LIGHTNING IMPACT ON TROPOSPHERIC OZONE OVER THE TROPICAL SOUTHERN INDIAN OCEAN

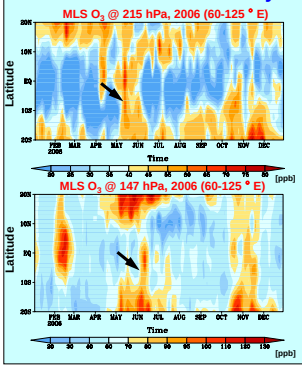
Li Zhang[1] (lzhang@atmos.ucla.edu), Qinbin Li[1,2], Jianjun Jin[2], Nathaniel Livesey[2]

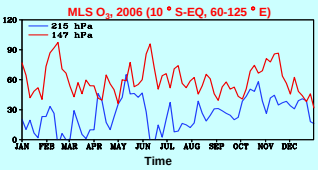
[1]Dept. of Atmospheric & Oceanic Sciences, University of California, Los Angeles [2]Jet Propulsion Laboratory, California Institute of Technology

INTRODUCTION

- Previous studies have shown that enhanced ozone mixing ratios and tropospheric column ozone (TCO) were observed over the Southern tropical Indian Ocean, including part of Indonesia in May of 2006 (Ziemke et al., 2008).
- We examined the middle and upper tropospheric ozone including TCO by using satellite data from Aura Microwave Limb Sounder (MLS), Tropospheric Emission Spectrometer (TES) instruments and the Aqua atmospheric Infrared Sounder (AIRS). Significant enhancements of ozone and TCO were observed over the Southern tropical Indian Ocean in May of 2006, 2007 (not as significant), and 2008.
- GEOS-Chem driven by GEOS-5 reanalysis data, with lightning NOx emission parameterized based upon convective cloud top height was able to capture the observed ozone enhancements, both in MLS and TES ozone mixing ratios and TES and AIRS TCO. Biomass burning had a rather small contribution to the ozone enhancements.
- Our analysis focused on the Southern tropical Indian Ocean (10 ° S-EQ, 60-125 ° E).

Ozone enhancements in May as observed by MLS

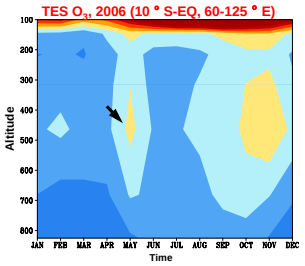


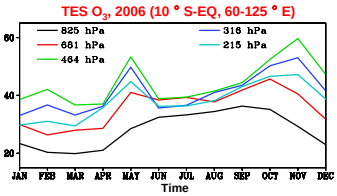


- Upper tropospheric O_3 during May-June 2006 were significantly enhanced over the S. Indian Ocean at 215 hPa and 147 hPa, with enhancements of 20-30 ppbv.
- Some noticeable time lag in O_3 enhancements at 147 hPa compared with 215 hPa – slow upward advection?

(Data are 5-day averages)

Ozone enhancements in May as observed by TES

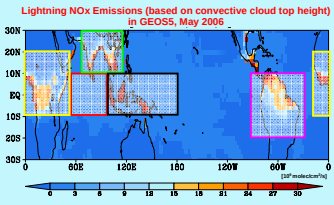




- The largest TES O_3 enhancement was observed in the middle to upper troposphere.
- The significant O_3 enhancements in middle and upper troposphere during Sep.-Dec. were due to Indonesia fires (Zhang et al., manuscript in preparation).

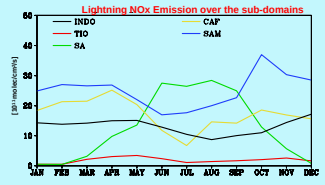
(Data are monthly averages)

REGIONAL LIGHTNING NOx EMISSIONS IN GEOS-Chem



Sub-domains:

- Indonesia (INDO): 10 ° S-10°N, 95°-150°E
- Tropical Indian Ocean (TIO): 10°S-10°N, 40°-95°E
- South Asia (SA): 10°-30°N, 70°-110°E
- Southern America (SAM): 20°S-15°N, 85°-35°W
- Central Africa (CAF): 10°S-20°N, 20°W-40°E



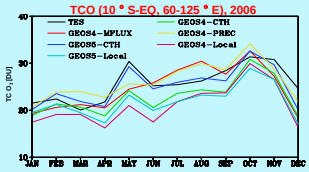
- The seasonal variations of lightning NOx emissions were quite different over the sub-domains. In May, the largest emissions were in South America and central Africa.
- Lightning NOx emissions over Indonesia showed little seasonal variation.
- The largest lightning NOx emission over the tropical Indian Ocean was in May, but the emissions were considerably smaller relative to the other regions.

COMPARISONS OF DIFFERENT LIGHTNING PARAMETERIZATIONS

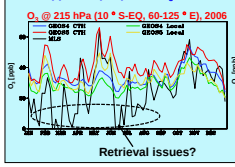
Lightning flash rates were parameterized in GEOS-Chem using convective cloud-top-height (CTH), convective mass flux (MFLUX), and convective precipitation (PREC) [Price and Rind 1992; Allen and Pickering, 2002].

