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Observational evidence of solar activity interaction with chlorine chemistry curbing Antarctic ozone loss

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Background

- Several mechanisms for solar influence on climate, some link to variability on **regional** rather than global **scale**.
- Solar wind brings electrons and protons from the Sun to the Earth. Earth's magnetic field causes some to "rain" into the atmosphere in the **polar areas → Energetic Particle Precipitation (EPP)**.
- **EPP** increases ionisation in the atmosphere, influencing **chemical balance of the stratosphere and mesosphere.**
  - Produces NO_x gases (e.g. NO + NO_2, so called **EPP-NO_x**), known to catalytically destroy ozone.
- NO_x is long-lived in polar winter and descend into the stratosphere. If still present when spring arrives, NOx increases could potentially interact with chlorine chemistry:

$$ClO + NO_2 \rightarrow ClONO_2$$

converting active chlorine to inactive reservoir)
  - Removes some ClO from the active chlorine catalytic cycles such as:

$$ClO + O \rightarrow Cl + O_2$$
$$Cl + O_3 \rightarrow ClO + O_2$$
$$\text{Net: } O + O_3 \rightarrow 2O_2$$

Hypothesis: NO_x can react with ClO, acting as a limiter for Cl_x driven ozone loss. Test with existing satellite datasets!

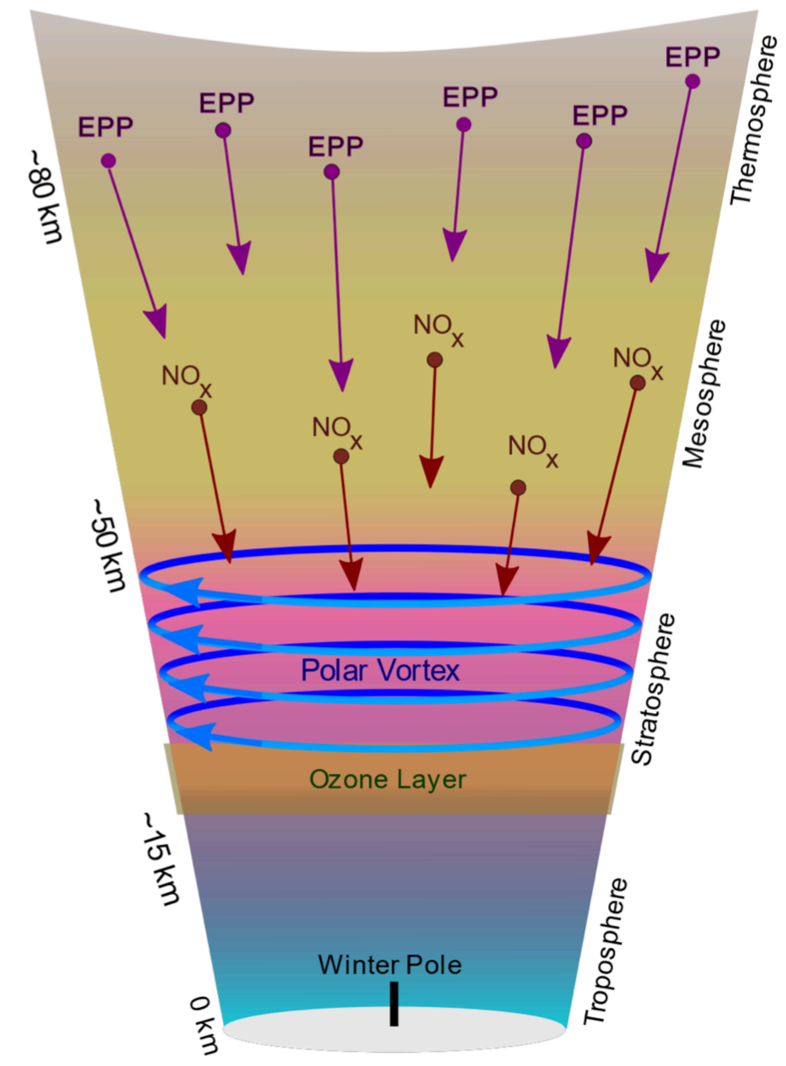

Figure 1. EPP-NO_x formation over the **winter** pole. EPP penetrates the mesosphere-lower thermosphere resulting in NO_x increases. The NO_x descends downward into the stratosphere in the polar vortex.

