Ozone (O$_3$) in the Atmosphere

The good, the bad, the mesospheric?
In the Troposphere ("Bad Ozone")

- Harmful pollutant
- Created in a reaction between nitrogen oxides (NOx), volatile organic compounds (VOCs) and sunlight
- Highest concentrations in warm summer weather
- Created in urban areas, blown hundreds of miles by the wind

Image Source: cfpub.EPA.gov
Sources of NOx and VOCs?

Human Pollution!

Sources of NOx

- 56% Motor Vehicles
- 22% Utilities
- 17% Fuel Combustion
- 5% Other

Sources of VOCs

- 50% Industrial/Commercial Processes
- 45% Motor Vehicles
- 5% Consumer Solvents
Why should we care?

- Breathing ozone can reduce lung function and create scar tissue in the lungs
- Ozone damages vegetation
  - Harms ecosystems
  - Reduces agricultural yields

Image Source: www.arcweb.archives.gov
In the Stratosphere ("Good Ozone")

• ~99% of ozone is found here
• Ozone layer is produced naturally
  \[ \text{O}_2 + \text{UV radiation} \rightarrow 2\text{ O} \]
  \[ \text{O} + \text{O}_2 + \text{M} \rightarrow \text{O}_3 + \text{M} \]
  (M is inert, usually \text{O}_2 or \text{N}_2)
• Also destroyed naturally
  \[ \text{O}_3 + \text{UV radiation} \rightarrow \text{O} + \text{O}_2 \]
  \[ \text{O} + \text{O}_3 \rightarrow 2\text{ O}_2 \]
In the Stratosphere (“Good Ozone”)

- Through these reactions, Ozone absorbs harmful radiation from sun (UVC and some UVB rays)
  - This protects plants and crops from damage, protects UV-sensitive marine life, and protects humans from skin cancer
  - Also warms the stratosphere
What about the ozone hole?

• In the Stratosphere

• Human use of aerosol sprays and air conditioners has changed chemistry of the atmosphere
  
  – Chlorofluorocarbons (CFCs) contain chlorine (Cl) and bromine (Br)

Image Source: ozonewatch.gsfc.nasa.gov
Cl destroys O₃ in Stratosphere

CFCl₃ + UV radiation → CFCl₂ + Cl

Chlorine is now free to react with O₃
Cl is a “serial killer”

\[ \text{Cl} + \text{O}_3 \rightarrow \text{ClO} + \text{O}_2 \]

\[ \text{ClO} + \text{O}_3 \rightarrow \text{Cl} + 2 \text{O}_2 \]

Ozone is destroyed, but Cl is unchanged

It lives to kill again!

Image Source: ozonewatch.gsfc.nasa.gov
Why is the hole over Antarctica?

- Very cold winters and surrounding oceans combine to create “polar vortex” of extremely cold air
- Polar Stratospheric Clouds form
- Droplets in clouds provide sites for chemical reactions that set the stage for ozone destruction when the sun comes out in the spring
Is the $O_3$ hole still a problem?

- Global community agreed to phase out $O_3$ depleting chemicals in 1987 (Montreal Protocol)
- CFCs are long-lived in atmosphere; $O_3$ layer not expected to recover before 2050

Image Source: ozonewatch.gsfc.nasa.gov
Ozone in the Mesosphere

• ~1% of atmospheric ozone is found here
• Ozone is created each night and then destroyed each day
• Seasonal variations?
• Protects Stratospheric ozone layer?
Ozone in the Mesosphere
Diurnal Variations

• $O_3$ is created at night
  
  \[ \text{O + O}_2 + \text{M} \rightarrow \text{O}_3 + \text{M} \]  
  (M is inert, usually $O_2$ or $N_2$)

• And destroyed during the day
  
  \[ \text{O + O}_3 \rightarrow 2 \text{O}_2 \]  
  \[ \text{O}_3 + \text{H} \rightarrow \text{OH} + \text{O}_2 \]  
  \[ \text{O}_3 + \text{UV} \rightarrow \text{O} + \text{O}_2 \]
Ozone in the Mesosphere
Seasonal Variations

- Water vapor and sunlight destroy $O_3$
  $H_2O + \text{UV radiation} \rightarrow H + OH$
  $O_3 + H \rightarrow OH + O_2$

- More water vapor in mesosphere during winter and summer?

MOSAIC data

Winter
  Seasonal variation above 80 km

Summer
No Ozone in the Thermosphere

• O atoms are too far apart to combine into $O_3$ molecules