Environment Monitoring and Research Centre

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Scientist ‘E’

भारत मौसम विज्ञान विभाग

INDIA METEOROLOGICAL DEPARTMENT

Environmental Monitoring & Research activities in IMD

- Ozone Monitoring (Surface Ozone, Vertical Distribution, Columnar Ozone)
- Aerosol Optical Properties Monitoring
- Black Carbon Aerosol Monitoring
- Precipitation Chemistry Monitoring
- Aerosol Chemistry Monitoring
- Trace Gases Monitoring
- Greenhouse Gases (Ranichauri, Uttarakhand)
- Solar Radiation

- **Ambient Air Quality Monitoring (Delhi, Pune, Mumbai, Ahmedabad)**

⇒ PM10, PM2.5, O_3, CO, NOx, BTX, SO_2, NH_3

- **Air Quality Forecasting Services**

⇒ From Regional Scale to Urban Street Scale

⇒ **3-days forecast and outlook for next 7-days**

⇒ **forecast of non-local fire contribution**

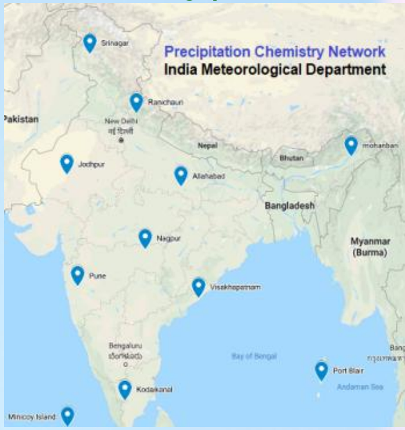
⇒ **AQ Forecast Models (SILAM - FMI-IMD Collaboration)**

→**WRF-Chem (IITM-NCAR Collaboration: Operational Run – IMD)**

→**ENFUSER (FMI-IMD Collaboration), NCUM Dust (NCMRWF)**

Precipitation and Aerosol Chemistry

- Precipitation Chemistry (major Cations, Anions, pH and Conductivity) monitoring through a network of 11 stations since **1970s**.



- State-of-art Precipitation Chemistry Laboratory at IMD, Pune with:
  - ❑Ion-chromatograph
  - ❑UV-VIS Spectrophotometer
  - ❑Atomic Absorption Spectrophotometer
  - ❑pH and Conductivity Meter
  - ❑Ultra-pure De-ionized Water Plant
- Participation in WMO Bi-annual International Laboratory Intercomparison
- High Volume Samplers for PM10, PM2.5 and Total Suspended Particulate Matter sample collection at Delhi, Ranichauri, Pune and Varanasi.
- Analysis of filter papers for chemical characterization of aerosols.

Precipitation Chemistry Parameters measured:

- pH, Specific Conductivity
- SO_4^{2-}, NO_3^-, Cl^-, PO_4^{3-}
- NH_4^+, Na^+, Ca^{2+}, Mg^{2+}, K^+
- Cation and Anion Balance




Laboratory Measurements at Pune

- **Atomic Absorption Spectrophotometer with Graphite Furnace**
  Metallic ions Ca^{2+}, Mg^{+}, Na^{+}, K^{+} etc
  Range: ppm to sub ppb level

- **Ion Chromatograph**
  Ions: SO_4^{2-}, NO_3^{-}, Cl^{-}, F^{-}, PO_4^{2-}, and NH_4^{+}
  All Major cations and anions including transition metals

- **pH and Conductivity meter**

- **Ultra-pure Deionized Water Purification Syste**

All calibrations using NIST certified Standards.

Precipitation Chemistry Laboratory at Pune participates in WMO's Laboratory Intercomparison Program conducted twice in a year by WMO World Data Center for Precipitation Chemistry (WDCPC).

Ozone Monitoring

Ozone Centre of IMD is designated as secondary regional ozone centre for Regional Association II (Asia) of World Meteorological Organization. The centre maintains a network of ozone monitoring stations including Maitri and Bharati in Antarctica. Following atmospheric Ozone components are measured currently:

- **Surface Ozone at 10 stations (1970s)**
- **Vertical Distribution (ozonesonde stations) (1960s)**
- **Total Columnar ozone (Dobson stations (1957-58)**

Aerosol Monitoring

Skyradiometer Network (20)

- **Aerosol Optical Properties**
- **Spectral Aerosol Optical Depth**
- **Angström exponent**
- **Single Scattering Albedo**
- **Aerosol Size Distribution**
- **Asymmetry Parameter**
- **Columnar Water Vapor**
- **Complex Refractive Index**
- **Aerosol Radiative Forcing**

Black Carbon (BC) Aerosol Monitoring (24)

- **Equivalent BC Aerosol Concentration**
- **Biomass Burning BC Concentration**
- **Fossil Fuel BC Concentration**
- **Spectral Absorption Coefficient**

BACKGROUND STATION, RANICHAURI

Station at a remote location in Uttarakhand

Measurement Started

Precipitation Chemistry
Solar Radiation
Micrometeorology
Sunsky Radiometer
Ozone

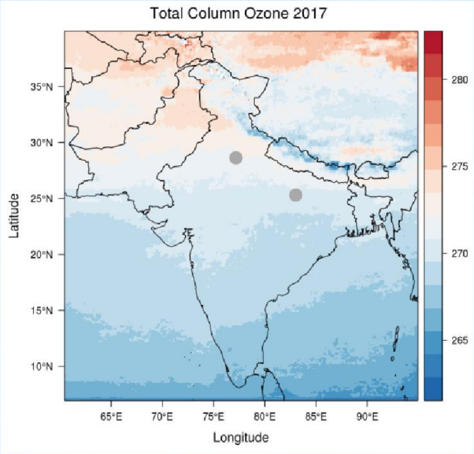
Black Carbon
Size Segregated Aerosol Chemical Composition
Continuous Greenhouse Gases Measurement
DMPS, CPC, APS

Proposed Measurements:
LIDAR
Microwave Rain Radar

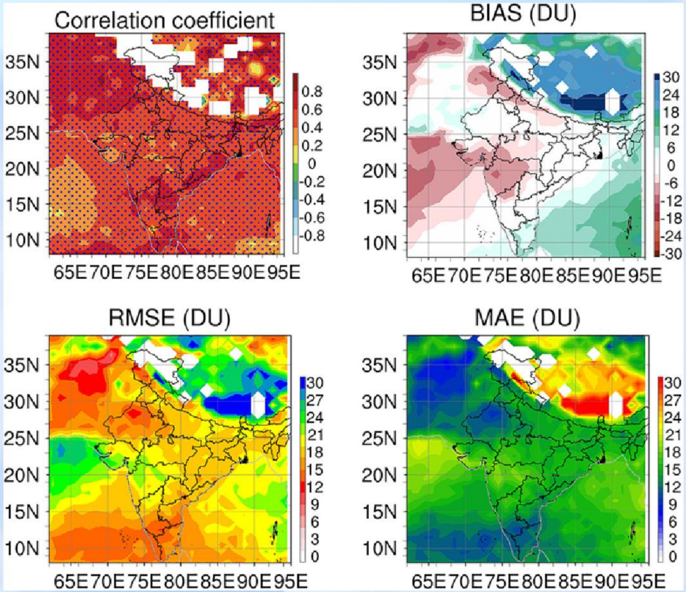
Satellite Based Monitoring

- **Total Column Ozone –INSAT-3D/3DR, AIRS, OMI**
- **Aerosol Optical Depth – INSAT-3D/3DR, MODIS**
- **Fire Counts – MODIS, SUOMI NPP VIIRS**
- **Dust Transport – SEVIRI, INSAT-3D/3DR**
- **Total columns of O_3, SO_2, CO, NO_2 -TROPOMI**

- The geostationary meteorological satellite INSAT-3D launched in July 2013 and INSAT-3DR launched in August 2016 by Indian Space Research Organisation (ISRO)
- 19 channel sounder
- 9.67 μm ozone absorption band provides the Total Columnar Ozone (TCO) during the clear sky conditions on hourly basis at spatial resolution 10 km x 10 km coverage 5-40^{o}N and 60-100^{o}E over the Indian region.



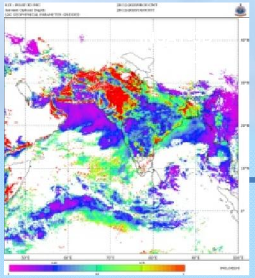
Annual Mean INSAT-3D TCO



Comparison of INSAT-3D TCO with AIRS

Kumar et al (2021) Science of Total Env

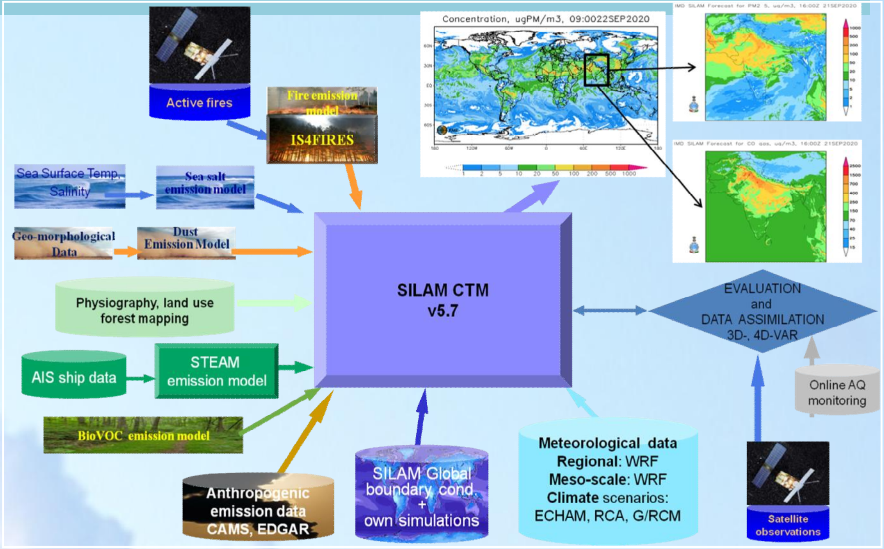
DOI: 10.1016/j.scitotenv.2021.148518



Operational Air Quality Forecast Models of IMD

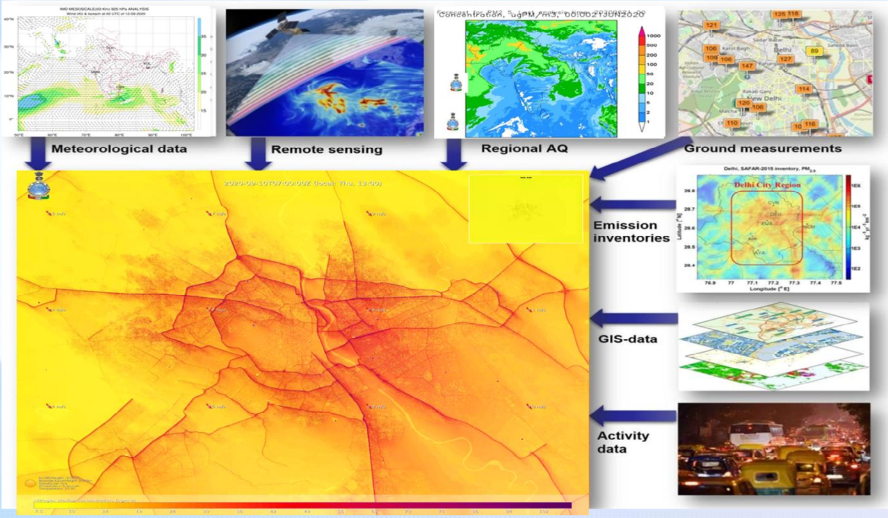
System for Integrated modeLling of Atmospheric coMposition (SILAM)

- Hourly AQ Forecast of pollutants PM10, PM2.5, O_3, CO, NOx, SO_2 for 72 hours.
- Domain: 60-100E, 0-40N, 3km x3km grid, 15 hybrid layers up to ~10km (~270hpa).



ENvironmental information FUsion SERvice (ENFUSER)

- Hourly AQ Forecast of (PM10, PM2.5, O_3, CO, NOx, SO_2 and other species) for 72 hours.
- Domain: Delhi (28.362N-28.86N, 76.901E - 77.56E)
- Spatial Resolution – 30m



Atmospheric Ozone Measurement

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THE OZONE LAYER

- What is it?
- Where is it?
- Why is it important to life on Earth?
- How are we as humans affecting it?

Physical Properties of Ozone

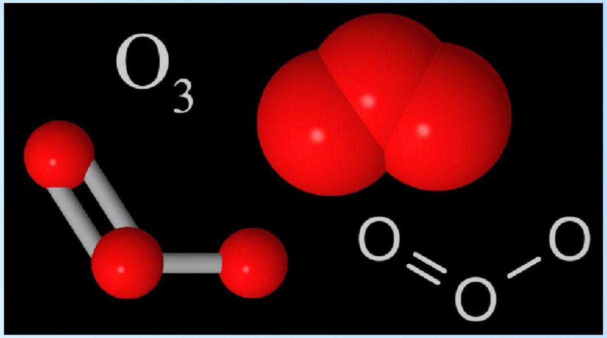
- O_3 is a colourless, odourless gas at ambient concentrations.

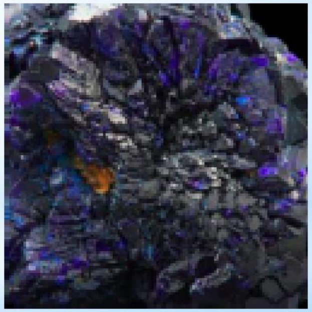
- At high concentration, it is a pale blue gas, slightly soluble in water and much more soluble in inert non-polar solvents such as carbon tetrachloride or fluorocarbons, where it forms a blue solution.

- At −112 °C temperature, it condenses to form a dark blue liquid.

