The Earth's Atmosphere

Dr. Sandip Mondal

Earth's atmosphere is a layer of gases surrounding the planet. The Earth is surrounded by a blanket of air, which we call the atmosphere. It reaches over 900 kilometers from the surface of the Earth.

Atmosphere

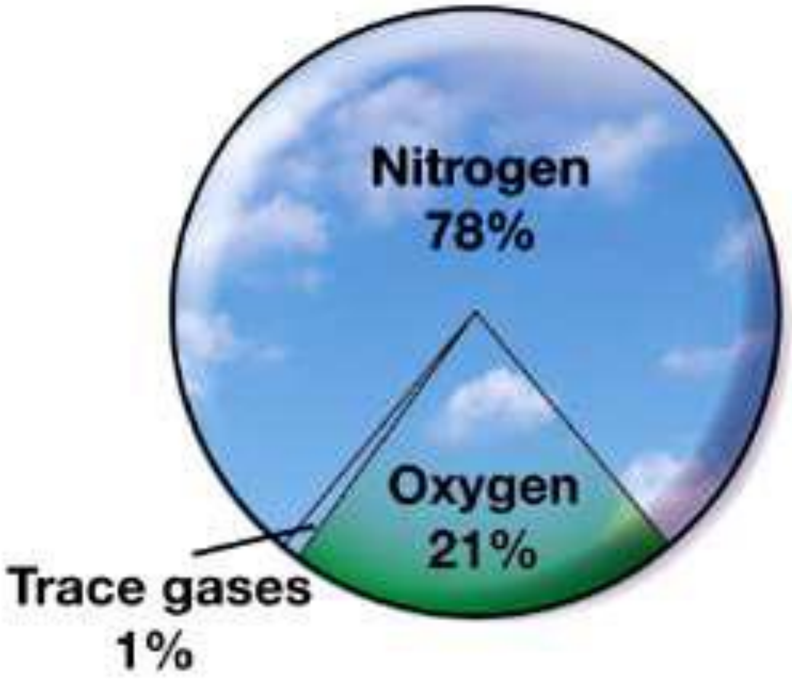
- Absorbs the energy from the Sun,
- Recycles water and other chemicals,
- Protects us from high-energy radiation and the frigid vacuum of space.
- The atmosphere protects and supports life.

The atmosphere is really very shallow compared to the size of the planet

- Just a thin veneer
- ¾ of the atmosphere by mass is in the lowest 33,000 ft, roughly 10 km
- Total mass of atmosphere is 5.3×10^{21} gms.
- Of this total mass 99.9% lies below 80km level

Composition of the Atmosphere

- Earth's atmosphere is made of a mixture of gases called air.
- **Nitrogen** gas makes up about 78% of Earth's atmosphere.
- The second most abundant gas is **oxygen**, which makes up 21% of Earth's atmosphere.
- The third **Argon** (Ar, 0.9%).
- **Carbon Dioxide** (CO_2, 0.03%).



The amount of **water vapour** varies from 1% (desert and polar regions) to 4%(warm and wet tropics) by volume of the atmosphere depending upon geographic location of an area and climatic condition.

Gas	Symbol	Content
Nitrogen	N_2	78.084%
Oxygen	O_2	20.947%
Argon	Ar	0.934%
Carbon Dioxide	CO_2	0.033%
Neon	Ne	18.20 parts per million
Helium	He	5.20 parts per million
Krypton	Kr	1.10 parts per million
Sulfur dioxide	SO_2	1.00 parts per million
Methane	CH_4	2.00 parts per million
Hydrogen	H_2	0.50 parts per million
Nitrous Oxide	N_2O	0.50 parts per million
Xenon	Xe	0.09 parts per million
Ozone	O_3	0.07 parts per million
Nitrogen dioxide	NO_2	0.02 parts per million
Iodine	I_2	0.01 parts per million
Carbon monoxide	CO	trace
Ammonia	NH_3	trace

99.998% (Nitrogen, Oxygen, Argon, Carbon Dioxide)

Major Constituents (99%):

- Nitrogen (N): 78%
- Oxygen (O2): 21%
- **Trace Constituents:**
- Argon (Ar), about 0.9%
- Water vapor (H2O), up to 10000 ppmv
- Carbon dioxide (CO2), 350 ppmv
- Ozone (O3), near 5-500ppbv at the surface, up to 10 ppmv in the stratosphere
- Methane (CH4), 1.7 ppmv
- and others....

ppmv = "parts per million by volume"

Non-Gas Constituents

- Hydrometeors -rain clouds, hail
- Particulates and aerosols
  - Aerosol is a liquid or solid dispersed in a gas, usually air
- Particulates can be
  - Inorganic- soil, smoke and soot from fire, dirt, sea salt, ash and dust from volcanic eruption, aerosol
  - Organic- seeds, spores, pollen, bacteria

Why are particles in the air important?

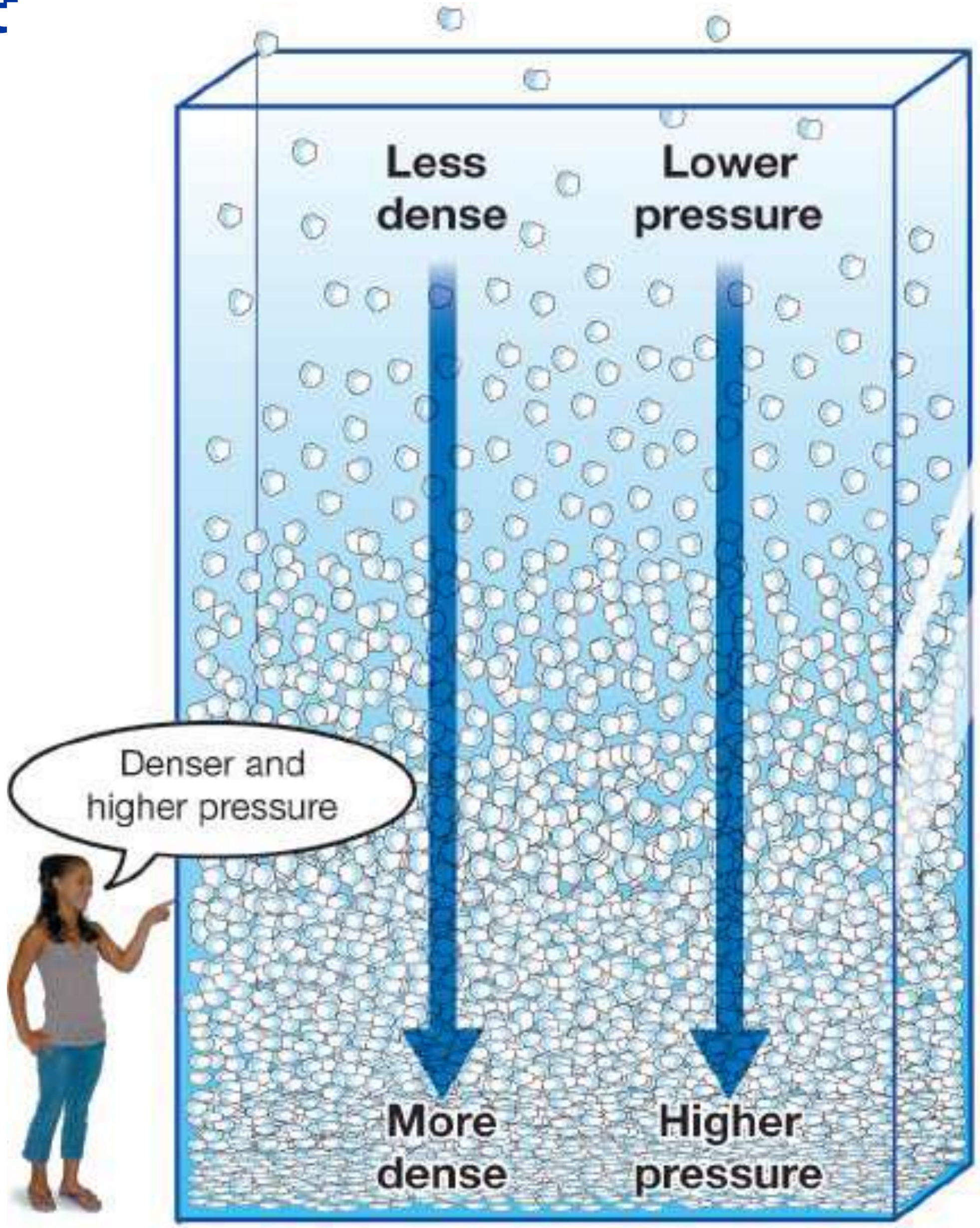
- Act as condensation and freezing nuclei!
  – Water likes to condense on or freeze on to particles
- Can absorb or scatter radiation
    - Reduce visibility
    - Can scatter solar radiation to space: cool planet
- Can impact human health.
  – Can irritate lungs, initiate asthma, heart disease

- Based on the composition, the atmosphere is often divided into two layers:
- **Homsophere:** The zone of homogeneous composition extends upto 80km above the surface.
- **Hetersphere:** The atmosphere beyond 80km height is not uniform, rather has a heterogeneous composition.

This layer consist of four spherical layers. The lowest layer is dominated by **molecular nitrogen**, next a layer of **atomic oxygen**, the third one dominated by **Helium atoms** and finally a layer of **Hydrogen atoms**.

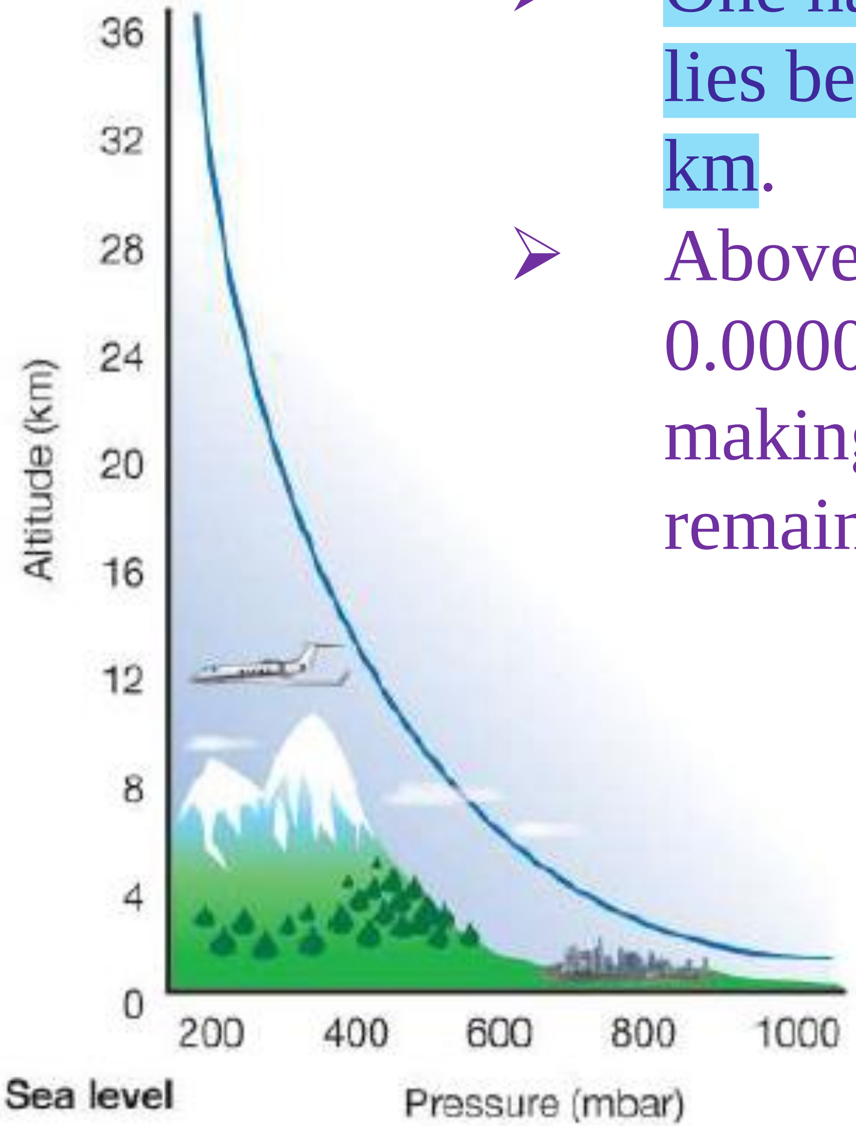
Pressure in the atmosphere

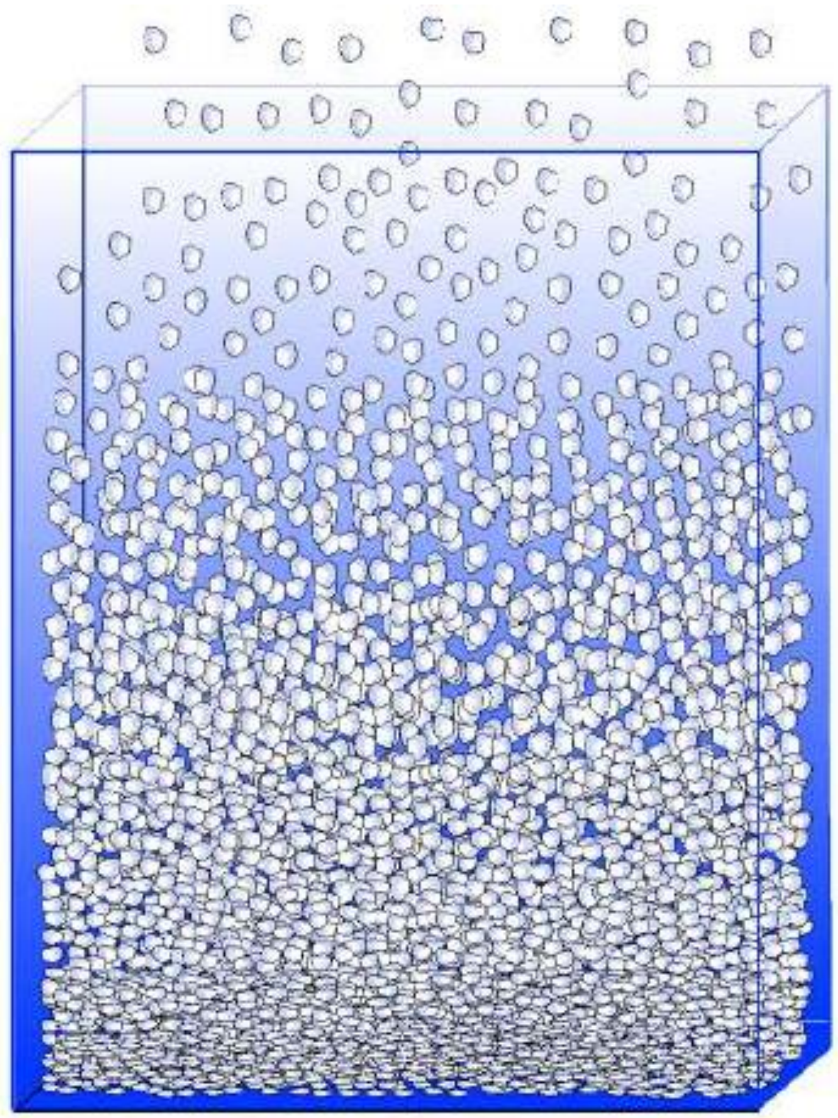
- **Atmospheric pressure** is the force per unit area exerted into a surface by the weight of air above that surface in the atmosphere of Earth.
- The gas molecules closest to Earth's surface are packed together very closely.
- This means pressure is lower the higher up you go into the atmosphere.

