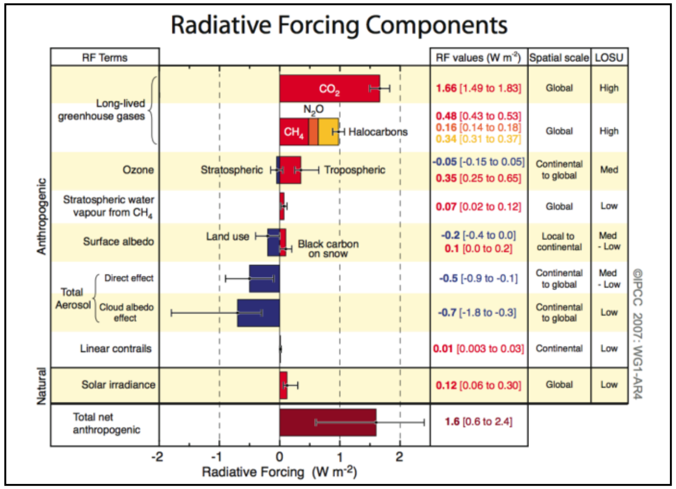
Sensitivity of Tropospheric Ozone to Emissions: Need for LEO and GEO Observations of Tropospheric Ozone and its Pre-cursors

John Worden, Jessica Neu, Kevin Bowman et al.

California Institute of Technology

Tropospheric Ozone is the Third Most Important Greenhouse Gas and an Air Pollutant



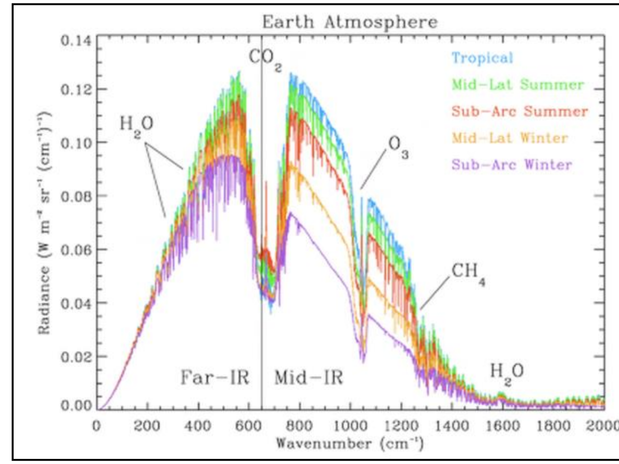


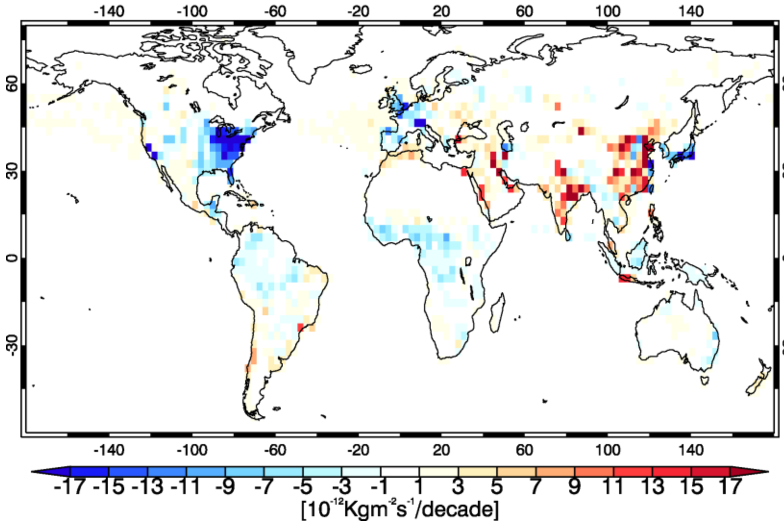
Fig. courtesy M. Mlynzcack (LaRC)

Ozone affects air-quality and plant health

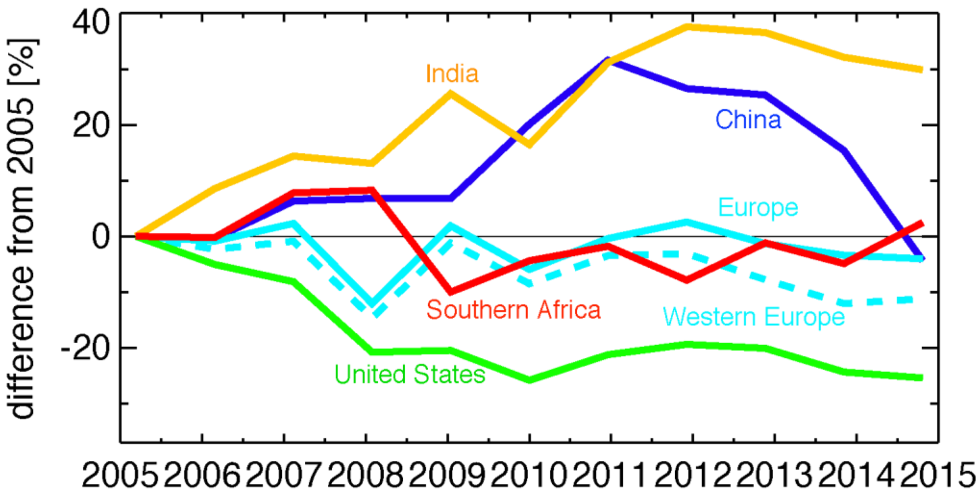
Reduced CO_2 uptake from damaged plants also strongly affects climate

