Ozone variations in the tropical upper troposphere and lower stratosphere based on Aura MLS and sonde data

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UTLS ozone at low latitudes

- Changes in upper tropospheric and lower stratospheric (UTLS) O_3 at low lats. are closely connected to circulation changes, vertical changes in particular
  > quasi-biennial oscillation (QBO) has a large impact on interannual change
  > long O_3 lifetime, not much reactive chlorine; expect small impact from chemistry
  > Long-term expectations/model results (*WMO, 2014*):
  GHG increases → enhanced tropical upwelling → decreasing O_3 values

- In UTLS, difficult measurements (strong vertical gradients, low O_3, and high variability)

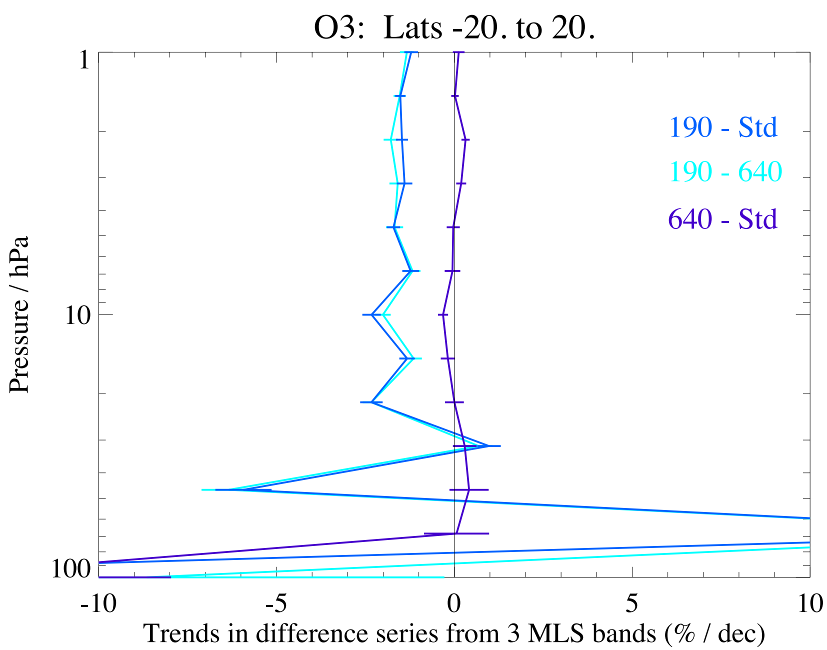
- Past work on O_3 trends in this region (*Randel and Thompson*, 2011; *Eckert et al*., 2012; *Kyrola et al*., 2013; *Gebhardt et al.*, 2014; *Sioris et al*., 2014; *Bourassa et al*., 2014) indicates that "continued ozone decreases are not detected in the presence of large natural variability during 2002-2013" (*WMO, 2014*)
  - is there a hiatus in the expected long-term decrease in tropical O_3 (*Aschmann et al*., 2014)?
  - this may be coupled to lower sea surface temperatures

- Here, we examine version 4 O_3 data from Aura MLS (launched in July 2004) and compare this to ozonesonde profile data at low latitudes
  > use Southern Hemisphere Additional Ozonesondes (SHADOZ) data (*Thompson et al*., 2007)

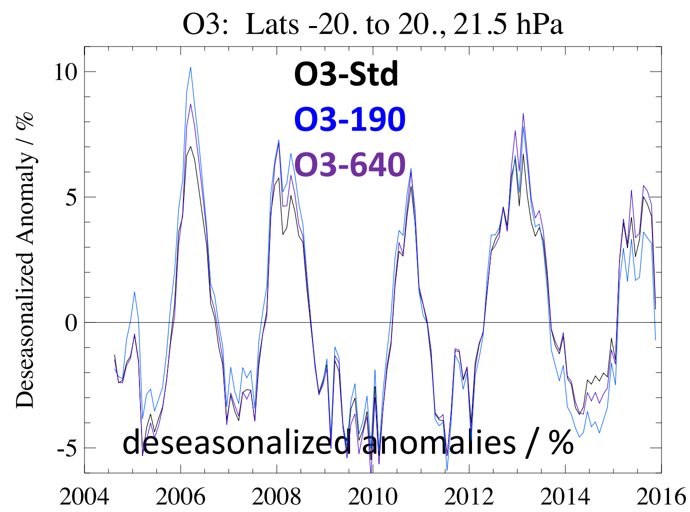
Temporal Stability of MLS Ozone Profiles