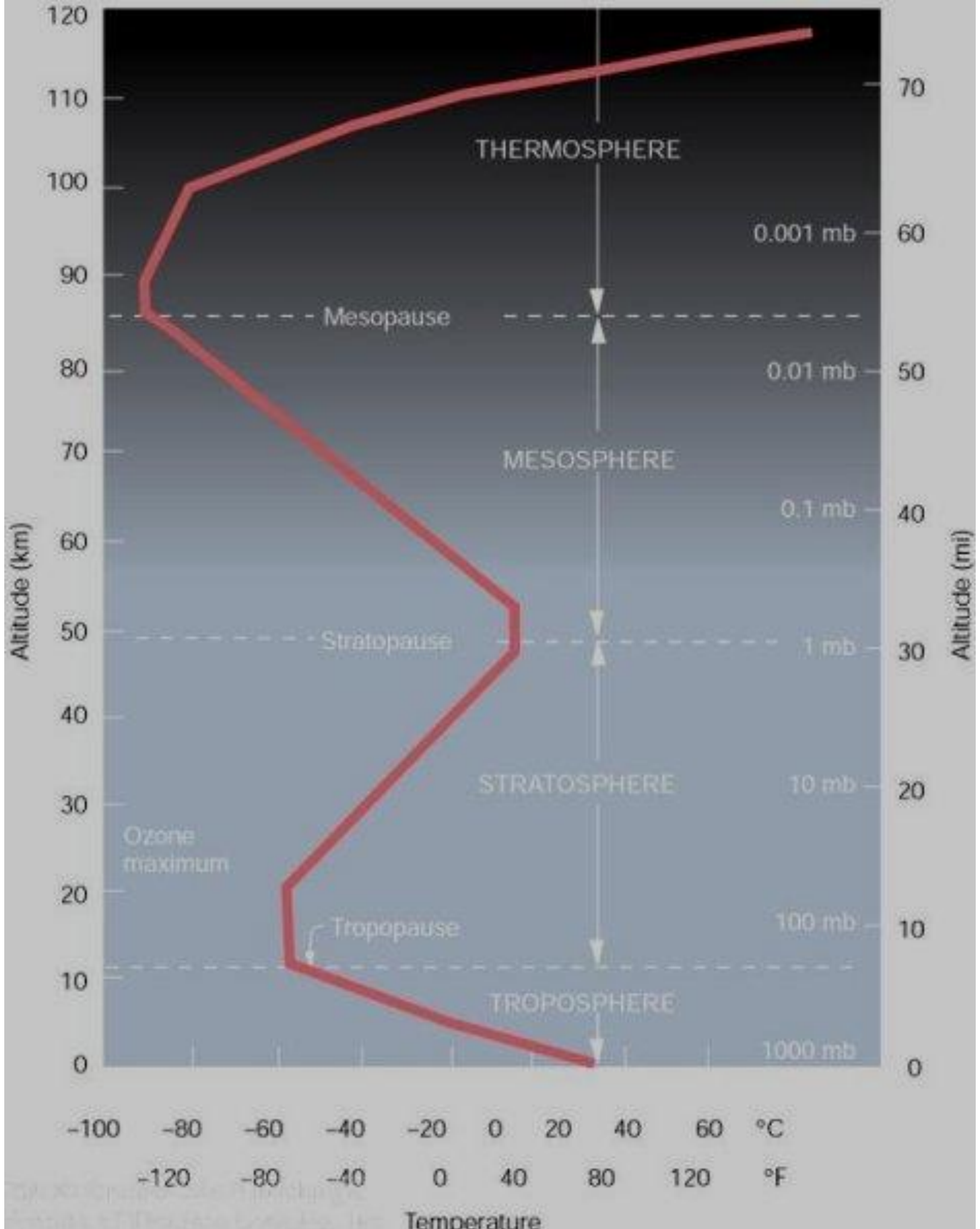


Pressure changes with altitude

- One half of the atmosphere lies below an altitude of 5.6 km.
- Above 100 km, only 0.00003% of all the gases making up the atmosphere remains.





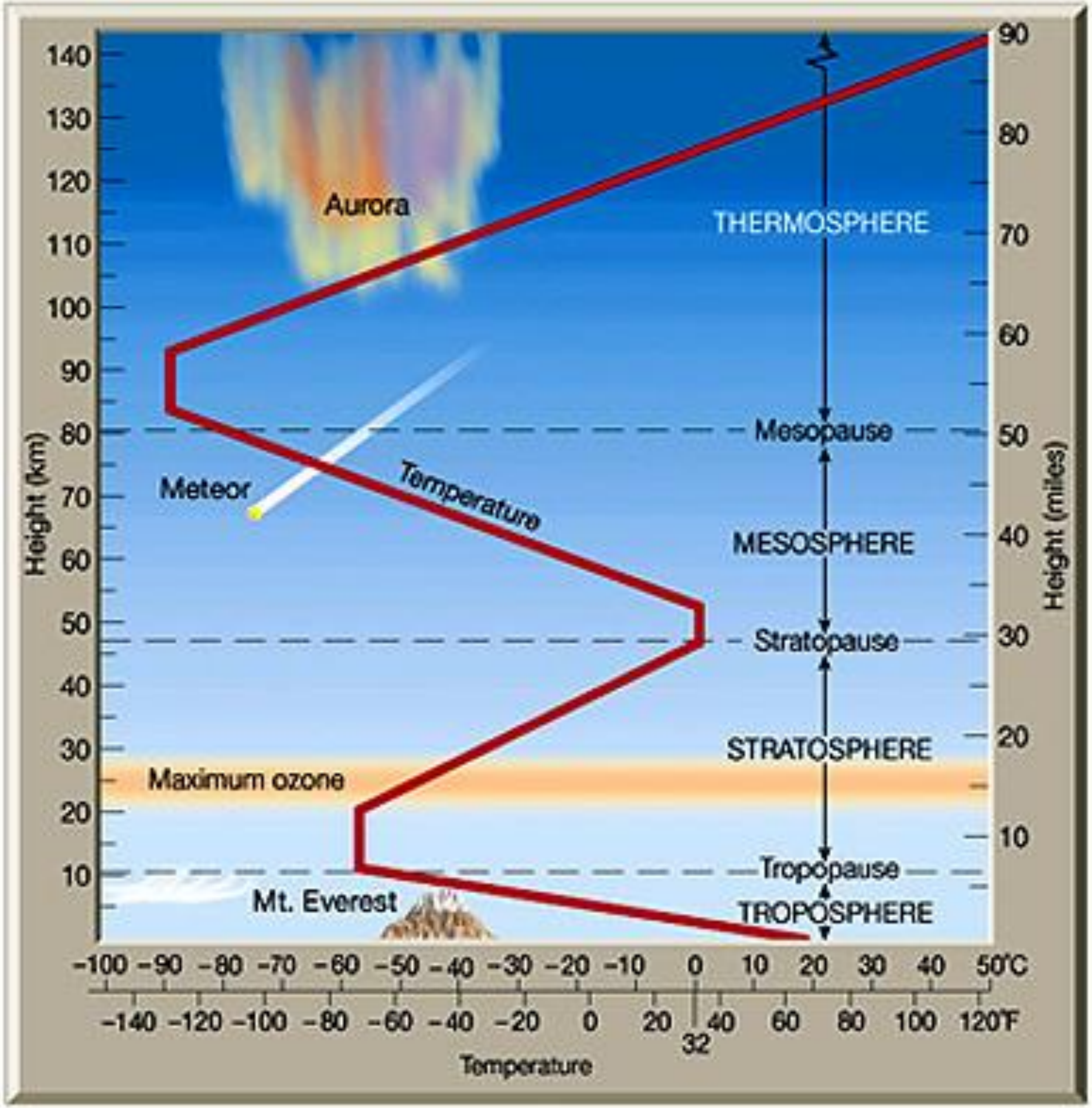


Layers of Atmosphere

The atmosphere has four layers

Exosphere

- Thermosphere
- Mesosphere
- Stratosphere
- Troposphere



Aurora
THERMOSPHERE
Mesopause
Meteor
Temperature
MESOSPHERE
Stratopause
STRATOSPHERE
Maximum ozone
Tropopause
Mt. Everest
TROPOSPHERE
Height (km)
Height (miles)
140
130
120
110
100
90
80
70
60
50
40
30
20
10
90
80
70
60
50
40
30
20
10
-100 -90 -80 -70 -60 -50 -40 -30 -20 -10 0 10 20 30 40 50°C
-140 -120 -100 -80 -60 -40 -20 0 20 40 60 80 100 120°F
32
Temperature

Troposphere

- Lowest and thinnest layer
- 16 km at equator, 8 km at poles; average 12 km
- 90% of the atmosphere's mass
- Temperature decreases with altitude at 6.5°C/km (**Environmental Lapse Rate**)
- This layer is characterized by strong vertical mixing, overturning, turbulence and weather phenomena.
- Almost all clouds and certainly all precipitation, violent storms are developed in this layer, so the troposphere is often called as **weather sphere**.

View of troposphere layer from an airplane's window.

Boundary between the troposphere, and the stratosphere is called the **Tropopause**

Stratosphere

- 12-50 km above the surface
- Temperature **increases** with altitude
- Almost no weather occurrence
- Stable (not a lot of vertical mixing) and dry
- Only occasionally get overshooting tops from convection pushing into this layer
- Contains high level of ozone

Ozone Layer: 20 to 40 km

- Upper boundary is called **Stratopause.**

Mesosphere

- Extends to almost 80 km high
- Gases are less dense
- Temperature decreases as altitude increases.
- Gases in this layer absorb very little UV radiation.
- Upper boundary is called Mesopause

Thermosphere

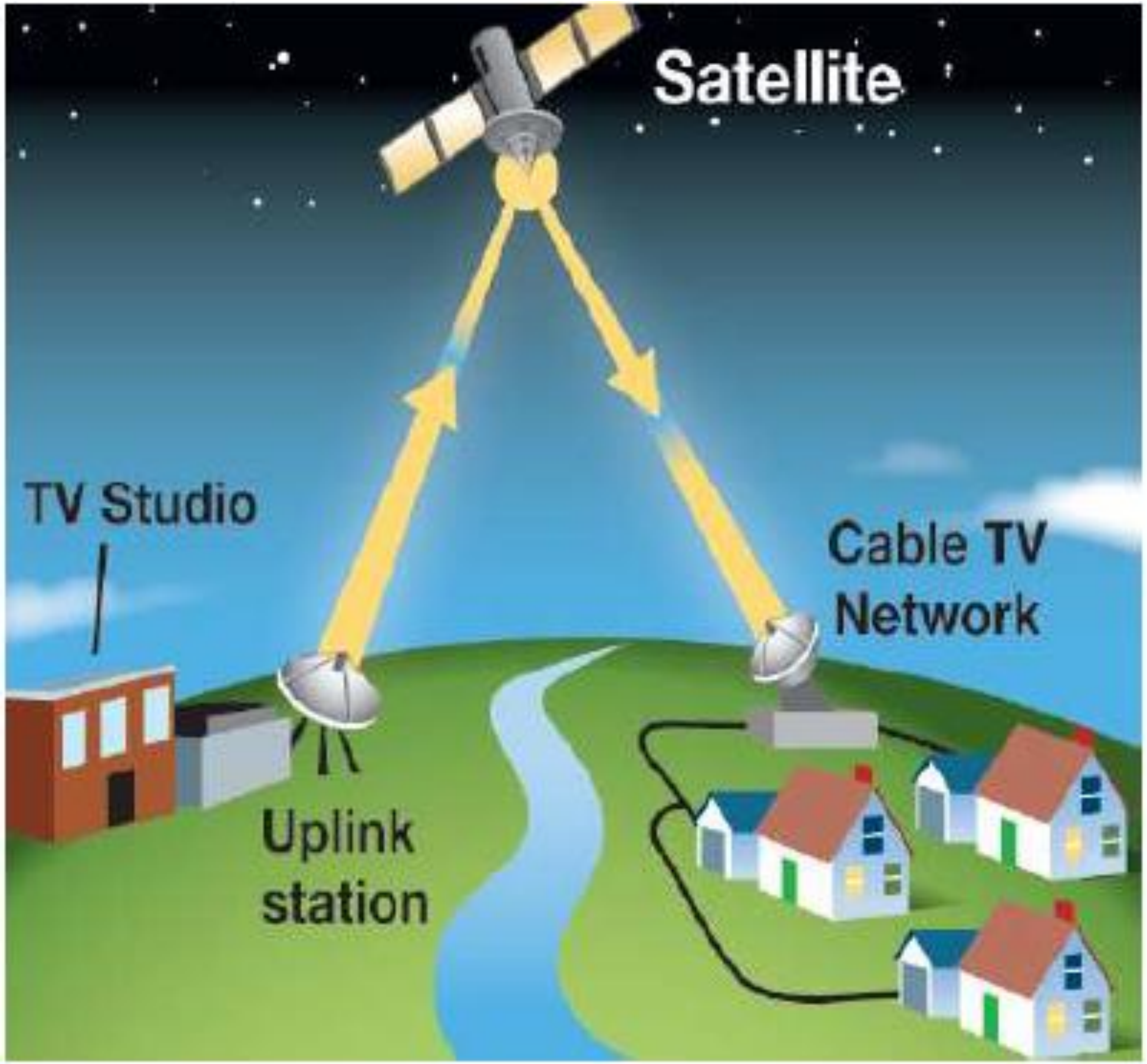
- Above the mesosphere and extends to almost 600 km high
- Temperature **increases** with altitude
- Readily absorbs solar radiation
- Temperature can go as high as 1,500°C
- Reflects radio waves

Ionosphere

- An electrically charged layer located in the altitude range between 60 to 600 km.
- Molecules of nitrogen and atoms of oxygen are readily ionized as they absorb high- energy, short wave solar energy (UV and X rays)
- The ionosphere can reflects radio waves.
- On the Basis of ion density, the ionosphere is subdivided into three layers
    - D (Dynamo) layer: 60-90 km
    - E (Heaviside-Kennelly layer): 90-150 km
    - F (Appleton layer): above 150 km
- The concentration of charged particles changes from day to night in the D and E layers. These layers weaken and disappear at night and reappear during the day
- The F layer is present both day and night

- Communication on Earth depends on satellites.

- Satellites transmit information used for television shows, radio broadcasts, data and photos used in weather reports, and long distance telephone calls.



