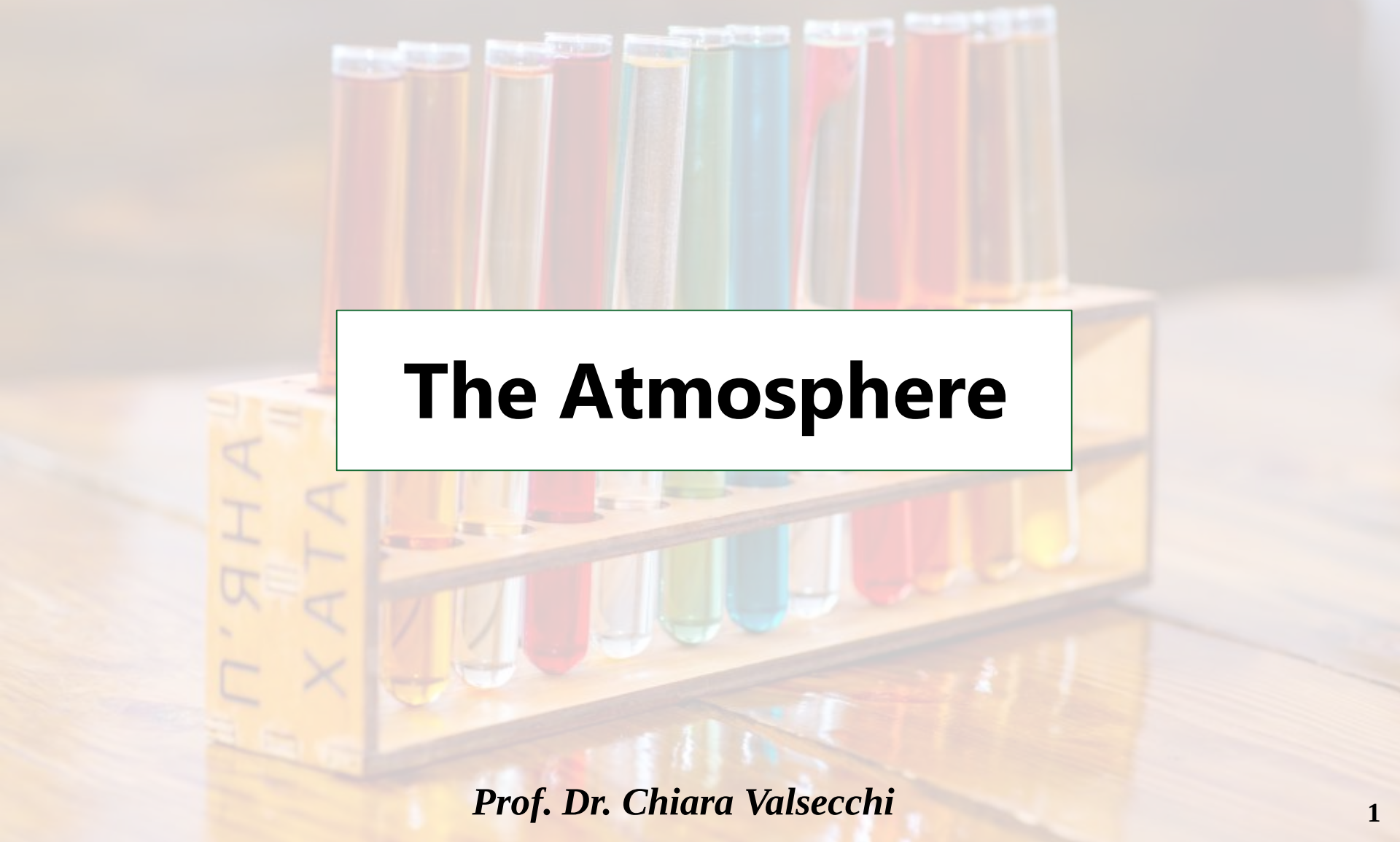

The Atmosphere

Prof. Dr. Chiara Valsecchi

Class Goals

- The structure of the Atmosphere
- Atmosphere Composition
- Atmosphere heat balance
- Global Warming

Atmosphere

Protect us from Sun heat and UV radiation

Provides CO_2 for plant photosynthesis

Provides N_2 for plant growth

Storage of water and its distribution

and…..

We have been polluting it constantly!!!

Definitions

Atmosphere – The mixture of gases, water droplets, and solid particles above the earth's surface

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Atmosphere – The mixture of gases, water droplets, and solid particles above the earth's surface

Weather – Short-term atmospheric phenomena lasting from hours up to about a week (e.g. thunderstorms, hurricanes, periods of high winds). From 10 to 15km above Earth's surface

Climate – Long-term atmospheric conditions lasting from weeks to years (e.g. average yearly precipitation, global warming)

Meteorology – The study of weather

Climatology – The study of climate

General facts

- If the Earth is the size of an apple, the atmosphere is thick like the skin.
- The atmosphere is a fluid

- There is a surface but no "top" (more than 200 km)
- half of the air molecules are within 5.6 km.

Structure of the Atmosphere

There are different ways to characterize the vertical structure of the atmosphere:

Density profile

Temperature profile (Most common)

Chemical profile

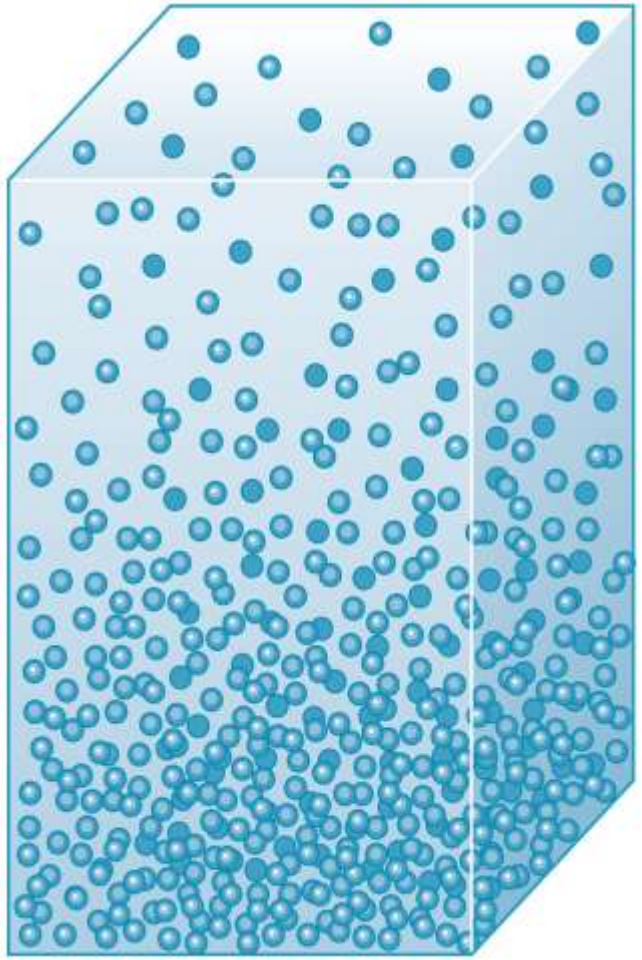
Electrical profile

Density Profile

The atmosphere is a compressible fluid

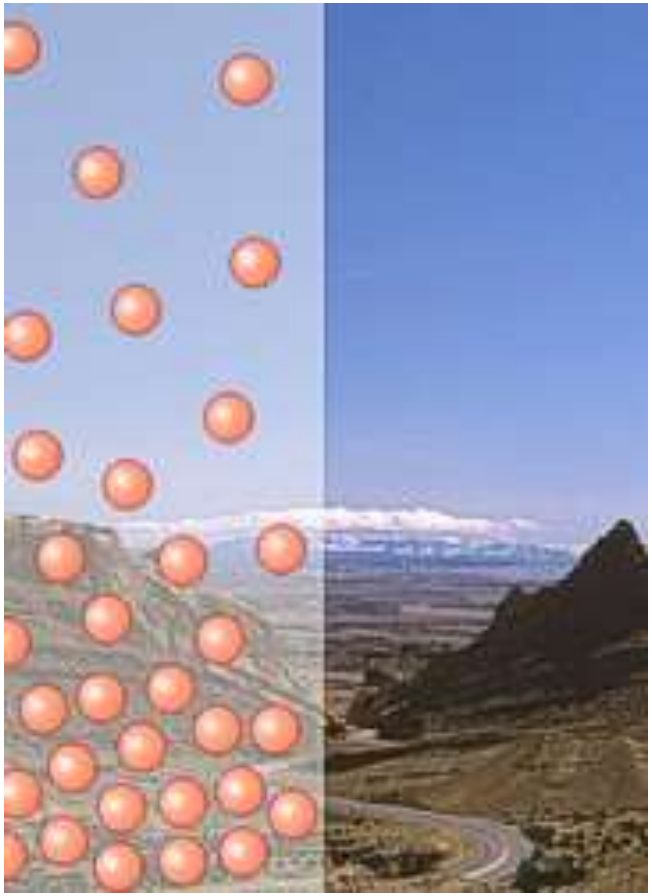
Density decreases with height:

Gravity pull



Air Pressure

Air pressure is simply the weight of air *above* an object: we feel air pressure, even if don't realize



Less molecules (same composition) at high altitude makes it harder to breath

Air pressure from reading stations are converted to Sea Level Pressure to observe surface low and high pressures.

Weather maps showing the pressure at the surface are drawn using millibars.

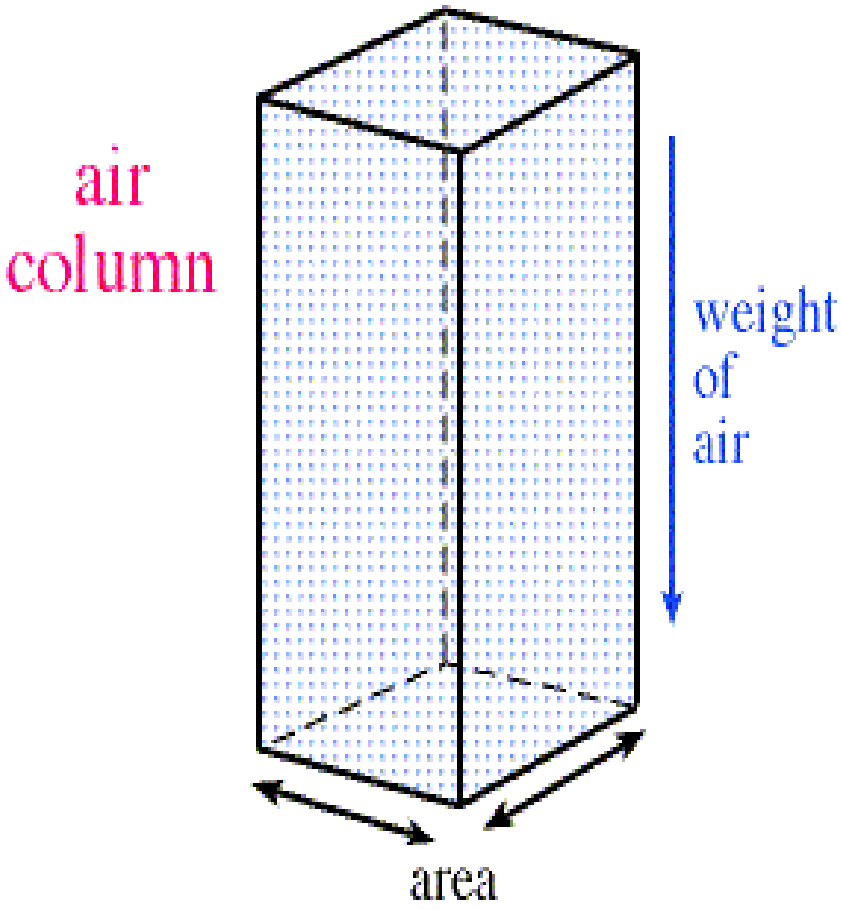
Pressure

Pressure = Force per unit area

Pressure in a free fluid is related to the weight of fluid above

1 millibar (mb) = Force to move 1g for 1cm for 1s

1 Pascal = 0.01 mb



Air Pressure

How much pressure (psi) is pushing on you right now?