Datasets

OMI/Aura
- NO_2 stratospheric column, O_3 total column

MLS/Aura
- O_3, ClO stratospheric profiles

MIPAS/Envisat
- $ClONO_2$ stratospheric profile

ACE-FTS/SCISAT
- $ClONO_2$ profile (not shown here)

Overall, covering years 2005-2017.

These results have been published. Please see further details of data and results in:

Gordon, Seppälä, and Tamminen (2020) Evidence for energetic particle precipitation and quasi-biennial oscillation modulations of the Antarctic NO_2 springtime stratospheric column from OMI observations, *Atmos. Chem. Phys.*, doi: 10.5194/acp-20-6259-2020

Gordon, Seppälä, Funke, Tamminen, and Walker (2021) Observational evidence of energetic particle precipitation NO_x (EPP-NO_x) interaction with chlorine curbing Antarctic ozone loss, *Atmos. Chem. Phys.*, doi:10.5194/acp-2020-847, 2021

1. Solar activity and EPP levels vary

Geomagnetic activity index A_p is a well known proxy of EPP variability. We use correlations with A_p to estimate the contribution of EPP to stratospheric NO_x.

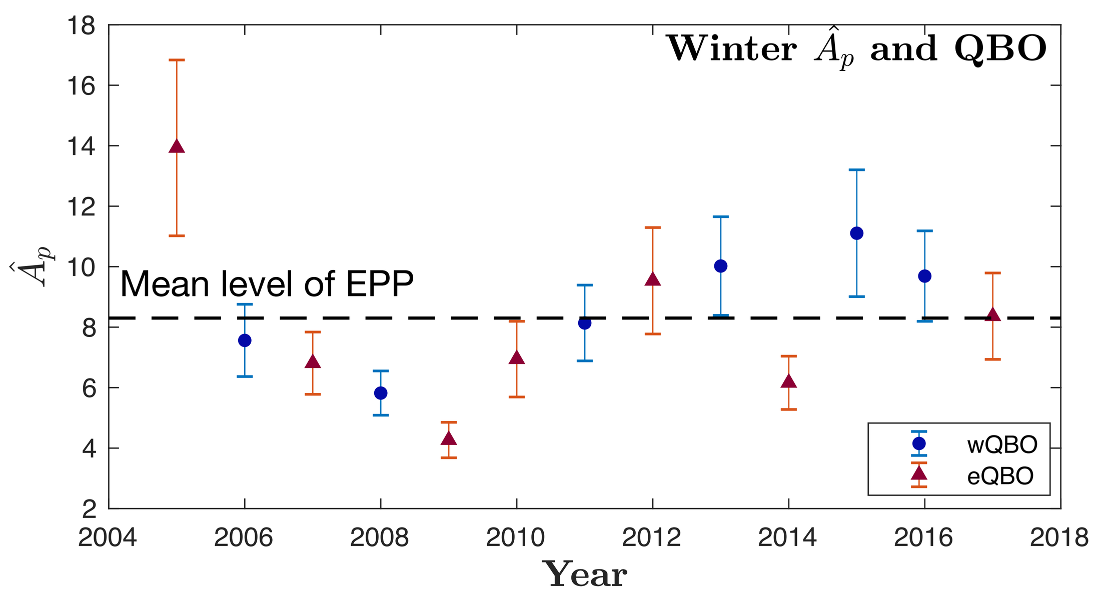

Figure 2. The SH polar winter average A_p (level of EPP), denoted $\hat{A}_p$ and the Quasi-Biennial Oscillation (QBO) phase (easterly=eQBO; westerly=wQBO) during the polar winter. We account for the QBO as it is know to modulate 1) transport of air from lower latitudes to the polar atmosphere affecting non-EPP source of NO_x, and 2) polar temperatures (wQBO: cold, effective removal of NO_x from stratosphere; eQBO: opposite)

