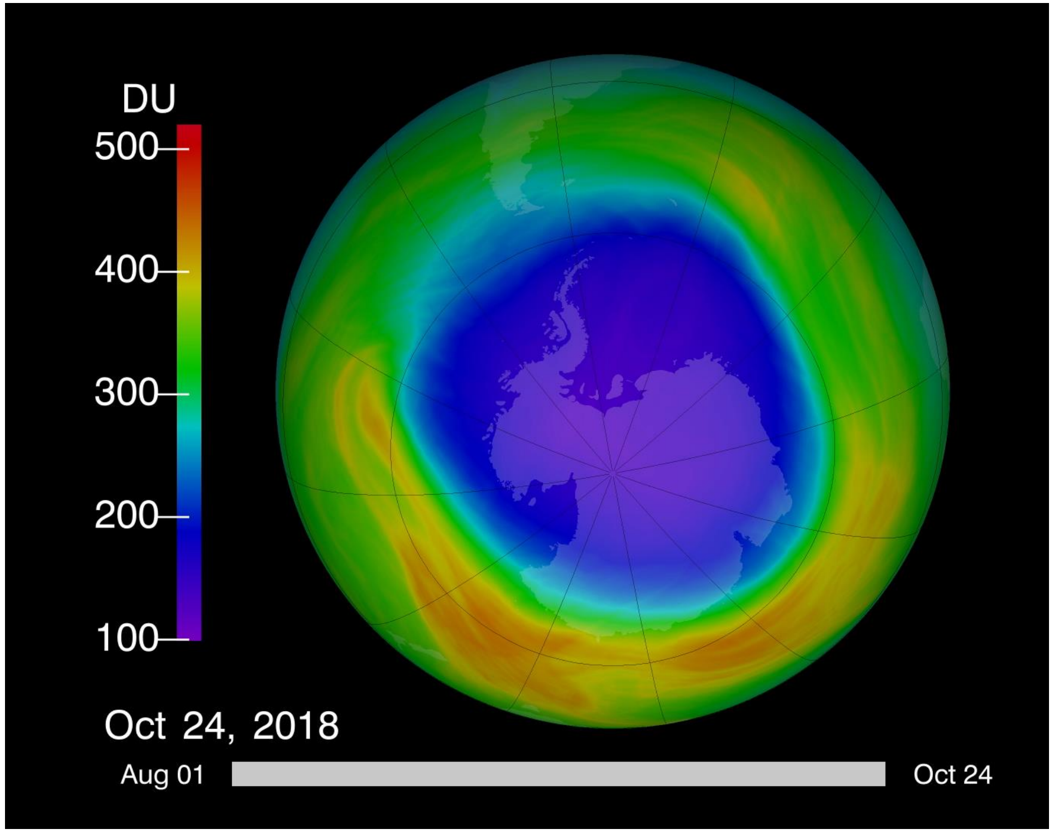


7.4 OZONE DEPLETION

College Board Topics 9.1 and 9.2

Related Reading: pg. 468 - 472

Learning Objectives and Essential Knowledge

ENDURING UNDERSTANDING

STB-4

Local and regional human activities can have impacts at the global level.

LEARNING OBJECTIVE

STB-4.A

Explain the importance of stratospheric ozone to life on Earth.

ESSENTIAL KNOWLEDGE

STB-4.A.1

The stratospheric ozone layer is important to the evolution of life on Earth and the continued health and survival of life on Earth.

STB-4.A.2

Stratospheric ozone depletion is caused by anthropogenic factors, such as chlorofluorocarbons (CFCs), and natural factors, such as the melting of ice crystals in the atmosphere at the beginning of the Antarctic spring.

STB-4.A.3

A decrease in stratospheric ozone increases the UV rays that reach the Earth's surface. Exposure to UV rays can lead to skin cancer and cataracts in humans.

ENDURING UNDERSTANDING

STB-4

Local and regional human activities can have impacts at the global level.

LEARNING OBJECTIVE

STB-4.B

Describe chemicals used to substitute for chlorofluorocarbons (CFCs).

