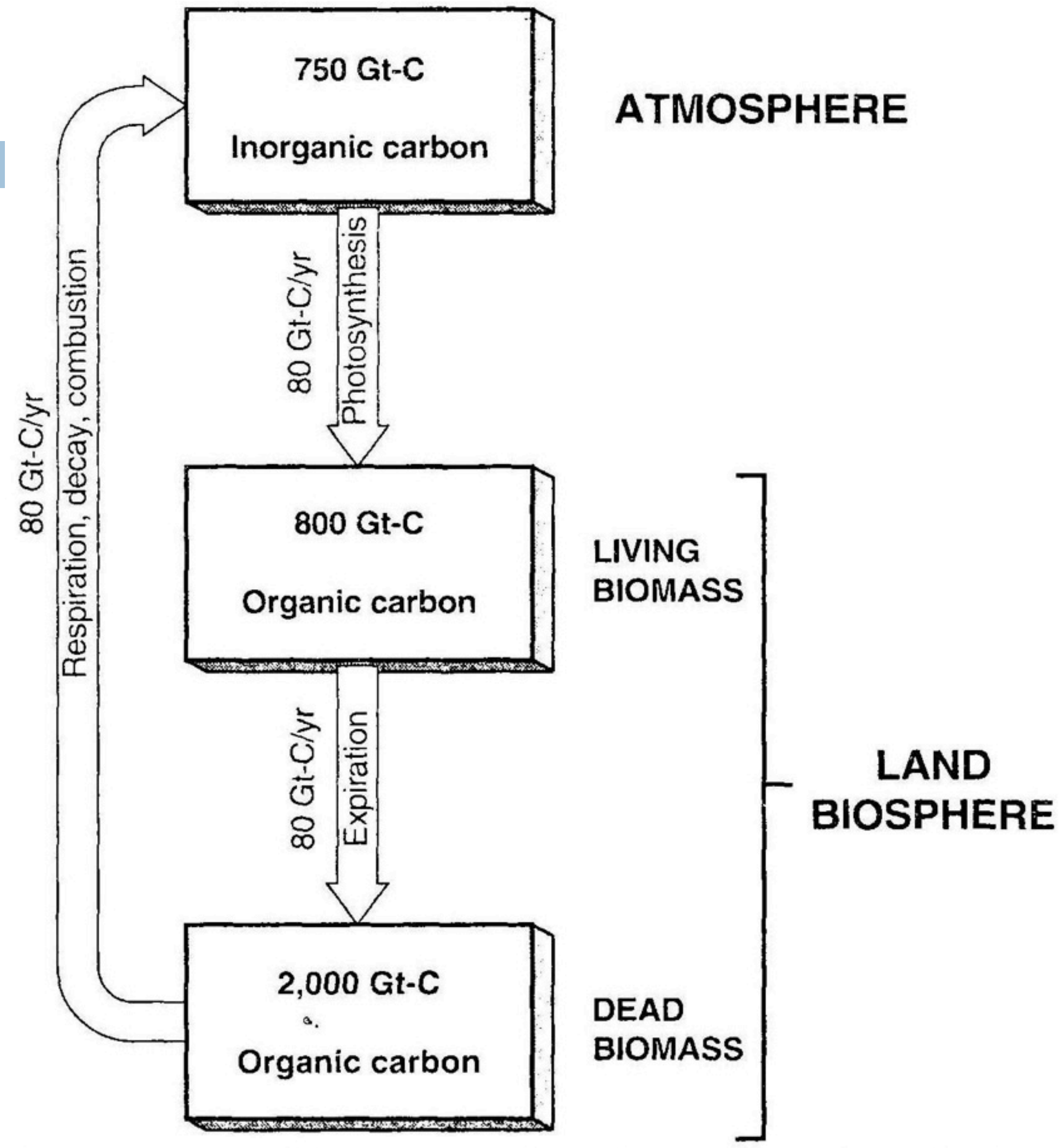
- Water quality
  - Toxins
  - Nutrients

Carbon cycle

- Multiple processes
- Multiple timescales

Terrestrial biosphere cycle

- Photosynthesis
  - Water, CO_2 and sunlight turned into carbohydrates and oxygen (O_2)
- Respiration
  - Includes decomposition by bacteria
- Combustion



Turco: Figure 10.11

Oceans

- Surface (100 m or less)
  - Well-mixed (winds)
  - Photosynthesis only in top few metres
    - Some life exists further down

- Deep ocean (average nearly 4 km deep)
  - Stratified
  - Mostly barren
  - Thermohaline: very slow circulation

