The Dynamical Implications of Changes in mid-Stratospheric Ozone since 1991

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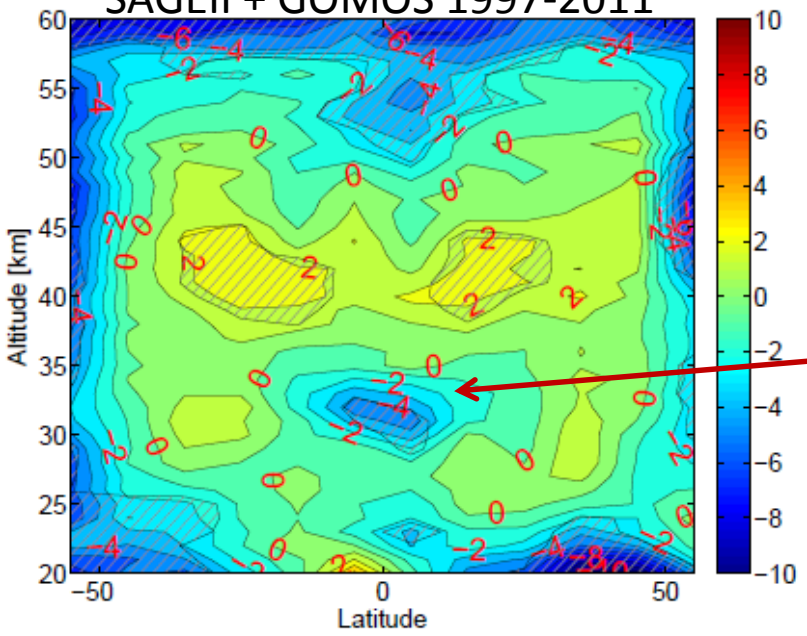
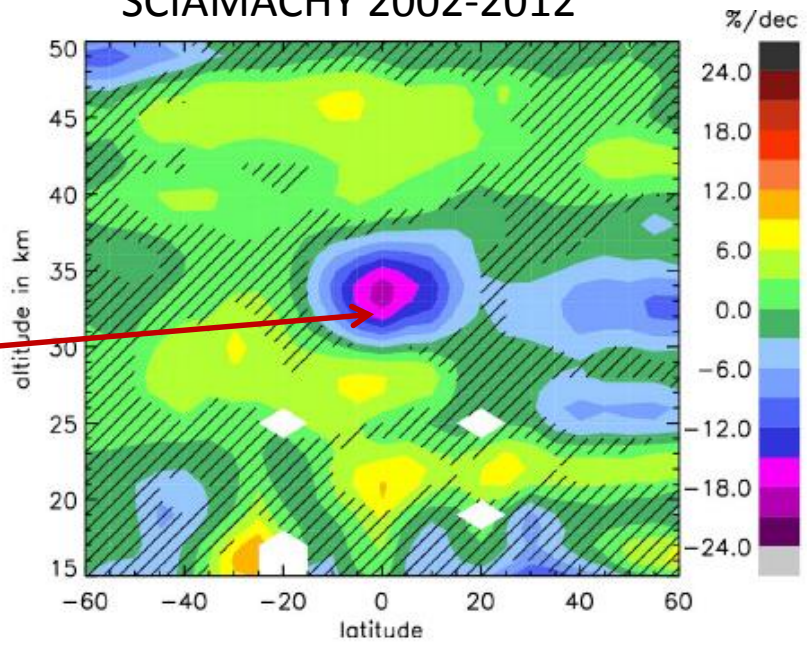
Published O_3 trends