2. Solar activity and stratospheric NO_x and O_3

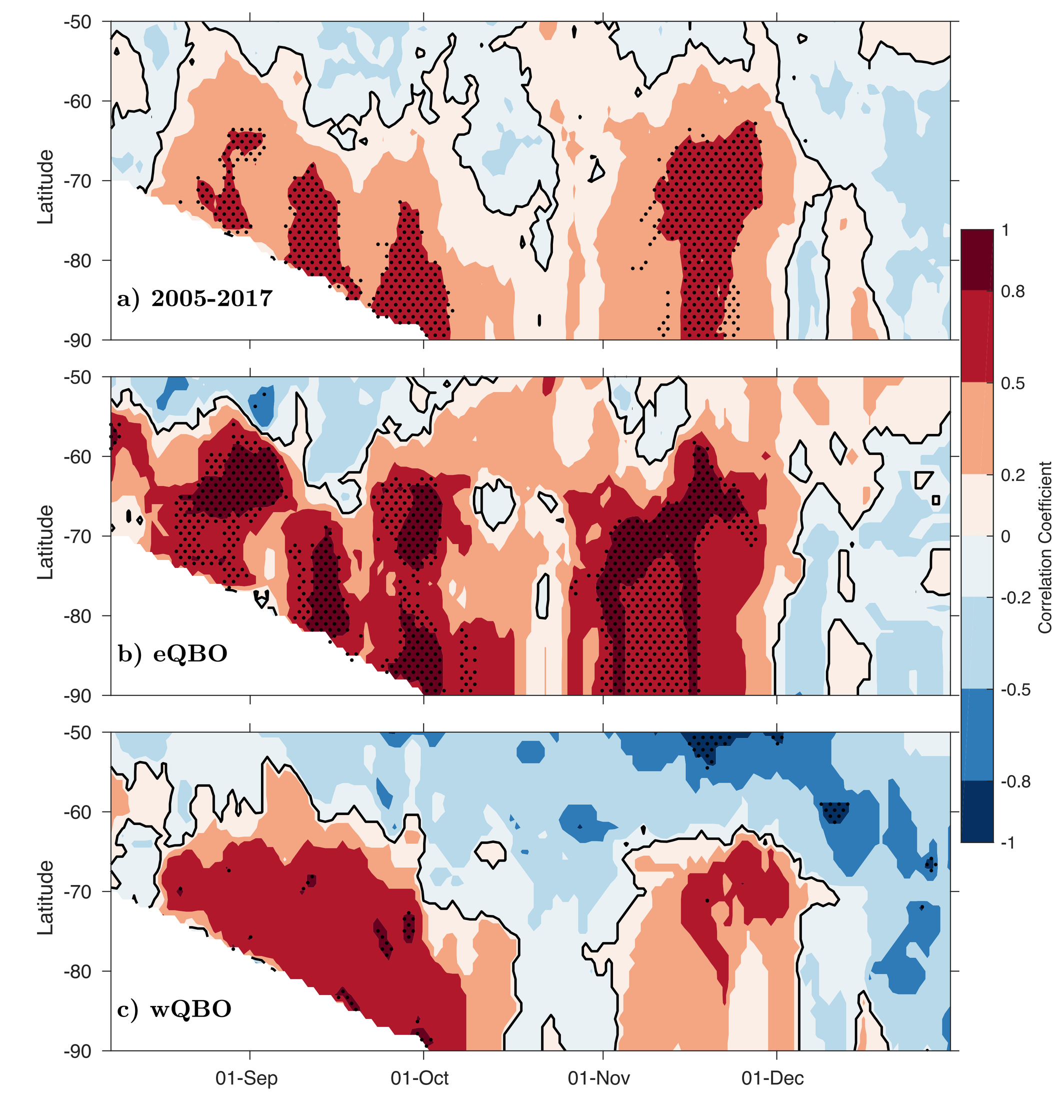

Figure 3. Correlation of A_p and OMI stratospheric NO_2 column for a) all years, b) eQBO years and c) wQBO years. **Winter EPP is highly correlated with stratospheric NO_x until December during eQBO.** EPP-NOx significantly contributes to stratospheric NO_x levels. Stippling = $\geq 95\,\%$ significance level.