ESSENTIAL KNOWLEDGE

STB-4.B.1

Ozone depletion can be mitigated by replacing ozone-depleting chemicals with substitutes that do not deplete the ozone layer. Hydrofluorocarbons (HFCs) are one such replacement, but some are strong greenhouse gases.

SUGGESTED SKILL

Concept Explanation

1.A

Describe environmental concepts and processes.

SUGGESTED SKILL

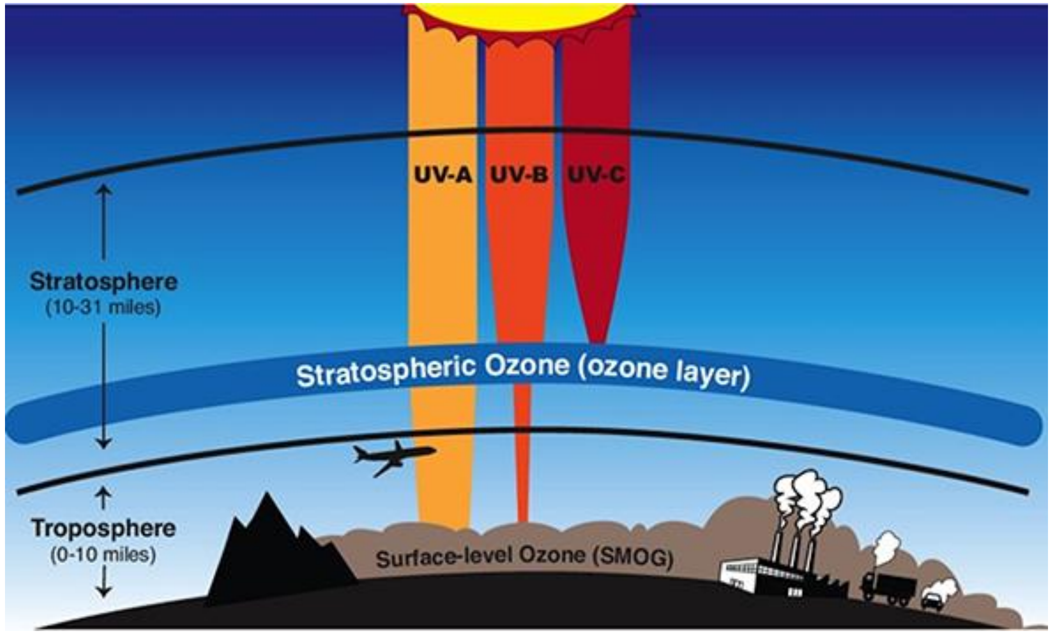
Environmental Solutions

7.B

Describe potential responses or approaches to environmental problems.

The stratospheric ozone layer

- The ***ozone layer*** is a region of the lower stratosphere, containing the greatest concentration of ozone (12 ppm).
  - Absorbs incoming ultraviolet (UV-C and most UV-B) radiation.
  - Protects life from radiation's damaging effects



- There is a natural balance in the formation and decomposition of stratospheric ozone.
  - ***Photodissociation*** of O_2 by UV-C radiation splits *molecules* of O_2 into two oxygen (O) *atoms*.

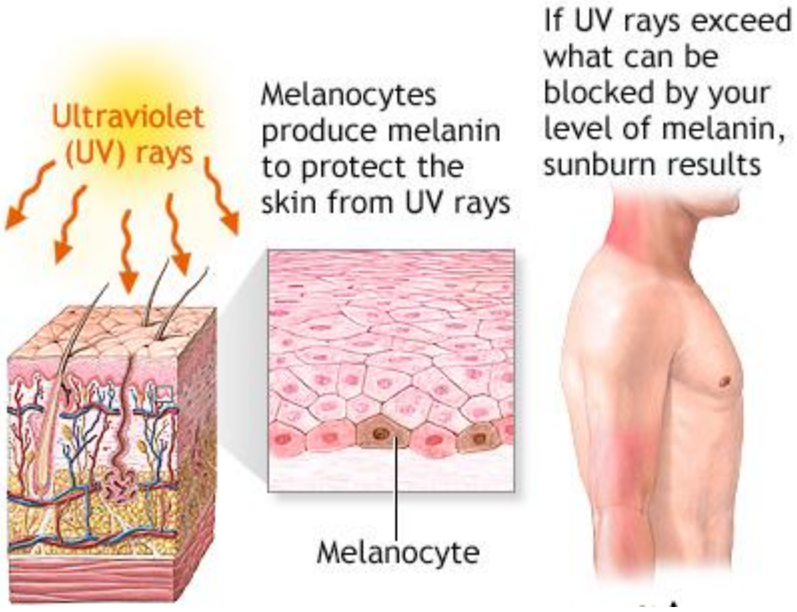
    O_2 + UV → 2 O (atoms)
  - The O atoms react with additional molecules of O_2 to form ozone (O_3).