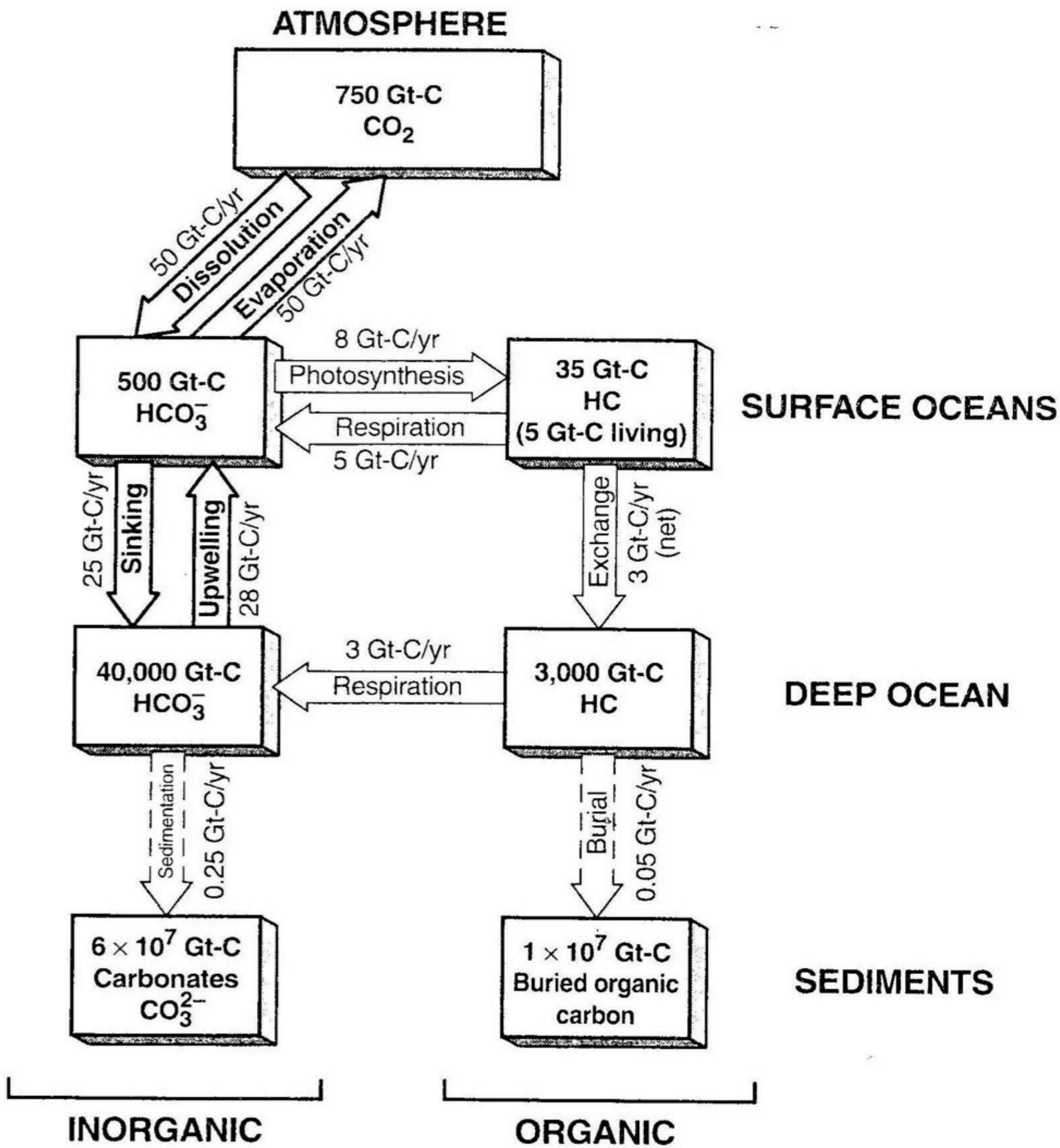
Air-sea cycle

Small biomass reservoir in ocean; small fluxes

Large exchange with atmosphere

Thermohaline: slow circulation to deep ocean

Turco: Figure 10.12

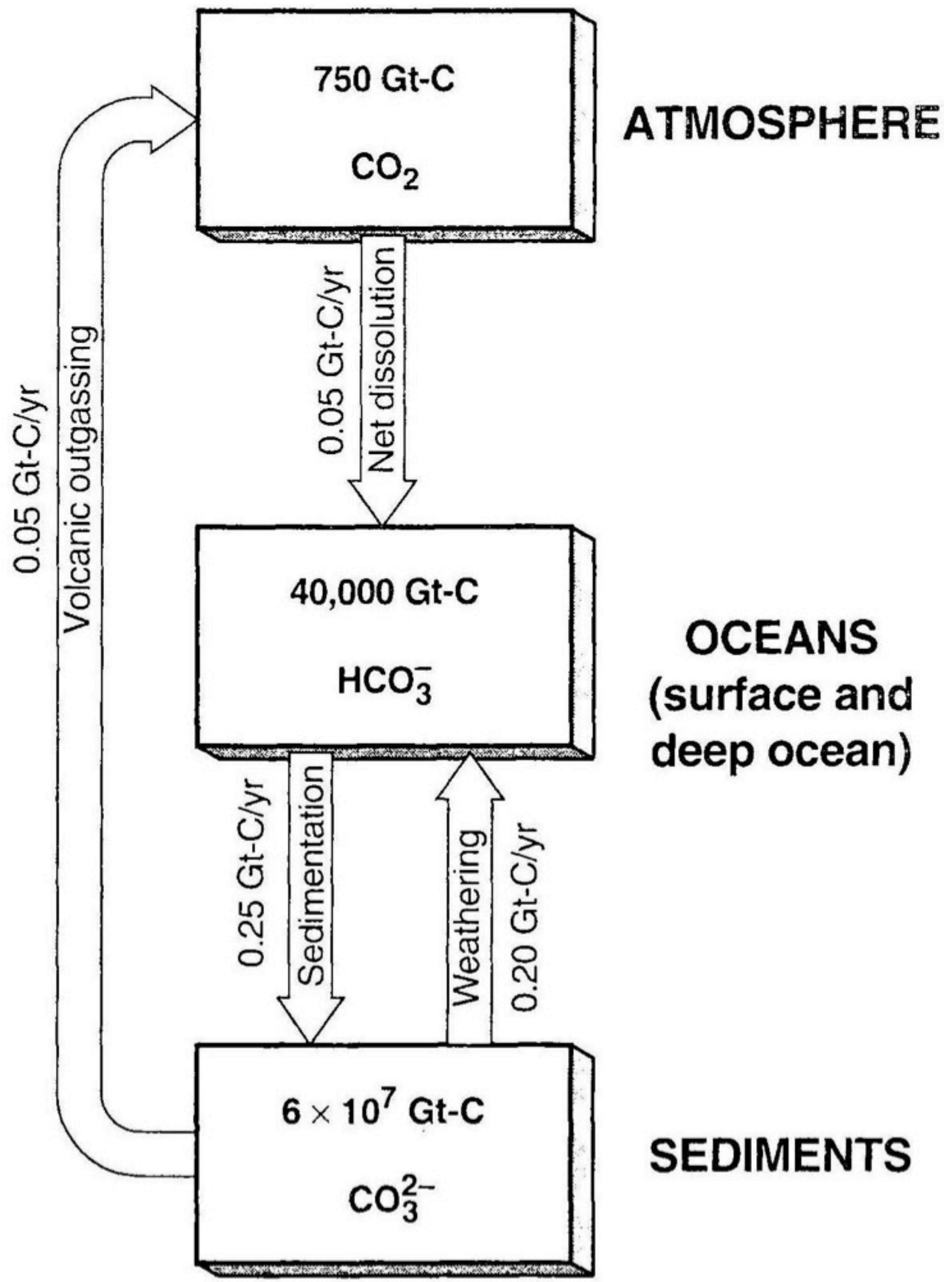


Recap: Fast Processes

- Air-biomass exchange: 80 GtC/year
- Air-ocean exchange: 50 GtC/year
- Surface-deep ocean exchange: 25 GtC/year
- Ocean-biosphere exchange: 5 GtC/year

