# Highlights from the 11-year record of tropospheric ozone from OMI/MLS and continuation of that long record using OMPS measurements (Paper # X3.14)

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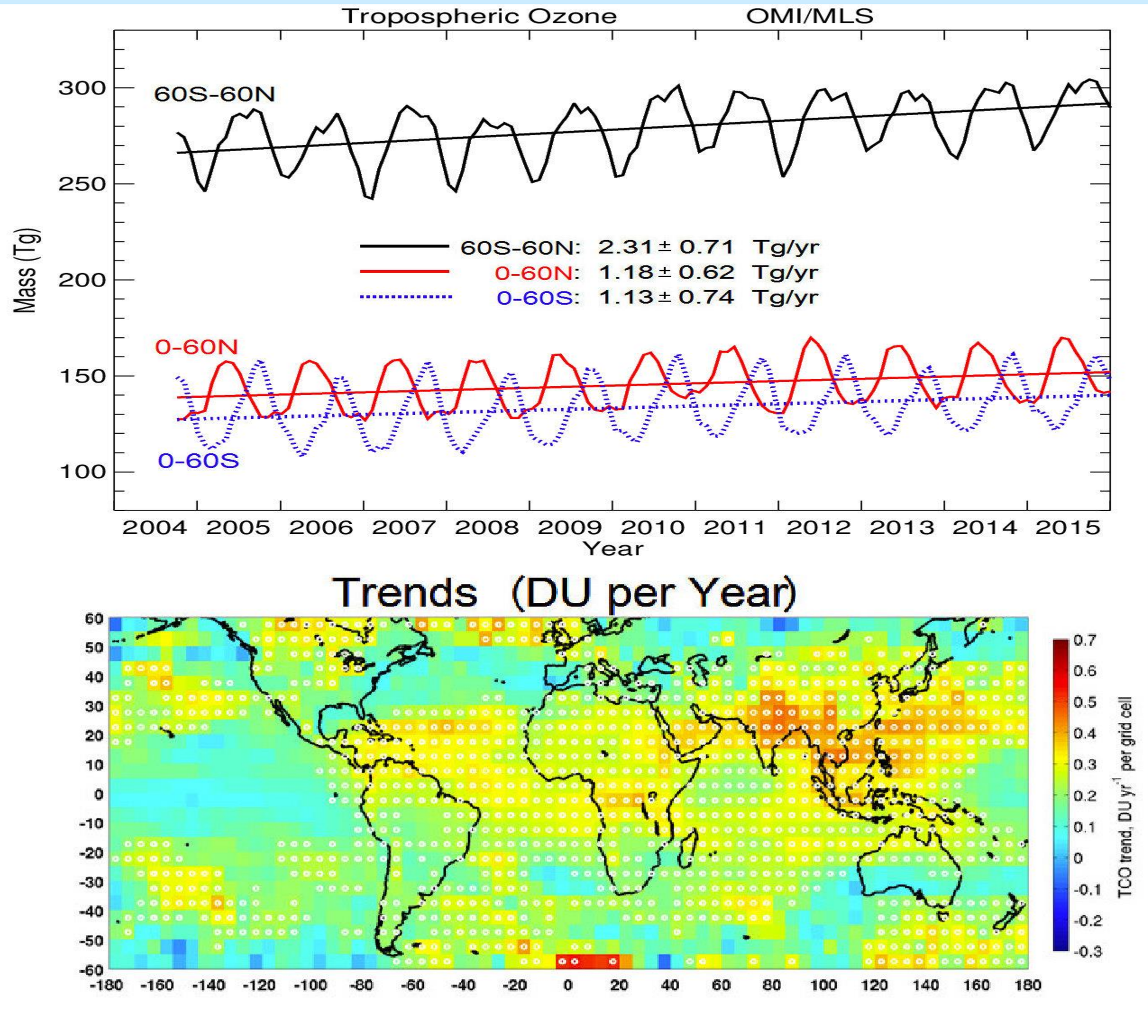
## Abstract

