Science Results Based on Aura OMI-MLS Measurements of Tropospheric Ozone and Other Trace Gases

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Tropospheric Ozone Measured by OMI/MLS and OMI CCD

Altitude

17 km

MLS Strat

OMI CCD Strat

Tropopause

Ozone Mixing Ratio

Optical Centroid Cloud Pressure (OCCP)

2 km

Troposphere

(CCD: “Convective Cloud Differential”)

OMI Total

PPBV
OMI CCD and OMI/MLS Tropospheric Ozone: October Months

CCD

OMI/MLS
OMI/MLS and Ozone sondes in the Extra-Tropics

Ankara
Lat: 39.97
Lon: 32.86

Boulder
Lat: 40.3
Lon: -105.16

Payerne
Lat: 46.8
Lon: 6.95

Wallops
Lat: 37.93
Lon: -75.47

OMI/MLS and Sonde Tropo O3

RMS = 7.6 ppbv
R = 0.79
Scientific Issues Addressed

- Quantify the role of biomass burning in the production of tropospheric ozone

- Evaluate El Nino effects on ozone and other trace gases in the troposphere

- Combine OMI and TOMS ozone measurements to develop a long climate record of tropospheric ozone from 1979 to the present time

- Study intra-seasonal/Madden-Julian Oscillation (MJO) variability

- Develop a method to measure ozone inside clouds
Publications Related to These Objectives


Tropospheric ozone is a toxic pollutant and an EPA criteria pollutant. As industrialization increases, pollutants flow from one country to another and from one continent to another.

Aura OMI and MLS combined measurements provide a clear picture of this global phenomenon.

Monthly average July and October 2009

Ozone from North America extends toward Europe

Ozone from Africa and South America fills the South Atlantic

Ozone from Europe and China extends eastward

Ozone from Africa spreads to Australia

Global maps of tropospheric column ozone during the month of largest amounts in the Northern Hemisphere (July) and Southern Hemisphere (October).
Tropospheric Ozone Generated from Biomass Burning is Locally Significant but Small in Global Perspective According to the GMI Model

Globally, biomass burning is at most about 4-5% of total tropospheric ozone. Other ozone sources include STE, fossil fuels, lightning, and soils.

Lightning is the dominant source of tropospheric ozone in the tropics on an annual-mean basis (Sauvage, et al., JGR, 2007)
El Nino Related Changes in Tropospheric Ozone in 2006

El Nino induced biomass burning and dynamical changes caused enhanced ozone in the western Pacific and reduced ozone in the eastern Pacific.

(S. Chandra, J. R. Ziemke, B. N. Duncan, et al., ACP, 2009)
El Nino induced dry conditions and biomass burning produced large localized concentrations of carbon monoxide over Indonesia in the western Pacific.

(S. Chandra, J. R. Ziemke, B. N. Duncan, et al., ACP, 2009)
El Nino Induced Changes in Tropospheric Ozone: Biomass Burning (top) Versus Dynamics (bottom)

The effect of biomass burning, although comparable to dynamics, was localized to the Indonesian region.

(S. Chandra, J. R. Ziemke, B. N. Duncan, et al., ACP, 2009)
“Ozone ENSO Index”
The Nino 3.4 Sea Surface Temperature (SST) ENSO Index from NOAA

NINO 3.4 3-MONTH RUNNING MEAN TIME SERIES

Nino 3.4 ENSO Index represents temperature anomalies averaged over the tropical eastern Pacific (5°S-5°N, 120°W-170°W)
Nino 3.4 ENSO Index is Correlated with Pacific Dipole in Tropospheric Ozone

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

Cross-Correlation Between Deseasonalized TOMS/OMI CCD Tropospheric Ozone and Nino 3.4 Sea Surface Temperature ENSO Index

(White regions: Significant at 99% CL)
A New “Ozone ENSO Index” (OEI) from TOMS and OMI
(J.R. Ziemke, S. Chandra, L. D. Oman, and P. K. Bhartia, 2010, ACP)

The OEI time series is derived by differencing column ozone from the two rectangular regions – this differencing (western minus eastern Pacific) cancels out the stratospheric ozone component and removes potential instrumental measurement offset and drift errors.
Summary

- OMI in conjunction with the GMI model have quantified the extent of biomass burning in production of tropospheric ozone – regional increases in tropospheric ozone are about 15-25%, but only ~4-5% in global average

- El Nino events produce large planetary scale changes in tropospheric ozone in the tropics – these changes are caused mostly by dynamics with a small contribution from biomass burning in Indonesia (associated with the dry conditions during El Nino)

- OMI combined with previous TOMS measurements yields a long-record (1979-present) of ozone. This long record has been used to develop an “ozone ENSO index” which is important for monitoring long-term changes in tropospheric ozone and as a diagnostic test for models
Additional Slides if Needed
OMI Can Measure Ozone Inside Deep Convective Clouds (Largely Comprised of Injected Boundary Layer Ozone)

Above is shown the concentration of upper tropospheric ozone inside deep convective clouds as measured by OMI. **Near zero ozone** is measured in the Pacific while much **larger ozone** is measured over Africa and South America.

