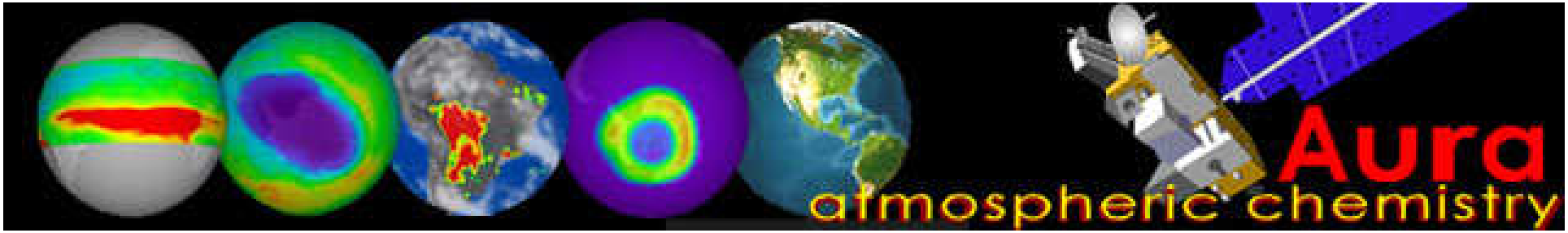
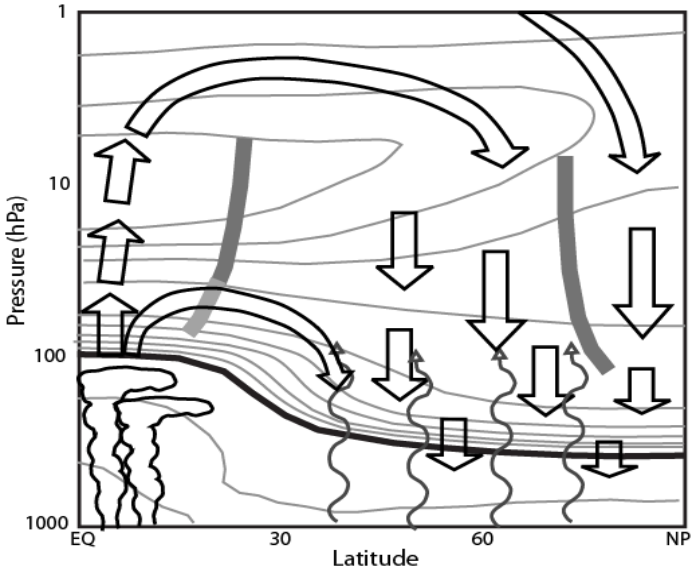


The Stratospheric Contribution to Tropospheric Ozone Variability and Trends

Jessica L. Neu (JPL / Caltech), John Worden, Nathaniel Livesey, Michelle Santee, Gloria Manney, Kevin Bowman, Willem Verstraeten, Doug Kinnison, Thomas Flury



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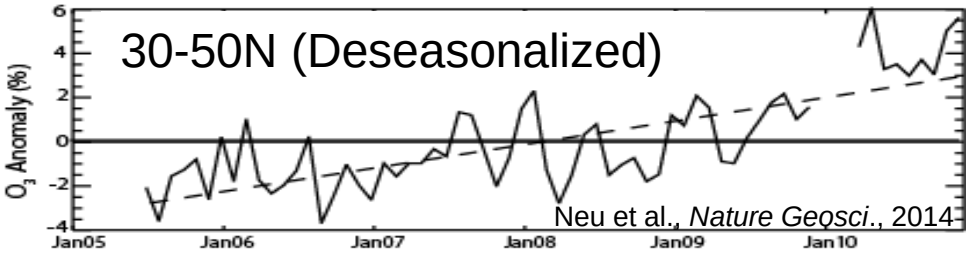
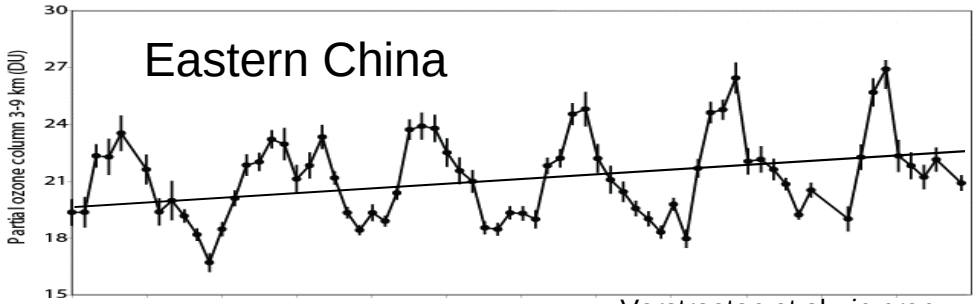
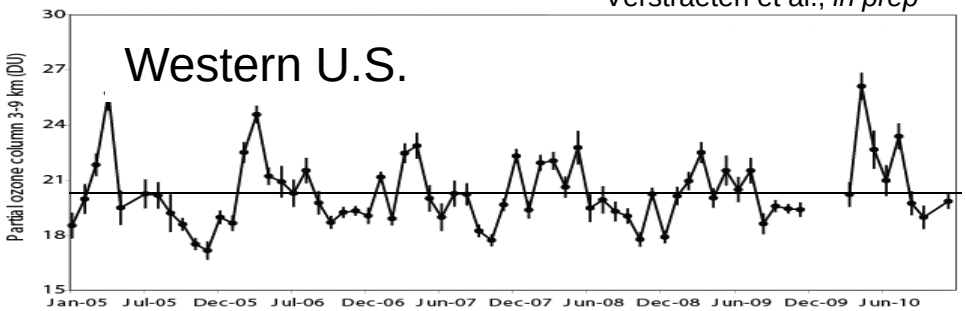
Tropospheric Ozone Variability and Trends from TES

