Stratospheric ozone hole (part 2)

1. Polar stratospheric clouds
2. In situ observations of PSC’s
3. Satellite observations of PSC’s - seasonality
4. Heterogenous chemistry on PSCs
5. Seasonal evolution of the ozone hole
6. Arctic ozone hole
7. O$_3$/climate feedbacks
1. Polar stratospheric clouds

Type I PSC:
- nitric acid trihydrate (HNO$_3$3H$_2$O) (“NAT”)
- ternary solution (H$_2$O, H$_2$SO$_4$, HNO$_3$) (supercooled)
- formation temp: 195 K
- diameter: 1 μm
- altitude: 10-24 km
- settling rate: 1 km/30 days

Type II PSC:
- water ice (H$_2$O)
- formation temp: 188 K
- diameter: >10 μm
- altitude: 10-24 km
- settling rate: >1.5 km/day
2. Polar stratospheric cloud detection

Antarctic PSC particles observed from aircraft with the Multi-angle Aerosol Spectrometer Probe
3. Polar stratospheric cloud seasonality

Antarctic PSC frequency observed from satellite (Polar Ozone and Aerosol Measurement)
4. Heterogeneous chemistry on PSC’s

\[ \text{ClONO}_2(g) + \text{HCl}(s) \rightarrow \text{Cl}_2(g) + \text{HNO}_3(s) \]

\[ \text{HOCl}(g) + \text{HCl}(s) \rightarrow \text{Cl}_2(g) + \text{H}_2\text{O}(s) \]

\[ \text{ClONO}_2(g) + \text{H}_2\text{O}(s) \rightarrow \text{HOCl}(g) + \text{HNO}_3(s) \]

\[ \text{N}_2\text{O}_5(g) + \text{H}_2\text{O}(s) \rightarrow 2\text{HNO}_3(s) \]

\[ \text{N}_2\text{O}_5(g) + \text{HCl}(s) \rightarrow \text{ClNO}_2(g) + \text{HNO}_3(s) \]
6. Catalytic ozone loss in the Antarctic ozone hole

\textit{ClO cycle:}
\begin{align*}
Cl + O_3 & \rightarrow ClO + O_2 \\
ClO + O & \rightarrow Cl + O_2 \\
\text{net: } O + O_3 & \rightarrow 2O_2
\end{align*}

\text{ClO dimer cycle:}
\begin{align*}
2 ( Cl + O_3 & \rightarrow ClO + O_2 ) \\
ClO + ClO & \rightarrow ClOOCl \\
ClOOCl & \overset{hv}{\rightarrow} ClOO + Cl \\
ClOO & \overset{hv}{\rightarrow} Cl + O_2 \\
\text{net: } 2O_3 & \rightarrow 3O_2
\end{align*}

\textit{Mixed Br,Cl cycle:}
\begin{align*}
Br + O_3 & \rightarrow BrO + O_2 \\
Cl + O_3 & \rightarrow ClO + O_2 \\
BrO + ClO & \rightarrow Cl + Br + O_2 \\
BrO + ClO & \rightarrow BrCl + O_2 \\
BrCl & \overset{hv}{\rightarrow} Br + Cl \\
\text{net: } 2O_3 & \rightarrow 3O_2
\end{align*}
5. Evolution of the Antarctic ozone hole

*denoxification* – conversion of NO\textsubscript{x} to nitric acid

*denitrification/dehydration* - removal of HNO\textsubscript{3} / H\textsubscript{2}O by gravitational settling of PSC’s
Yes, but much less extensive ozone loss than in the Antarctic. Why?
large annual variability in loss and geographic extent
9. Arctic vs. Antarctic PSC’s

Arctic:
- Vortex less isolated
- Warmer
- Fewer PSC’s formed
- Land topography

Antarctic:
- Vortex more isolated
- Colder
- More PSC’s formed
- Circumpolar ocean
10. Stratospheric chemistry and dynamics are coupled... potential for $O_3$/climate feedbacks

colder stratosphere → more PSC’s

CFC-induced $O_3$ loss → less ozone

larger $O_3$ hole
11. Stratospheric chemistry and dynamics are coupled... potential for $\text{O}_3$/climate feedbacks

Predicting the future trajectory of stratospheric $\text{O}_3$ involves more than just chemistry.