Tropospheric Ozone Pre-cursors Have Changed Dramatically In The Last Decade

NOx emission trend: 2005-2015

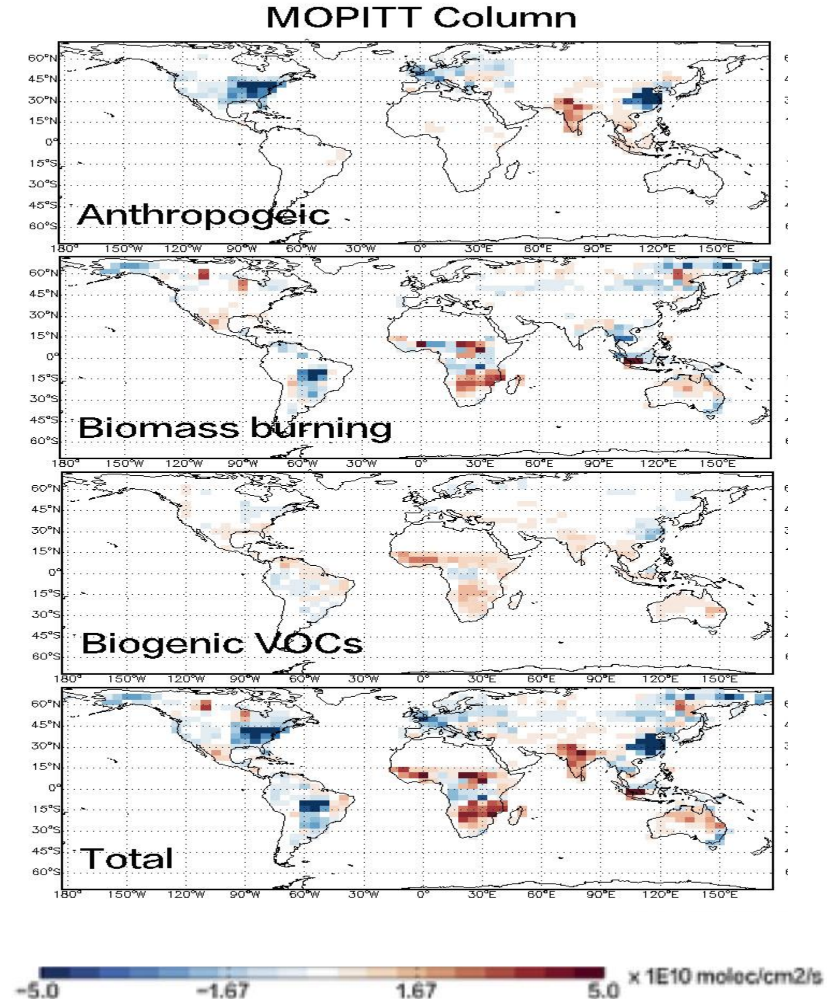


NOx emissions



Miyazaki et al., ACP 2012; ACPD

CO Emission trends from 2001-2015

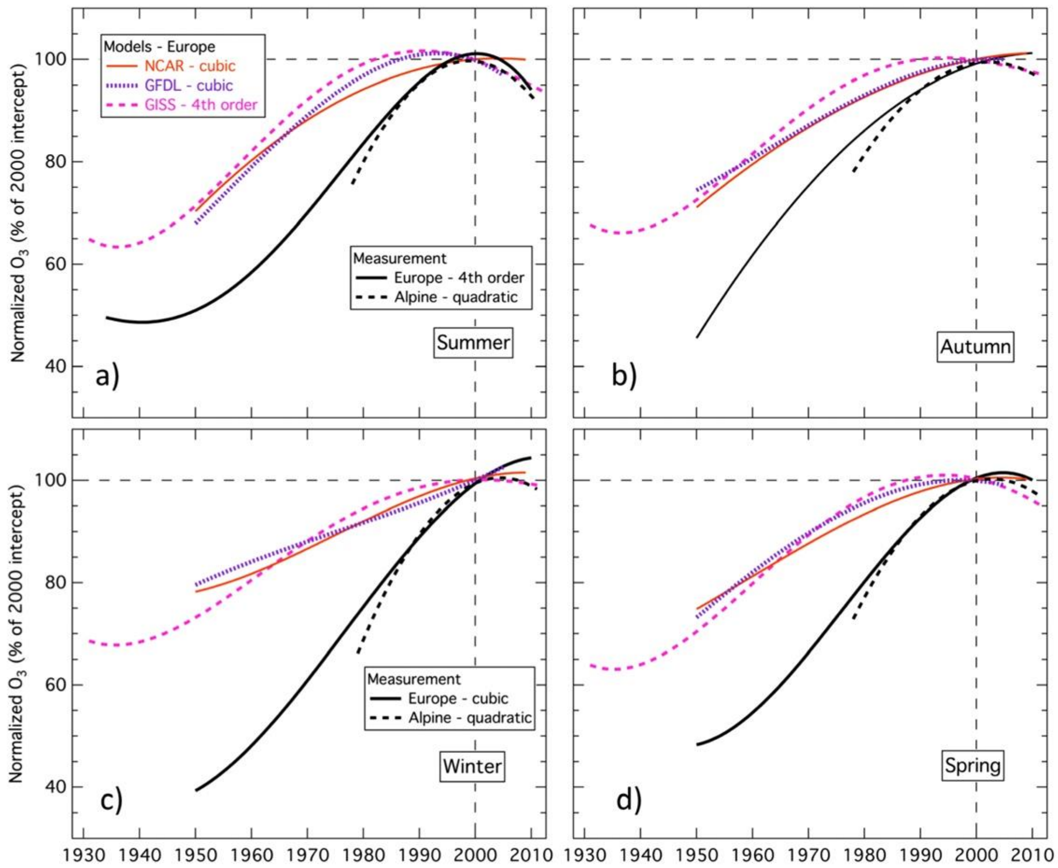


e.g. H. Worden et al., ACP 2012

Yin et al., ACP 2016;