    O_2 + O → O_3
  - Photodissociation of O_3 can also regenerate oxygen molecules (O_2)

    O_3 + UV → O_2 + O or $2O_3$ + UV → $3O_2$
- Naturally occurring chemicals (NO, N_2O, and OH^-) destroy ozone and keep its concentration lower than it would be otherwise.

Effects of Ozone Depletion

- Ozone depletion increases the amount of UV-B reaching the surface of Earth.
- Increases of UV-B, increase the formation of tropospheric O_3 leading to an increase in problems associated with photochemical smog.



- Human Health
  - UV-B is a ***mutagen*** (alters DNA nucleotide sequences).
  - Laboratory and epidemiological studies demonstrate that UV-B causes ***skin cancers*** including ***melanomas.***
  - Increased frequency and intensity of sunburns
  - UV-B radiation has been linked to the development of ***Cataracts*** (a clouding of the eye's lens causing impaired vision).

Human activities accelerate the decomposition of stratospheric ozone

Nitrous Oxide (N_2O)

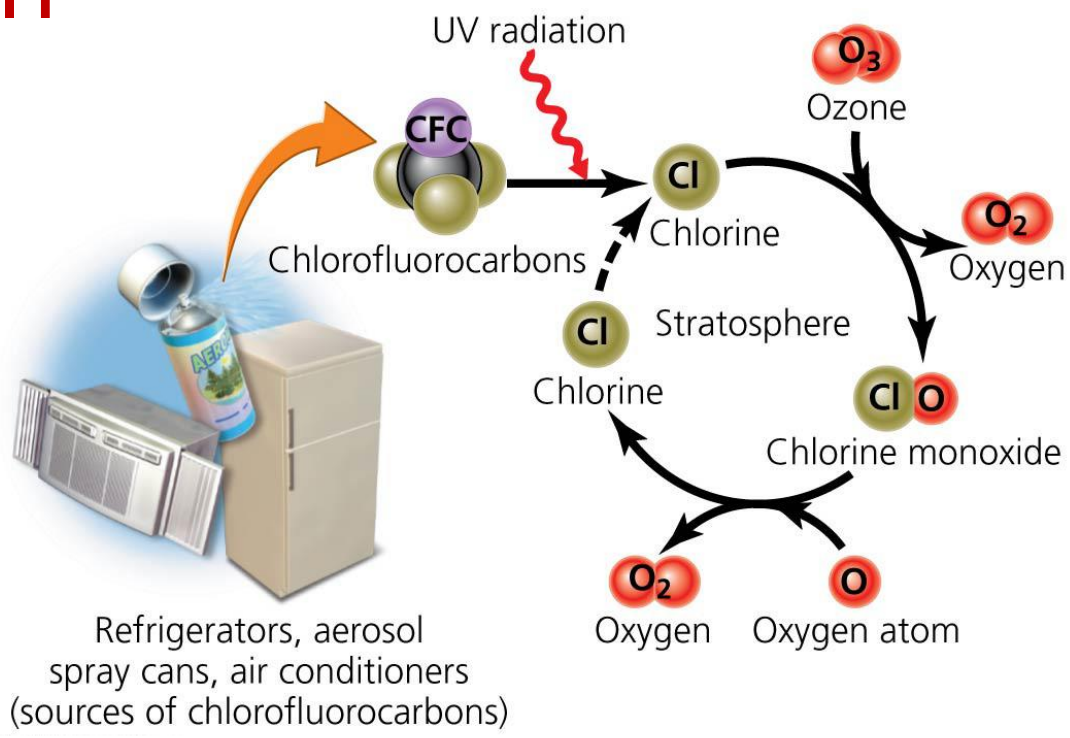
- Denitrification ($NO_3^- \rightarrow N_2$) is a natural process performed by soil bacteria that releases Nitrous oxide (N_2O) in the process.
  - N_2O is a stable compound in the troposphere, but photodissociates into Nitric Oxide (NO) in the presence of UV-C and UV-B in the stratosphere.
  - NO reacts with O_3 in the atmosphere to form NO_2 and O_2, thereby destroying stratospheric ozone.
- Increased use of nitrogen fertilizers has increased soil nitrogen (NH_3/NH_4^+ and NO_3), which increases the rate of denitrification and increases the production of N_2O in the atmosphere.