Aurora

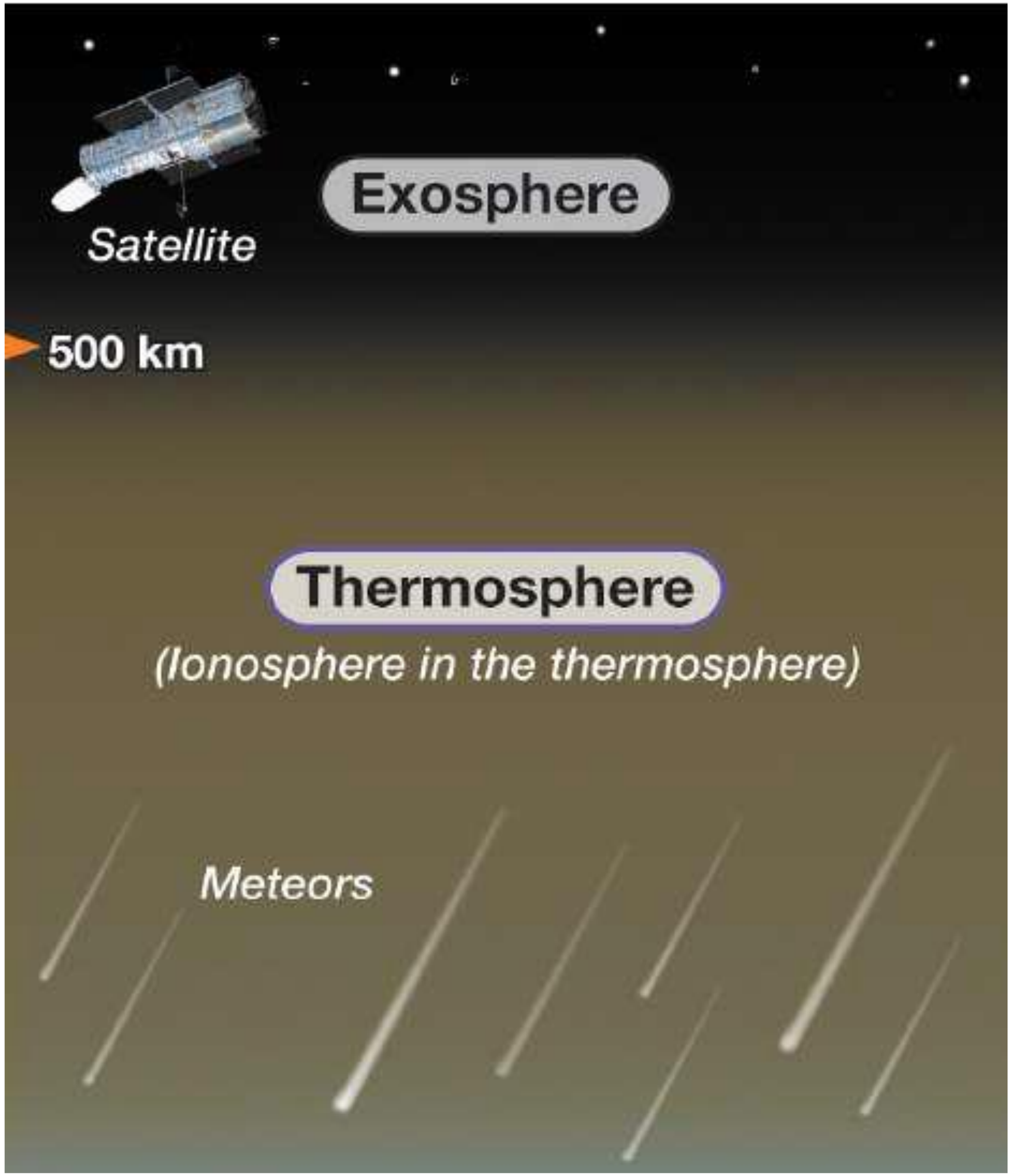
- One of nature’s most interesting spectacle take place in ***the ionosphere***

- The **Aurora borealis** in the northern hemisphere and the **aurora australis** in the southern hemisphere appear in a wide variety form.

- The occurrence of auroral displays is correlated in time with *solar-flare activity* and *geographic locations*, with the earth’s *magnetic poles*

Exosphere

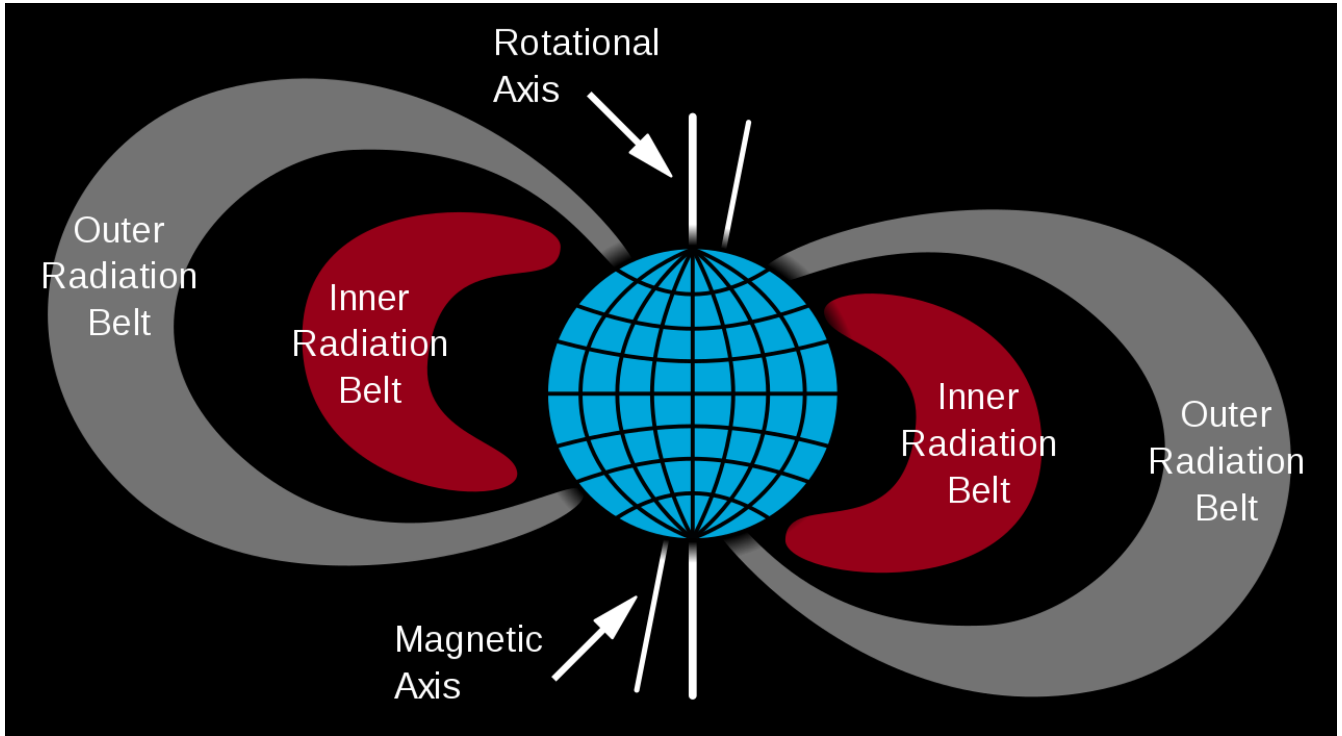
- This layer lies beyond the ionosphere.
- The exosphere begins at about 500 km above Earth and does not have a specific outer limit.
- Satellites orbit Earth in the exosphere.
- The air density such that an air molecule moving directly outward has a 50% chance of escaping rather that colliding with another molecule.



Magnetosphere

- A Van Allen radiation belt is a zone of energetic charged particles.
- It include two belt. The two belt consists of meson, photon, positron, energetic electrons, and alpha particles.
- The inner belt: 2400 to 5600 km

The outer belt , ranging from 13000 to 15000 km, trapping the solar wind, the magnetic field deflects those energetic particles and protects the atmosphere from destruction



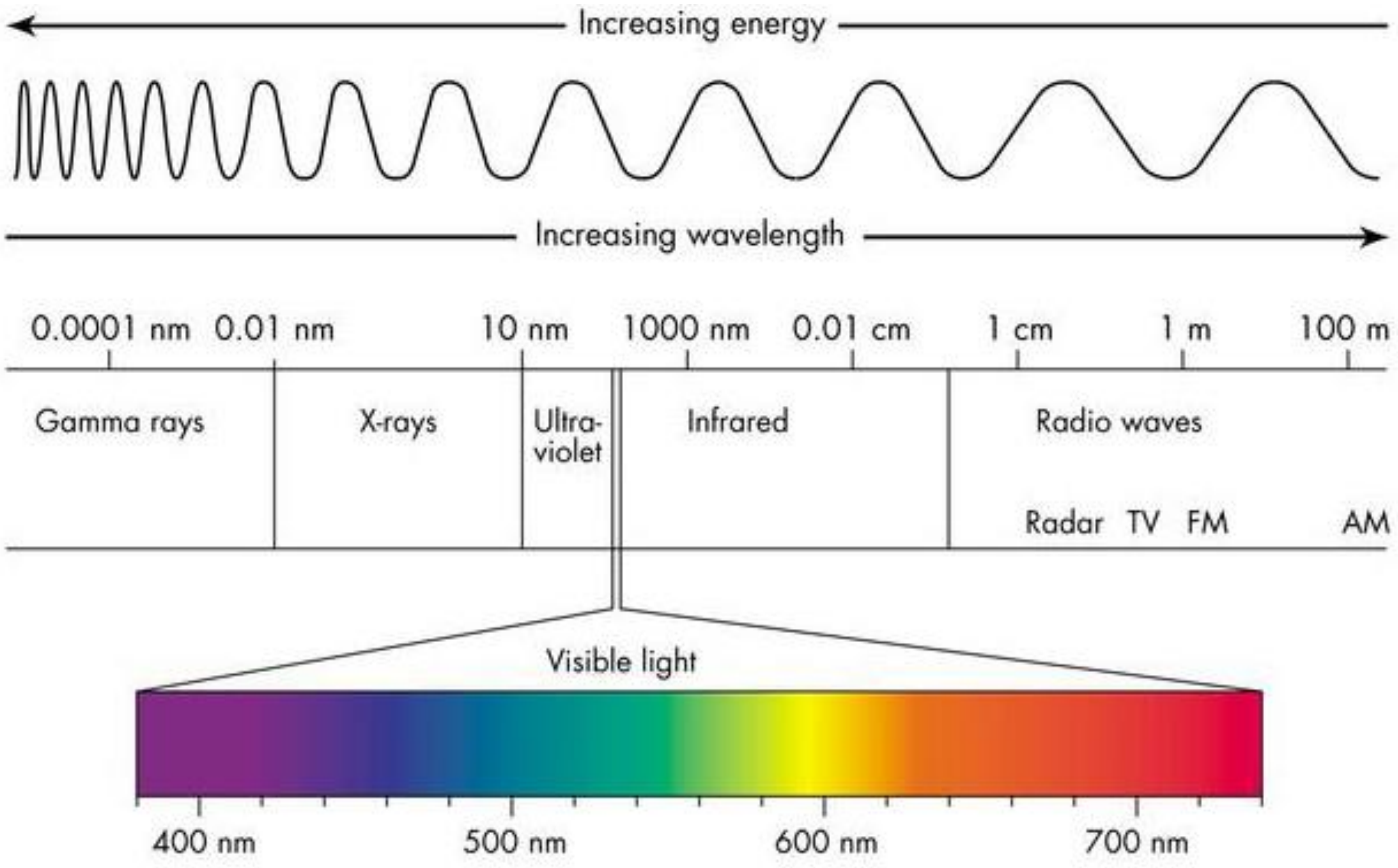
Insolation

The sun emits all of the forms of radiation but in varying composition.

- Visible light (0.4 to 0.7 µm): 43%
- IR radiation: 49%
- UV radiation: 7%
- X-Ray, γ ray and radio waves: less than 1 %
- λ_{max} (Sun) = 0.483 µm
- λ_{max} (Earth) = 9.66 µm

➢ Terrestrial radiation:

1 to 30 µm



Average distribution of insolation

Incoming radiation = 100%

✓Scattered to space by the atmosphere (back scatter) = 6%

✓Reflected from clouds = 20%

✓Reflected from earth’s land-sea surface = 4%

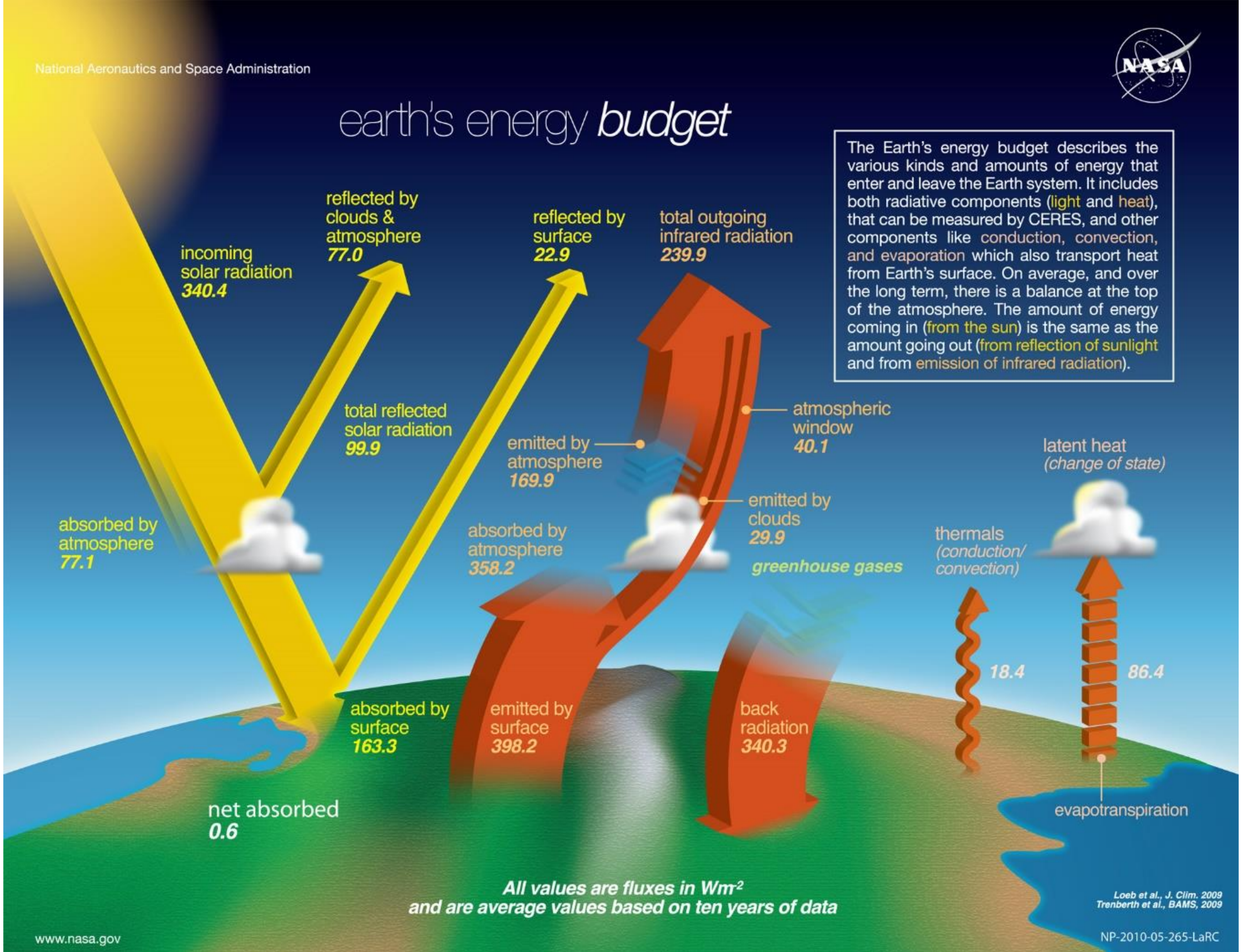
Total 30% loss to space by reflection and scattering

