# ENVE203
# Environmental Engineering Ecology
# (Oct 08, 2012)



Elif Soyer

‘Ecosystem and Physical Environment’

# Cycling of Materials within Ecosystems

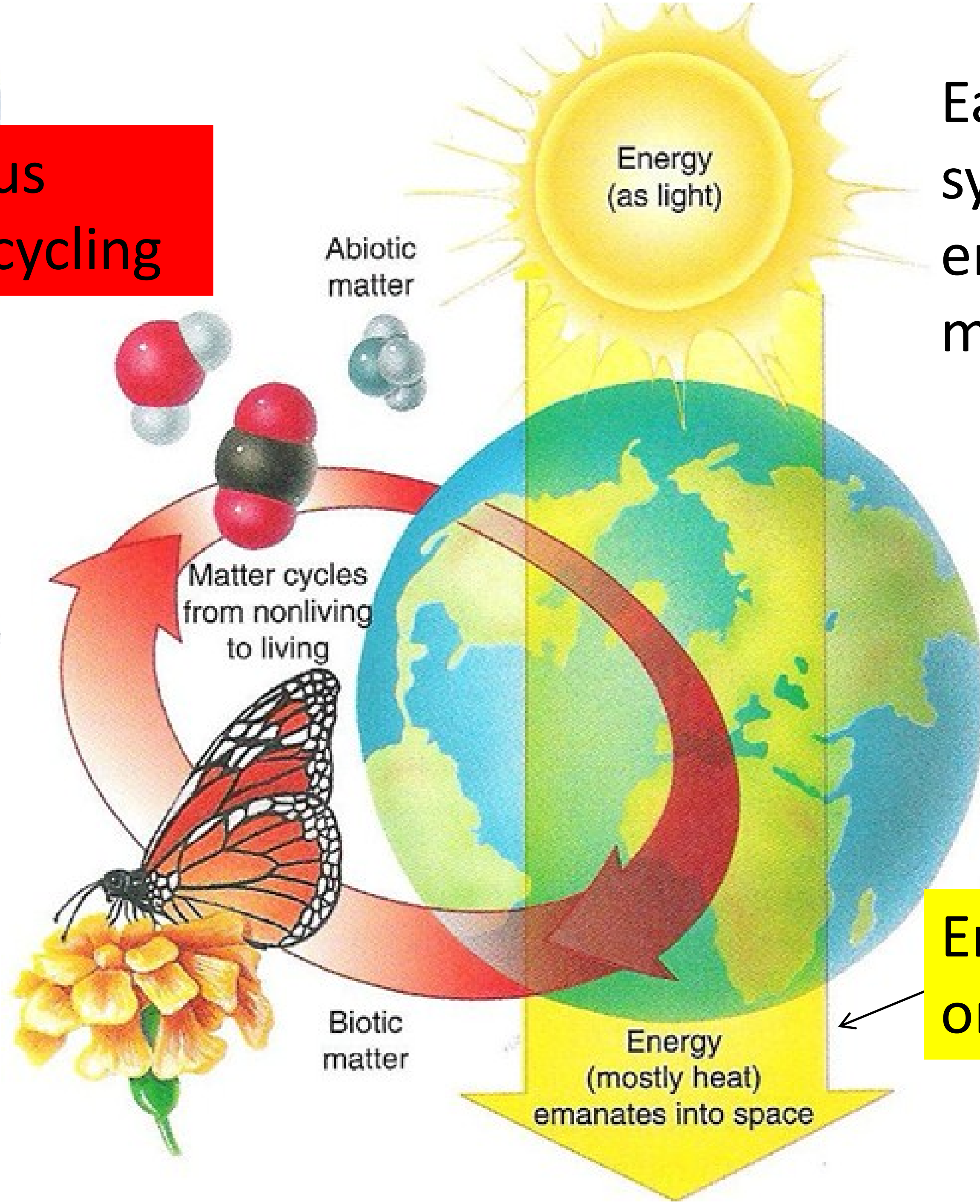
**Energy** flows in one direction through an ecosystem



**Matter** moves through systems in numerous cycles

- from one part of an ecosystem to another
- from one organism to another
- from living organisms to the abiotic environment and back again

continuous material cycling




Earth’s system of energy and matter

Energy flow: one direction

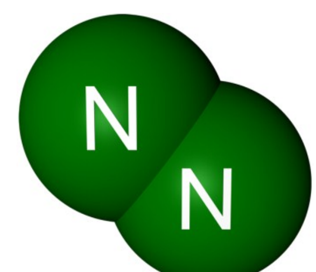
# Biogeochemical Cycles

Involve biological, geologic, and chemical interactions

5 biogeochemical cycles of matter:

- Carbon
- Nitrogen
- Phosphorus
- Sulfur
- Hydrologic (water)

Chemical compounds of cells

# Biogeochemical Cycles

- Carbon
- Nitrogen
- Sulfur

Elements that form gaseous compounds



- Water

readily evaporates

Move over long distances in the atmosphere

- Phosphorus

does not form gaseous compounds (only local cycling occurs easily)

# Biogeochemical Cycles

Human activities are increasingly disturbing the balance of biogeochemical cycles

# THE CARBON CYCLE

Global circulation of carbon from the environment to living organisms and back to the environment

# THE CARBON CYCLE

Organisms need carbon

## Atmosphere

- 0.038% $CO_2$



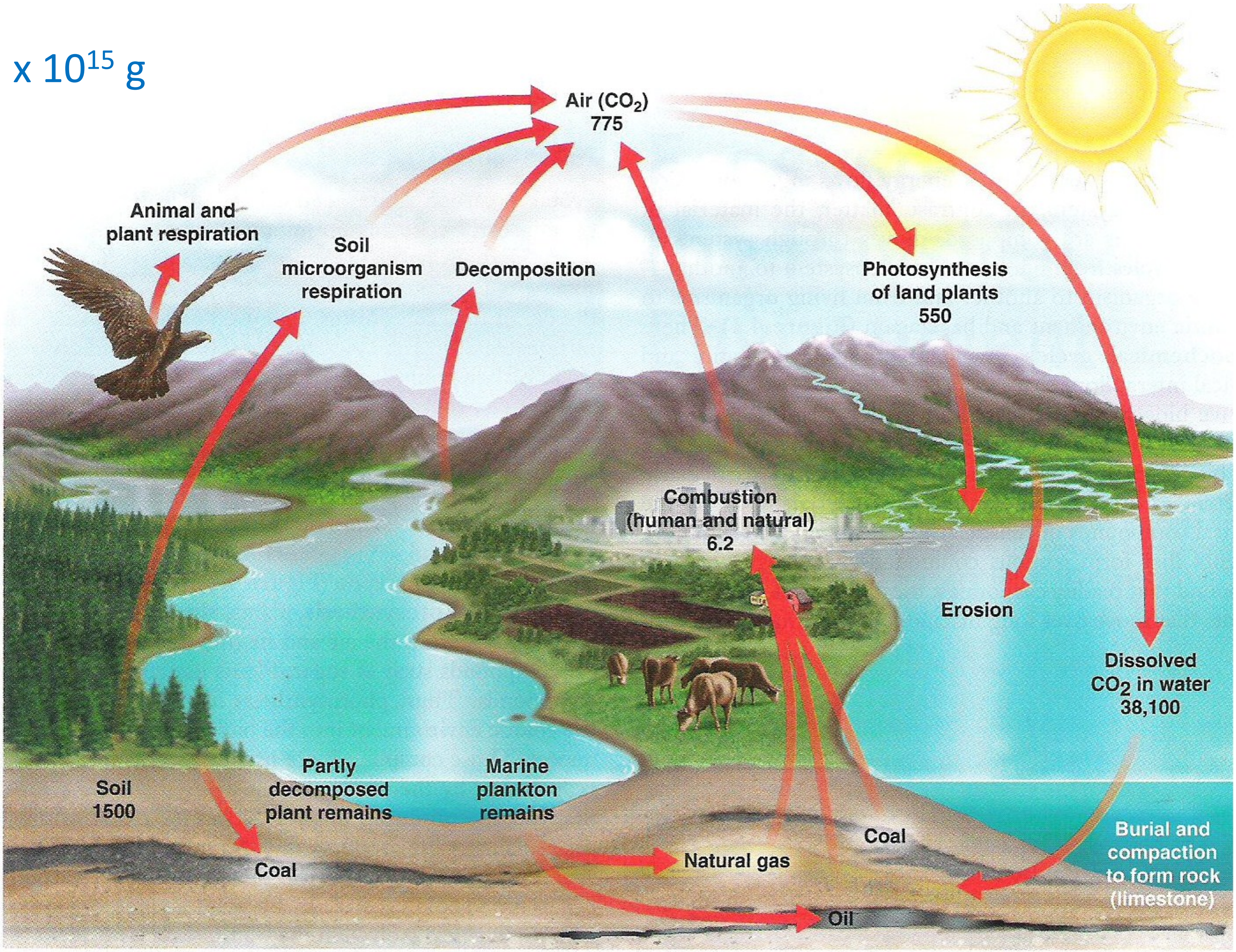
## In oceans

- dissolved $CO_2$ (carbonate, $CO_3^{2-}$ and bicarbonate, $HCO_3^-$)
- dissolved organic carbon from decay processes