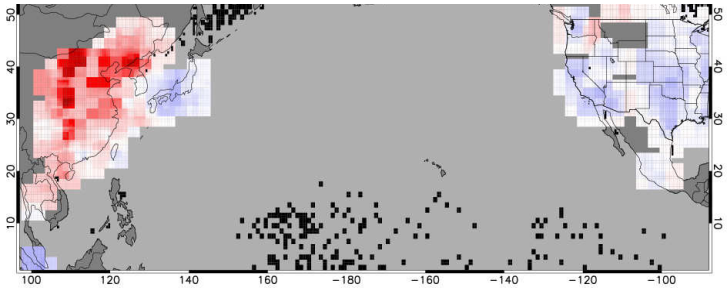


Neu et al., *Nature Geosci*., 2014



Verstraeten et al., *in prep*





2005-2010 NO_x Changes Constrained by OMI NO_2

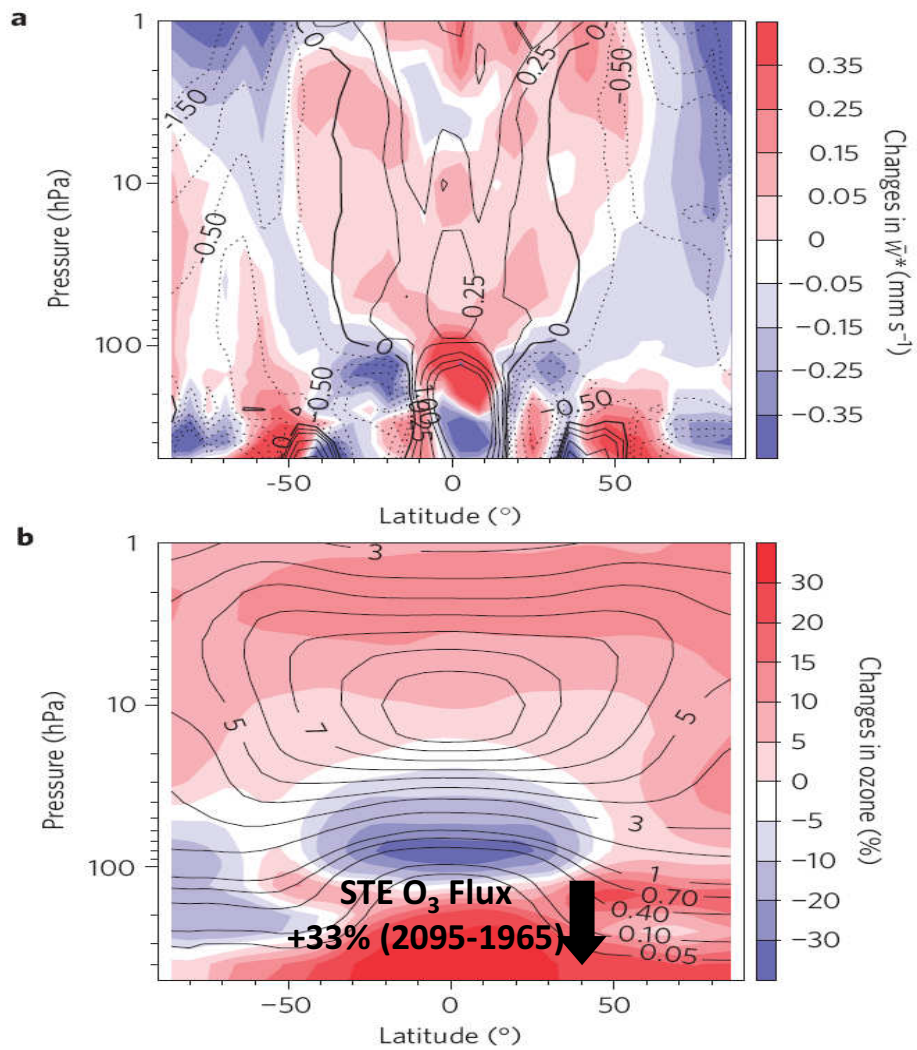
- **TES measurements show that mid-tropospheric ozone is increasing throughout northern midlatitudes.**
- **There is no temporal variation in the TES bias against sondes, so we believe TES trends are real (Verstraeten et al., 2013)**
- **There are regional differences in TES trends and in precursor emissions. Ozone over Eastern China has been increasing, while ozone over the Western U.S. has remained constant.**
- **Interannual variability is large relative to the trends and complicates interpretation.**

What Role Does the Stratosphere Play?