Since October 2004 the Ozone Monitoring Instrument (OMI) and Microwave Limb Sounder (MLS) onboard the Aura satellite have provided over 11 years of continuous tropospheric ozone measurements. These OMI/MLS measurements have been used in many studies to evaluate dynamical and photochemical effects caused by ENSO, the Madden-Julian Oscillation (MJO) and shorter timescales, as well as long-term trends and the effects of deep convection on tropospheric ozone. Given that the OMI and MLS instruments have now extended well beyond their expected lifetimes, our goal is to continue their long record of tropospheric ozone using recent Ozone Mapping Profiler Suite (OMPS) measurements. The OMPS onboard the Suomi National Polar-orbiting Partnership NPP satellite was launched on October 28, 2011 and is comprised of three instruments: the nadir mapper, the nadir profiler, and the limb profiler. Our study combines total column ozone from the OMPS nadir mapper with stratospheric column ozone from the OMPS limb profiler to measure tropospheric ozone residual. The time period for the OMPS measurements is March 2012 – present. For the OMPS limb profiler retrievals, the OMPS v2 algorithm from Goddard is tested against the University of Saskatchewan (USask) Algorithm. The retrieved ozone profiles from each of these algorithms are evaluated with ozone profiles from both ozonesondes and the Aura Microwave Limb Sounder (MLS). Effects on derived OMPS tropospheric ozone caused by the 2015-2016 El Nino event are highlighted. This recent El Nino produced anomalies in tropospheric ozone throughout the tropical Pacific involving increases of ~10 DU over Indonesia and decreases ~5-10 DU in the eastern Pacific. These changes in ozone due to El Nino were predominantly dynamically-induced, caused by the eastward shift in sea-surface temperature and convection from the western to the eastern Pacific.

## Trends in Tropospheric Ozone




(Owen Cooper, 2016)

**Figure 1**. Top: Time series of OMI/MLS tropospheric column ozone showing statistically significant increases in global and hemispheric averages during the Aura record (Cooper and Ziemke, BAMS, 2015; Ziemke and Cooper, BAMS, 2016). Bottom: Annual mean trends in OMI/MLS tropospheric ozone – the global trends including the regional increases in tropospheric ozone from India to China are closely similar to the increases in tropospheric NO2 as measured by the OMI instrument (L. Lamsel, personal communication, 2016).

## Ozone ENSO Index (OEI)

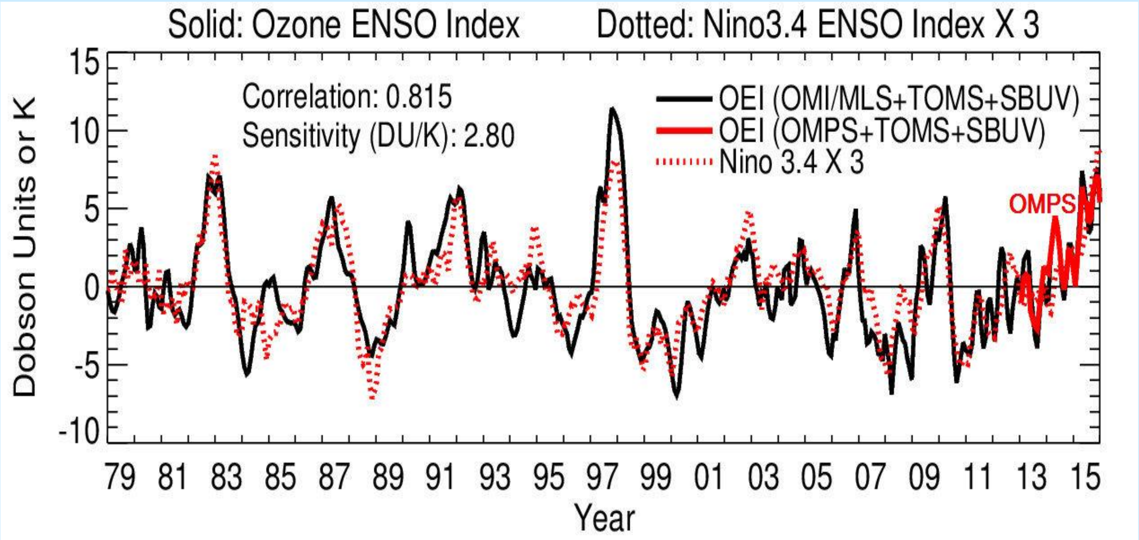



**Figure 2**. The ozone ENSO index (OEI) is derived by subtracting western minus eastern Pacific tropospheric column ozone (Ziemke et al., ACP, 2010). The OEI identifies changes in tropospheric ozone caused by ENSO events and has a long time record beginning 1979. The OEI is important for long-term monitoring of ENSO events as well as a diagnostic tool for models that simulate tropospheric ozone. The OMPS measured OEI is over-plotted (solid red) for 2013-2015. The OMPS tropospheric ozone was calculated by subtracting OMPS v2 LP stratospheric column ozone (with WMO NCEP 2K/km tropopause) from OMPS v1 nadir-mapper total ozone. OMPS tropospheric ozone can well continue the long record of tropospheric ozone from Aura OMI/MLS (starting October 2004) in the event that either OMI or MLS is no longer able to retrieve ozone.