Chlorofluorocarbons (CFCs)

- ***Halocarbons*** are man-made, ozone-depleting substances produced from small hydrocarbons with added chlorine, bromine, or fluorine.
- Industry mass produced ***chlorofluorocarbons (CFC's)*** to be used used as refrigerants, fire suppressants, aerosol propellants, electronics cleaners, and for making polystyrene foam.
- CFCs are stable and generally nonreactive, so can reach the stratosphere and remain there for a century.
  - Originally believed to be safe for the environment because of this stability.

CFC's and Ozone Destruction

- In the stratosphere, UV radiation breaks CFCs apart and removes chlorine atoms from them.
  - The chlorine atom changes an ozone molecule to ordinary molecular oxygen and chlorine monoxide (ClO)
    - $Cl + O_3 \rightarrow ClO + O_2$
  - ClO from the previous reaction destroys a second ozone molecule, producing O_2
    - $ClO + O_3 \rightarrow Cl + 2O_2$
    - This regenerates the original chlorine atom, allowing it to repeat the process and continue to destroy numerous ozone molecules in cyclical series of reactions.
  - Chlorine atoms have a residence time of up to two hundred years in the stratosphere and during this time they can destroy 100,000 ozone molecules.
    - CFC's are much more destructive to O_3 than N_2O.