SAGEII + GOMOS 1997-2011



SCIAMACHY 2002-2012

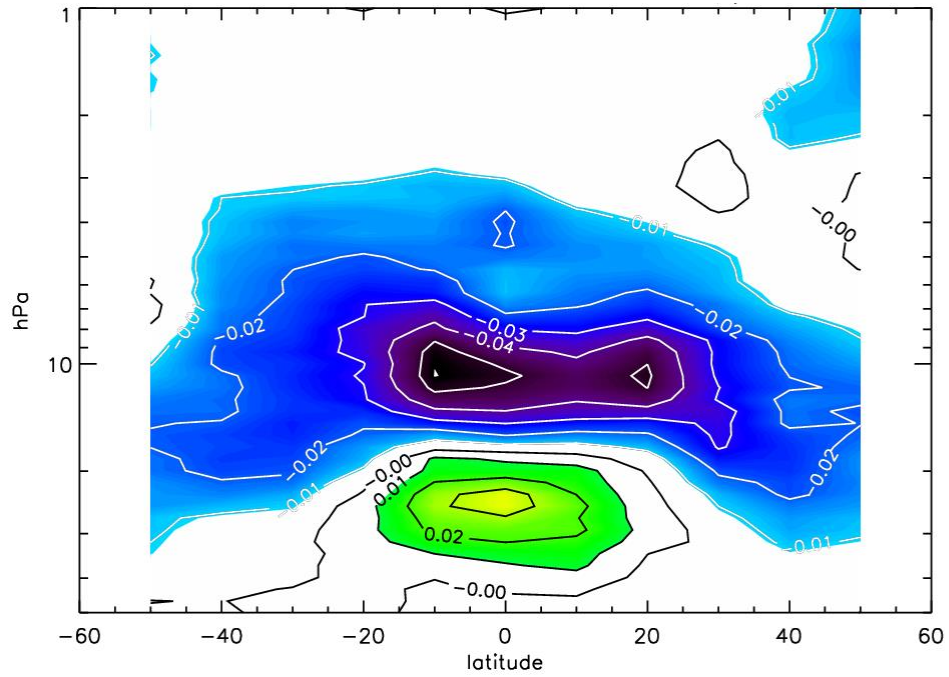


Kyrola et al.,
ACP 2013

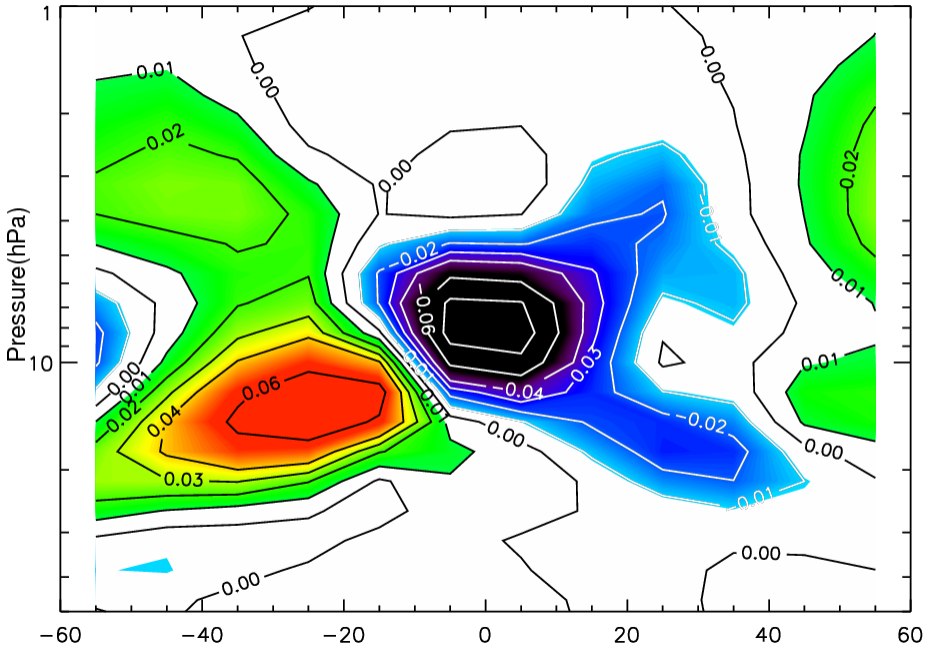
Gebhardt et al.,
ACP 2014

O_3 recovery in most regions, but
large long-term O_3 decrease near 30km in tropics

HALOE O_3 trend 1991-2005 (ppmv/yr)



MLS O_3 trend 2004-2013 (ppmv/yr)



Peak observed O_3 trends (~10 hPa):

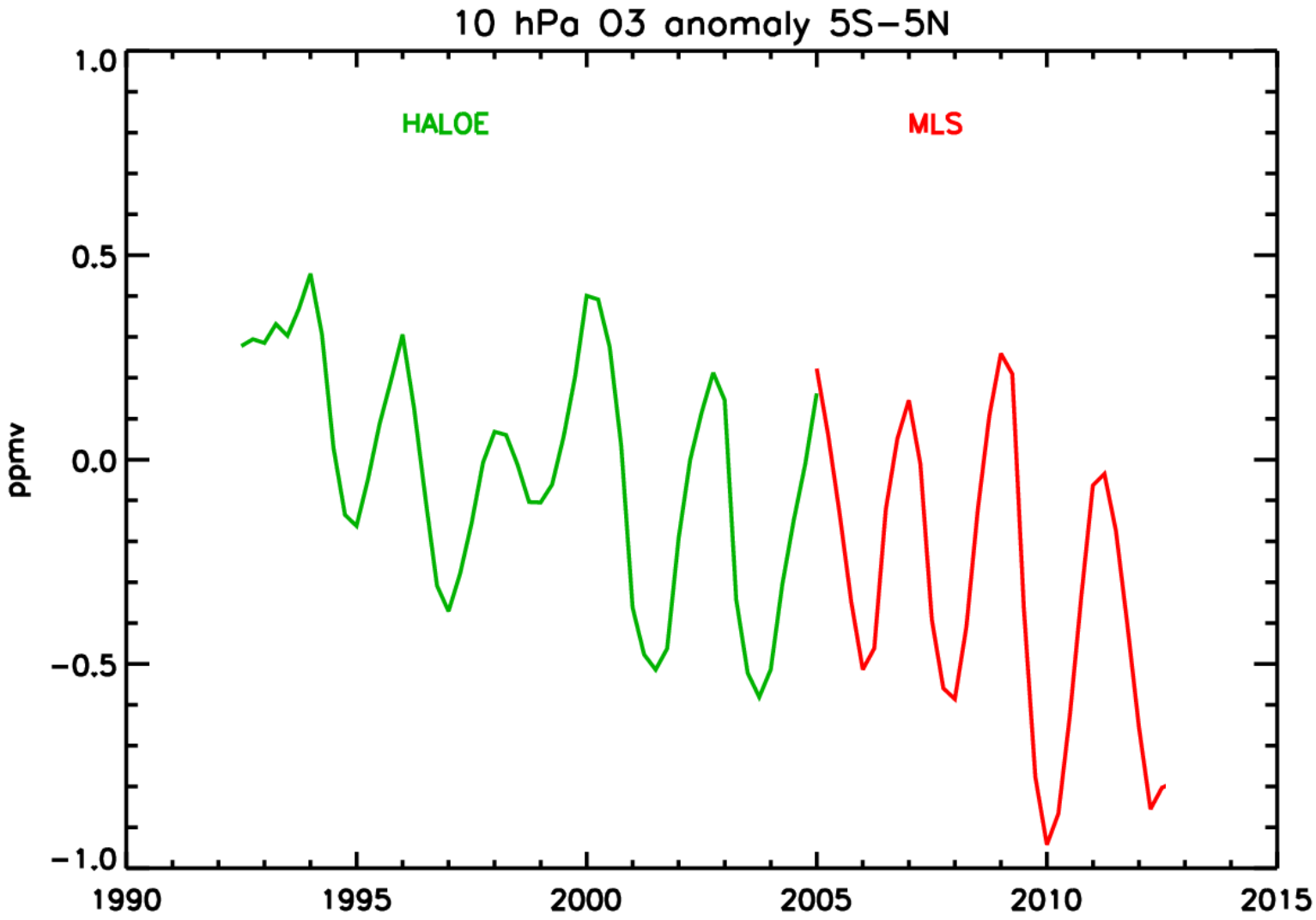
~60 ppbv/yr for HALOE

~100 ppbv/yr for MLS

Some emission scenario calculations:

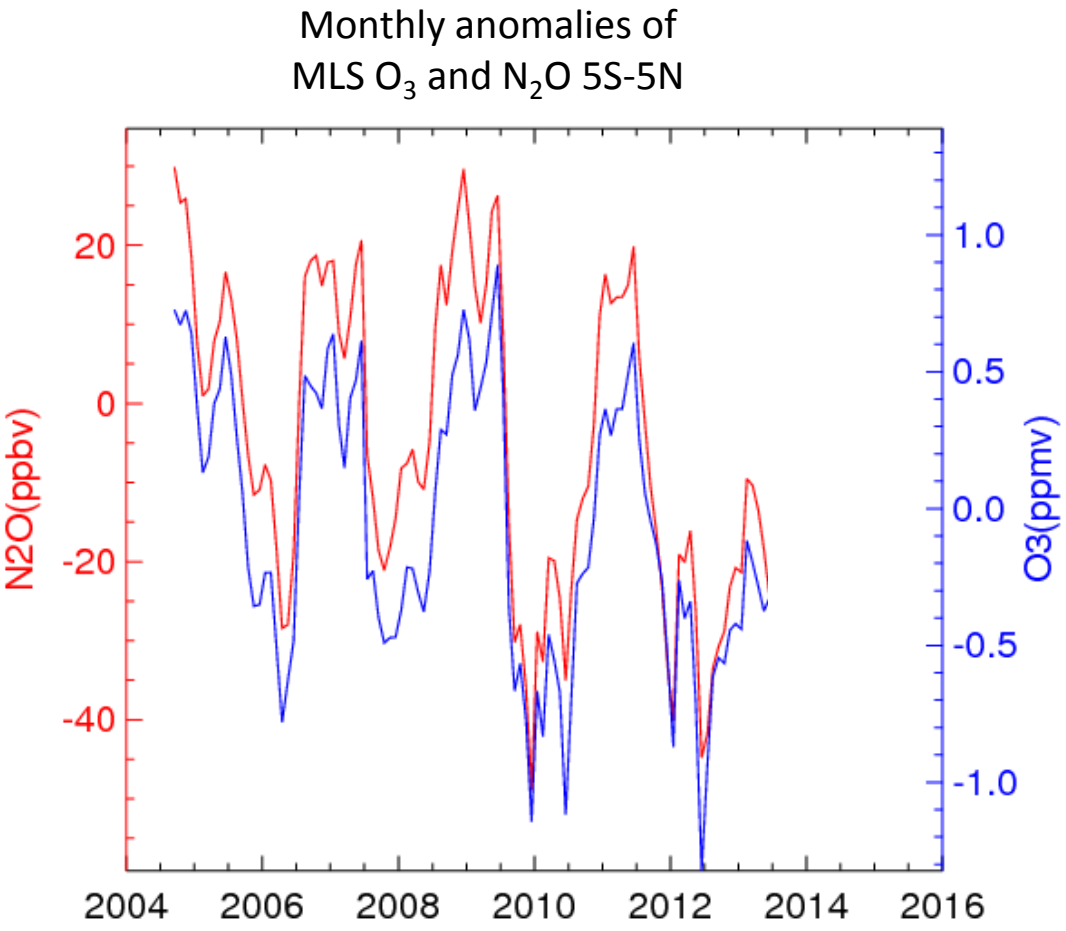
20 ppbv increase in surface N_2O over 20 year (IPCC A1B) => 5-7ppbv/yr decrease in O_3

Portmann et al., 2012



Annual average anomalies shown 4-times per year.
MLS is shifted to match up with HALOE during overlap period.
Decrease seems unrelated to solar cycle.