- It is dangerous to allow this liquid to warm to its boiling point, because both concentrated gaseous ozone and liquid ozone can detonate.

- Below −193.2 °C, it forms a violet-black solid.

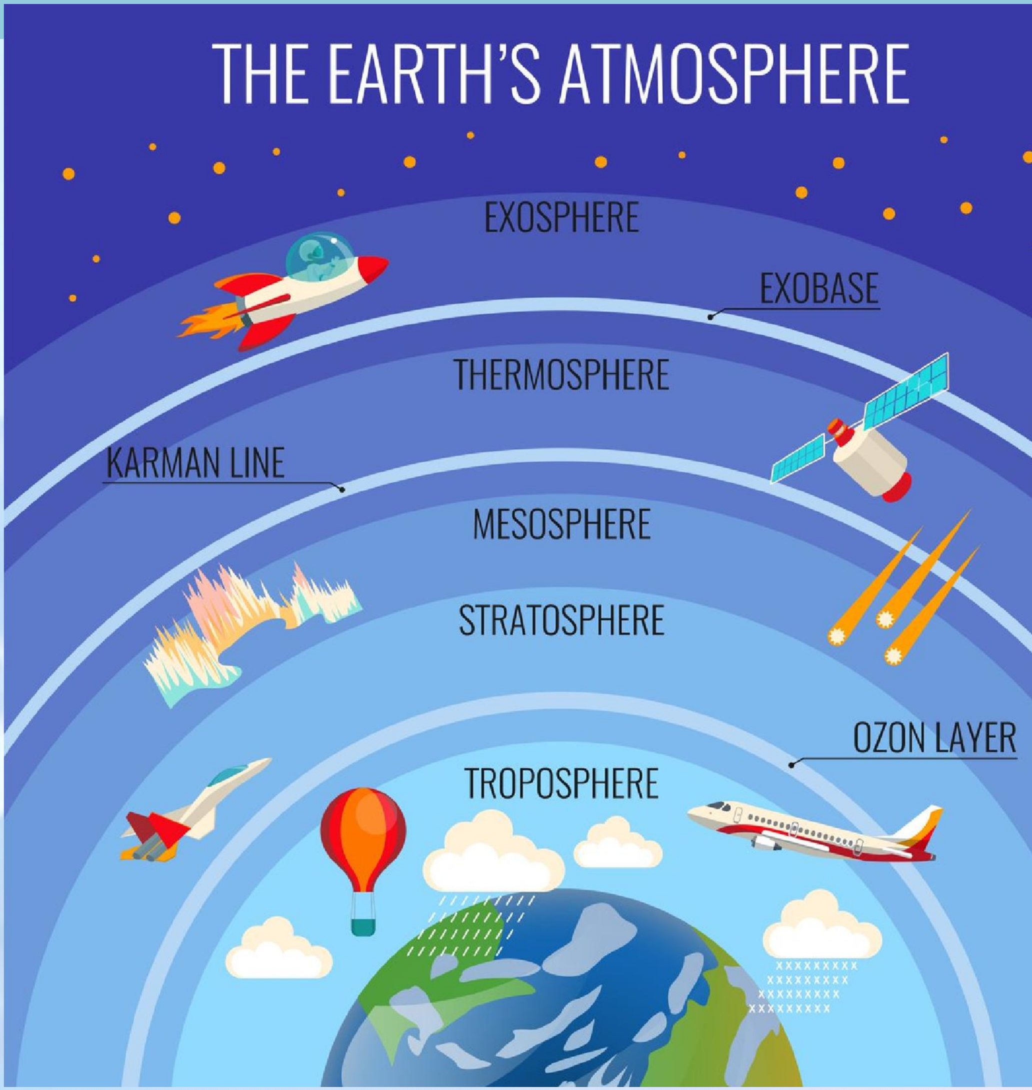




OZONE *"Can't live with it, can't live without it"*

- Most O_3 (**90%**) is found in a layer between 15 and 35 km above the surface. **This layer is called as the ozone layer.**

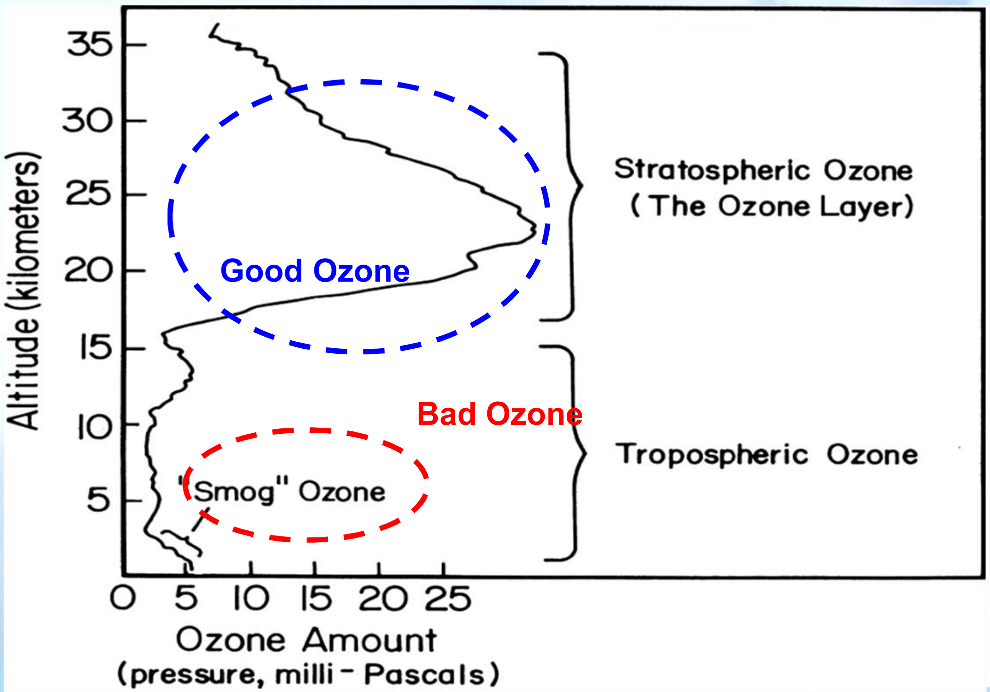
- **About 10% of ozone is present in troposphere, located at a distance of about 6-10 miles from the surface of the earth.**

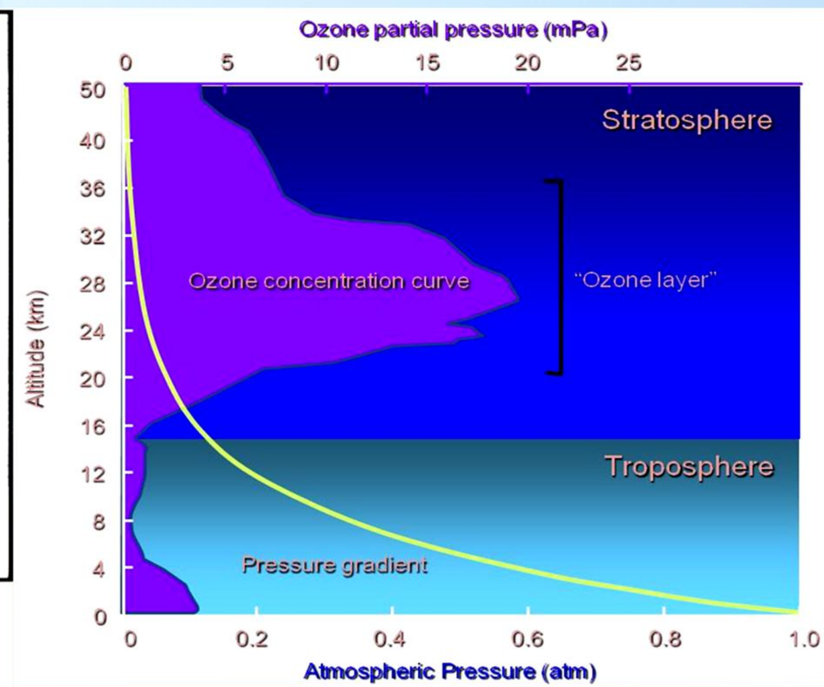


The **Kármán line** is the altitude where space begins. It is 100 km (about 62 miles) high. It commonly represents the border between the Earth's atmosphere and outer space.

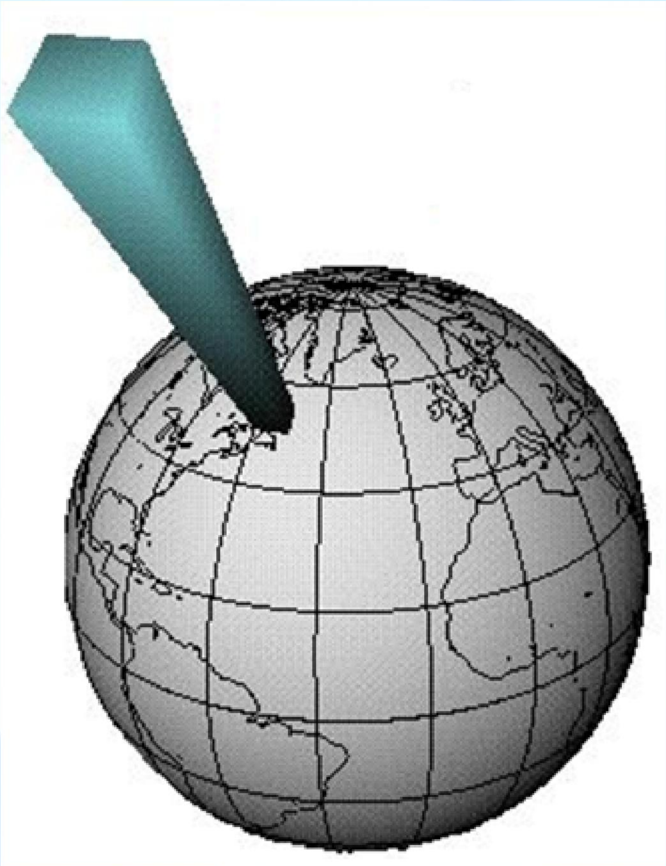
Variation of Ozone with Altitude

- Ozone concentration has significant vertical variation in the atmosphere as shown in Fig. given below. The Ozone layer can be divided into two main parts :
- **Tropospheric Ozone**
  - Surface Ozone
  - Upper Tropospheric Ozone
- **Stratospheric Ozone**