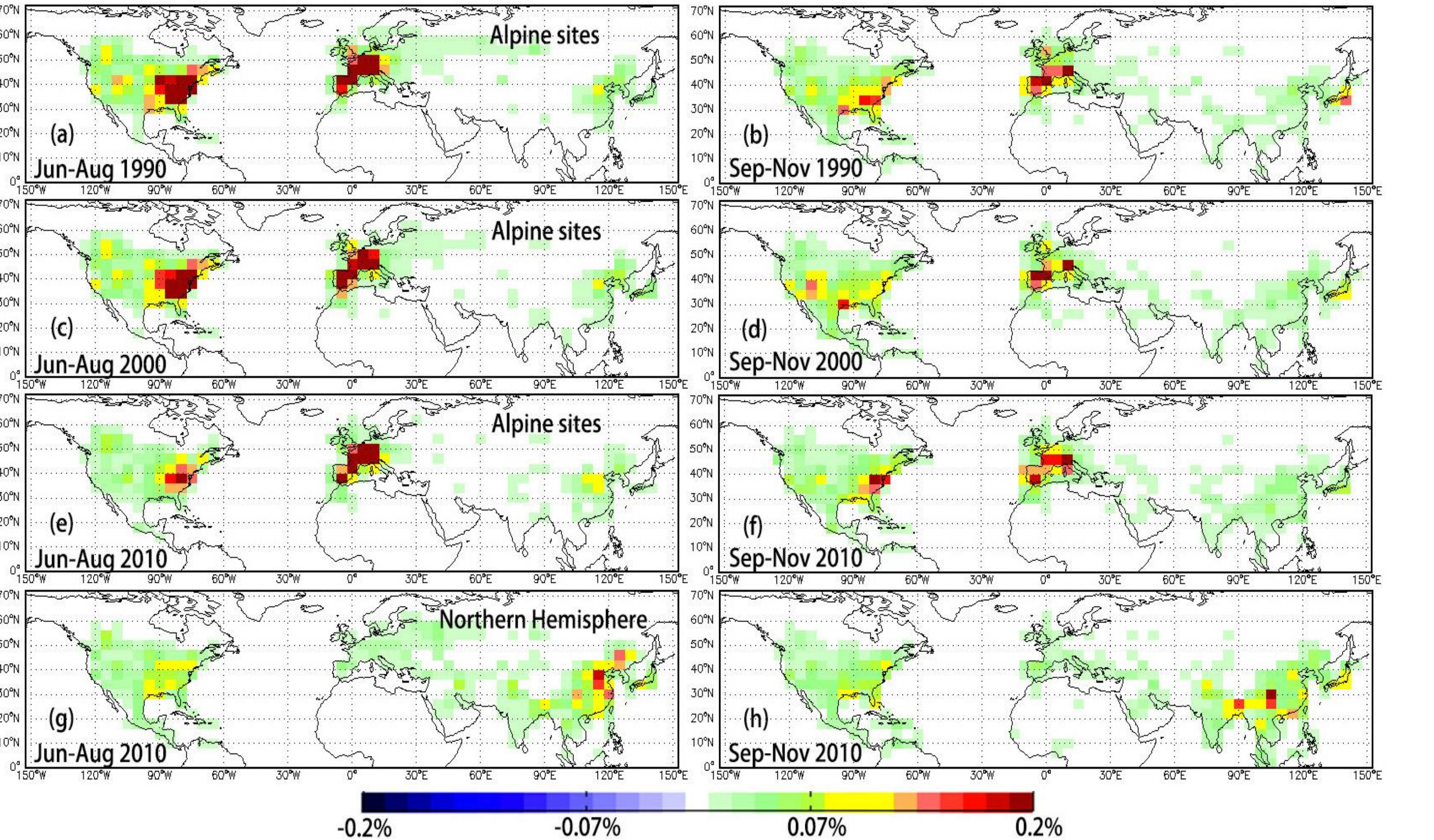
Jiang et al., ACPD submitted

Sensitivity of Free-Tropospheric Ozone Over Europe to Global Emissions



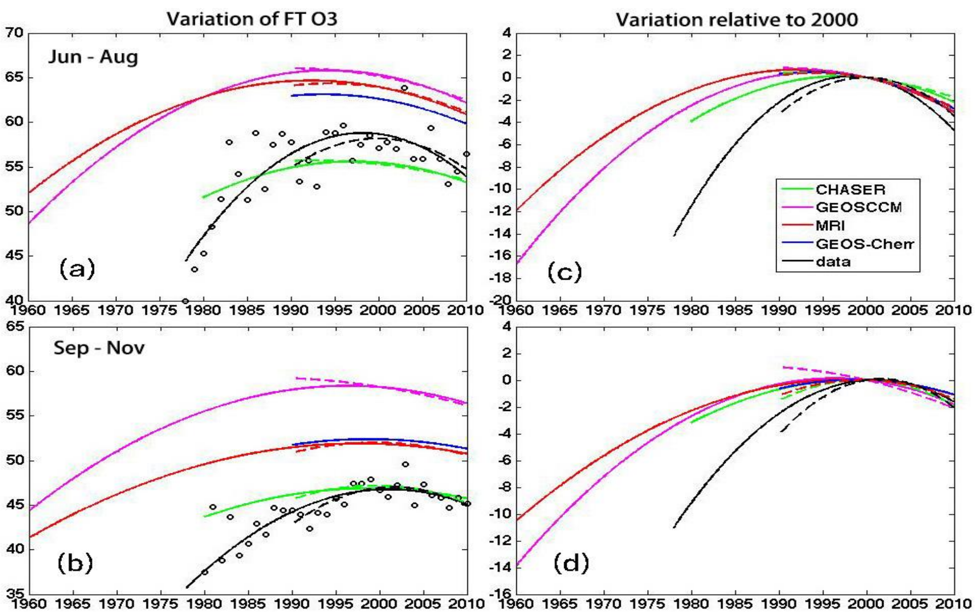
Change in ozone between ~1940 to the present is much larger in data than model

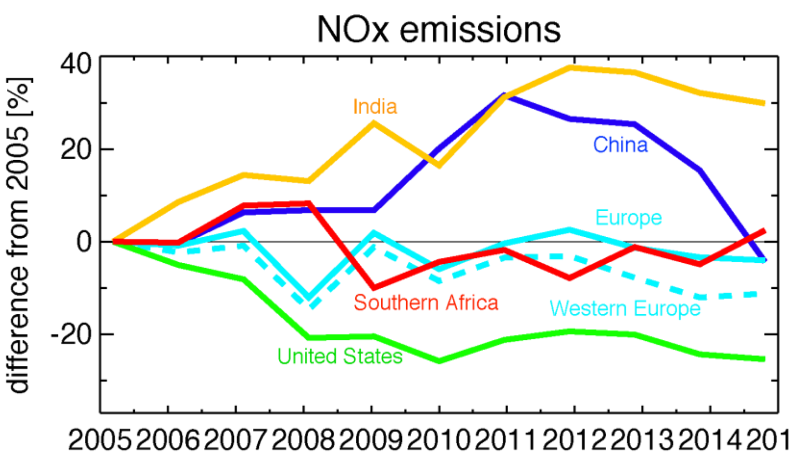
Parrish et al., JGR 2014


Alpine sites
(a)
Jun-Aug 1990
(b)
Sep-Nov 1990
Alpine sites
(c)
Jun-Aug 2000
(d)
Sep-Nov 2000
Alpine sites
(e)
Jun-Aug 2010
(f)
Sep-Nov 2010
Northern Hemisphere
(g)
Jun-Aug 2010
(h)
Sep-Nov 2010
-0.2%
-0.07%
0.07%
0.2%

