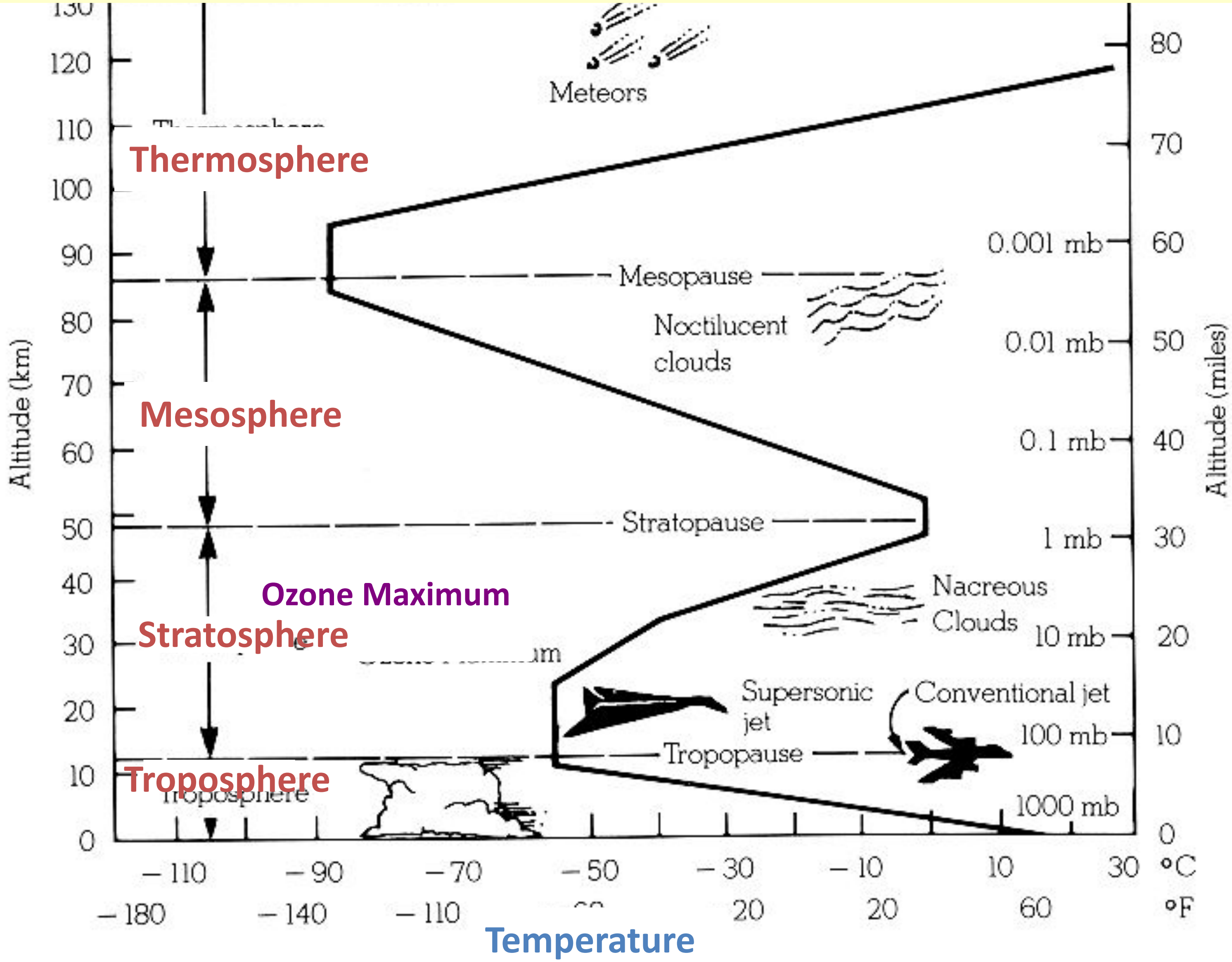
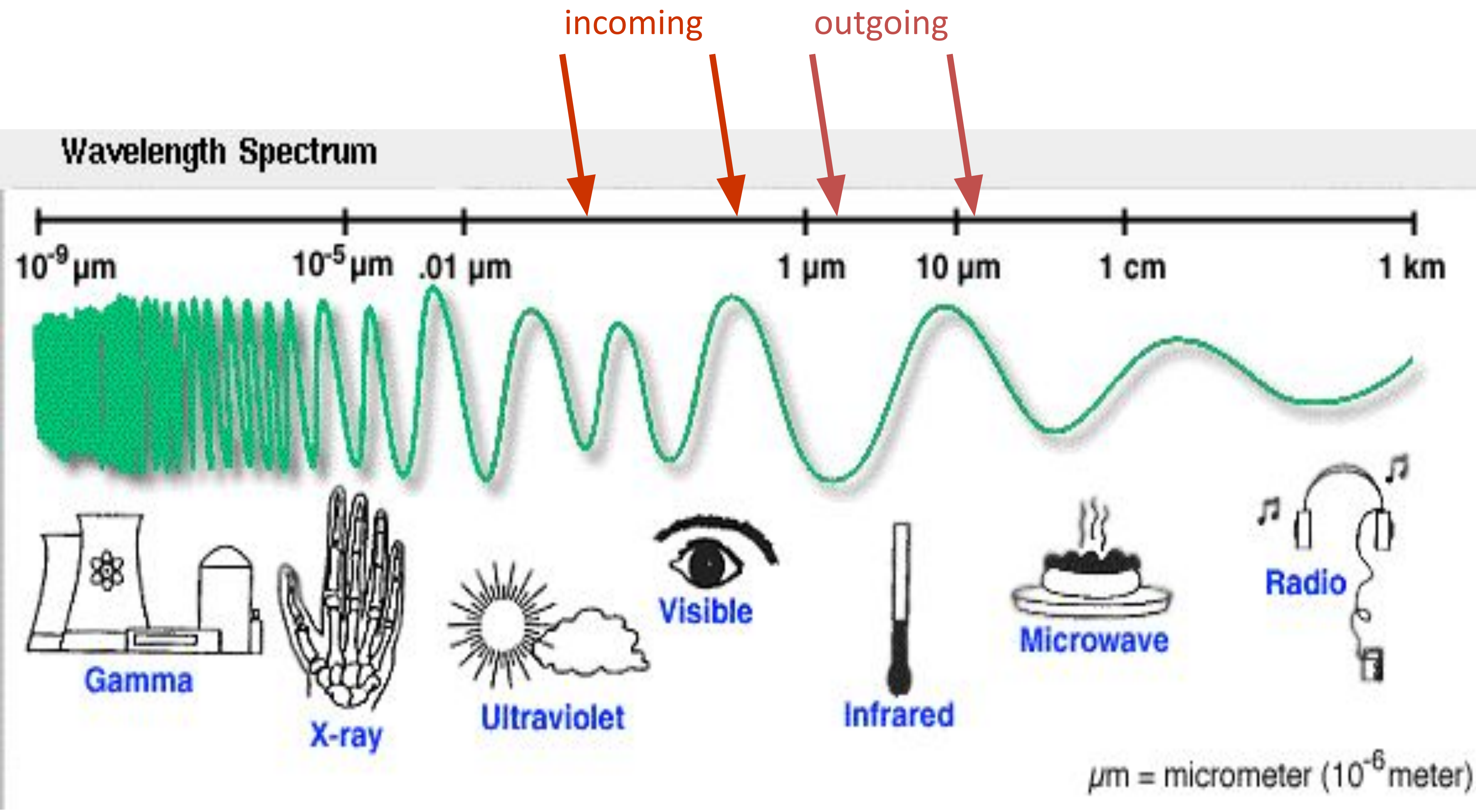
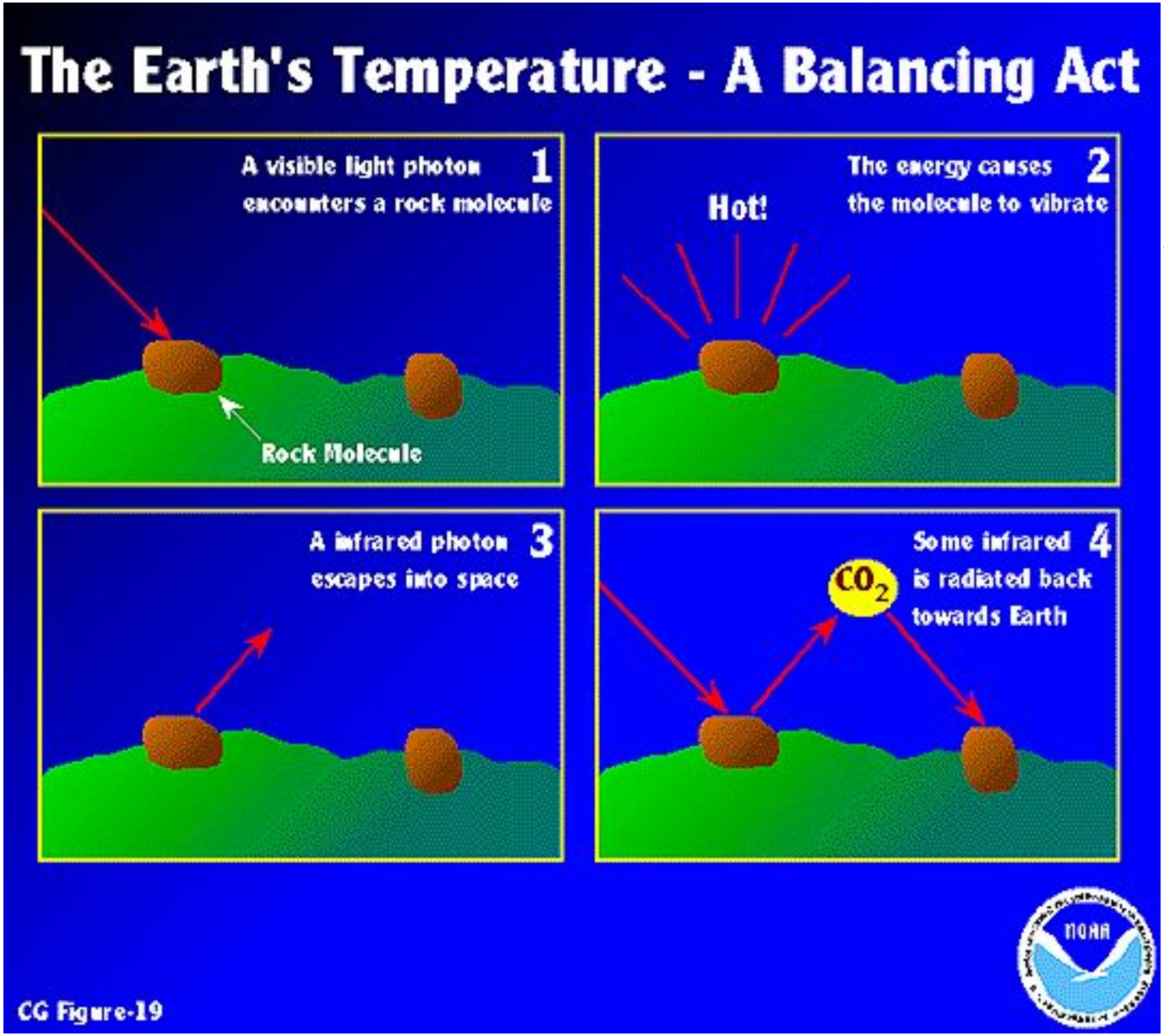
Water vapor
Nitrous oxide
Aerosols