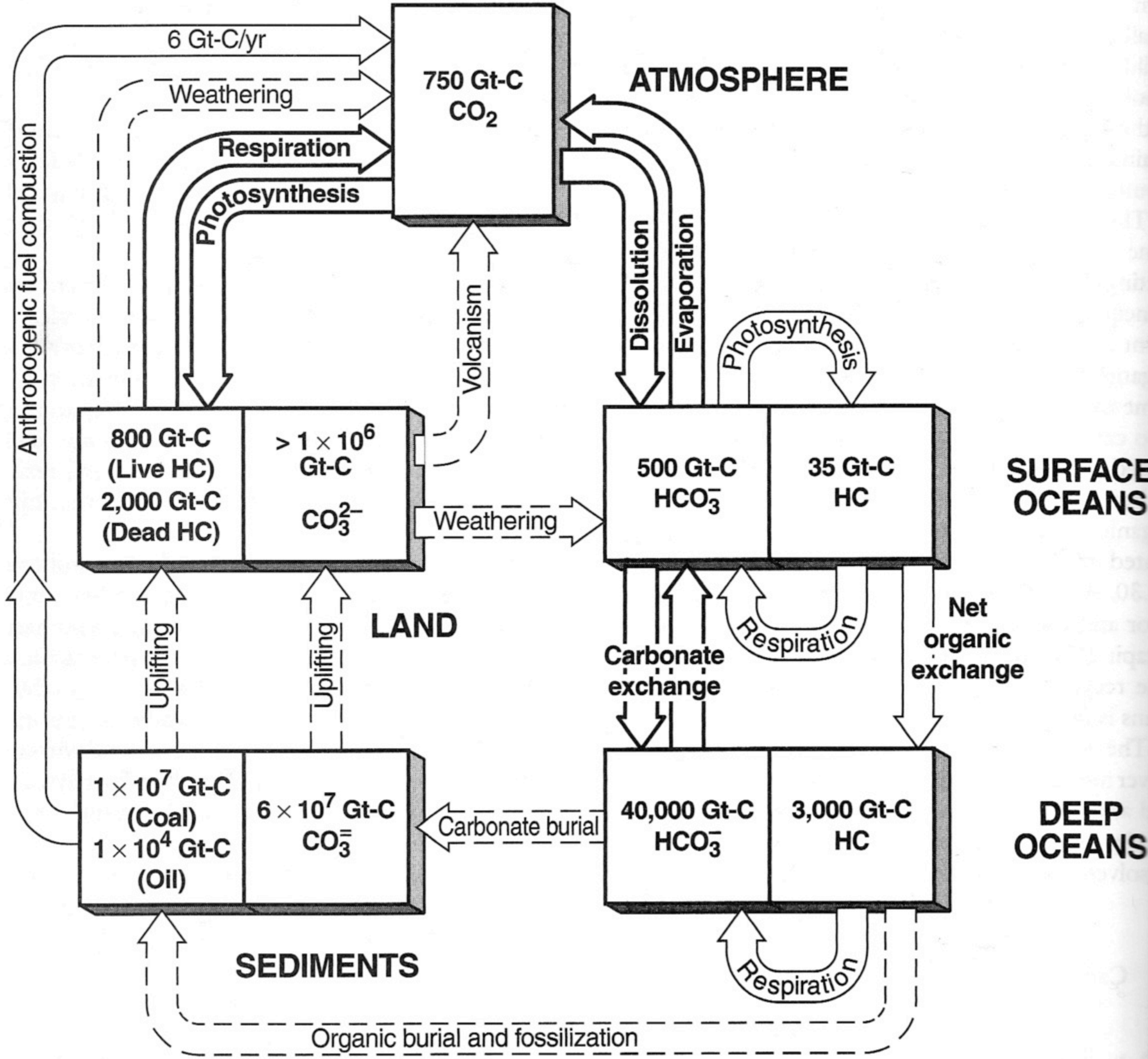
Geologic carbon cycle

- Geologic time scale
  - Note the very small size of fluxes
- Dissolution
- Sedimentation
  - Mostly $CaCO_3$
  - Uplift/weathering
  - Subduction
- Outgassing



Turco: Figure 10.10

Turco: Figure 10.13



Importance

- Plant food
- Greenhouse effect from CO_2
  - Also Methane (CH_4)
    - Anaerobic decomposition
    - Transformed into CO_2 in atmosphere

Human impact

- Gradual burial of organic material over hundreds of millions of years
  - Converted by temperature and pressure into fossil fuels
  - Extracted and consumed for energy
  - Unbalanced flux to the atmosphere of 7-8 GtC/year
- Deforestation: increased flux from biosphere to atmosphere of 2 GtC/year
- Also increases in methane (CH_4), and carbon monoxide (CO)

Effects of additional CO_2

- Global warming
- Fertilization of plant growth
- Increased carbonic acid in ocean
  - Decreased calcium carbonate formation
  - Uncertain other direct effects

Global geochemical cycles, continued