Sensitivity of Free-Tropospheric Ozone Over Europe to Global Emissions

Parrish et al., JGR 2014



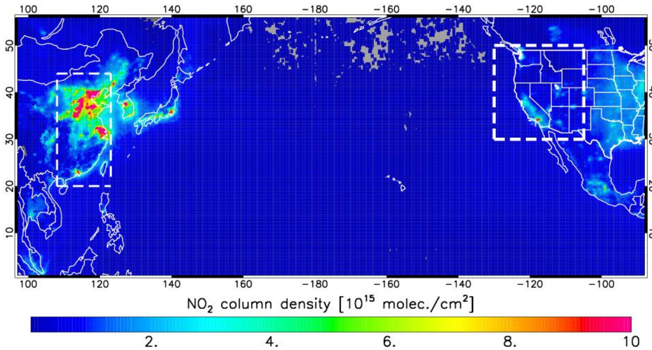


Having bottom-up emissions constrained with top-down estimates using EOS satellite measurements improves sensitivity of ozone to emissions but does not remove the discrepancy between predicted and actual ozone variability

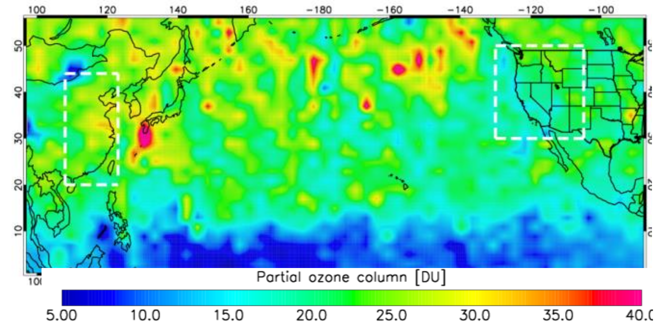
Response of Free-Tropospheric Ozone to Asian and N. American Emissions as Observed by Aura

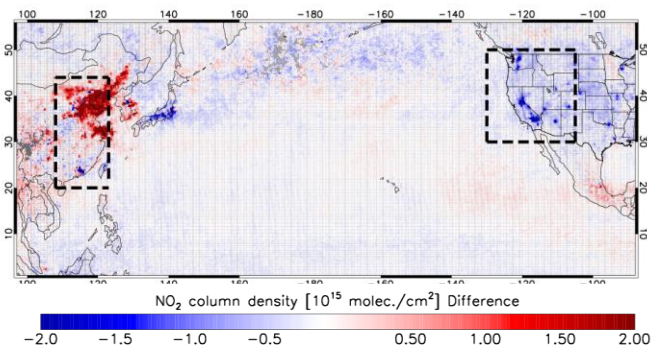
Verstraeten et al., Nature Geo 2015

2009-2010 NO_2

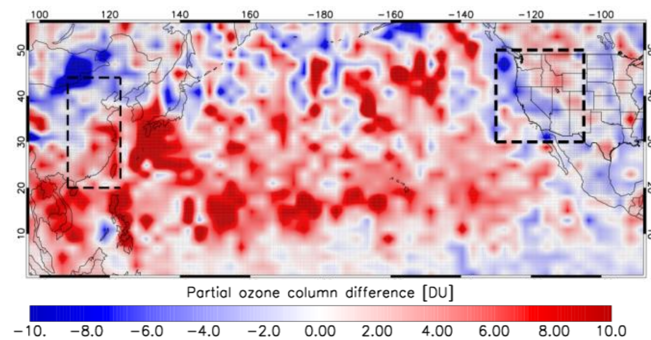


2009-2010 O_3





2010-2005 NO_2



2010-2005 O_3

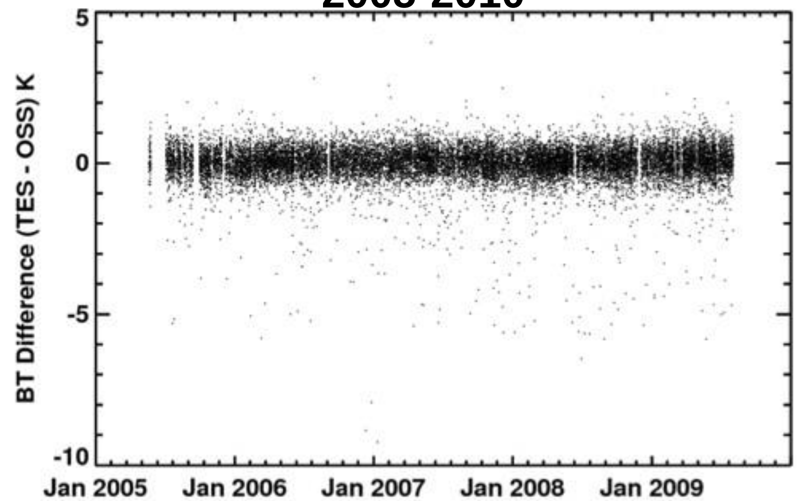
Do increasing NOx emissions in Asia explain increasing ozone over Asia?

How is tropospheric ozone over N. America responding to increasing Asian emissions and decreasing N. American emissions?