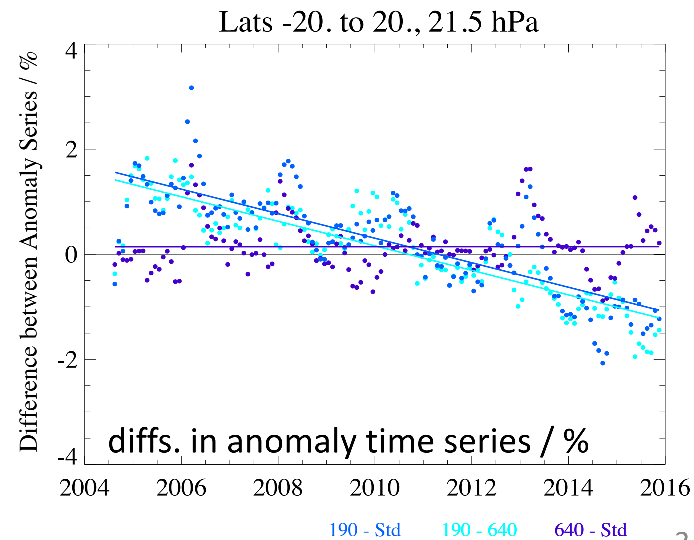
- Analyses have shown that MLS O_3 values are very stable with respect to ground-based profiles (*Nair et al.*, 2012; *Hubert et al.*, 2016); typically, MLS strat. O_3 stability < 2%/decade.
- We investigate MLS O_3 time series from <u>different</u> radiometers/bands.
  - most of the variability cancels out in difference series, and we obtain linear trends in diffs.

O3-Std: Ozone Standard Product from 240 GHz radiometer
O3-190: Ozone Product from 190 GHz radiometer (also for H_2O)
O3-640: Ozone Product from 640 GHz radiometer



MLS v4 Ozone Data

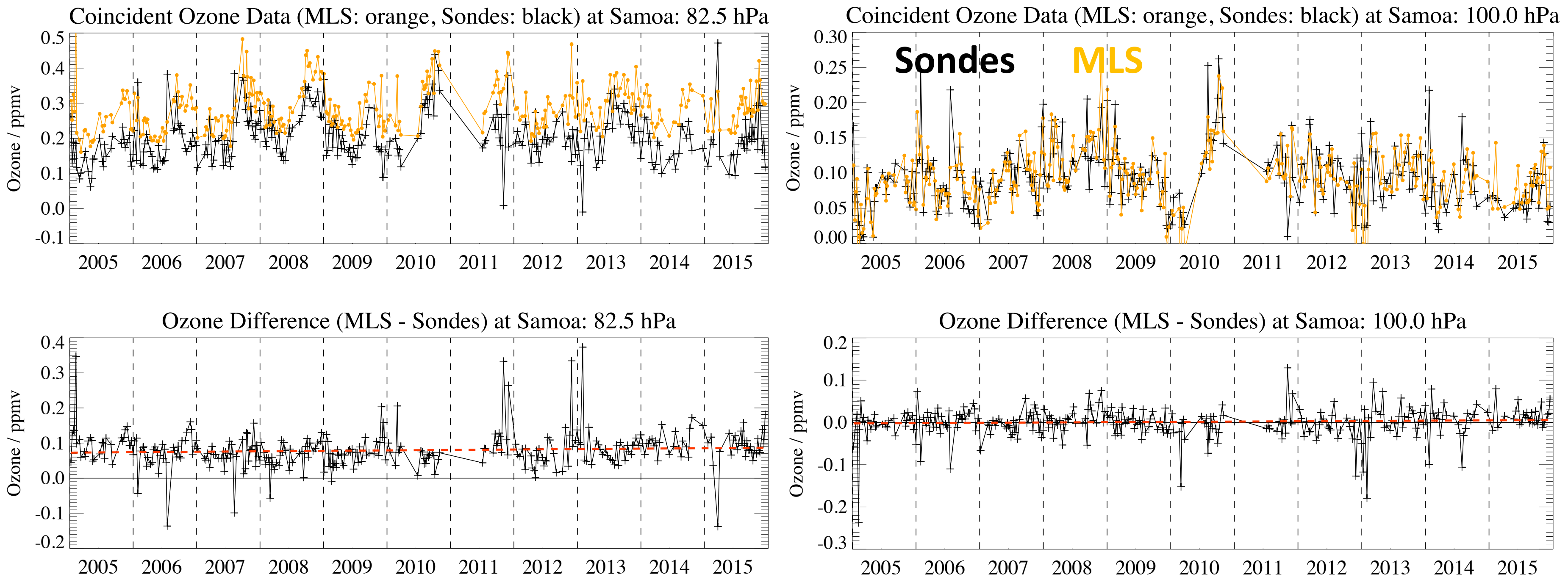




- **O3-190 differs the most from the other 2 ozone bands.**
- **O3-Std & O3-640 are stable to < 1 %/dec from 1 to 70 hPa.**
- Similar (or better) results at mid-latitudes - not shown here.