Structure of the Atmosphere



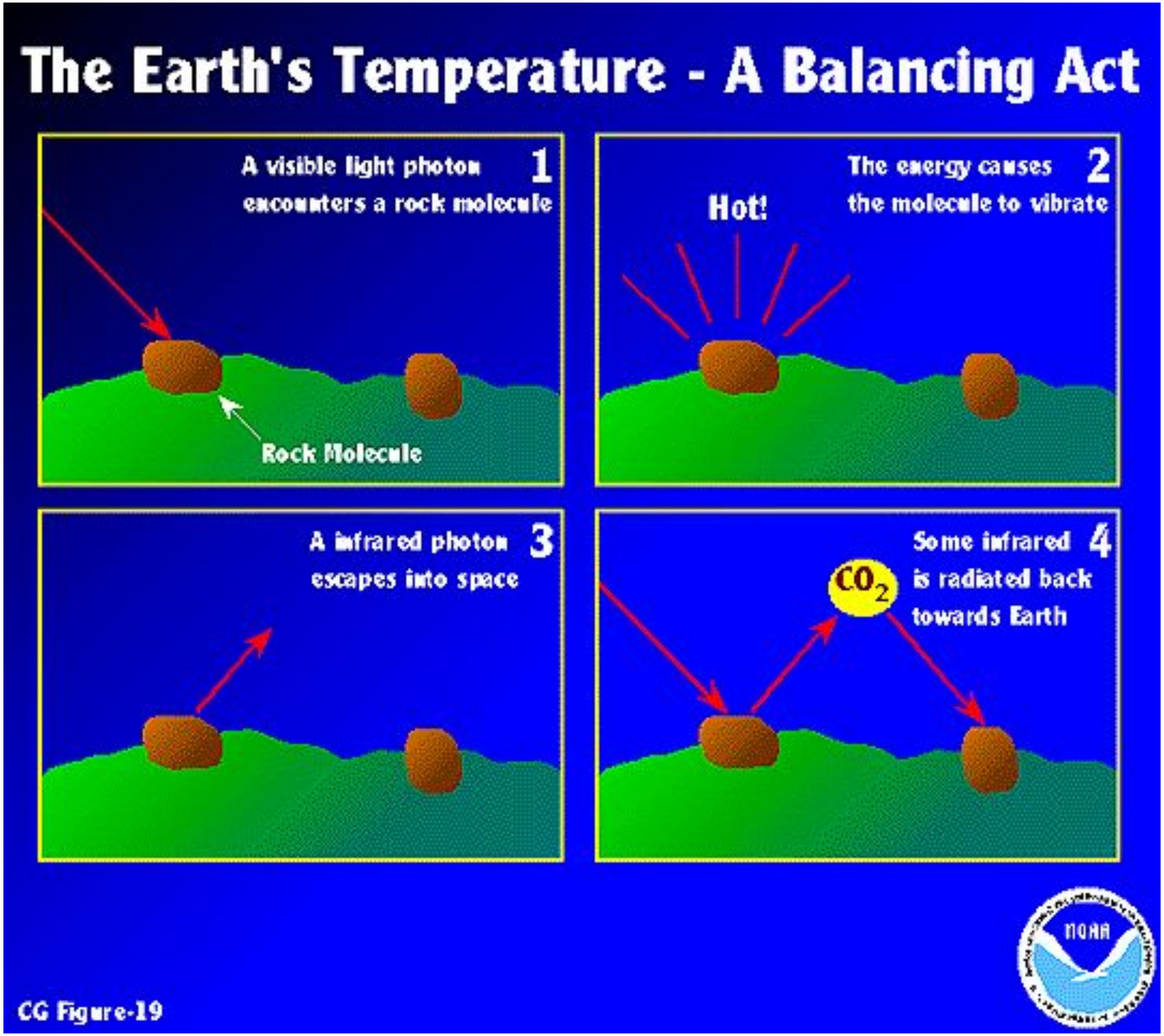
Electromagnetic Spectrum





1. Shorter, high
Energy wavelengths
Hit the earths
Surface

2. Incoming energy
Is converted to heat



3. Longer, infrared
Wavelengths hit
Greenhouse gas
Molecules in the
atmosphere

4. Greenhouse gas
Molecules in the
Atmosphere emit
Infrared radiation
Back towards earth

78% nitrogen

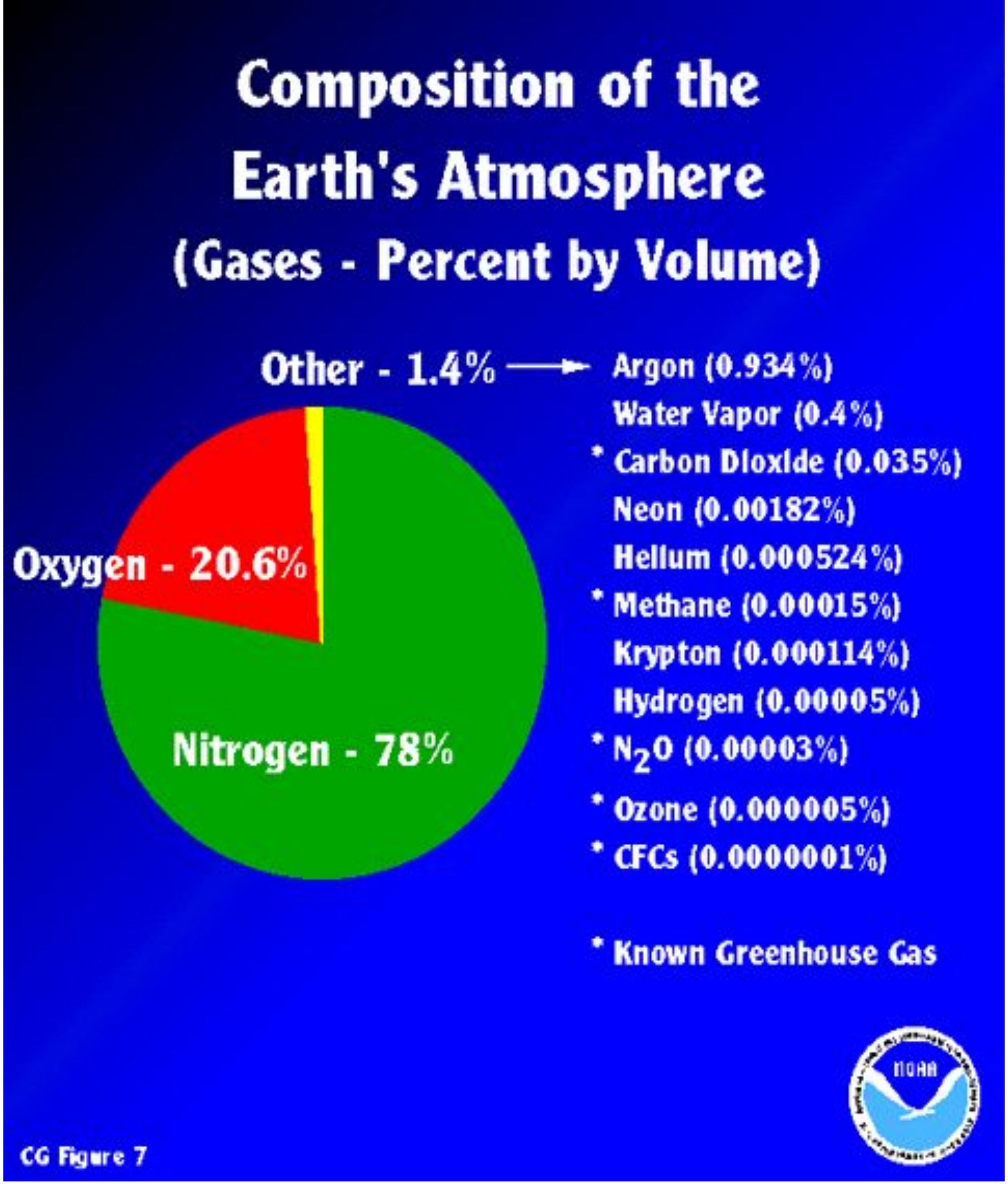
20.6% oxygen

< 1% argon

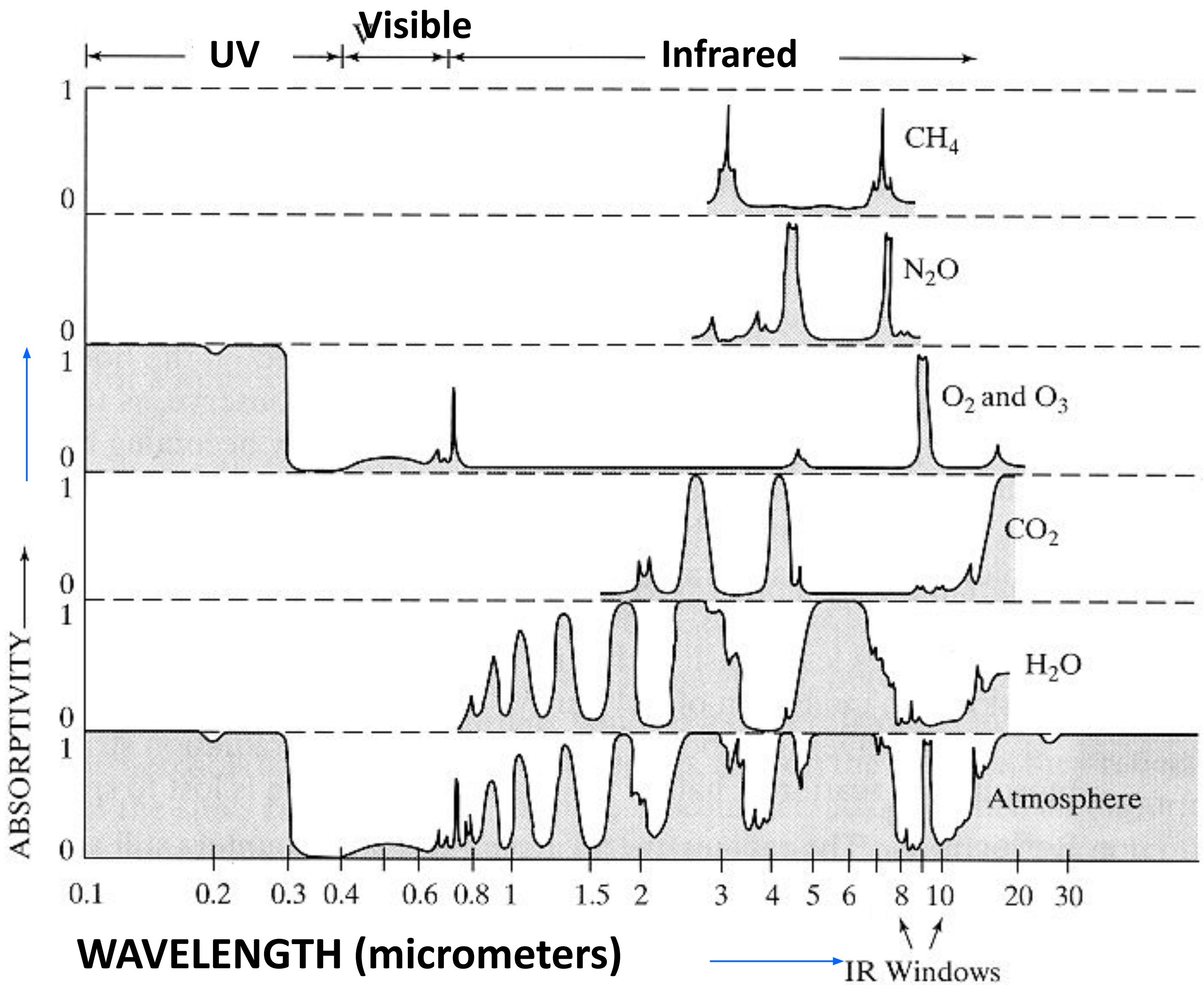
0.4% **water vapor**

0.036% **carbon dioxide**

traces gases:
Ne, He, Kr, H, O_3
Methane, **Nitrous Oxide**



Absorption Spectra of Atmospheric Gases



CH_4

N_2O

O_2 & O_3

CO_2

H_2O

atmosphere

Anthes, p. 55

Greenhouse gases absorb infrared radiation and prevent it from escaping to space.