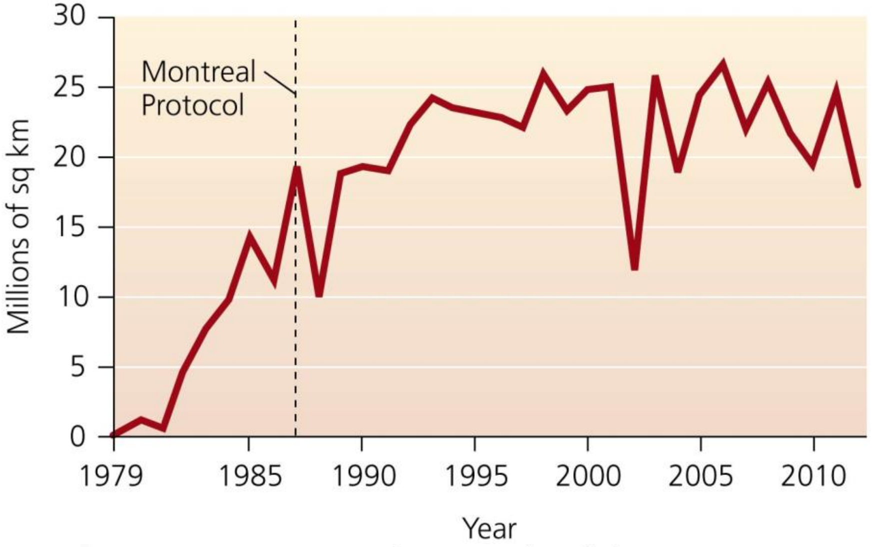


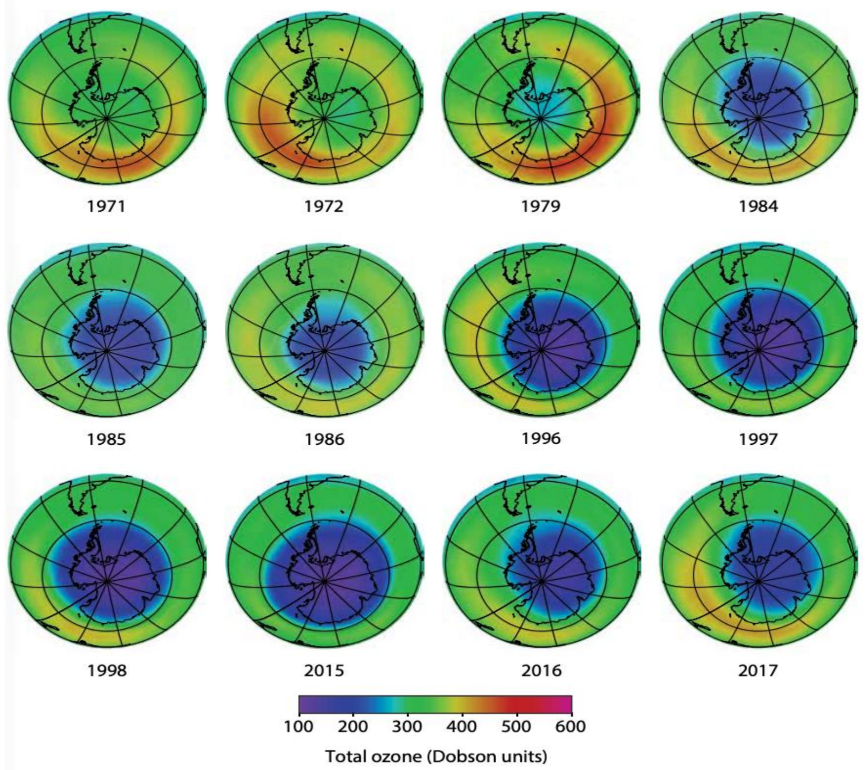
The Antarctic ozone hole appears each spring

- The path from CFC to Ozone-destroying Cl atoms is not an immediate or direct path.
  - Cl atoms freed from CFC's first form a series of chemical intermediates (HCl and $ClONO_2$) that are very stable under normal conditions in most of the atmosphere.
  - Throughout the year, these stable, unreactive compounds accumulate in the atmosphere from the splitting of CFC's.
  - Winter brings the strengthening of whirlpool-like wind currents over Antarctica (the ***Polar vortex***) which prevents the air from mixing with the rest of earth's atmosphere.
  - Cold, dark Antarctic winters lead to the formation of high-altitude ***polar stratospheric clouds*** in the center of the polar vortex.
- Within the extreme cold (-90˚C) of polar stratospheric clouds, reactions occur that would be impossible anywhere else in the atmosphere.
- These reactions, involving HCl and $ClONO_2$, produce a more reactive form of chlorine, chlorine gas (Cl_2), which accumulates in the polar vortex throughout the Antarctic winter.
- The return of the sun and its UV radiation in the Antarctic spring (September) splits the Cl_2, releasing Cl atoms, and results in rapid thinning of stratospheric ozone over the Antarctic each spring, known as the ***Ozone Hole***.
- Ozone levels drop to about half their historic levels by the end of October.
- As the atmosphere warms in the spring, the polar vortex weakens, the Cl dissipates, and O_3 enriched air returns.