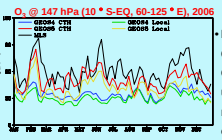
TES Tropospheric Column O3 (TCO)

- GEOS5 with CTH parameterization captured the TCO enhancement in 2006 and provided the best agreement with observations. Using a local redistribution of lightning flashes (based on satellite observations) showed little improvement.
- GEOS4 with CTH parameterization underestimated the TCO, though it was able to reproduce the relative enhancement.
- The TCO enhancement in May 2006 over S. Indian Ocean can not be simulated by GEOS4 with MFLUX and PREC parameterization.



MLS Upper Tropospheric O_3



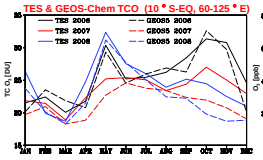


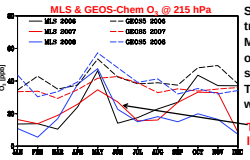
Retrieval issues?

- Model results driven by GEOS5 with CTH parameterization showed a broad O_3 enhancement at 215 hPa in the upper troposphere in May, but with much less variation than the observations.

The following model results were from GEOS-Chem simulations driven by GEOS5 with CTH lightning parameterization.

O_3 INTERANNUAL VARIABILITY AND LIGHTNING CONTRIBUTIONS

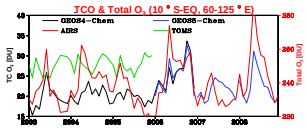




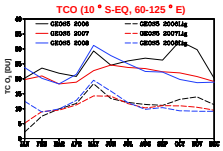
Significant TCO and upper tropospheric O_3 enhancements in May of 2006 and 2008, both in the observations and in the model. No significant enhancement in May 2007. The inter-annual variability was very well captured in the model.

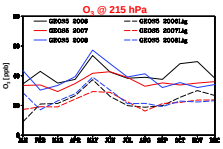
The retrieval issues led to artificially low average MLS O_3 at 215 hPa.

Enhanced total column ozone in May of 2006 and 2008 was seen in AIRS retrievals. Model results driven by GEOS5 reproduced these enhancements. Model simulations driven by GEOS5 data were in much better agreement with AIRS observations than those driven by GEOS4 data.



INTERANNUAL LIGHTNING CONTRIBUTONS

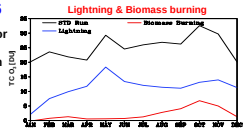




Model sensitivity experiments indicate that lightning contributes to the peaks in May of 2006 and 2008 which are associated with the significant enhanced O_3 mixing ratios and TCO during the periods. More than 60% of the enhancements in TCO over S. Indian Ocean are contributed by lightning NOx emissions.

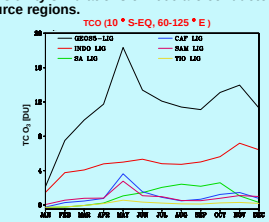
COMPARASON OF RALATIVE CONTRIBUTIONS IN 2006

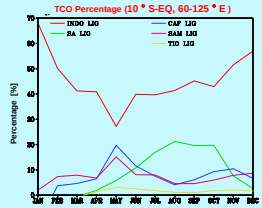
Lightning contributions peaked in May and were directly responsible for the ozone enhancements. Biomass burning has a rather small contributions to the TCO compared to lightning over S. Indian Ocean in May. The significant biomass burning impact was during Sep. to Nov., which was associated with the Indonesian fires [Logan et al., 2008; Chandra et al., 2009; Nassar et al. 2009; Zhang et al., 2010].



RELATIVE CONTRIBUTION OF REGIONAL LIGHTNING NOx EMISSION TO TCO ENHANCEMENT IN MAY

Sensitivity simulations of 2006 are conducted to quantify the relative contributions from these source regions.





Contribution to TCO (DU) in May

Global Lightning: 18.34
INDO: 4.99
SA: 1.06
CAF: 3.63
SAM: 2.76
TIO: 0.55
All Sub-domains: 13.01

Lightning Percentage Contribution (%) in May

Compared to global Lightning:
INDO: 27.2%
SA: 5.8%
CAF: 19.8%
SAM: 15.1%
TIO: 3.0%
All Sub-domains: 71.0%

Compared to all factors:
Lightning: 62.5%
INDO: 17.0%
SA: 3.6%
CAF: 12.4%
SAM: 10.8%
TIO: 1.89%
All Sub-domains: 44.4%

SUMMARY

- Significant enhancements of middle and upper tropospheric ozone including tropospheric column ozone (TCO) were observed over the tropical southern Indian Ocean in May of 2006 and 2008 from the Aura Microwave Limb Sounder (MLS) and Tropospheric Emission Spectrometer (TES) instruments and the Aqua Atmospheric Infrared Sounder (AIRS). No significant enhancement was observed in 2007.
- GEOS-Chem driven by GEOS-5 meteorological data, with a lightning NOx emission parameterized based upon convective cloud top height, was able to capture the ozone enhancements and the associated interannual variability, both in MLS and TES ozone mixing ratios and TES and AIRS TCO.
- Lightning NOx emissions contributed over 60% of the enhancements in TCO. Lighting NOx emissions from Indonesia accounted for 27% of the total TCO consistently throughout the year, and were thus not responsible for the relative ozone enhancements.
- Lightning NOx over Central Africa and South America contributed 12% and 11% respectively to the TCO in May. These contributions peaked in May and were directly responsible for the ozone enhancements. Our model results indicted that biomass burning had a rather small contribution to the ozone enhancements.