- What role does the stratosphere play in tropospheric ozone variability and trends?
- Chemistry-climate models predict increases in the stratospheric circulation and stratosphere-to-troposphere ozone flux in response to GHGs
- How do we expect the stratospheric contribution to change in the future?

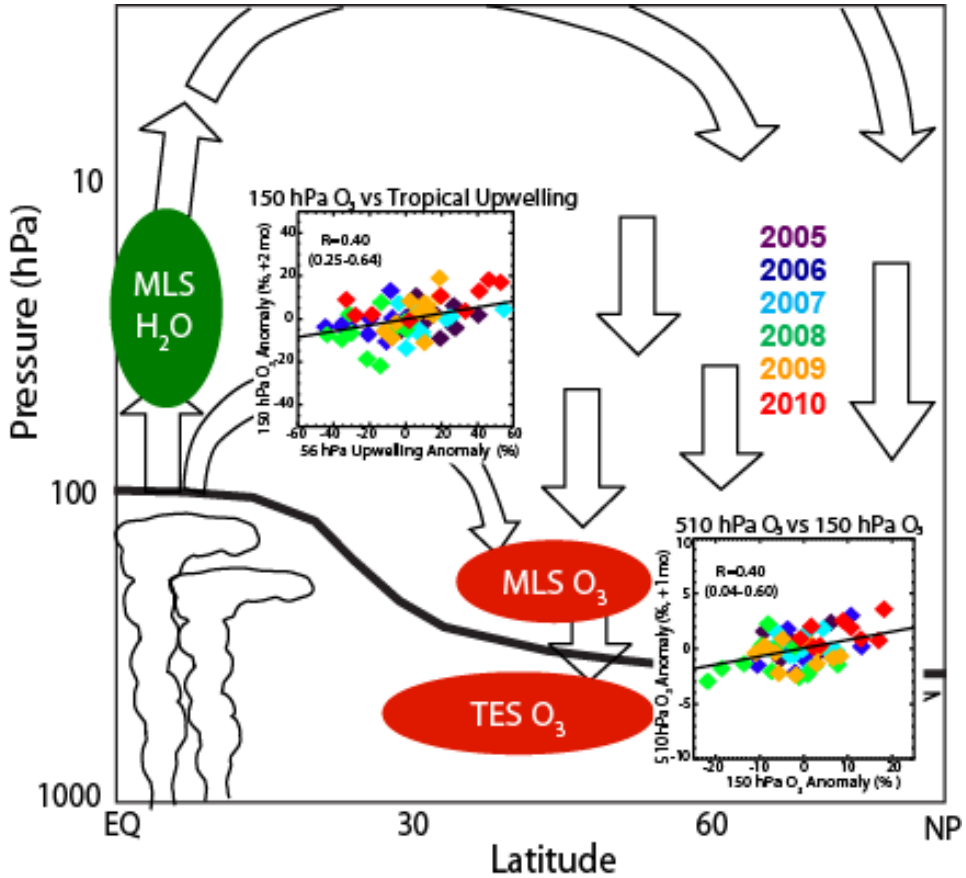
Future changes in Circulation and O_3

From Hegglin and Shepherd, 2009



Stratospheric Contribution to Tropospheric O_3 Variability

Natural variability in the stratospheric circulation allows us to empirically derive the response of tropospheric ozone to changes in the circulation