The *Positive* Correlation Between O_3 and N_2O



Understanding the relationship between N_2O and O_3

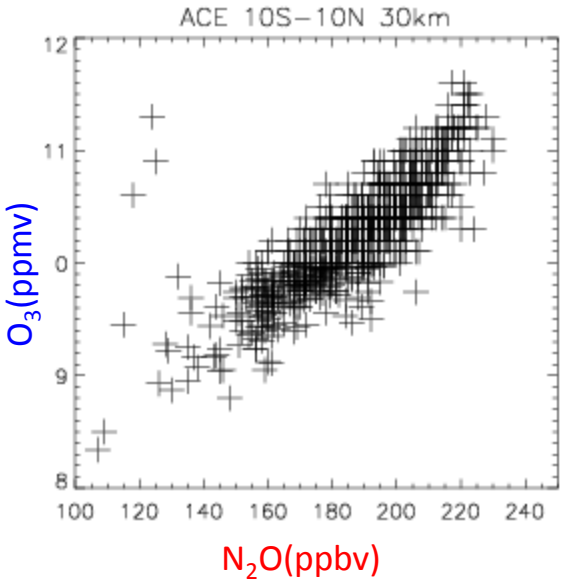
ACE-FTS measurements
10S-10N 30km

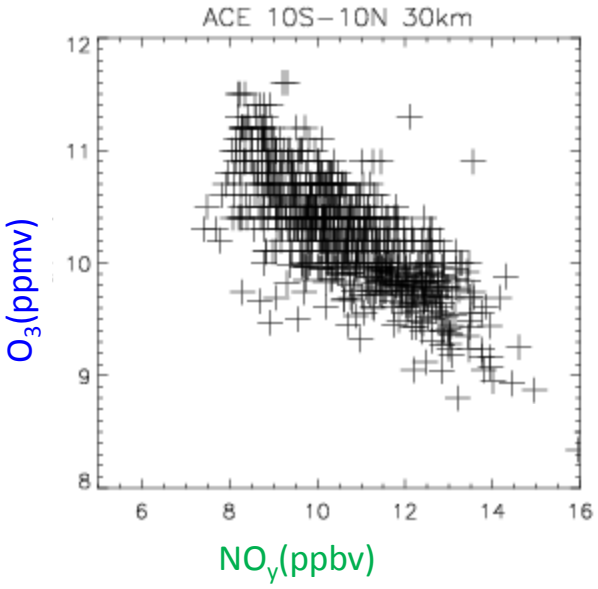
O_3

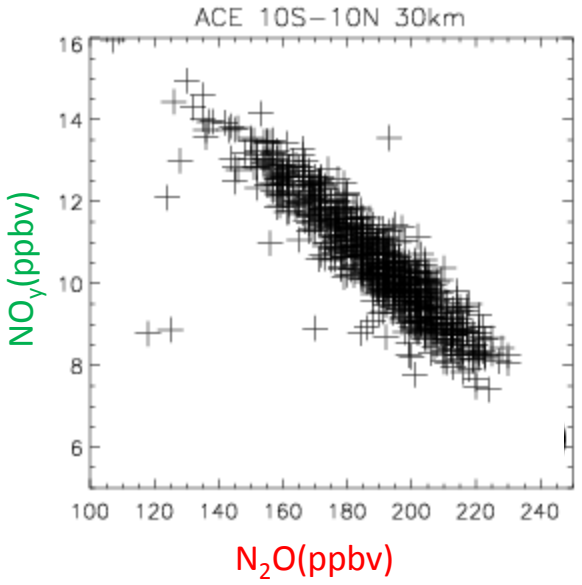
N_2O

$NO_y = NO+NO_2+HNO_3+2*N_2O_5$

ACE sunrise and sunset measurements are both shown here





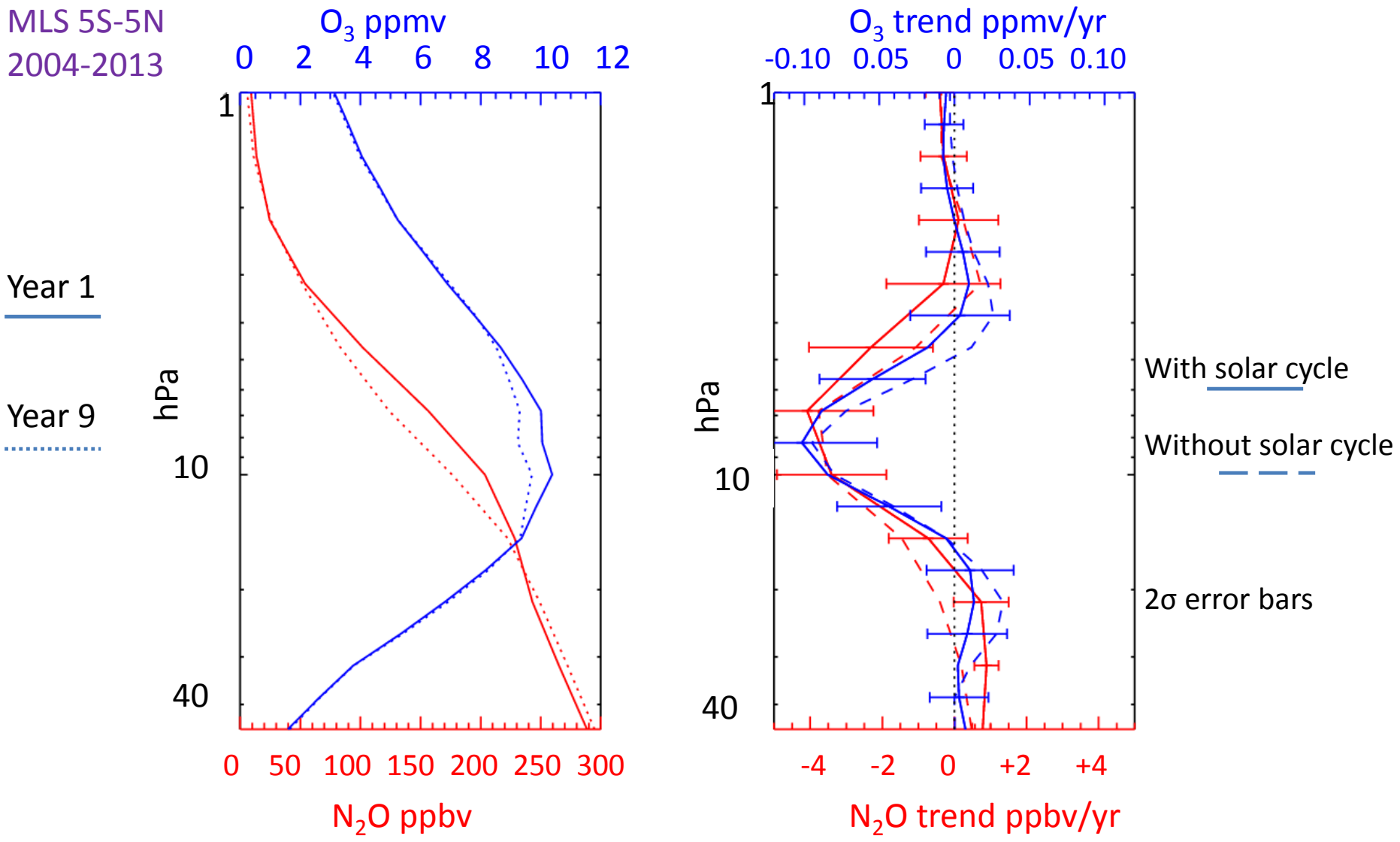


N_2O anti-correlates with NO_y

NO_y anti-correlates with O_3

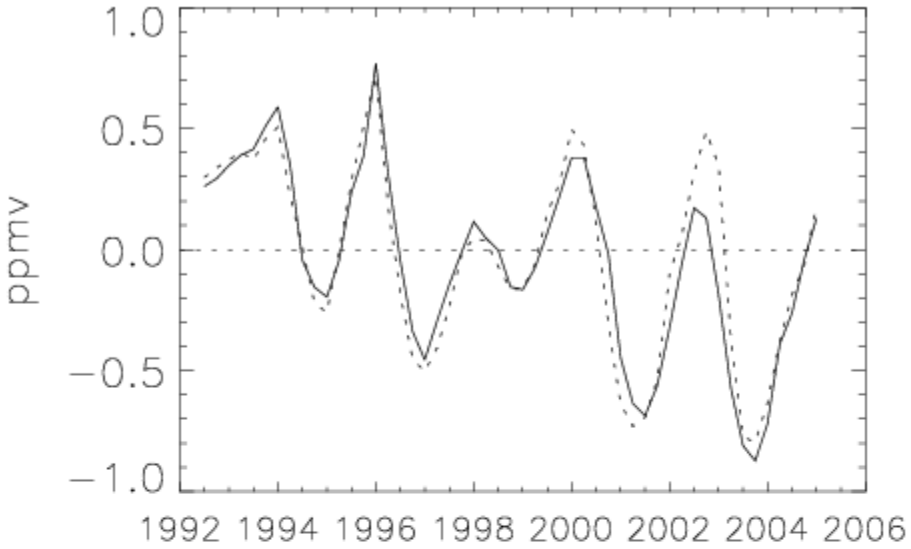
→ N_2O correlates with O_3

Vertical profiles of tropical O_3 and N_2O changes from linear trends



HALOE timeseries 5S-5N, 10 hPa

HALOE O_3

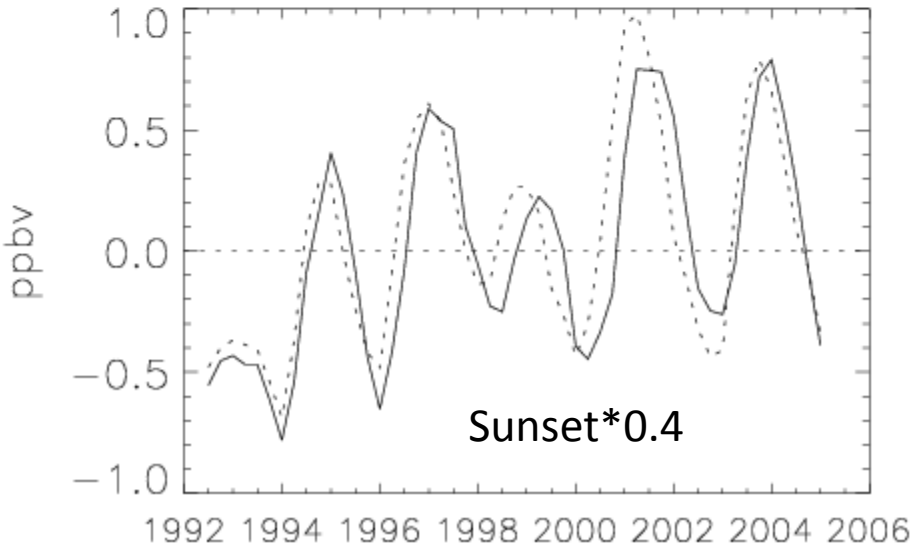


HALOE does not provide N_2O, but it does provide NO and NO_2

O_3 and $NO+NO_2$ annual average anomalies shown 4-times per year.