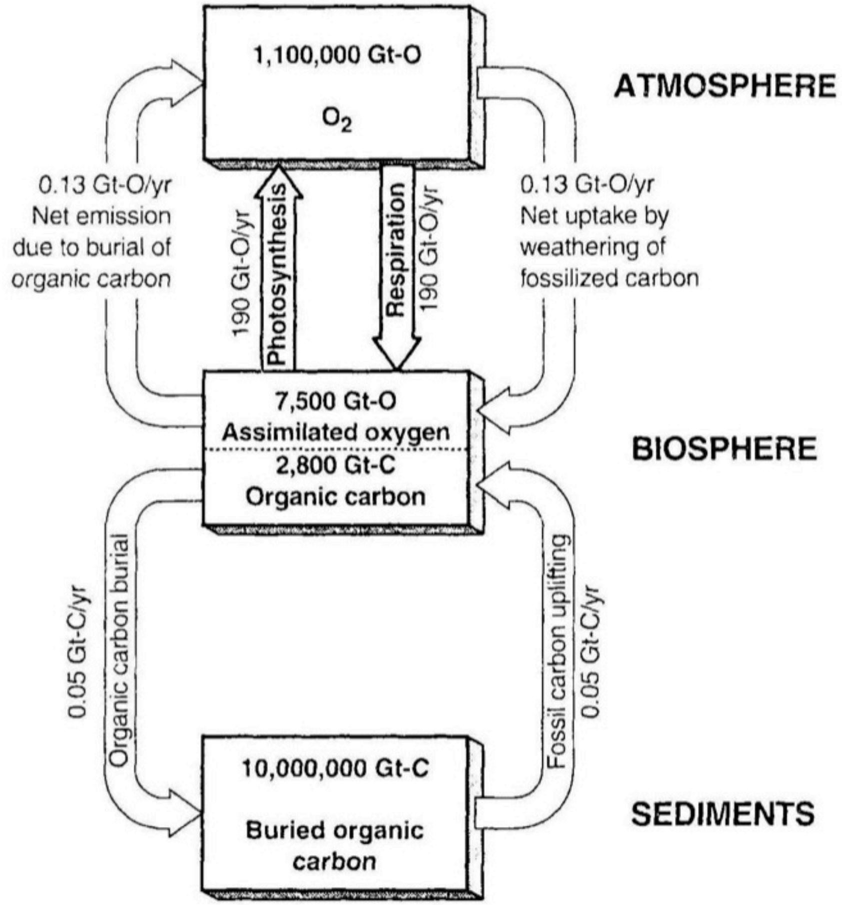
- Oxygen cycle
- Nitrogen cycle
- Sulfur cycle

Oxygen

- 1 million GtO in the atmosphere (mostly O_2)
  - Much, much more oxygen is contained in the crust in the form of mineral oxides
- Very reactive
- Source: photosynthetic consumption of CO_2
  - $6CO_2 + 6H_2O + \text{sunlight} \rightarrow C_6H_{12}O_6 + 6O_2$
  - O_2 is a by-product of this reaction
  - Removes carbon from the atmosphere; if the carbon is not returned to the atmosphere, there is a net oxygen source

Oxygen cycle

- Link: 0.18 $GtCO_2$
  - 0.05 GtC
  - 0.13 GtO
- Burial is largely sediments in the ocean
- Long-term: sink is balanced by recycling buried carbon



Turco: Figure 10.9

Importance

- Critical to aerobic respiration
  - Historically, led to the evolution of complex organisms
- Required for combustion
  - Forest fires
- Absorbs UV radiation
  - Leads to presence of ozone (O_3) in atmosphere
  - Some O_2 is split apart by UV radiation and reacts with other O_2 to form O_3