Average sea-level pressure = 14.7 psi
= 1013.25 mb (millibar)
= 101325 Pa
= 29.92 in Hg
= 1 atmosphere (atm)

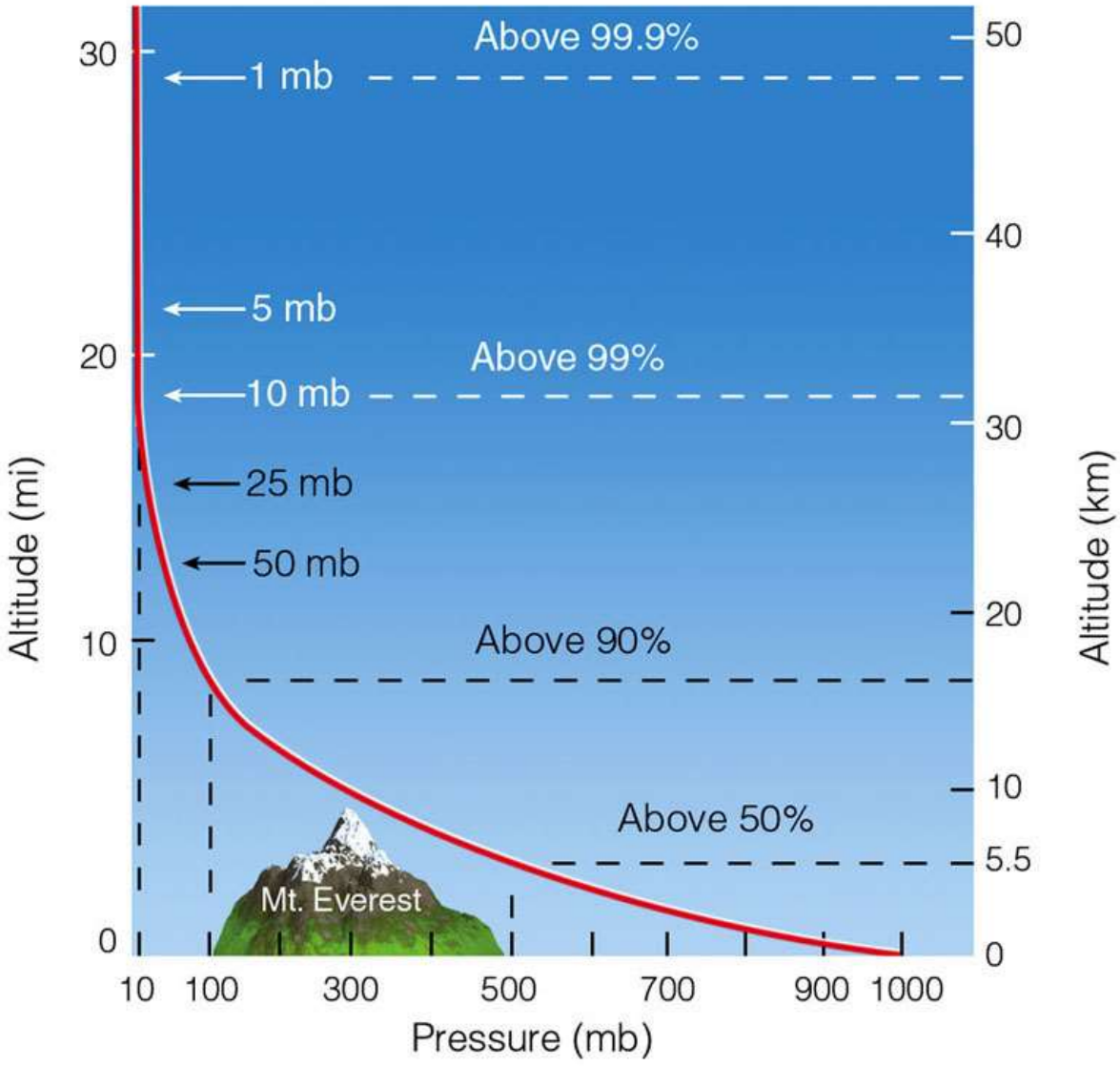
Record high sea-level pressure = 1083.8 mb (Siberia, 1968)

Record low sea-level pressure = 870 mb (Typhoon Tip, 1979)

Air Pressure Profile

At an altitude of 5500m the pressure is 500 mb, would put you at half of the sea level pressure

Top of Mt. Everest is above 70% of all molecules in the atmosphere. Pressure of 300mb



Profile by temperature

Divided in 5 big layers

Each layer has a limit, called “pause” where the maximum changes occurs

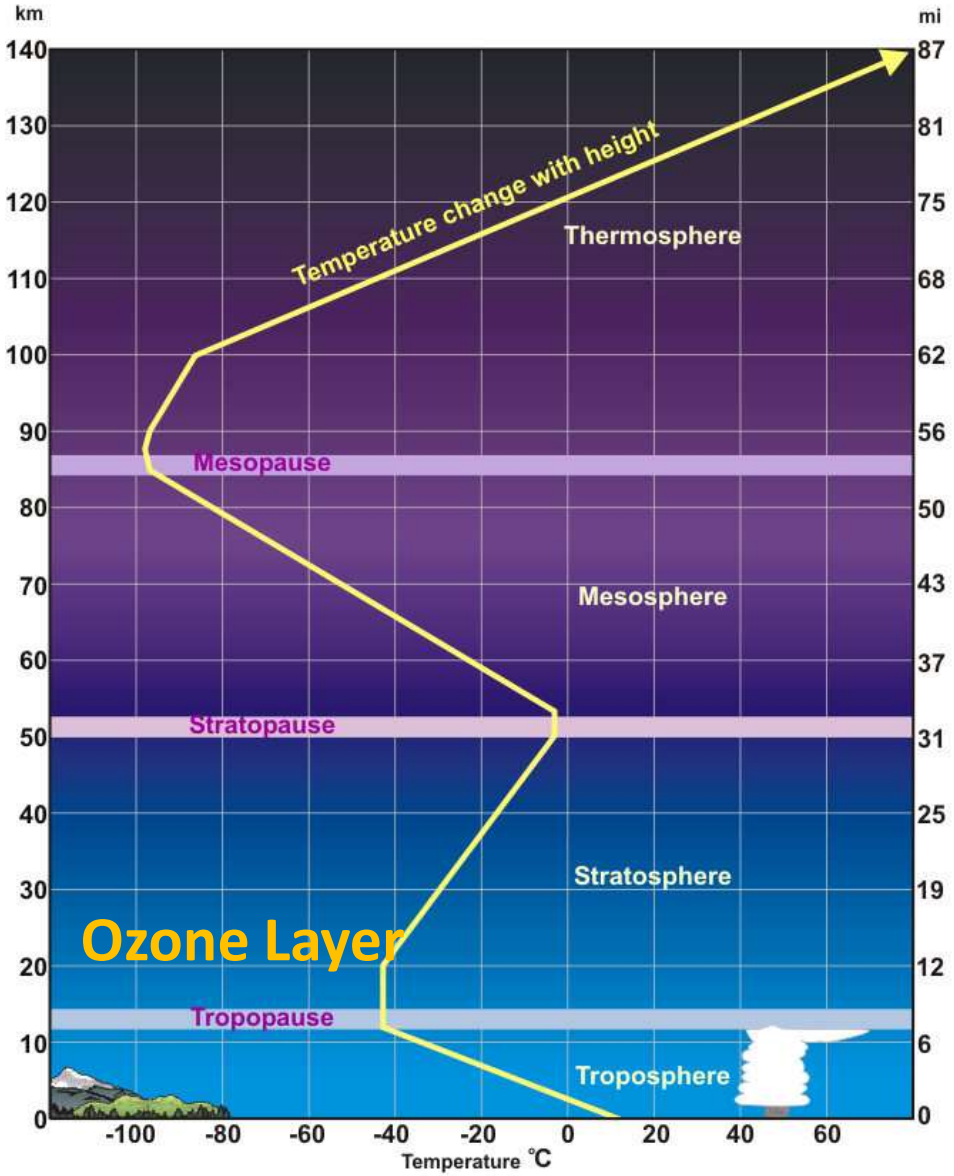
Troposphere

Ozone layer

Stratosphere

Mesosphere

Thermosphere



Troposphere

Located at 0-20km

Contains 80% of atmospheric mass

Temperature generally decreases with height:

from 17°C to -51°C

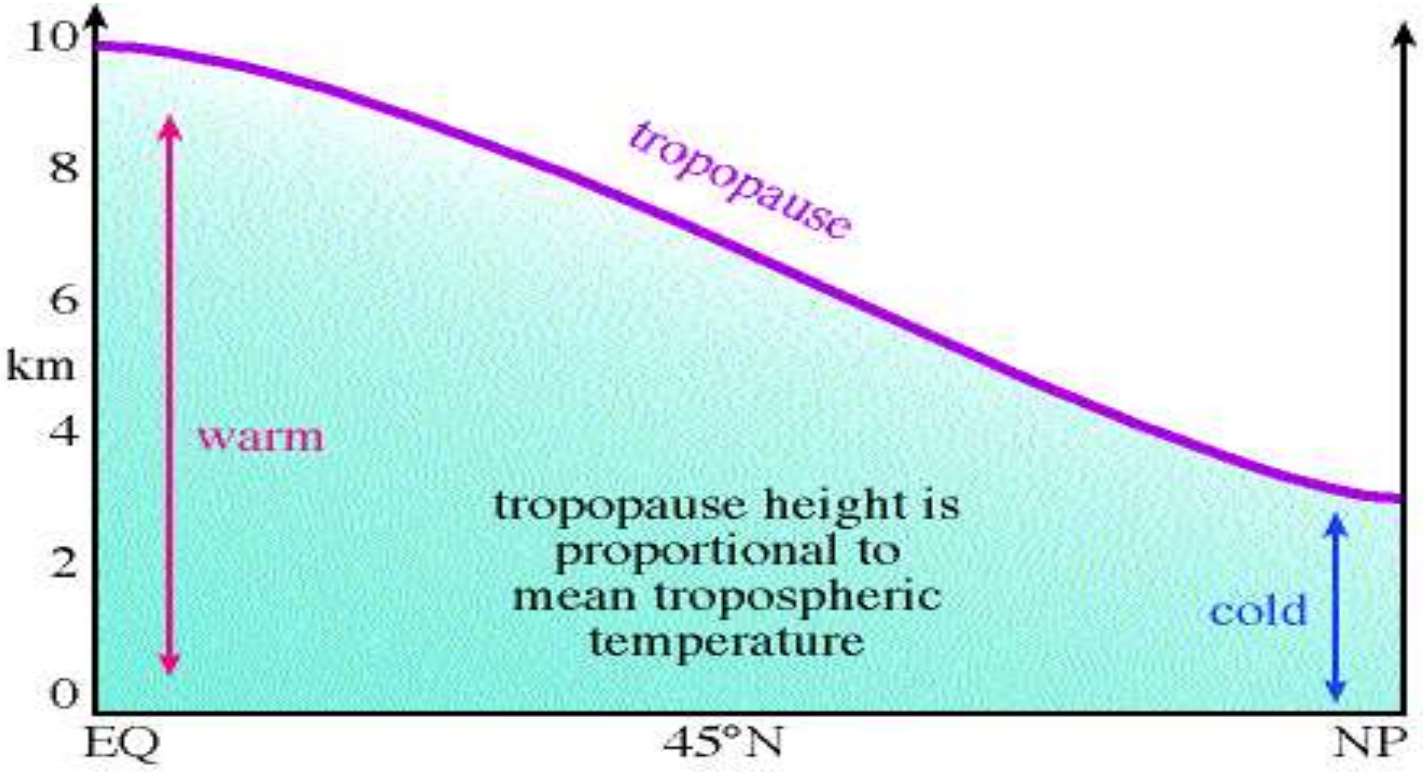
Lower part: **Boundary layer** (3km), where pollutants accumulate and most of weather event occur

Top of troposphere is called the **tropopause:** where water forms ice and falls back:

We do not lose Oxygen! Keep atmosphere!

Troposphere

At the equator it is around 18-20 km high, at the poles just under 6 km high



Stratosphere

Located from about 11-50 km

Contains about 19.9% of atmospheric mass

Very little water vapour

Ozone layer is located in stratosphere

Temperature increases with height from -60°C to -15 °C – due to O_3 absorbtion of UV

Top of stratosphere is called the **stratopause**

Mesosphere

Located from about 50-80km

Contains 0.1% of atmospheric mass

Temperature decreases with height in the mesosphere: from -15°C to -120°C

Gases are still thick enough to slow down meteorites → they burn → trails in the night sky

Thermosphere

Also called Ionosphere → northern lights

Thermosphere located above 80km – 290km (?)