The Antarctic ozone hole over time

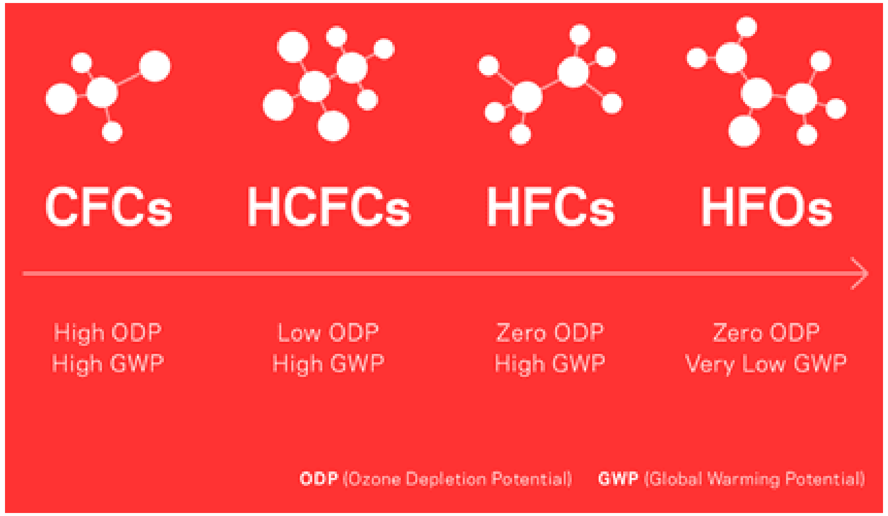
- Much of the recent fluctuation in the size of the Ozone hole reflects variations in weather from one winter to the next.
  - Consistent cold temperatures, strengthen the polar vortex and the formation of polar stratospheric clouds.
  - Such conditions increase the accumulation of Cl_2 molecules during the Antarctic winter.
  - This leads to more Cl atoms being released in the spring and the greater thinning of the stratospheric ozone layer.