Coincident O_3 from Tropical Aura MLS and Sonde Profiles (2005-2015)

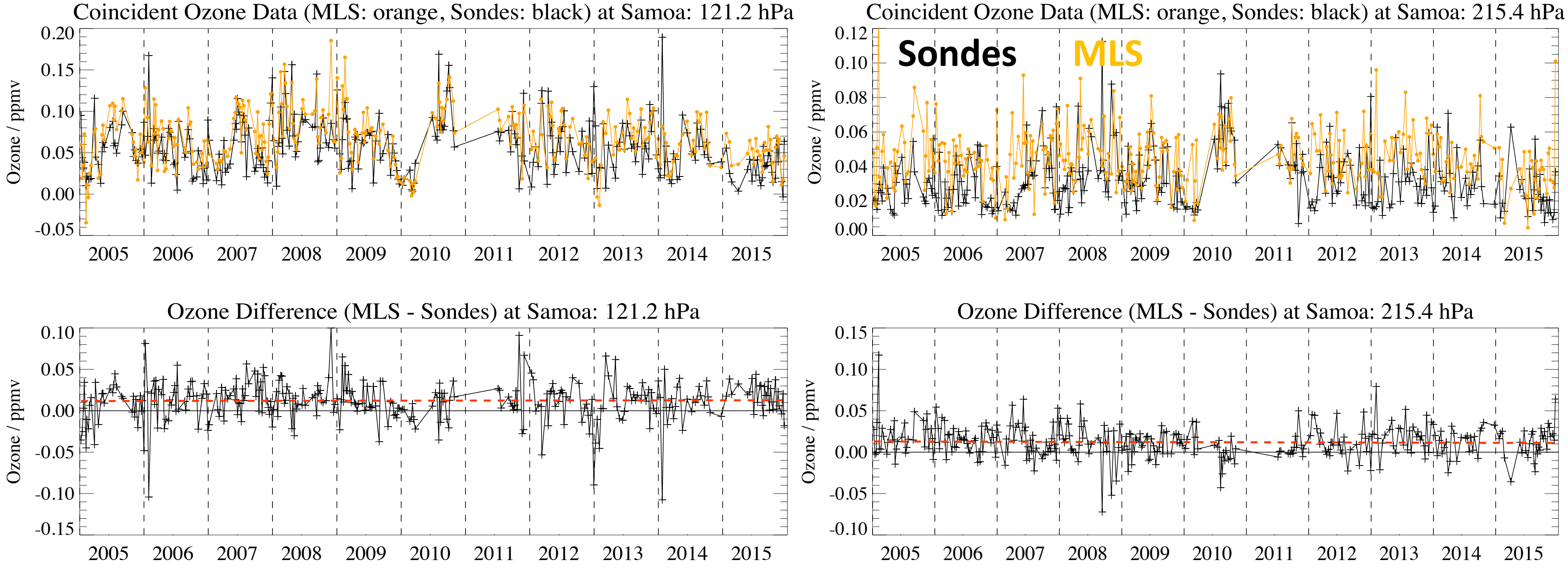
Sample Time Series for Samoa site: 82 hPa and 100 hPa



- Pick a few coincident MLS profiles, and get average MLS profile for each sonde profile
  - Coincidence criteria: within ±2° latitude and ± 15° longitude.
- Sonde profiles (x_{sonde}) are smoothed using averaging Kernels A_{MLS} (& a priori values x_a) from MLS: $x_{sonde}(smooth) = x_a + A_{MLS}(x_{sonde} - x_a)$ (*Rodgers and Connor*, 2003).
- **We calculate average differences and simple linear trends/drifts (MLS – Sondes) (red dashed lines above) from the difference series.**

Coincident O_3 from Tropical Aura MLS and Sonde Profiles (2005-2015)

Sample Time Series for Samoa site: 121 hPa and 215 hPa



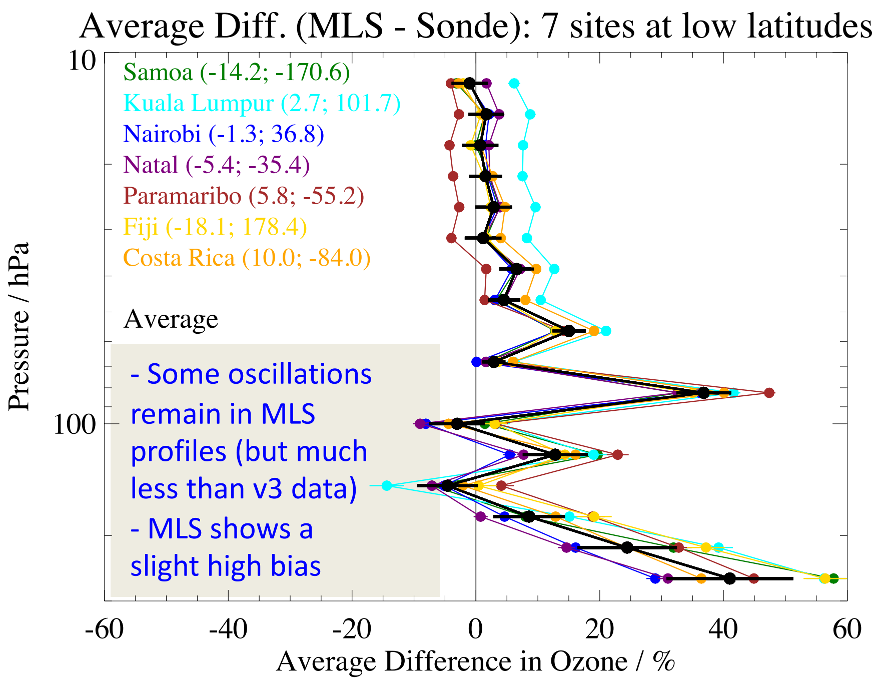
- We use **7 low latitude SHADOZ sites** with sufficient launches over the time period.
  - one to several sonde launches per week on average (2005 through 2015)
  - Samoa, Kuala Lumpur, Nairobi, Natal, Paramaribo, Fiji, Costa Rica