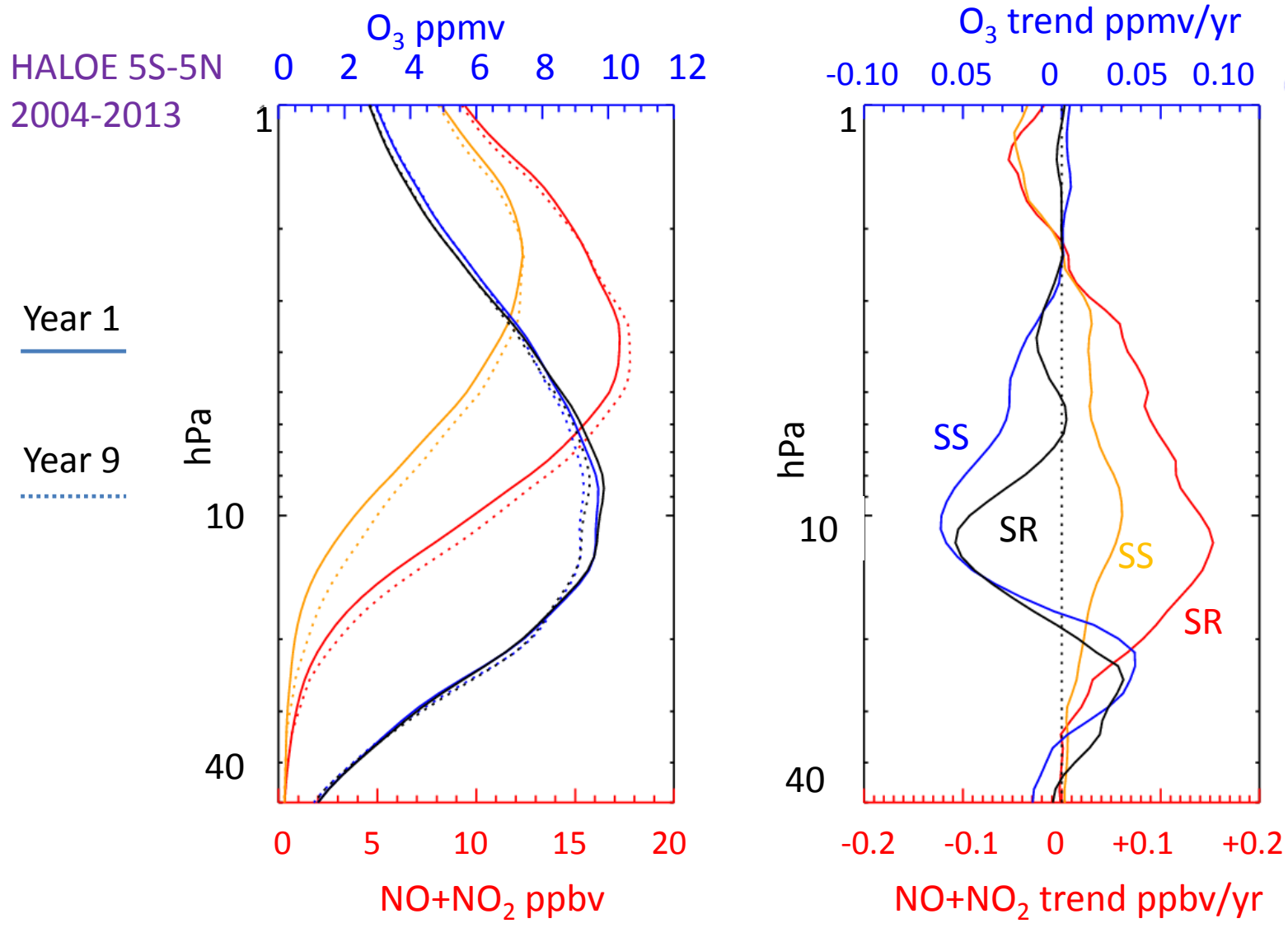
Sunset ——
Sunrise -------

HALOE $NO+NO_2$



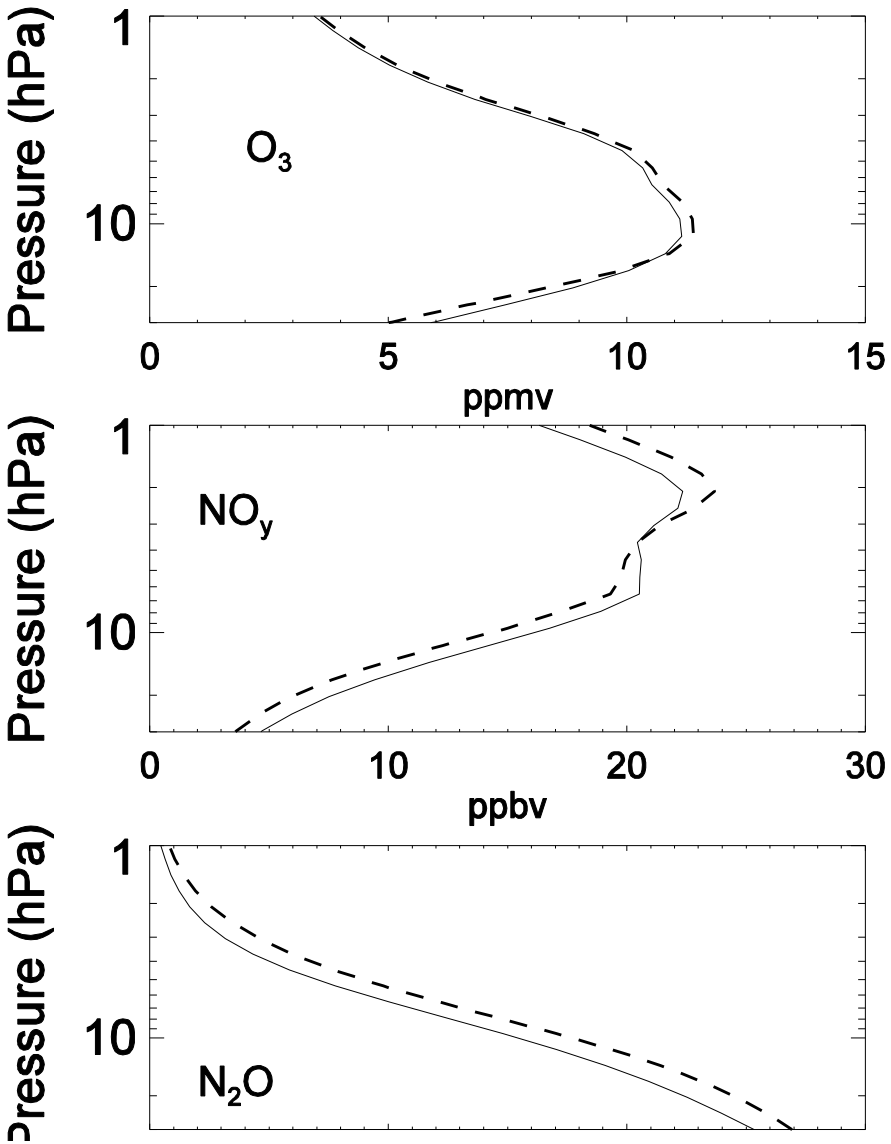
$NO+NO_2$ vs. O_3 shows a strong anti-correlation over long timescales.