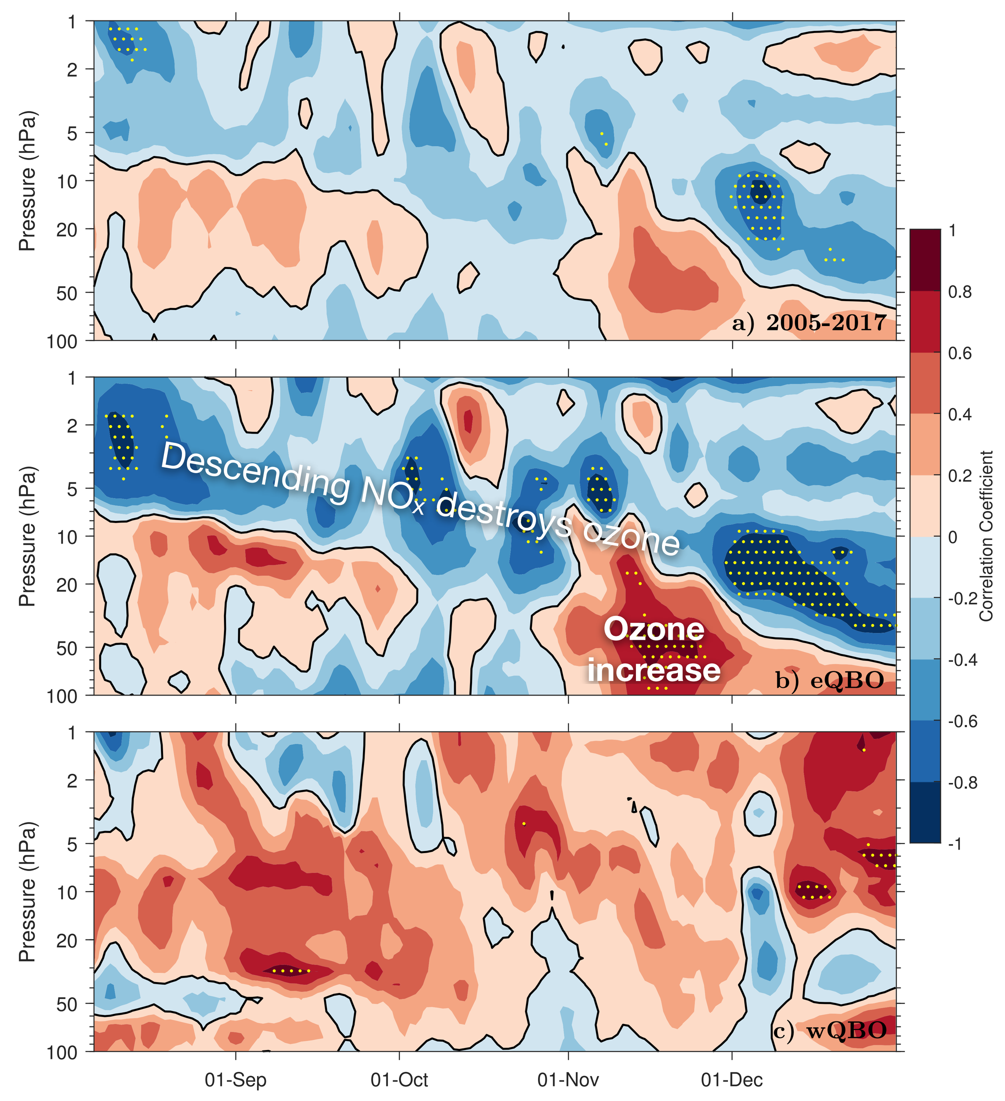

Figure 4. MLS SH polar (60S-82S) O_3 profile correlation with EPP levels. Descending NO_x drives ozone loss from upper stratosphere (in August) down to 50hPa (December). **Significant positive correlation takes place below 20hPa in November indicating increased ozone.**