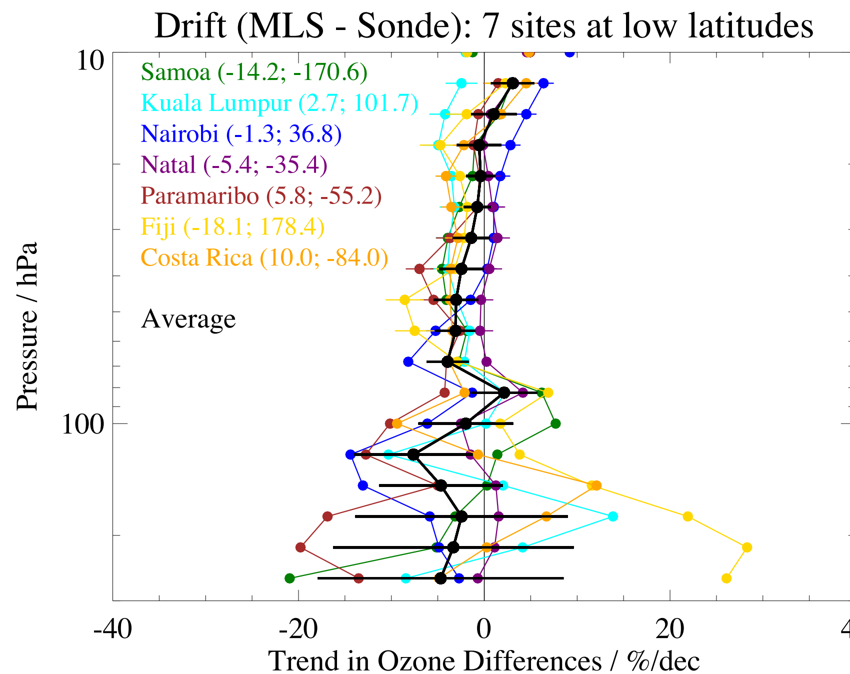
  Credit/thanks to all the investigators who provided these public datasets.

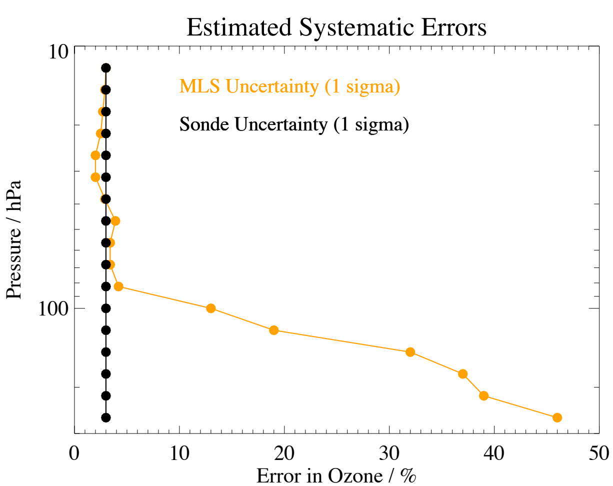
- We obtain average differences and trends of differences.

Coincident O_3 from Tropical Aura MLS and Sonde Profiles (2005-2015)

Average Differences (Biases) and Drifts from 7 ozonesonde sites







Error bars in avg. results above: twice the standard error (based on the scatter in the 7 site results)