Carbon dioxide, methane, and nitrous oxide are very good at capturing energy at wavelengths that other compounds miss

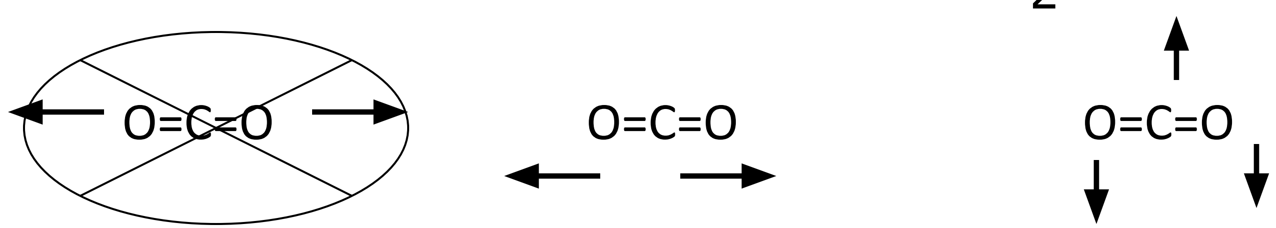
Climate Change

- Greenhouse Gases

- To be an effective greenhouse gas, a molecule must:

  - absorb light in the infrared region (must have dipole moment for vibration mode)

  - 3 modes of vibration for CO_2 shown



Symmetric vibration not allowed

Earth's Atmospheric Gases

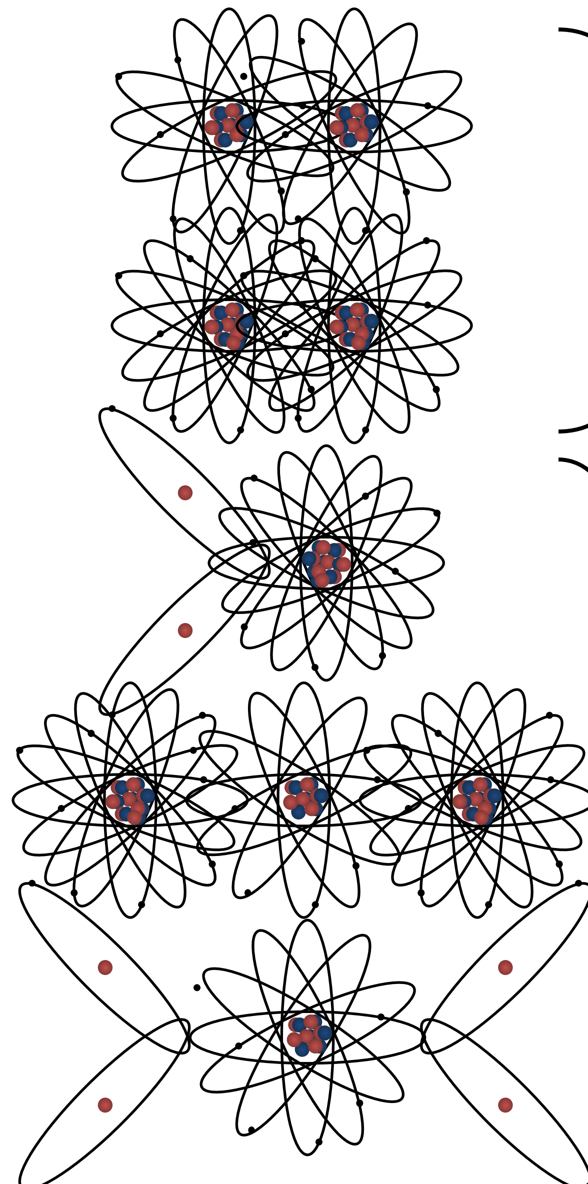
Nitrogen (N_2)

Oxygen (O_2)

Water (H_2O)

Carbon Dioxide (CO_2)

Methane (CH_4)



Non-Greenhouse Gases 99%

Greenhouse Gases 1%

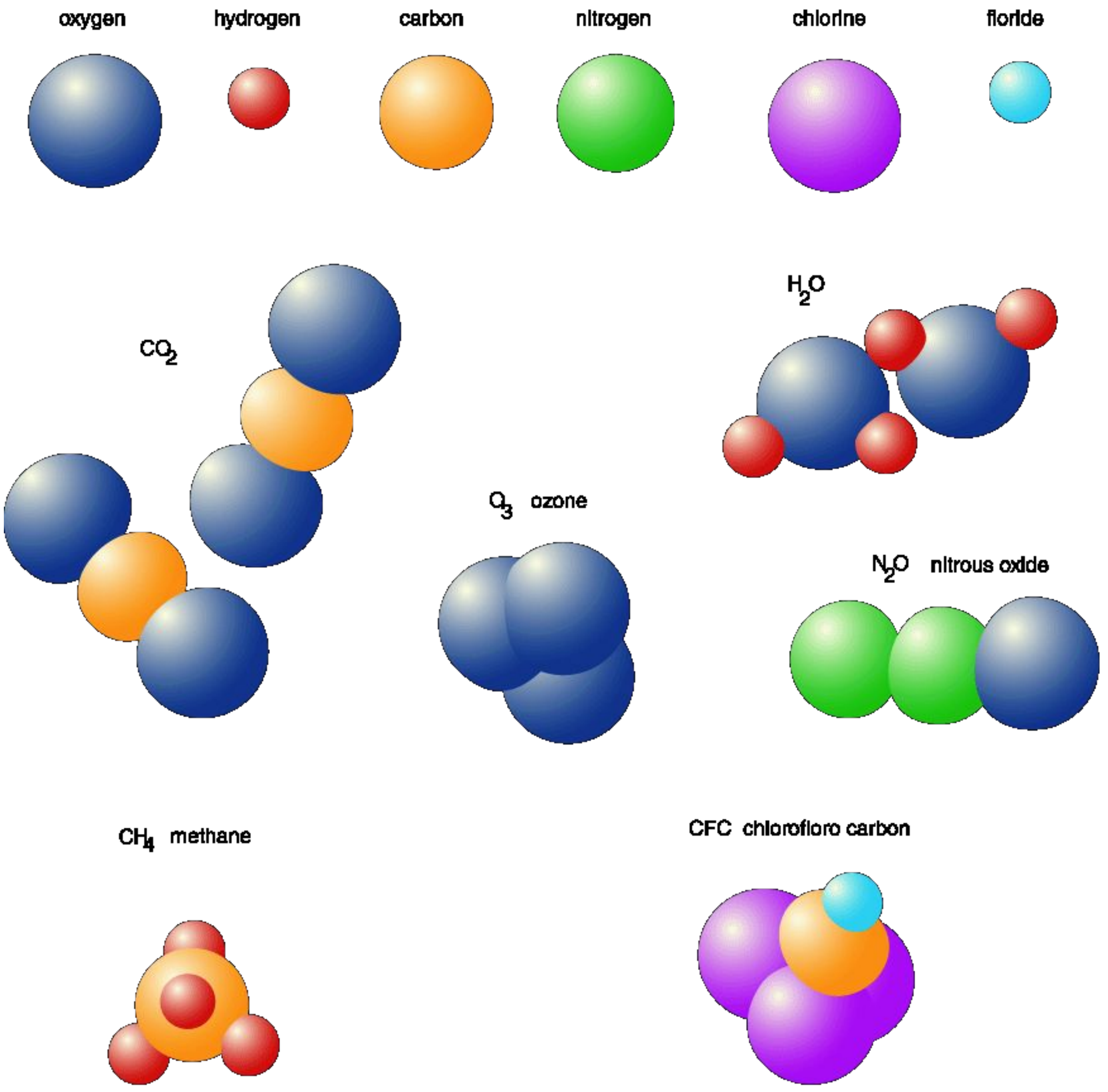
Greenhouse Gases

Carbon Dioxide

Water

Methane

Nitrous Oxide



Greenhouse Gases

- Molecules must absorb light in the right regions

  - roughly 7 to 25 μm region

  - however, in some regions (5 to 7 and 13 to 17 μm), essential no light from surface makes it to space due to current gases present

  - for this reason, CO_2 is less effective as a greenhouse gas (at least for additional CO_2)

- Greenhouse Gases

- Molecules absorbing light in the “IR window” regions are more effective
- Additional CO_2 is not as effective as additional N_2O (absorbs at 7.5 to 9 μm) on a forcing per ppm basis

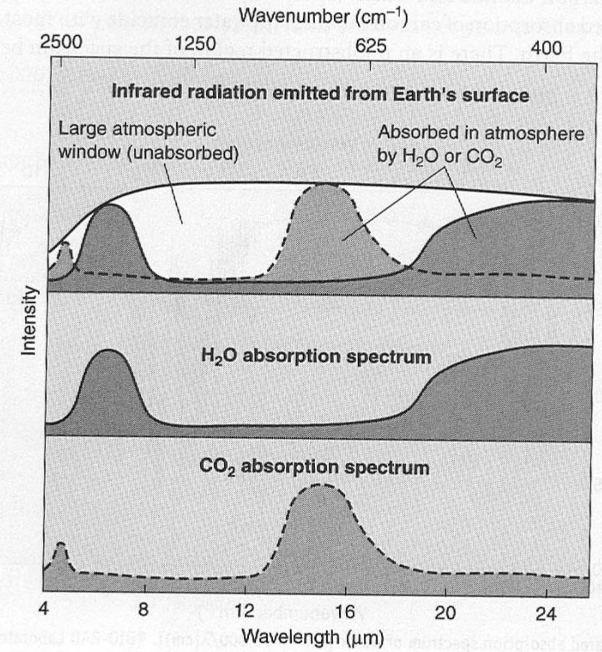


Figure 3.14 Absorption of radiation emitted from the earth's surface by carbon dioxide and water vapor.

From Girard (old text)

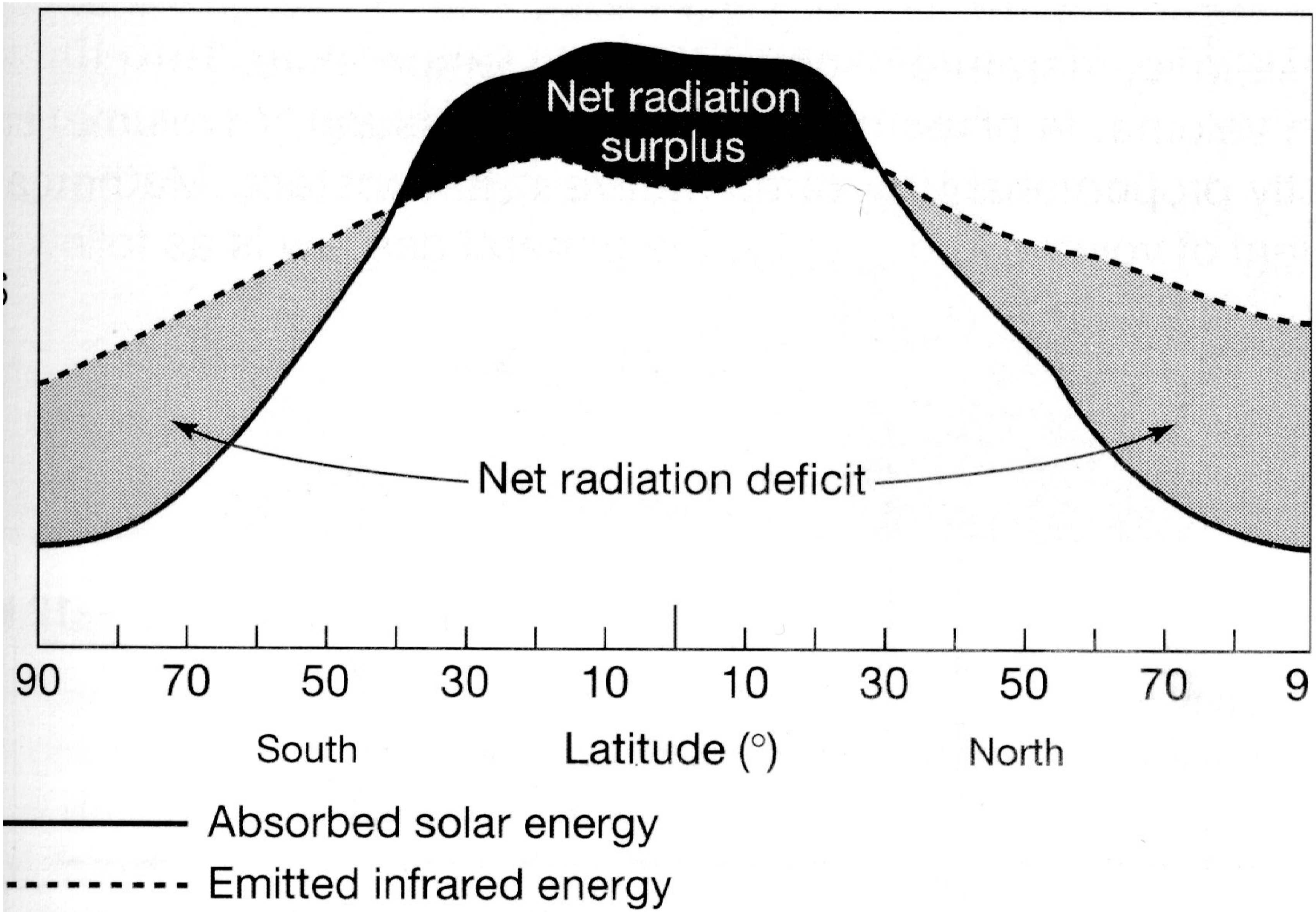
Selected Greenhouse Gases

- **Carbon Dioxide (CO_2)**
  - Source: Fossil fuel burning, deforestation
  - Anthropogenic increase: **30%**
  - Average atmospheric residence time: **200 years**
- **Methane (CH_4)**
  - Source: Rice cultivation, cattle & sheep ranching, decay from landfills, mining
  - Anthropogenic increase: **145%**
  - Average atmospheric residence time: **7-10 years**
- **Nitrous oxide (N_2O)**
  - Source: Industry and agriculture (fertilizers)
  - Anthropogenic increase: **15%**
  - Average atmospheric residence time: **140-190 years**

Greenhouse Effect & Global Warming

- The ***"greenhouse effect"*** & ***global warming*** are **<u>not</u>** the same thing.
  - Global warming refers to a rise in the temperature of the surface of the earth
-
- An increase in the ***concentration of greenhouse gases*** leads to an increase in the the ***magnitude of the greenhouse effect***. (Called enhanced greenhouse effect)
  - This results in global warming

Global Energy Redistribution



Radiation is not evenly distributed over the
Surface of the earth. The northern latitudes have an energy deficit and the low latitude/ equator has an excess. But the low latitudes don’t indefinitely get hotter and the northern latitudes don’t get colder.

