UNLOCKING THE PUZZLE OF TROPICAL OZONE CHANGES

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‘Tropical column ozone levels are almost unchanged since 1964-1980’
(WMO, 2014)
WOULD WE NOT HAVE EXPECTED TROPICAL OZONE TO DECLINE?

Randel & Wu, JGR 2007

• Indeed SAGE indicates decline in the stratosphere.
• This is not consistent with the total column observations…

Fahey & Hegglin, 20 QAs WMO 2011

• CCMVal models indicate a decline in the past as well, in line with the increase in ESC.
Reconciliation of halogen-induced ozone loss with the total-column ozone record

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METHODOLOGY - OBSERVATIONS

- Ground-based global long-term observations of total column ozone.
- Satellite limb observations of vertically resolved stratospheric ozone.
  - Newly generated and quality-controlled monthly zonal mean time series from the SPARC Data Initiative

Tegtmeier, Hegglin, et al., JGR 2013
SPARC Report No. 8, in print
METHODOLOGY – MODEL

- Canadian Middle Atmosphere Model (CMAM) nudged to meteorological reanalyses from 1960 to 2009 (using ERA40/ERA-I before/after 1979).
  - Chemistry evolves freely but is strongly slaved to the meteorology (as in a CTM).

- Two parallel CMAM simulations are performed that both include the known forcings from GHGs and air pollutants,
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  1. Evolving abundances of ozone-depleting substances (ODS)
  2. Fixed ODSs at 1960 levels (cODS run)
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allows for removing dynamical variability and identification of ODS-induced ozone loss by simply using the difference between the two simulations.
TROPICS: TOTAL AND PARTIAL COLUMN

Shepherd et al. (2014); Chapter 2, WMO 2014

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  - Shows that there is no inherent discrepancy between the total-column and stratospheric ozone records in the tropics.
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• Nudged CMAM agrees well with stratospheric observations.
  • Shows that there is no inherent discrepancy between the total-column and stratospheric ozone records in the tropics.

• We can hence also trust the tropospheric column in CMAM and infer that strong increases in tropospheric ozone have masked stratospheric ozone loss.

IUGG General Assembly 2015 – A15
Using the difference between the two simulations, ODS-induced ozone loss can be quantified with high temporal resolution.
TROPICS: LOSS AND RECOVERY

• Using the difference between the two simulations, ODS-induced ozone loss can be quantified with high temporal resolution.
  • Closely follows ESC, with volcanic enhancement.
  • Recovery has started, with a decrease in ozone loss of somewhat more than 10% by 2006-2009.

Pre-1980s ozone loss is 40% of the non-volcanic max!
SUMMARY & OUTLOOK

• Our study reconciled an apparent discrepancy between limb and total column observations in the tropics.
  - The combined use of models and measurements was key to the interpretation of the observations.

• Changes in tropospheric ozone have partially masked stratospheric ozone decline in the tropics, in addition to that from CO$_2$-induced cooling.
  - Tropospheric ozone changes can be expected to potentially confound identification of ozone recovery.

• Pre-1980 ozone loss was 40% of the non-volcanic maximum.

• We identified and quantified tropical ozone recovery to be around 10% of the non-volcanic maximum by 2006-2009.
  - Both findings apply also to the SH and NH mid-latitudes (not shown).

• The findings imply that our understanding of future changes in the ozone layer will rely on a holistic one-atmosphere approach, the availability of vertically resolved ozone observations, and continued modeling efforts.
20 Q&As about the Ozone Layer

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Nudged CMAM roughly follows ground-based observations from Dobson and Brewer instruments.

- Observed long-term annual-mean decrease of 10 DU (~3%) is clearly attributable to ODS
- ODS-induced decrease prior to 1980 is partially offset by the increase in tropospheric ozone
SOUTHERN HEMISPHERE MIDLATITUDES – TOTAL COLUMN

- Nudged CMAM follows observations
  - Observed long-term maximum non-volcanic decrease of 19 DU (6%) is clearly attributable to ODS
  - Dynamical variability induces dip in mid-1980s, masks Pinatubo-induced loss, and drives observed increase from late 1990s to mid 2000s
SOUTHERN HEMISPHERE MIDLATITUDES – PARTIAL COLUMN

- Decomposition into tropospheric (black) and stratospheric (gray) partial columns:
  - The stratospheric ozone in the nudged CMAM follows the observations extremely well
  - Very little tropospheric ozone increase in the SH
NORTHERN HEMISPHERE MIDLATITUDES – TOTAL COLUMN

- Nudged CMAM follows observations, except in mid-1970s, and with an offset after 1980
  - Observed long-term annual-mean decrease of 12 DU (3.5%) is attributable to ODS
  - Strong interannual variability evident in cODS run, including after El Chichon and Mt Pinatubo eruptions

![Graph showing 35°–60° N total-column O₃ with a correlation coefficient of r^2 = 0.67](image)
NORTHERN HEMISPHERE MIDLATITUDES – PARTIAL COLUMN

- Decomposition into tropospheric (black) and stratospheric (gray) partial columns:
  - Nudged CMAM agrees very well with observations of stratospheric ozone from limb sounders
  - Suggests offset in total column ozone due to a too large long-term increase in tropospheric ozone (cf. Young et al. 2013)