## Sedimentary rocks

- Limestone, $CaCO_3$

x $10^{15}$ g



Air ($CO_2$)
775
Animal and
plant respiration
Soil
microorganism
respiration
Decomposition
Photosynthesis
of land plants
550
Combustion
(human and natural)
6.2
Erosion
Dissolved
$CO_2$ in water
38,100
Soil
1500
Partly
decomposed
plant remains
Marine
plankton
remains
Coal
Natural gas
Coal
Oil
Burial and
compaction
to form rock
(limestone)

# THE CARBON CYCLE
# **Photosynthesis**

Incorporates carbon from the abiotic environment into the biological compounds of producers



- Plants, algea and certain bacteria
- Remove $CO_2$ from air and fix (incorporate) into chemical compounds

# THE CARBON CYCLE
# **Fossil fuels, combustion**

Carbon in biological molecules may not recycled back to the abiotic environment for a long time

Coal, oil, and natural gas: fossil fuels



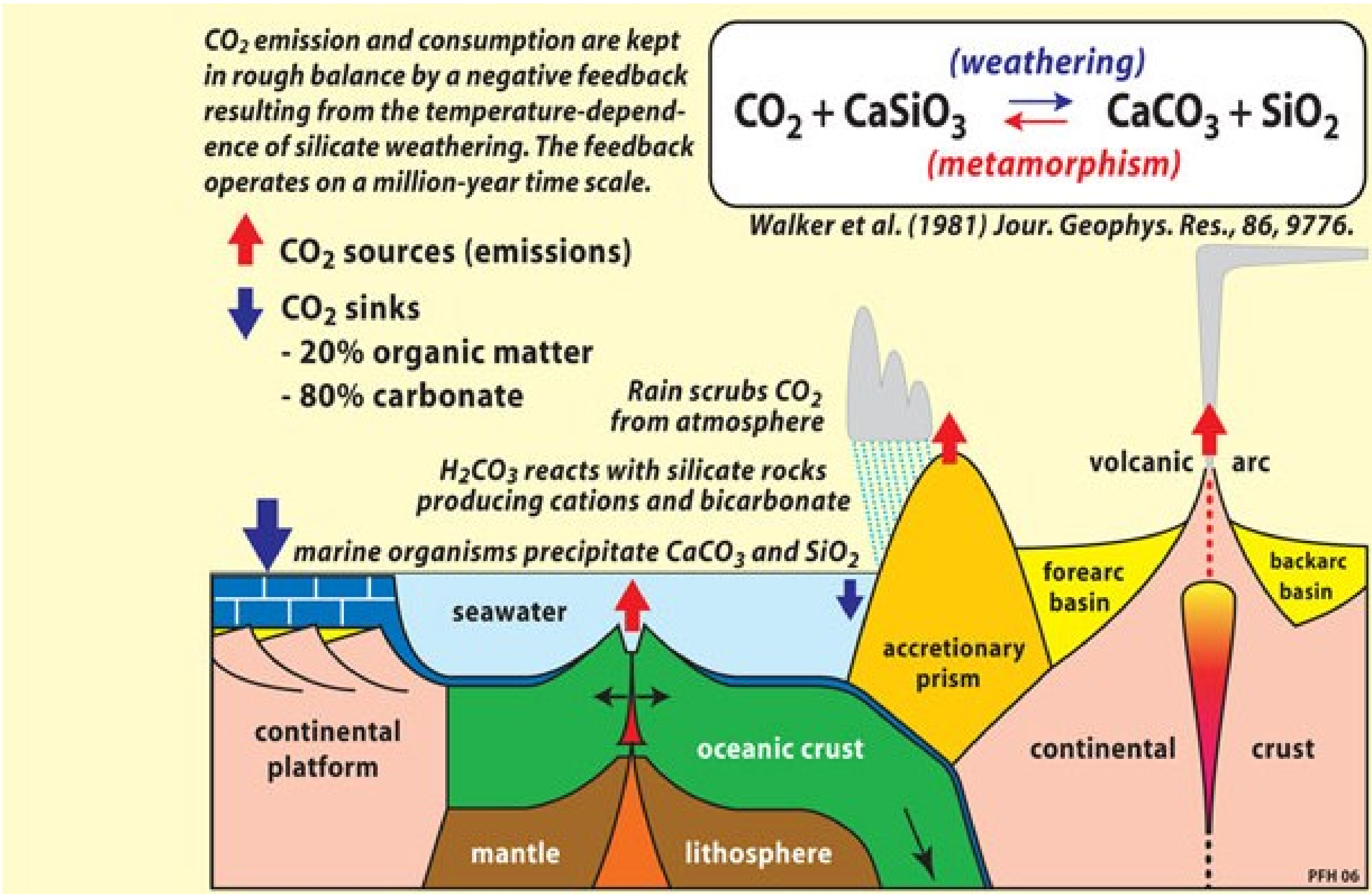
Wood of trees, organic compounds of unicellular marine organisms

Carbon in fossil fuels and wood can return to the atmosphere by burning, or combustion

Organic molecules + $O_2 \rightarrow CO_2 + H_2O$ + heat + light

# The Carbon-Silicate Cycle

Carbon cycle interacts with the silicon cycle



# Human Induced Changes to the Carbon Cycle

Industrial Revolution, since 1750

Burning increasing amounts of fossil fuels:

- Large amounts of C from underground deposits to the atmosphere



$CO_2$

1700s 0.029% of the atmosphere

Now 0.038%

0.06% (double the preindustrial level!) by the end of 21$^{th}$ century

# Human Induced Changes to the Carbon Cycle

Increase of $CO_2$ in the atmosphere
Human induced global climate change

- Increasing temperatures
- A rise in sea level
- Altered precipitation patterns
- Increased wildfires
- Flooding
- Drought
- Heat waves
- Extinction of organisms
- Agricultural distruption

# THE NITROGEN CYCLE

Global circulation of nitrogen from the environment to living organisms and back to the environment

# THE NITROGEN CYCLE

Crucial for all organisms

Essential part of biological molecules such as proteins and nucleic acids (e.g. DNA)