Why?

The atmosphere and ocean transfer energy from
low
latitudes to high

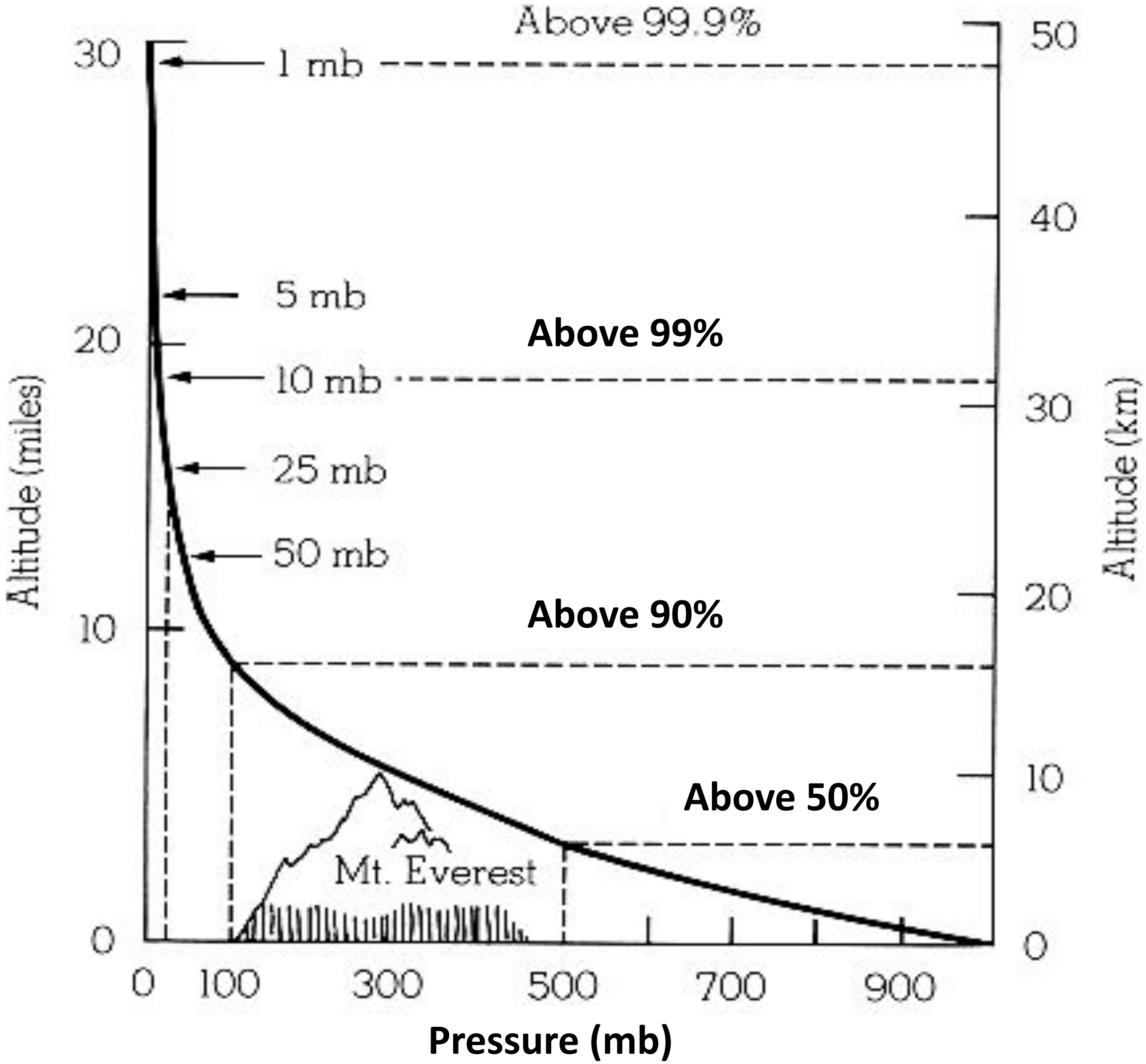
The climate engine II

- Since earth does rotate, air packets do not follow longitude lines (Coriolis effect)
- Speed of rotation highest at equator
- Winds travelling polewards get a bigger and bigger westerly speed (jet streams)
- Air becomes unstable
- Waves develop in the westerly flow (low pressure systems over Northern Europe)
- Mixes warm tropical air with cold polar air
- Net transport of heat polewards

Atmospheric Pressure Decreases With Height

Most of the energy is captured close to the surface

That energy drives climate and weather



50 percent of mass of the atmosphere is within 6 km of the surface

Cloud effects

- Low clouds over ocean
  - more clouds reflect heat (cooling)
  - fewer clouds trap heat (warming)
- High clouds
  - more clouds trap heat (warming)

- high: 5-14 km; low < 2km

Tatiana Grozetskaya/Shutterstock.com

Cheryl Casey/Shutterstock.com

Fig. 19-10, p. 513

- Greenhouse Gases

- H_2O as a greenhouse gas
  - the molecule responsible for the most greenhouse effect heating
  - the third most prevalent molecule in the atmosphere (on average, but composition is variable)
  - direct anthropogenic sources are insignificant (at least outside of deserts and the stratosphere)
  - also responsible for cooling through increasing albedo (in clouds) so normally kept separate from other greenhouse gases
  - water vapor is important indirectly as planet heating increases water vapor (this is covered under feedbacks)

- The sun plays a key role in the earth's temperature
- Researchers think that atmospheric warming is not due to an increase in energy output from the sun
  - Since 1975
    - Troposphere has warmed
    - Stratosphere has cooled

- Warmer temperatures create more clouds
  - Thick, low altitude cumulus clouds – decrease surface temperature
  - Thin, cirrus clouds at high altitudes – increase surface temperature

- Water vapor is one of the most important elements of the climate system. A greenhouse gas, like carbon dioxide, it represents around 80 percent of total greenhouse gas mass in the atmosphere and 90 percent of greenhouse gas volume.
- Water vapor and clouds account for 66 to 85 percent of the greenhouse effect, compared to a range of 9 to 26 percent for CO2. So why all the attention on carbon dioxide and its ilk? Is water vapor the real culprit causing global warming?
- The answer is that water vapor is indeed responsible for a major portion of Earth’s warming over the past century and for projected future warming. However, water vapor is not the cause of this warming. This is a critical, if subtle, distinction between the role of greenhouse gases as either forcings or feedbacks. In this case, anthropogenic emissions of CO2, methane, and other gases are warming the Earth. This rising average temperature increases evaporation rates and atmospheric water vapor concentrations. Those, in turn, result in additional warming.

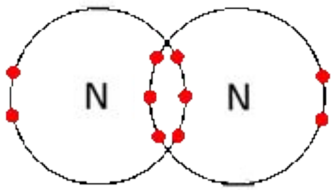
Nitrogen

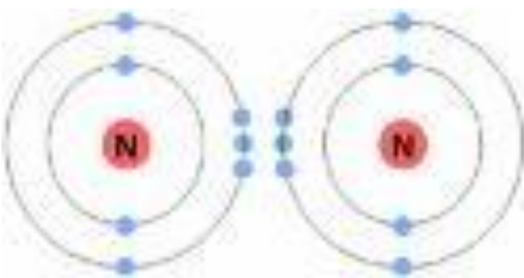
- Nitrogen (N) is an essential component of DNA, RNA, and proteins, the building blocks of life.

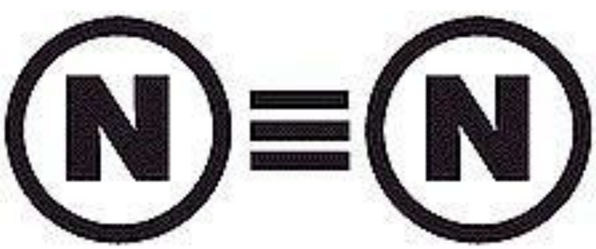
- All organisms require nitrogen to live and grow.

- The majority (78%) of the Earth's atmosphere is N_2.