(J. Ziemke, J. Joiner, S. Chandra, et al., ACP, 2009)
25-Year Trends in Upper and Lower Stratospheric Column Ozone (Left Panel) and Tropospheric Column Ozone (Right Panel)

(Ziemke, et al., 2005, JGR)
Daily tropospheric ozone from OMI/MLS and the GMI model agree well in the tropics on all timescales (including a 1-2 month Madden-Julian Oscillation)
Western Pacific Along ITCZ

El Nino Induced Increases

Daily tropospheric ozone from OMI/MLS and the GMI model agree well in the tropics on all timescales (including a 1-2 month Madden-Julian Oscillation)
OMI/MLS VMR Intra-Seasonal (1-2 month signals) Signal-to-Noise Ratio
Both OMI/MLS and SHADOZ Ozone sondes Tropospheric Ozone in Costa Rica Indicate Substantial Intra-Seasonal Variability

OMI/MLS: Mean Tropospheric Volume Mixing Ratio
Ozonesondes: 300 hPa volume mixing ratio (re-scaled to OMI/MLS)
OMI NO$_2$ over India and Asia

- March 2006
- May 2006
- July 2006
- September 2006

Tropospheric Column NO$_2$ (DU)
OMI/MLS Tropospheric Ozone over India and Asia

March 2006

May 2006

July 2006

September 2006

Tropospheric Column Ozone (DU)
Key Regions for Studying the Impact of Biomass Burning and ENSO Events in Generating Tropospheric Ozone and Other Important Trace Gases

(Ziemke, et al., 2009, GRL)
OMI/MLS Tropospheric Ozone and OMI Aerosol Index for the Four Selected Regions
(Ziemke, et al., 2009, GRL)

**South America:** Coherent Inter-annual variability present in aerosols and ozone

**Atlantic Ocean:** Seasonal cycle in ozone is nearly the same as over South America and Africa despite little change in presence of biomass burning aerosols

**West Africa:** ~2 month delay between peak ozone and peak aerosols caused by a time-delay involving coupled transport and photochemistry

**Indonesia:** Weak seasonal cycles in ozone and aerosols. Increases in ozone occurred during 2004/2006 El Nino events (related to coupled dynamics and biomass burning)
Two GMI Model Runs:
(1) With biomass burning (Blue curves)
(2) Without biomass burning (Red curves)

Main Conclusions:

- Model and measurement agree well in general seasonal variability including month to month changes
- Ozone from biomass burning (Blue minus Red curves) is at most 5-8 ppbv out of 35-50 ppbv mean background
- Model and measurement (Blue and Black curves, resp.) have localized discrepancies of 3-8 ppbv in regions of biomass burning (i.e., SA, WA, IND)
GMI Model Indicates Biomass Burning is Locally Significant but in Global Perspective is a Small Contribution to Tropospheric Ozone

(Ziemke, et al., 2009, GRL)

Ozone from Biomass Burning:
~15-25% Locally
~4-5% Globally

Other Products from Biomass Burning:
~7-9% Global NOx (NO + NO2)
~30-40% Global CO
OMI CCD and OMI/MLS Tropospheric Ozone: September Months

CCD

OMI/MLS

CCD Tropo Ozone (Dobson Units) September 2005

OMI/MLS Tropo Ozone (Dobson Units) September 2005

CCD Tropo Ozone (Dobson Units) September 2006

OMI/MLS Tropo Ozone (Dobson Units) September 2006

CCD Tropo Ozone (Dobson Units) September 2007

OMI/MLS Tropo Ozone (Dobson Units) September 2007

CCD Tropo Ozone (Dobson Units) September 2008

OMI/MLS Tropo Ozone (Dobson Units) September 2008
OMI CCD and OMI/MLS Tropospheric Ozone: November Months

CCD

OMI/MLS

Tropospheric Column Ozone (DU)
Stratospheric Column Ozone: Almost no zonal variability in tropical low latitudes
(Ziemke, et al., 2010, ACP)
Global Modeling Initiative (GMI) Chemistry and Transport Model (Duncan et al., 2007, ACP)

- Full troposphere/stratosphere model for 2004-2007

- Resolution: 2° latitude × 2.5° longitude, 42 vertical levels (surface to 0.01 hPa)

- 117 species, 322 chemical reactions, 81 photolysis reactions

- Chemical mass balance equations integrated using the SMVGEAR algorithm [Jacobson, 1995, Atmos. Environ.]

- Photolysis frequencies are computed using the Fast-JX radiative transfer algorithm [M. Prather, personal communication]

- Uses Global Fire Emission Database, version 2 (GFEDv2)

- Model is run with/without biomass burning emissions
Important Properties of the “Ozone ENSO Index”

- Not affected by inter-instrument calibration offsets or drifts over time

- Useful for monitoring of tropospheric ozone in relation to climate-related decadal changes

- Useful diagnostic test for models: Models should be able to reproduce the OEI and its sensitivities with sea surface temperature and pressure
Some Future Plans

- Derive a merged dataset of CCD tropospheric and stratospheric column ozone from TOMS and OMI (i.e., 1979-current)

- Extend the CCD data to mid-high latitudes to study trends in extra-tropical tropospheric and stratospheric ozone (Are CCD stratospheric ozone trends consistent with a decadal increase in the Brewer-Dobson Circulation?)

- Evaluate ability of measuring tropospheric ozone associated with urban pollution in mid-latitudes (Daily measurements are good from the tropics out to subtropics, but can we do well enough at higher latitudes to adequately measure pollution events?)

- Cross-analyze tropospheric ozone from OMI/MLS, models (GMI, CCM), and data assimilation to determine their strengths and weaknesses, and to use these products to study topics such as STE, intra-seasonal variability, tropospheric ozone budget, pollution events, decadal trends, etc.
The Nino 3.4 Sea Surface Temperature (SST) ENSO Index for the Aura Time Period

Nino 3.4 ENSO Index represents temperature anomalies in the tropical eastern Pacific (5°S-5°N, 120°W-170°W)
Ozone from Biomass Burning: ~15-25% Local, ~4-5% Global