For the recent 2015-2016 El Nino event (**Figure 3**), the OMPS tropospheric ozone shows nearly identical anomaly patterns as OMI/MLS. These ozone anomalies include large increases over the western Pacific (via reduced convection + Indonesia biomass burning), large decreases over the eastern Pacific (caused by increased convection), and regional increases over Brazil (caused largely by dry conditions and large-scale biomass burning induced by the El Nino event).

## The 2015-2016 El Nino

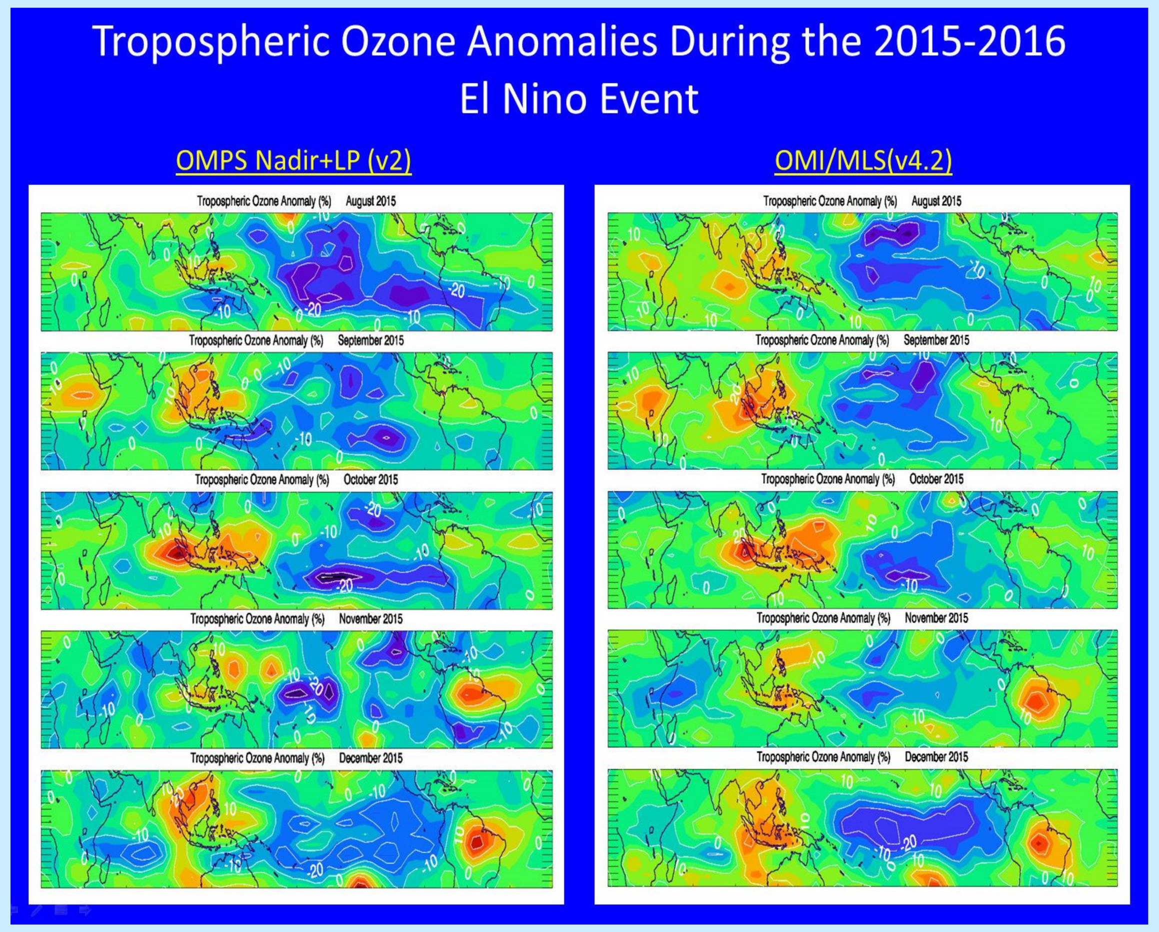



**Figure 3**. Left: OMPS tropospheric ozone anomalies (i.e., deseaonalized data) during the Indonesian dry burning season months. Right: Same as left but for OMI/MLS. The main features of the 2015 El Nino event are enhanced ozone in the western Pacific and reductions in the eastern Pacific, and also increases in ozone in Brazil beginning November 2015 caused by the El Nino induced dry conditions and biomass burning.

## Madden-Julian Oscillation (MJO) And Shorter Timescales

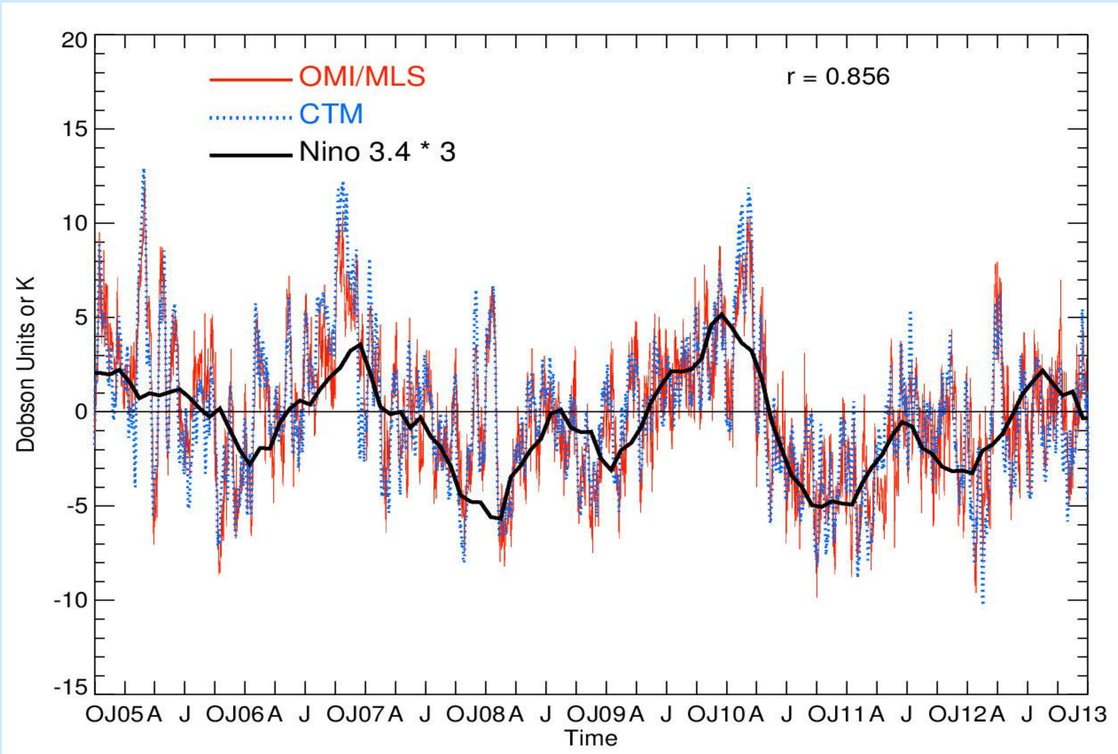



**Figure 4**. Comparison between daily time series of OMI/MLS ozone dipole index (ODI, red solid curve) and ODI derived from the GMI chemical transport model (dotted blue curve). Also plotted is the Nino 3.4 Index (black curve). The ODI is a generalization of the OEI by using daily rather than monthly averages.

The ODI is important for monitoring MJO events and as a diagnostic test on all time scales for models that simulate tropospheric ozone._The two ODI time series in **Figure 4** between OMI/MLS and the GMI CTM are remarkably similar from low-frequency ENSO to 1–2 month periods (e.g., MJO), to even daily/weekly periods. This figure is from Ziemke et al. [ACP, 2015] where it was also shown that tropospheric ozone variability in the tropics from intra-seasonal to daily changes exceeds total variability due to ENSO.