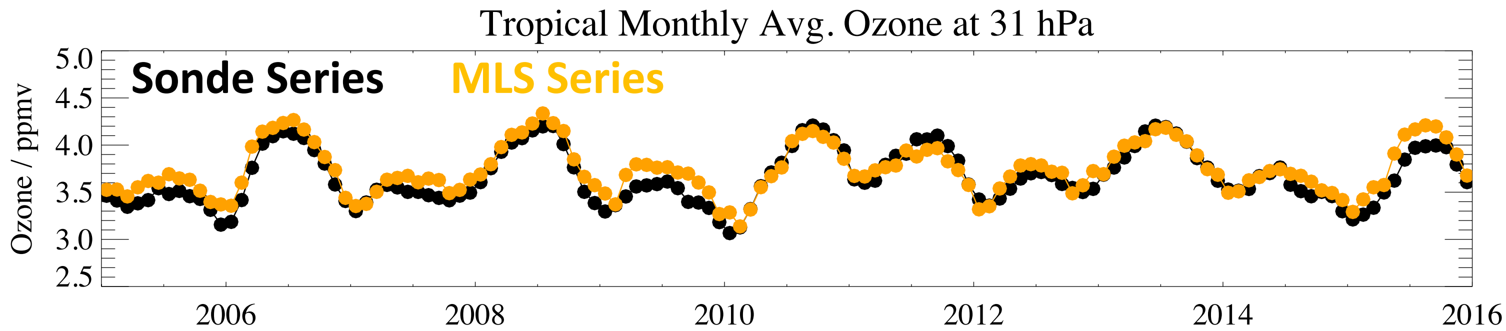
Systematic uncertainties

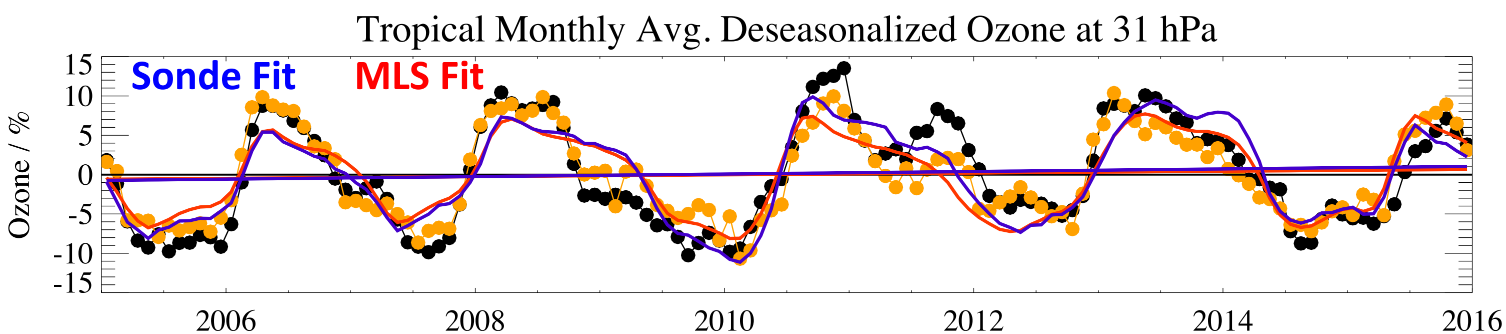
- Estimates for MLS are based on retrieval sensitivity tests
- For sondes, use 3% at all pressures (for simplicity)

- MLS trends tend to be slightly < avg. sonde trends (by a few %/decade) but site-to-site variability is large.
- Typical drifts are consistent with zero drift.

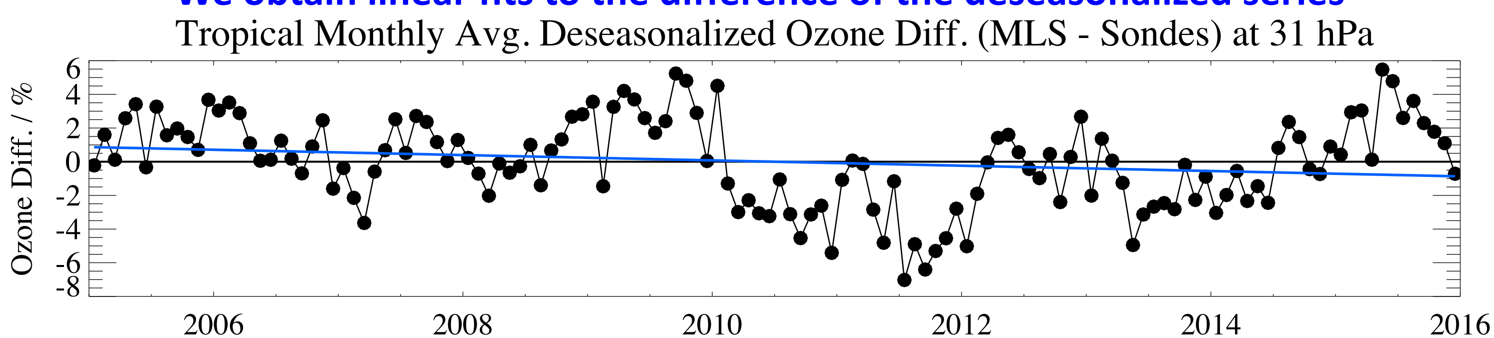
Tropical Monthly Mean O_3: MLS versus Sondes

- Average the datasets from the 7 sites into monthly averages
- Use Multiple Linear Regression (MLR) to fit the deseasonalized time series