✓Radiation absorbed by the atmosphere and by clouds = 19%

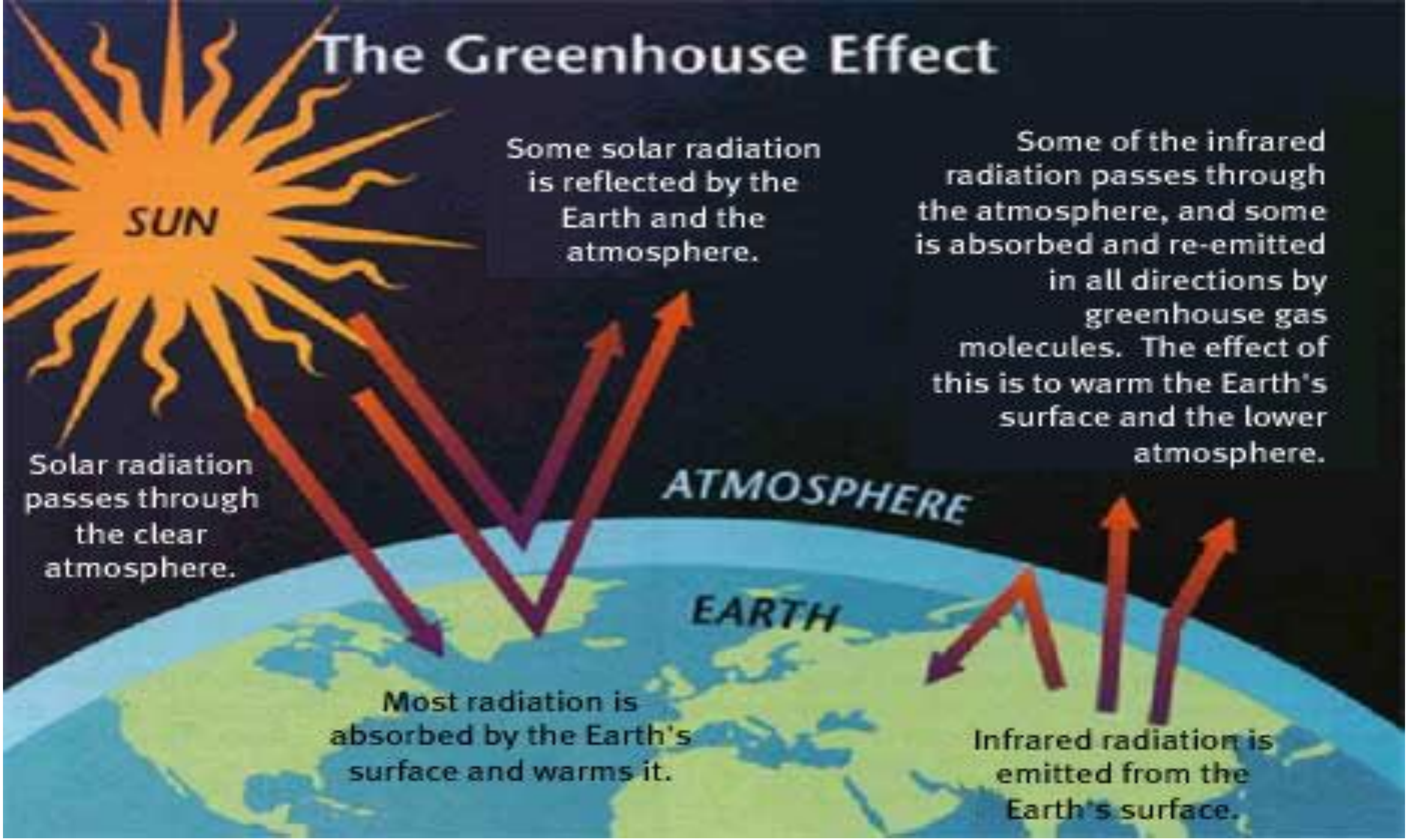
✓Direct solar radiation to earth = 25%

✓Diffused radiation to the surface (scattered) = 26%

Total 51% solar radiation absorbed at the surface.



National Aeronautics and Space Administration
NASA
earth's energy budget
The Earth's energy budget describes the various kinds and amounts of energy that enter and leave the Earth system. It includes both radiative components (light and heat), that can be measured by CERES, and other components like conduction, convection, and evaporation which also transport heat from Earth's surface. On average, and over the long term, there is a balance at the top of the atmosphere. The amount of energy coming in (from the sun) is the same as the amount going out (from reflection of sunlight and from emission of infrared radiation).
incoming solar radiation 340.4
reflected by clouds & atmosphere 77.0
reflected by surface 22.9
total outgoing infrared radiation 239.9
total reflected solar radiation 99.9
emitted by atmosphere 169.9
atmospheric window 40.1
latent heat (change of state)
emitted by clouds 29.9
absorbed by atmosphere 77.1
absorbed by atmosphere 358.2
greenhouse gases
thermals (conduction/ convection)
18.4
86.4
absorbed by surface 163.3
emitted by surface 398.2
back radiation 340.3
evapotranspiration
net absorbed 0.6
All values are fluxes in Wm-2 and are average values based on ten years of data
Loeb et al., J. Clim. 2009
Trenberth et al., BAMS, 2009
www.nasa.gov
NP-2010-05-265-LaRC


The Greenhouse Effect
SUN
Some solar radiation is reflected by the Earth and the atmosphere.
Some of the infrared radiation passes through the atmosphere, and some is absorbed and re-emitted in all directions by greenhouse gas molecules. The effect of this is to warm the Earth's surface and the lower atmosphere.
Solar radiation passes through the clear atmosphere.
ATMOSPHERE
EARTH
Most radiation is absorbed by the Earth's surface and warms it.
Infrared radiation is emitted from the Earth's surface.

Greenhouse effect

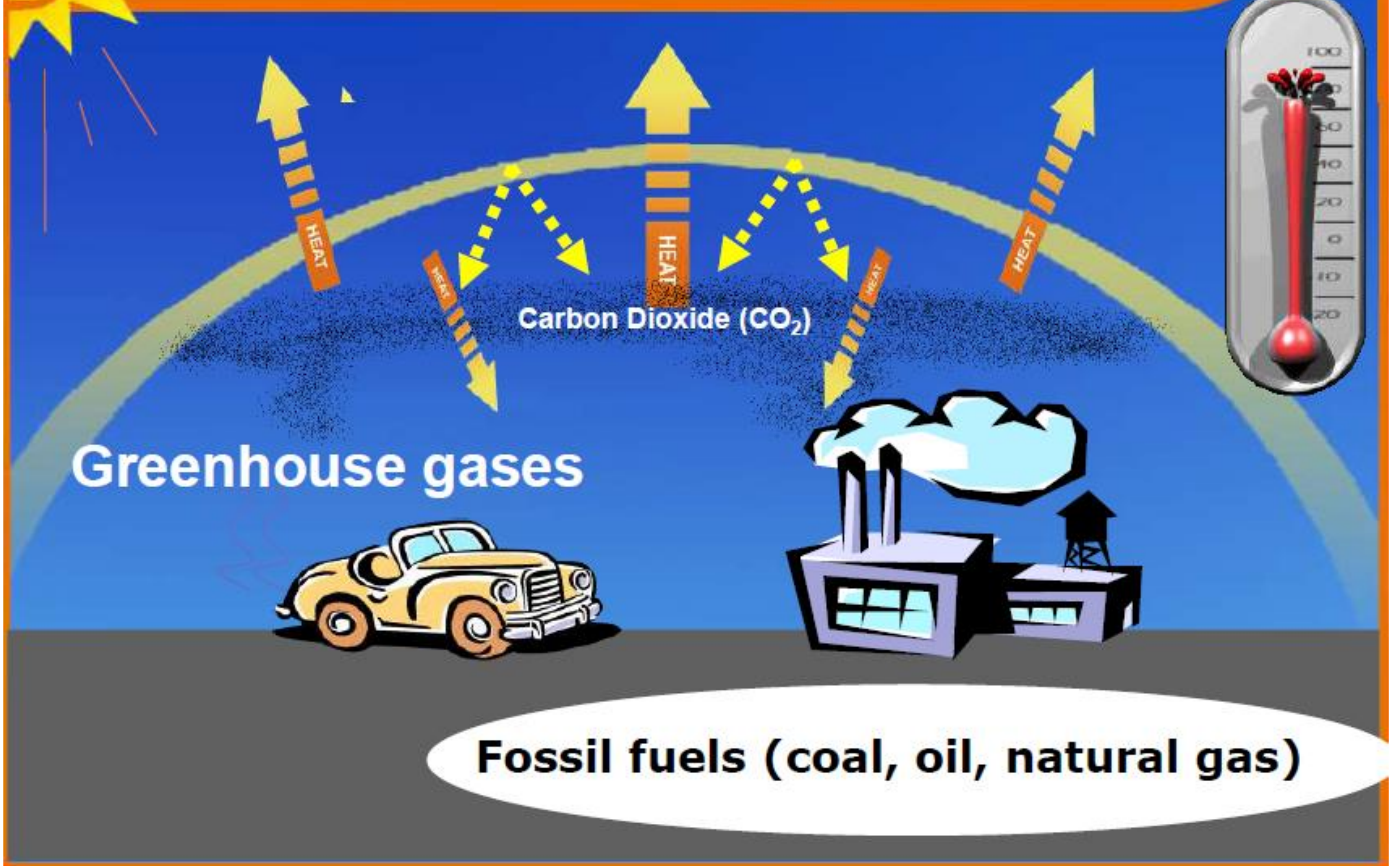
When gases in the atmosphere absorbed terrestrial radiation, they warm, but eventually they radiate this energy away. Some travels upward and some downward which is again absorbed by the earth. Thus the earth's surface is being continuously supplied with heat from the sun as well as from the atmosphere. This energy will again be emitted by the earth's surface, and some will be returned to the atmosphere, which will, in turn, radiated some earthward, and so forth.

This extremely important phenomenon has been called the greenhouse effect.

Greenhouse gases

- **Water Vapour:** Water vapour is the most important greenhouse gases accounting for about 80% of natural greenhouse warming. Remaining 20% contributes by other gases.
- **CO_2 (Carbon dioxide):** Effective greenhouse gas. Any change in the air’s CO_2 content could alter temperature in the lower atmosphere.
- **CH_4 (Methane):** It absorbs IR radiation 20 to 30 time more effectively than CO2, making it an important greenhouse gas despite its relatively low concentration.
- **O_3 (Ozone):** Tropospheric O_3 contributes to the greenhouse effect as well as to the production of photochemical smog.
- **N_2O (Nitrous Oxide):** It may make a contribution to greenhouse warming that approaches half of methane.
- **CFCs (Chlorofluorocarbons):** These are very effective greenhouse gases. CFC-12 has 20000 times the capacity of CO_2 to trap IP radiation whereas CFC -11 has 17500 times more capacity.
- **Trace gases**: Cumulative effect as great as CO_2 in warming the earth.

How Global Warming Works



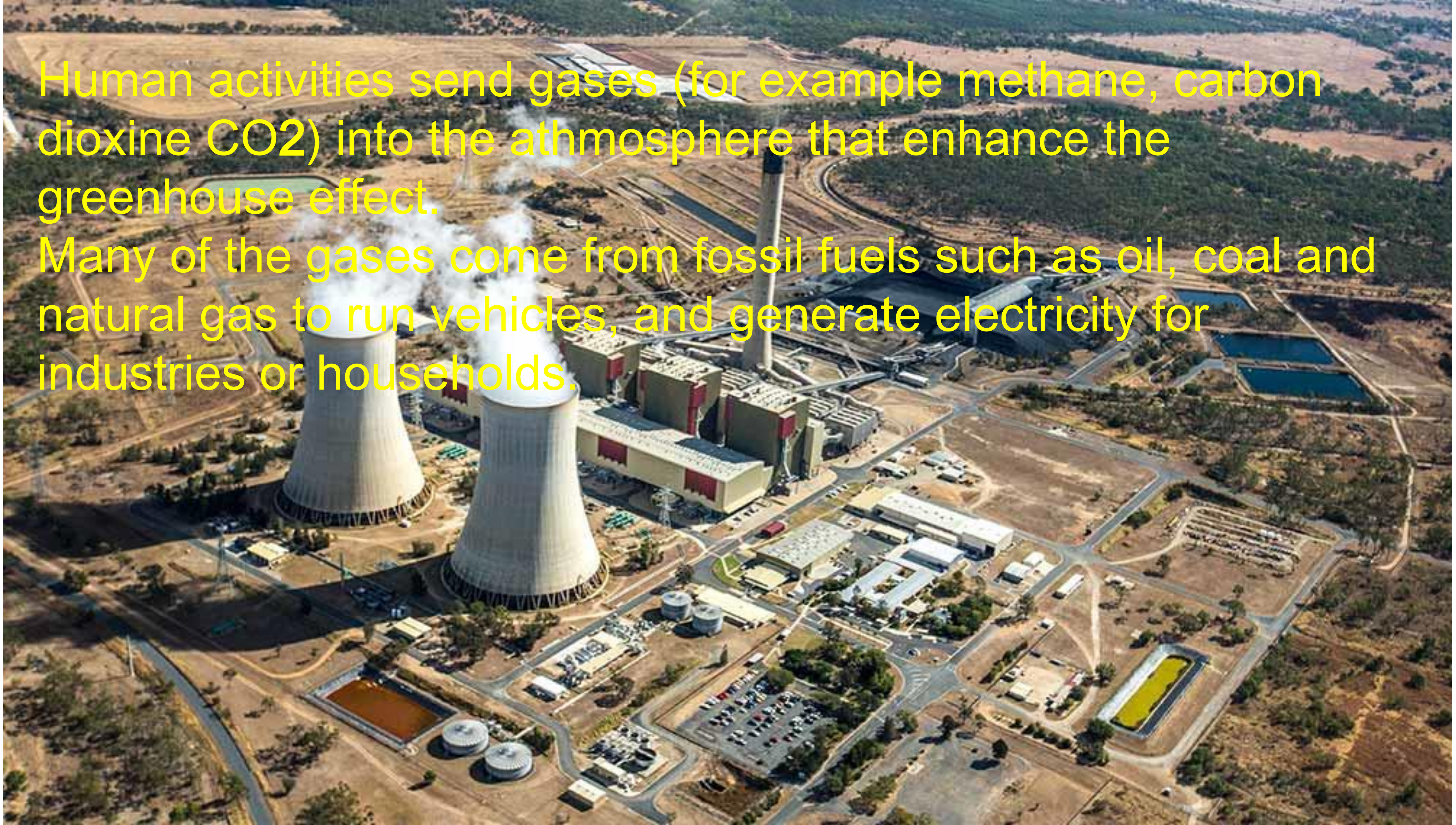
CAUSES OF GLOBAL WARMING


POLLUTION FROM COAL, NATURAL GAS, AND OIL


CO_2 FROM AIRPLANES & VEHICLES


POPULATION INCREASE


DEFORESTATION



Human activities send gases (for example methane, carbon dioxine CO_2) into the athmosphere that enhance the greenhouse effect.

Many of the gases come from fossil fuels such as oil, coal and natural gas to run vehicles, and generate electricity for industries or households.

When the atmosphere contains too much of those gases, the whole atmosphere and the Earth becomes hotter, like it does in a greenhouse. The atmosphere holds on to too much heat, instead of letting it escape into space.