Nitrogen's triple bond

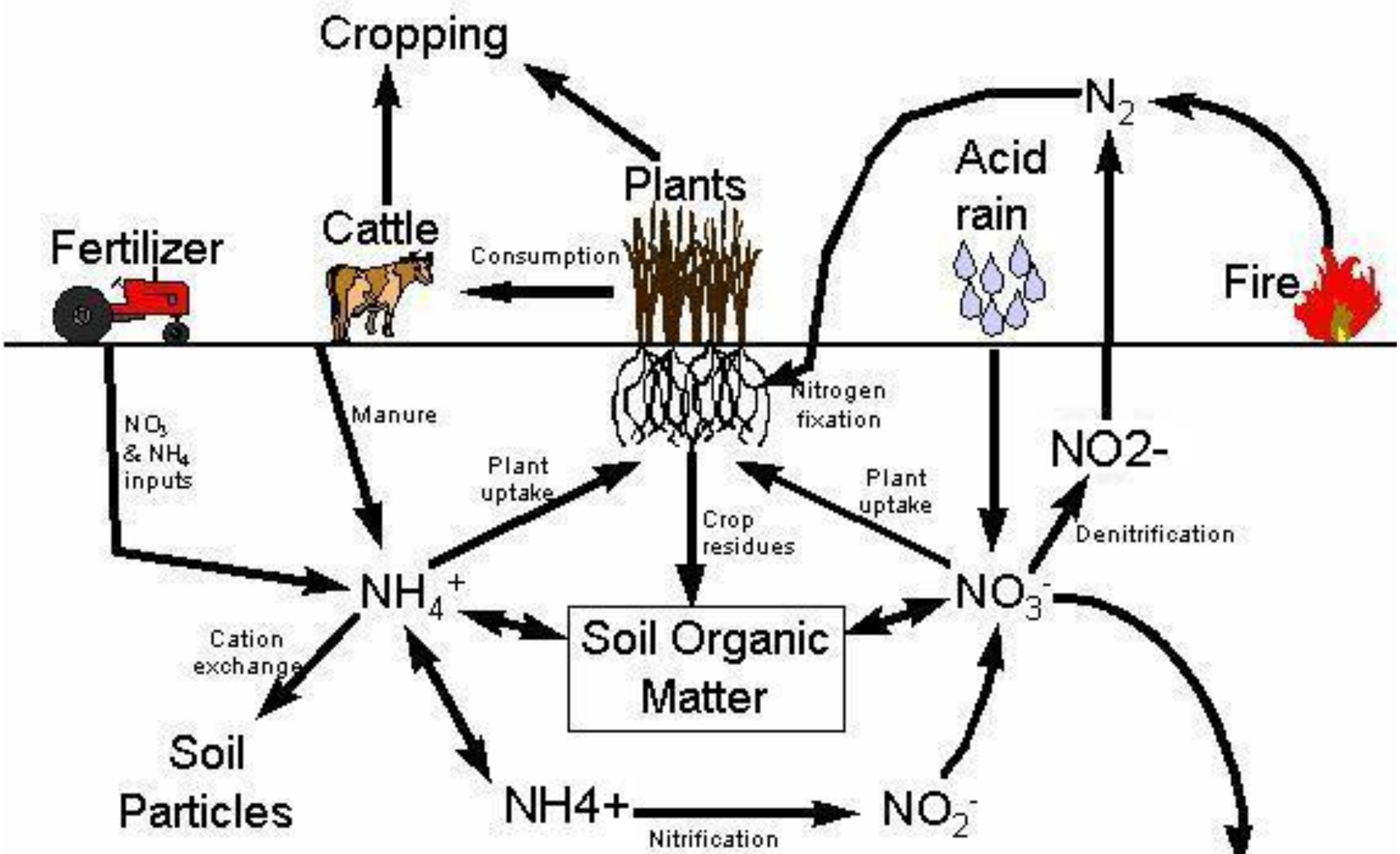




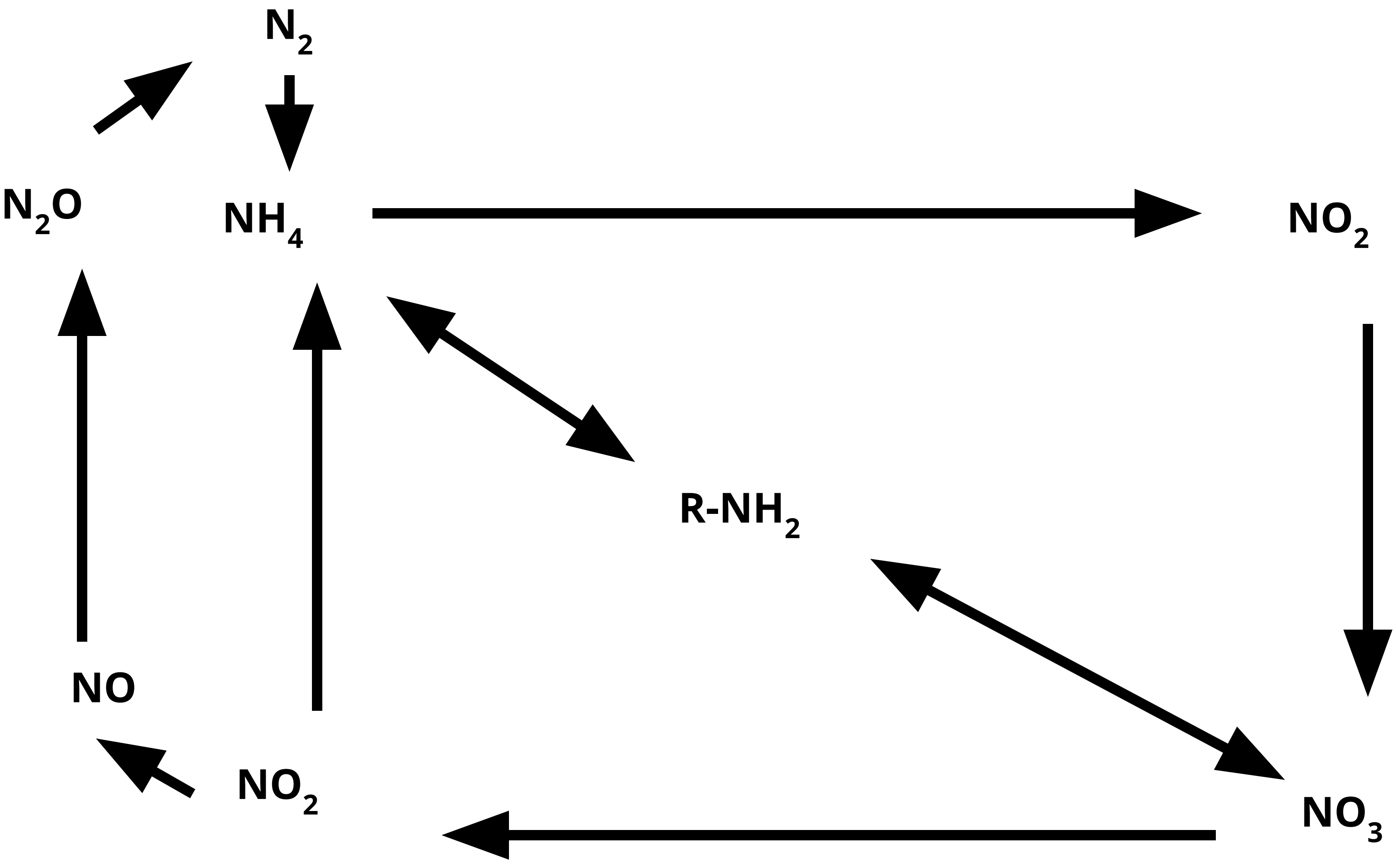


- Although the majority of the air we breathe is N_2, most of the nitrogen in the atmosphere is **unavailable** for use by organisms.

- This is because the strong **triple bond** between the N atoms in N_2 molecules makes it relatively inert (like a noble gas).



NITROGEN CYCLE



N2
N2O
NH4
NO2
R-NH2
NO
NO2
NO3

Forms of Nitrogen

- Urea □ $CO(NH_2)_2$
- Ammonia □ NH_3 (gaseous)
- Ammonium □ NH_4
- Nitrate □ NO_3
- Nitrite □ NO_2
- Atmospheric Dinitrogen □N_2
- Organic N

How can we use N_2?

WE CAN'T!

But BACTERIA & … can…

- In order for plants and animals to be able to use nitrogen, N_2 gas must first be **converted** to more a chemically available form such as ammonium (NH_4^+) or nitrate (NO_3^-).

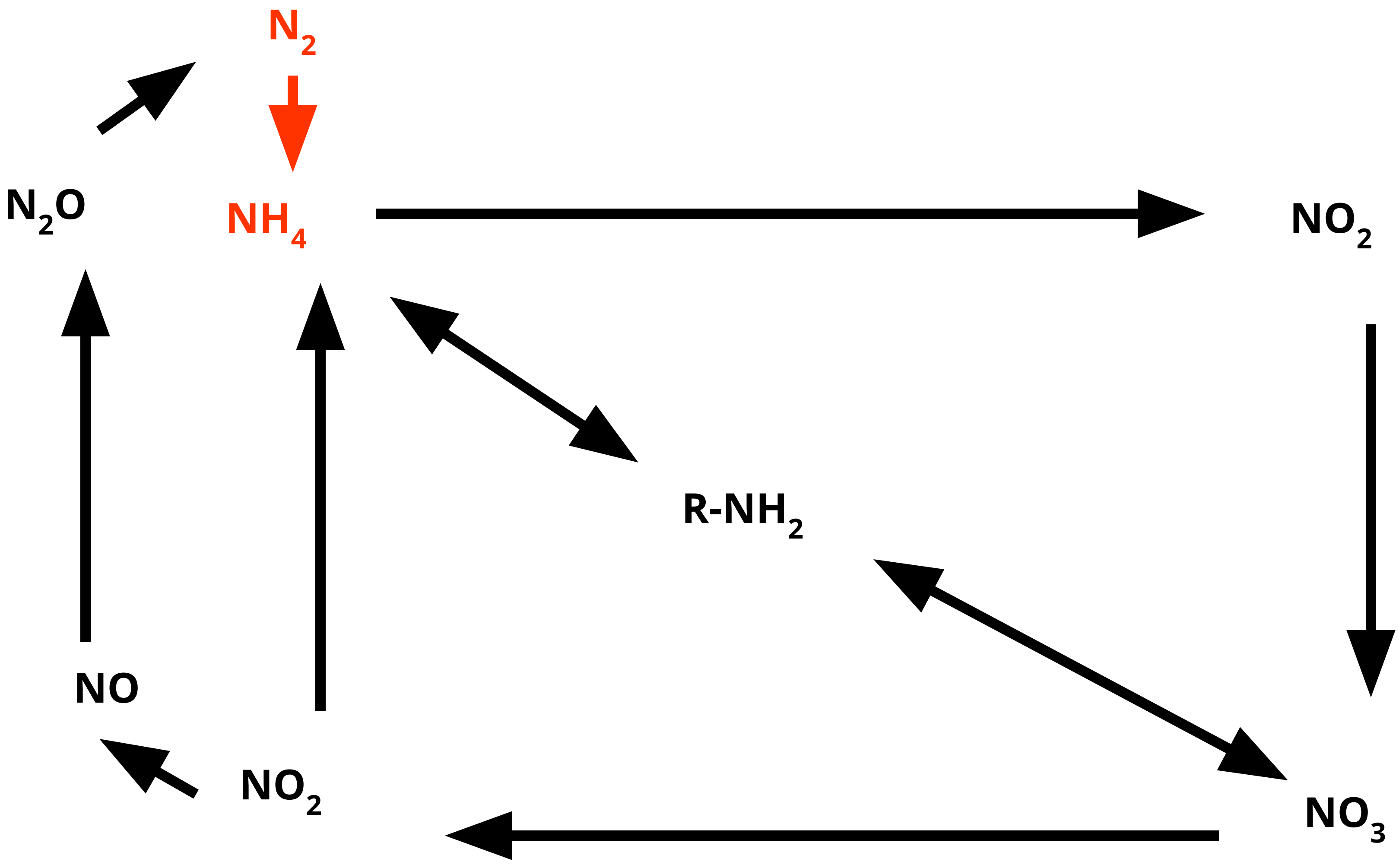
Nitrogen Fixation (N_2 --> NH_3 or NH_4^+)

ENVIRONMENTAL

High-energy natural events which
break the bond N_2

Examples:
- lightning
- forest fires
- hot lava flows

Nitrogen Fixation



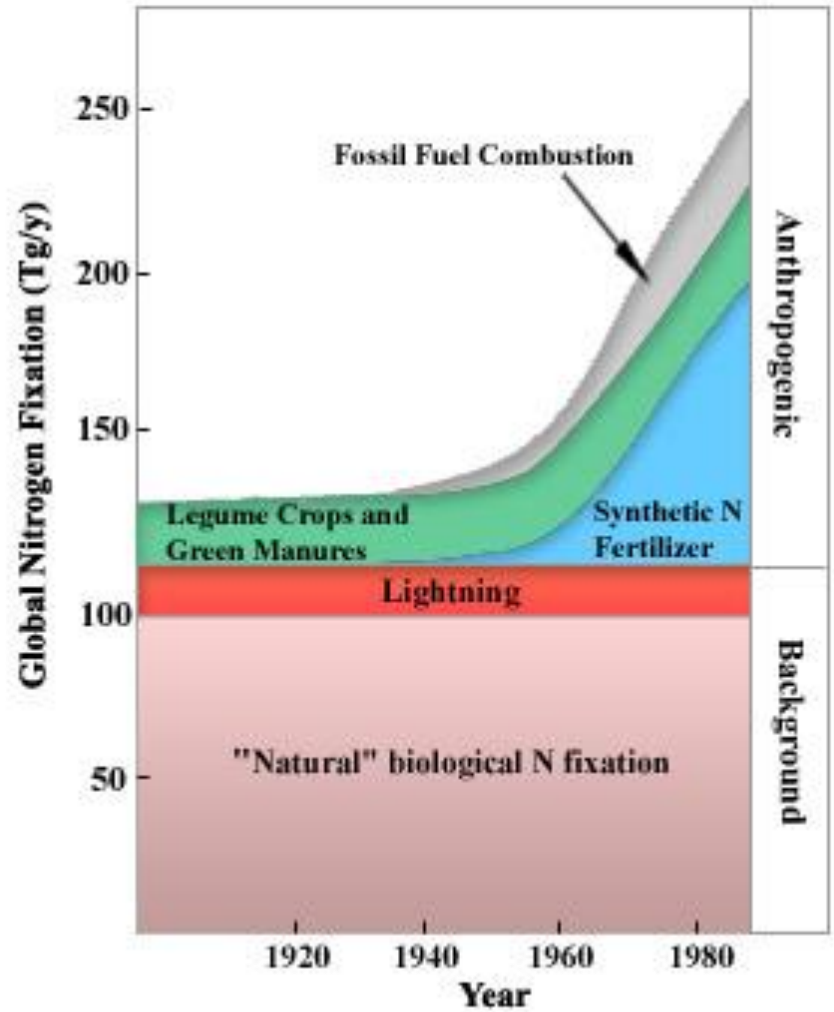
Nitrogen Fixation N_2 --> NH_3 or NH_4^+

How?