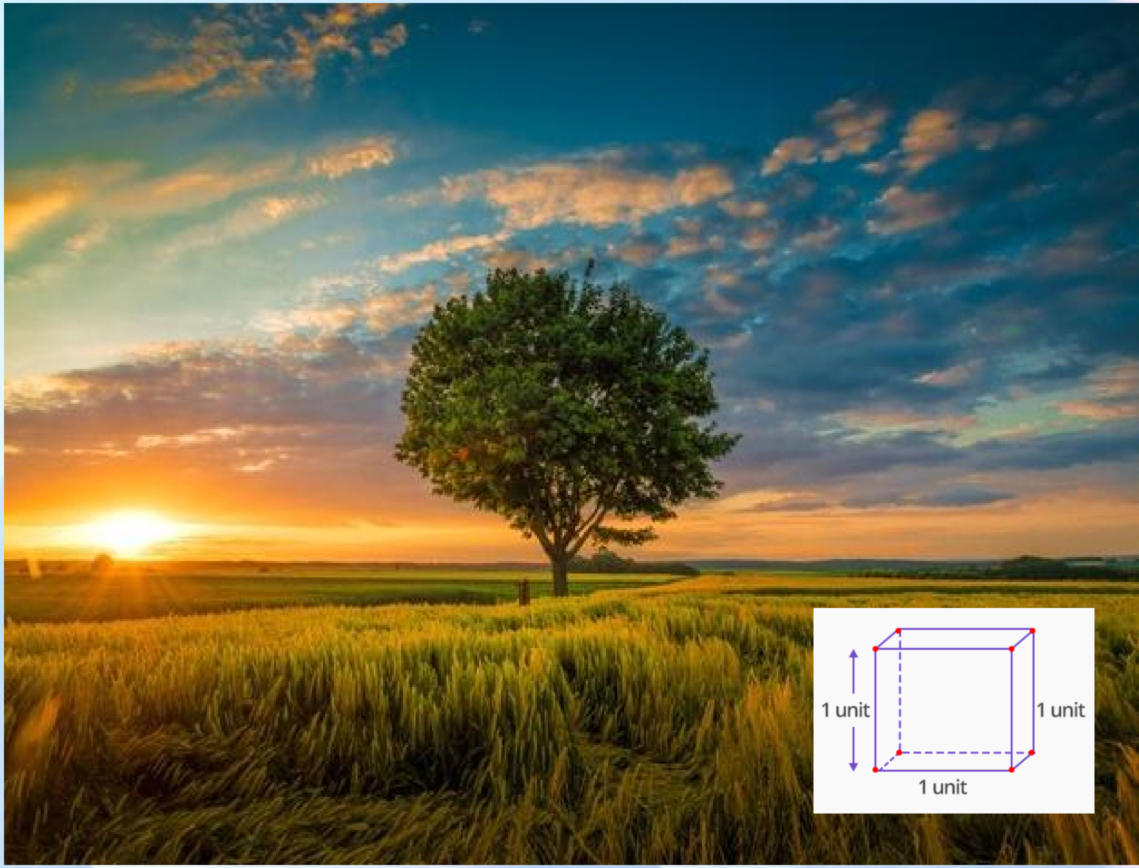


Total Column Ozone



Unit area Column from Earth's Surface to top of the atmosphere

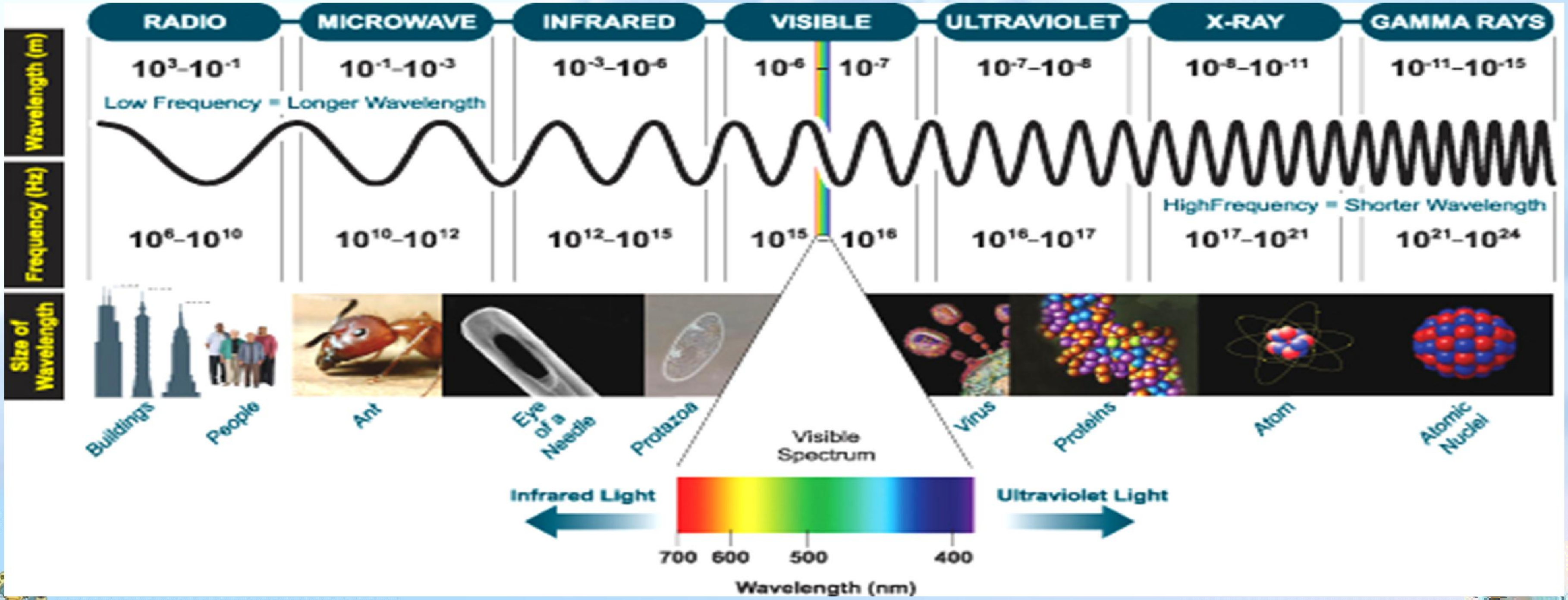
Surface Ozone



Unit Area Cube

Why is it important to life on Earth?

- On a daily basis, the sun radiates its energy toward Earth. One form of this energy is Ultra Violet radiation, also known as UV rays.
- UV rays are relatively high energy waves that provide Earth with the warmth it needs to support life as we know it.

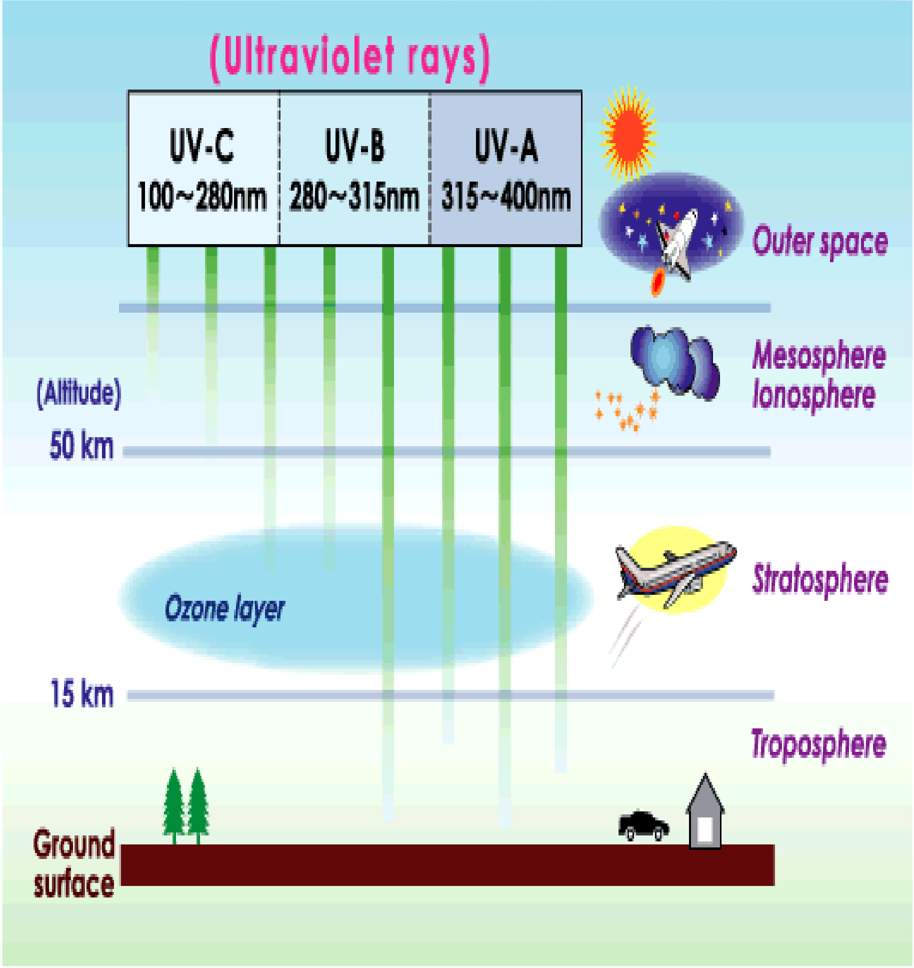


Ozone Absorption in the UV Band

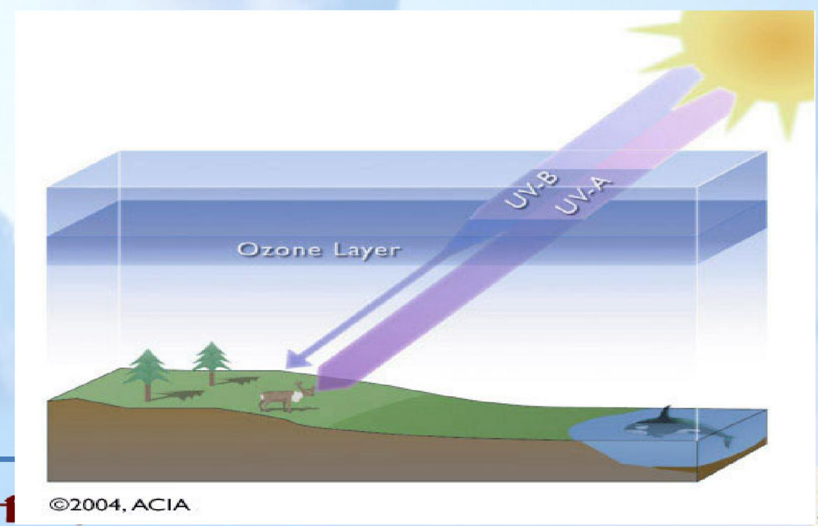
- UV radiation includes wavelengths from 200 to 400 nm

- UV-A 315 ~ 400 nm
- UV-B 280 ~ 315 nm
- UV-C 100 ~ 280 nm

- UV-C
  - Nearly all UV-C is absorbed in the upper atmosphere
- UV-B
  - 90% of UV-B is absorbed by the atmosphere, mostly by O_3
- UV-A
  - Not strongly absorbed by the atmosphere



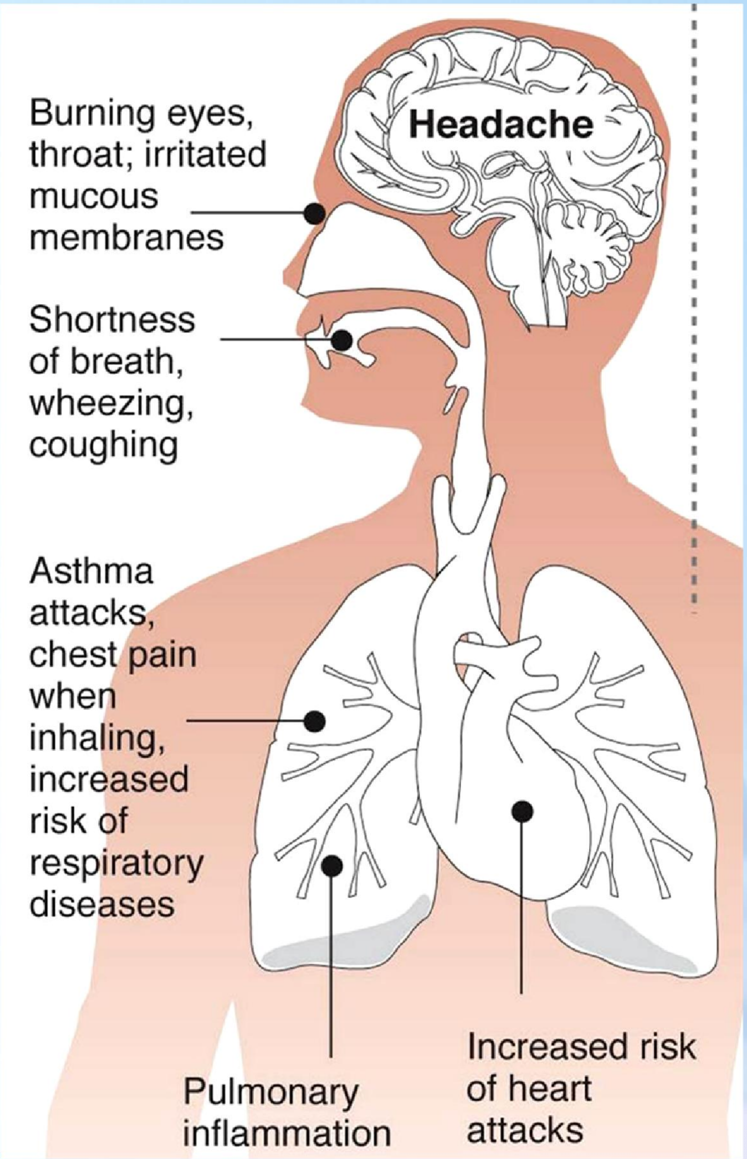
So what might life be like without the ozone layer?



Acute and Chronic Health Effects of Surface Ozone

- Ozone is known to have the many health effects at concentrations common in urban air e.g.

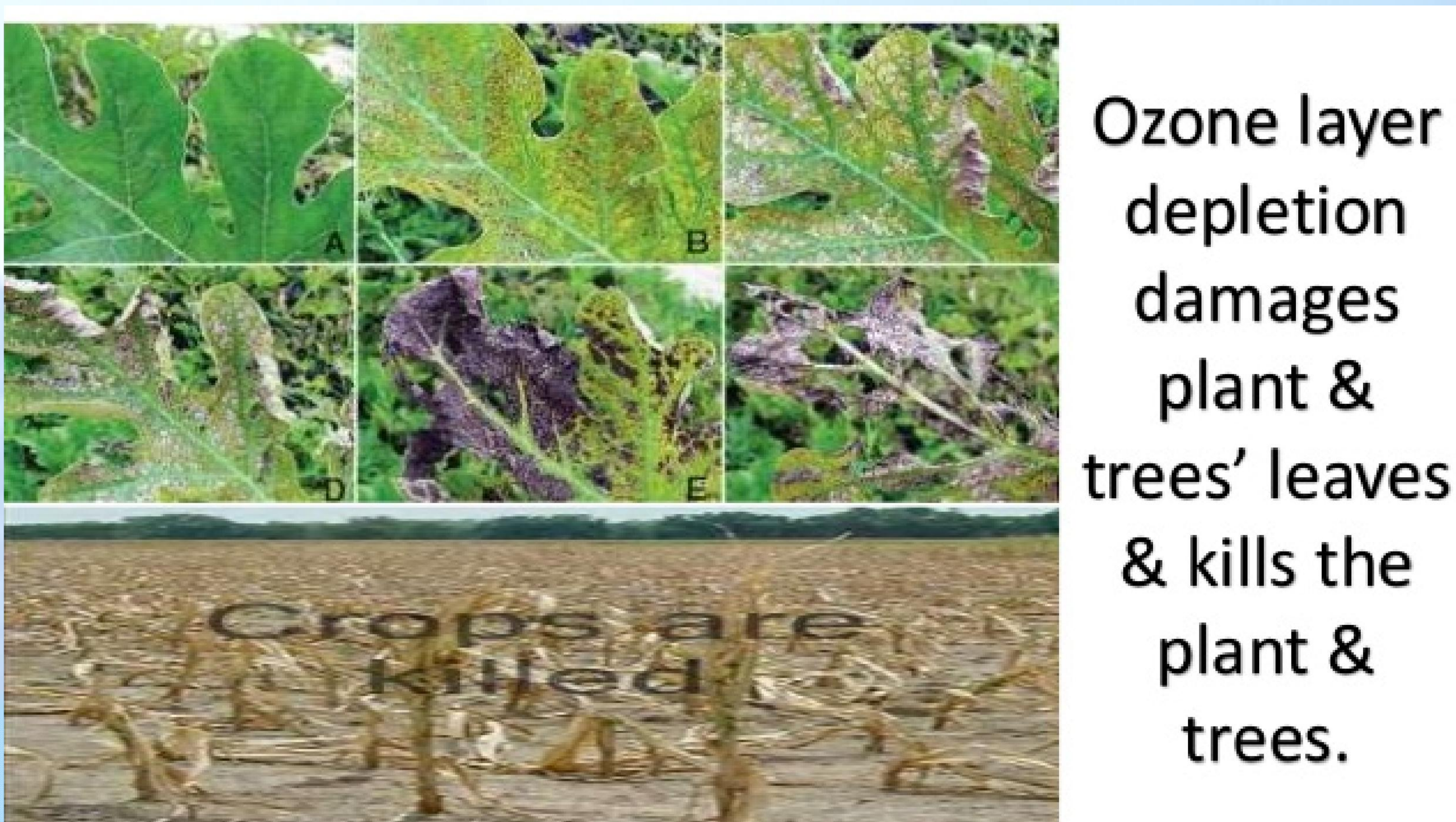
  - Irritation of the respiratory system
  - Causing coughing
  - Throat irritation, and/or uncomfortable sensation in the chest, reduced lung function, making it more difficult to breathe deeply and vigorously
  - Aggravation of asthma etc.



