Chlorine and Ozone Depletion are Declining Inside the Antarctic Ozone Hole – MLS Observations and the GMI Chemistry Transport Model Agree

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Summary: We use Aura Microwave Limb Sounder (MLS) satellite data from 2004-2016 to measure O$_3$ over Antarctica in early July and then compare it to O$_3$ in mid-September. During this period nearly all O$_3$ change is due to depletion. The HCl measurements shown here represent the sum of all ozone-destroying chlorine compounds, C$_{ly}$. The HCl change for constant N$_2$O shows us there is less chlorine now than a decade ago – independent of atmospheric dynamical variability. The MLS-calculated O$_3$ depletion responds to changing C$_{ly}$ levels, and the model’s agreement confirms our understanding of the chemical processes controlling polar ozone. This is evidence that the Montreal Protocol is working: Antarctic C$_{ly}$ is decreasing in the and the ozone destruction is decreasing along with it.

References:

Data Sources:
NASA Aura Microwave Limb Sounder (MLS) v4.2 Level 2 O₃, HCl, and N₂O data, 2004-2016.
The NASA Global Modeling & Assimilation Office (GMAO) Modern Era Retrospective for Research and Applications 2 (MERRA2) reanalysis temperature and potential vorticity products.

Technical Description of Figures:
Chart 1. Co-located MLS N₂O and HCl observations inside the Antarctic ozone hole from 2013-2016 (red) and 2004-2007 (blue). The difference between the means of each distribution (solid lines) is highlighted by the arrow. The shift of the distribution toward lower HCl, represents a decline in Antarctic chlorine.
Chart 2. Time series of O₃ depletion and total inorganic chlorine (Clᵥ) inside the ozone hole, 2005-2016. Depletion is calculated as the change in vortex-averaged 261-12 hPa partial column O₃ between early July and mid-September. The Clᵥ time series was inferred using lower stratospheric vortex-averaged MLS N₂O (which is strongly anti-correlated with Clᵥ) combined with the annual mean Clᵥ decline of 25 ppt/yr (Chart 1). A 1:2:1 filter was applied to each time series to remove biennial variability in each signal, revealing O₃ depletion's response to changing chlorine. (Biennial variability in the depletion comes from temperature variability while in the Clᵥ data it comes from composition variability that is unrelated to temperature.)

Scientific Significance: One of the challenges in attributing Antarctic ozone recovery to declining chlorine levels is the lack of quantitative measurements of chlorine-containing compounds inside the ozone hole. This study takes advantage of Antarctic chemistry that converts all of the inorganic Cl species into HCl during a brief period each spring. The MLS HCl measurements during this period represent the sum of Cl compounds that can destroy O₃. This gives us a way to measure all the chlorine each year from 2004-2016, but without N₂O we can’t say why it’s changing. Using the co-located MLS N₂O measurements along with HCl (Chart 1) provides a fixed dynamical reference point. We see that for constant values of N₂O, HCl is really declining, and that can only happen because stratospheric chlorine loading is declining.

Scientific significance, societal relevance, and relationships to future missions: Identifying recovery of the Antarctic ozone hole is challenging because year to year changes in the hole are primarily controlled by temperature. Stratospheric chlorine levels are expected to decline because of the Montreal Protocol (MP) and its subsequent amendments. The decline is slow because the atmospheric lifetimes of ozone depleting substances are long. This study is important because it shows the MP is working: it identifies both a decline in chlorine levels inside the ozone hole attributable to the MP and a decline in ozone depletion in response to chlorine changes. The value of N₂O and HCl measurements for interpreting O₃ changes supports the need for these measurements in the future as we continue to measure ozone.

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