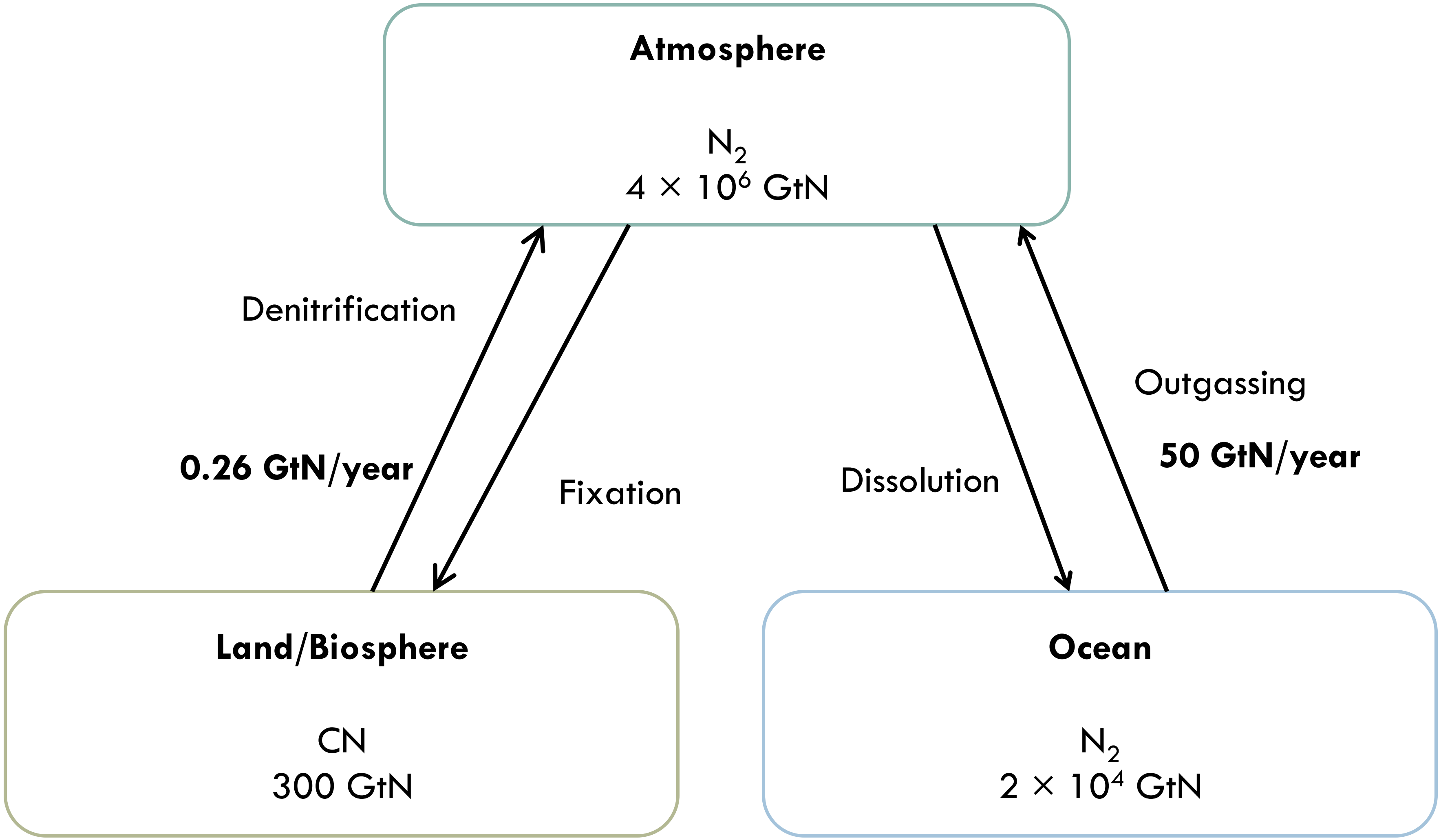
Human impact

- Insignificant
- Atmosphere: $\tau = 5000$ years
  - If photosynthesis stopped respiration would deplete the atmosphere in 5000 years
- Fossil fuel combustion
  - Sinks O_2 at rate of 18 GtO/year
  - Turco estimate: all accessible fossil fuels would sink 23000 GtO from atmosphere