Atmosphere

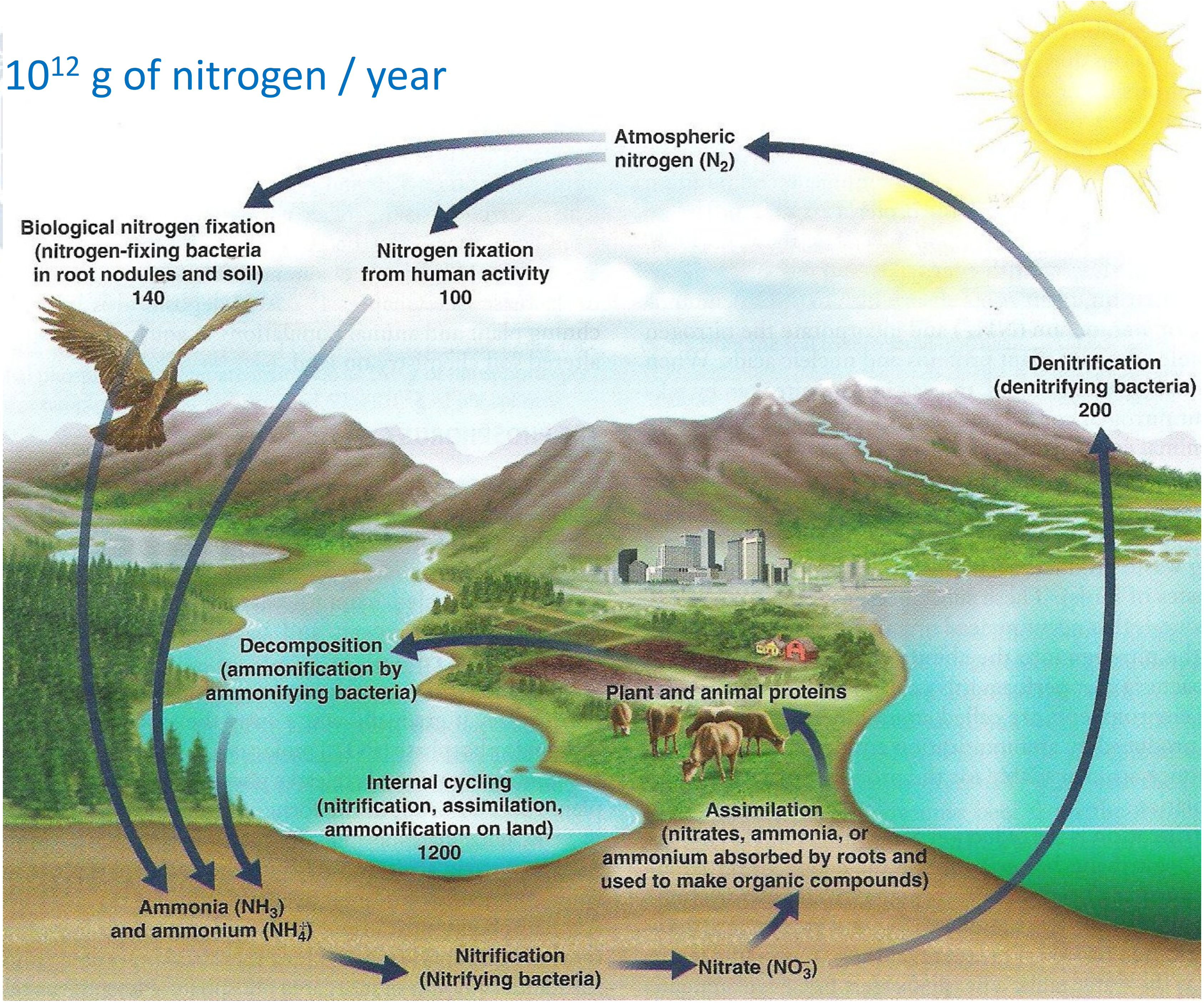
- A two-atom molecule, nitrogen gas: 78%
- Not readily combine with other elements: Each nitrogen molecule is so stable (three covalent bonds linking the two atoms)
- First must be broken apart

# THE NITROGEN CYCLE

5 steps:

- Nitrogen fixation
- Nitrification
- Assimilation
- Ammonification
- Denitrification

Bacteria are exclusively involved in all these steps except assimilation x $10^{12}$ g of nitrogen / year



# THE NITROGEN CYCLE
# Nitrogen fixation

Conversion of gaseous nitrogen to ammonia ($NH_3$)

Nitrogen is fixed into a form that organisms can use

- Combustion
- Volcanic action
- Lightning discharges
- Industrial processes

Supply enough energy to break apart atmospheric nitrogen, fix considerable nitrogen

# THE NITROGEN CYCLE
# Nitrogen fixation

Biological nitrogen fixation in soil and aquatic environments:

Nitrogen fixing bacteria (e.g. cyanobacteria)

Enzyme: nitrogenase (function only in the absence of $O_2$)

Split atmospheric nitrogen, combine nitrogen and hydrogen

- Beneath the layers of oxygen-excluding slime on the roots of certain plants
- Inside special nodules (Rhizobium)
- Special oxygen-excluding cells (filamentous cyanobacteria)

# THE NITROGEN CYCLE
# Nitrification

Conversion of ammonia ($NH_3$), or ammonium ($NH_4^+$) to nitrate ($NO_3^-$)

Nitrifying soil bacteria

# THE NITROGEN CYCLE
# Assimilation

Plant roots absorb $NO_3^-$, $NH_3$ or $NH_4^+$

Incorporate the nitrogen of these molecules into plant proteins and nucleic acids



Animals consume plant tissues...

taking in plant nitrogen compounds (aminoacids) and converting to animal compounds (proteins)

# THE NITROGEN CYCLE
# Ammonification

Conversion of biological N compounds into $NH_3$ and $NH_4^+$

Ammonifying bacteria



Organisms produce N containing waste products (urea, in urine) and uric acid (wastes of birds)

Decomposition of these substances as well as N compounds that occur in dead organisms relases N into the abiotic environment as $NH_3$

# THE NITROGEN CYCLE
# Denitrification

Reduction of $NO_3^-$ to $N_2$

Denitrifying bacteria (reversed action of nitrogen fixing bacteria and nitrifying bacteria)

Prefer to live and grow where there is little or no free oxygen

# Human Induced Changes to the Nitrogen Cycle

During 20th century, humans doubled the amount of fixed nitrogen entering the global nitrogen cycle



