Using Observations of HNO$_3$ and N$_2$O to Quantify HCl and Ozone Sensitivity to Variability of the Stratospheric Circulation

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Why do we care about interannual variability in stratospheric dynamics?

- Interannual variability masks detection of trends
  a) Masks recovery of chlorine as measured by HCl column amounts
  b) Complicates detection of expected upward trend in total ozone or lower stratospheric ozone due to chlorine change

- On longer time scales, models predict speedup of BDC
  a) No clear confirmation of these predictions by measurements
  b) Interannual variability of dynamics masks slow predicted change
Motivation: HCl column variation at northern mid-latitudes driven by circulation

Can we find surrogate for dynamical influence on HCl variation?

Deseasonalized HCl Anomalies at 32 hPa for 30-50N Latitude Band

### Deseasonalized HCl Anomalies at 32 hPa for 30-50N Latitude Band

<table>
<thead>
<tr>
<th>Year</th>
<th>HCl Deviation (%)</th>
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<tbody>
<tr>
<td>2004</td>
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<td>2006</td>
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<td>2008</td>
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<td>2010</td>
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<td>2014</td>
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<td>2016</td>
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<td>2018</td>
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**Graph:**
- Lat = 30-50N
- P = 32 hPa

**Legend:**
- Small Positive Trend
- No Statistical Significance

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Consider altitude profiles of \( \text{N}_2\text{O} \) and HCl from Aura MLS

- \( \text{N}_2\text{O} \) and HCl both respond to dynamical changes through their spatial gradients
- They are anti-correlated at a given latitude and pressure level

Suggests that \( \text{N}_2\text{O} \) variations could be used to model/remove variability in HCl observations to reveal trend

Monthly mean anomalies of \( \text{N}_2\text{O} \) and HCl from Aura MLS measurements at 32 hPa averaged between latitudes of 30 to 50N.

HCl Anomalies with seasonal cycle and \( \text{N}_2\text{O} \) co-variation removed

HCl Anomalies with seasonal cycle and N₂O co-variation removed

Lat = 30-50N
P = 32 hPa

Year

HCl Deviation (%)


-20 -10 0 10 20

Negative Trend
Statistically Significant at 2σ

Fit linear trend to HCl time series at each altitude of reported MLS measurements

- First use simple linear trend model
  \[ HCl = \mu + \alpha \cdot \text{trend} + \beta \cdot \text{seasonal} + \epsilon \]
- Then add term for N\textsubscript{2}O anomalies
  \[ HCl = \mu + \alpha \cdot \text{trend} + \beta \cdot \text{seasonal} + \gamma \cdot \text{N}_2\text{O} + \varepsilon \]

Trend changes sign with smaller uncertainty

*HCl slope from August 2004 through August 2016 from MLS data between 30 and 50 N latitudes. Shaded areas are 2\(\sigma\) uncertainty estimates for trend.*

What about $O_3$?

- Using $N_2O$ as fitting term reduces uncertainty in $O_3$ trend
- Using HNO$_3$ yields similar results (not shown)
- Calculated trend becomes positive in middle stratosphere as expected, but results are not significant

Accounting for dynamical variability in $O_3$ trends will be more difficult

*$O_3$ slope from August 2004 through August 2016 from MLS data between 30 and 50 N latitudes. Shaded areas indicate 2σ uncertainty estimates of the trend.*
Usefulness of dynamical tracer depends on correlations that are determined by gradients

O$_3$ and N$_2$O or HNO$_3$ are strongly correlated only in the lower stratosphere

HCl and N$_2$O strongly anti-correlate over most of stratosphere

Only correlations < -0.5 and > 0.5 shown

Can we do better using column HNO$_3$ with column O$_3$?

- Correlation is $> 0.5$ over entire SH and between 40-60N
- Warrants further examination

Would be very useful as we could extend study back in time using column measurements from NDACC stations

Conclusions

- Dynamical variability introduces uncertainty into trend analysis of chemical constituents such as $O_3$ and HCl.
- Many studies have used dynamical surrogates such as QBO, ENSO, AMO in trend models to try to remove (explain) this variance.
- We propose using constituent correlations to accurately model the “whole dynamical” impact on species variability.
- We have shown important example of removing variability in HCl measurements from Aura MLS by using measurements of N$_2$O.