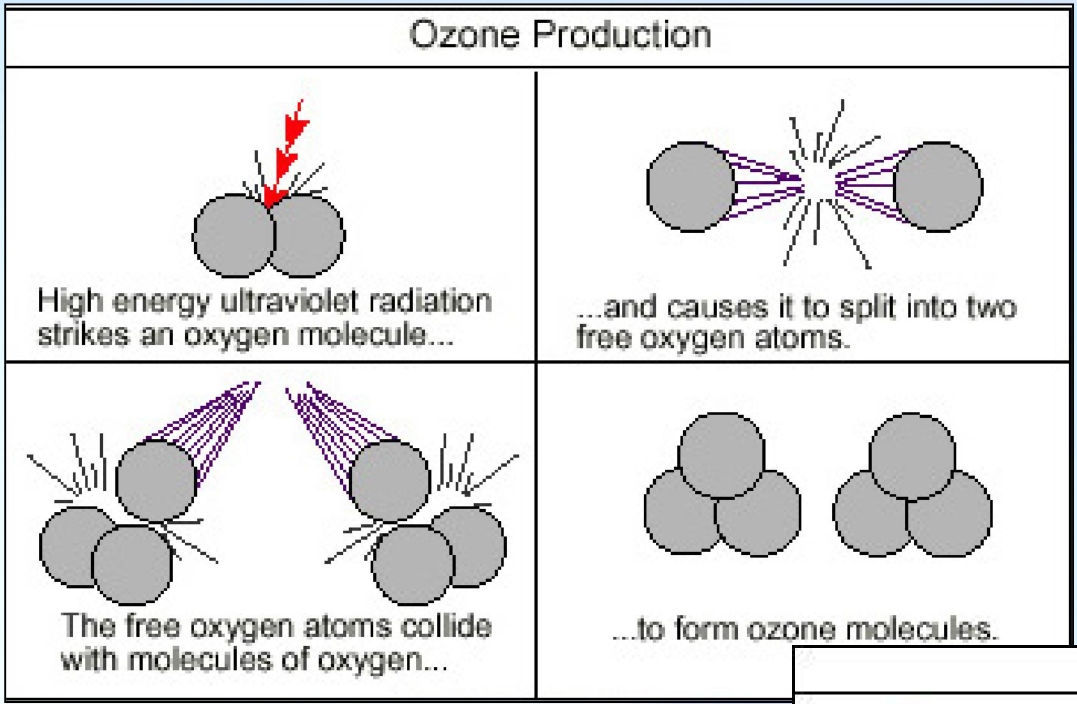
Effects of Ozone on Crops

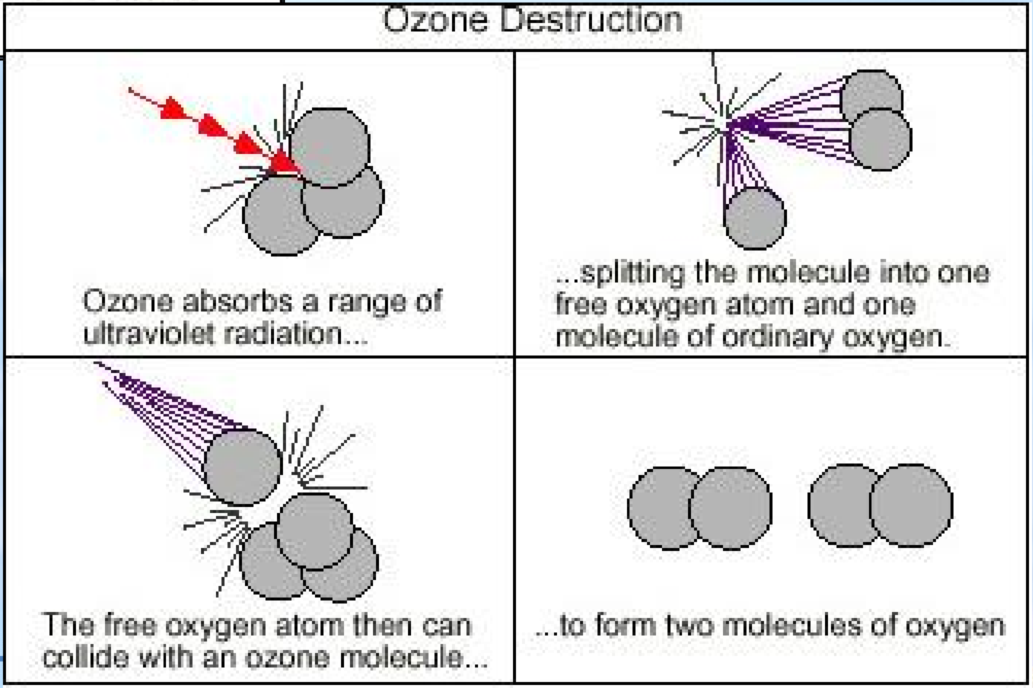
- Ozone (alone or in combination with other pollutants) accounts for ~ 90% of the air pollution-induced crop loss in the U.S.

- Impacts include leaf injury, reduced plant growth, decreased yield, changes in crop quality and decreased reproduction.



How is ozone formed in the Stratosphere?





How is ozone formed in the Stratosphere?

Chapman mechanism - Sidney Champman, 1930

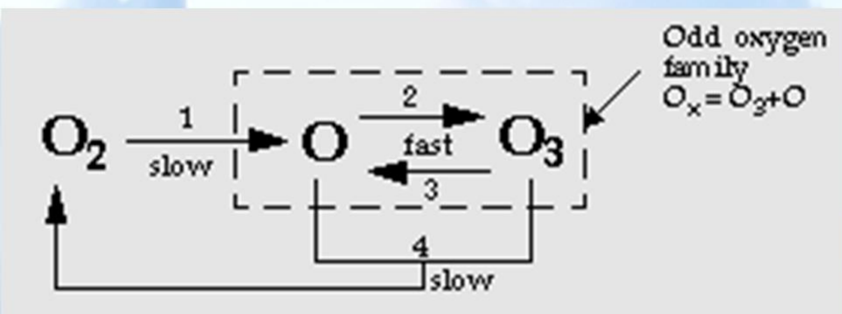
1. $O_2 + h\nu\ (\lambda < 242\ nm) \rightarrow O + O$

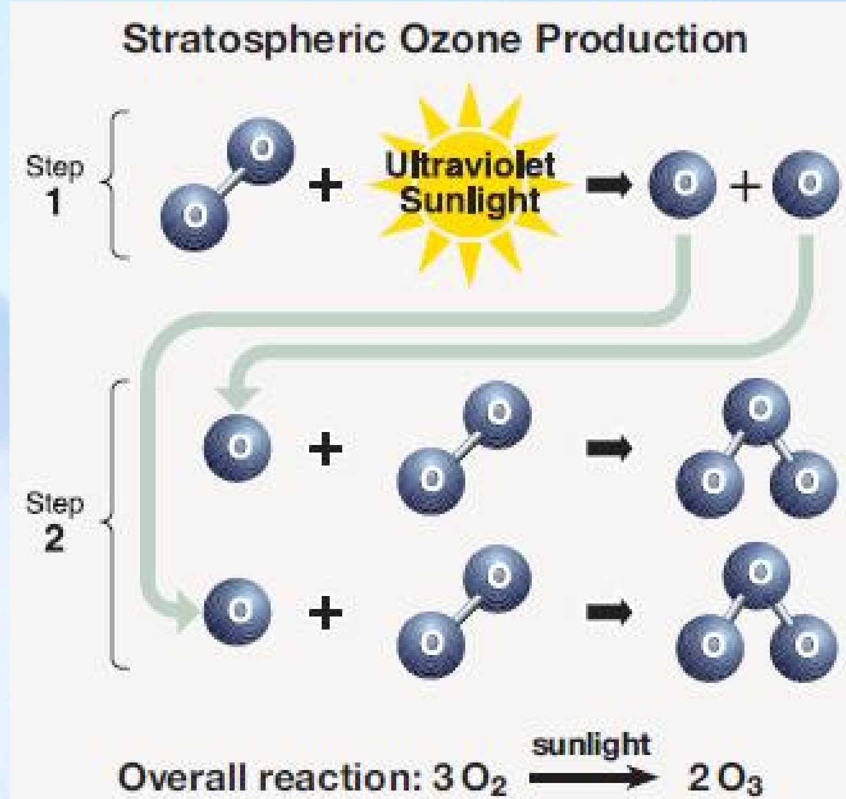
   $k_1 \sim 5 \times 10^{-11}\ s^{-1}$
2. $[O + O_2 + M \rightarrow O_3 + M]$

   $k_2 \sim 5.6 \times 10^{-34}\ cm^6\ mol^{-2}\ s^{-1}$
3. $O_3 + h\nu \rightarrow O + O_2$

   $k_3 \sim 9.5 \times 10^{-4}\ s^{-1}$
4. $O + O_3 \rightarrow 2\ O_2$

   $k_4 \sim 1 \times 10^{-15}\ cm^3\ mol^{-1}\ s^{-1}$

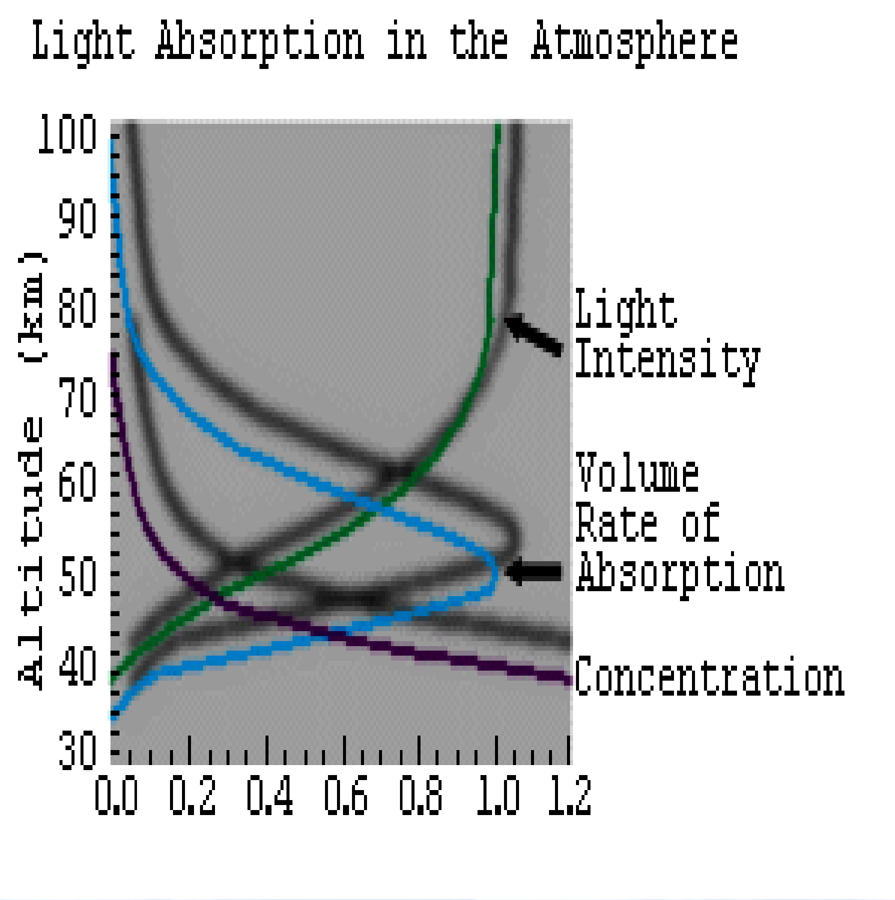




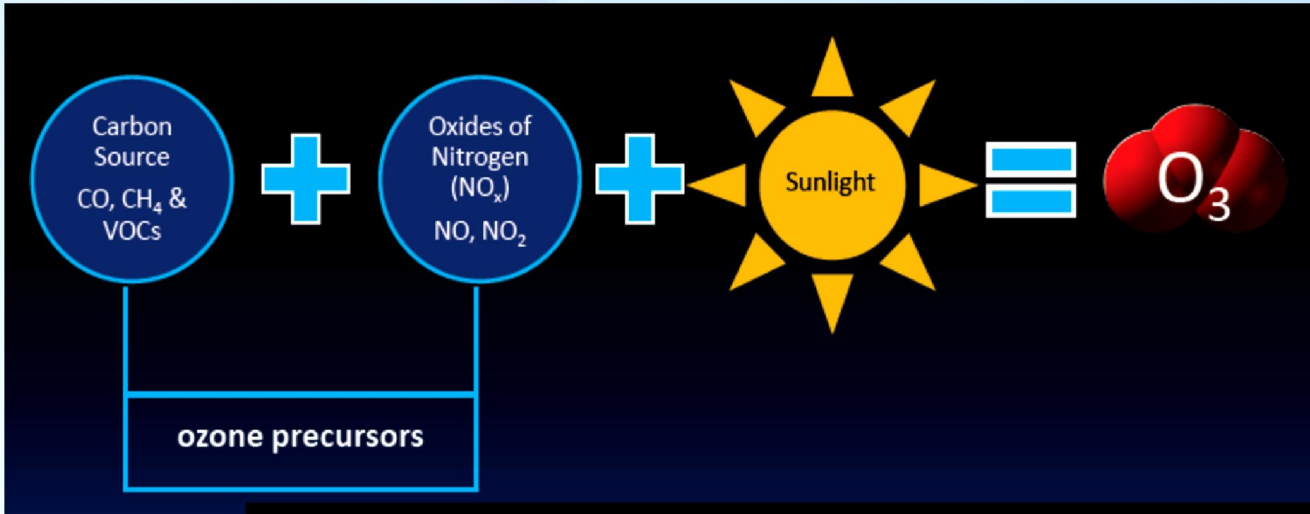
Note: k_1 and k_3 depend on intensity of light; above values are for mid day

Ozone Layering

- The two ingredients for stratospheric ozone production are molecular oxygen and UV sunlight.
- On the topside of the layer, production is limited by the availability of molecular oxygen, which drops off exponentially with altitude.
- On the bottom-side of the layer, production is limited by the availability of UV sunlight (which gets rapidly absorbed by ozone itself).
- The net effect of these two factors is to produce the characteristic layer for ozone.