Vertical profiles of tropical O_3 and NO_x changes from linear trends



O_3 (Sunrise and Sunset)
$NO+NO_2$ (Sunrise and Sunset)

Simulating changes in tropical upwelling.



Need to compare model with fast upwelling and slow upwelling

Use simple 2D model (Bacmeister et al., 1998)

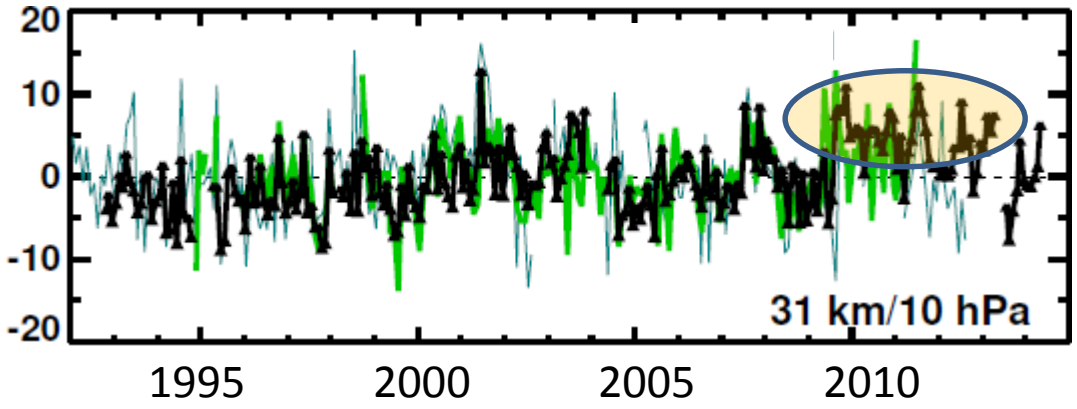
1) Baseline model (solid)
2) Increased upwelling model (Added a 0.3K/day heat source at 18km at equator, dashed).

Changes at 10 hPa are similar to observed trends

Slower upwelling gives
Decreased N_2O
Increased NO_y
Decreased O_3

What about outside the tropics?

Lauder (45S) Ozone

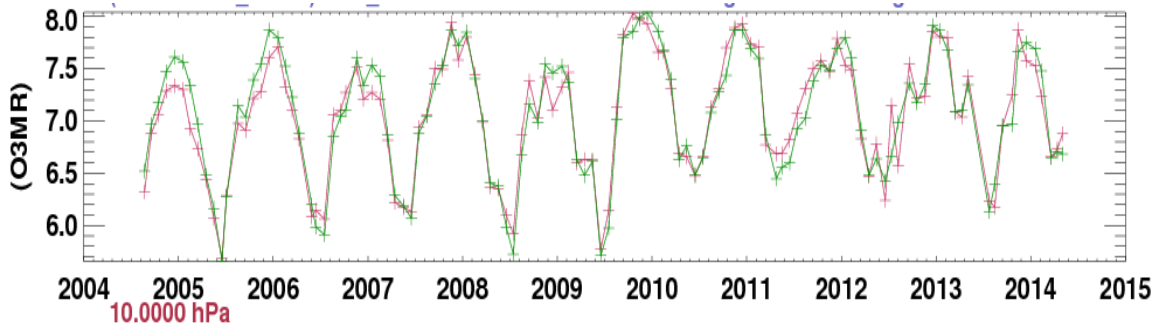


NDACC Microwave Ozone Profiling Instrument (MOPI1)

Lidar

Sonde

Unusually high 10 hPa O_3 from 2009-2013.
Large increase in mid-2009. Large decrease in mid-2013.
Good agreement between MOPI1 and MLS.