Land use and forestry

When you break down the environment, the natural beings in the environment — such as plants and animals — cannot do as much to correct what's breaking down. So, for example, we know that plants absorb carbon dioxide, then store it as aboveground and belowground mass. This is called biological carbon sequestration and it takes carbon dioxide out of the air and puts it into storage; it's also called sink

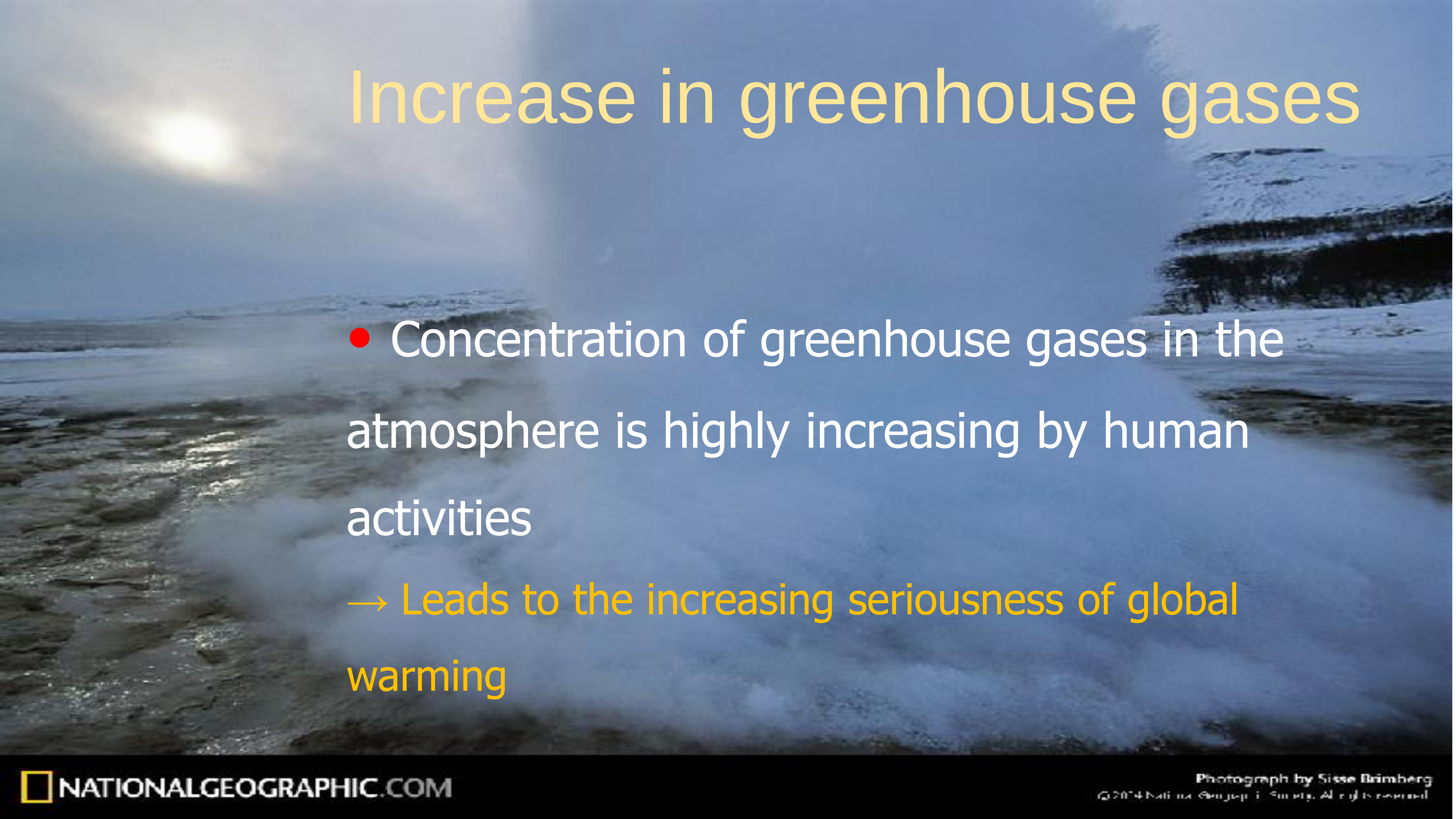
Transportation

According to the EPA's report Inventory of U.S. Greenhouse Gas Emissions and Sinks, transportation is the largest source of greenhouse gas emissions, accounting for 28.9 percent of all 2017 greenhouse gas emissions. Transportation accounts for everything from burning fossil fuels for cars, ships, trucks, trains, and planes.

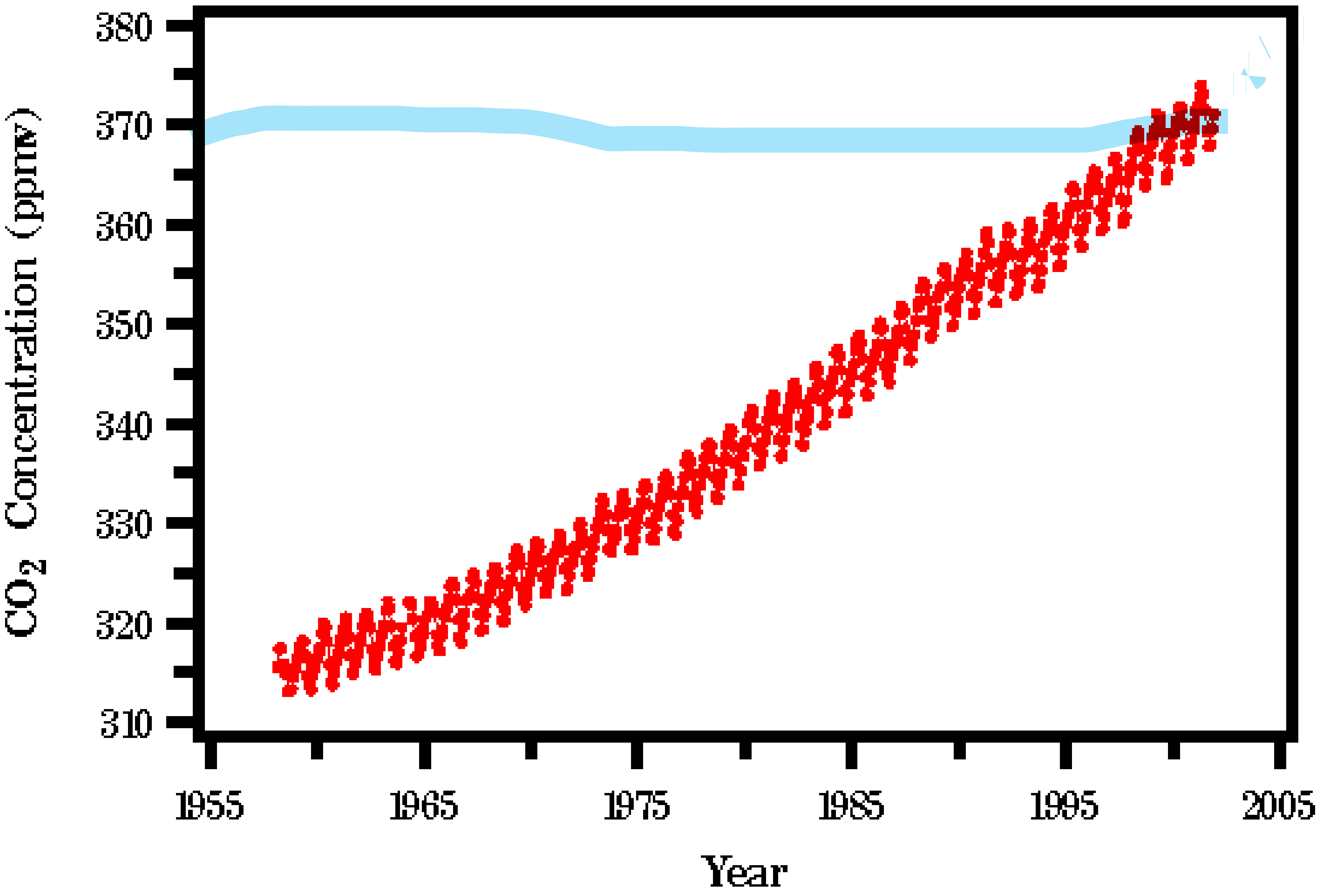
Increase in greenhouse gases

- Concentration of greenhouse gases in the atmosphere is highly increasing by human activities

→ Leads to the increasing seriousness of global warming

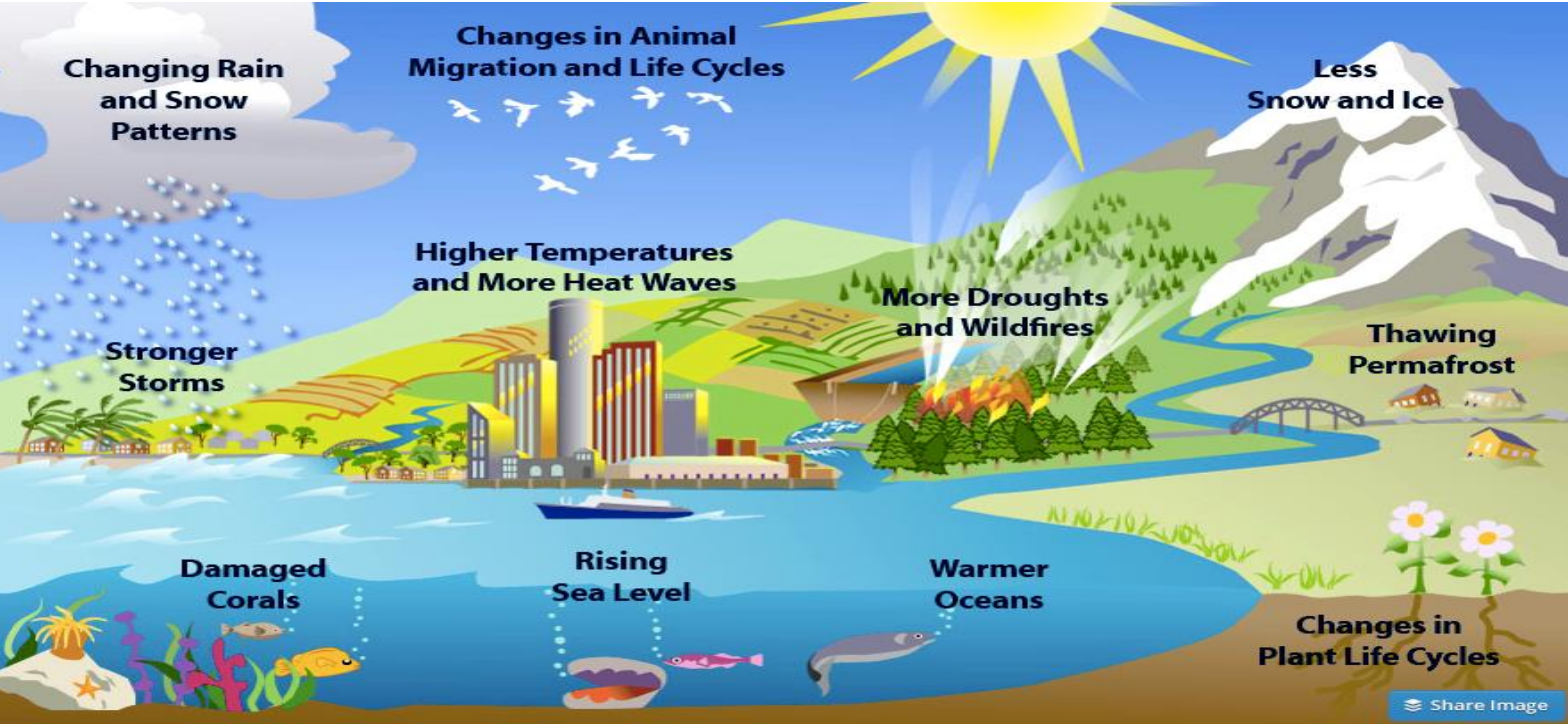


Carbon dioxide concentration as measured at Mauna Loa, Hawaii. These measurements represent the globally mixed concentration.



Source: Dave Keeling and Tim Whorf (Scripps Institution of Oceanography)

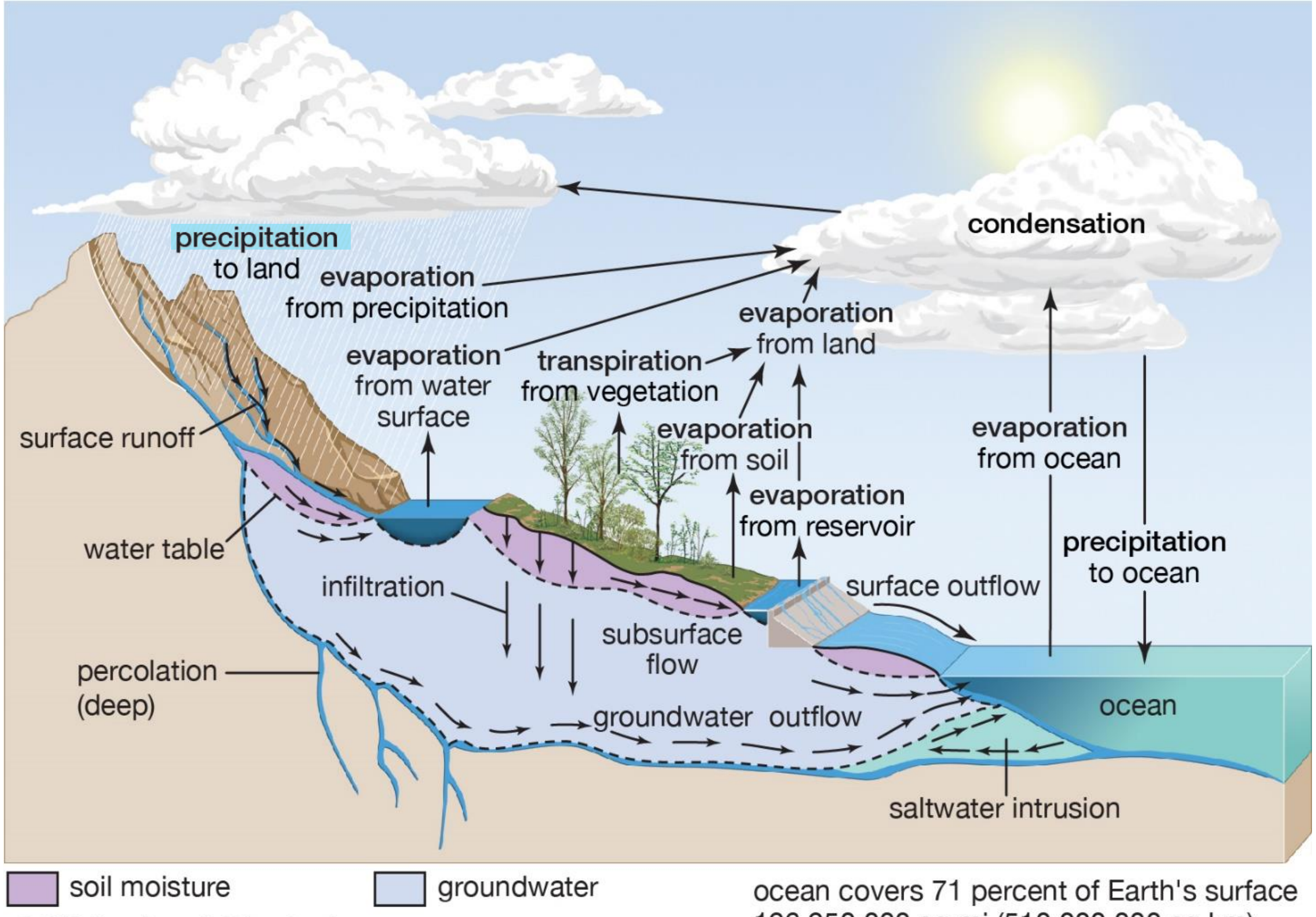
Environmental effects of Global warming



1. Global precipitation change: A warmer atmosphere will lead to increased evaporation from ocean, lakes, and streams and lead to more precipitation.

