Science Accomplishments from a Decade of Aura OMI/MLS Tropospheric Ozone Measurements


Primary Science Accomplishments:

- Improving understanding of the variability of tropospheric ozone from decadal change to ENSO, to Intra-Seasonal/Madden-Julian Oscillation and shorter time periods
- Improving understanding of the sources of tropospheric ozone from biomass burning and lightning to stratosphere-troposphere exchange
- Measuring ozone inside deep convective clouds
- Evaluation of chemistry-transport models of tropospheric ozone, both free-running and driven by pre-determined meteorology
Space-Based Constraints on the Production of Nitric Oxide (NO) by Lightning

Annual Average Tropospheric Column Ozone

- **OMI/MLS**
- **GEOS–Chem (standard)** (6 Tg N per year)
- **GEOS–Chem (nolight)**

(White areas: <40% of GEOS-Chem tropospheric ozone coming from lightning)
Recent biomass burning events in the tropics and elevated concentrations of tropospheric ozone


GMI-MERRA Chemical Transport Model

OMI/MLS Measurements

Western Africa  5S-20S, 5E-20E

OMI/MLS Measurements

Indonesia  10S-5N, 100E-115E
Evaluation of the 2006 El Niño and the GMI Chemical-Transport Model

- Tropospheric Column Ozone
- Year 2006 (El Niño) minus 2005 (neither El Niño nor La Niña)
- Most all variability is dynamical and not from Indonesian biomass burning
Aura OMI/MLS Measurements of Tropospheric Column Ozone over Deep Convective Clouds


**OMI:** Measures above-cloud column ozone

**MLS:** Measures stratospheric column ozone
A Tropospheric Ozone ENSO Index (OEI) Derived From Satellite Measurements of Total Column Ozone for 1979-Present

(J. R. Ziemke, S. Chandra, L. D. Oman, P. K. Bhartia, 2010, ACP)

- Measurements: OMI, TOMS, and SBUV Tropospheric Ozone
- ENSO Produces East-West “Dipole” in Tropospheric Ozone
- OEI = West Pacific Minus East Pacific Tropospheric Ozone each month
El Nino Southern Oscillation (ENSO) is the dominant mode of tropical variability on interannual timescales.

Its influence extends beyond the thermal and dynamical and into the chemical composition of the troposphere.

Ziemke et al. 2010 found a dipole in tropospheric ozone between the western and eastern Pacific region. The ENSO 3.4 Index (blue curve) from sea surface temperature anomalies is very well correlated to the difference between western and eastern Pacific ozone columns (black curve). Ziemke et al. identify this difference as an Ozone ENSO Index.

An Ozone ENSO Index (OEI) computed using the Goddard Earth Observing System (GEOS) version 5 chemistry-climate model (CCM) reproduces the observed OEI. Observed sea surface temperatures are used in the simulation; natural and pollutant emission sources are repeated annually.

This work shows that using specified sea surface temperatures is more important in producing this index then other possible sources of variability.

Figure: Comparison of GEOS CCM model (red curve) and data derived (black curve) Ozone ENSO Index (OEI) with ENSO 3.4 Index (multiplied by 3, blue curve) for the 1985 to 2009 time period.
Assessment and Applications of Aura OMI/MLS Ozone Data Products


**ASSIM**: GMAO data Assimilation (Wargan et al., 2014)

**TRAJ**: Trajectory-mapping (Schoeberl et al., 2007)

**PROF**: OMI profile retrieval (Liu et al., 2010)

**GMI**: Global-Modeling Initiative chemical transport model (Strahan et al. 2007; Duncan et al., 2008)

Conclusion: ASSIM appears to be the best overall product
The Ozone ENSO Index (OEI) for all Products and GMI Model are Nearly Identical, but Differ from the Niño 3.4 ENSO Index (Black Curve) Due to Intra-Seasonal/Madden-Julian Oscillation (MJO) Variability
Western Russia Wildfires in the Summer of 2010 and Anomalous Increases in Tropospheric Ozone

**Conclusion**: The main driver of the anomalous increases in tropospheric ozone appears to be anomalous change in meteorology rather than biomass burning (e.g., blocking high and subsidence in the region – Witte et al., 2011, ACP)
Recent State of Global Tropospheric Column Ozone from Aura OMI and MLS Instruments

(O. R. Cooper and J. R. Ziemke, 2013, BAMS; 2014, BAMS)

60S-60N:  +1.9 +/- 0.9 Tg/yr
NH:  +0.7 +/- 0.8 Tg/yr
SH:  +1.2 +/- 1.0 Tg/yr
Summary

- The OMI/MLS measurements have been very beneficial in characterizing natural properties of tropospheric ozone and for evaluating chemical-transport models.