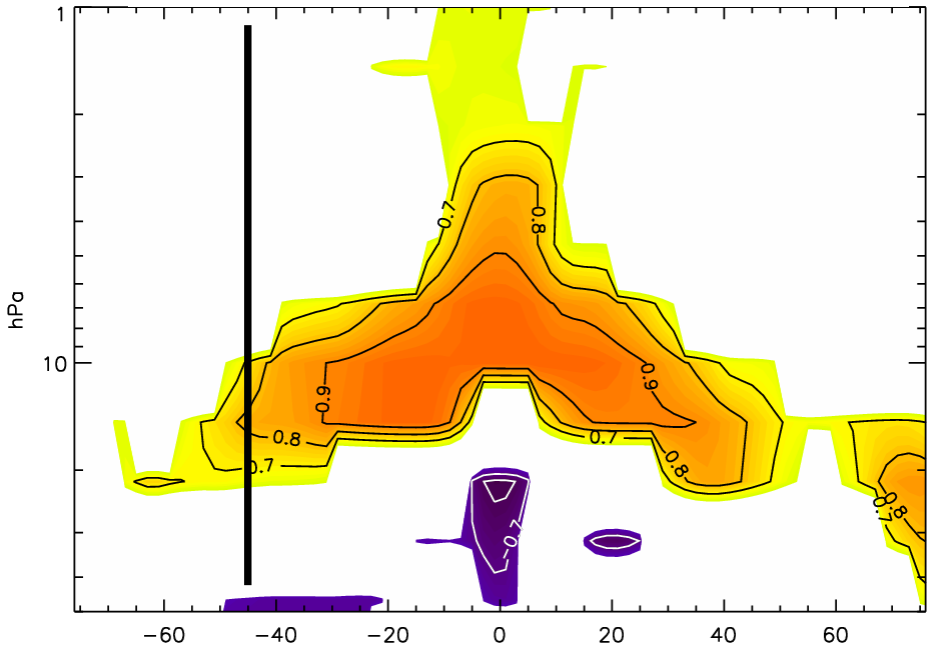


MOPI1

MLS

N_2O outside the tropics

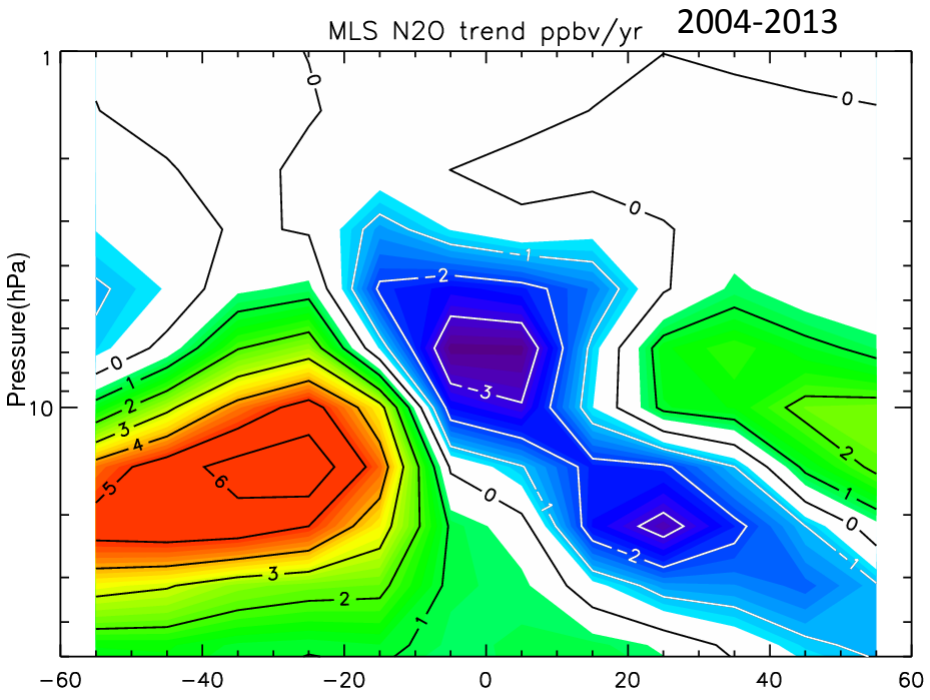
N_2O-O_3 monthly anomaly correlation

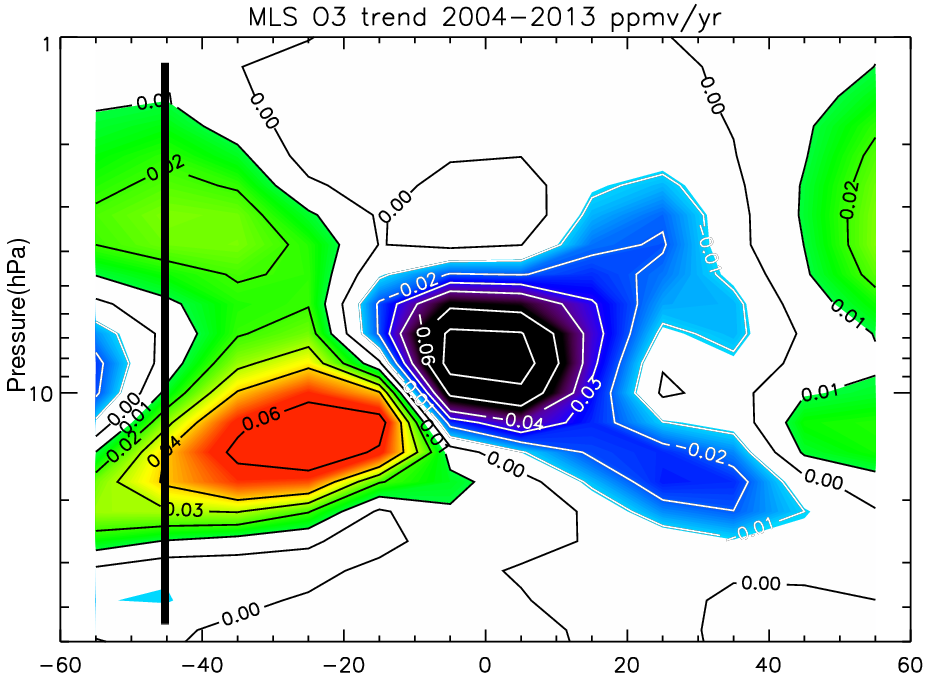


N_2O and O_3 trends from MLS since 2004 suggest:

- Older air at 10 hPa at equator
- Younger air in Southern Hemisphere between 20 hPa and 10 hPa

No such signature of younger air in HALOE O_3 (1991-2005)