Nitrogen

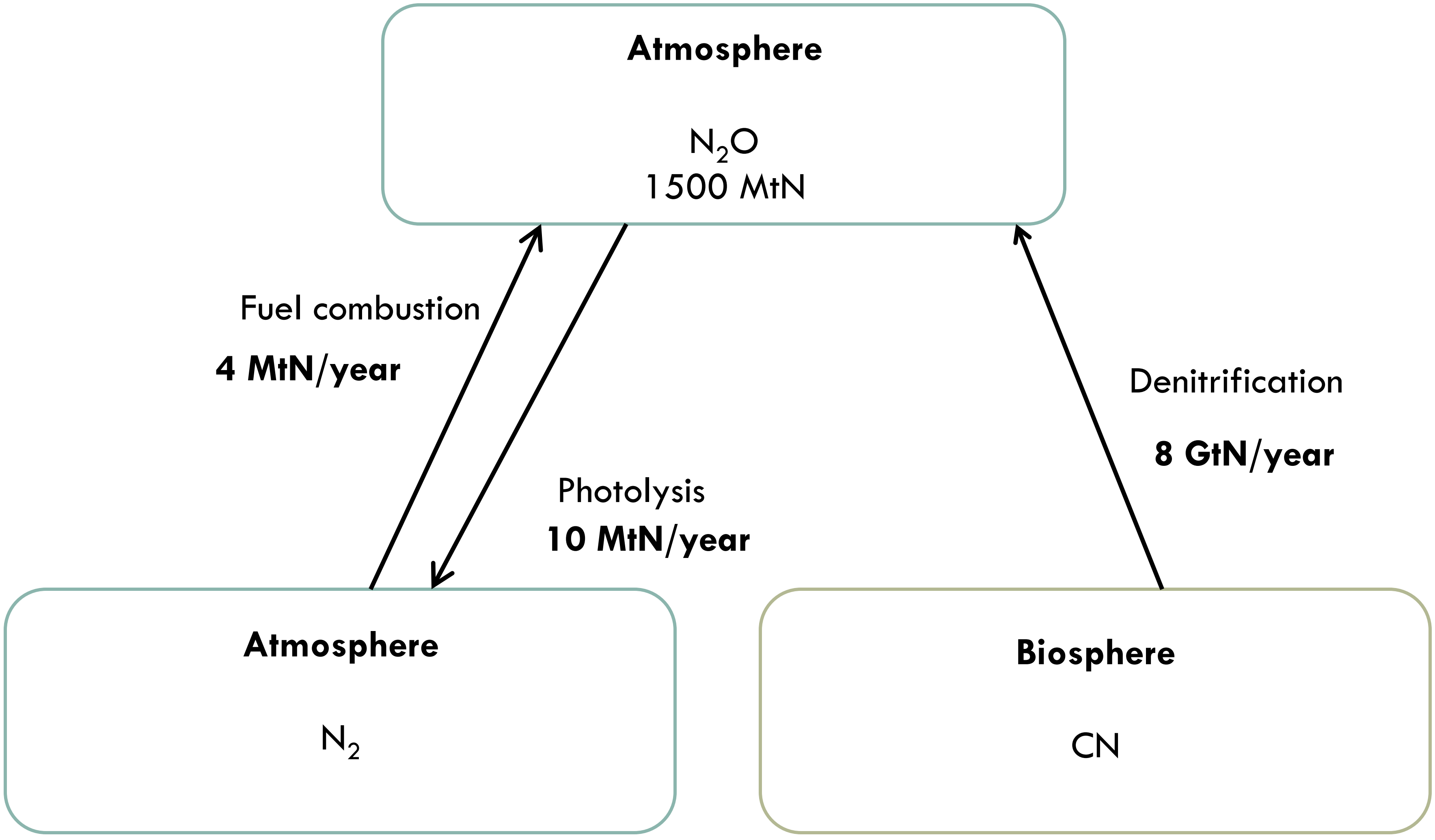
- N_2 is 78% of the atmosphere by volume
  - Inert gas
  - Some bacteria specialize in nitrogen fixation
- N_2O is a trace gas
  - Also inert
- NO_x (NO and NO_2)
  - Reactive gases
  - Soluble