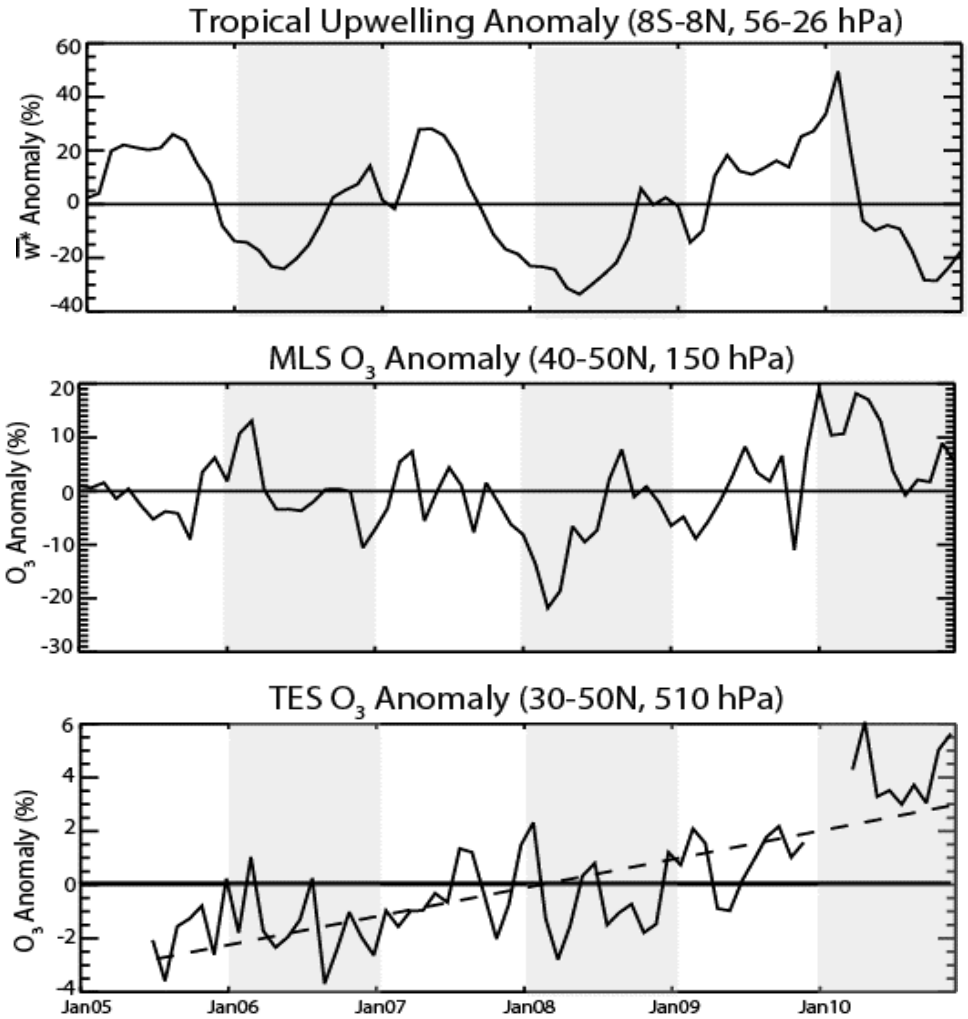


Neu et al., *Nature Geo*. (2014)

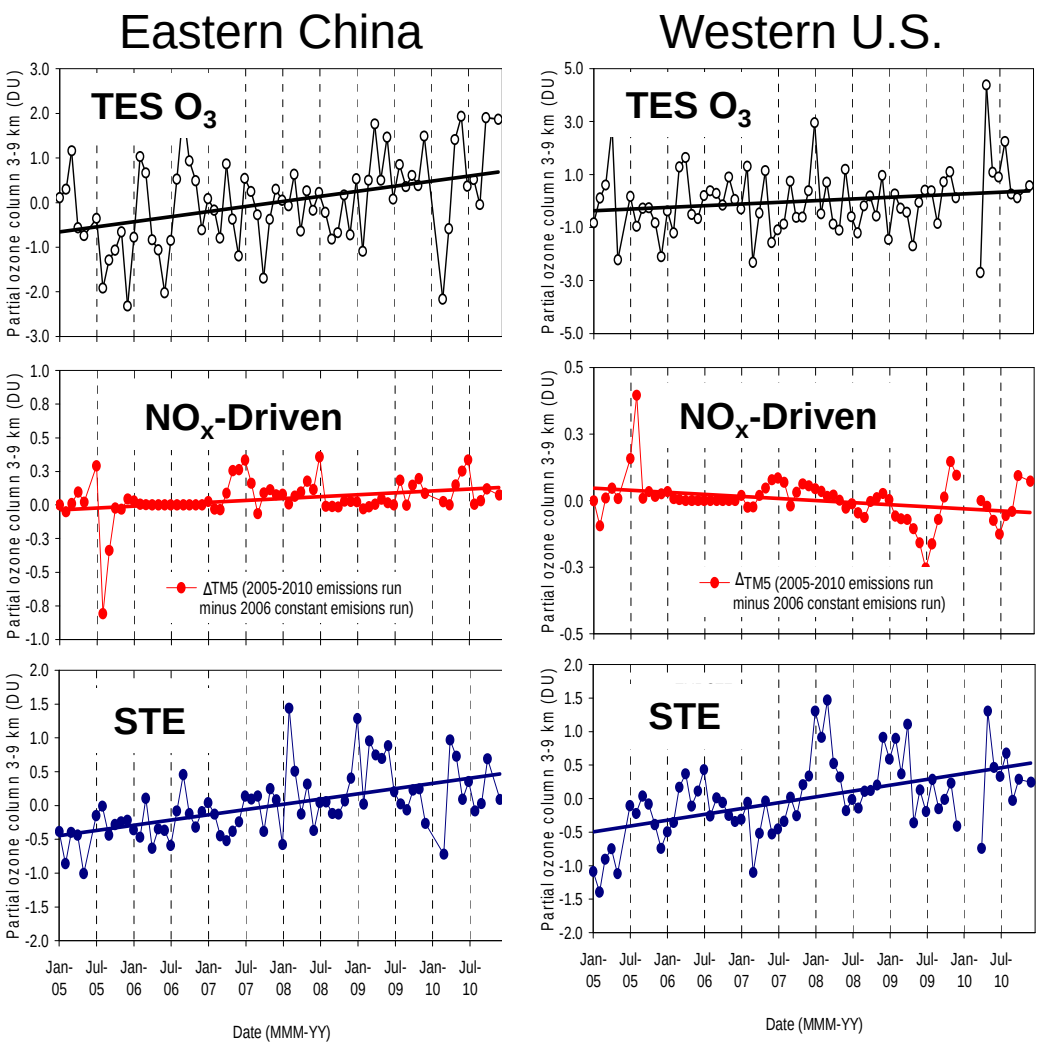
- **Anomalies in MLS O_3 in the northern midlatitude lower stratosphere are correlated with anomalies in the tropical ascent rate 2 months prior**
- **Detrended anomalies in TES O_3 in the northern midlatitude mid-troposphere are correlated with anomalies in MLS O_3 at 150 hPa 1 month prior.**
- **Changes in stratospheric O_3 account for ~16% of the variability in O_3 in the northern midlatitude mid-troposphere**
- **A ~25% increase in stratospheric O_3 resulting from an increase in the stratospheric circulation gives a ~2% increase in tropospheric O_3**