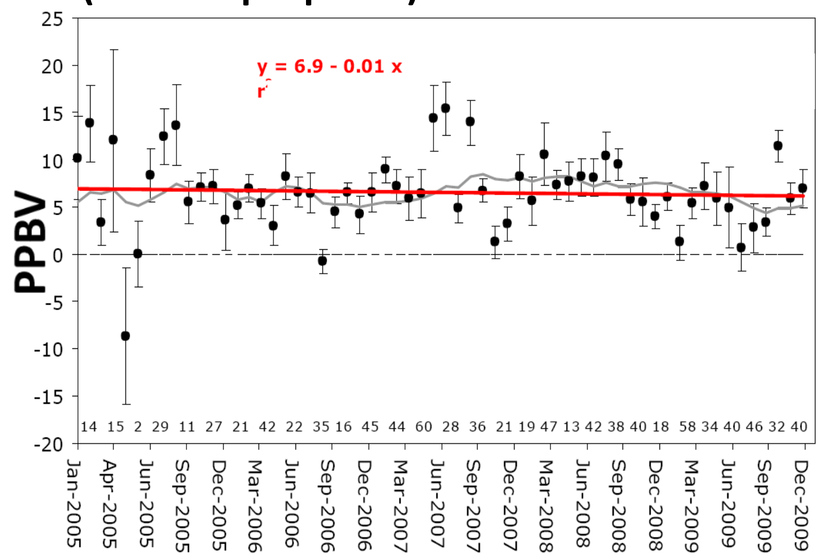
Temporal Stability of TES Radiances Ensures Temporal Stability in TES Composition Retrievals

Connor et al., AMT 2011
Verstraeten et al., AMT 2013

TES Minus Ocean (Sea Surface Temperature) 2005-2010



TES (Free-Troposphere) Minus Ozone-Sondes



Calibration stability makes TES composition retrievals suitable for model evaluation and trend analysis

Response of Free-Tropospheric Ozone to Asian and N. American Emissions as Observed by Satellite