Fixed nitrogen: N chemically combined with H, O, or C

Fixed nitrogen is used for fertilizer

Precipitation → washes

# Human Induced Changes to the Nitrogen Cycle

Precipitation → washes nitrogen fertilizer into

rivers

lakes

and coastal areas



Growth of algea

Oxygen depleted dead zones

# Human Induced Changes to the Nitrogen Cycle

Nitrates from fertilizers → leaching to groundwater

Dangerous to infants and small children

Nitrate reduces the oxygen-carrying capacity of a child's blood



Blue baby syndrome

# Human Induced Changes to the Nitrogen Cycle

Combustion of fossil fuels

Nitrogen oxides produce **photochemical smog**

Mixture of air pollutants

- Injures plant tissues
- Irritates eyes
- Causes respiratory problems

Nitrogen oxides react with water in the atmosphere to form acids

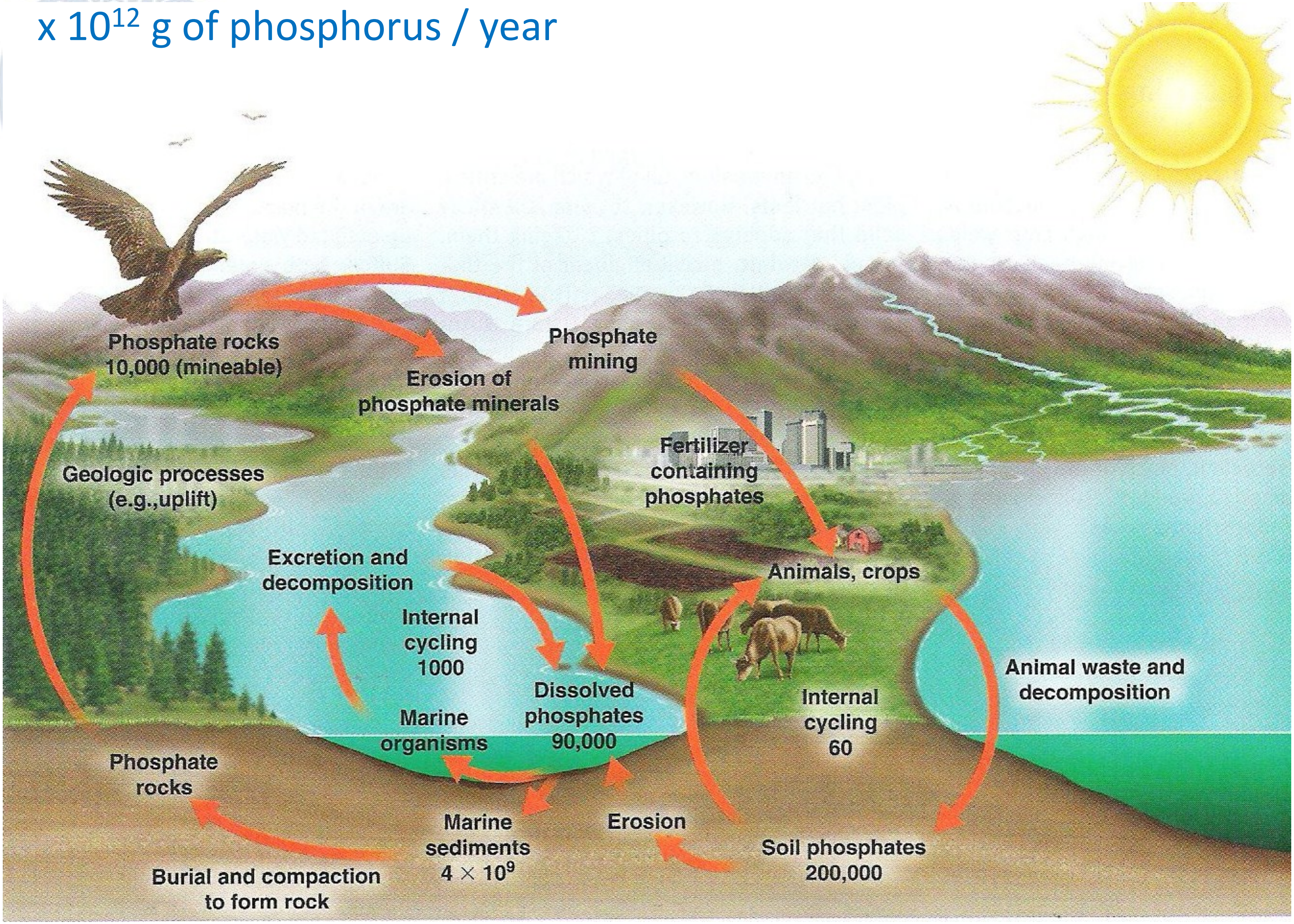
- pH of surface waters and soils decreases
- Decline in plant and animal populations in aquatic ecosystems, altered soil chemistry on land

# THE PHOSPHORUS CYCLE

Global circulation of phosphorus from the environment to living organisms and back to the environment



Phosphorus cycles from the land to sediments in the ocean and back to the land x $10^{12}$ g of phosphorus / year



# THE PHOSPHORUS CYCLE

does not form compounds in the gaseous phase

does not appreciably enter the atmosphere

(except during dust storms)

# THE PHOSPHORUS CYCLE

Water runs over phosphate ($PO_4^{3-}$) containing and other minerals containing phosphorus

Erosion of P into the soil

Plant roots absorb in the form of inorganic phosphates

In cells → incorporated into biological molecules

(e.g. Nucleic acids, and ATP)

Dissolved P enters aquatic communities:

Absorption and Assimilation by algea and plants

# Human Induced Changes to the Phosphorus Cycle

Acceleration the long-term loss of P from land

Cattle breeding

Wash into the waters



P that washes from the land into the ocean is permenantly lost from the terrestrial P cycle (and from further human use)

# Human Induced Changes to the Phosphorus Cycle

A limiting nutrient to plants and algea in certain aquatic systems

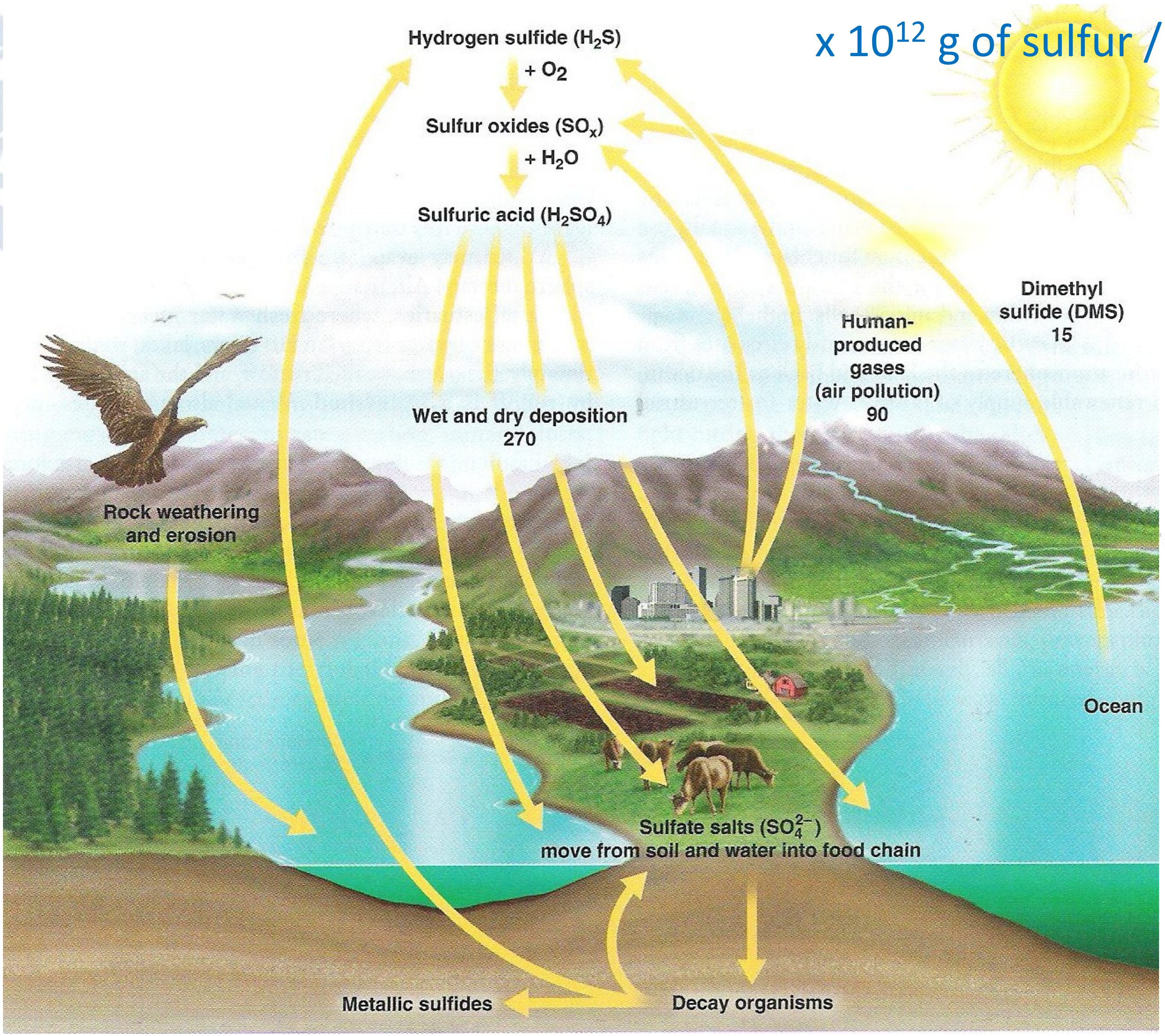
Excess P from fertilizer or sewage

enrichment of water and undesirable changes



# THE SULFUR CYCLE

Global circulation of sulfur from the environment to living organisms and back to the environment x $10^{12}$ g of sulfur / year



# THE SULFUR CYCLE

Most sulfur is underground in sedimentary rocks and minerals

Erode and relase sulfur-containing compounds into the ocean



Sulfur gases enter atmosphere from natural sources both in the ocean and on the land

- Sea spray
- Forest fires and dust storms

} Sulfates into the air

# THE SULFUR CYCLE

Volcanoes

$H_2S$

Sulfur oxides ($SO_x = SO_2$ and $SO_3$)



Sulfur gases → a minor part of the atmosphere

$H_2S + O_2 \rightarrow$ sulfur oxides

sulfur oxides + $H_2O \rightarrow H_2SO_4$

# THE SULFUR CYCLE

Plant roots absorb sulfate and assimilate by incorporation into plant proteins

Animals consume plant proteins and convert them to animal proteins

# Human Induced Changes to the Sulfur Cycle



Coal, and to a lesser extent oil, contain sulfur

Burning...