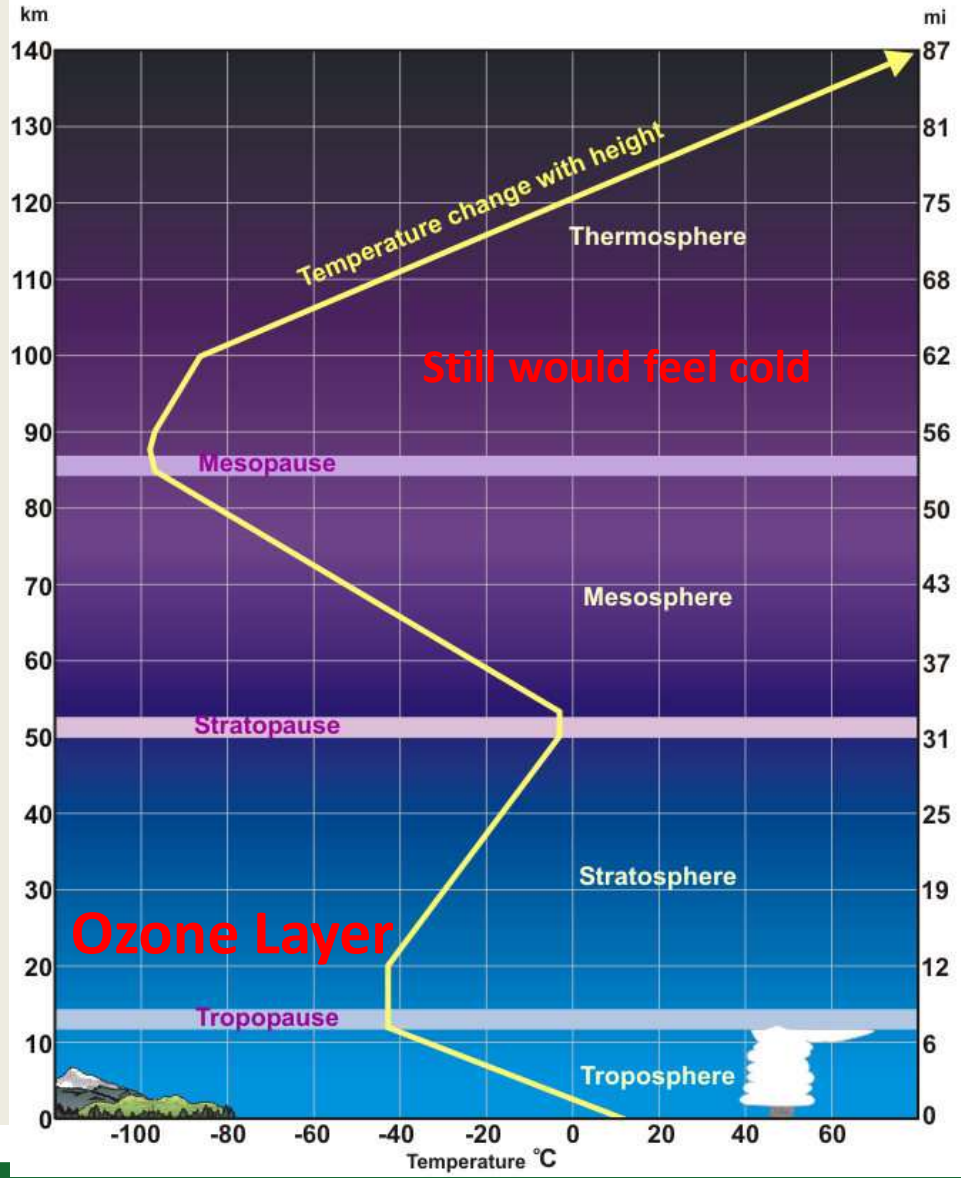
Temperature increases with height: only the higher energy ultraviolet and x-ray radiation from the sun is absorbed (2000 °C)

Curiosity: this layer of the atmosphere would still feel very cold because of the extremely thin air. The total amount of energy from the very few molecules in this layer is not sufficient enough to heat our skin.

Thermosphere

Summary

- **Troposphere**
  - From 0 to 20 km
  - All weather fenomenons
  - Contains 80% of air mass
  - Temp decrease with height
- **Stratosphere**
  - from 11-50 km
  - Temp increases with height
  - Ozone (0_3) layer
  - Absorbs most of the damaging ultraviolet sunlight (UV-B)
- **Mesosphere**
  - From ~30 to 53 miles up
  - Temp decreases
  - Majority of meteors burn up
- **Thermosphere**
  - Upper atmosphere 80 to ~300
  - Very few molecules
  - Hot but cold



Which ?

Composition

1. Gases (permanent and variable)
2. Water droplets (clouds and precipitation)
3. Microscopic solid particles (aerosols)

1. Permanent Gases

Permanent gases form a constant proportion of the atmosphere, and have long residence times (thousands to millions of years)

TABLE 1–2 Permanent Gases of the Atmosphere

Constituent	Formula	Percent by Volume	Molecular Weight
Nitrogen	N_2	78.08	28.01
Oxygen	O_2	20.95	32.00
Argon	Ar	0.93	39.95
Neon	Ne	0.002	20.18
Helium	He	0.0005	4.00
Krypton	Kr	0.0001	83.8
Xenon	Xe	0.00009	131.3
Hydrogen	H_2	0.00005	2.02

Residence Time

Residence Time: how long it takes for a substance to come back to the ground, due to the gravimetric pull.

Variable Gases

Variable gases vary in atmospheric concentration in both time and space

TABLE 1–3 Variable Gases of the Atmosphere

Constituent	Formula	Percent by Volume	Molecular Weight
Water Vapor	H_2O	0.25	18.01
Carbon Dioxide	CO_2	0.038	44.01
Ozone	O_3	0.01	48.00

Variable Gases

H_2O: maintains the cycle of life. Most impactful greenhouse gas

CO_2: a greenhouse gas (very effective absorber and emitter in the infrared). Also CH_4

O_3: good in stratosphere (protects from UV), bad near the surface (corrosive to lungs)

SO_2: emitted by volcanoes and fuels. Responsible for acid rain

NO_2: produced by combustion. Acid rain and smog.

Water Vapor

Extremely important variable gas with short residence time: ~10 days

Highest concentrations is near the surface and in tropics (~4%)

Lowest concentration in deserts and at high altitudes (~0%)

VERY powerful greenhouse gas (both in vapor form and as clouds)

Humidity

Partial pressures represent the maximum pressure that one gas can exert at that temperature.

The water saturation pressure is the most amount of vapor partial pressure at one temperature before it condense.

Water vapor can be measured with a barometer:

If I measure a pH_2O of 0.0102 mb, at 20 °C, then:

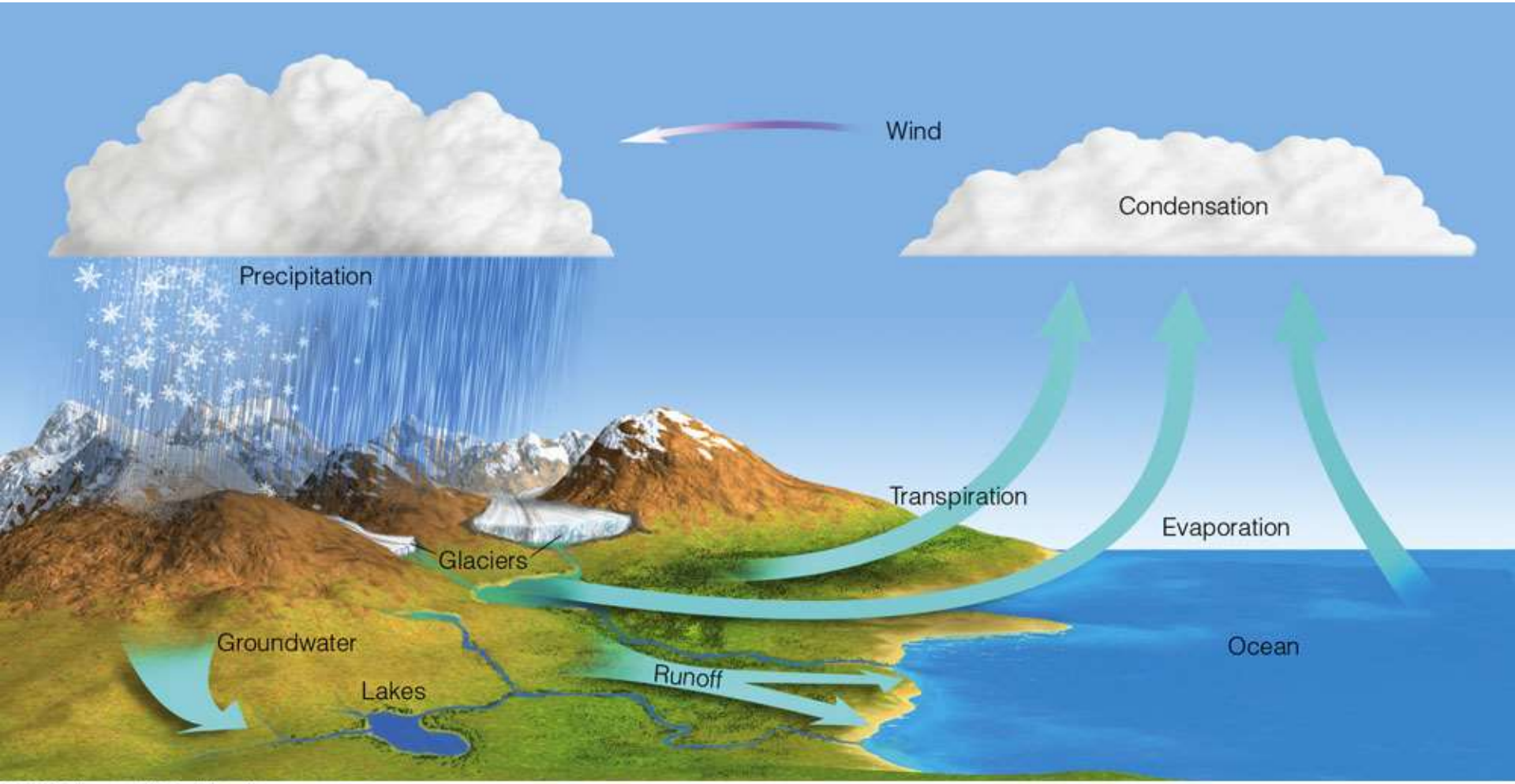
$$\frac{0.0102}{0.02307} = 44.2\% \text{ humidity}$$

Saturated Partial Pressure of Water Vapor in Air

Temperature °C	pH_2O, atm
–10	0.00257
–5	0.00396
0	0.00603
10	0.01683
20	0.02307
25	0.03126
30	0.04187
35	0.05418

Water Vapor

The Hydrologic Cycle

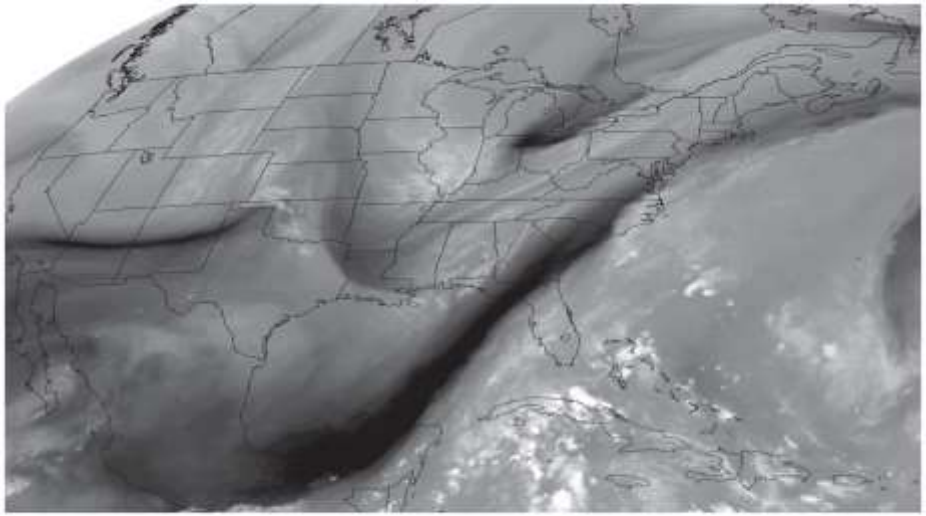


Water Vapor Satellite

Satellite imagery reveals variable nature of water vapor concentration

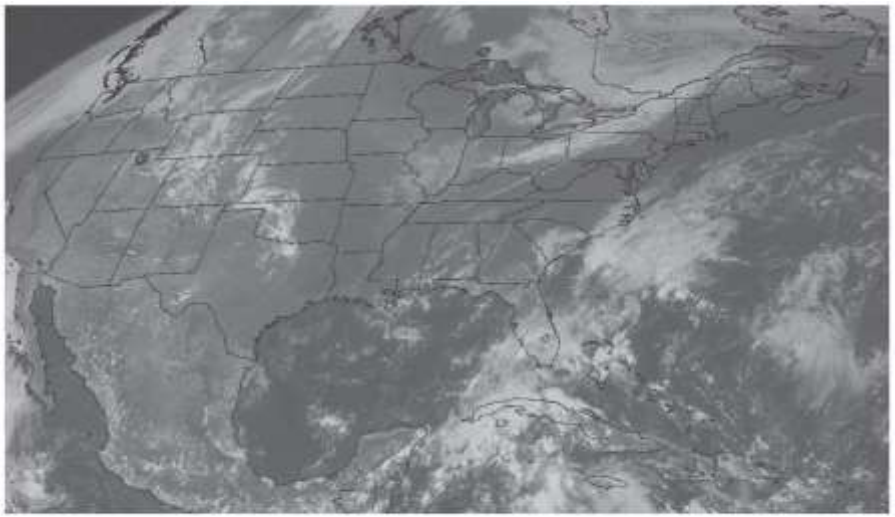
Water vapor satellite imagery also reveals moist and dry regions of the atmosphere (visible imagery does not)

Water vapor imagery



(a)

Visible imagery



(b)

Carbon Dioxide

Carbon dioxide (CO_2) – Concentration 386 ppm and residence time of 150 years.

Not the worst greenhouse gas, but it is caused by fuel combustion.