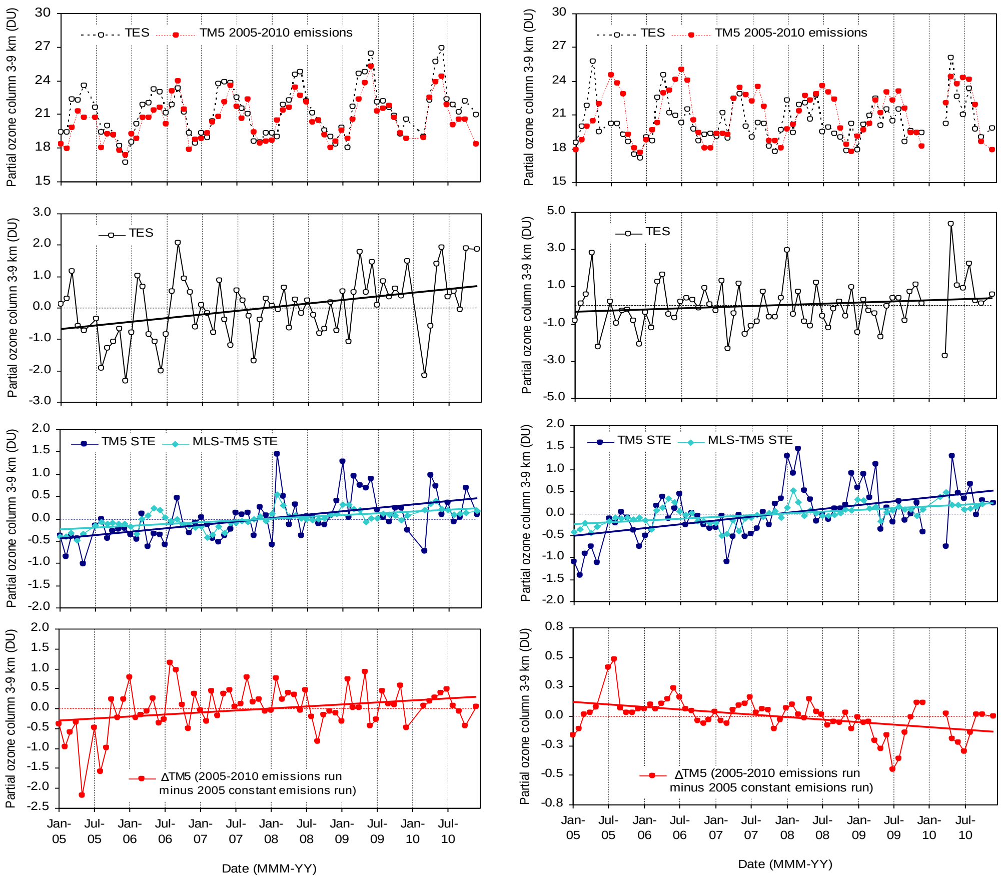
Verstraeten et al., Submitted

Asian Ozone and Budget | W. USA Ozone and Budget

Total Ozone Trend
~1.1%/yr Obs
~1.3%/yr Model
Or ~5.5 ppb/6 yrs

Emissions
~0.6% / yr

Strat/Trop
~0.8% / yr model
~0.5% / yr data



Total Ozone Trend
~0.6%/yr Obs
~0.7%/yr Model

Emissions
~-0.1% / yr

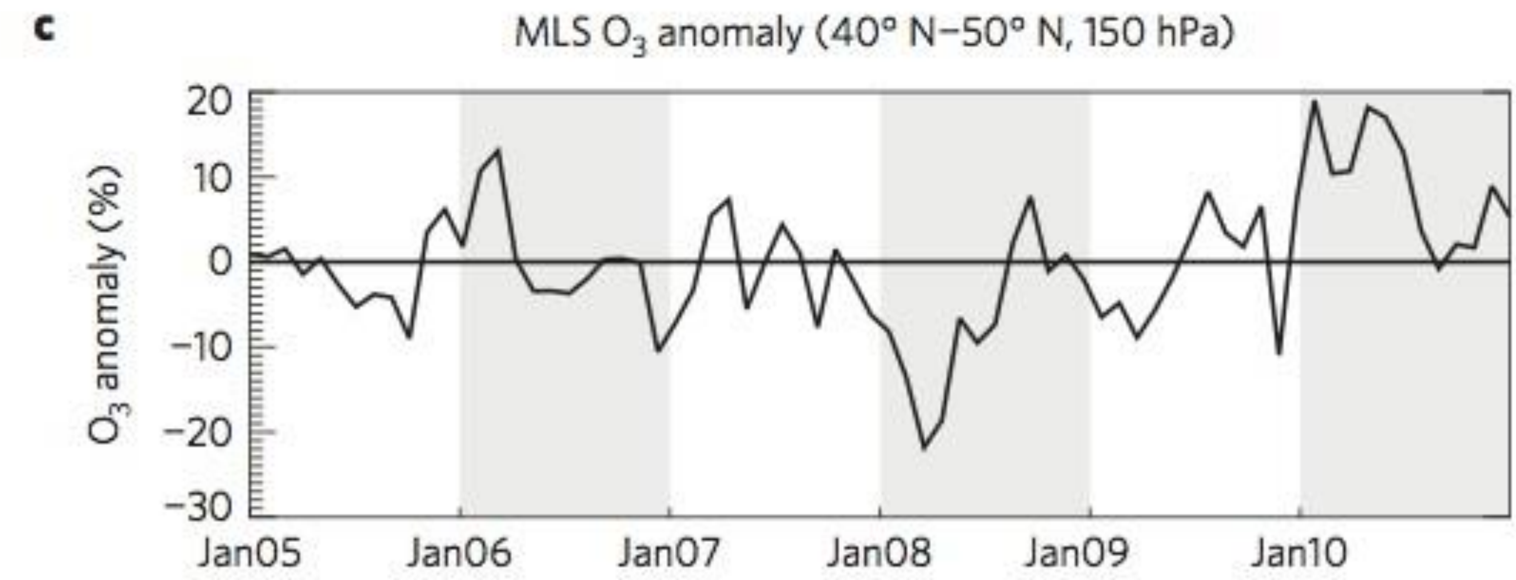
Strat/Trop
~0.8% / yr model
~0.5% / yr data

- **TM5 model estimates bulk of increase over Asia is due to STE but with statistically significant (P~0.005) contribution from emissions (~10% increase in emissions → ~0.9 ppb ozone over Asia)**
- **Data from Aura MLS indicate strat/trop exchange only important in 2009/2010 due to QBO**
- **Asian ozone offsets approximately 47% of N. American emissions reductions.**

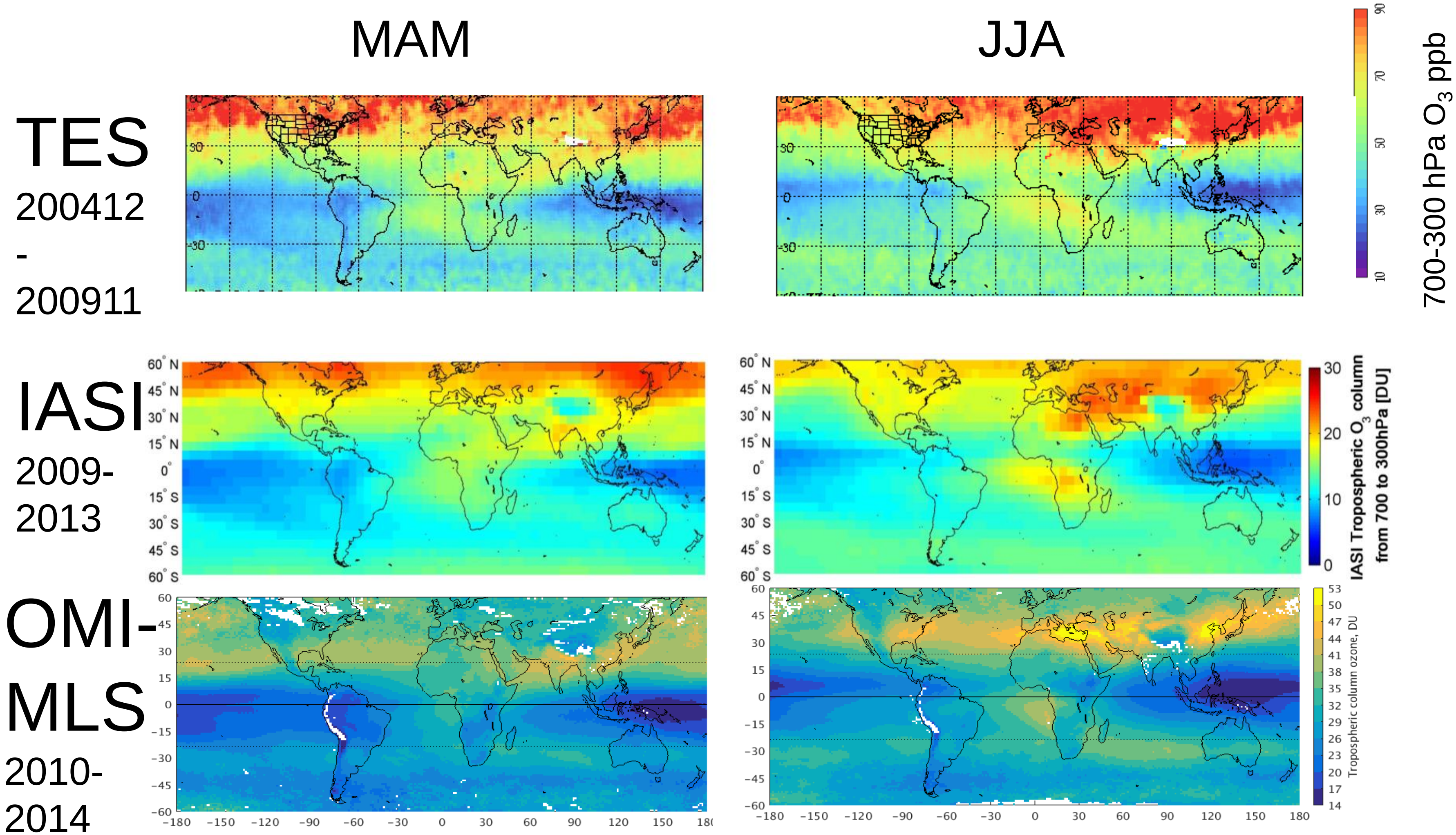
Strat / Trop Exchange likely too high in models → Role of anthropogenic emissions too small

From *Neu et al., Nature Geoscience*, 2014

At the hemispheric scale: No obvious increase in exchange of ozone between the stratosphere and troposphere