3. November year-to-year variability

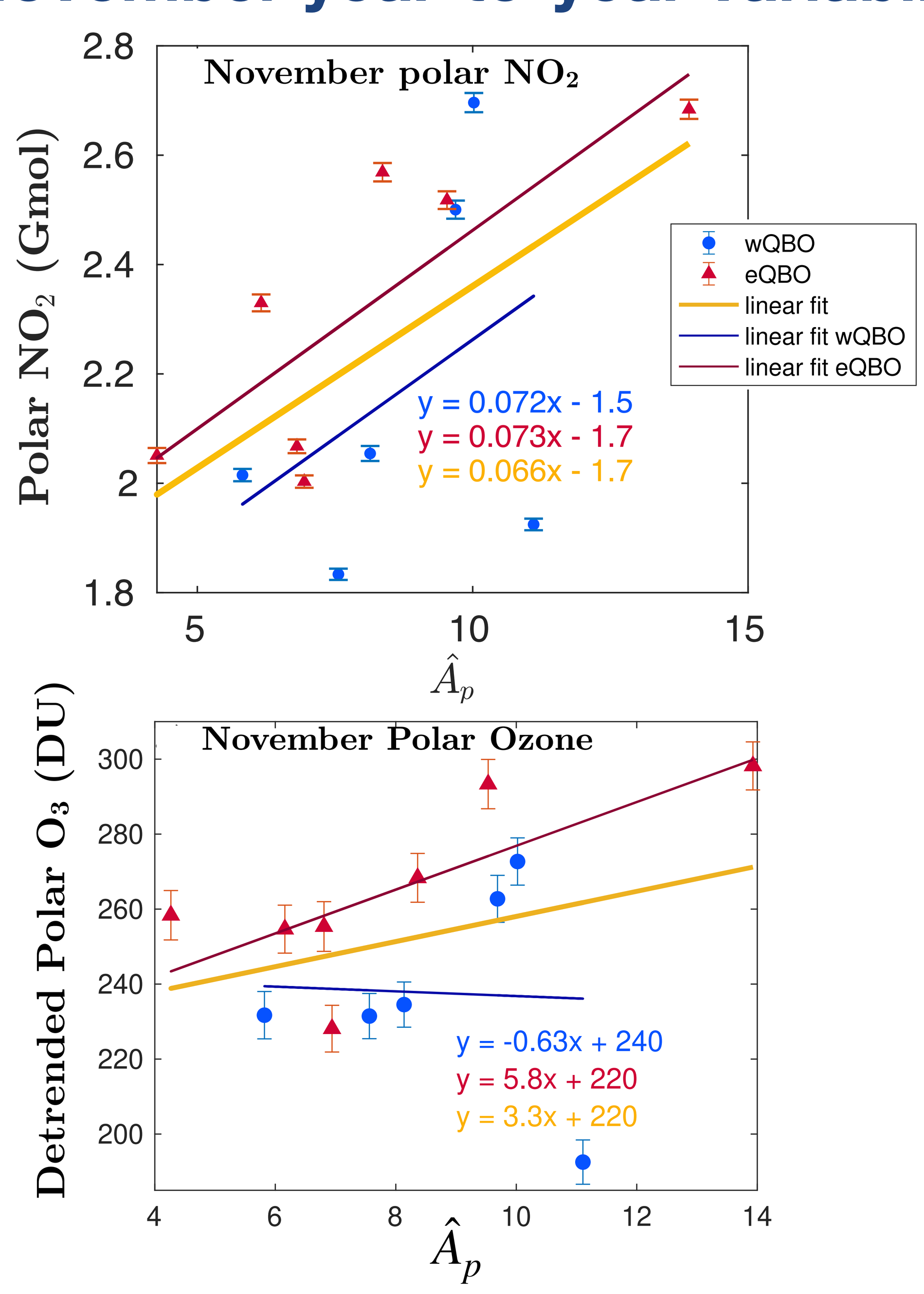

Figure 5. Top: OMI mean November polar (60S-90S) NO_2 column in Giga moles vs wintertime EPP level. Bottom: OMI mean November polar (60S-90S) O_3 column in DU vs wintertime EPP level.