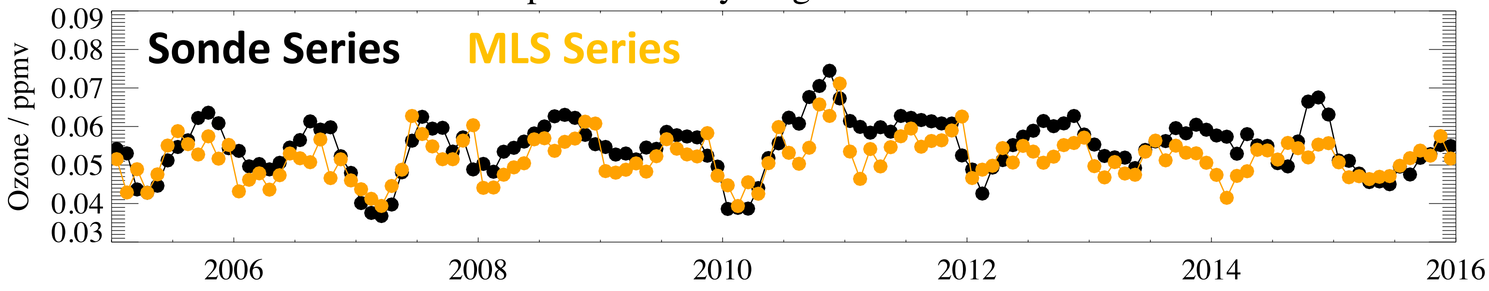
We obtain linear fits to the difference of the deseasonalized series



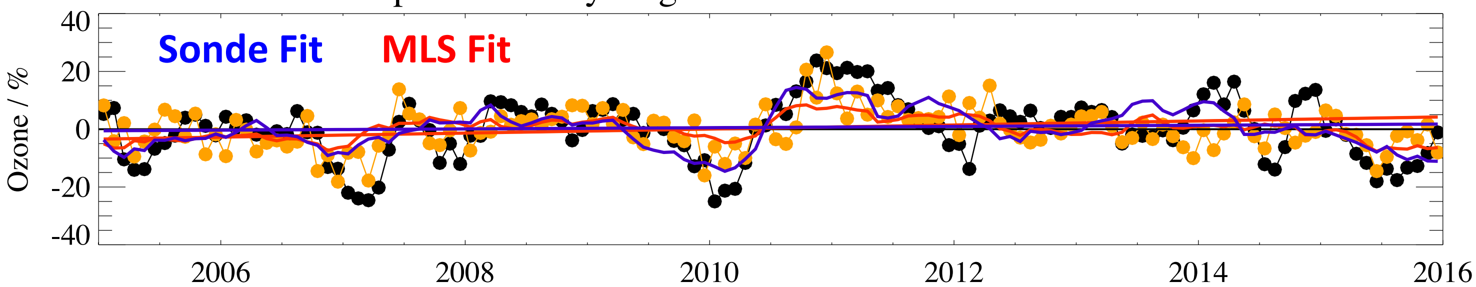
Tropical Monthly Mean O_3: MLS versus Sondes

- Average the datasets from the 7 sites into monthly averages
- Use Multiple Linear Regression (MLR) to fit the deseasonalized time series