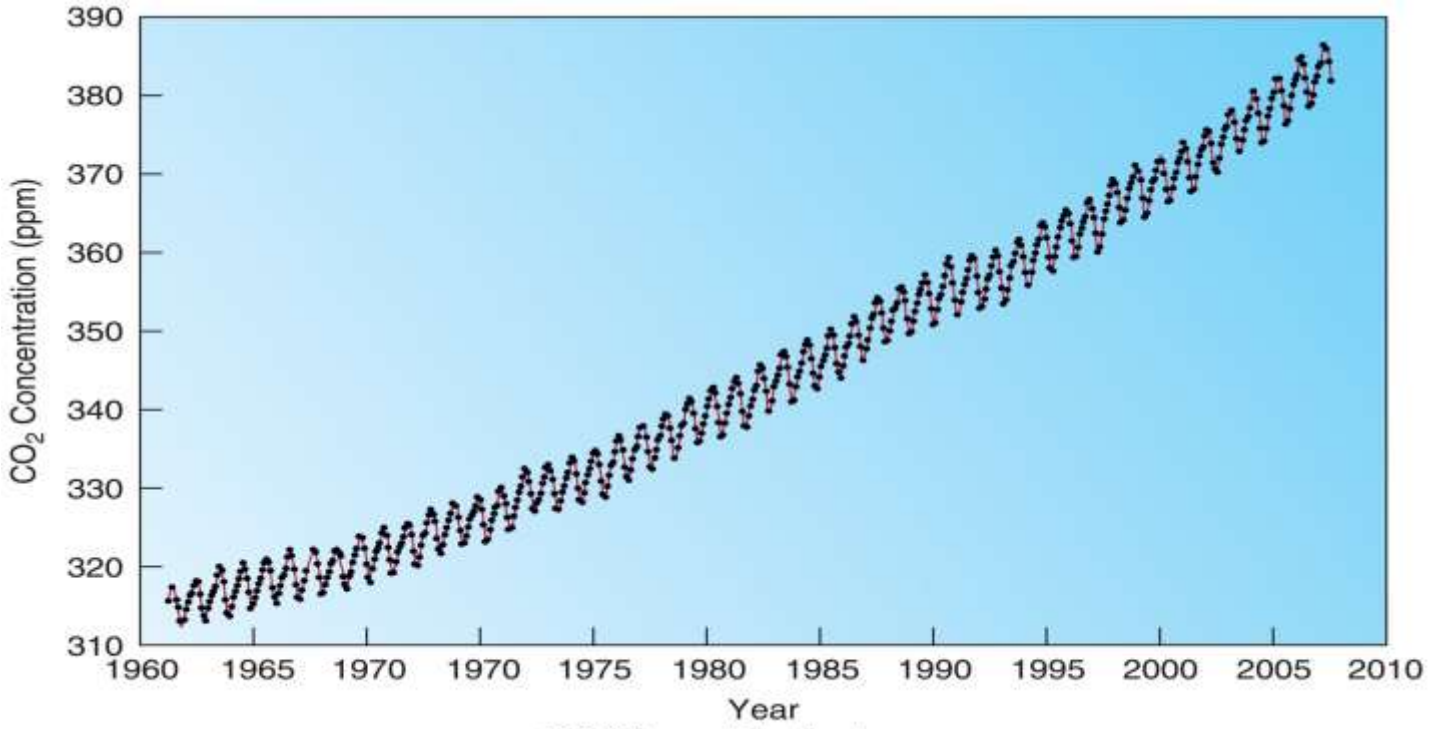
Sources - 1) Plant and animal respiration
2) Volcanoes
3) Organic decay
4) Combustion

Sinks - 1) Photosynthesis (plants)
2) The oceans

Carbon Dioxide

Seasonal oscillation and long term increase in concentration (due to combustion and deforestation)

More than 20% since 1958.



Mauna Loa Observatory (Hawaii)

Methane

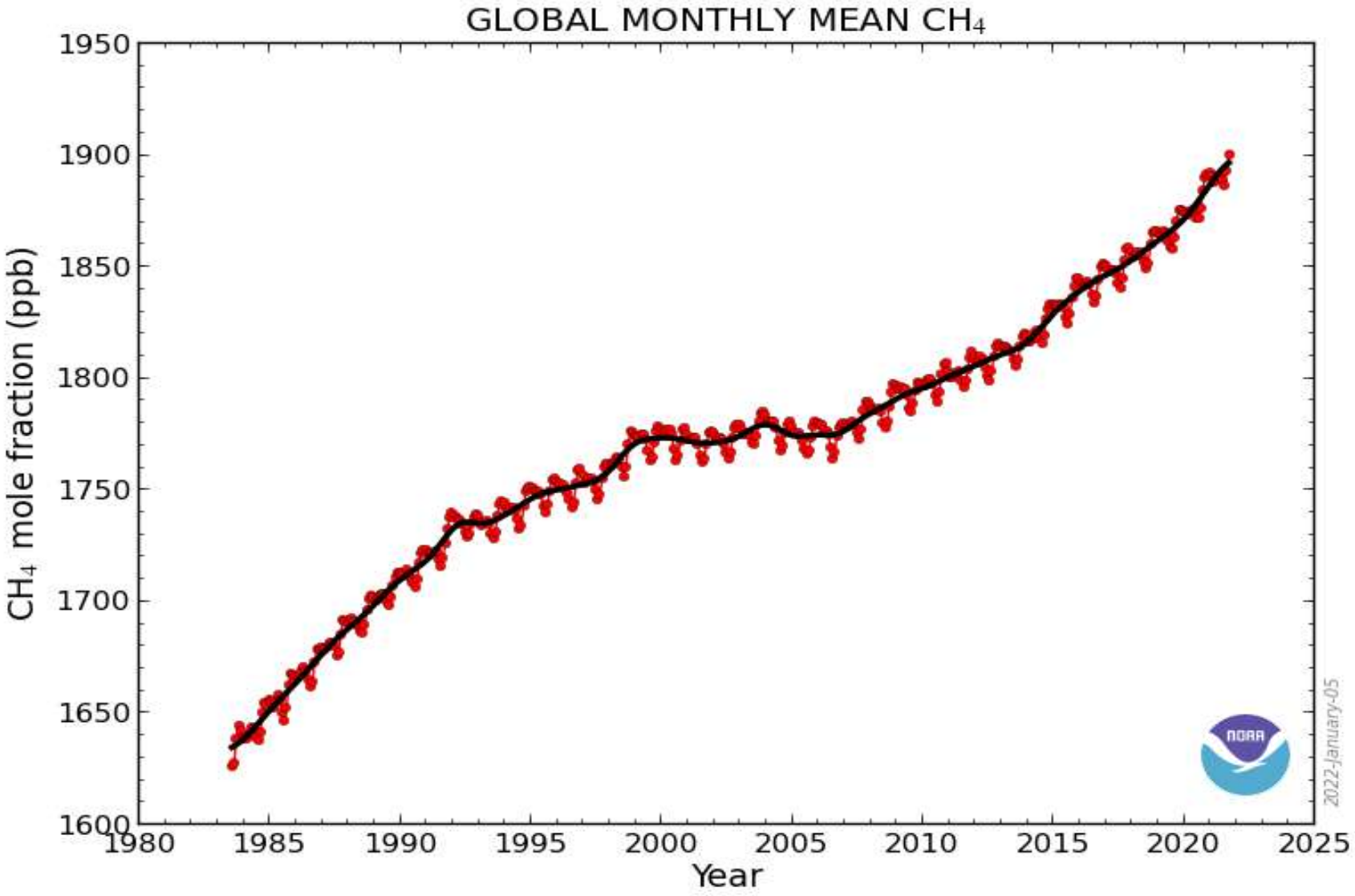
Methane (CH_4) – A variable gas with residence time ~10 years. Concentration of 1.8 ppm

Sources - 1) Rice cultivation, wetlands
2) Mining
3) Biomass burning
4) Fossil fuel extraction
5) Animal digestion

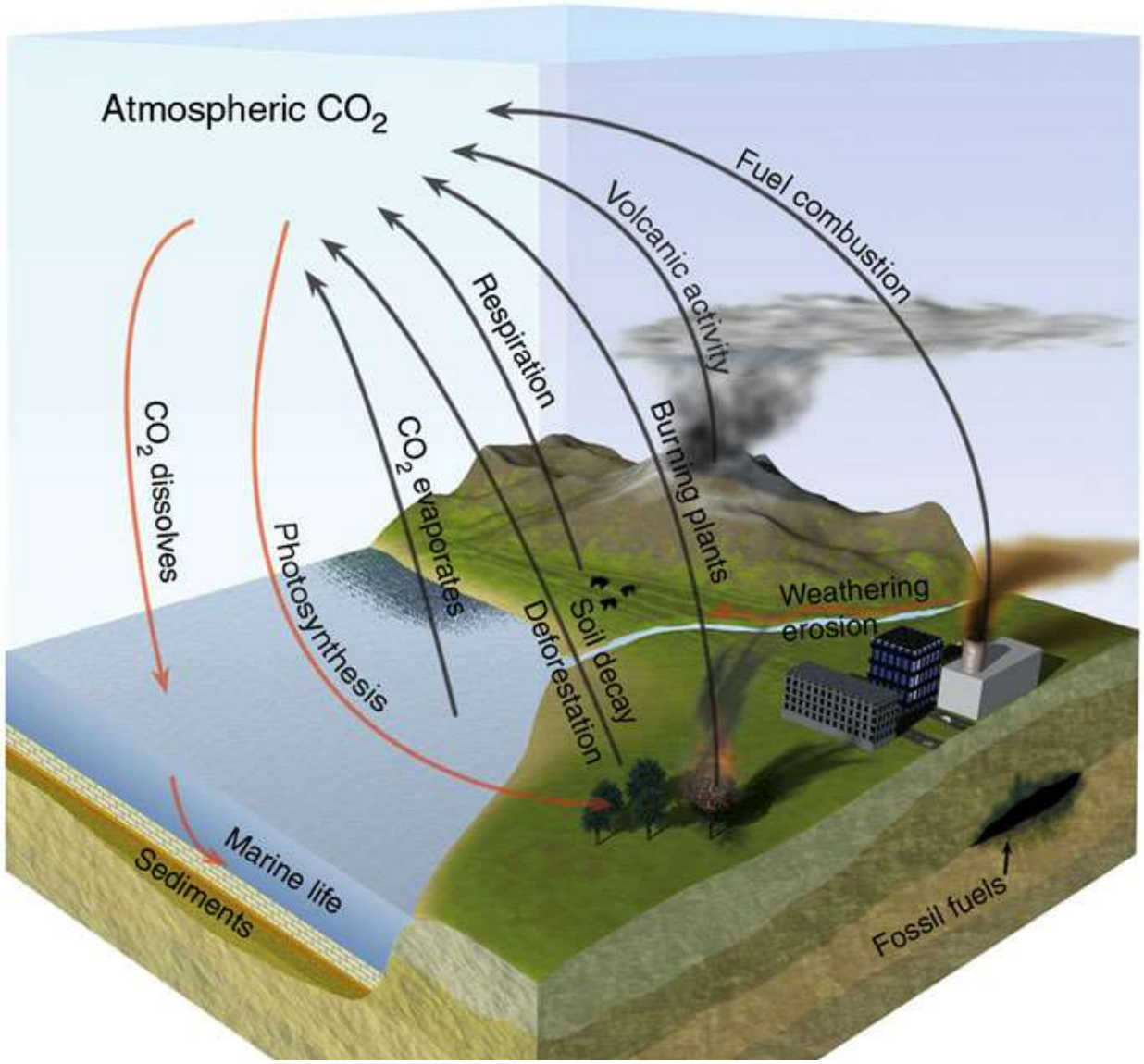
Oxidizes rapidly, hence low concentrations

Large concentrations proposed to explain greenhouse warming of early Earth

Methane


GLOBAL MONTHLY MEAN CH_4
CH_4 mole fraction (ppb)
1950
1900
1850
1800
1750
1700
1650
1600
1980
1985
1990
1995
2000
2005
2010
2015
2020
2025
Year
NOAA
2022-January-05

The Carbon Cycle



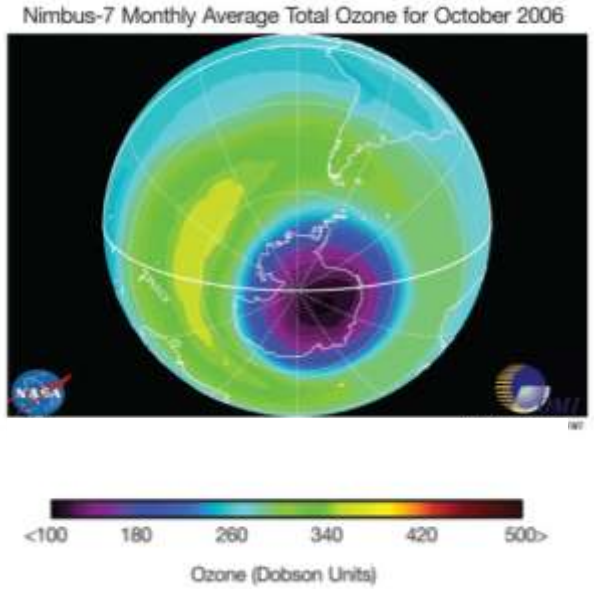
Ozone – O_3

A beneficial and harmful variable gas

Stratosphere: concentration of 15 ppm, occurs from natural chemical reaction.