## Measuring Ozone in Thick Clouds

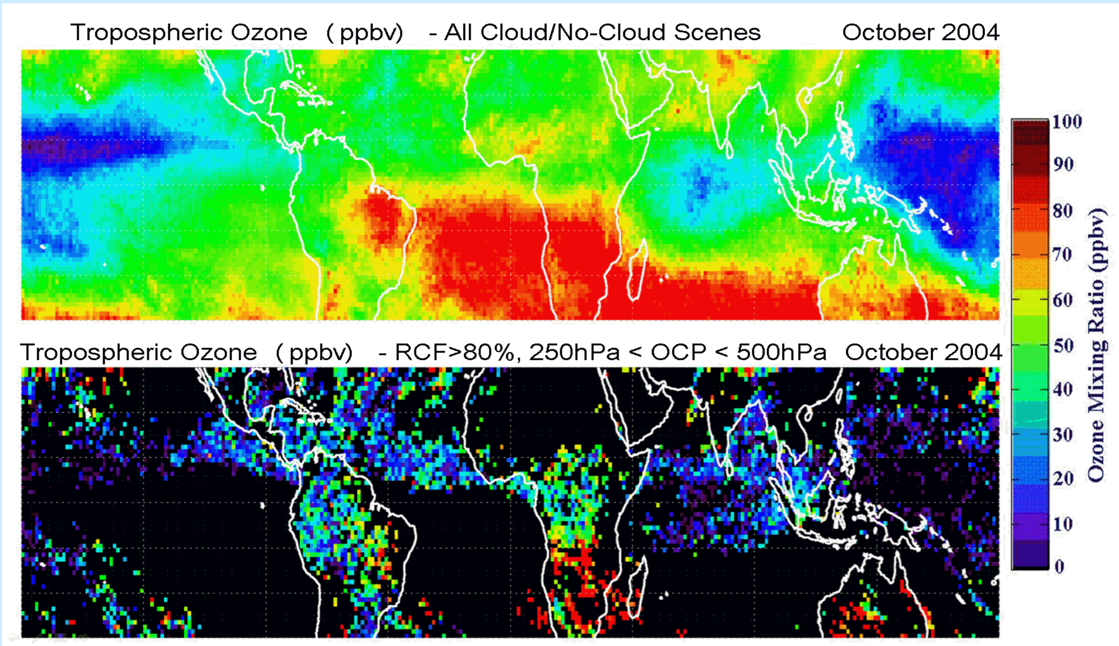



**Figure 5**. Top: Clear-sky (cloud fractions < 30%) mean tropospheric ozone volume mixing ratio (VMR) in units ppbv. Bottom: Mean VMR measured in the upper levels of deep convective clouds. All measurements are derived by combining OMI and MLS ozone along with OMI UV cloud pressures. The cloud-ozone record from Aura OMI/MLS extends from October 2004 – present .

Characterizing ozone in thick clouds is important to determine the extent of ozone relationships with H2O and OH production, cloud microphysics and transport, model evaluation, and impact on climate change. Only satellite measurements can produce a cloud-ozone data product due to great difficulty making such measurement from other sources (aircraft, ground) under the extreme meteorological conditions.