N_2 cycle

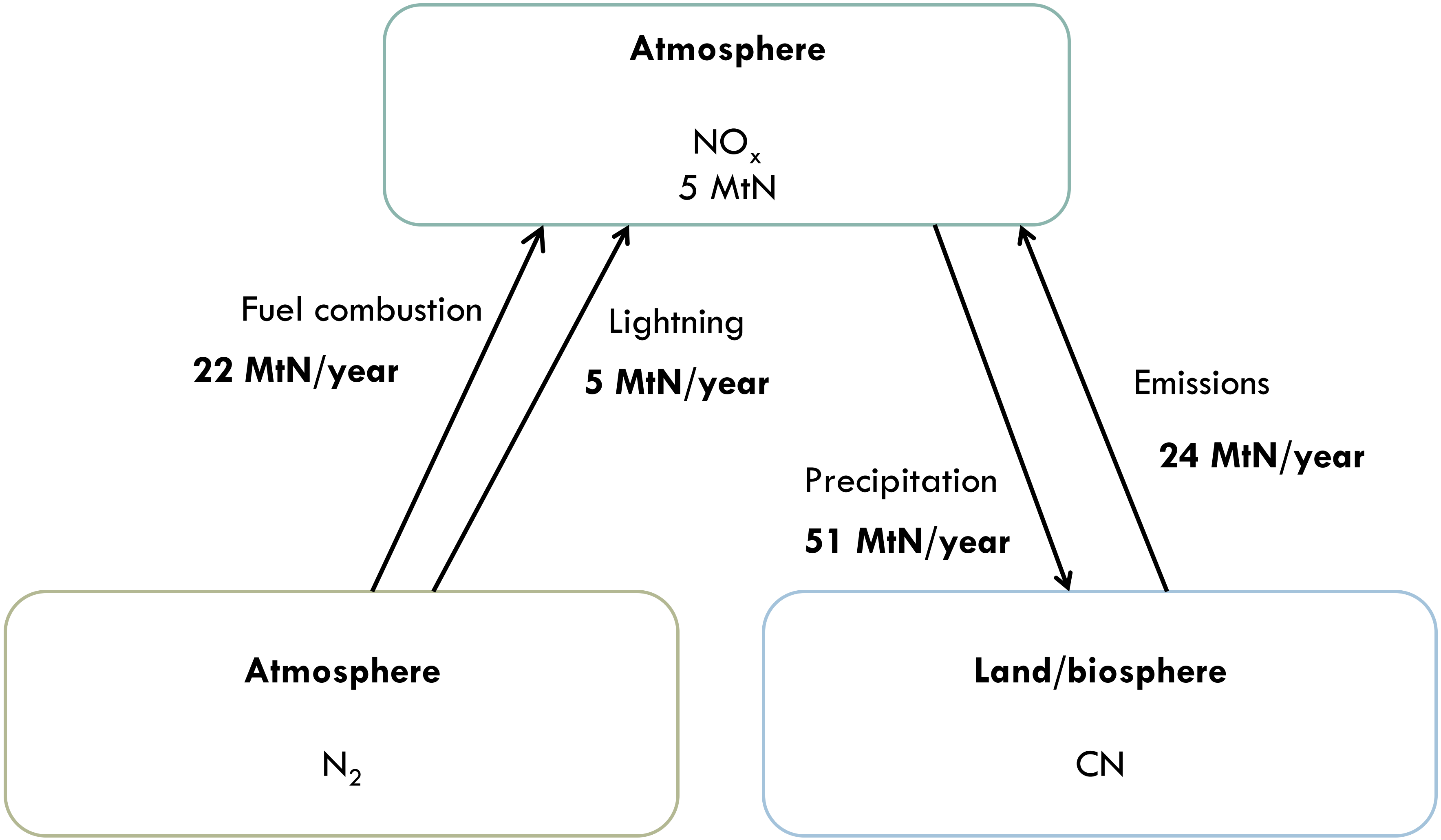


Atmosphere
N_2
4×10^6 GtN
Denitrification
0.26 GtN/year
Fixation
Dissolution
Outgassing
50 GtN/year
Land/Biosphere
CN
300 GtN
Ocean
N_2
2×10^4 GtN

N_2O cycle


Atmosphere
N2O
1500 MtN
Fuel combustion
4 MtN/year
Photolysis
10 MtN/year
Denitrification
8 GtN/year
Atmosphere
N2
Biosphere
CN

NO_x cycle


Atmosphere
NOx
5 MtN
Fuel combustion
22 MtN/year
Lightning
5 MtN/year
Precipitation
51 MtN/year
Emissions
24 MtN/year
Atmosphere
N2
Land/biosphere
CN

Importance

- N_2
  - Nitrogen fixation is vital for the biosphere
- N_2O
  - Potent greenhouse gas
  - 'Regulates' stratospheric ozone
- NO_x
  - Smog
  - Acid rain
  - Fertilizer

Human influence

- Fertilizer
  - Eutrophication
  - Increased N_2O
- Fossil fuels
  - Increased N_2O and NO_x
- Fires
  - Increased NO_x