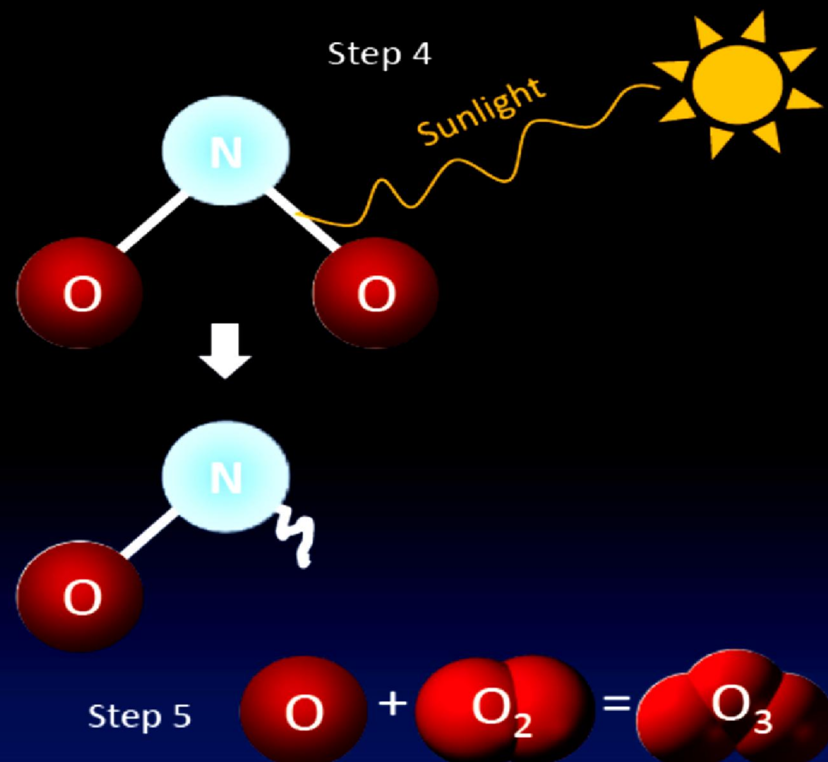
Formation of Tropospheric Ozone



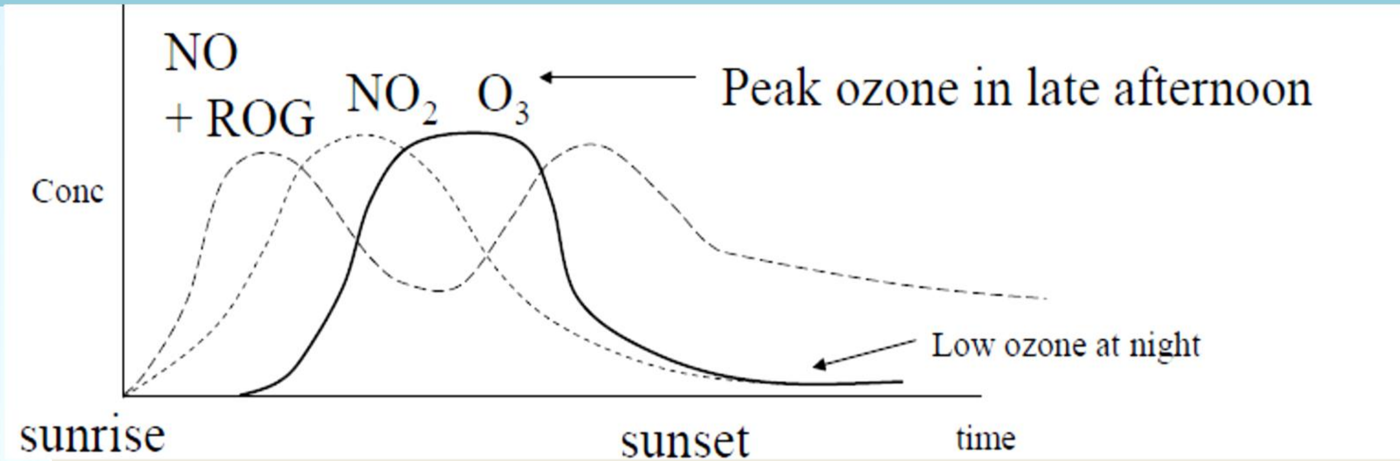
Let's take a closer look at steps 4 and 5 in the equation with CO as the precursor:

1. $CO + OH \rightarrow CO_2 + H$
2. $H + O_2 \rightarrow HO_2$
3. $HO_2 + NO \rightarrow OH + NO_2$
4. **$NO_2 + hv \rightarrow NO + O$**
5. **$O + O_2 \rightarrow O_3$**

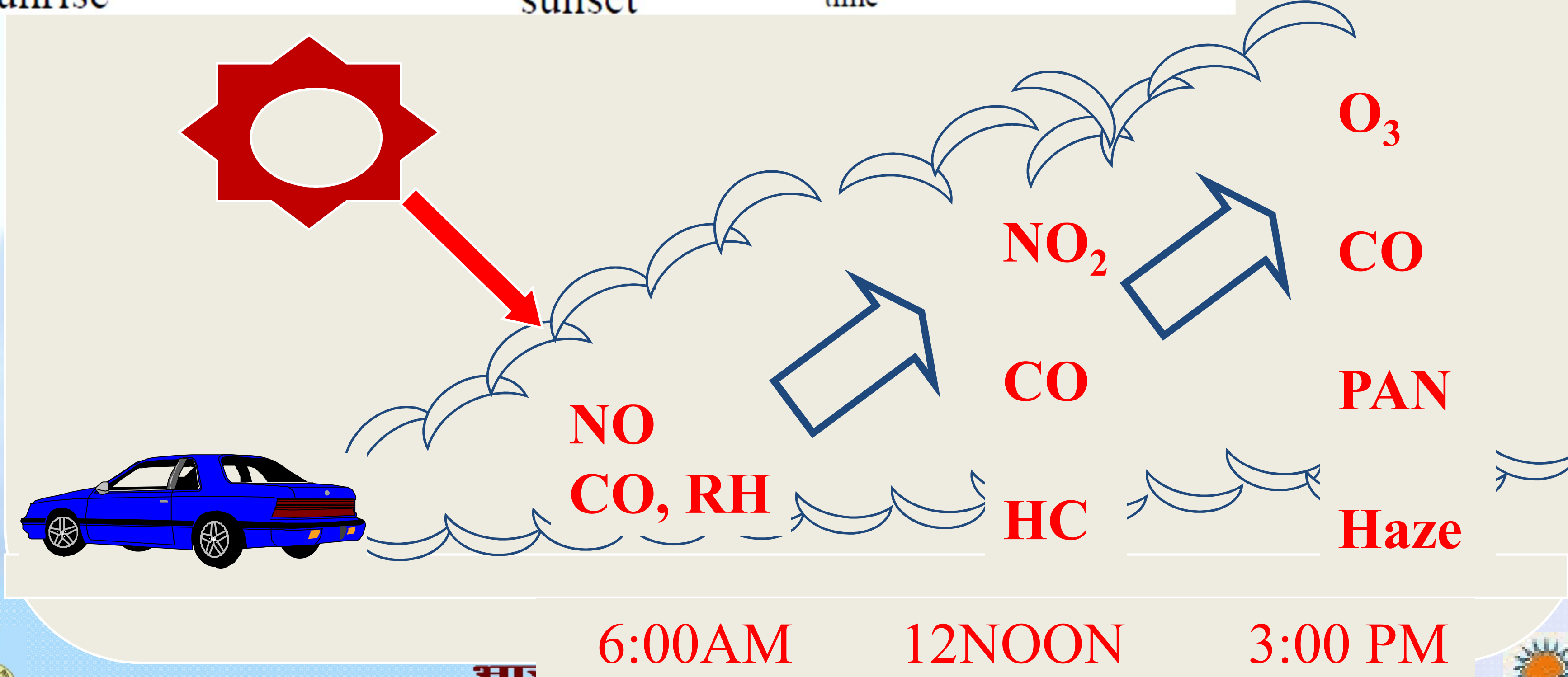
This is one of the reasons that sunlight is needed to produce ozone. Sunlight also is needed to make the OH radical.



Diurnal Variation of Surface O_3



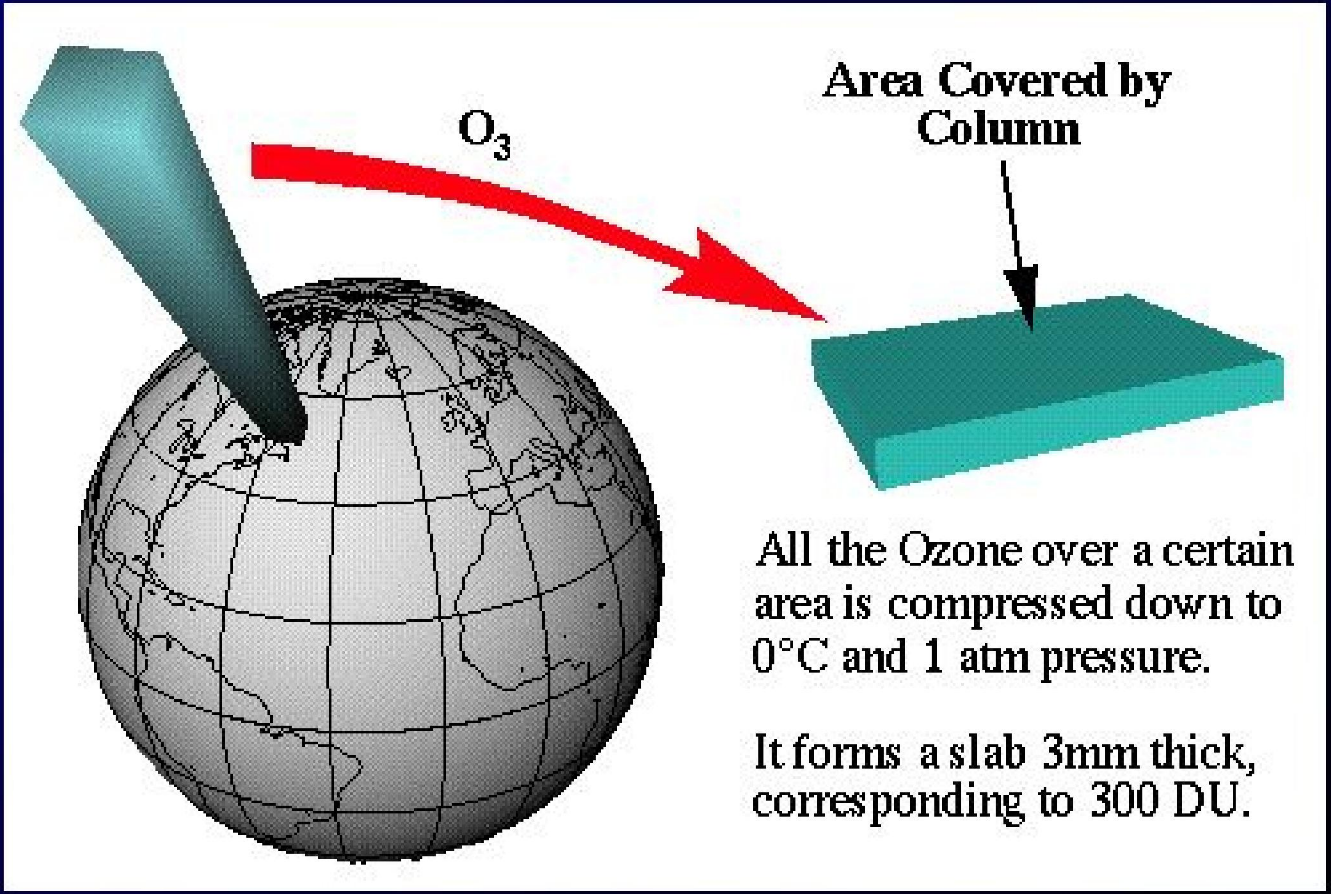
ROG : Reactive Organic Gases



Ozone Layer "Thickness"

- Conventionally, the relative abundance of O_3 in the stratosphere is measured using "Dobson units", or DU

