SF$_6$ Lifetime Adjustment Based on Measured Loss in the Stratospheric Polar Vortex

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- Sulfur hexafluoride (SF$_6$) is a potent greenhouse gas and important tracer of stratospheric transport but has somewhat uncertain loss.

- We use *in situ* measurements in the stratospheric polar vortex and mesospheric transport characteristics to derive annual SF$_6$ loss and estimate a revised SF$_6$ lifetime.
SF$_6$ Characteristics

- Used primarily in the electrical industry as a dielectric medium, makes electricity grid more efficient therefore saves CO$_2$ emissions.

- Potent greenhouse gas with one of the highest known radiative efficiencies (0.57 W/m$^2$/ppbv) and the highest GWP for 100 year time horizon (23,500 based on 3200 year lifetime).

- Mixing ratio is < 10 ppt and current growth rate is 4-5%/year.

- Useful as a diagnostic of mean age of air in the stratosphere due to rapid growth and long lifetime.

- Dominant loss mechanisms are Lyman-α photolysis and electron attachment at altitudes > 50-60 km (details are somewhat uncertain).

Totterdill et al., 2015
Tough to make trace gas measurements above 35 km (except from satellites).

Trace gases with lifetimes > ~300 years are likely to be destroyed in the mesosphere and above.
Mesospheric Descent Into Stratospheric Polar Vortex

The entire mass of the mesosphere (several times over) descends into each of the stratospheric polar vortices every year!
Mesospheric Descent Into Stratospheric Polar Vortex

Model trajectories show that air in the mesosphere can move from pole to pole in months.

Air parcels descend and remain isolated in the vortex through March.

Vortex edge in March
Mesospheric Descent Into Stratospheric Polar Vortex

Circulation reverses in SH winter.
Measurements in the Stratospheric Polar Vortex

As part of SOLVE campaign, Lightweight Airborne Chromatograph Experiment (LACE) measurements from balloon launch at Kiruna, Sweden on March 5, 2000.
Measured vs. Modeled Vortex Trace Gas Profiles

Descent of tracers with mesospheric influence in the vortex is well represented by WACCM.

Measured profile is well representative of the vortex.
Measurement Based Mean Age in Polar Vortex

NH Vortex Mean Ages From $\text{SF}_6$ and $\text{CO}_2$ Measurements

from $\text{SF}_6$
from $\text{CO}_2$

Difference tells us the amount of $\text{SF}_6$ loss

“Real” mean age

“Too old” mean age due to $\text{SF}_6$ photochemical loss
Inferred SF$_6$ Loss in Polar Vortex

Fractional Loss of SF$_6$ Observed in the Polar Vortex March 5, 2000

Nearly 50% SF$_6$ loss at the max balloon altitude.

Translate the SF$_6$-CO$_2$ mean age difference into SF$_6$ fractional loss based on growth rate.
Inferred SF$_6$ Loss in Polar Vortex

Interpolate the SF$_6$ loss profiles to the top of the vortex under two different assumptions guided by WACCM.
Density Weighted $\text{SF}_6$ Loss in Polar Vortex

Profile shape in upper strat has small effect on density weighted loss.

Peak density weighted loss is in lower strat.
SF$_6$ Lifetime Calculation

SF$_6$ loss per year is given by the integrated mass of the loss in both vortexes divided by the total mass of the atmosphere:

$$\frac{dL_{SF_6}}{dt} = 2 \times \int_{z_0}^{z} A_V(z) \times \rho(z) \times F_{SF_6}(z) dz / M_A$$

SF$_6$ lifetime given by the inverse of the above annual loss rate is 800 to 900 years depending on upper vortex loss assumption with additional uncertainty of ±100 years due to uncertainty of vortex size.

**Assumptions**

1. Mesospheric air only descends into the stratospheric polar vortexes.
2. We sampled representative polar vortex air mass.
Implications and Conclusions

- Reduction of SF$_6$ lifetime from 3200 to 900 years only reduces GWP by 5% for 100 year time horizon, but 50-75% reduction for time horizons > 2000 years.

- Hard to quantify overall radiative impact of SF$_6$ because it’s main use results in lower CO$_2$ emissions.

- *In situ* measurements in the stratospheric polar vortex are useful for better understanding transport and photochemistry throughout the middle atmosphere.