Stratospheric Contribution to Tropospheric O_3 Trends

- **A trend in the stratosphere-to-troposphere ozone flux at the hemispheric scale requires either:**
  - **A trend in the stratospheric circulation**
  - **A trend in lower stratospheric ozone**
  - **A change in mass of the lowermost stratosphere**
    (Holton et al., 1995)
- **The mid-tropospheric ozone trend is not related to a trend in stratospheric circulation or lower stratospheric ozone at the hemispheric scale.**



Stratospheric Contribution to Tropospheric O_3 Trends

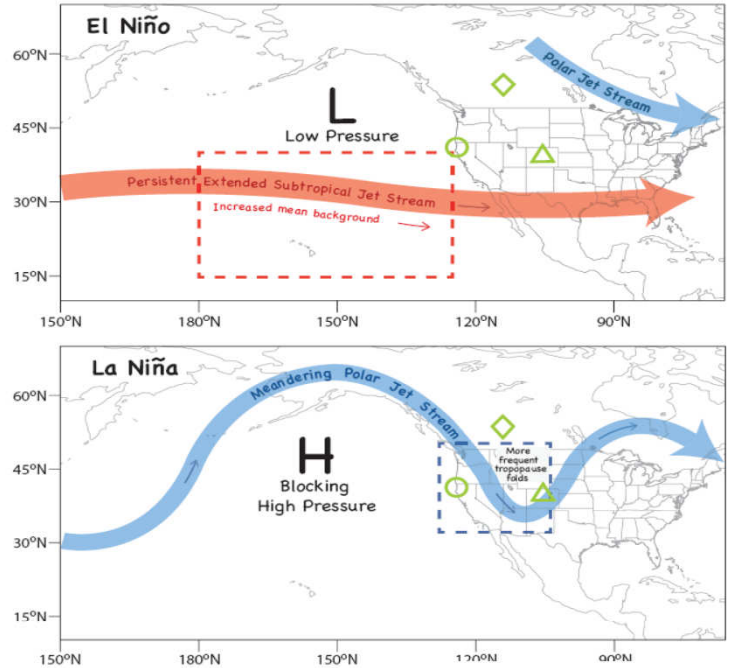


Verstraeten et al., *in prep*

- **The TM5 CTM is able to reproduce the trends in TES ozone over Asia and the Western United States.**
- **The model simulations indicate that increases in STE dominate the net changes in tropospheric ozone over these regions.**
- **STE accounts for ~90% of the net mid-tropospheric ozone change, while emissions account for ~10%**
- **TM5 stratospheric ozone is nudged to monthly mean observations of total column ozone from a multi-sensor reanalysis data set (*van der A et al*, 2010)**

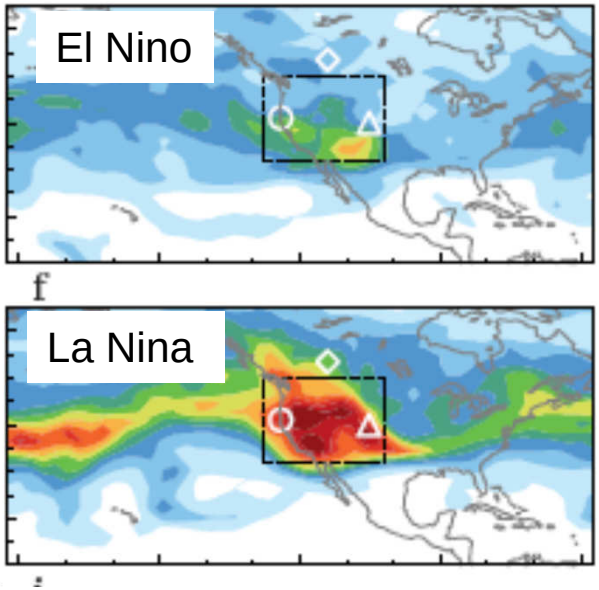
Regional Shifts in STE?