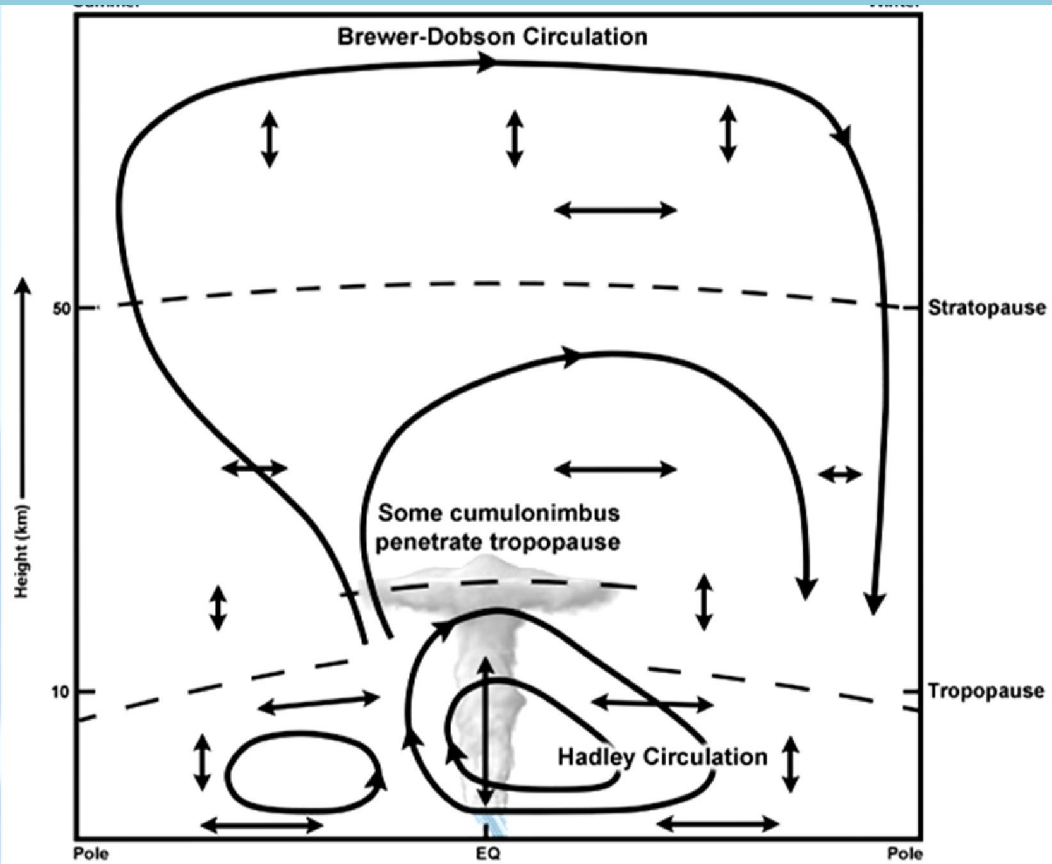
Ozone occurs in a layer, centered at around 30 km altitude, reaching a peak abundance of ~10 parts per million. Even at the peak of the ozone layer, it is still very much a trace constituent - two orders of magnitude down from CO_2 and 5 or 6 orders down from O_2 and N_2. If we were to take all the ozone in a column overhead and bring it down to sea level (room temperature and pressure) it would occupy a layer of only 3 mm in thickness.



Spatial Distribution Total Columnar Ozone over Globe

- Most ozone is formed in the tropics but is rapidly transported to higher latitudes by Brewer–Dobson large-scale circulation.

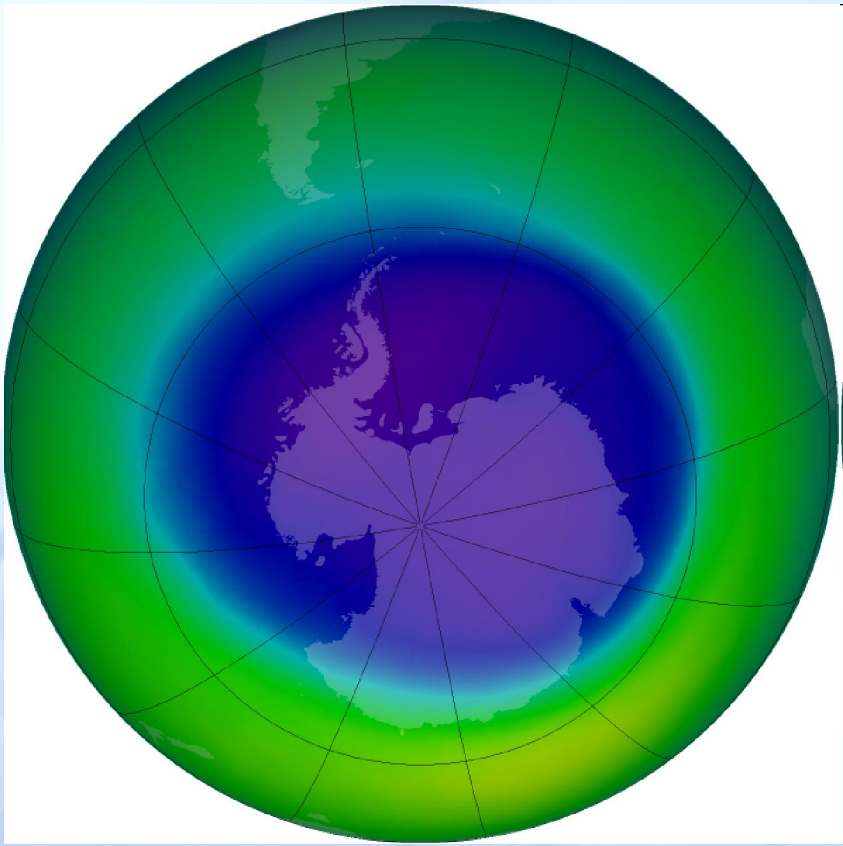
- Brewer-Dobson circulation consists of a meridional circulation in each hemisphere, with air rising into the stratosphere in the tropics (where there is little seasonal variation in ozone), moving poleward, with descent and entrainment into the troposphere at high latitudes.



This mass circulation transfers ozone from the tropical production regions and allows accumulation near the poles, accounting for the spring polar maximum (James 1994). The Brewer-Dobson circulation is driven by buoyancy waves in the atmosphere which form when air flows over high mountains and tall thunderstorms.

The “Ozone Hole”

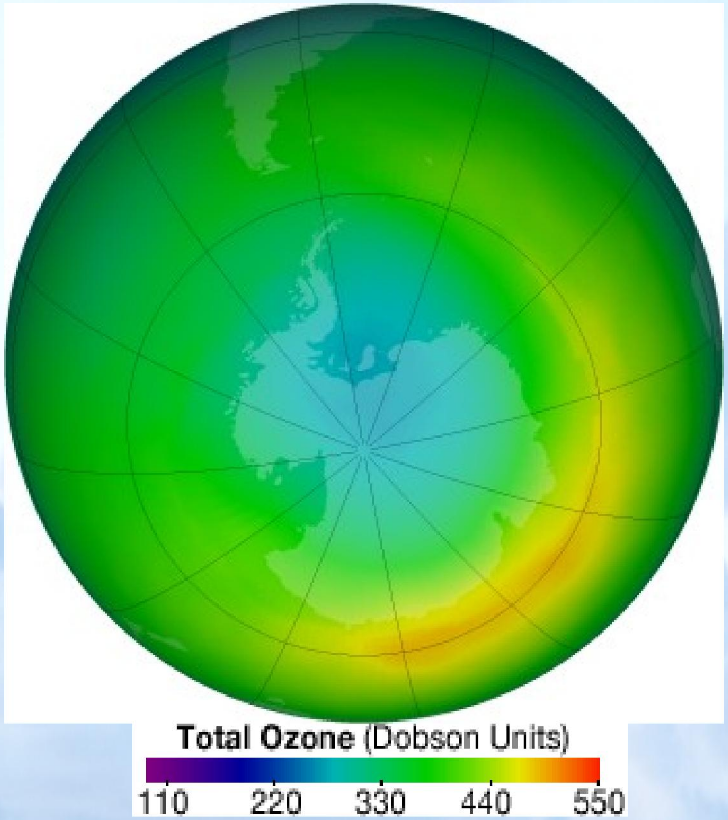
What is the “ozone hole?”



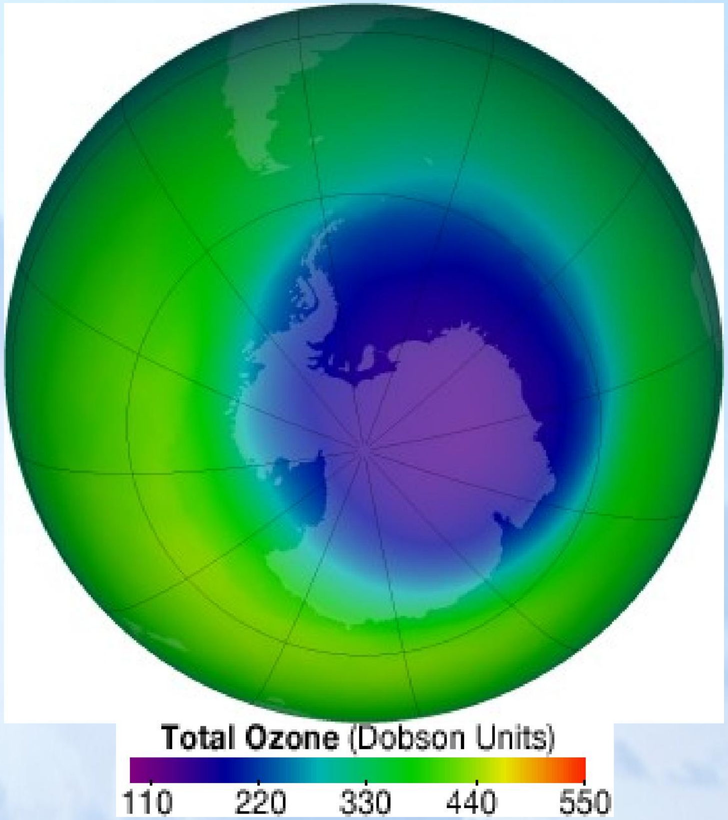
The ozone hole is the region over Antarctica with total ozone 220 Dobson Units or lower.

(The avg. total column ozone in the atmosphere is about 300 DU.)

So what about the hole in the ozone layer?



October 1979

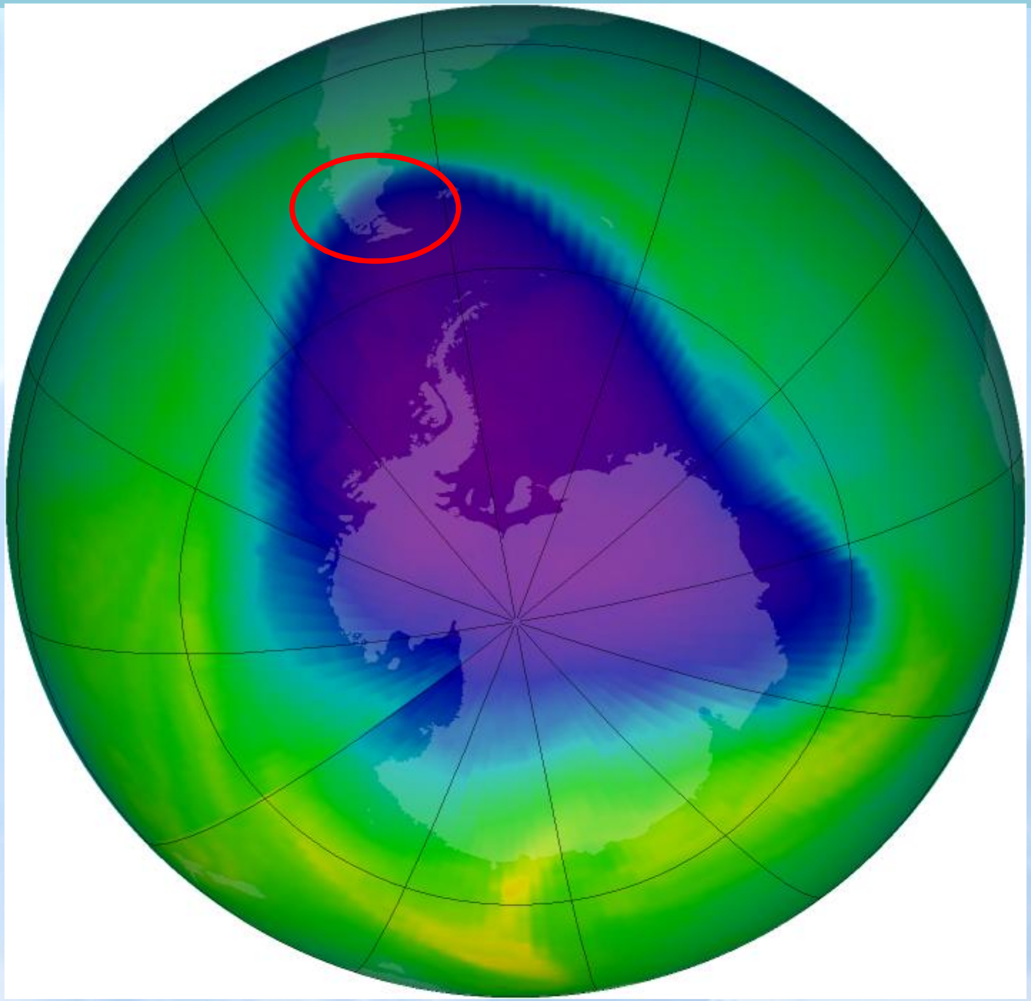


October 2007

The Ozone Hole

- Since the 1970's the ozone hole was been increasing in size over the Antarctic.

- For the first time, in September of 2000, the ozone hole became so large it actually left populated areas of southern Chile fully exposed to the effects of the Sun's UV rays.



Chile's Ozone Hole

Ozone Hole

- Each spring in the stratosphere over Antarctica (Spring in the southern hemisphere : September, October, November.), atmospheric ozone is rapidly destroyed by chemical processes.