Absorbs UV radiation!!

Depletion is detrimental to life.



Natural ozone cycle

$O_2 + uv \rightarrow O + O$

$O_2 + O \rightarrow O_3$

$O_3 + uv \rightarrow O + O_2$

Ozone – CFCs

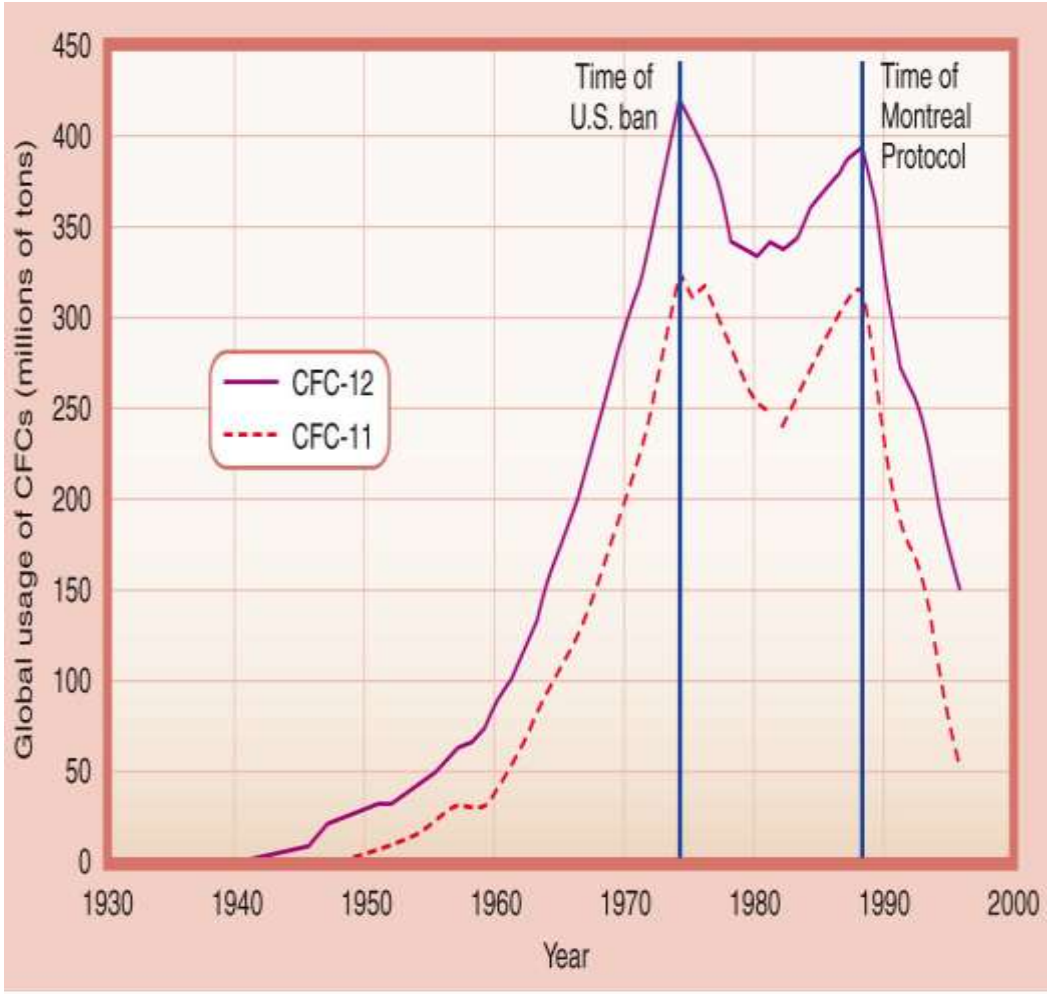
CFC's (Chlorofluorocarbons)

- destroy stratospheric ozone
- radiation from the sun causes the CFCs to break down and releases one chlorine atom
- chlorine is a catalyst: it destroys one O_3 molecule and then is free to find another

With CFCs:

$$CFC + uv \rightarrow Cl + CFC\text{-}product$$
$$Cl + O_3 \rightarrow ClO + O_2$$
$$O + ClO \rightarrow Cl + O_2$$

Global CFCs



A global success story!

Ozone – O_3

In Troposphere:

Major component of smog

Bad for the lungs, irritant

Created by chemical reactions between **NOx** gases (produced by combustion) and volatile organic compounds (**VOCs**).

Can increase to 0.15 ppm in polluted air

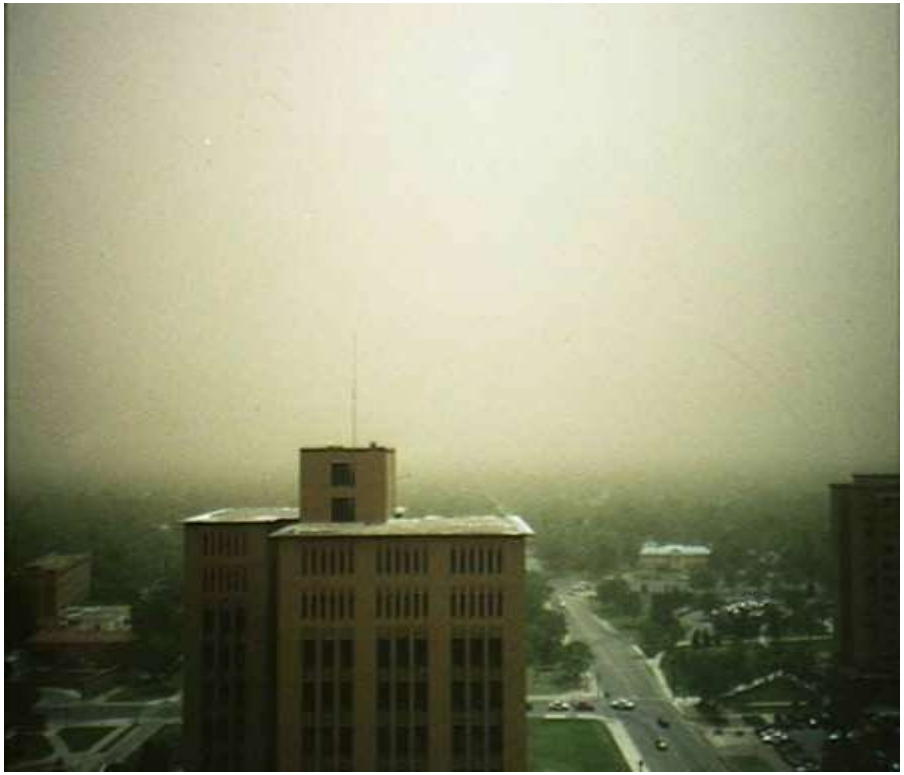
Aerosols

Aerosols – Small solid particles (e.g. dust, smoke, sea spray, volcanic ash, bacteria, pollen)

Typical density = 2g/cm^3
Typical diameter < 10 microns (if larger = particulate)
Residence time = days to weeks
Mostly from natural sources

Act as cloud condensation nuclei: without aerosols, there would never be clouds!!!