MLS and NDACC Ground-Based Microwave O_3 2004-2013

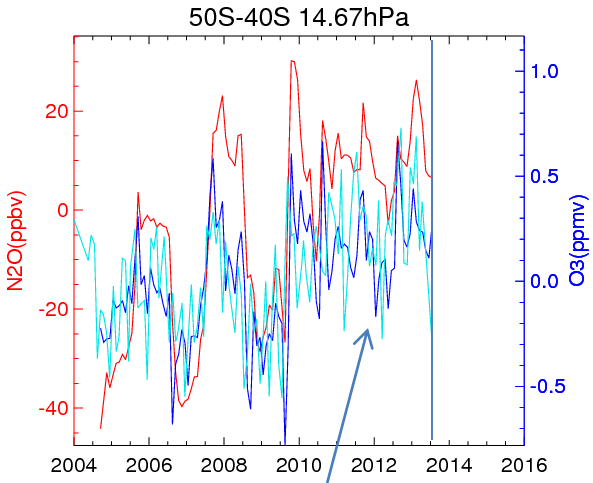
MLS O_3

MOPI (Microwave O_3 Profiling Instruments) at NDACC Lauder and Mauna Loa sites

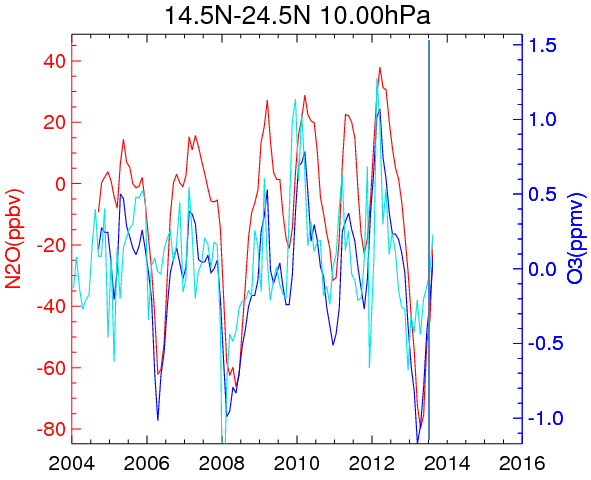
MLS N_2O

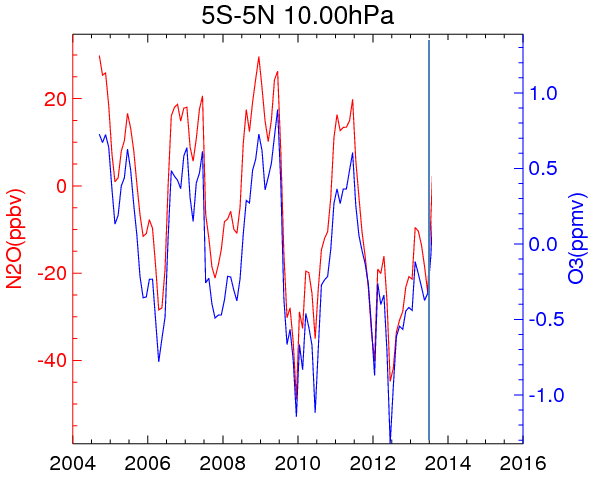
N_2O and O_3, especially in the tropics, show a strong correlation at ~10 hPa.

Lauder

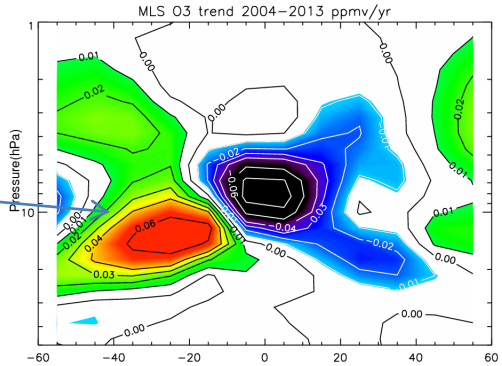


Mauna Loa





Prolonged period of increased N_2O and O_3 over Lauder



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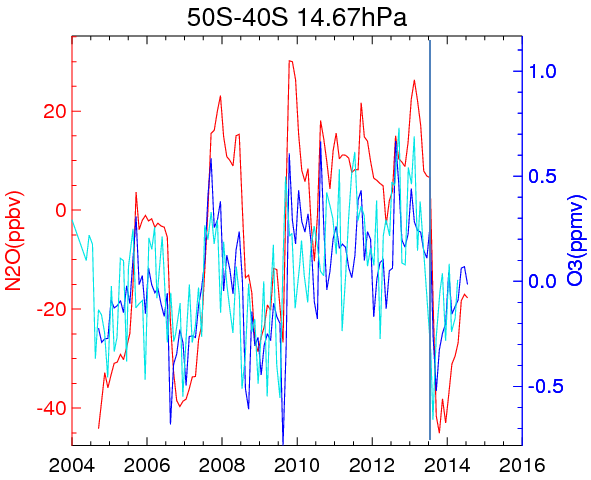

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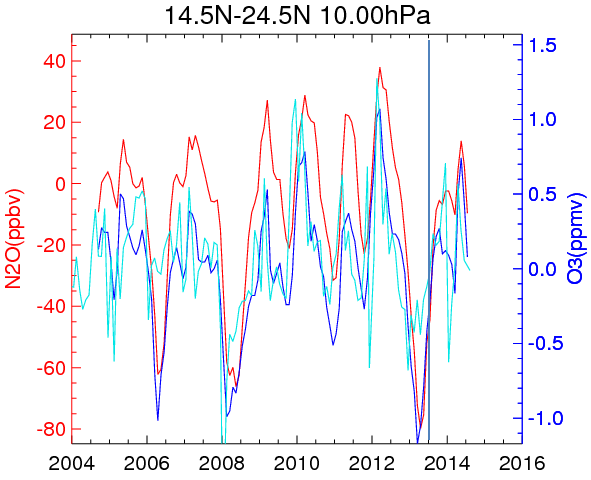

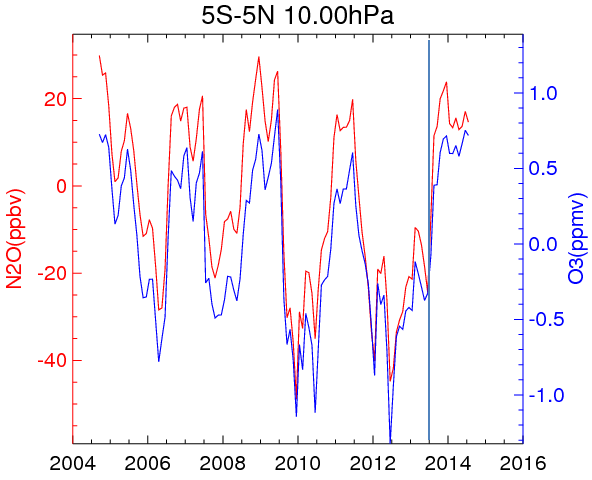

Summary

- Previously reported tropical ozone decreases at 10 hPa shown to extend over 20 years (1991-2013).

- Decrease in O_3 coincides with large decrease in N_2O (MLS) **and** large increase in NO_x (anticorrelates with N_2O).

- Likeliest explanation is **dynamical**. Slower upwelling leads to
  Decreased N_2O
  Increased NO_x
  Decreased O_3

- Other, interesting results:
  1) From 2009-2013 10 hPa O_3 over Lauder was the highest ever observed.
  2) Over the last decade SH mid-latitude N_2O and O_3 show opposite behavior from tropics
  3) In mid-2013 there was a large increase in tropical 10 hPa O_3 and a decrease at SH mid-latitudes