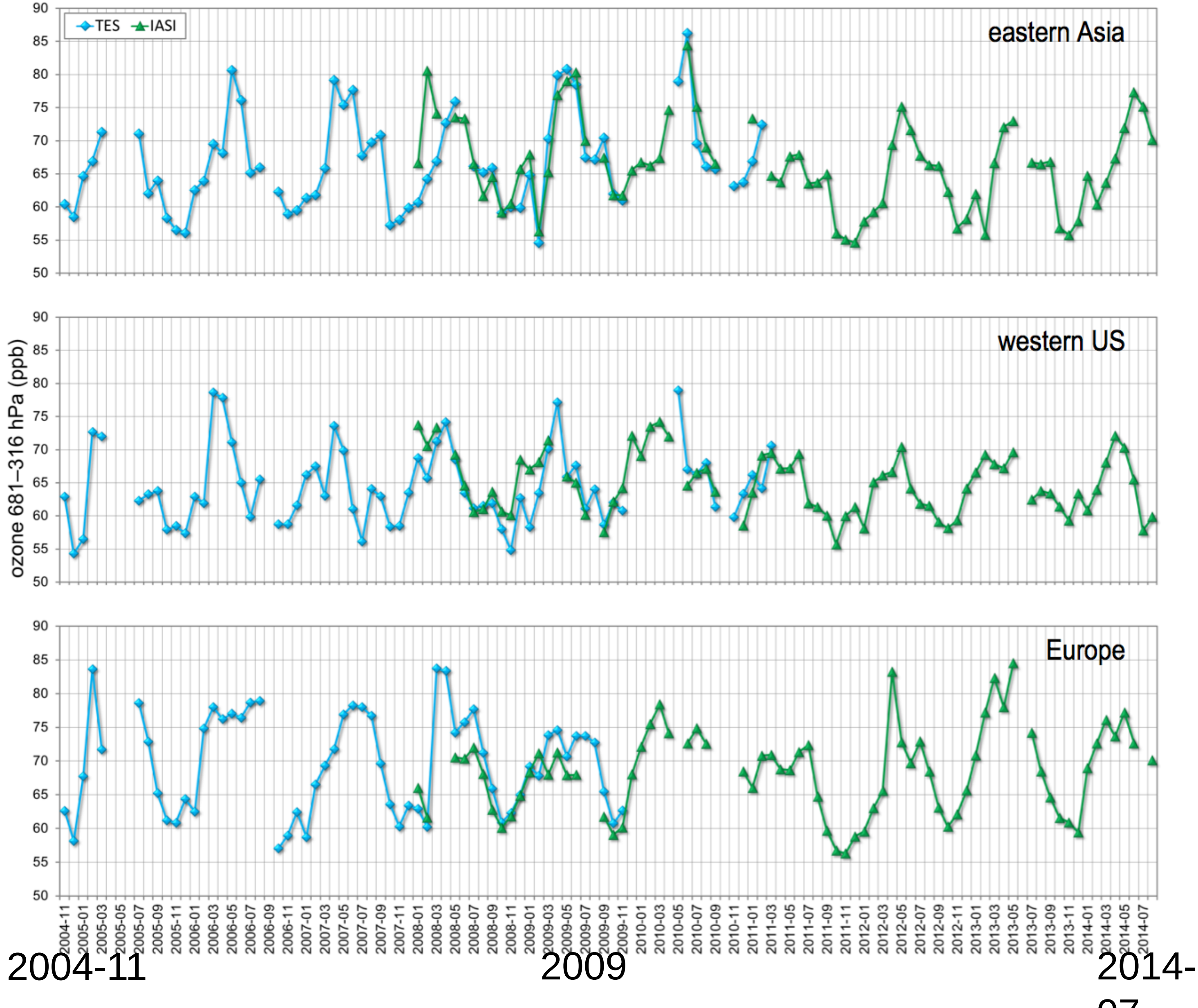
To resolve these discrepancies we need validated long-term records of Tropospheric ozone (and its pre-cursors)



Tropospheric ozone products that can be used to characterize sensitivity of tropospheric ozone to emissions

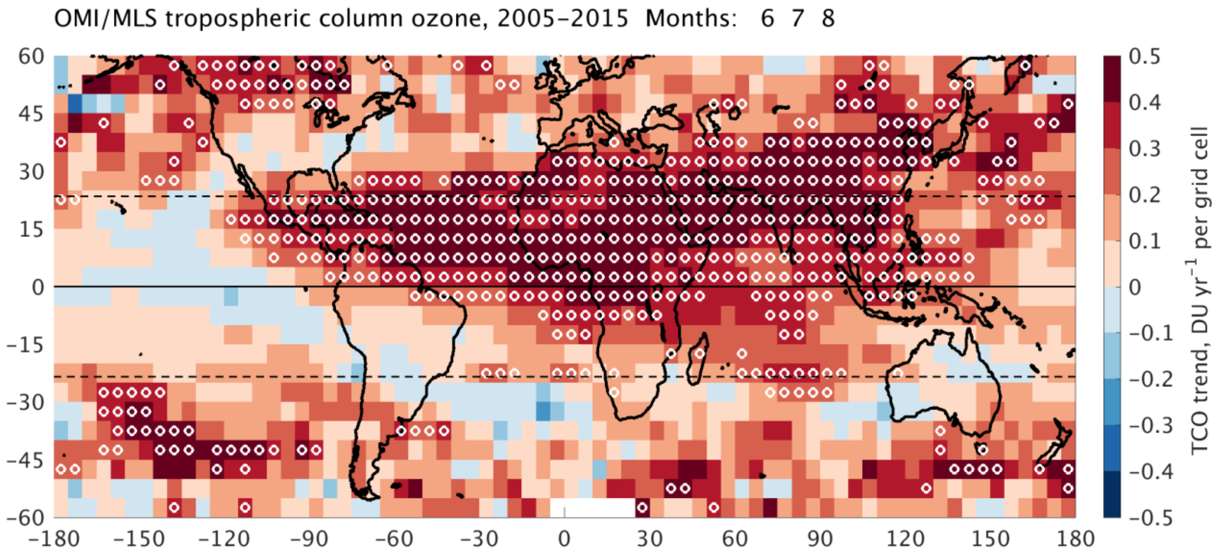
Combined TES/IASI 700-300 hPa O_3

[Oetjen et al., ACP, 2016]