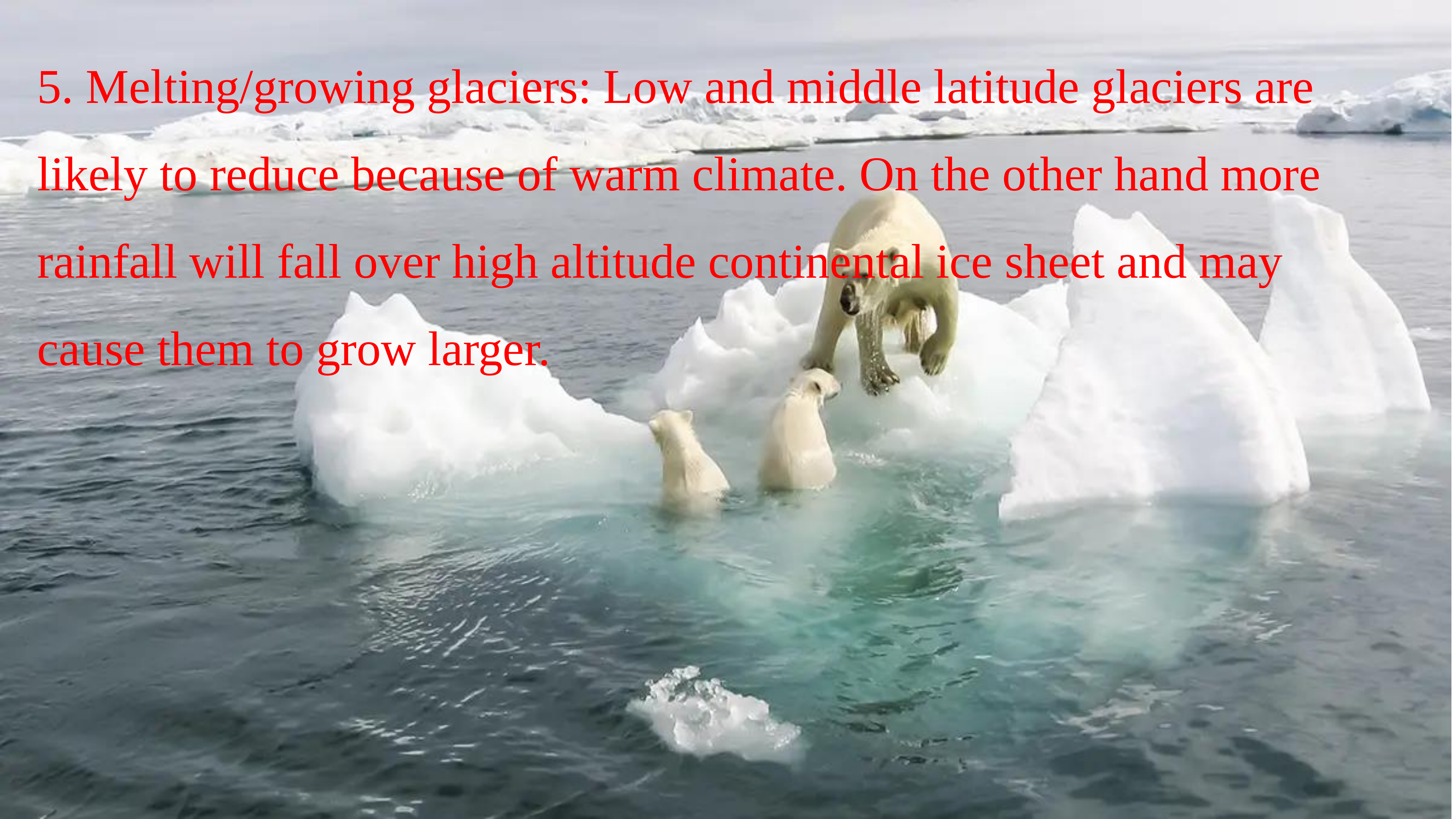
2. Change in hydrologic cycle:

Significant local and regional changes in stream runoff and groundwater levels.



3. Change in vegetation: Shifts in pattern of rainfall are likely to upset ecosystems. Eventually it may shift the boundaries of forest and agricultural regions.

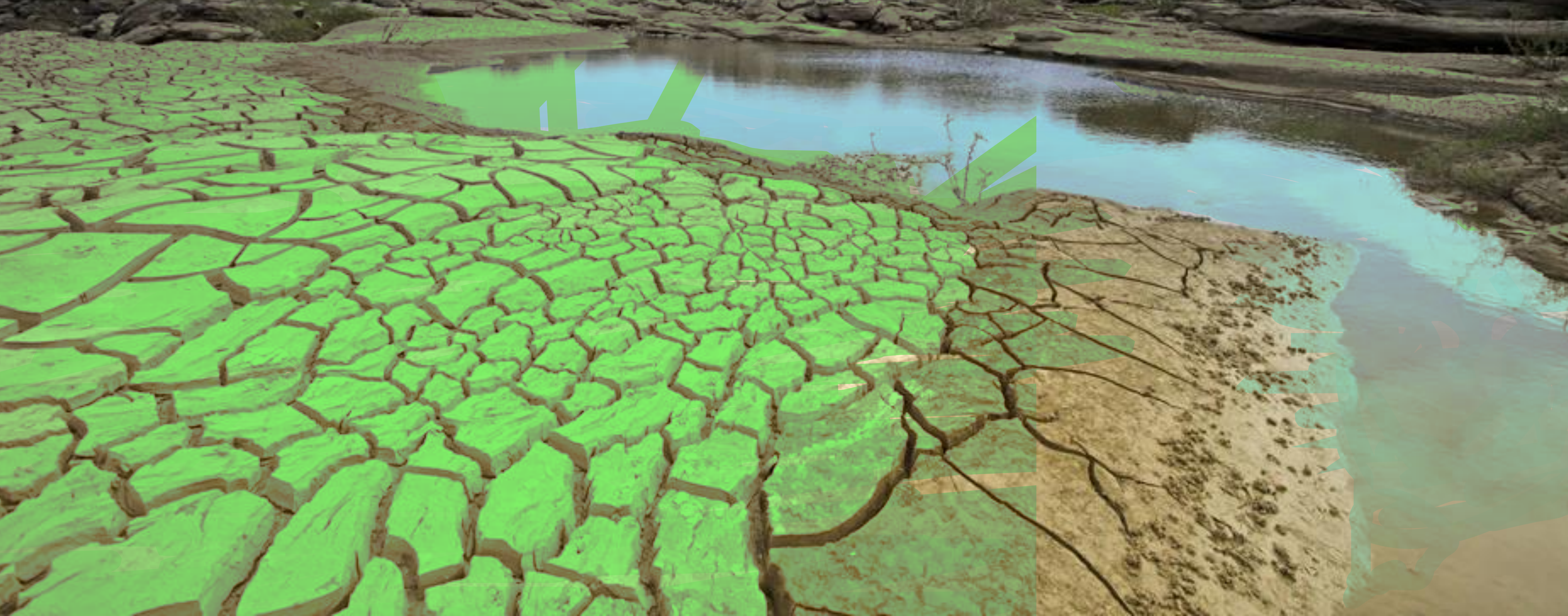
4. Increased storminess: The frequency and/or intensity of violent storms may increased because of warm ocean water which could feed more energy into high magnitude storm.



5. Melting/growing glaciers: Low and middle latitude glaciers are likely to reduce because of warm climate. On the other hand more rainfall will fall over high altitude continental ice sheet and may cause them to grow larger.

6. Reduction of sea ice: As the climate warm, total sea ice is expected to be reduced.

7. Thawing of frozen ground: Rising summer air temperature will begin to thaw vast regions of perennially frozen ground at high altitude.



8. Global rise in sea level: The sea level will rise because of global warming. Two probable reasons for sea level rise are thermal expansion of warming ocean water and melting of glaciers and polar ice. The various models predict that the rise may be anywhere from 20 cm to 2 m at the end of this century. The rising sea will inundate coastal regions and make tropical regions even more vulnerable to larger and more frequent cyclonic storms.

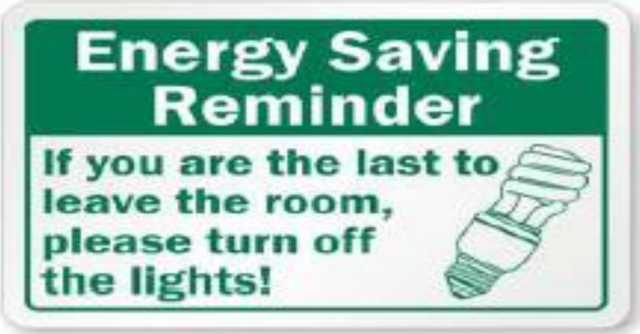
9. Decomposition of organic matter in soil: As temperature increases, the rate of decomposition of organic matter in soil increase. Soil decomposition release CO_2 to the atmosphere, thereby further enhancing the greenhouse effect.

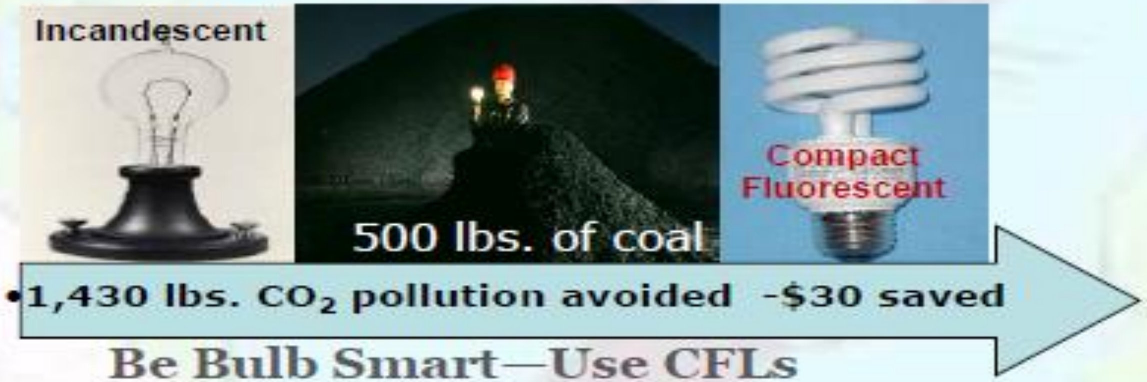
10. Breakdown of gas hydrates: Because of global warming gas hydrates breakdown and releases methane to the atmosphere, thus further enhance the greenhouse effect.

The ecosystem which sustains the livelihood of Arctic residents is melting the ice as temperature rise. The layer of permafrost is melting, causing an inland lake to drain into the ocean and killing fresh water fish.


No space to live

Turn off your computer or the TV when you're not using it.





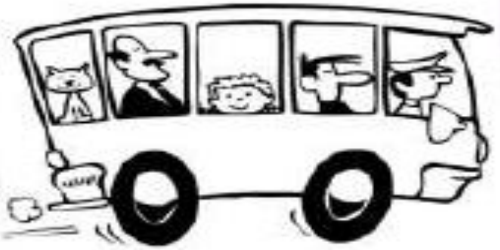
Be Bulb Smart—Use CFLs

Recycle

Dress lightly when it's hot instead of turning up the air conditioning.