Aerosols



Lubbock Dust Storm

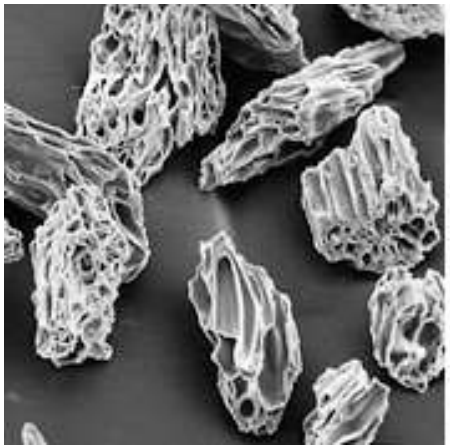
Aerosols

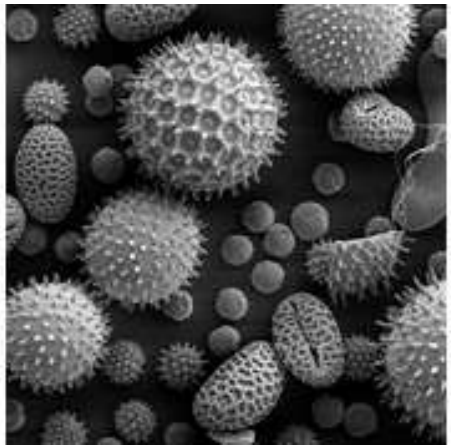
Forest fire smoke in CA

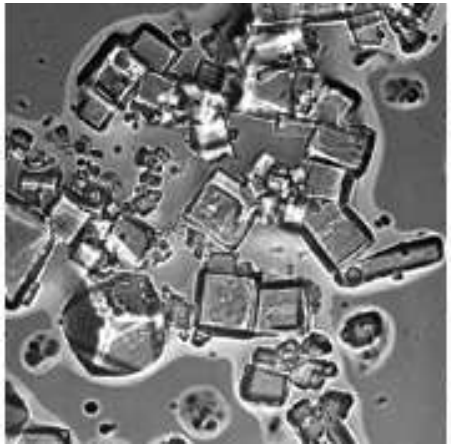
Haboob in Phoenix, AZ

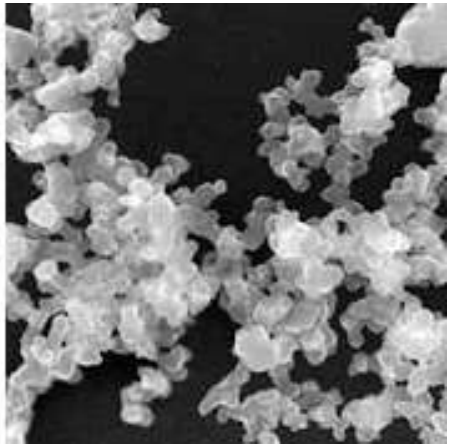
Eruption of Mount St. Helens

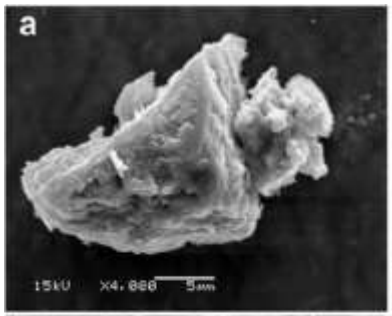
Aerosols

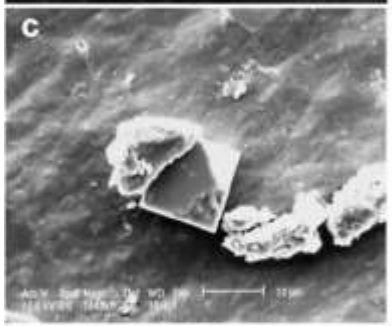


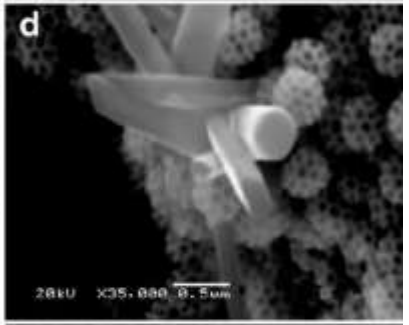


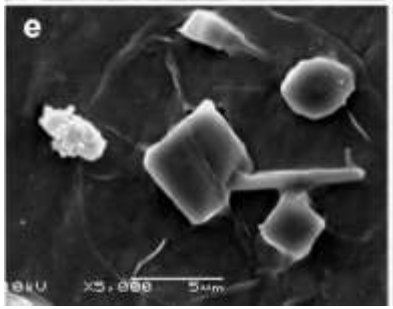


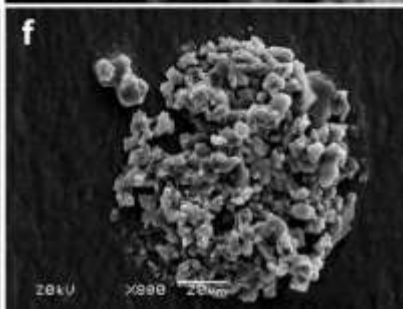










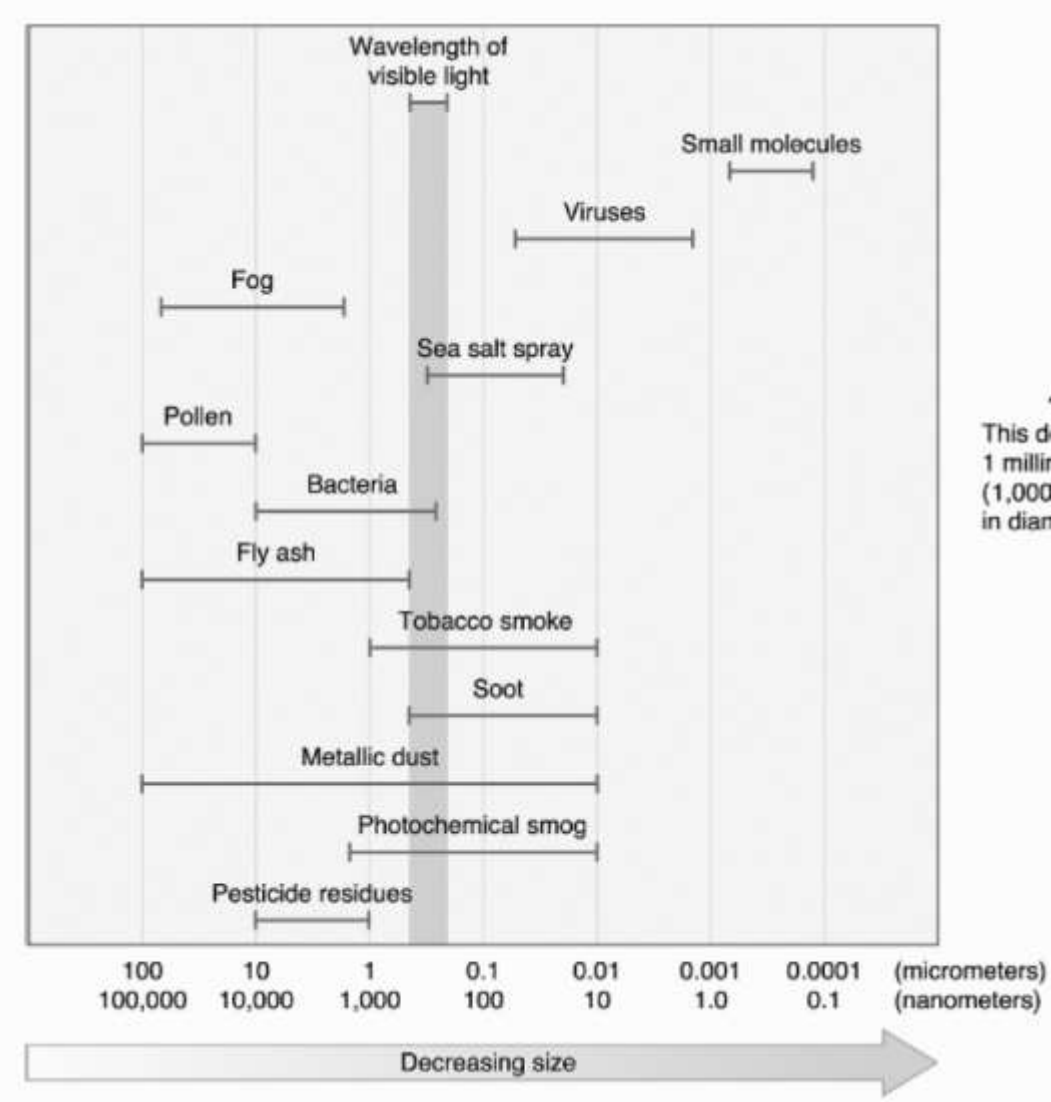


Aerosols - pollution

Large particles >10 μm: settle within 1 to 2 days.

Medium-sized particles, 1 to 10 μm: several days.

Fine particles <1 μm may remain in the troposphere for several weeks and in the stratosphere for up to 5 years:
Most hazardous to human health



Aerosols - Pollution

Epidemiologic studies in the 1970s found a link between short-term increases in the PM10 of 10 $\mu g/m^3$ and an increase in hospitalization for respiratory disease and asthma.

PM2.5 = particles of diameter 2.5 μm or smaller.

The current WHO federal standard is for annual average standard of 12.0 $\mu g/m^3$ and a 24-hour average standard of 35 $\mu g/m^3$.

Atmospheric Pollution

Chengdu Air Quality Index (AQI)

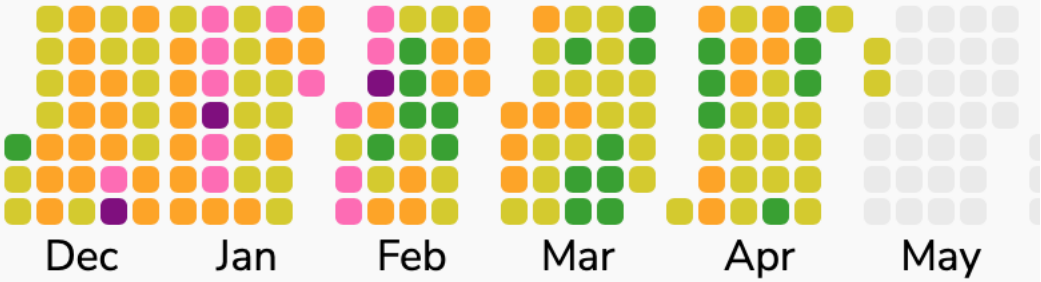
Real-time PM2.5, PM10 air pollution level Sichuan

Last Update: 18 Apr 2023, 11:05pm

MODERATE

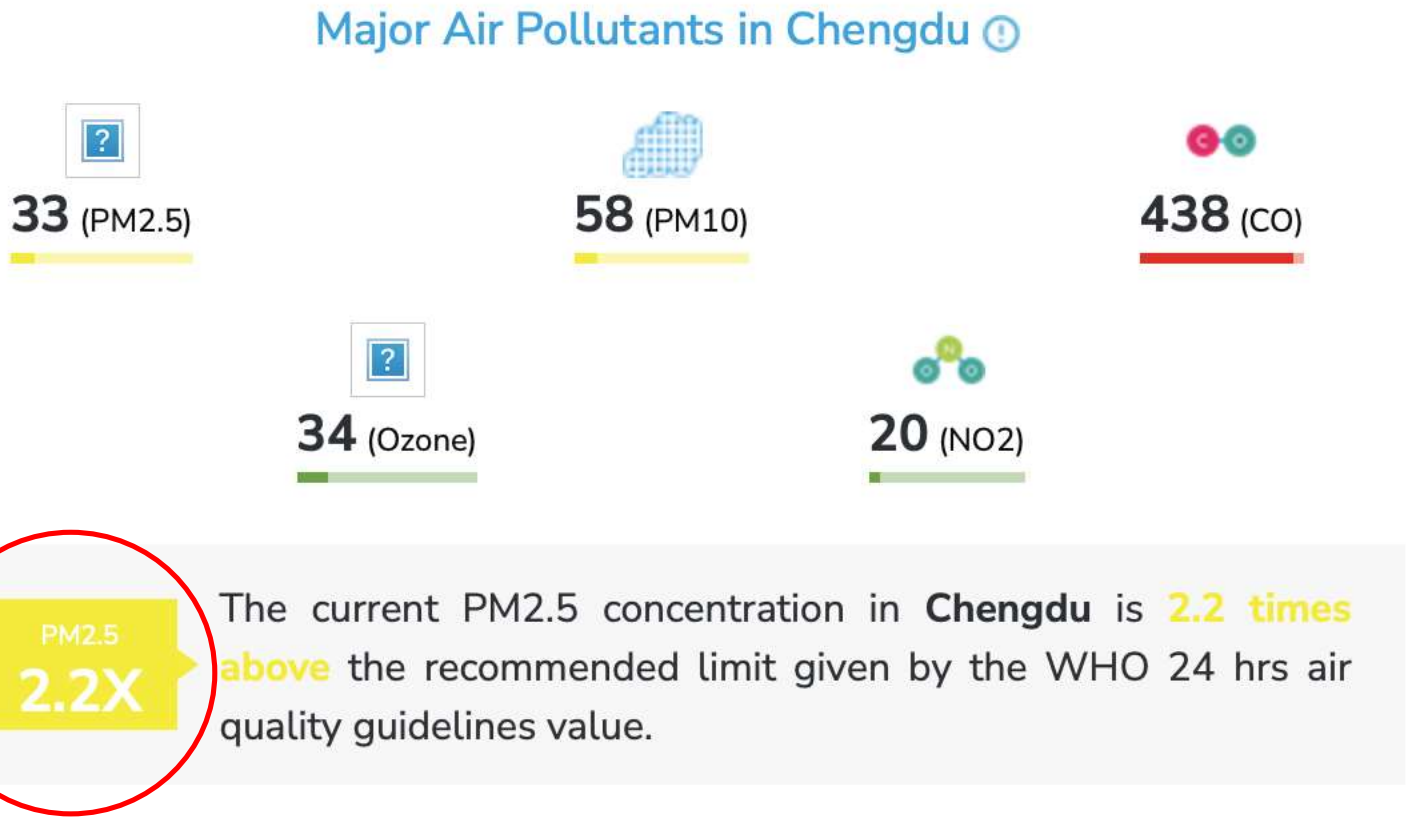
98

(AQI-US)

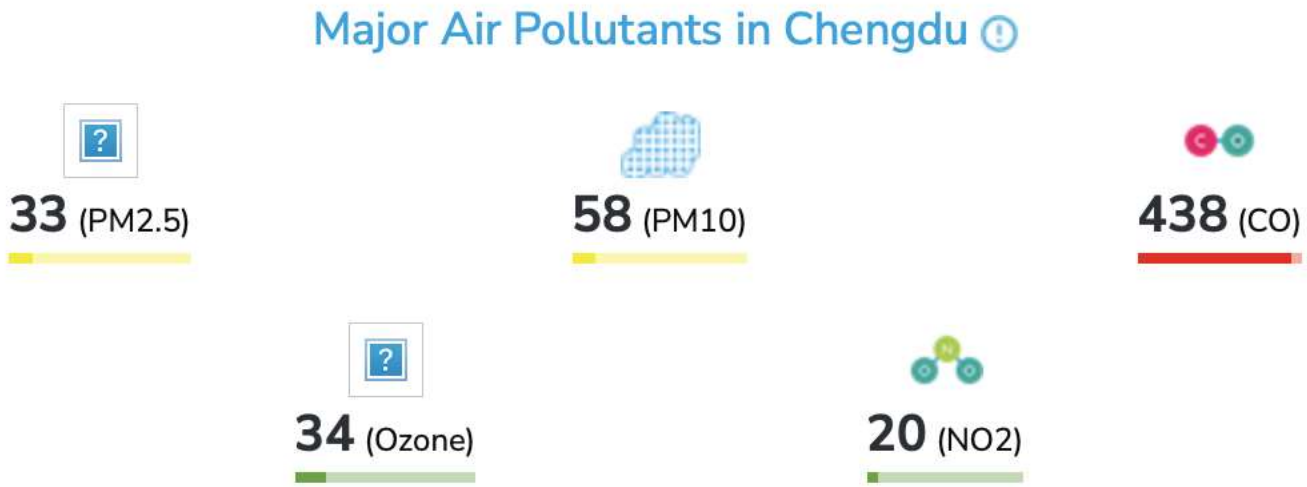


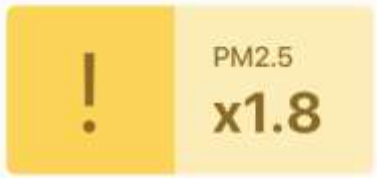
0-50	51-100	101-200	201-300	301-400	401-500
Good	Moderate	Poor	Unhealthy	Severe	Hazardous

Atmospheric Pollution



Atmospheric Pollution





PM2.5 concentration in Milano is currently 1.8 times the WHO annual air quality guideline value

Atmospheric Pollution

Influenced by meteorological conditions

Temperature:

- ✓Influences the diffusion of pollutants

Wind:

- ✓The direction & speed of wind for movement of air pollutants

Humidity

- ✓Influences the precipitation of pollutants on earth
- ✓Many toxic pollutants combine with water vapor to precipitate

Atmospheric pressure

- ✓Influenced the movement of pollutants in an area

Aerosols – good effects

Why are particles in the air important?

1. Act as condensation and freezing nuclei:

   Water condense or freeze onto particles

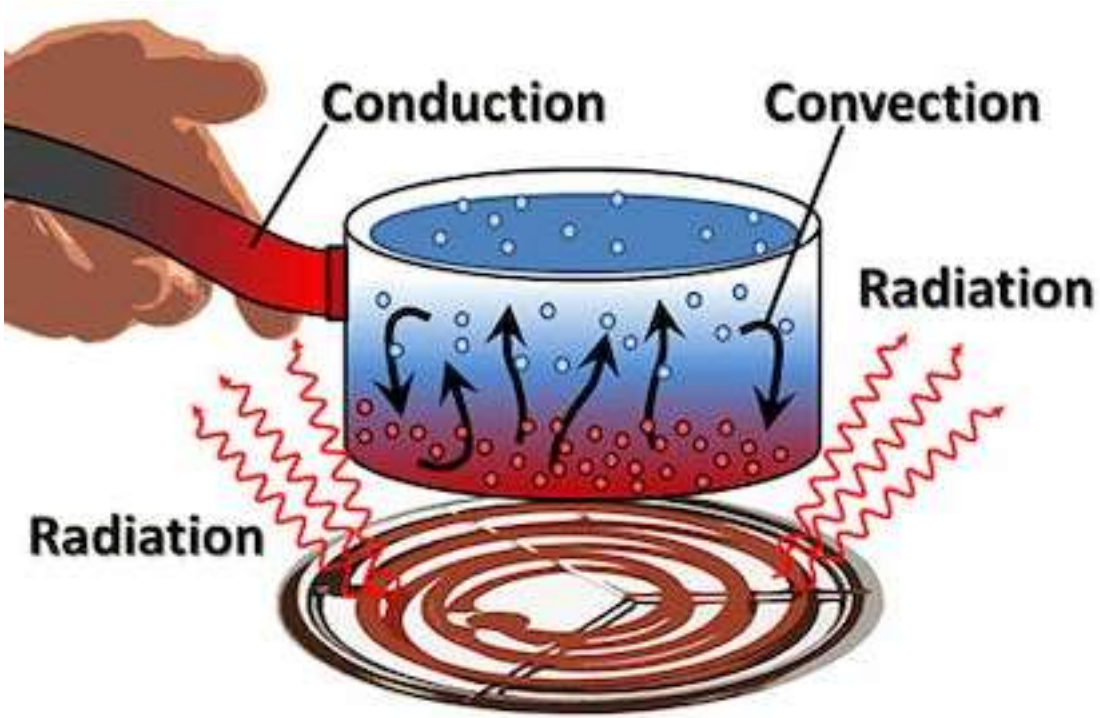
2. Can absorb or scatter radiation:

   Reduce visibility

   Can scatter solar radiation to space: cool the planet

Transfer of heat

1. Radiation
2. Conduction
3. Convection



Radiation

The transfer of heat energy by electromagnetic radiation. Earth is heated by this process.