Tropical Monthly Avg. Ozone at 146 hPa

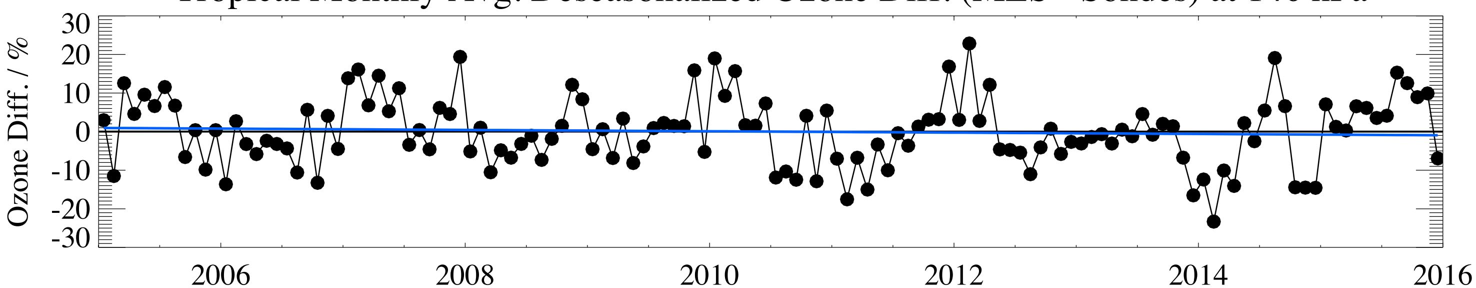


Tropical Monthly Avg. Deseasonalized Ozone at 146 hPa

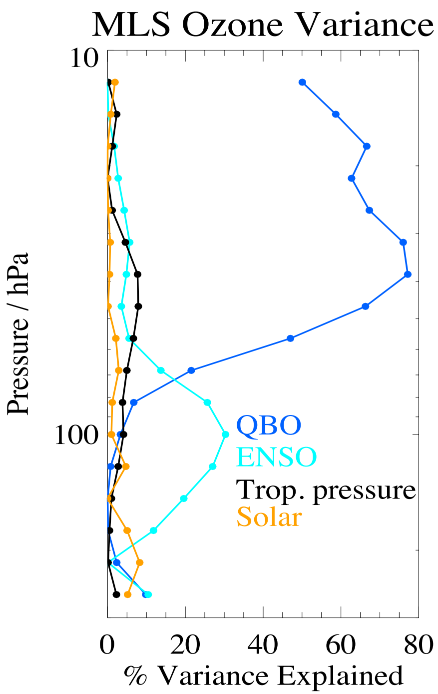


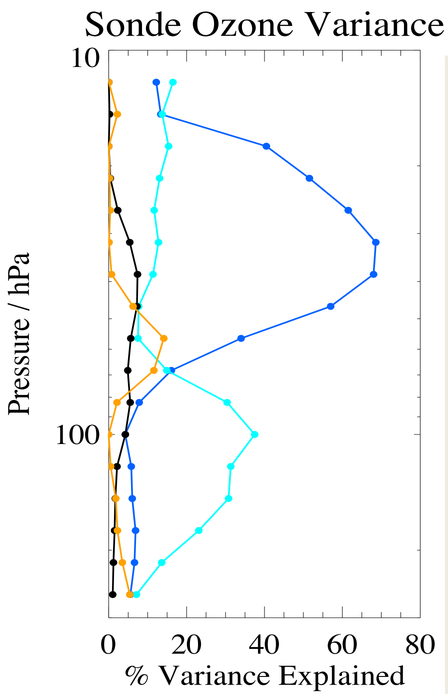
We obtain linear fits to the difference of the deseasonalized series

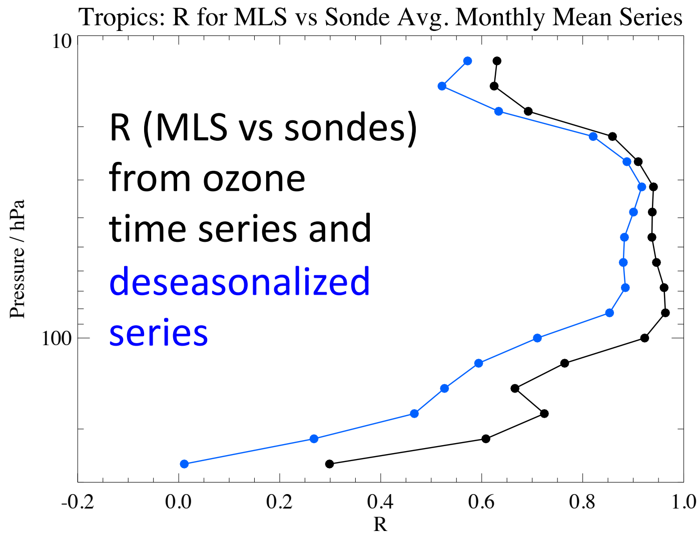
Tropical Monthly Avg. Deseasonalized Ozone Diff. (MLS - Sondes) at 146 hPa