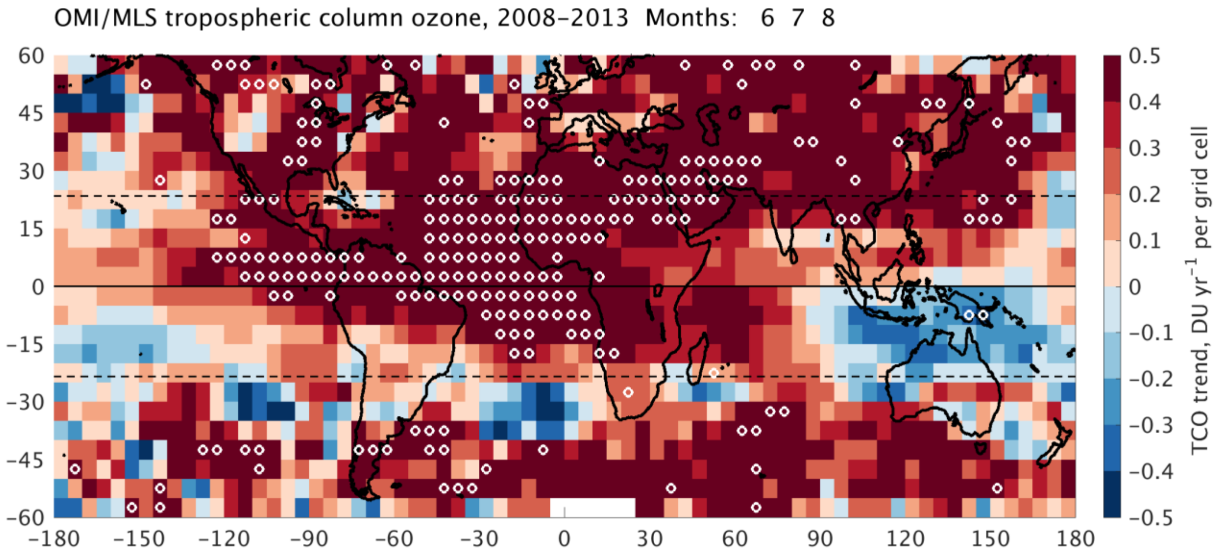
OMI-MLS trends

(Owen Cooper et al.)



2005-2015 (JJA)

White dots indicate statistically significant trend



2008-2013 (JJA)

To match IASI record In Wespes et al., ACP, 2016.

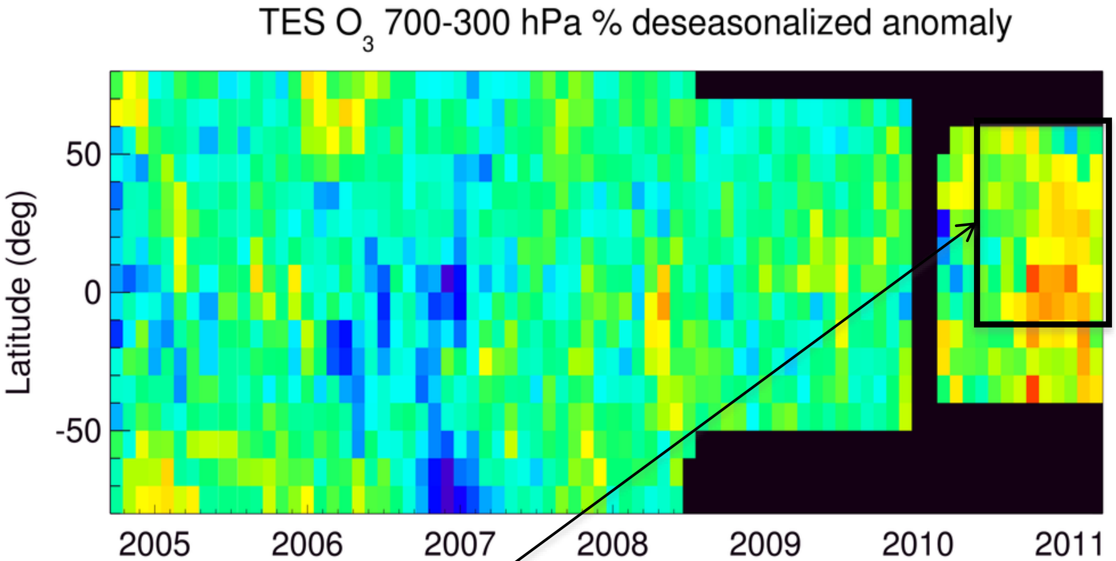
Summary

- **Shift in Ozone Pre-cursors is changing the distribution and trends of ozone.**
- **However, the relationship between tropospheric ozone burden and its pre-cursors are still not understand with substantial consequences in our ability to predict future ozone levels.**

1) **We need continued measurements of ozone profiles in the stratosphere and troposphere as well as spatially resolved measurements of its pre-cursors → requires a constellation of GEO and LEO orbits**
    - **We will have dedicated composition sounders from TEMPO, GEMS, TROPOMI, and Sentinel to obtain TCO, NO2, and formaldehyde – a tracer of VOC's**
    - **We could get ozone profile and ozone pre-cursor measurements (methanol, PAN, NH3, and CO) from CRIS and IASI series → but there is no dedicated program to retrieve these measurements**
    - **We may not have measurements in the future from MLS which is a critical constraint on STE**

2) **Need to resolve different measurement approaches (e.g. MLS/OMI relative to TES/IASI) to ensure observed trends are real and not due to data artifacts**
    - **Continued, consistent calibration and validation measurements are critical for creating a robust set of measurements**
    - **Need to account for the effect of sampling and instrument sensitivity on trends (e.g. Yoon et al., ACP 2013)**

Mean Value Deseasonalized % Anomalies



Anomaly =
100 * (x_{month}(lat) –
time mean [x_{month}(lat)])
/time mean

Tropics and
N. mid-lat reach
highest % anomaly
2010-2011