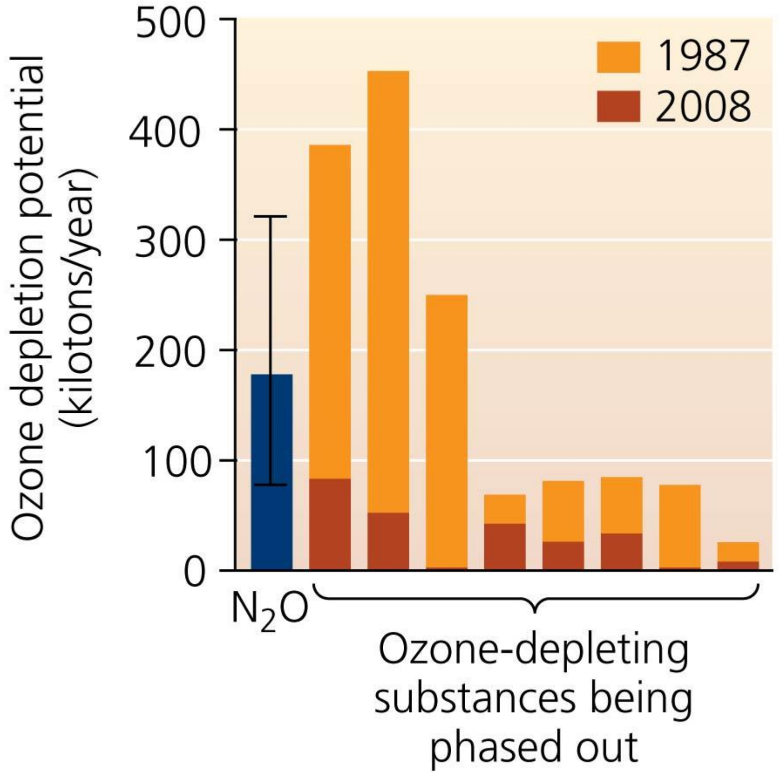




Reducing Ozone Depletion

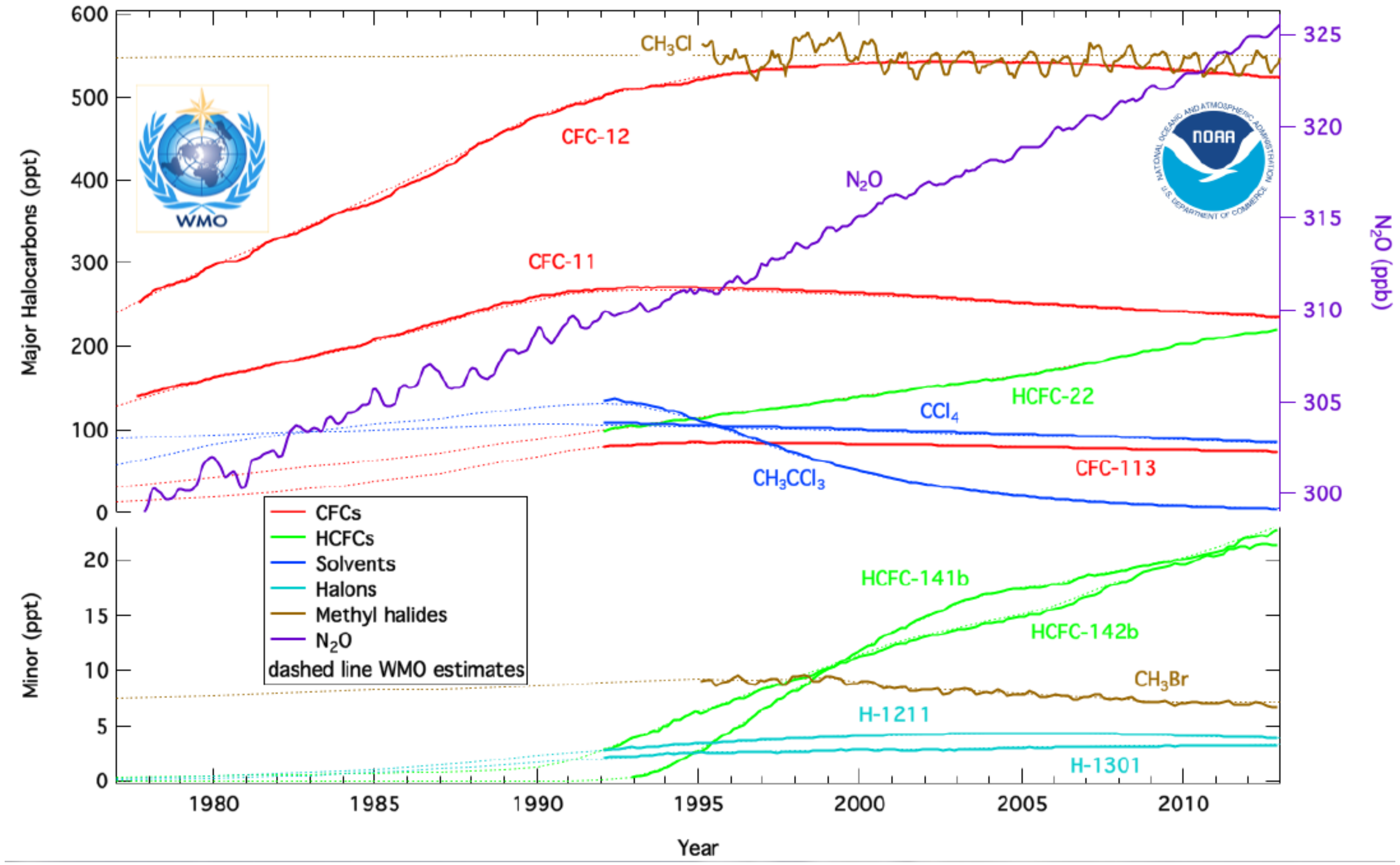
- 196 Nations signed the ***Montreal Protocol*** in 1987 agreeing to cut CFC production in half by 1998.
  - Response to the rapid growth of the ozone hole since its discovery on the mid-1970's and the role of CFC's in stratospheric ozone depletion.
  - Five follow up treaties have deepened the cuts, moved up the timeline, and expanded the list of regulated substances.
  - Most of the substances covered by the Montreal Protocol have now been phased out.
  - Industry has replaced CFC's with environmentally safer substances such as Hydrochlorofluorocarbons (HCFC's) and Hydrofluorocarbons (HFC).
  - Like CFC's HCFC's and HFC's are strong greenhouse gases with great global warming potential (GWP) which is increasing pressure to replace them with hydrofluoroolefin's (HFO's).
  - Nitrous Oxide (N_2O) is now the leading cause of stratospheric ozone depletion.





Challenges still face us

- Nations can ask for specific exemptions to the ban and some nations have not ratified the Montreal protocol.
- The ozone layer is not expected to recover until 2060 – 2075.
- Much of the 5 billion tons of CFCs have yet to diffuse to the stratosphere.
- Stratospheric CFC concentrations should peak around 2020.
- The long residence time of CFCs in the atmosphere is creating this time lag effect.



Video Resources

- Stratospheric Ozone
  - https://www.youtube.com/watch?v=dLXJV4A6KPE