Power plants

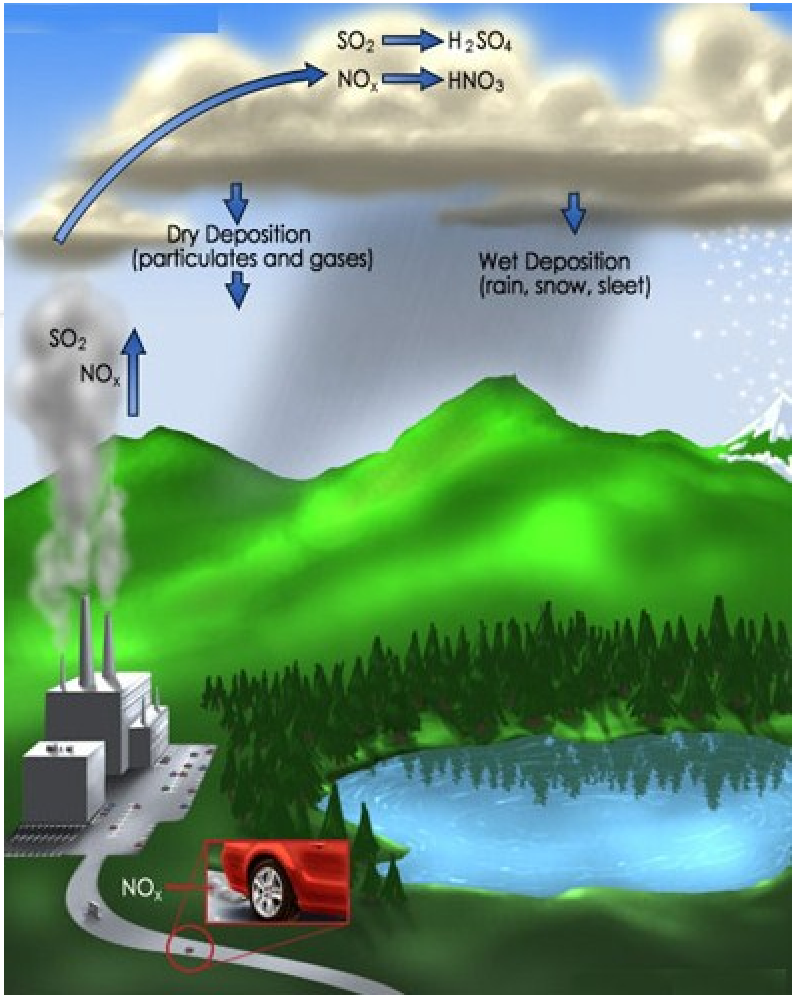
Factories

Motor vehicles

$SO_2$

Acid deposition





# HYDROLOGIC CYCLE

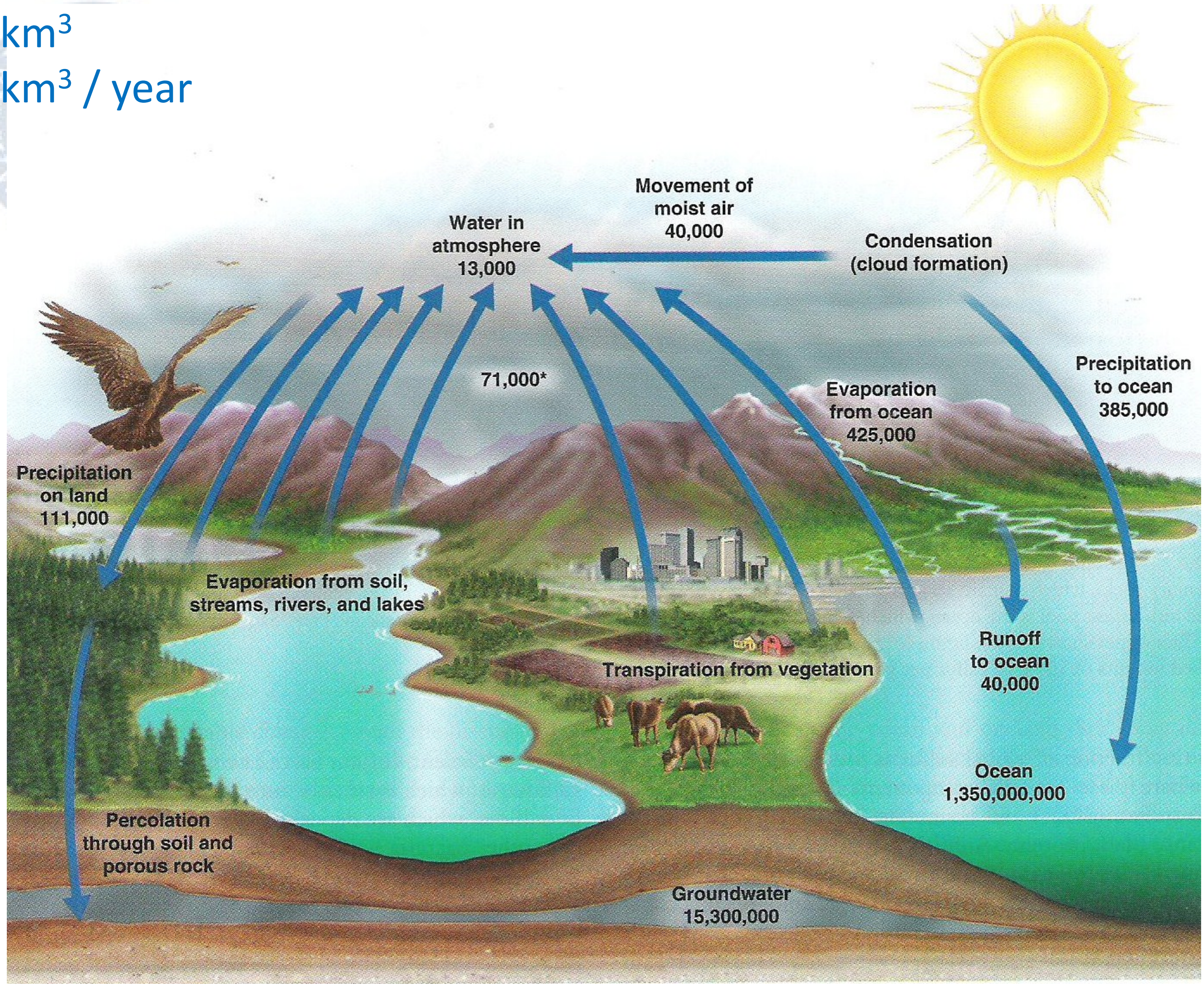
Global circulation of water from the environment to living organisms and back to the environment