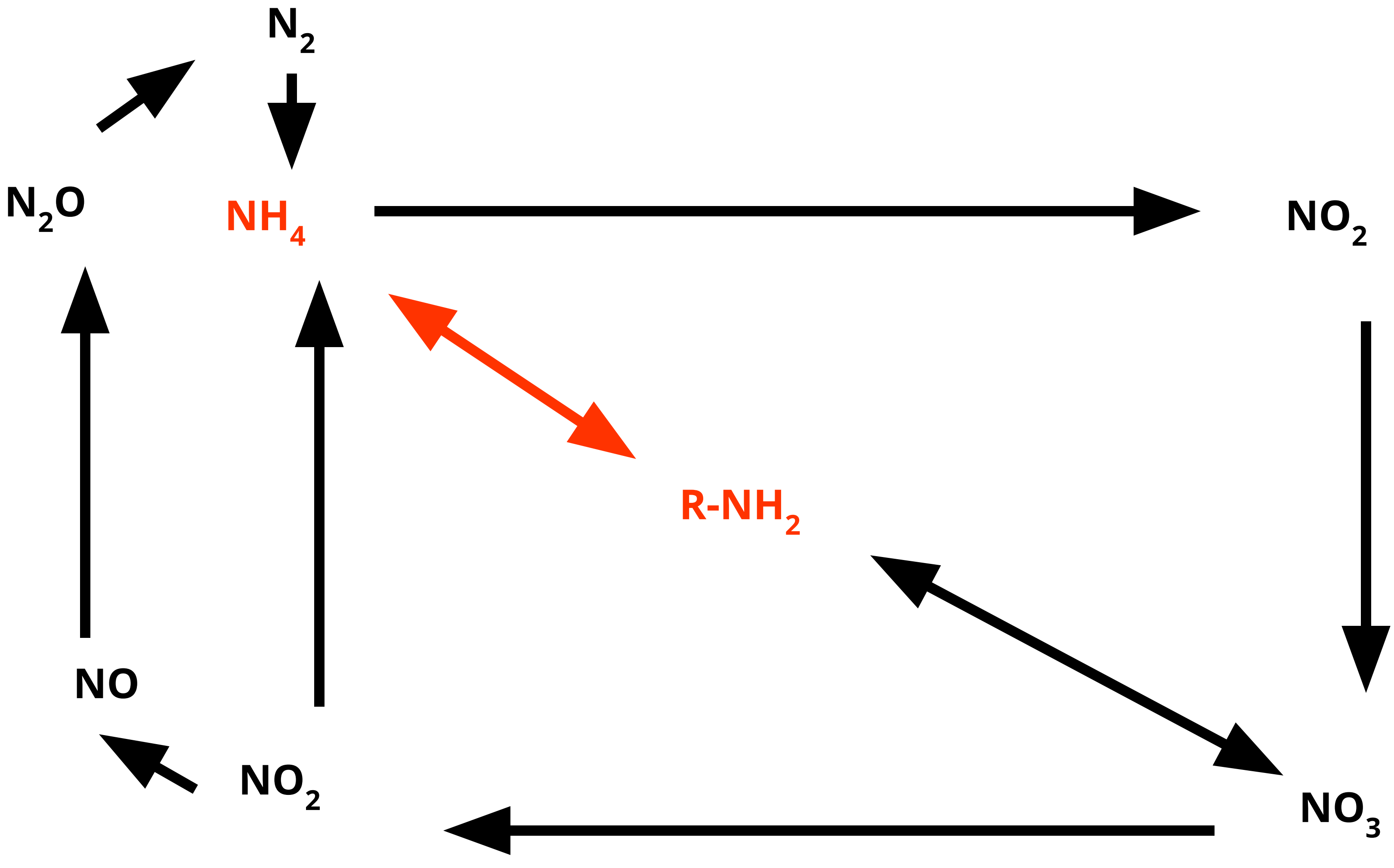
HUMAN IMPACT

- Burning fossil fuels,
- using synthetic nitrogen fertilizers,
- and cultivation of legumes

all fix nitrogen.



Ammonification or Mineralization

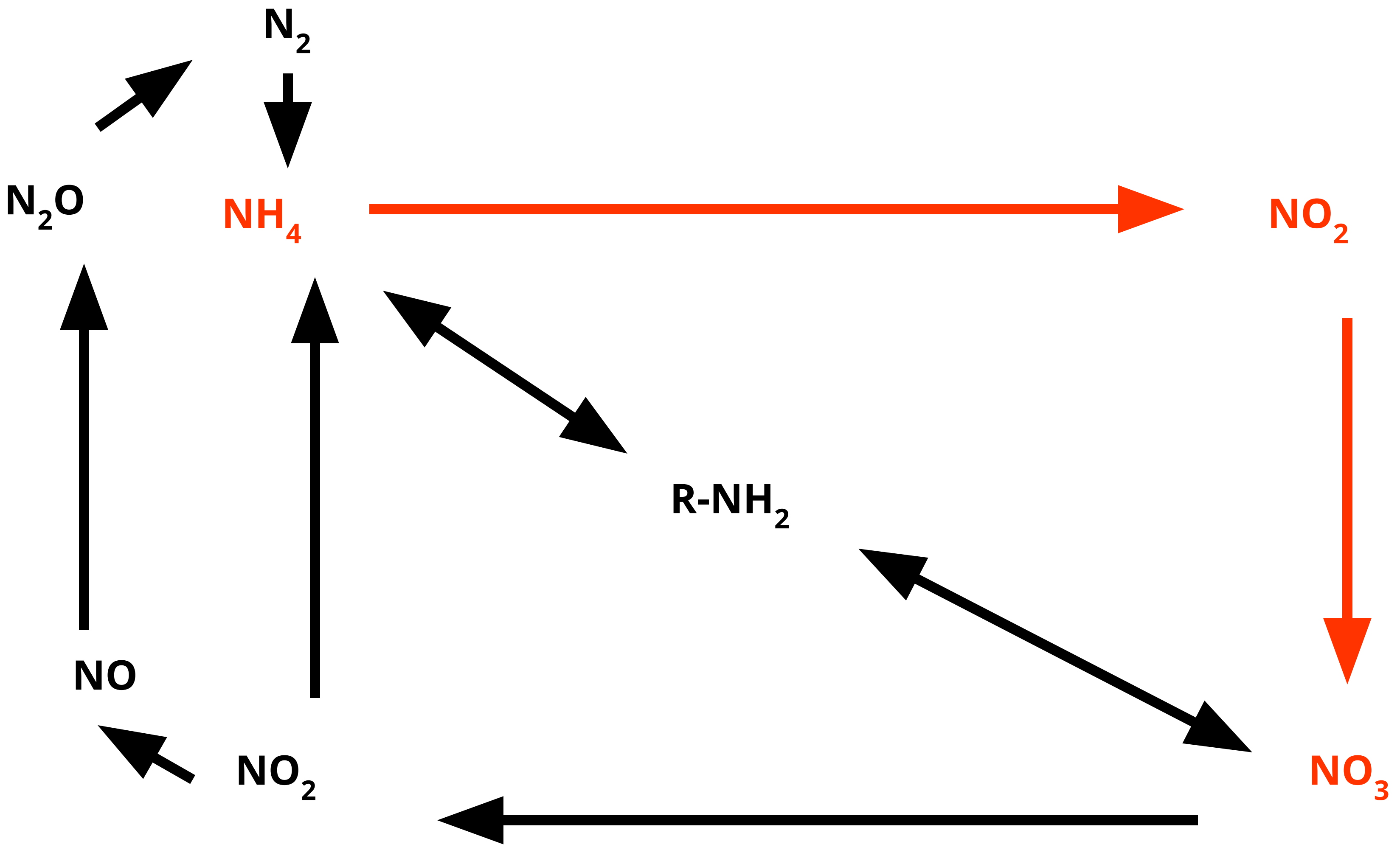


Nitrogen Mineralization also called Ammonification

Organic N --> NH_4^+

- **Decay** of dead things, manure, etc.
- Done by **decomposers** (bacteria, fungi, etc.)
- During this process, a significant amount of the nitrogen contained within the dead organism is converted to ammonium (NH_4^+).