Drive LESS, drive SMART

Use a bicycle or bus



Fuel efficient cars

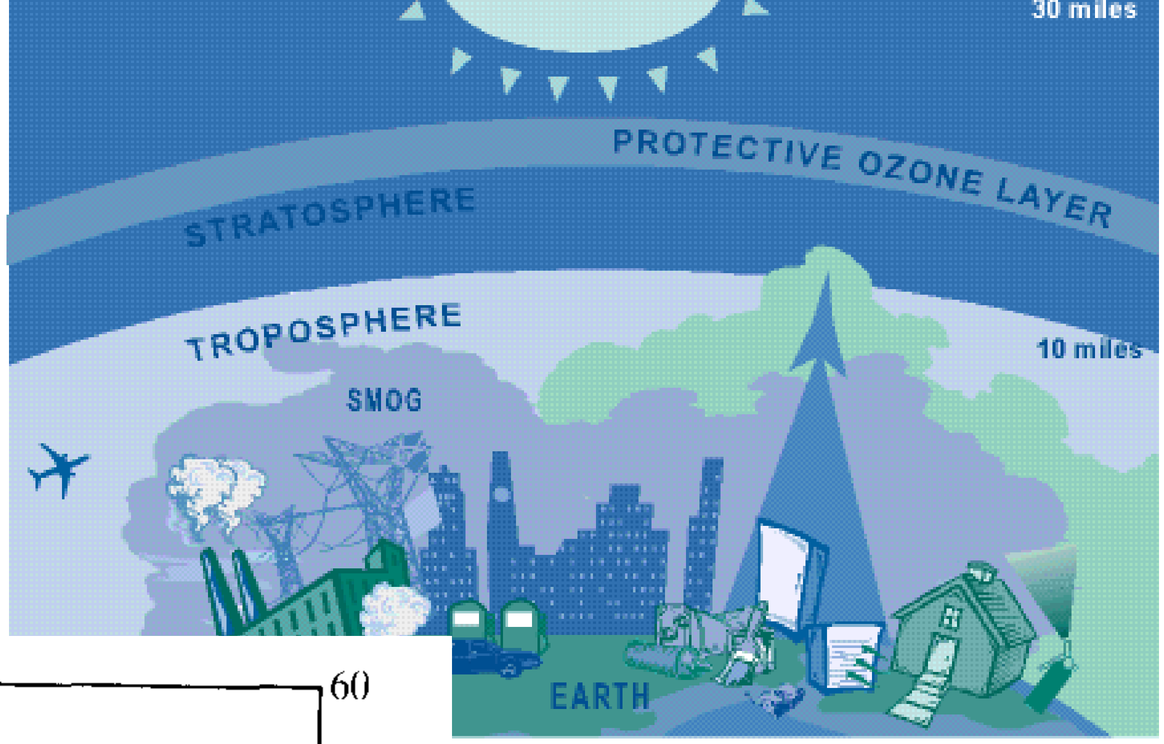
Solar Power

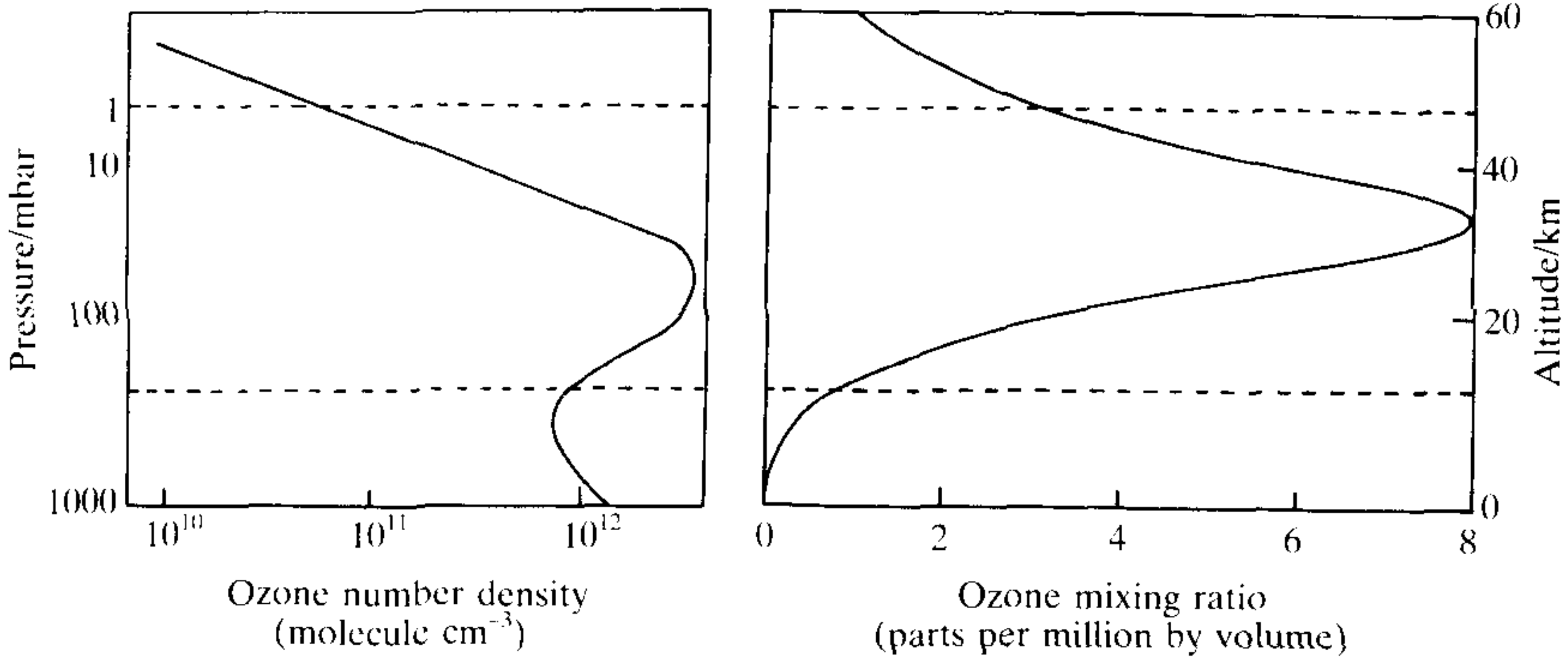
Wind Power

Kyoto Protocol

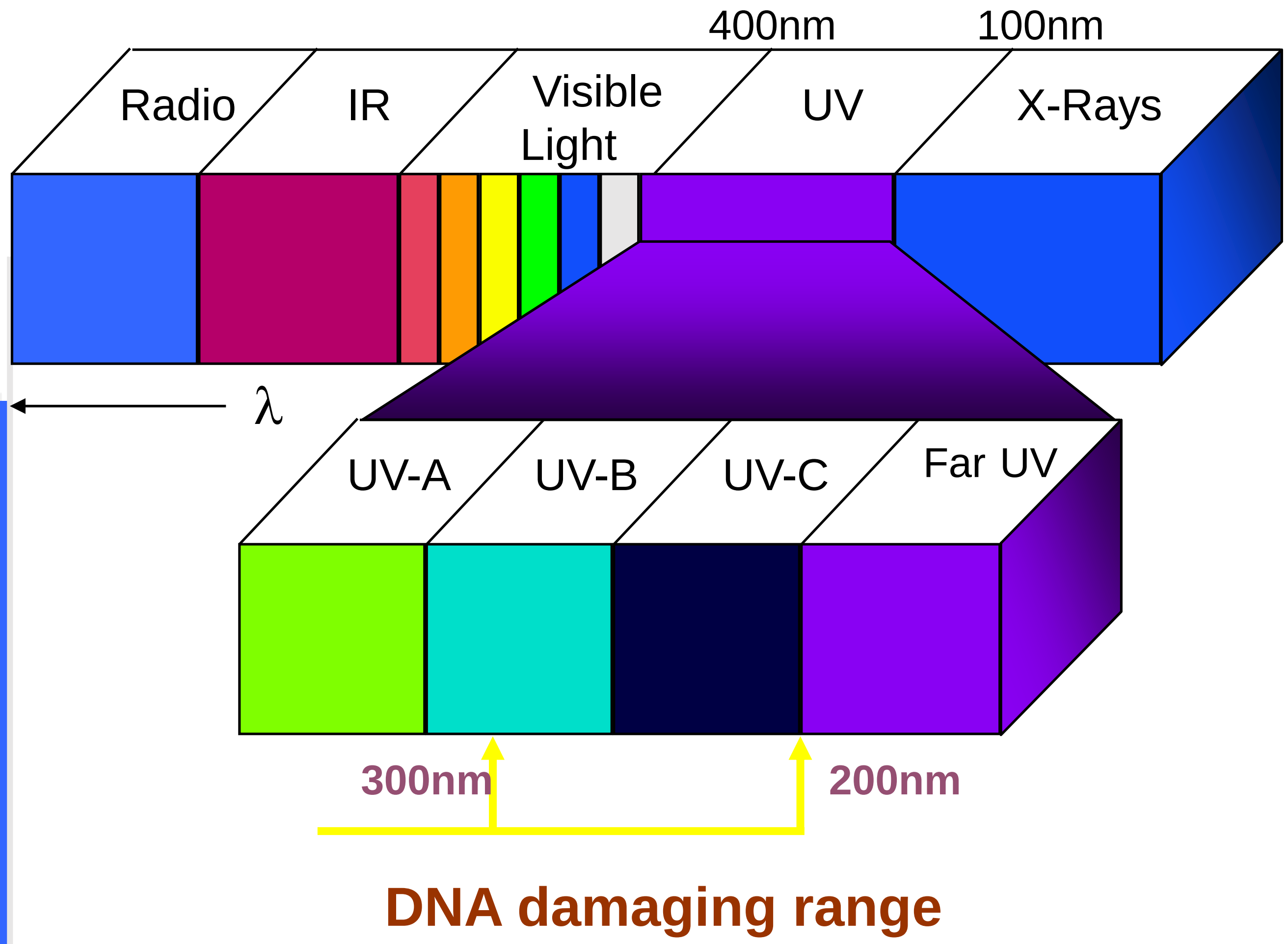
- A un- brokered treaty was signed by in 1997 in Kyoto Japan.
It was called the Kyoto Protocol.
- It commits the rich countries to binding cut in their emission
of greenhouse gases, such as carbon dioxide.
- The developed countries agreed to cut their emissions by a
collective average of 5 percent below their levels in 1990 by
2008-2012.
- Representative Climate Conference (COPC) in Nov 2000,
and discussed about the implementation of the Kyoto Protocol.

The Ozone Layer





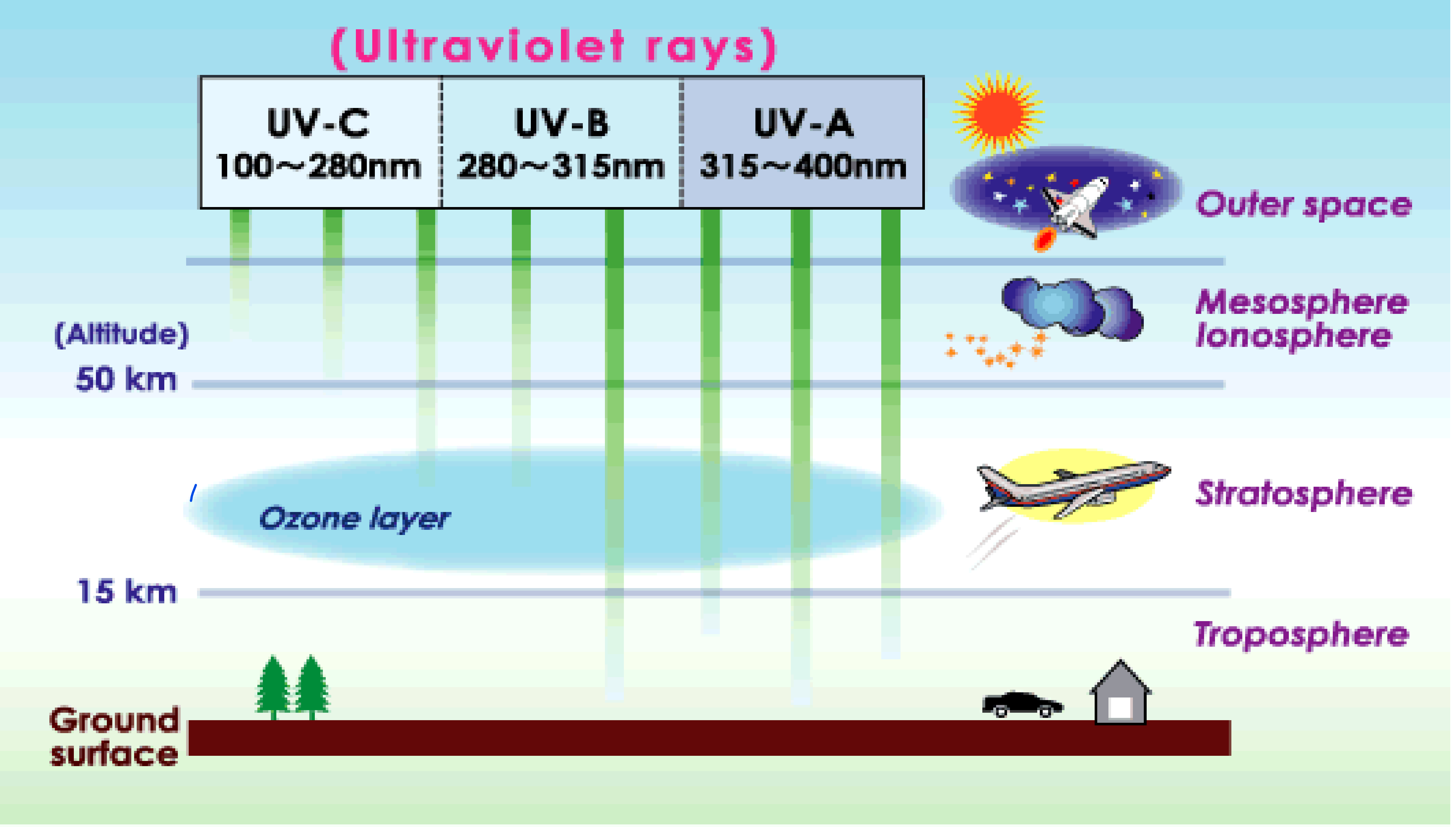
The Ultraviolet Spectrum



- **UV light: 100 to 400 nm**

UV spectrum – 4 regions

- Far UV: 100 – 200 nm
- UV – C : 200 – 280 nm
- UV – B : 280 – 315 nm
- UV – A : 315 – 400 nm


(Ultraviolet rays)
UV-C
100～280nm
UV-B
280～315nm
UV-A
315～400nm
Outer space
Mesosphere
Ionosphere
(Altitude)
50 km
Ozone layer
Stratosphere
15 km
Troposphere
Ground surface

The Ozone Layer

1. O_3

2. A gas composed of three atoms of oxygen

3. Bluish gas that is harmful to breathe

4. Nearly 90% of earth's ozone is in the **stratosphere** and referred to as the **ozone layer.**

5. Ozone absorbs a band of ultraviolet radiation called **UVB.**

Formation of Ozone Layer

- **1930**
  - Sydney Chapman proposed a series of reactions to account for the ozone layer: *the Chapman Cycle*
  - Four chemical reactions
    - *Initiation* O_2 + light → 2O (120 – 210 nm)
    - *Propagation* (cycling)

      $O + O_2 + M$ → $O_3 + M^*$ (generates heat)

      O_3 + light → $O_2 + O$ (220 – 320 nm)
    - *Termination* $O_3 + O$ → $2O_2$

The Ozone Layer Depletion

- Ozone layer depletion, is simply the wearing out (reduction) of the amount of ozone in the stratosphere. Unlike pollution, which has many types and causes, Ozone depletion has been pinned down to one major human activity.
- Industries that manufacture things like insulating foams, solvents, soaps, cooling things like Air Conditioners, Refrigerators and 'Take-Away' containers use something called chlorofluorocarbons (CFCs).
- Other ozone-eating chemicals are pesticides such as methyl bromide, halons used in fire extinguishers, and methyl chloroform used in businesses.

The Ozone Layer Depletion

Four main "families" of chemicals responsible for catalyzing ozone destruction:

1. Nitrogen oxides: NO_x
   - $NO + NO_2$
2. Hydrogen oxides: HO_x
   - $OH + HO_2$
3. Chlorine: ClO_x
   - $Cl + ClO$
4. Bromine: BrO_x
   - $Br + BrO$

A common type of catalytic destruction cycle (there are others)

$$Y + O_3 \rightarrow YO + O_2$$

$$YO + O \rightarrow Y + O_2$$

where Y = NO, OH, Cl or Br

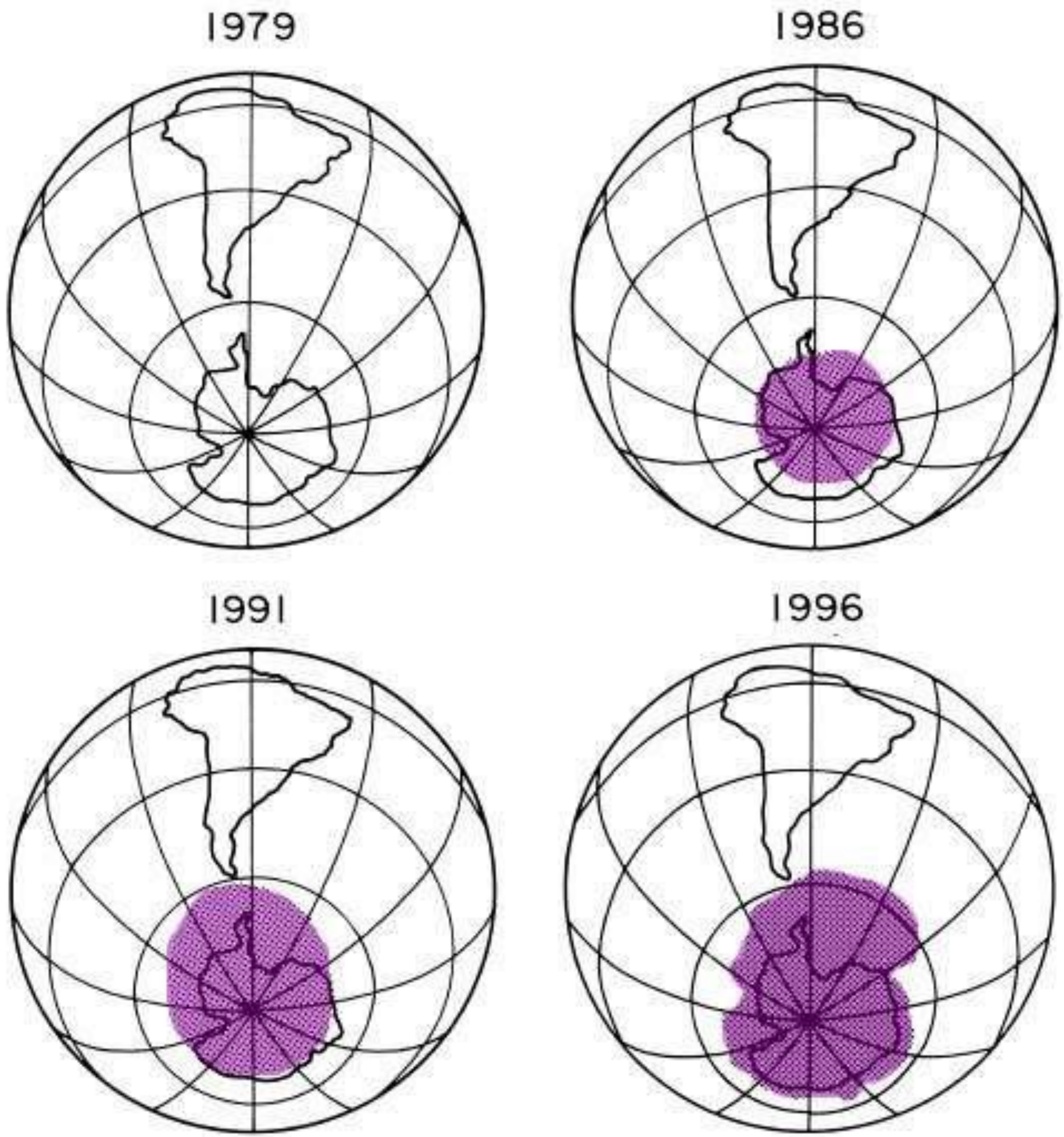
CFCs

- CFCs are ***chlorofluorocarbons***; they are small molecules that contain chlorine, fluorine and carbon atoms. Usually there are only 1-2 carbon atoms.
- CFCs are sometimes called ***Freons*** (that was their trade name for DuPont)
- CFCs are referred to by a number. The most common CFCs are: CFC-11, CFC-12, CFC-113 (formulas on the next page)
- HCFCs are CFCs that contain hydrogen. This makes them more reactive to the OH radical, decreasing their tropospheric lifetime. That means that, on a pound-per-pound basis, HCFCs ("soft CFCs") destroy less stratospheric ozone than CFCs ("hard CFCs") because a smaller fraction of HCFCs "survive" to reach the stratosphere