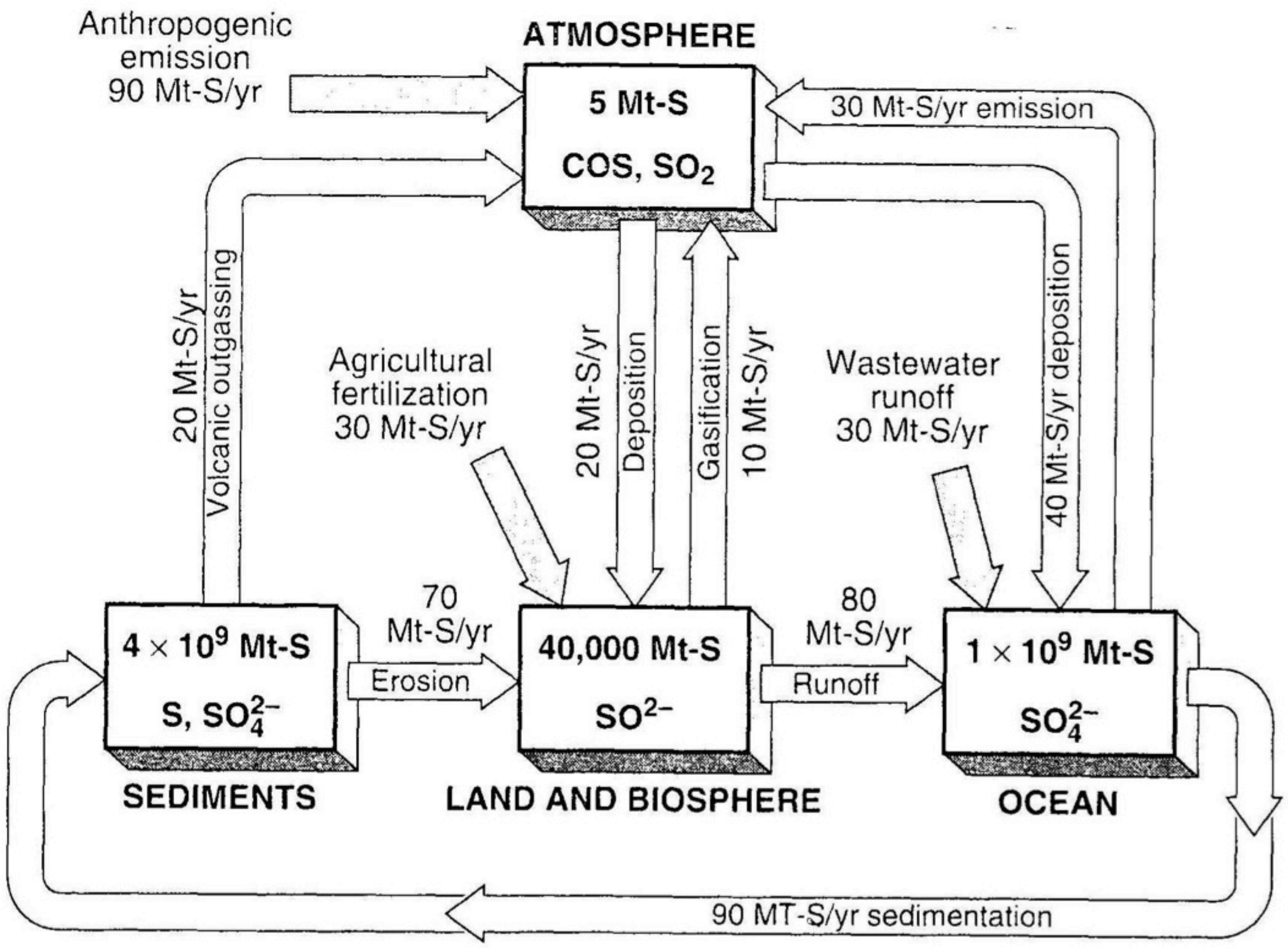
Sulfur

- Mainly found in mineral form
- Important trace nutrient
  - Present in fossil fuels
- Sulfuric acid
  - Common industrial uses
  - Car batteries

Atmospheric Sulfur

- Natural sources:
  - Oceans
  - Volcanoes
  - Biological activity
- Sink:
  - Precipitation (deposition)

Sulfur cycle



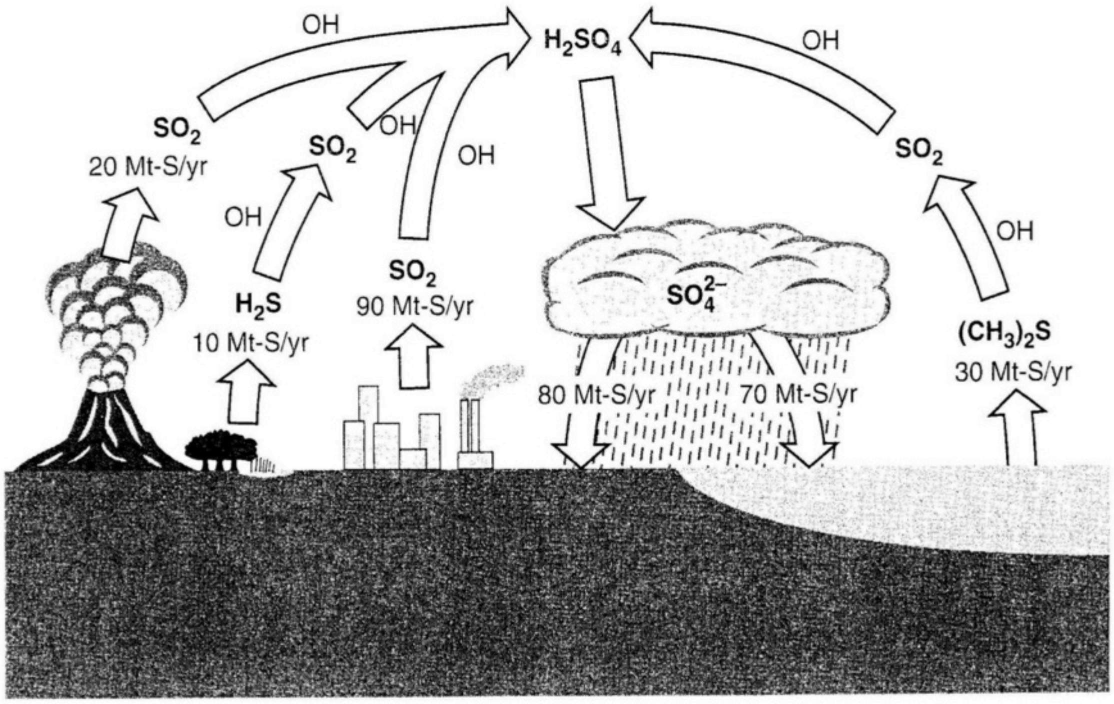
Turco: Figure 10.5

Importance

- Essential nutrient
- Major source of cloud condensation nuclei (CCN)
  - Gaia hypothesis:
    - Ocean phytoplankton release sulfur gases
    - Modify albedo
    - Biospheric thermostat?

Human impact

- Gaseous emissions
  - Fossil fuels
  - 90 MtS/year
  - Acidic rain and fog
- Fertilizer
  - 30 MtS/year
- Wastewater
  - 30 MtS/year



Turco: Figure 10.6

Reservoir review

Chemical	Atmosphere	Ocean	Biosphere	Crust
S	Minor	Large	Small	Large
N	Large	Minor	Small	Minor
O	Small	Small	Minor	Large
C	Minor	Small	Minor	Large

Turco: Table 10.1

Next lecture

- Air pollution and air quality
- Smog