Nitrification



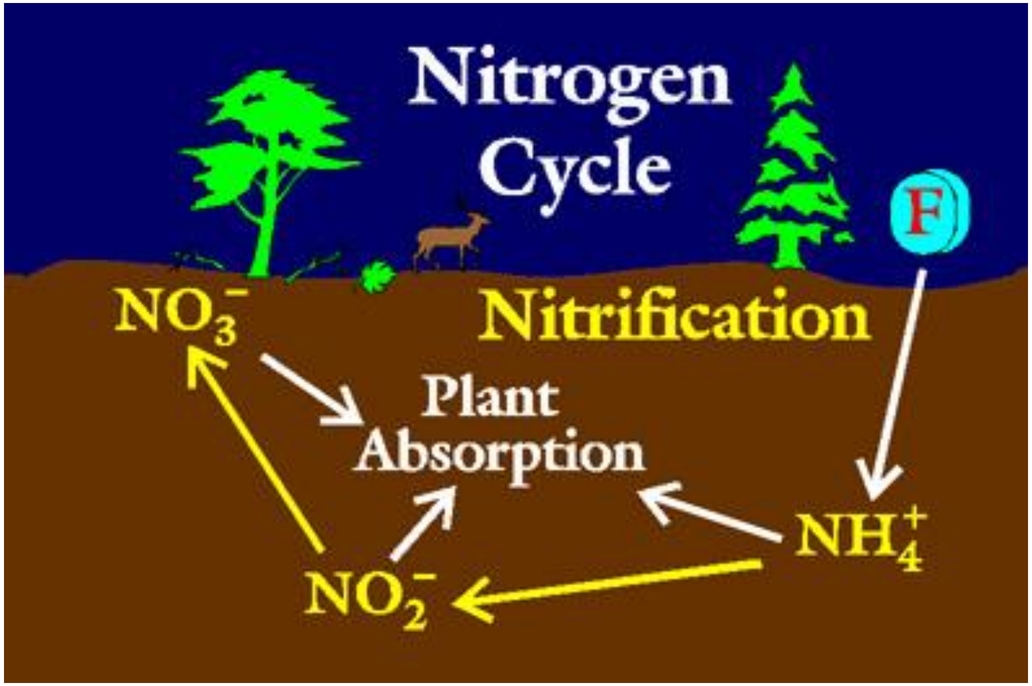
Nitrification

NH_3 or NH_4^+ --> NO_2^- --> NO_3^-

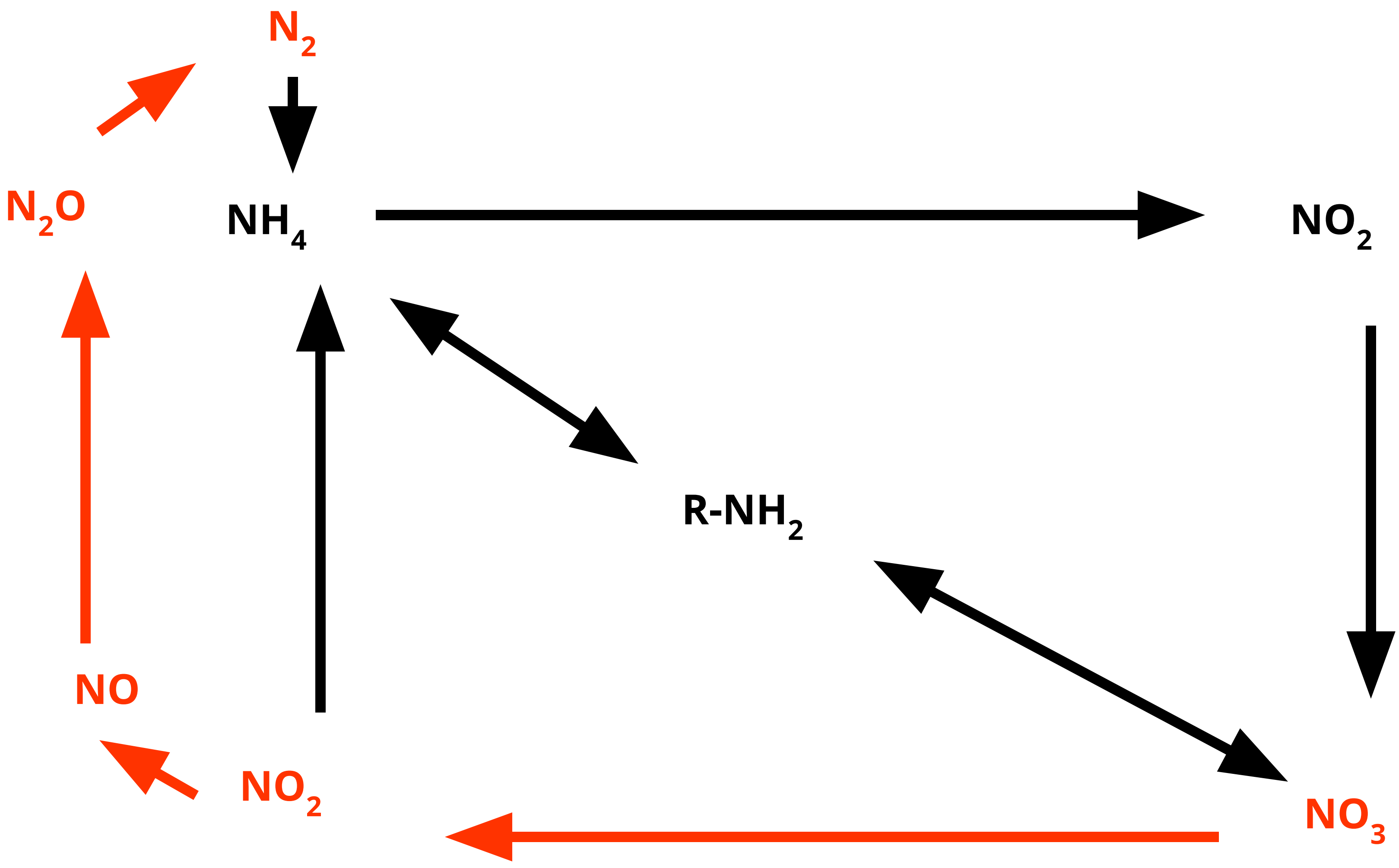
(Nitrifying) Bacteria add oxygen to nitrogen in two steps:

- STEP 1:
  Bacteria take in NH_3 or NH_4^+ & make NO_2^- = nitrite

- Step 2:
  Bacteria take in NO_2^- & make NO_3^- = nitrate



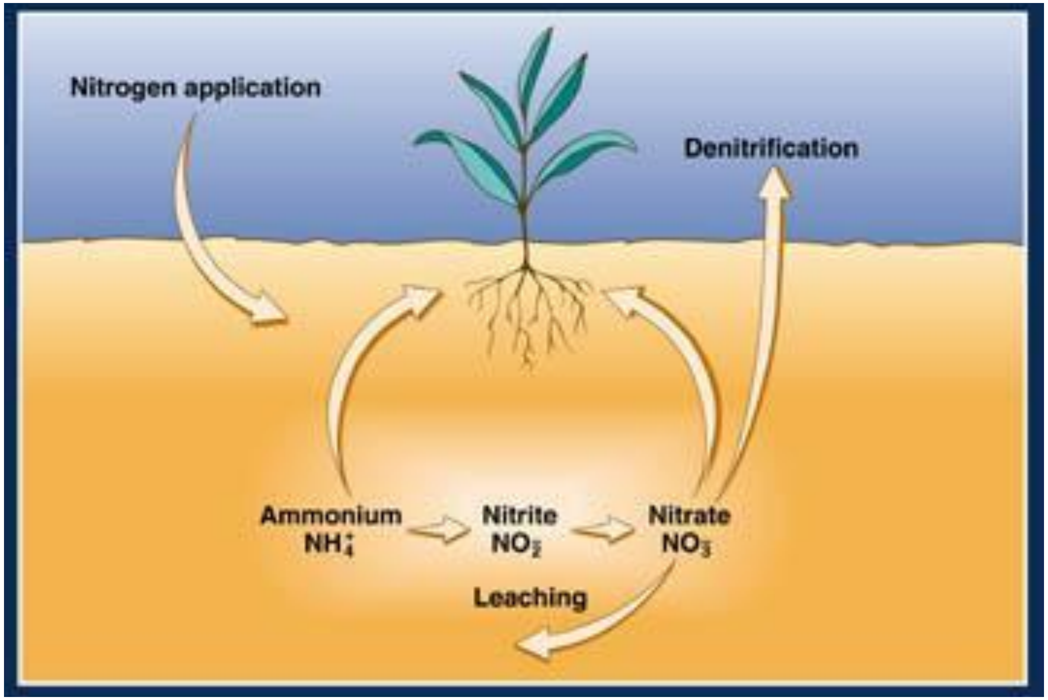
Denitrification



Denitrification
NO_3^- --> N_2

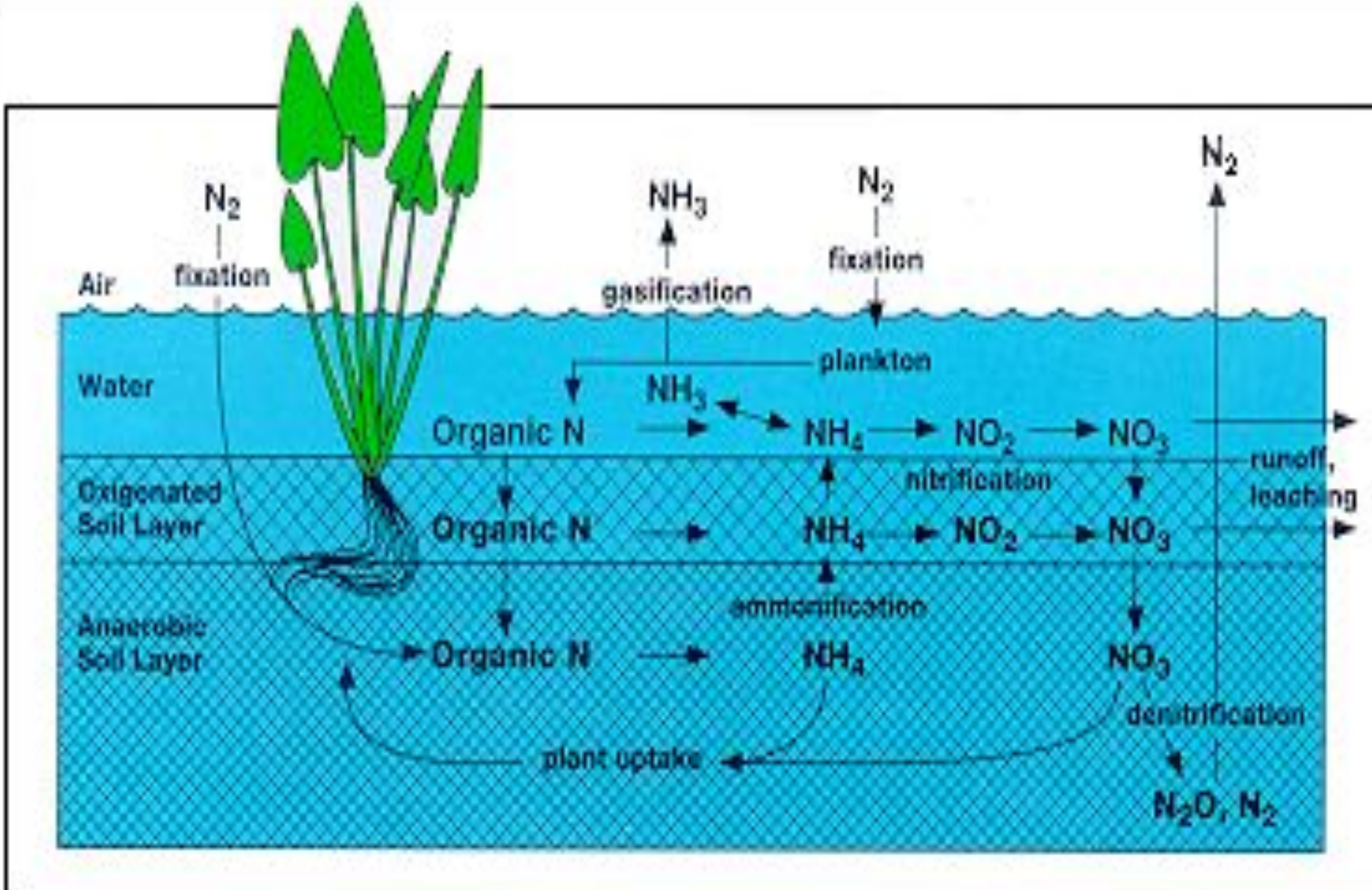
(Denitrifying) Bacteria do it.

[Denitrification]() **removes** nitrogen from ecosystems, and converts it back to atmospheric N_2.



Denitrification

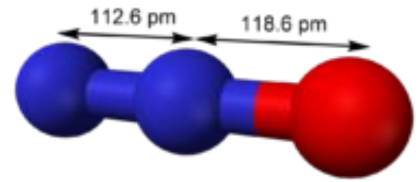
- Removes a limiting nutrient from the environment
- $4NO_3^- + C_6H_{12}O_6 \square\ 2N_2 + 6\ H_20$
- Inhibited by O_2
- Not inhibited by ammonia
- Microbial reaction
- Nitrate is the terminal electron acceptor



Nitrogen cycling in wetlands progresses more rapidly where there is a thin oxygenated soil layer present.

After Mitsch & Gosselink 1993

Nitrous oxide N_2O



Nitrous oxide, commonly known as **laughing gas**, **nitrous**, **nitro**, or **NOS** is a chemical compound with the formula N_2O.

At room temperature, it is a colorless, odorless non-flammable gas, with a slightly sweet taste.

It is used in surgeryand dentistry for its anaesthetic and analgesic effects.

It is known as "laughing gas" due to the euphoric effects of inhaling it, a property that has led to its recreational use as a dissociative anaesthetic.

It is also used as an oxidizer in rocket propellants, and in motor racing to increase the power output of engines.

At elevated temperatures, nitrous oxide is a powerful oxidizer similar to molecular oxygen.

Nitrous oxide gives rise to nitric oxide (NO) on reaction with oxygen atoms, and this NO in turn reacts with ozone.

As a result, it is the main naturally occurring regulator of stratospheric ozone.

N_2O/O_2 sedation

- It is necessary to use oxygen with nitrous oxide so that the blood remains appropriately oxygenated.
- A mixture of 20% nitrous oxide and 80% oxygen has the same analgesic equipotence as 15 mg of morphine.

- Nitrous oxide can be used as an oxidizer in a rocket motor
- In vehicle racing, nitrous oxide (often referred to as just "nitrous") allows the engine to burn more fuel by providing more oxygen than air alone, resulting in a more powerful combustion. The gas itself is not flammable at a low pressure/temperature, but it delivers more oxygen than atmospheric air by breaking down at elevated temperatures. Therefore, it is often mixed with another fuel that is easier to deflagrate.

- The gas is approved for use as a food additive (also known as E942), specifically as an aerosol spray propellant. Its most common uses in this context are in aerosol whipped cream canisters, cooking sprays, and as an inert gas used to displace oxygen, to inhibit bacterial growth, when filling packages of potato chips and other similar snack foods.

The production of adipic acid is the largest source to nitrous oxide. It specifically arises from the degradation of the nitrolic acid intermediate derived from nitration of cyclohexanone.

- Of the entire anthropogenic N_2O emission (5.7 teragrams N_2O-N per year),
- agricultural soils provide 3.5 teragrams N_2O–N per year.
- Nitrous oxide is produced naturally in the soil during the microbial processes of nitrification, denitrification, nitrifier denitrification and others.