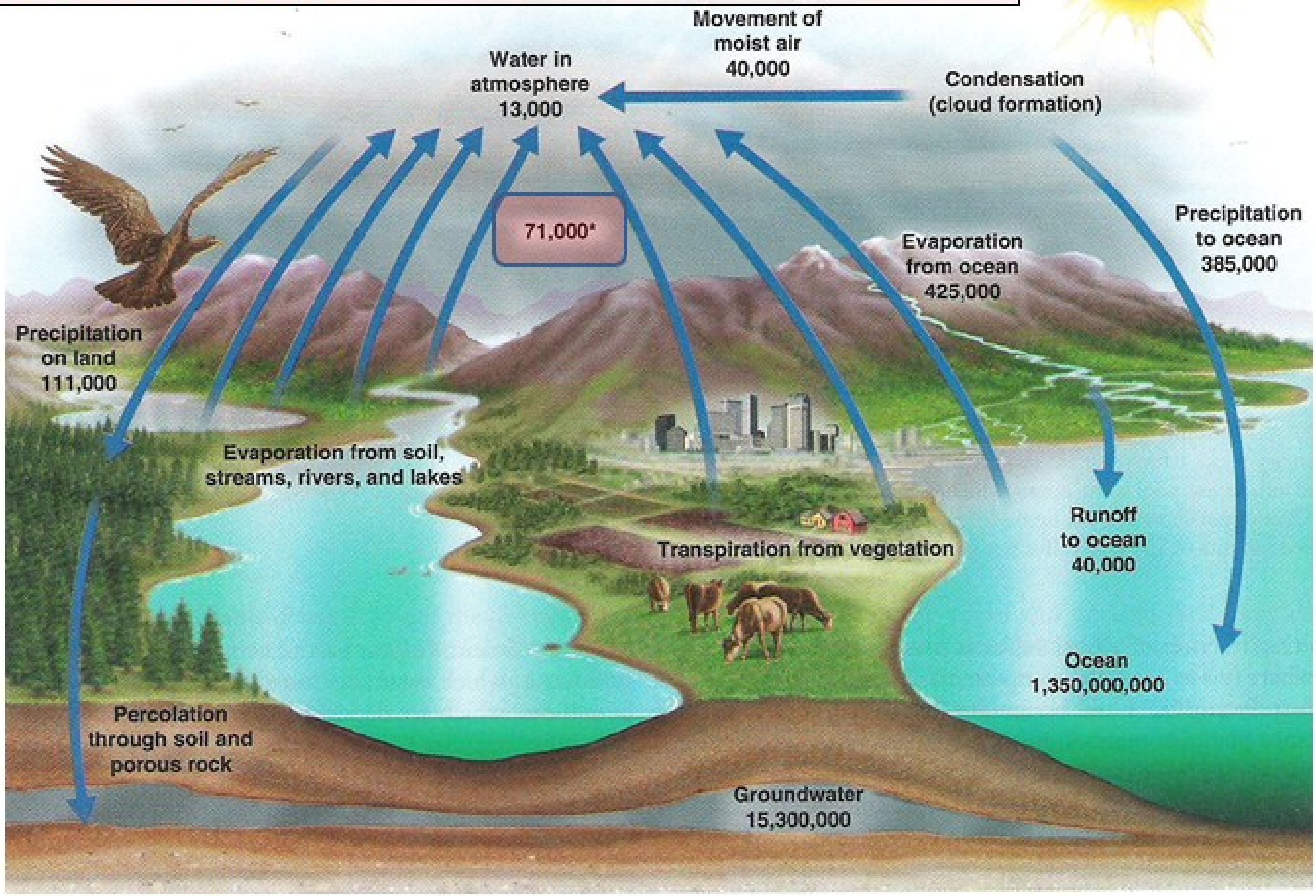
Water continuously circulates from the ocean to the atmosphere to the land and back to the ocean

$km^3$

$km^3$ / year


Movement of moist air 40,000
Water in atmosphere 13,000
Condensation (cloud formation)
71,000*
Evaporation from ocean 425,000
Precipitation to ocean 385,000
Precipitation on land 111,000
Evaporation from soil, streams, rivers, and lakes
Transpiration from vegetation
Runoff to ocean 40,000
Ocean 1,350,000,000
Percolation through soil and porous rock
Groundwater 15,300,000

Transpiration from plants
Evaporation from soil, streams, rivers, and lakes
71,000 km$^3$ / year



# HYDROLOGIC CYCLE

All forms of life use water

- as medium for chemical reactions
- for the transport of materials within and among the cells



Transpiration:

The loss of water vapor from land plants

~97% of the water a plant's roots absorb from the soil is transported to the leaves

transpiration occures from the leaves

# HYDROLOGIC CYCLE

Runoff:

Movement of water from land to rivers, lakes, wetlands, and, ultimately, the ocean

Watershed:

The area of land drained by runoff

Groundwater:

Amount of water that percolates downward through the soil and rock

Fresh water stored in underground

# Human Induced Changes to the Hydrologic Cycle

Some research suggests ‘*air pollution may weaken the global hydrologic cycle*’

Fossil fuel combustion and burning of forests →



<u>AEROSOLS</u>:

tiny particles of air pollution consisting mostly of sulfates, nitrates, carbon, mineral dusts, and smokestack ash

# Human Induced Changes to the Hydrologic Cycle

Aerosols enhance the scattering & absorption of sunlight and cause clouds to form

↓

Less likely to release their precipitation

Aerosols affect the availability and quality of water

# Human Induced Changes to the Hydrologic Cycle

Climate change caused by $CO_2$ alters the global hydrologic cycle

increasing glacial and polar ice-cap melting

increasing evaporation in some areas

# Additional aspects of the pysical environment that affect organisms

Solar radiation

Atmosphere

Ocean

Weather & Climate

Internal planetary processes

# Solar Radiation

Sun warms the planet, including the atmosphere, to habitable temperatures

Without sun's energy → temperature would approach absolute zero (-273 $^{o}$C) → all water, even in the ocean would freeze

Sun powers

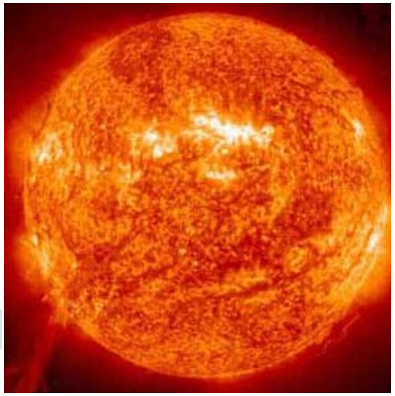
- Hydrologic cycle
- Carbon cycle and other biogeochemical cycles