## USask Algorithm for OMPS LP

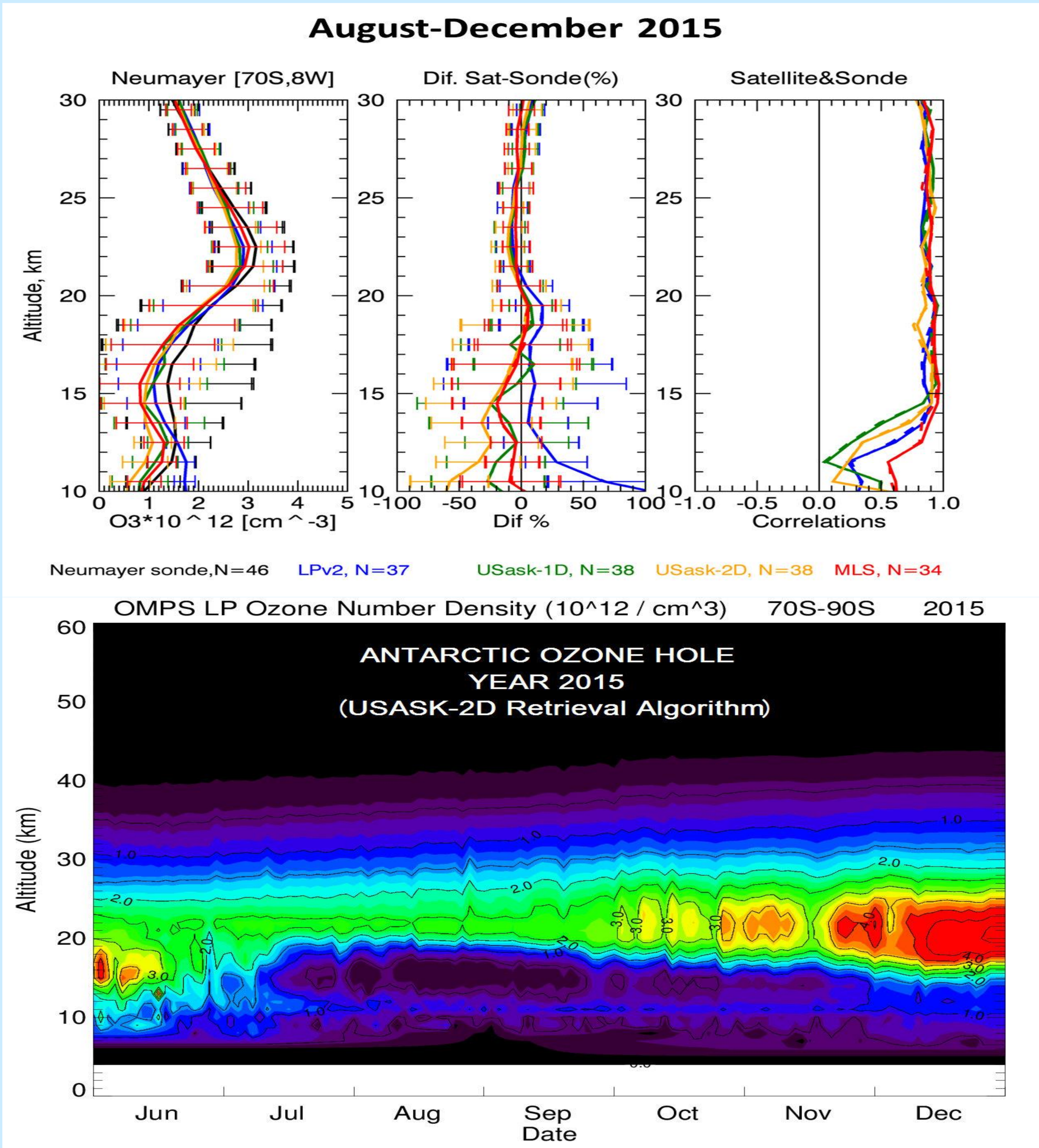



**Figure 6**. Top: Ozone number density profile comparisons at Neumayer (70S,8W) between ozonesondes, OMPS LP v2, OMPS USask-1D, and OMPS USask-2D. Bottom: The 2015 Antarctic ozone hole (here, 70S-90S measurements) with ozone number density retrieved from the OMPS USask-2D algorithm. The USask-2D algorithm (from Univ. of Saskatchewan) is an improvement for OMPS LP ozone profile retrieval compared to the OMPS v2 algorithm.

## Summary

- Tropospheric ozone from OMI/MLS during the Aura record has increased measurably, especially from India to China. These global patterns of decadal increases/trends are very similar to OMI NO2.
- ENSO events have a large influence on the variability of tropospheric ozone. El Nino events (such as the recent 2015-2016 El Nino) coincide with an eastward shift in convection across the dateline that dynamically increases ozone in the western Pacific and decreases ozone in the eastern Pacific.
- El Nino also induces exceptionally dry conditions and uncontrolled biomass burning over both Indonesia and Brazil as did happen during the intense 2015 -2016 El Nino event.
- The MJO and shorter time scale variability in tropospheric ozone exceeds total variability generated by ENSO in the tropics. It is shown that the GMI CTM well reproduces all time scales including MJO and shorter periods.
- Cloud ozone measured from OMI/MLS (October 2004 – present) is a useful data product for characterizing the properties of ozone in deep convective clouds.
- The USask-2D algorithm has been applied to the OMPS LP ozone retrieval and indicates an improvement from the current OMPS v2.