- **TM5 simulates large increases in the stratospheric contribution to tropospheric ozone over Asia and the Western U.S. despite no indication of a trend in STE at the hemispheric scale.**
- **Lin et al. (2014, in revision) also find an increase in STE over the Western U.S. in the AM3 model for 1980-2010 and link this to increasing frequency of La Nina conditions.**
- **Has there been a regional shift in where / how frequently STE occurs within northern midlatitudes?**



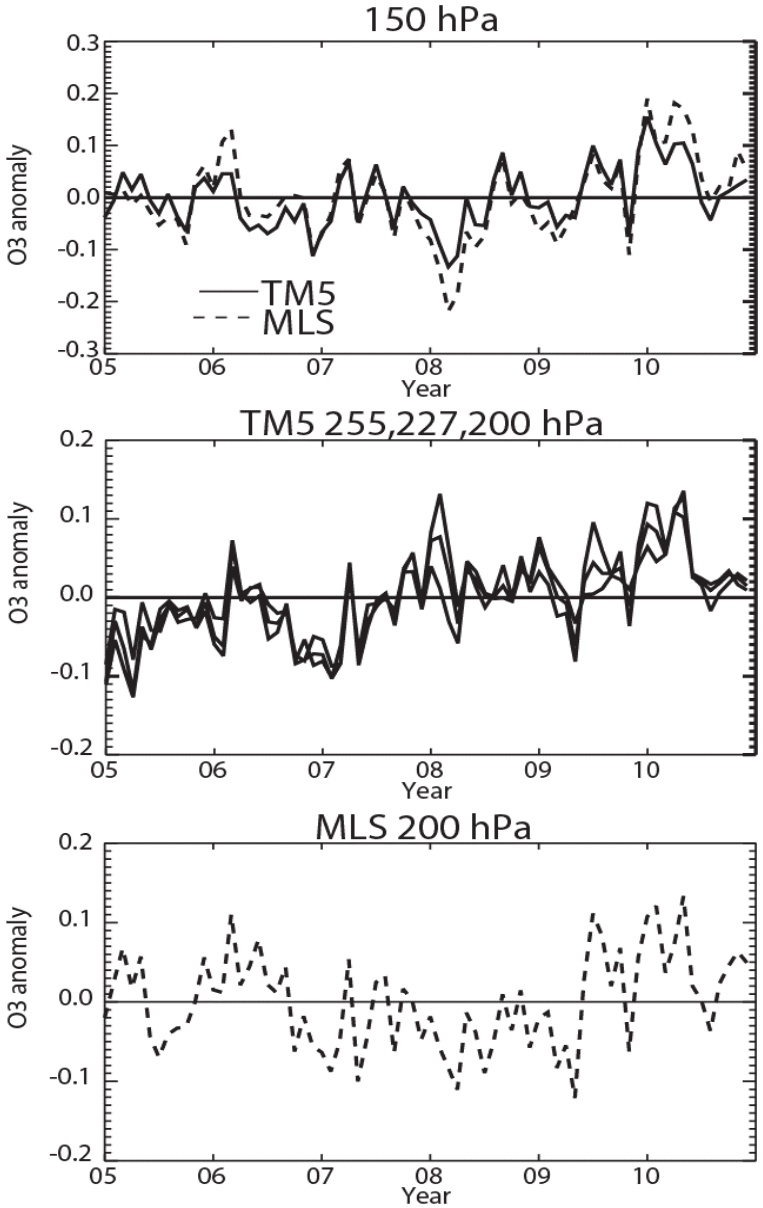
Jet stream dependence on ENSO

Lin et al. (2014, in revision)



Variance in Daily O_{3Strat} at 500 hPa

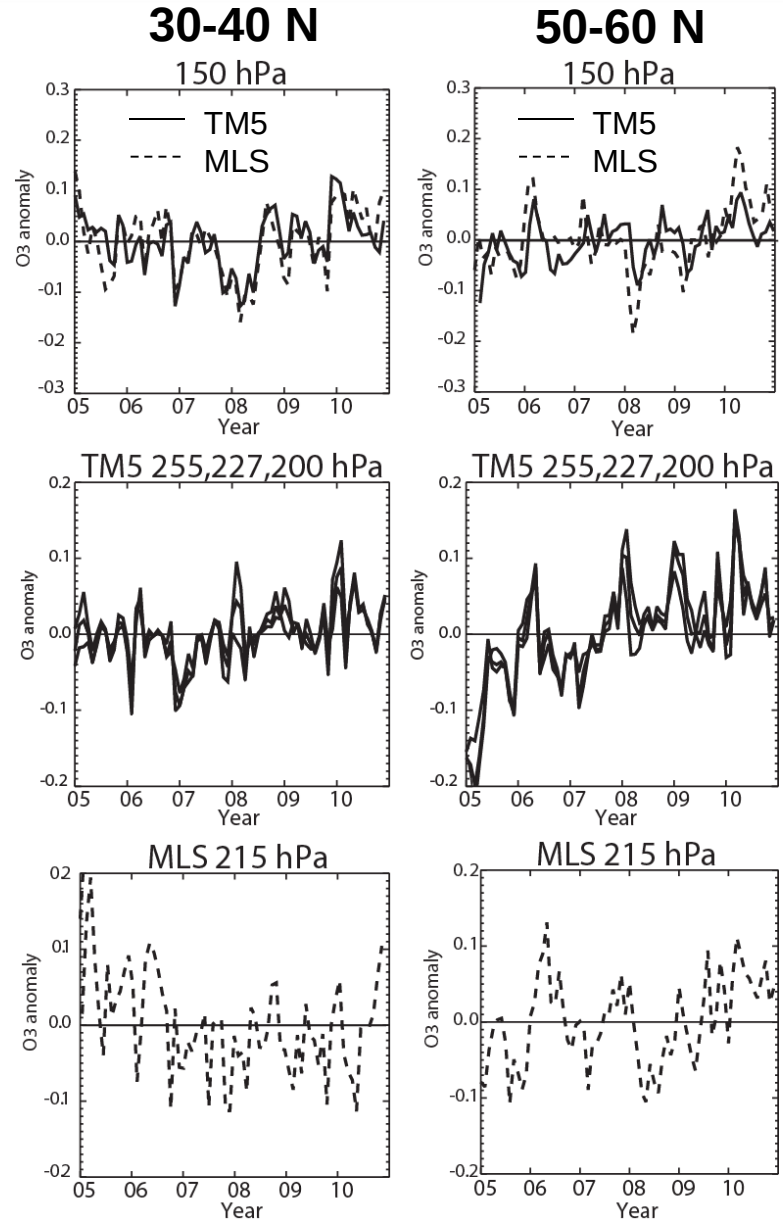
TM5 vs MLS Lower Stratospheric Ozone: 40-50 N