4. What about stratospheric chlorine?

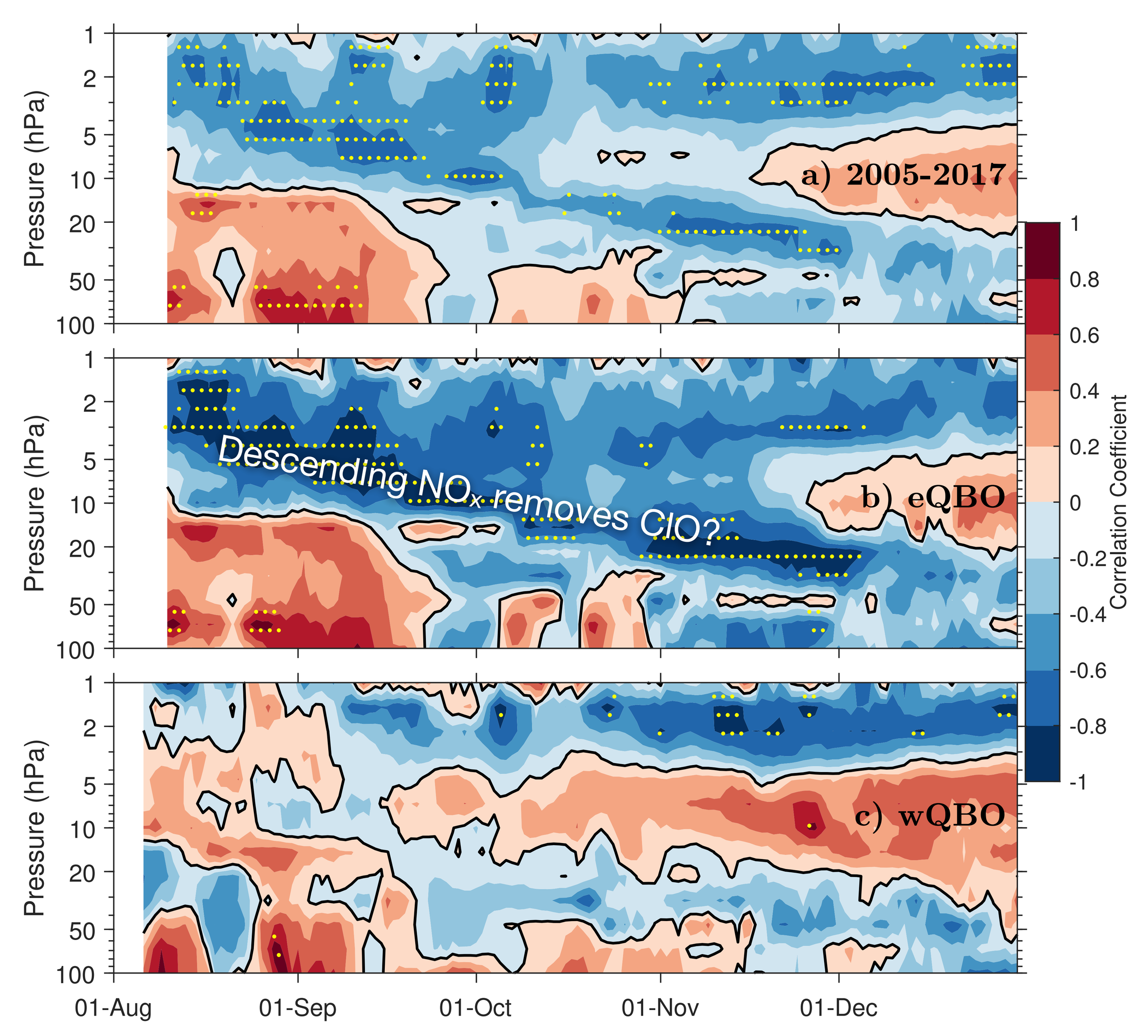

Figure 7. Polar (60S-82S) MLS ClO profile correlation with EPP levels for a) all years, b) eQBO years and c) wQBO years. The descending NO_x feature also present in ozone (Figure 4) is also present in ClO. Reduction in active chlorine would explain increase in Nov ozone.

The reaction to remove the active ClO is
$$ClO + NO_2 \rightarrow ClONO_2$$
If this is taking place we should observe an increase in the inactive $ClONO_2$!

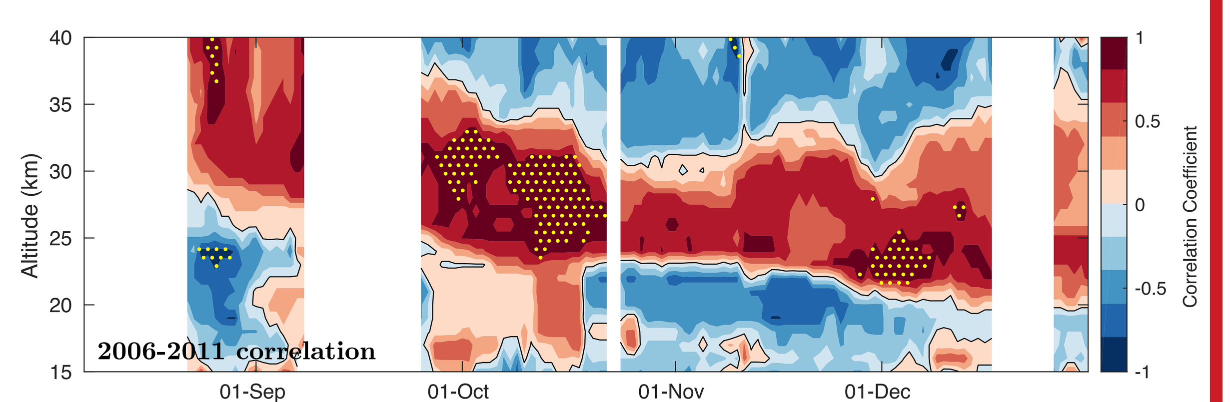

Figure 8. MIPAS polar (60S-90S) $ClONO_2$ profile correlation with EPP levels. High EPP levels are correlated with increased $ClONO_2$, indicating **conversion to chlorine reservoir is taking place during high solar activity years.**

Summary

More EPP = More NO_x → Reacts with ClO producing inactive $ClONO_2$ → O_3 recovery.

First observational evidence of this unaccounted for source of ozone variability!