Regression fits and explained variance



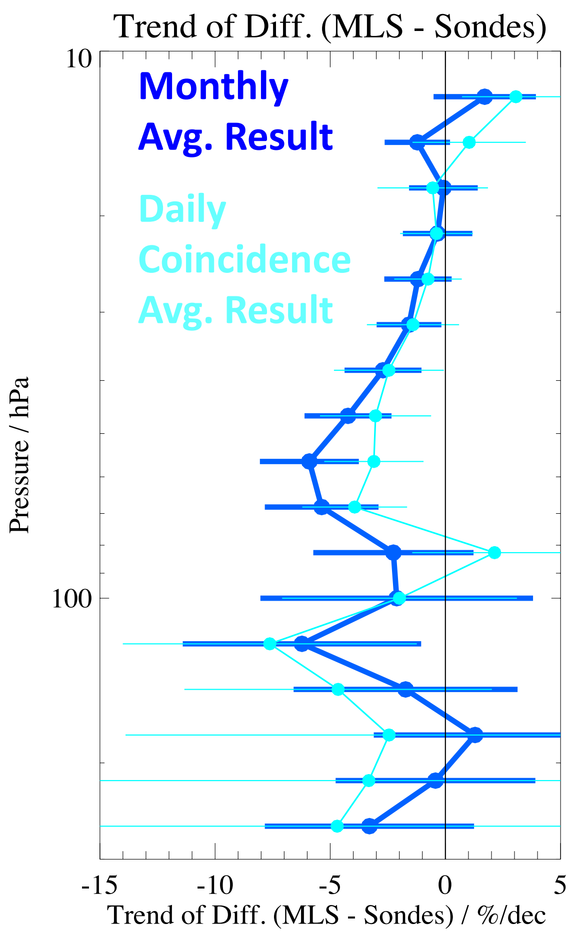




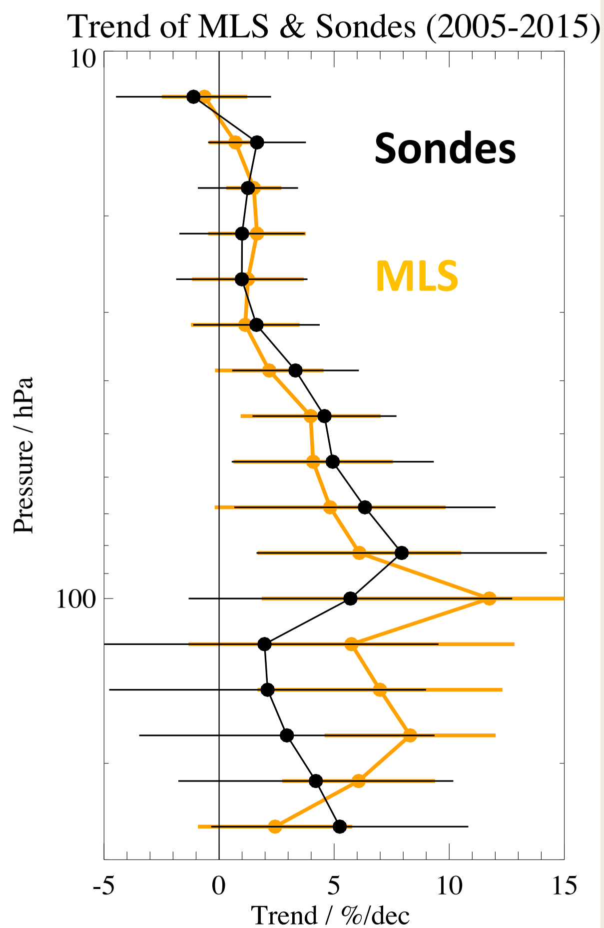
- **MLR fits include the following terms**
- Constant and Linear Trend terms
- QBO terms (from 30 hPa & 50 hPa winds)
  > from Freie Universität Berlin, Inst. of Meteor.
- Multivariate El Nino-Southern Oscillation (ENSO) index (MEI)
  > from NOAA CDC (*Wolter,* 2013)
- Tropopause pressure term
  > from NCEP Reanalysis (*Kalnay et al*., 1996)
- Solar cycle term
  > from Natural Resources Canada
- **Explained Variance** is shown at (top) left; the QBO and ENSO terms dominate (with a fair amount of unexplained variance in the UT).
  > see also *Randel & Thompson* (2011), *Oman et al.* (2013), other past work, regarding impacts from QBO & ENSO
- **MLS and sondes agree well on the explained variance from fitted variables**

Ozone Trends and Drifts (2005-2015) at Low Latitudes

Drifts: MLS - Sonde Avg.



Trends: MLS and Sonde Data



- UTLS tropical ozone trends (2005-2015) are on the positive side (~5%/decade) for both MLS and avg. **sonde** data.
  - Results are similar (within error bars) to the results from *Gebhardt et al.* (2014) for 2002-2012.
- There is a small negative drift for MLS vs sonde avg. from both **monthly** and **coincident** avg. results.
- However, these results are generally not significant (except near 50 hPa).

Consistent with no continued decrease in 2005-2015.
How significant is the increasing trend? How “long-term”? Attribution?

Summary

- We have investigated **ozone in the tropical UTLS** based on 2005-2015 Aura MLS v4 and SHADOZ sonde data (Samoa, Kuala Lumpur, Nairobi, Natal, Paramaribo, Fiji, Costa Rica).
- **O_3 variability** arises mainly from QBO ($p < 70$ hPa) and ENSO ($p > 70$ hPa) components.

- Based on averaged results from these 7 tropical ozonesonde sites:
  - MLS is unbiased vs sondes from 10 to 30 hPa, but shows a positive bias (0 to 40%) in the UT and near the tropopause. Some MLS vertical oscillations remain at low lats/alts.
  - **Typical drifts are consistent with zero drift** (except near 50 hPa) but tend to be negative by a few %/decade (MLS gives smaller trends).
  - Monthly averages and coincidence averages give similar results.
  - MLS and sondes show trends of ~2 to 10%/decade, with 2σ errors of 3 to 7%/decade.
    > this may not be a (real) long-term trend, but rather, a tendency for this past decade.
    > results are in agreement with a hiatus in the (expected) long-term decrease.

- Unambiguous detection of a long-term trend of < 2%/decade will remain challenging.
  - having more years of data will allow for some refinements, <u>assuming</u> the same stability.
  - we also plan to update the GOZCARDS ozone data record (with Ray Wang et al.).

- This is <u>ongoing and somewhat preliminary work</u>.
  Future work: use reprocessed sonde data (see Thompson et al. and Witte et al. posters), more study of trends, fits, error bars, sonde representativeness, etc…