- **At 150 hPa, neither TM5 nor MLS show a trend in zonal mean 40-50N stratospheric ozone. TM5 captures the variability quite well.**
- **For p>200 hPa, TM5 shows a positive trend, which is not seen in MLS ozone at 200 hPa.**
- **TM5 underestimates ozone for 2005-2006 and overestimates it for 2007-2008. 2009-2010 are well-simulated.**
- **Caveat: We have not yet examined whether changes in 200 hPa ozone from MLS are consistent across data versions.**

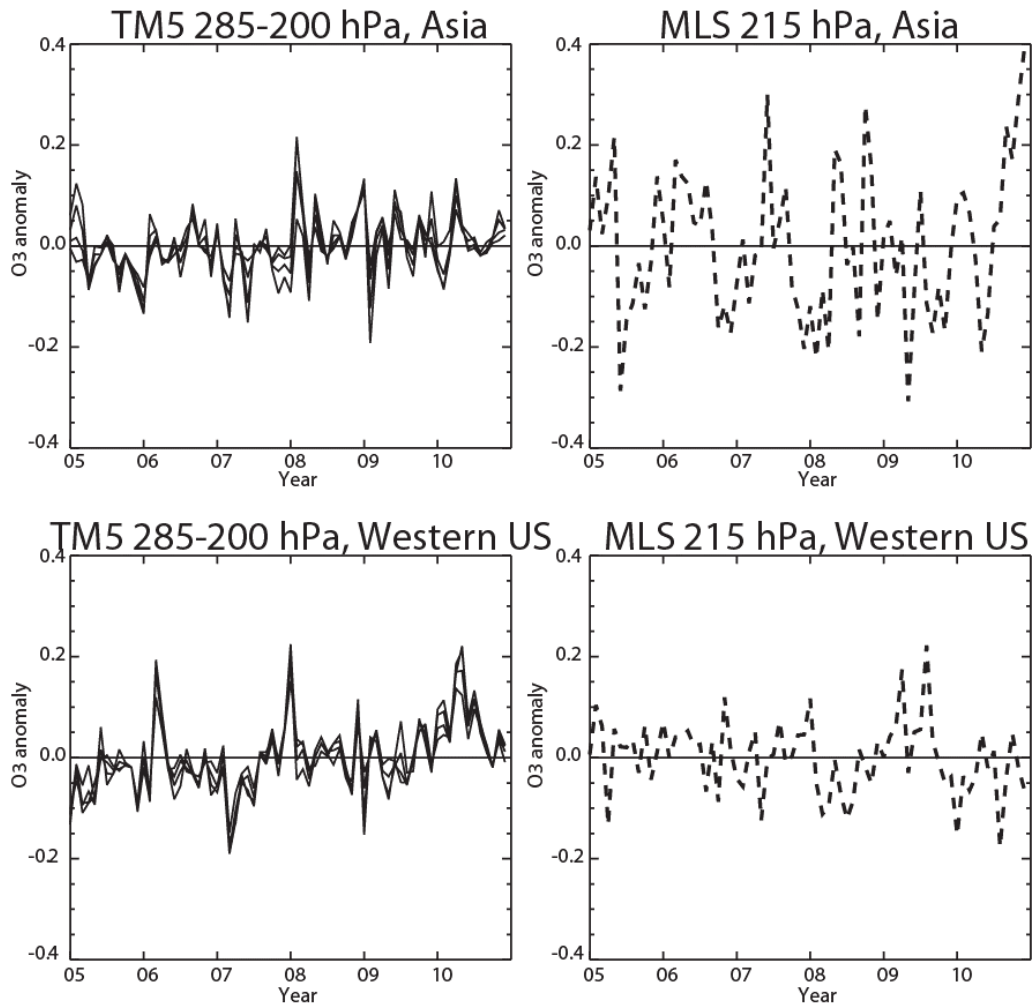
TM5 vs MLS Lower Stratospheric Ozone: 30-40N and 50-60N