- A vortex of winds develops around the pole and isolates the polar stratosphere. When temperatures drop below -78°C (-109°F), **thin clouds form of ice, nitric acid, and sulphuric acid mixtures.**

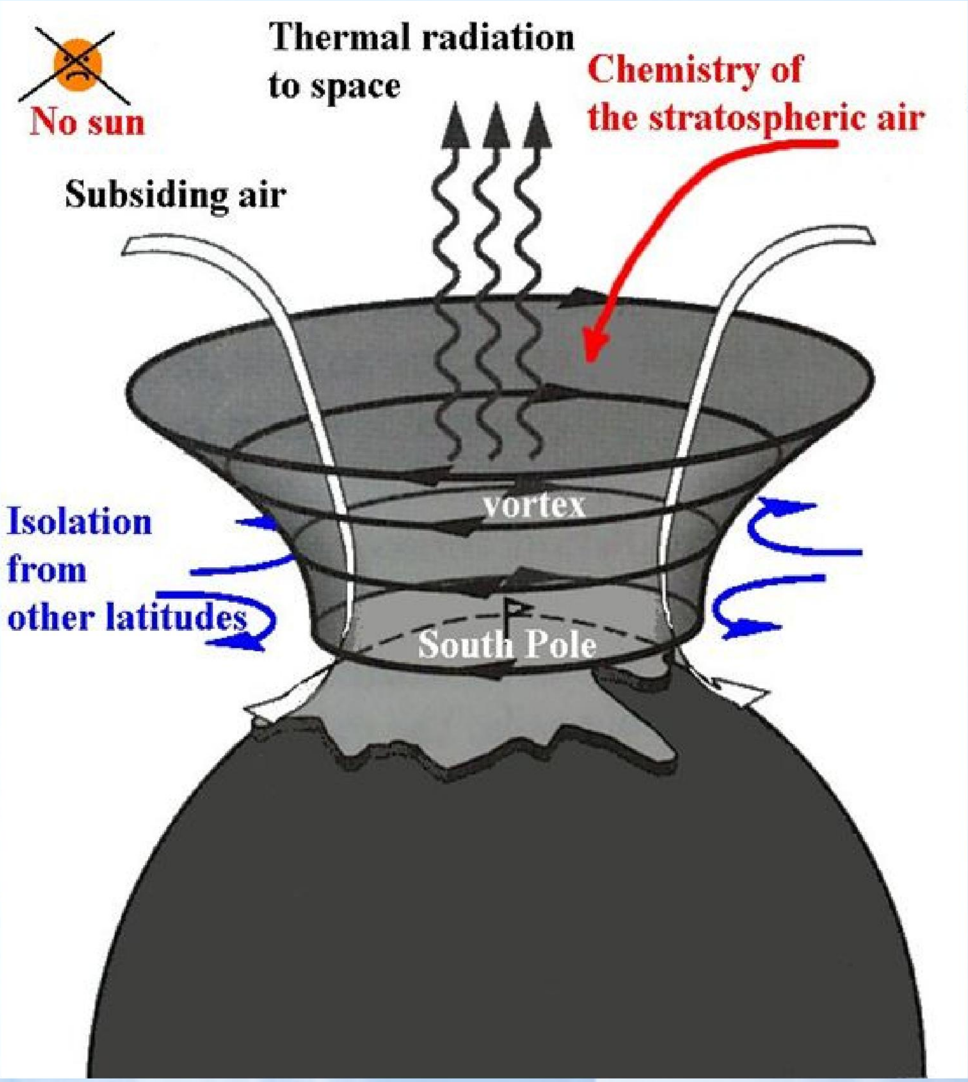
- Chemical reactions on the surfaces of ice crystals in the clouds release active forms of CFCs. Ozone depletion begins, and the ozone "hole" appears.

- Over the course of two to three months, approximately 50% of the total column amount of ozone in the atmosphere disappears. At some levels, the losses approach 90%.

- This is known as the Antarctic ozone hole. In spring, temperatures begin to rise, the ice evaporates, and the ozone layer starts to recover.

- Circulating air creates a stream of air, called the "polar vortex" in winter

- Trapped air becomes very cold during the polar night, forming polar stratospheric clouds (PSCs)



CFC Ozone Depletion Theory

- **CFCs build up, and migrate through atmosphere**
  - takes 6-8 years to reach the stratosphere, where they stay for more than 100 years
- **CFCs are broken up by sunlight emitting Cl atoms**
  - $Cl_2CF_2 + h\nu \longrightarrow ClCF_2 + Cl$
- **Cl atoms destroys ozone**

These ice particles provide a surface for reactions:

$$HCl + ClONO_2 \longrightarrow Cl_2 + HNO_3$$

HCl from the earth, and chlorine nitrate produce chlorine molecules

$$Cl_2 + h\nu \longrightarrow 2Cl$$

Spring sunlight breaks chlorine molecules into atoms

$$Cl + O_3 \longrightarrow ClO + O_2$$

Chlorine atoms destroy ozone

$$ClO + O_3 \longrightarrow Cl + 2O_2$$

Chlorine monoxide also destroys ozone

Chemical equation

$CFCl_3$ + UV Light ==> $CFCl_2$ + Cl
Cl + O_3 ==> ClO + O_2
ClO + O ==> Cl + O_2

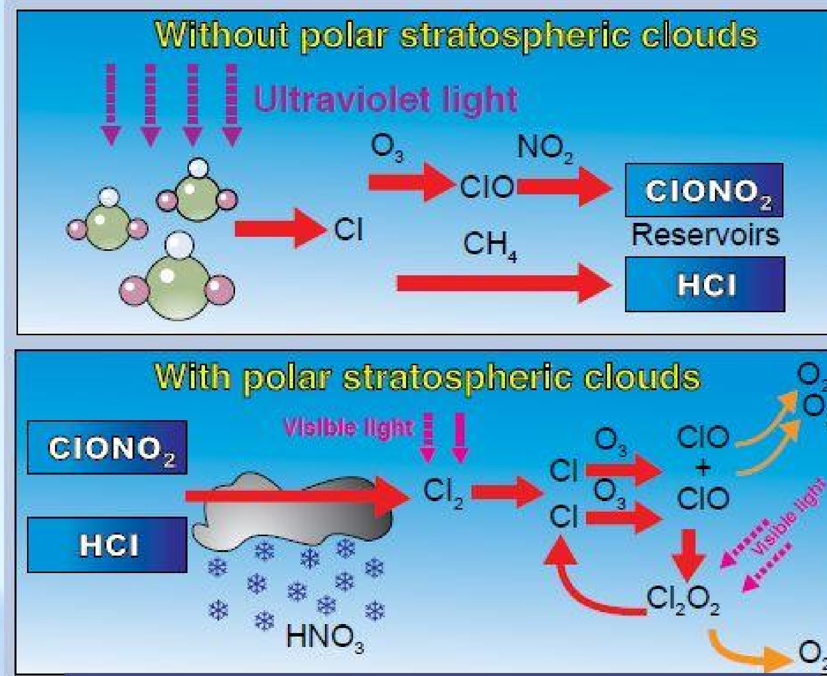
The free chlorine atom is then free to attack another ozone molecule :

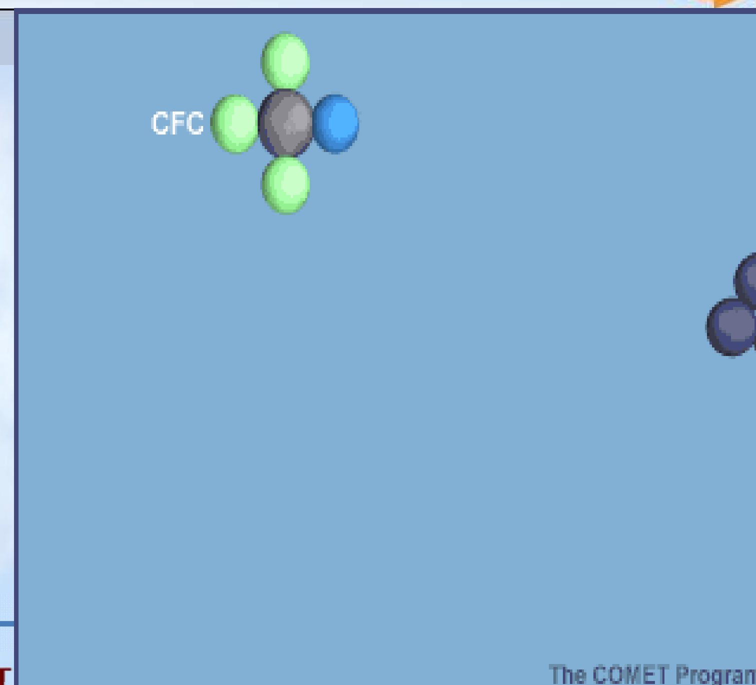
Cl + O_3 ==> ClO + O_2
ClO + O ==> Cl + O_2

and again ...

Cl + O_3 ==> ClO + O_2
ClO + O ==> Cl + O_2

and again... for thousands of times.

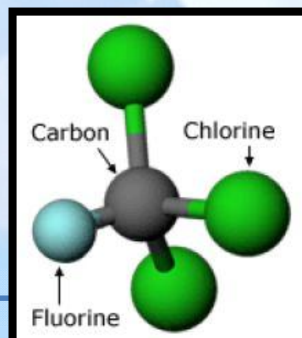




Ozone Depletion in the Antarctic Springtime

1) HCl + $ClONO_2$ → HNO_3 + Cl_2
2) Cl_2 + sunlight → Cl + Cl
3) 2Cl + O_3 → 2ClO + $2O_2$
4) 2ClO + 2O → 2Cl + $2O_2$

NET = $2O_3$ to $3O_2$

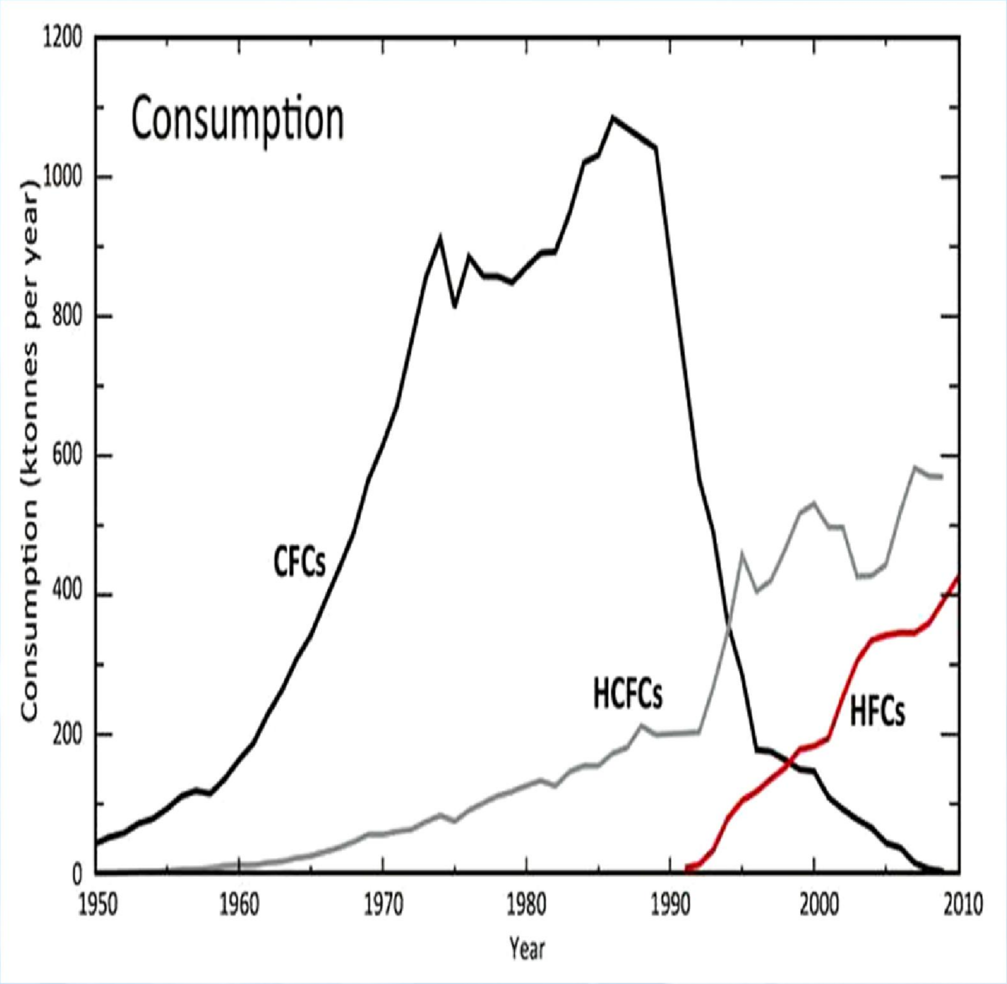


How are we as humans affecting the ozone layer?

- Since 1928, Chlorofluorocarbons have been produced, originally as nonflammable refrigerants for use in refrigerators, and eventually for use in fire extinguishers, dry cleaning agents, pesticides, degreasers, adhesives, and as propellants for aerosol products.

- As these CFCs have been released into the atmosphere, the level of ozone in the stratosphere has decreased.

- CFCs have an estimated lifespan of more than 100 years.



Various sources

- Since 1928, Chlorofluorocarbons have been produced, originally as nonflammable refrigerants for use in refrigerators, and eventually for use in fire extinguishers, dry cleaning agents, pesticides, degreasers, adhesives, and as propellants for aerosol products.

- As these CFCs have been released into the atmosphere, the level of ozone in the stratosphere has decreased.