- The 10-year OMI/MLS record (and growing) is an important dataset for measuring global tropospheric ozone decadal change, ENSO, MJO, and shorter time period variability.

- OMI and MLS have yielded new tropospheric ozone products where each product has unique useful properties by itself such as high horizontal density of measurements, vertical profile information, measuring cloud-ozone, etc.
Extra Figures
OMI/MLS Tropospheric Ozone Seasonal Characteristics of Maximum and Minimum Local Amounts
(O. R. Cooper et al., 2014, Elementa)
Are There Urban Signatures in the Tropospheric Ozone Column Products Derived from Satellite Measurements?

(J. Kar et al., 2010, ACP)
The Measurement Products Show Anomalous Increases in Tropospheric Ozone over Northern Africa/Mediterranean and East Asia in Northern Summer Months
What is Causing These Increases in Tropospheric Ozone During the Aura Time Record in ASSIM, TRAJ, and CTM?

Change in Tropospheric Column Ozone 2005-2012

(VERTICAL BARS: +/- 2σ)
GMAO Mid-latitude Ozone Profiles: Clear QBO in SH and Mix of QBO and Other Variability in the NH
GMAO Data Assimilation Provides Ozone Profiles for Monitoring Sudden Stratospheric Warming Events and Inter-Annual Changes in the Antarctic Ozone Hole
Tropospheric and Stratospheric Column Ozone from GMAO Data Assimilation
Tropospheric and Stratospheric Column Ozone from Trajectory Mapping Method
GMI Model has Temporal Time Lag with the QBO in Stratospheric Ozone
What is the Radiative Forcing Contribution from Tropospheric Ozone?

Although the amount of ozone in the stratosphere is 10 times more than tropospheric ozone, global radiative forcing from tropospheric ozone is much larger than from stratospheric ozone (IPCC 2013 Report).

Radiative forcing from tropospheric ozone has clear regional patterns.

Global increases in tropospheric ozone and radiative forcing appear detectable from Aura OMI/MLS ozone measurements.
Aura OMI/MLS Measurements of Tropospheric Column Ozone over Deep Convective Clouds

(J. R. Ziemke and S. Chandra, 2012; ACP)

**OMI**: Measures above-cloud column ozone

**MLS**: Measures stratospheric column ozone

(Aura OMI/MLS Measurements for Oct04-Jul10 in Dobson Units)
The Daily Ozone ENSO Index Has Large Intra-Seasonal Signals
ODI Coherence Calculations

**Coherence Between OMI/MLS and CTM Daily ODI**

Period (Days)

Coherence Squared

99.9%

99%

95%

(CTM is Highly Coherent with OMI/MLS Down to About a 1-2-Week Period)

**Coherence Phase Between OMI/MLS and CTM Daily ODI**

Period (Days)

Coherence Phase (Degrees)

(Phase Shift Should Ideally be Zero at all Frequencies)
Ozone Mixing Ratios Inside Tropical Deep Convective Clouds from OMI Satellite Measurements

(J. R. Ziemke, J. Joiner, S. Chandra, et al., 2009, ACP)
Aura MLS shows very small zonal variability of deseasonalized monthly-mean stratospheric column ozone in the tropics (~1-2 DU at most)
Zonal Variability of Tropical Stratospheric Column Ozone

The trajectory-mapped ozone shows small zonal variability in the tropics and is most consistent with previous measurements from SAGE and HALOE.
Daily Ozone Dipole Index (ODI) Time Series

The Daily Ozone ENSO Index Has Large Intra-Seasonal Signals

- **OMI/MLS**
- **CTM**
- **Nino 3.4 * 3**

The CTM Captures Most all Low to High Frequency Signals

The Daily Ozone Dipole Index Has Large ISO Signals

- **OMI/MLS**
- **CCM**
- **Nino 3.4 * 3**

The CCM Only Gets The ENSO Very Low Frequency Signal
ODI Coherence Calculations

CTM is Highly Coherent with OMI/MLS Down to About a 1-2-Week Period

CCM is Only Coherent with OMI/MLS for ENSO

Phase Shift Should Ideally be Zero at all Frequencies
Inter-Decadal Changes in Annually-Averaged MOD Total Column Ozone and CCD Pacific-Mean Stratospheric Column Ozone
Inter-Annual Variability of Tropospheric Ozone (ASSIM, TRAJ, GMI): Eight-year Increases Don’t Seem ENSO Related
Inter-Annual Variability of Tropospheric Ozone (ASSIM, TRAJ, GMI): Eight-year Increases Don’t Seem ENSO Related
The Ozone Response to ENSO in Aura Satellite Measurements and a Chemistry Climate Simulation