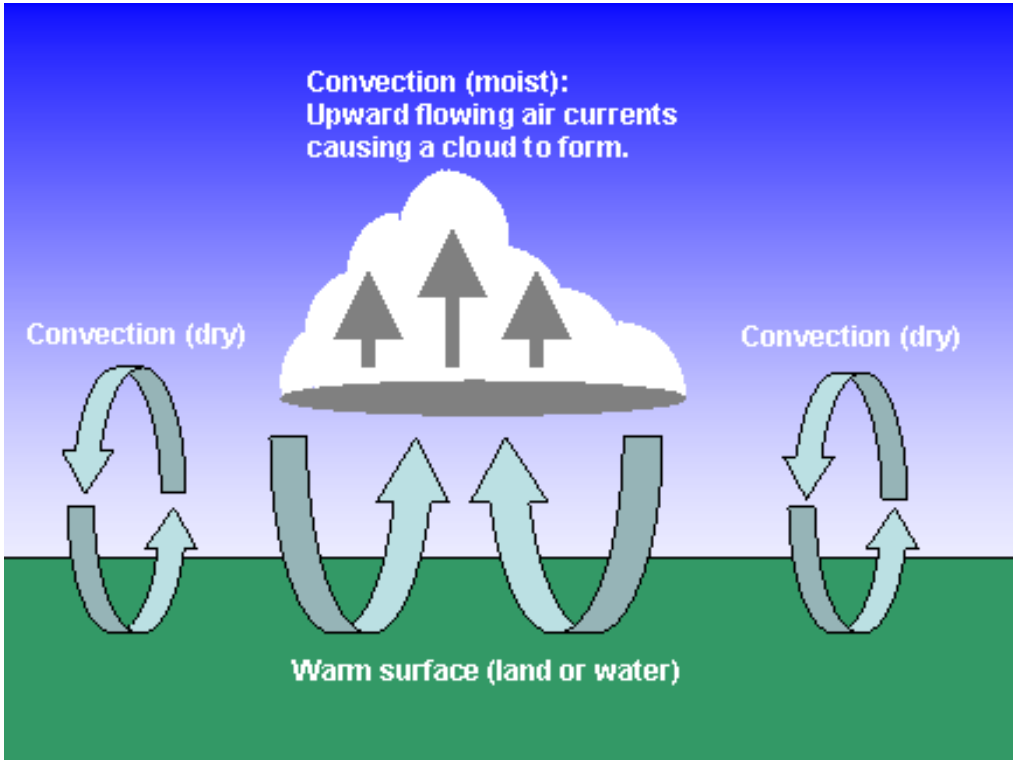
Various substances (dirt, rocks, water, concrete, sand, etc.) absorb this energy and they transmit through convection to the surrounding atmosphere, and to us.

Radiation

Convection

Convection

- The transfer of heat energy in a fluid.
- Commonly seen in the kitchen when you see boiling water
- Air in the atmosphere acts a fluid → wind formation



Earth's Energy balance

Two processes are in place to maintain the average Earth's temperature at 15 °C:

- Reflection of incoming light from the sun (is not adsorbed)

- Dissipation of energy (after absorption)

Earth's Energy balance

Reflection of incoming light

Only 69% of solar radiation is absorbed by earth:

- 23% is absorbed by water droplets in clouds and ozone
- **46% by the gound**

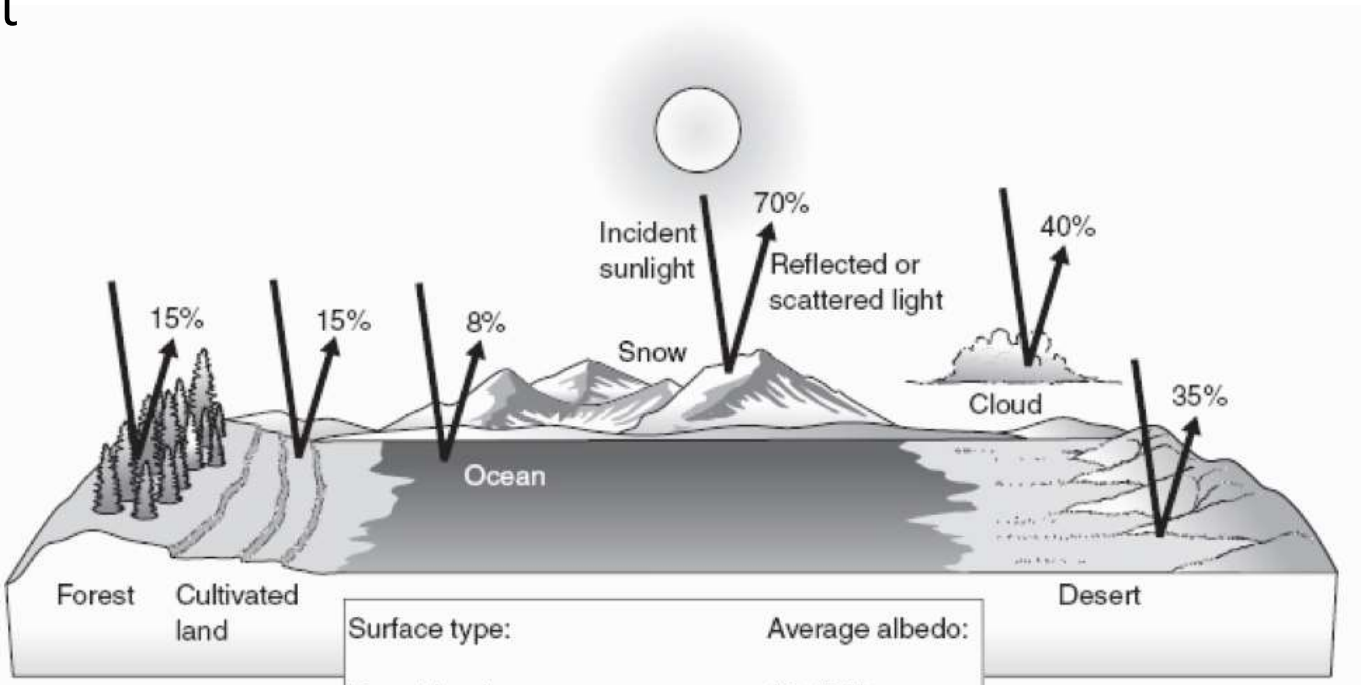
All the rest is reflected back to space: this is called ALBEDO.

- Clouds, dust, smoke, and volcanic ash, affect the albedo

The dust ejected by the eruption of Mount Pinatubo (1991) increased albedo and caused a slight drop in global average temperature.

Albedo

Scheme on how each part affect the Albedo – reflection of light



Surface type:	Average albedo:
Forest land	10–20%
Agricultural land	10–20%
Deserts	25–40%
Snow cover (above 60° latitude)	60–80%
Oceans (70° latitude and above)	15–20%
Oceans (below 70° latitude)	6–10%
Clouds (average over all types)	35–40%
Overall average	**31%**

Earth's Energy balance

Release after absorption:

31% is absorbed at the Earth's surface and is used as an energy source for life

Dark colored objects (asphalt) absorb more and release heat faster.

The sun strongest wavelength is 510nm = green. The Earth loses energy in the infrared at 10 μm (thermal energy)

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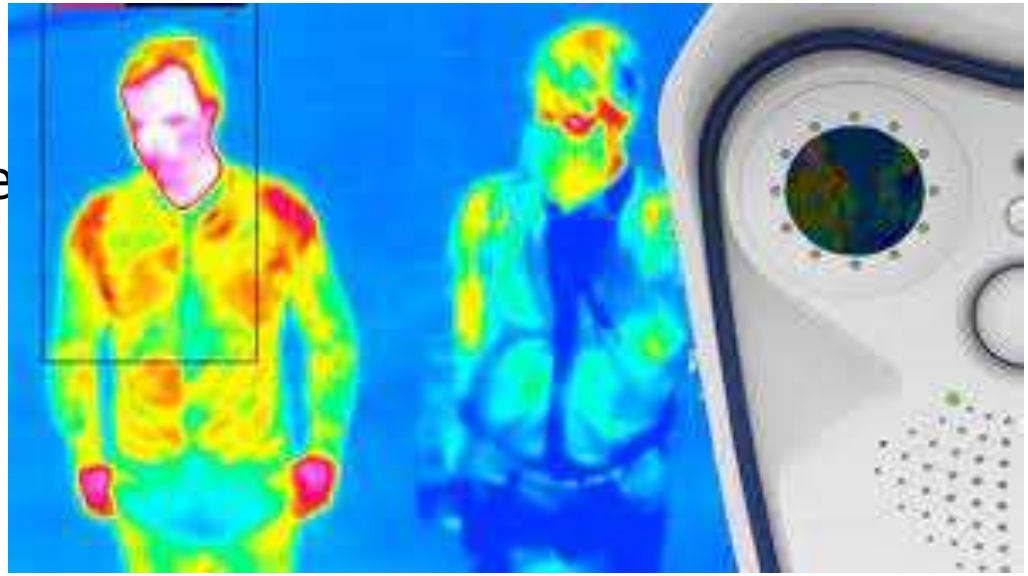
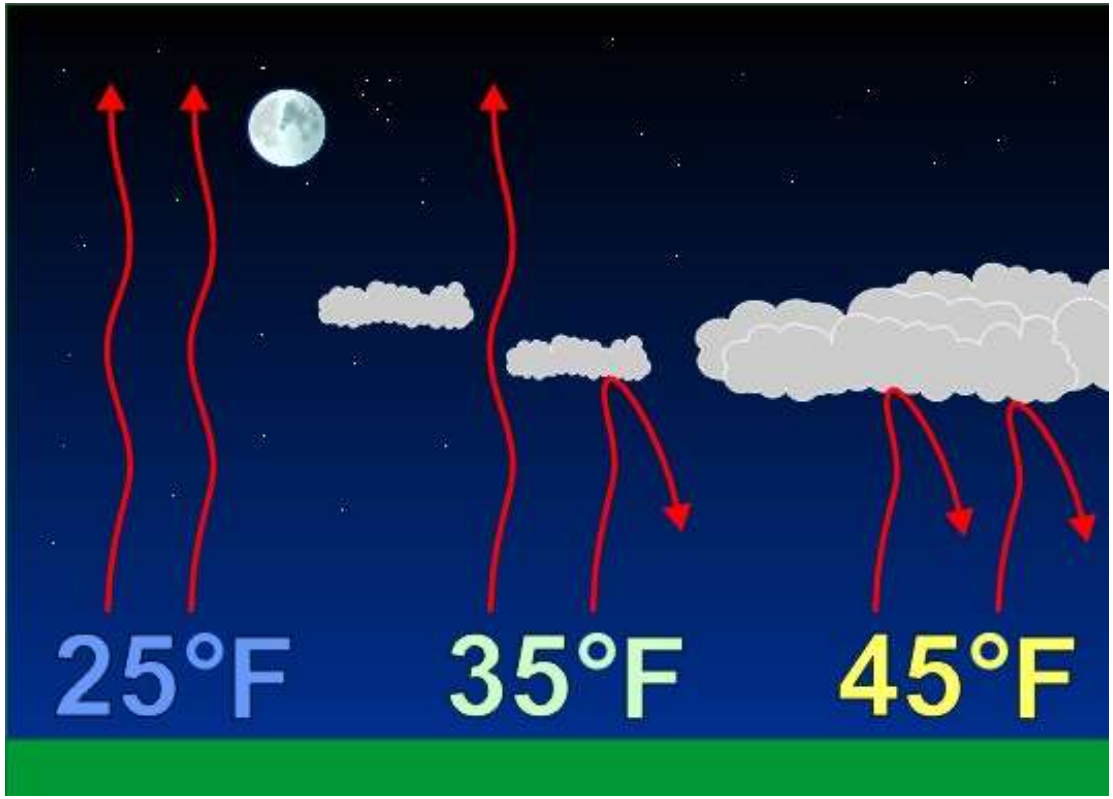


Earth's Energy balance

The heat that the Earth is releasing it is trapped by:

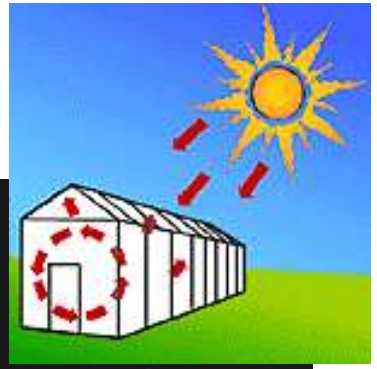
1) Aerosols and clouds → more controlled temperature variation during day and night

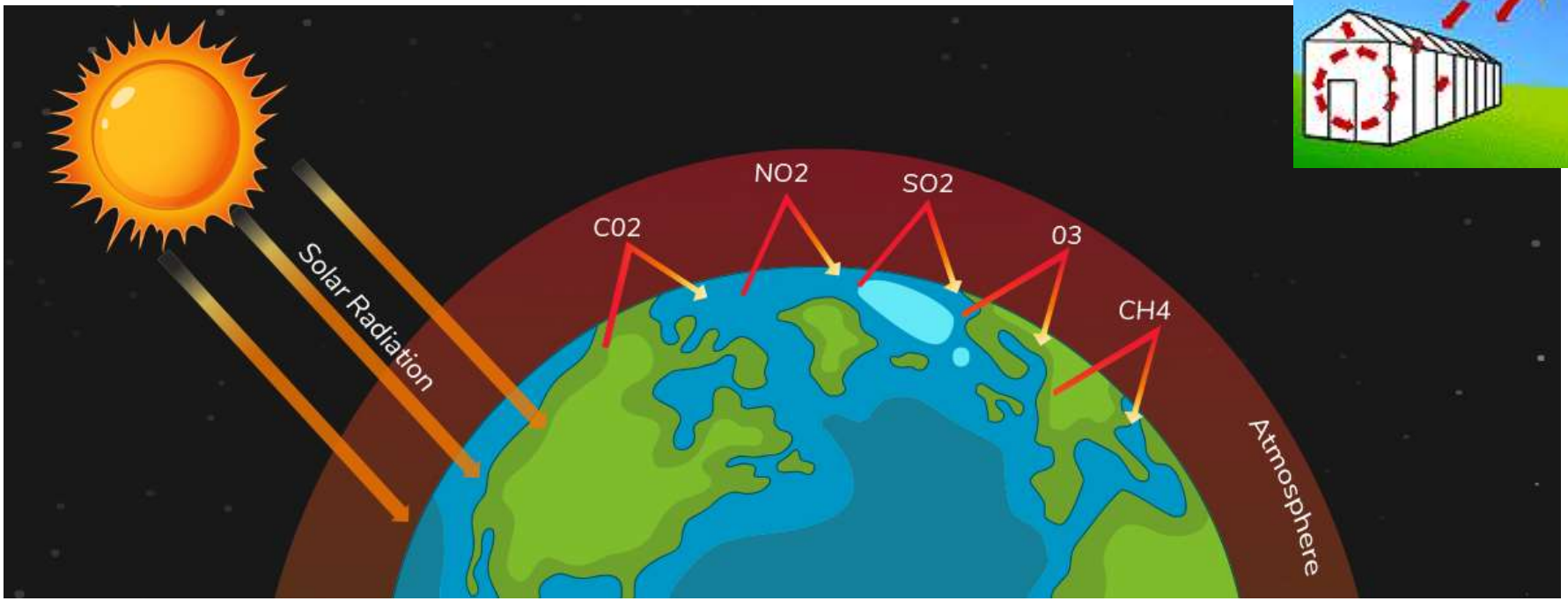


Earth's Energy balance

2) By variable gases in the atmosphere:

Greenhouse Effect = Earth's temperature increases





Greenhouse Effect

It is a natural process, essential for life on Earth.
Without, the surface would have a mean temperature of –19°C.

However, because of the increase of variable gases in the atmosphere due to human pollution

too much Greenhouse Effect

Global Warming

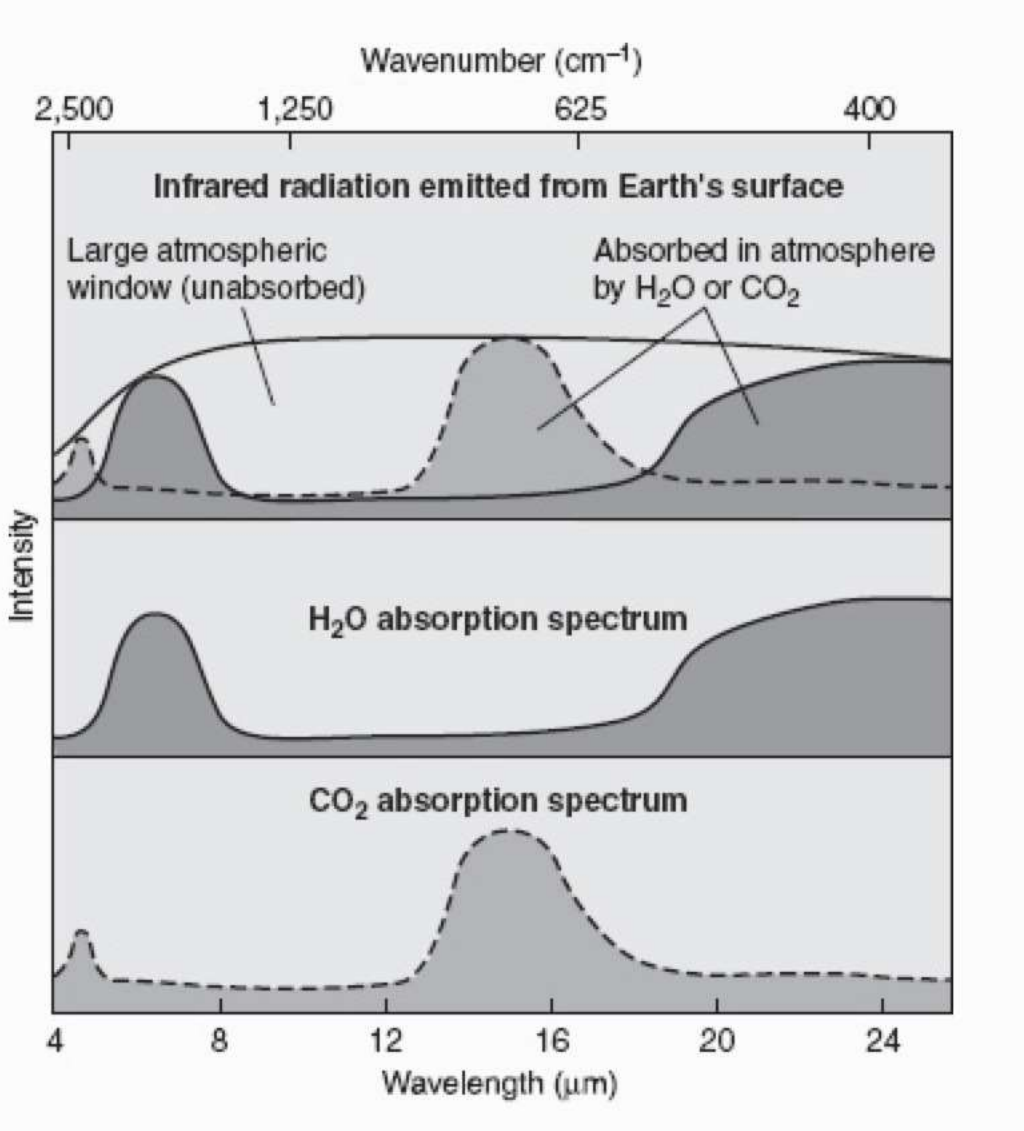
Global Warming

Human activities produce four principal greenhouse gases: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and halocarbons.

Concentration is not everything!

Methane, for example, is approximately 25 times more effective than carbon dioxide at trapping heat (IR radiation).

Global Warming



Atmosphere's window:

CO_2 absorbs IR radiation (heat) where water cannot

Now we have more CO_2 in the atmosphere, more absorption

Higher temperature at the surface

Effects of Global Warming

1) ice in polar caps will begin to melt → water is darker than ice, absorbs more heat

2) water in the ocean expands flooding in lowlands and coastal areas

3) Overall changes in weather patterns

Global Warming

It is difficult to STOP:

the melting of some permafrost, which will release the trapped methane.

The application of synthetic nitrogen fertilizers increases the concentration of nitrate in the soil → atmosphere

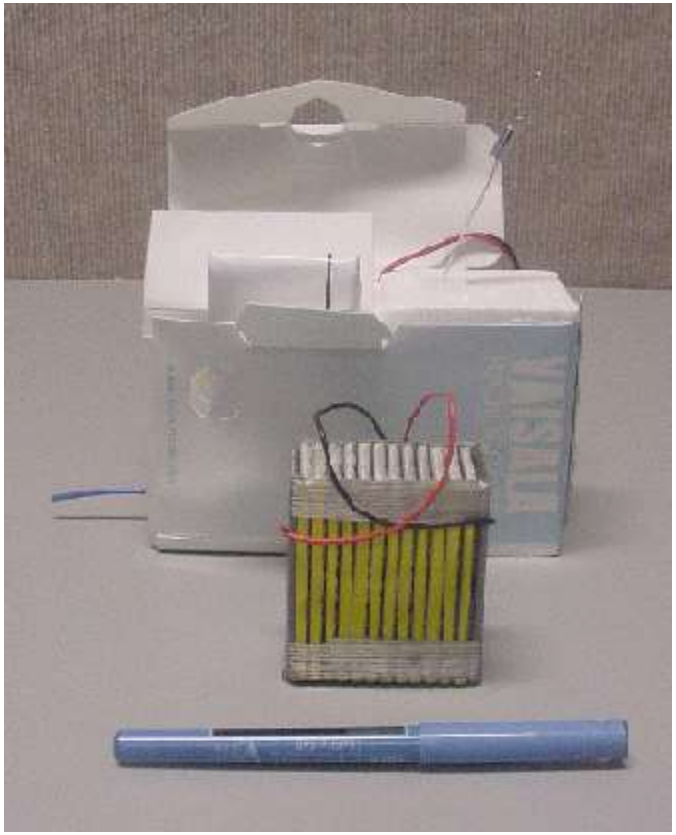
First phase (1910 to 1940): the global mean temperature rose 0.35°C;
Second phase (1970 to present), the global mean temperature rose 0.55°C.

Everyone should start to do his part, now !

ATMOSPHERE DATA COLLECTION

Upper Air - Radiosondes

Radiosondes are released everyday from weather stations up for 35 km in the atmosphere, sending back weather information along the way.



Weather Baloon

The instruments pictured measure temperature, relative humidity, pressure, and wind speed/direction

Air Sampling

1. Filtration

- Air is filtered through the membrane
- The membrane is then placed on a paper saturated with an appropriate medium & incubated

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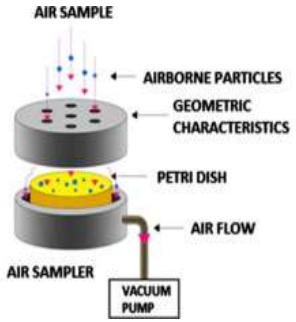
2. Impaction

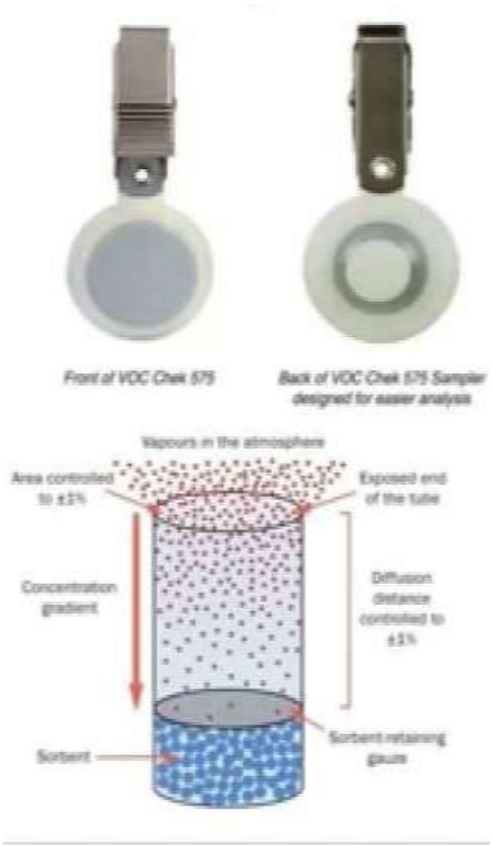
- ✓Collecting the atmospheric particles on the surface of a solid/semi-solid agar medium
- ✓The air is sucked through a slit onto a rotating culture plate kept underneath the device
- ✓**Air centrifuge** is used
- ✓Suitable for large sized particles



Air Sampling

3. Impingement

- **To collect atmospheric particles in a liquid medium**
- **The air is sucked through** a glass instrument



Air Sampling

3. Impingement

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- **The air is sucked through** a glass instrument

4. Sieve (cascade) samplers

- It is desired to collect samples of air on the basis of the particle size of the pollutant :
- Larger particles are collected on top
- Smaller ones towards the bottom sieves