# Solar Radiation

Photosynthesis organisms

↓

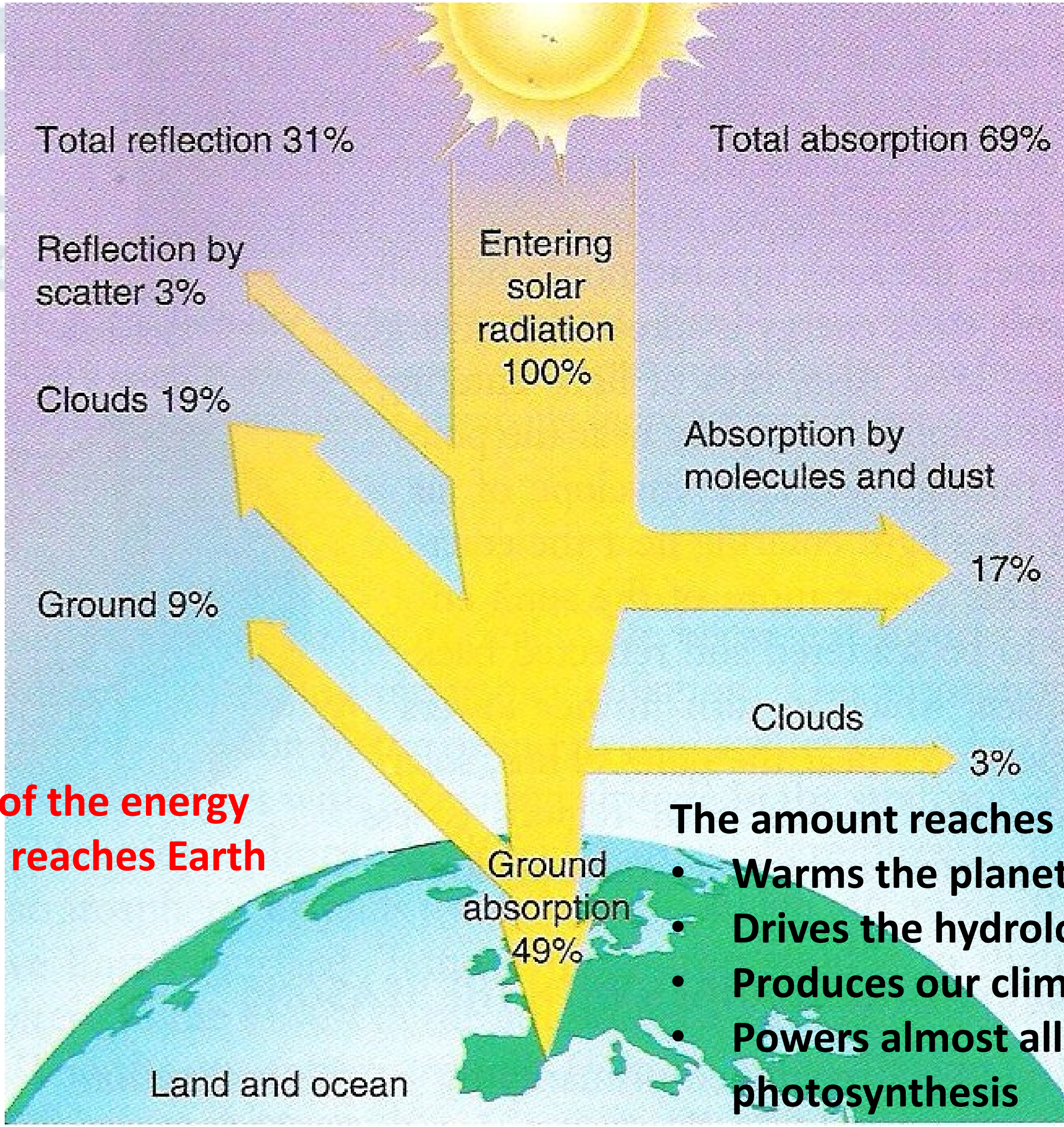
Almost all life forms





Sun’s energy:

- the product of a massive nuclear fusion reaction
- emmitted into space in the form of electromagnetic radiation (visible light, infrared and ultraviolet radiation)

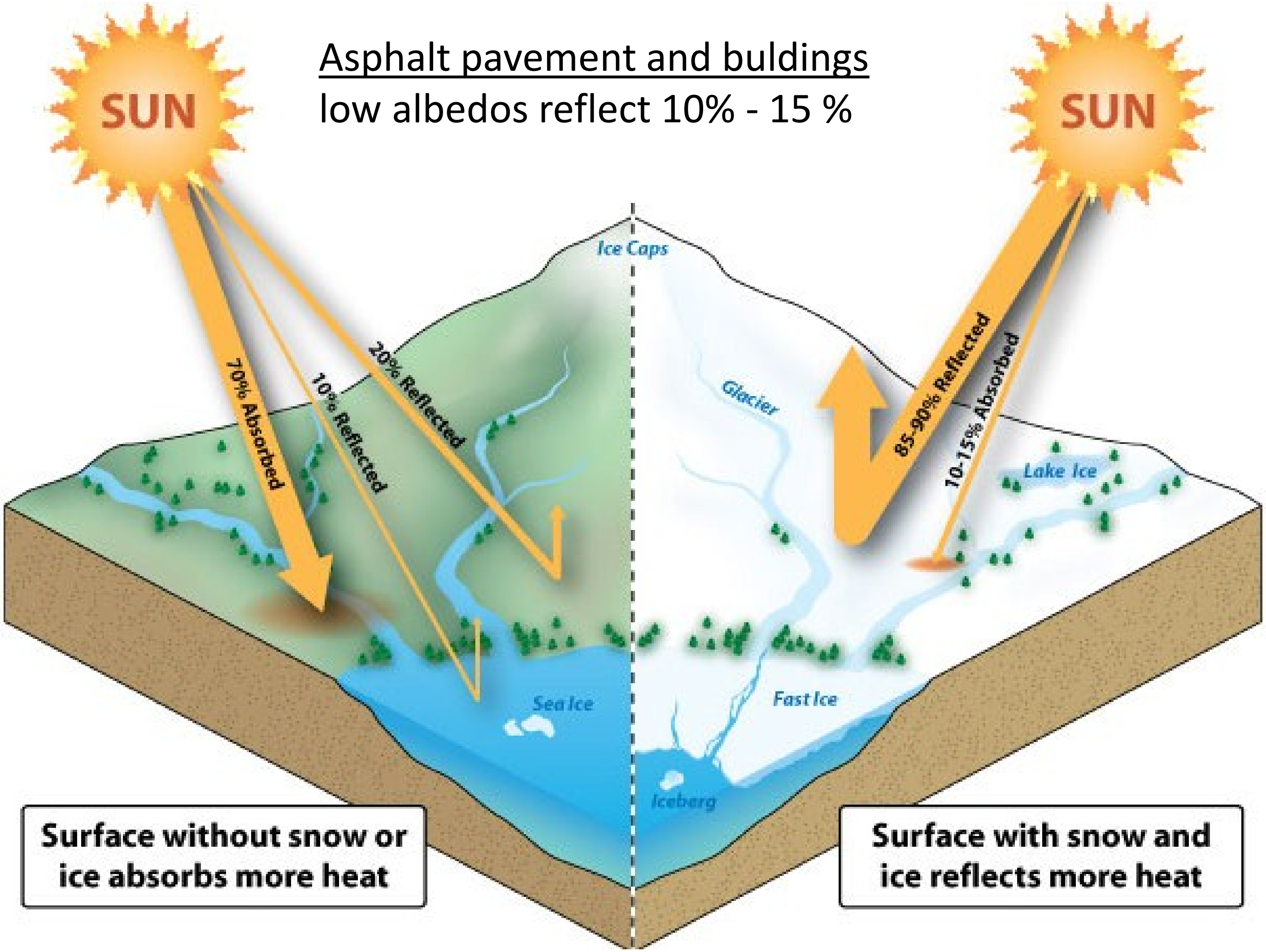



**most of the energy never reaches Earth**

**The amount reaches**

- **Warms the planet's surface**
- **Drives the hydrologic and other cycles**
- **Produces our climate**
- **Powers almost all life through photosynthesis**

<u>Asphalt pavement and buldings</u>
low albedos reflect 10% - 15 %




<u>Ocean and forests</u>
reflect only about 5%

<u>Glaciers and ice sheets</u> have high albedos and reflect 80% - 90% of the sunlight hitting their surface

<u>Albedo</u>:
The proportional reflectance of solar energy from Earth’s surface

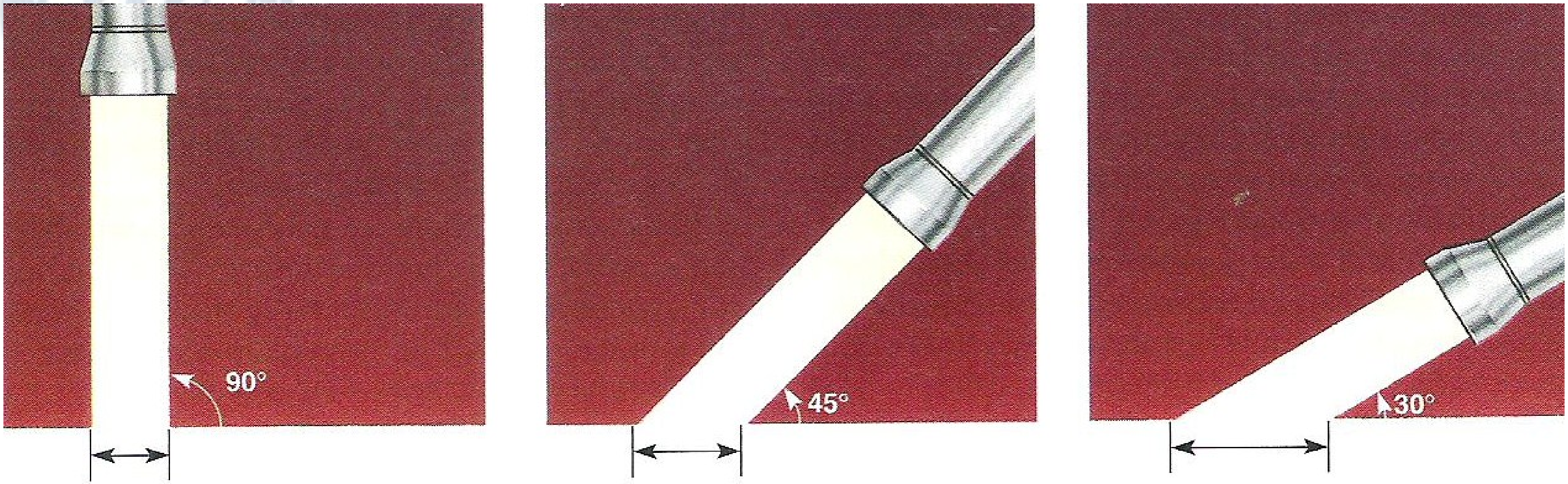
# Solar Radiation
# Temperature Changes with Latitude