Cumulative effect

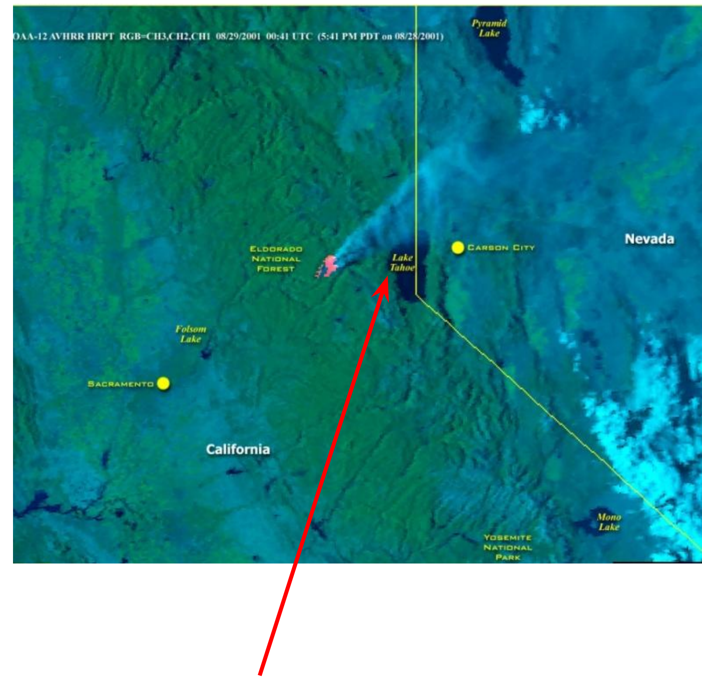
- Recent experiments show that interaction between water vapor, N_2O and cosmic radiation increases cloud production.

- Other Effects on Climate

- Tropospheric Ozone
  - Anthropogenic emissions have lead to increase
  - Increases are heterogeneous, plus hard to determine pre-industrial concentrations
- Stratospheric Ozone
  - Loss in Stratosphere leads to cooling (more loss of energy out to space)
  - However, loss of stratospheric ozone also leads to greater UV absorption (and heating) in troposphere
  - As ozone loss is reversed, some heating may occur

- Other Effects on Climate

- Aerosol Effects – Light Scattering Aerosol
  - As was discussed previously in visibility, aerosol particles of diameter 0.2 to 1 μm is very efficient in scattering light
  - A significant fraction is scattered in the backwards direction, so this effectively increases planetary albedo
  - Increase in albedo leads to cooling



Notice how smoke from Star fire is whiter vs. forest background

- Other Effects on Climate

- Aerosol Effects – Light Absorption
  - Most aerosol constituents do not absorb significantly in the visible region (where light is most prevalent)
  - A big exception is soot (elemental carbon emitted in inefficient combustion)
  - Soot clouds lead to atmospheric warming (even if cooling the surface over short-term)

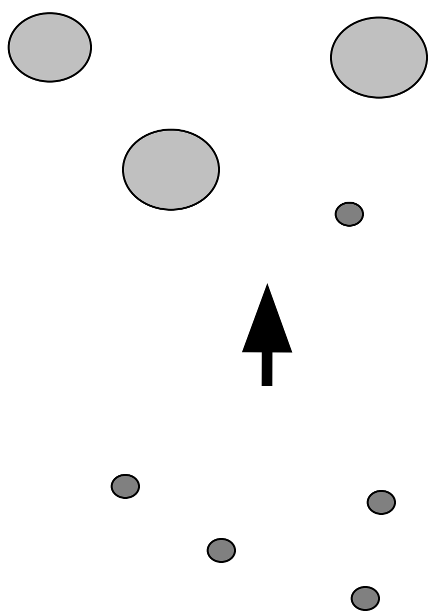
Notice how smoke from Kuwait oil fires is black vs. desert background

http://www.lpi.usra.edu/publications/slidesets/humanimprints/slide_16.html

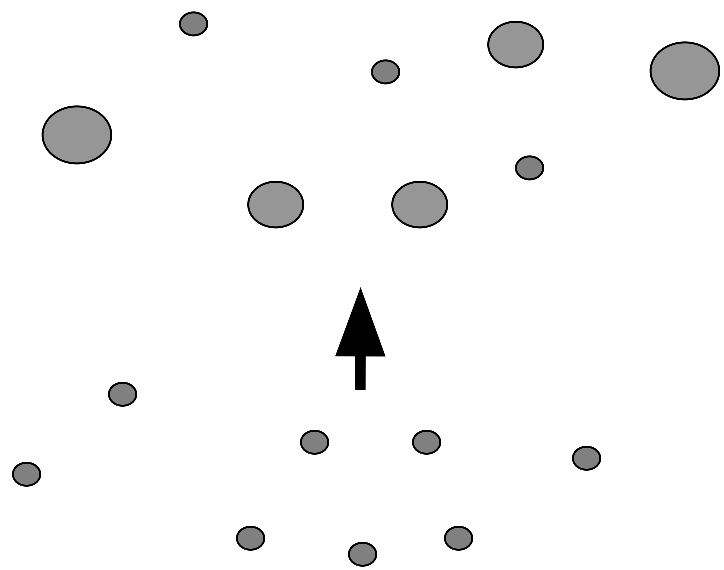
- Other Effects on Climate

- Indirect Effect of Aerosols
  - One type is through modification of cloud reflectivity

Clean Case:
fewer but larger droplets



Polluted Case:
more but smaller droplets



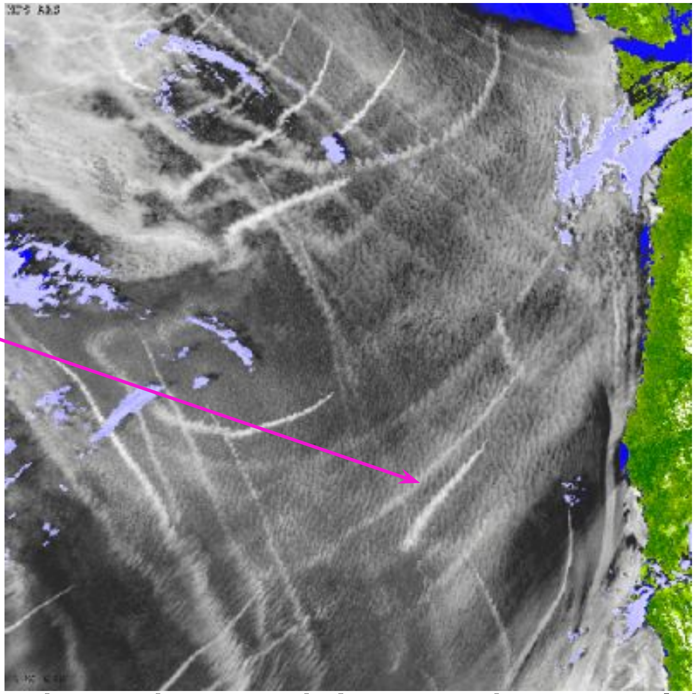
Climate Change

- Other Effects on Climate

- Indirect Effect of Aerosols
  - Larger droplets reflect light more poorly per g of cloud water
  - Polluted clouds look whiter from space

Ship tracks are indicative of localized pollution

Most apparent where: clouds are normally clean and with thin clouds (thick clouds have high albedos regardless)

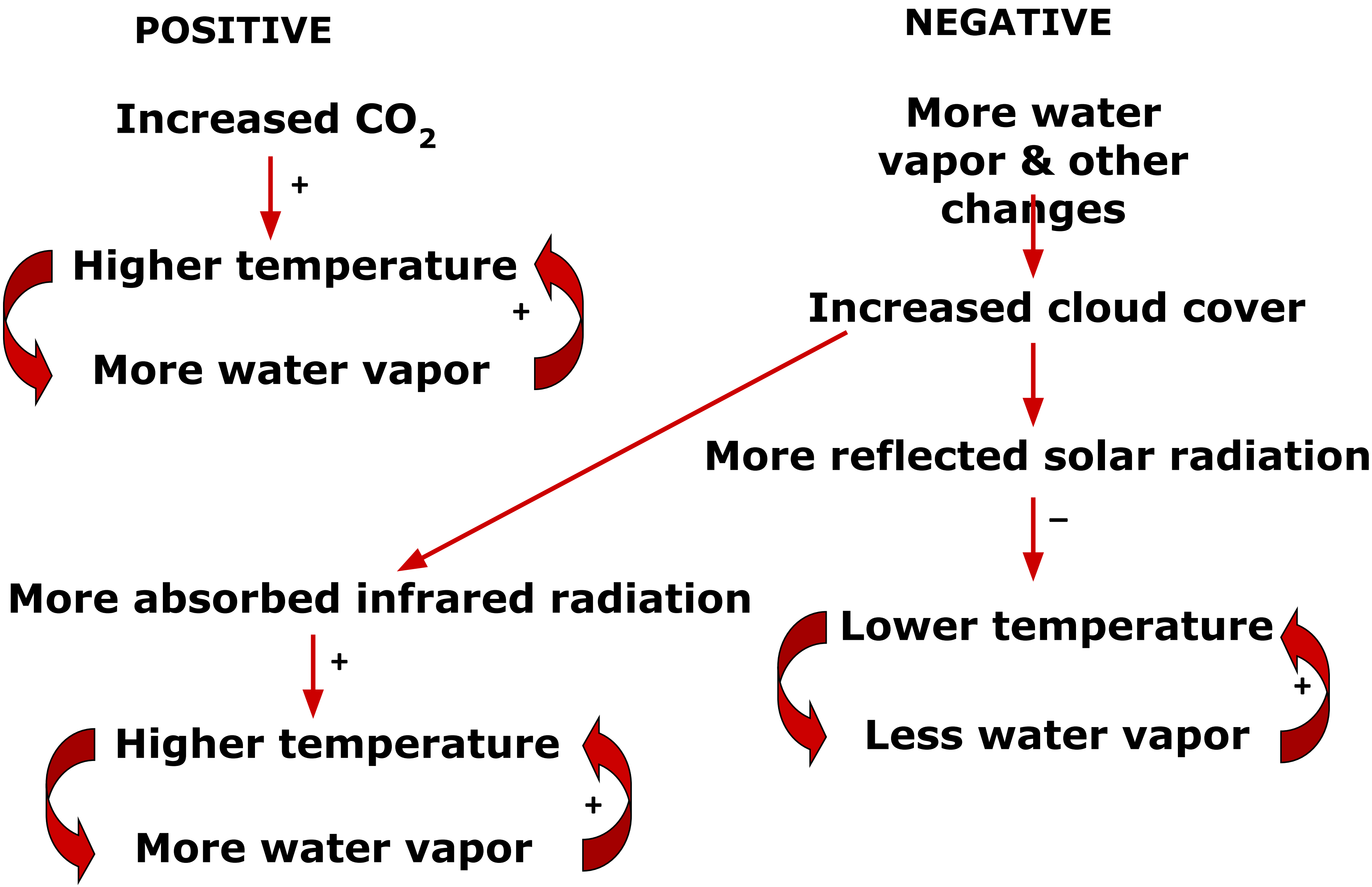


Source: http//www-das.uwyo.edu/~geerts/cwx/notes/chap08/contrail.html

Outdoor Air Pollution Can Temporarily Slow Atmospheric Warming

- Aerosol and soot pollutants
  - Can enhance or counteract projected global warming
  - Sulfate particles reflect sunlight
  - Soot particles absorb sunlight

Atmospheric Feedbacks



Feedback Effect

- The climate system is very complicated. A change in one component of the system may cause changes in other components. Sometimes the changes in other components enhance the initial change, then we say that these changes have *positive feedback* to the system. If the changes result in the reduction of the original change, then they have *negative feedback*.

- Both positive and negative feedback processes may exist in the climate system. In studying the global climatic change, we cannot make conclusions based on intuition, but have to take all such possible complicated effects into account. A good climate model would have treated all of them realistically.

An example of positive feedback

- When the climate becomes warmer (either due to the increase of CO_2 in the atmosphere or other unknown mechanisms), the ocean may also become warmer. A warmer ocean has lower solubility of CO_2 and hence will release more CO_2 into the atmosphere. This may cause the climate to become even warmer than before. Thus the dependence of solubility of CO_2 on temperature has a positive feedback on the climate system.

An example of negative feedback

- Consider a clear region over the ocean. Since there is no cloud, the sun shines on the ocean surface, causing it to warm up. This makes this part of the ocean warmer than other parts and the air over it tends to rise (causing convection). Rising air expands and cools, causing clouds to form. The formation of clouds will block out the sun and the solar heating of the ocean surface will cease. The surface will start to cool down. Thus the cloud formation due to surface heating and convection is a negative feedback to the climate system.