- For other latitude bands, TM5 and MLS also agree well at 150 hPa, and neither shows a trend in ozone.
- For p>200 hPa, TM5 again underestimates ozone for 2005-2006 and overestimates it for 2007-2008, leading to large differences in the time series compared to MLS
- In both TM5 and MLS, long-term changes in ozone for p>200 hPa appear to be unrelated to changes in the deep branch of the stratospheric circulation
- Long-term changes in MLS ozone at 215 hPa need to be better-quantified

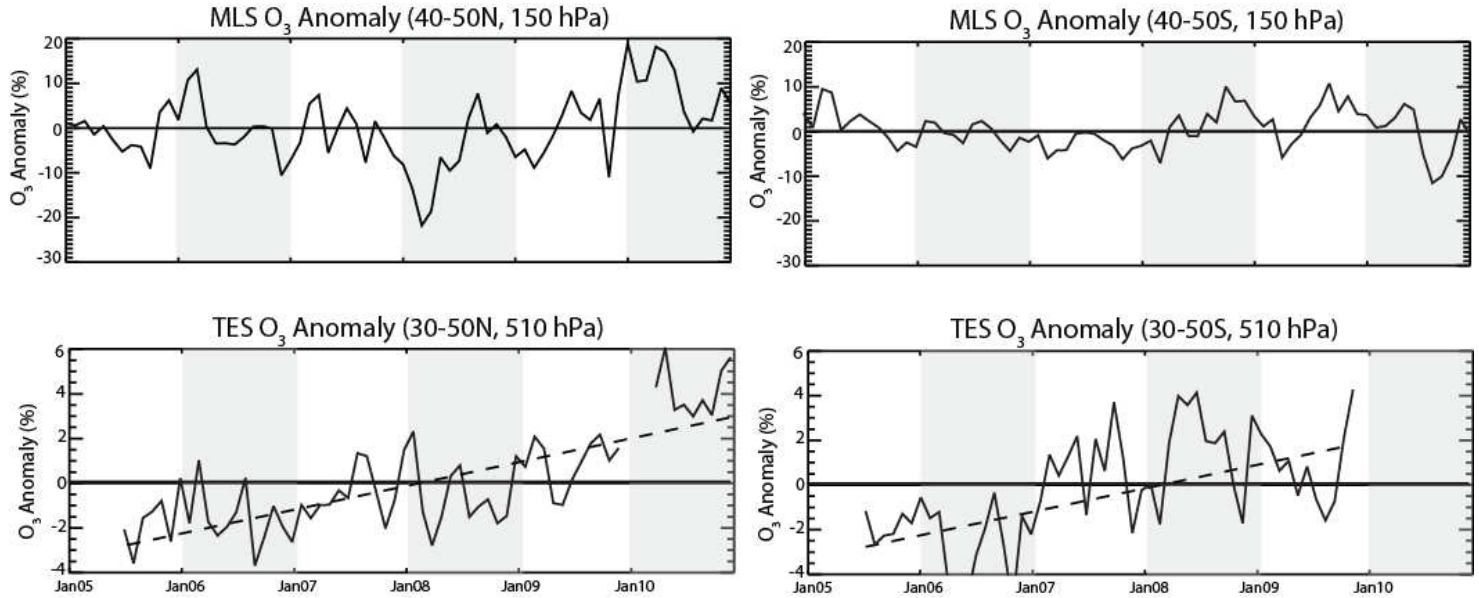


TM5 vs MLS Lower Stratospheric Ozone: Asia & U.S.

- **If there is a trend in STE over Asia and the Western U.S., it does not appear to be coming from a local increase in lower stratospheric ozone.**
- **This does not rule out a change in the frequency of folding events.**
- **However, upper tropospheric ozone is not locally controlled. The positive trend in 40-60N ozone in TM5 indicates that it likely overestimates the stratospheric contribution to tropospheric ozone trends in general. => Larger role for emissions?**



What about the Southern Hemisphere?



- **Southern hemisphere midlatitude lower stratospheric ozone has ~1/3 the variability seen in the northern hemisphere.**
  - **=> Synchronicity between seasonal cycle and ENSO/QBO?**
- **Southern hemisphere midlatitude mid-tropospheric ozone variability is as large as seen in the northern hemisphere, and there is a similar (though smaller) positive trend. Tropospheric ozone variability is not obviously related to stratospheric variability**
- **What drives trends and variability in Southern Hemisphere mid-tropospheric ozone?**

Summary

- **The stratosphere drives much of the interannual variability in mid-tropospheric ozone in northern midlatitudes, but its role in the southern midlatitudes is much less clear.**
- **Recent modeling studies suggest that the stratosphere has played an important role in tropospheric ozone trends over Asia and the Western U.S. during the past decade.**
- **MLS measurements indicate there has been no trend in the stratospheric circulation or ozone for p<150 hPa, but changes may have occurred at 215 hPa.**
- **Comparisons to MLS indicate that TM5 may overestimate the stratospheric contribution to tropospheric ozone trends, and thus underestimate the role of emissions.**
- **More work is needed to understand whether there have been regional shifts in STE in response to changes in ENSO or other climate modes.**