Sun's energy does not reach all places uniformly

Earth's <u>roughly spherical shape</u> and <u>tilt</u> of its axis



Variation in the exposure of the surface




**1 unit of surface area**
One unit of light is concentrated over 1 unit of surface area
*Sunlight shines vertically near the equator is concentrated on Earth's surface*

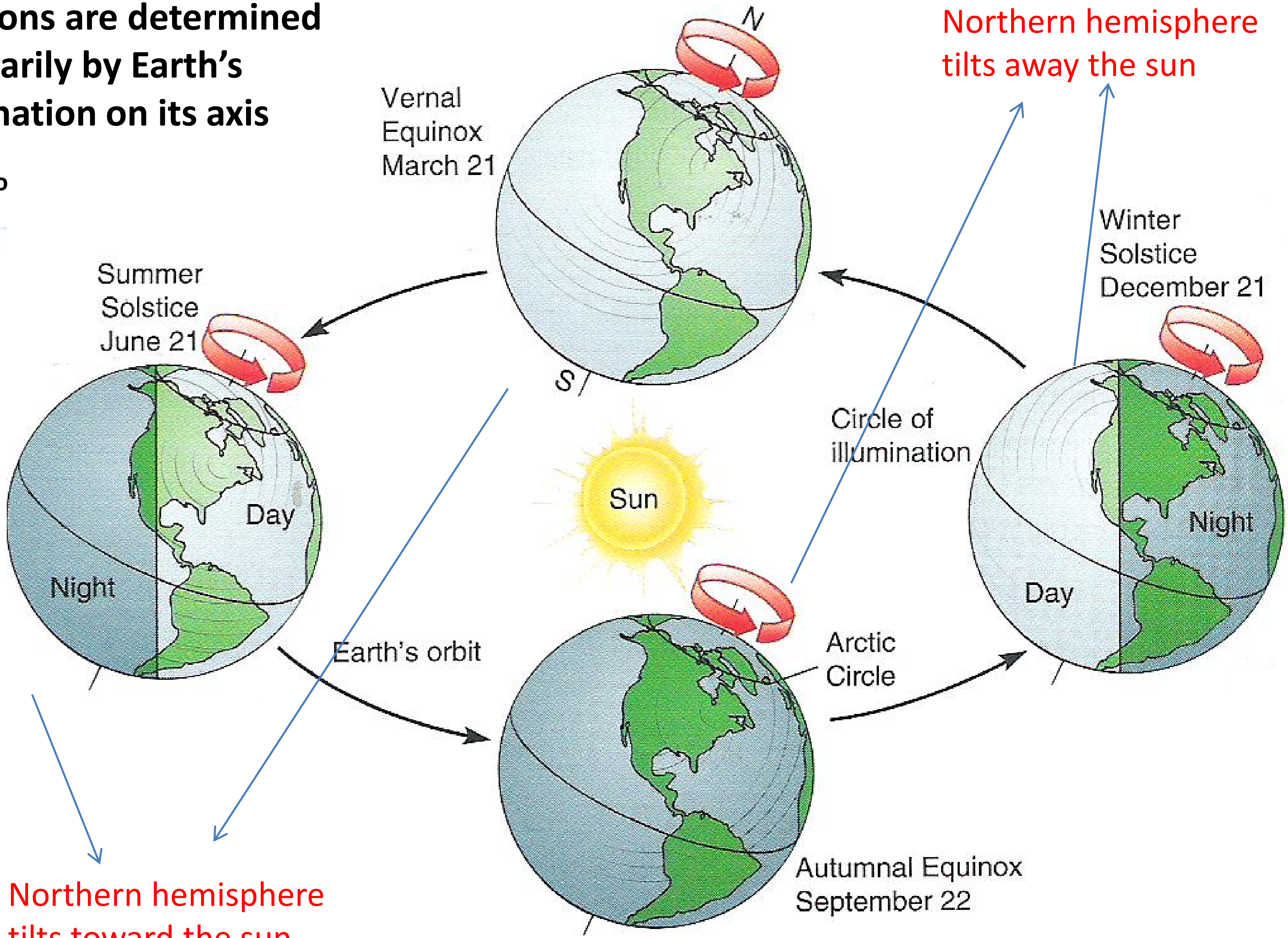
**1.4 units of surface area**
One unit of light is dispersed over 1.4 units of surface area

**2 units of surface area**
One unit of light is dispersed over 2 units of surface area

*Toward the poles sun spreads the same amount of radiation over larger and larger areas*

**Seasons are determined primarily by Earth's inclination on its axis**

**23.5°**




## Temperature Changes with Seasons

# The Atmosphere

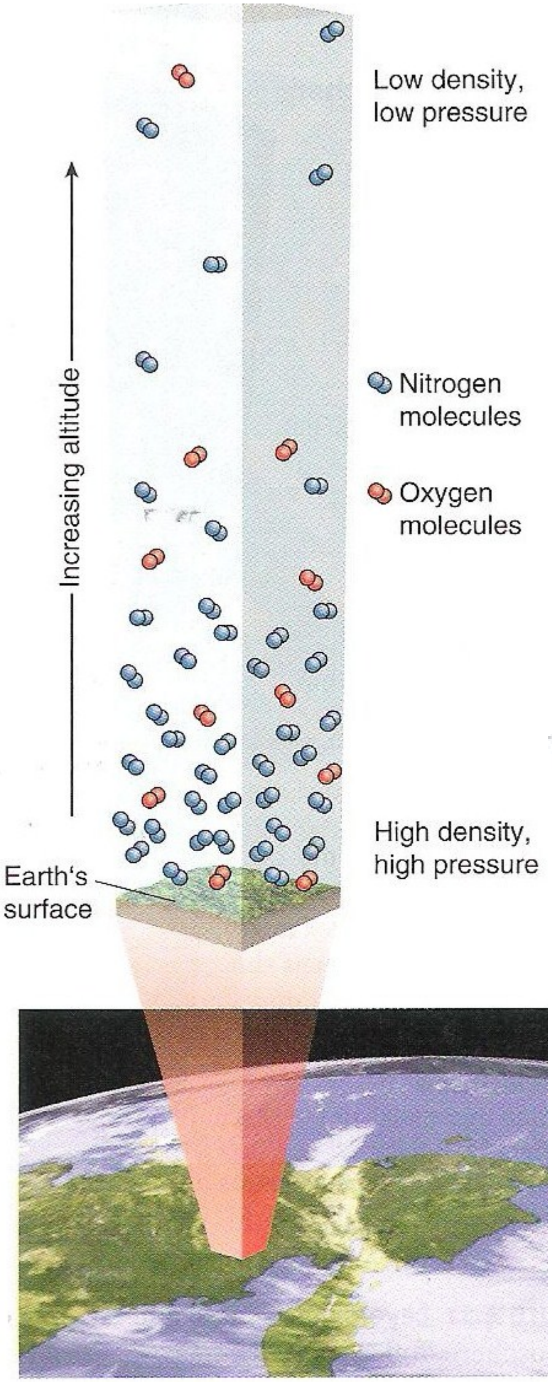
Invisible layer of gases that envelops Earth

Oxygen 21%

Nitrogen 78%

Argon, carbon dioxide, neon, helium 1%

Water vapor, trace amounts of various pollutants (e.g. Methane, ozone, dust particles, microorganisms, and chlorofluorocarbons)




# The Atmosphere

Protects Earth's surface from most of the sun's UV radiation and X-rays

Allows visible light and some IR radiation to penetrate, they warm the surface and lower atmosphere

A balance between oxygen-producing photosynthesis and oxygen-using respiration maintains the current level of $O_2$

# Layers of the Atmosphere