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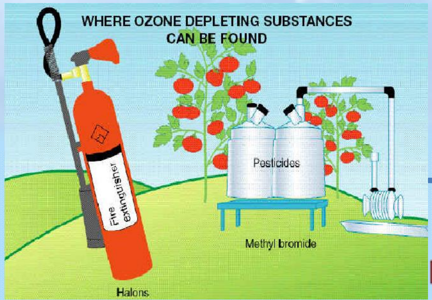
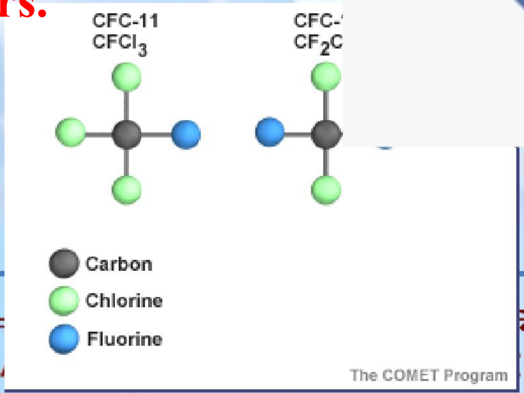
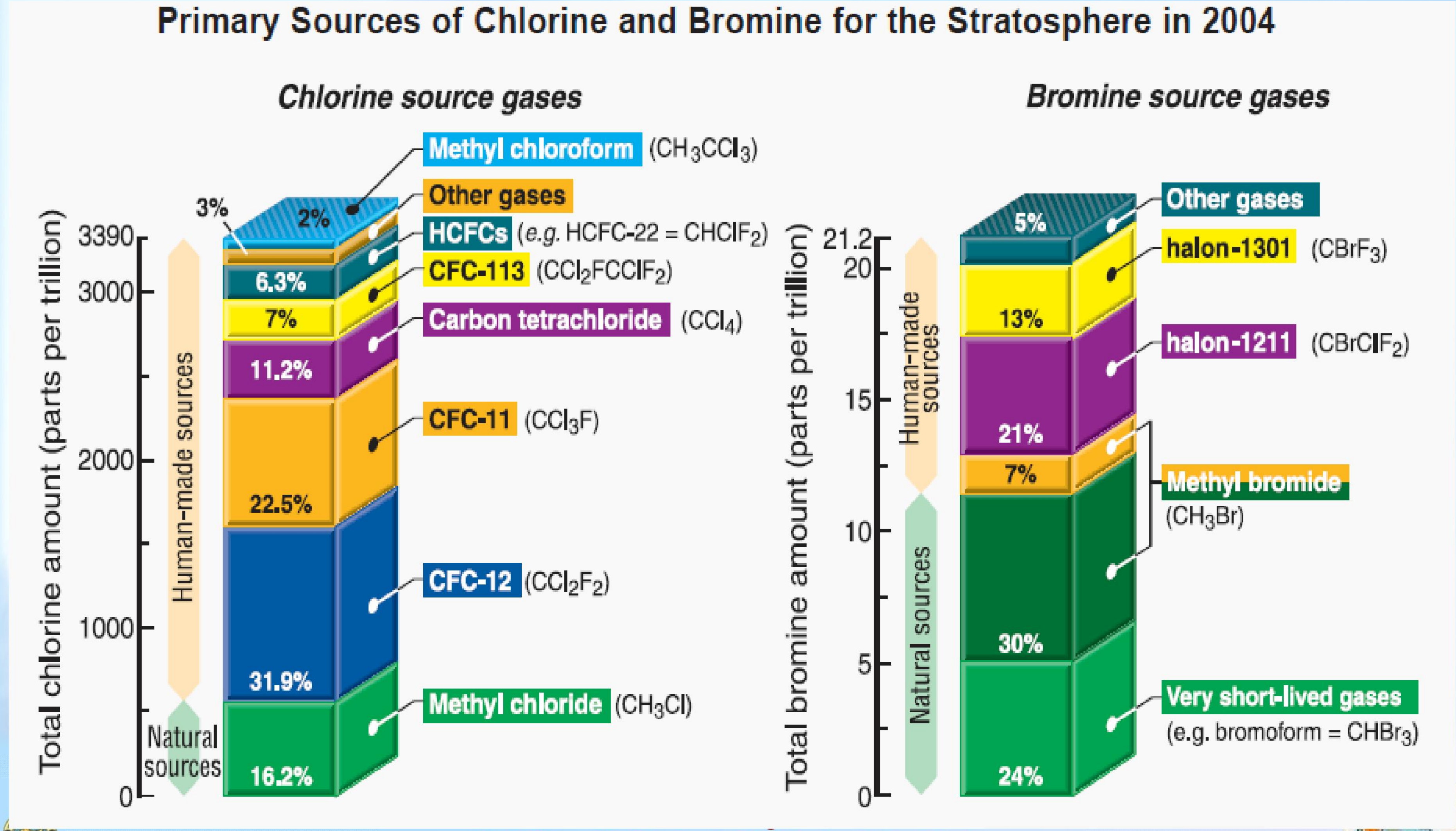




Ozone-Depleting Substance(s) (ODS):

CFCS, HCFCS, HALONS, METHYL BROMIDE, CARBON TETRACHLORIDE, METHYL CHLOROFORM



How does ozone depletion affect global warming and ultimately climate change?

- As ozone levels in the stratosphere are depleted, more solar radiation penetrates the Earth's atmosphere.
- This affect results in an increase in solar radiation reaching the Earth's surface adding to an increase in surface temperature.
- In turn, global warming actually results in a warming of the troposphere, but a cooling of the stratosphere, hindering the ozone layer's natural chemistry for repairs.

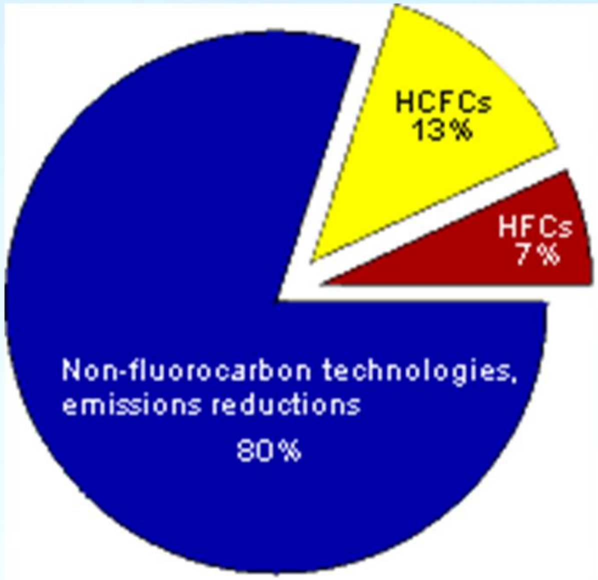
So what are we doing about it?

- After the discovery of ozone depletion in the late 1970's, many countries agreed that something must be done worldwide to stop the production of man-made, ozone harmful products.

- The international community adopted the Vienna Convention in 1985 followed by the Montreal Protocol in 1987.

- The latest reports confirm that it has led to the phasing out of about 95% of the consumption of ozone-depleting substances (ODS) listed in the agreement. In turn, this has led to the prospect of the ozone layer recovering by 2050 to 2075.

- Furthermore, the phasing out of ozone-depleting substances has helped to fight climate change since many of these chemicals are also powerful greenhouse gases. According to a recent study, the phasing out of substances under the Protocol led to more reductions in greenhouse gases than what is foreseen under the Kyoto Protocol.



Replacement of CFCs in Developed Countries

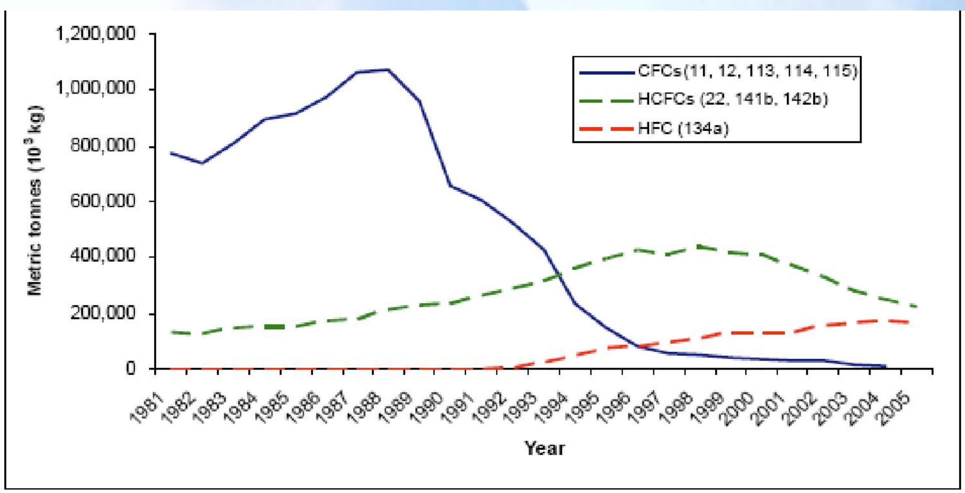
80% Reduction in Fluorocarbon Use, and Hence Emissions Reduction Has Been Achieved

CFC Replacements

The success of ozone protection has been possible because science and industry have been able to develop and commercialize alternatives to ozone-depleting chemicals.

- Substitutes for CFCs in electronics: Carbon Dioxide
- Substitutes for CFCs foam-blowing: Water, Carbon Dioxide, Hydrocarbons, Hcfcs
- Substitutes for CFCs in refrigeration and air-conditioning: HCFCs initially, Hydrofluorocarbons (Hfcs), Hydrocarbons, And Ammonia
- Substitutes for methyl bromide: 1,3-dichloropropene, Chloropicrin, Methyl Iodide and Sulfuryl Fluoride

Worldwide production of CFCs, HCFCs, and HFCs



There are currently no replacements for Halons as fire retardants in civilian aircraft. These are no longer being manufactures but there are global stockpiles.

Ozone Measurement in IMD

- The first Columnar Ozone Observations were made in 1928-29 at Kodaikanal as part of Dobson's worldwide Total Ozone Measurements.
- IMD acquired first Dobson Spectrophotometer in 1940.
- Development of Indian Ozone sonde by Instrument division of IMD in 1964. Vertical Ozone profiles using indigenous balloon-borne ozone-sondes were observed fortnightly at 4 stations including Maitri.
- IMD's National Ozone Centre at New Delhi is designated as Secondary Regional Ozone Centre for Regional Association II (Asia) of the World Meteorological Organisation.
- The centre maintains and controls a network of ozone monitoring stations including Maitri (Antarctica).
- Total ozone is measured with Dobson/Brewer Ozone Spectrophotometer from five locations including Maitri (Antarctica).

Ozone Measurement in IMD

- Surface ozone measurements using electrochemical method had recorded continuously at 7 stations Srinagar, Pune, Nagpur, New Delhi, Kodaikanal, Trivandrum and Maitri.
- IMD had also installed Serinus 10 Surface UV Ozone Analyzers at nine locations e.g. New Delhi, Pune, Nagpur, Kodaikanal, Guwahati, Portblair, Ranichouri, Thiruvananthpuram, Antarctica and Varanasi.
- Ozone data is being regularly sent to World Ozone Data Centre, Canada for archival. The data is available in the internet on: http://www.woudc.org.
- IMD is collaborating at both the national and international levels through international inter-comparison of instruments, conducting experiments to study tropospheric ozone over the Indian ocean, comparing satellite data with ground truth and studying diurnal and seasonal variations in the ozone layer over Indian and Russian stations.

History of Ozone Program in India

1928 — First Total Ozone Observation in India
The first Total Columnar Ozone Observations in India were made in 1928-29 at Kodaikanal as part of Dobson's worldwide Total Ozone Measurements by British Scientists.

1940 — First Dobson Spectrophotometer in IMD
IMD acquired first Dobson Spectrophotometer in 1940.

1955 — Dobson Observations at Srinagar & New Delhi
IMD started Daily Observations by Dobson Spectrophotometer at Srinagar & New Delhi in November, 1955.

1957 — Dobson Observations at Kodaikanal
IMD started Daily Observations by Dobson Spectrophotometer at Kodaikanal in July, 1957.

1963 — Dobson Observations at Varanasi
IMD started Daily Observations by Dobson Spectrophotometer at Varanasi in December, 1963.

1966 — First Surface Ozone Observation at Pune
IMD started surface ozone observation at Pune in September, 1966 using ECC Analyzer.

1971 — First Vertical Ozone-sonde Observations by IMD
IMD started first Vertical zone-sonde observations in 1971 at New Delhi, Pune & Thiruvananthapuram.

1972 — Surface Ozone Observations at New Delhi
IMD started surface ozone observation at New Delhi in November, 1972 using ECC Analyzer.

1973 — Dobson Observations at Pune & Surface Ozone at Thiruvananthapuram
IMD started Daily Observations by Dobson Spectrophotometer at Pune in March, 1973 and Surface ozone observations at Thiruvananthapuram in March 1993.

1976 — Surface Ozone Observations at Kodaikanal
IMD started surface ozone observation at Kodaikanal in June, 1976 using ECC Analyzer.

1978 — Surface Ozone Observations at Nagpur
IMD started surface ozone observation at Nagpur in April, 1978 using ECC Analyzer.

1978 — Surface Ozone Observations at Nagpur
IMD started surface ozone observation at Nagpur in April, 1978 using ECC Analyzer.

1981 — Surface Ozone Observations at Srinagar
IMD started surface ozone observation at Srinagar in July, 1978 using ECC Analyzer which continued up to August, 1988.

1986 — Vertical Ozone-sonde at Antarctica
IMD started Vertical zone-sonde observations in 1986 at Antarctica.

1989 — First Brewer Spectrophotometer in IMD
IMD acquired first Brewer Spectrophotometer in 1989 and installed it at New Delhi.

1994 — Brewer Spectrophotometer at Pune
IMD installed Brewer Spectrophotometer at Pune in 1994.

1999 — Brewer Spectrophotometer in Antarctica
IMD installed Brewer Spectrophotometer at Maitri, Antarctica in 1999.

2016 — Surface Ozone Observations at Jammu
IMD started surface ozone observation at Jammu in November, 2016.


THIS IS THE SOLUTION WE'VE DEVISED FOR DEALING WITH THE FLOODING CAUSED BY CLIMATE CHANGE.
Chris Madden

Thank You