Destruction of Ozone Layer by CFCs

- "Hard" CFCs are unreactive to OH and other reactive radicals in the troposphere. They are also pretty insoluble in water. That means their tropospheric lifetimes are easily long enough that the majority of tropospheric CFCs pass through the tropopause into the stratosphere.
- Once there, they are subject to light of shorter wavelengths (ie, more energetic photons). In particular, many CFCs absorb in the "uv window" (centered at 205 nm) between strong O_2 and O_3 absorption. That means most can photodissociate in the bottom half of the stratosphere.
- Photodissociation releases chlorine atoms:
  - For example: $CFCl_3$ + light → $CFCl_2$ + Cl (l < 225 nm)
- Chlorine atoms deplete odd oxygen (Ox) largely by the following cycle
  - Cl + O_3 → ClO + O_2
  - ClO + O → Cl + O_2

Ozone hole at polar region

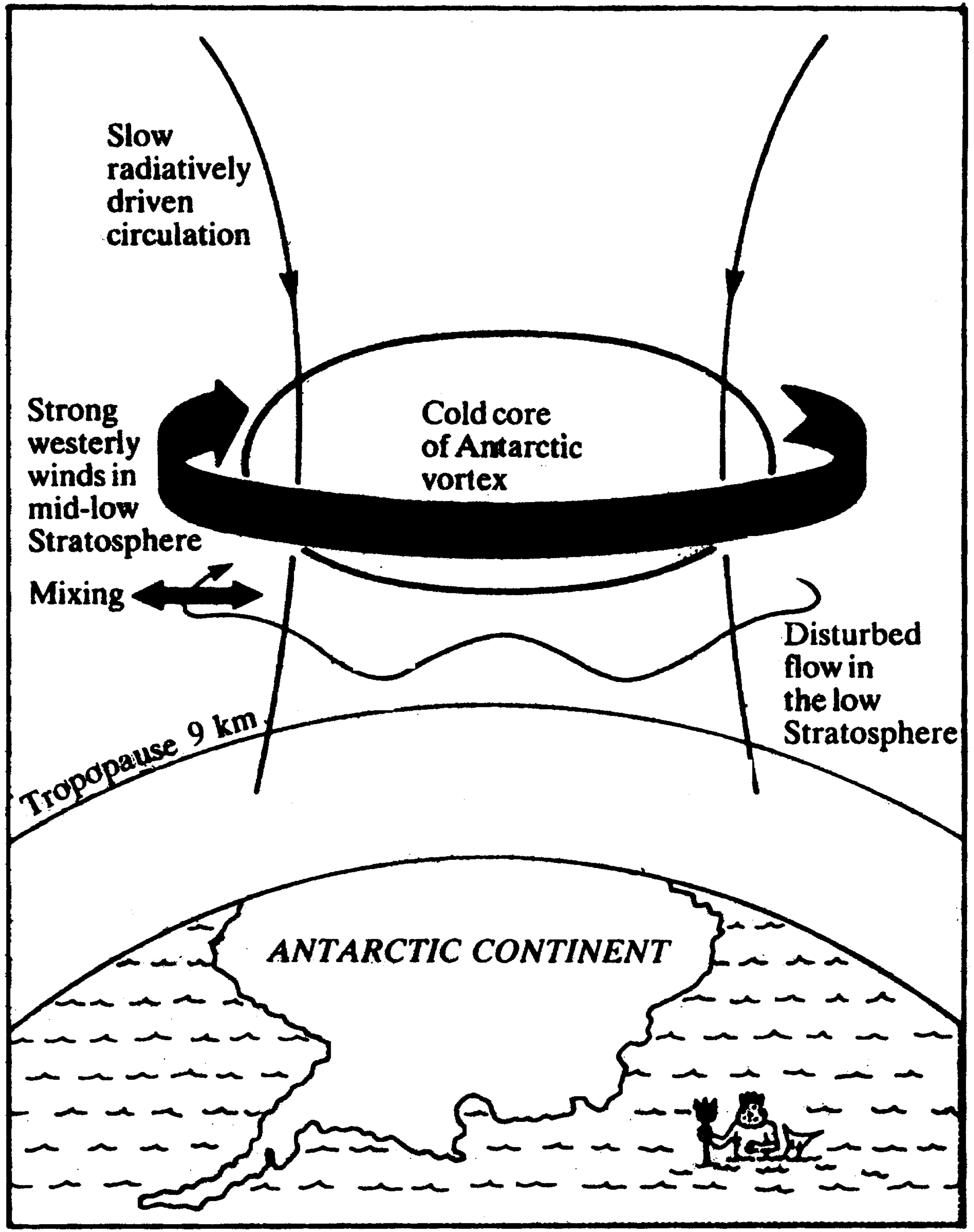


Unique Feature of Antarctic Meteorology: Winter Vortex

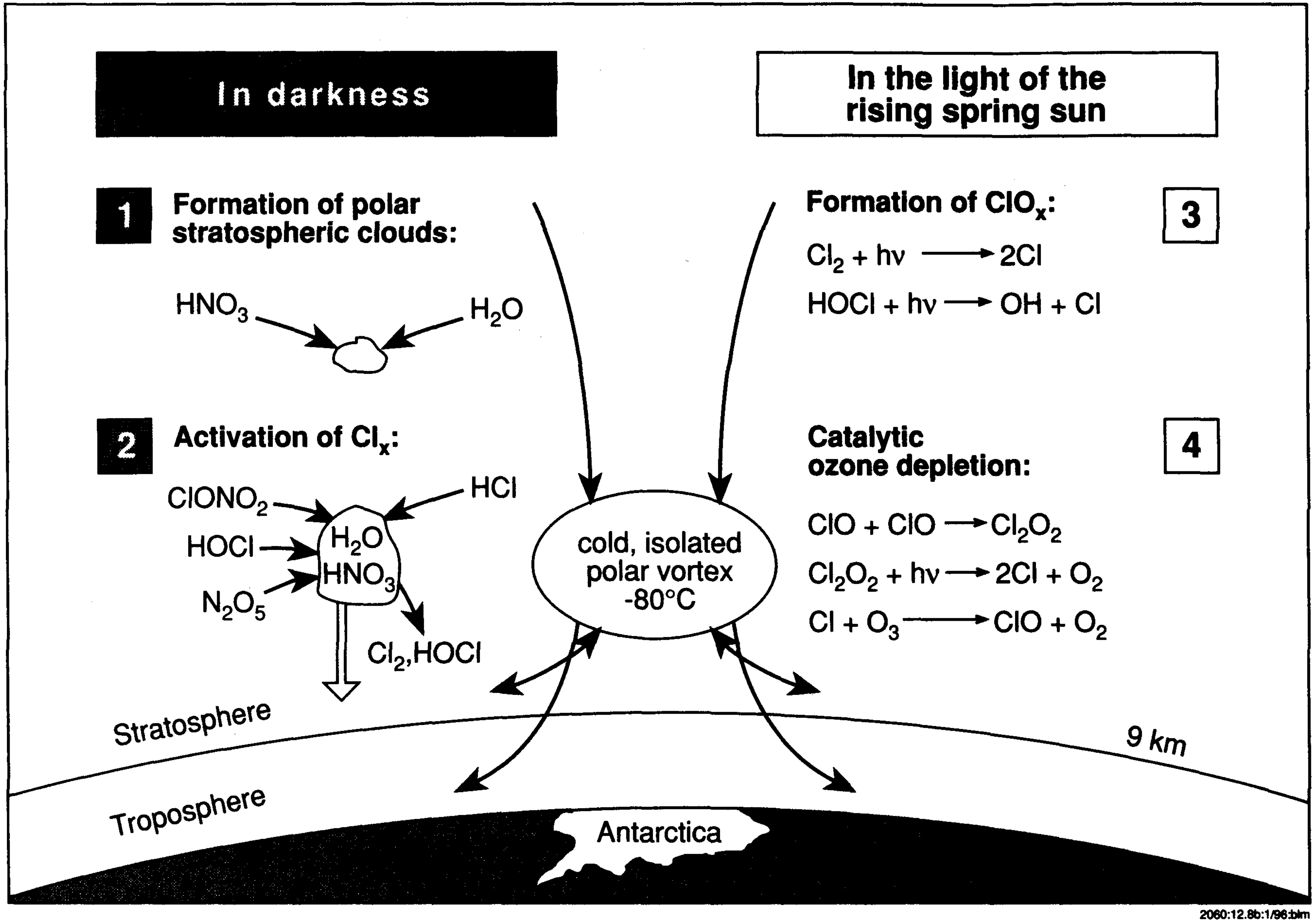
- Polar vortex develops during the winter

- Atmosphere is effectively isolated from the rest of the southern hemisphere

- Interior temperatures plummet during long winter night – large area is below 200K, and it can get as cold as 180K



Ozone Hole



In darkness
In the light of the rising spring sun
1 Formation of polar stratospheric clouds:
HNO3
H2O
2 Activation of Clx:
ClONO2
HOCl
N2O5
HCl
H2O
HNO3
Cl2,HOCl
cold, isolated polar vortex -80°C
Formation of ClOx:
3
Cl2 + hν → 2Cl
HOCl + hν → OH + Cl
Catalytic ozone depletion:
4
ClO + ClO → Cl2O2
Cl2O2 + hν → 2Cl + O2
Cl + O3 → ClO + O2
Stratosphere
9 km
Troposphere
Antarctica
2060:12.8b:1/96:blm

Antarctic Reactions

Winter reactions

- Polar vortex: -90 ^{o}C ➔ Ice clouds
- $ClONO_2 + H_2O \rightarrow HOCl + HNO_3$
- $HOCl + HCl \Leftrightarrow Cl_2 + H_2O$

Spring reactions

- $Cl_2 + h\upsilon \rightarrow 2\ Cl$ *in early spring*
- $Cl + O_3 \rightarrow ClO + O_3$ *destructive loop*
- $HNO_3 + Cl \rightarrow ClONO_2$ *in photocatalysis*

Impacts of Ozone Depletion

1) HARM TO HUMAN HEALTH:

(a) More skin cancers, sunburns and premature aging of the skin.

(b) More cataracts, blindness and other eye diseases.

2) ADVERSE IMPACTS ON AGRICULTURE:

(a) Plant growth, especially in seedlings, is harmed by more intense UV radiation.

(b) Major crop species are particularly vulnerable to increased UV, resulting in reduced growth, photosynthesis and flowering.

3) EFFECTS ON PLANTS:

Physiological and developmental processes of plants are affected by UVB radiation, even by the amount of UVB in present-day sunlight.

4) EFFECT ON ANIMALS:

(a) In domestic animals, UV overexposure may cause eye and skin cancers.

(b) Species of marine animals in their developmental stage (e.g. young fish, shrimp larvae and crab larvae have been threatened in recent years by the increased UV radiation under the Antarctic ozone hole.

5) EFFECT ON MATERIALS:

(a) Wood, plastic, rubber, fabrics and many construction materials are degraded by UV radiation. The economic impact of replacing and/or protecting materials could be significant.

Measures to Prevent the Ozone Depletion

1) Limit private vehicle driving
2) Use eco-friendly household cleaning products
3) Avoid using pesticides
4) Developing stringent regulations for rocket launches
5) Banning the use of dangerous nitrous oxide

International Measures

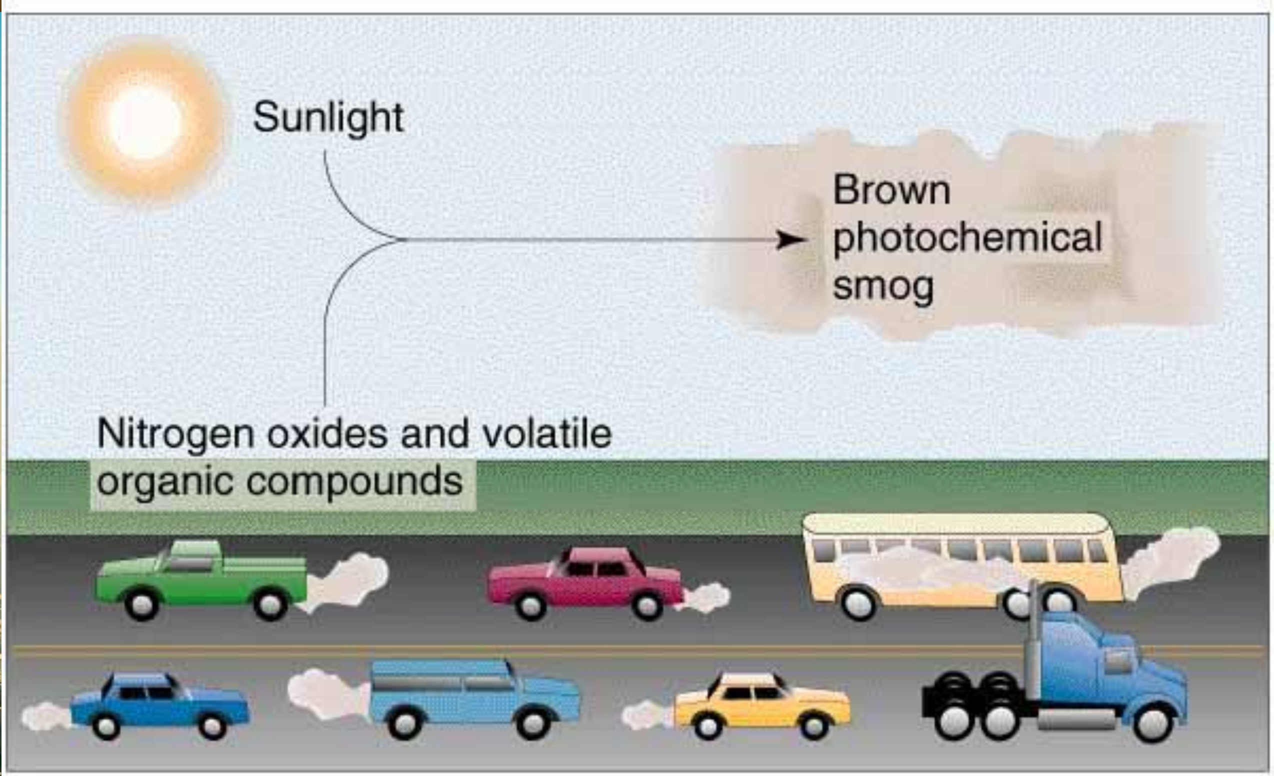
1. Montreal protocoal signed in 1987.
2. Comprise of 189 countries now.
3. To reduce CFC substances

National Level Measures

1. Singapore banned use of CFC products in 1991.
2. Countries can control the import and manufacture of CFC product.

Photochemical smog

- **Photochemical smog** is a type of **smog** produced when ultraviolet light from the sun reacts with nitrogen oxides in the atmosphere. It is visible as a brown haze, and is most prominent during the morning and afternoon, especially in densely populated, warm cities.


Sunlight
Brown photochemical smog
Nitrogen oxides and volatile organic compounds

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Thank you