5.3 OZONESONDE AND NOAA-UNIQUE SOUNDER MEASUREMENTS OF AEROSE 2010 OZONE VIA LIGHTNING-INDUCED NITROGEN OXIDES AND BIOMASS BURNING EMISSIONS OVER THE TROPICAL ATLANTIC OCEAN

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1. INTRODUCTION

Tropospheric ozone is a greenhouse gas and contributes positively to Earth's radiative budget (IPCC, 2007). It is abundant over the Equatorial Atlantic Ocean. The relative maximum in ozone is a ridge in the Tropospheric Ozone Wave One. The ridges in the tropospheric column ozone are found over the Equatorial Atlantic Ocean and Southern Hemisphere Indian Ocean. These ridges are in sync with relative minima over the Central and Southern African continent and Pacific Ocean. The minima and maxima increase in magnitude and reach a peak in September. Ozone Monitoring Instrument (OMI, Ziemke et al., 2006) Tropospheric Column Ozone (TCO) are greater than 55 Dobson Units (DU, Figures 1a-b) in the ridges by September.

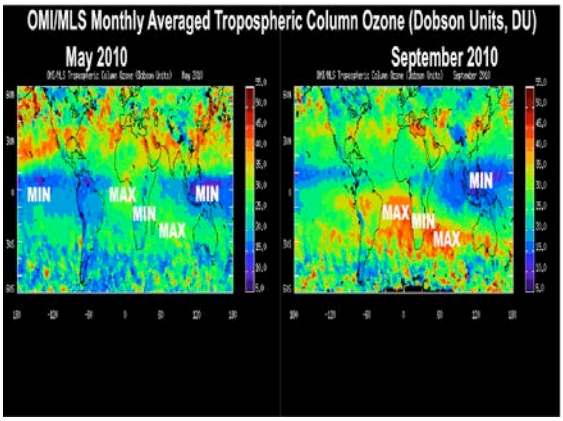

Figure 1. Monthly averaged OMI Tropospheric Column Ozone for a) May 2010 and b) September 2010 for the entire globe.

Observations have detected enhanced tropospheric ozone over the Equatorial Atlantic Ocean. The Aerosols and Ocean Science Expeditions ozonesondes have been launched from the R/V Ronald H Brown Ship for nine years (Nalli et al., 2011) and simultaneously with the Southern Hemisphere Additional Ozonesondes at Ascension Island. Even with these measurements, there are still temporal and spatial gaps in the ozone data over the eastern Equatorial Atlantic Ocean. The NASA OMI, Microwave Limb Sounder (MLS), and the Tropsopheric Emissions Spectrometer (TES) are used to measure ozone precursor emissions (i.e. nitrogen oxides, NO_x, and carbon monoxide, CO) and ozone and close the gap. These sources are experimental instead of operational. The NOAA-Unique trace gas products are no cost to the public, and have an Atmospheric Infrared Spectrometer (AIRS, Aumann et al., 1995) heritage, hence they provide an opportunity to NOAA-Unique Sounders data which are operational.

Biomass burning emissions contribute to the Equatorial Atlantic Ocean ozone ridge of the Ozone Wave One. In June 2006, Smith et al., (2014, in prep) uses the combined meteorology/chemistry model, the Chemistry Version of the Weather Research and Forecasting Model. When examining differences between the biomass burning and control baseline simulations ozone increase were 30+ ppbv off of the coast of Angola and the Democratic Republic of Congo in the lower troposphere. The biomass burning source grows in areal coverage and emissions rates in the Southern Hemisphere over the summer. Lightning-induced nitrogen oxides are a second-order source of ozone over the Equatorial Atlantic Ocean. Smith et al. (2014b, in prep) suggests that LNO_x contributes to 11-15 ppbv ozone over the Equatorial Atlantic Ocean.

Lightning flash counts increase in the Northern Hemisphere over summer leading to increased NO_x that is transported over the Equatorial Atlantic Ocean and photochemically produces ozone over the Equatorial Atlantic Ocean. These findings suggest that these two sources lead to the September peak in TCO.

The objectives of this study will use the WRF-Chem Model to validate NOAA-Unique Sounder products such as the Infrared Atmospheric Sounding Interferometer (IASI) to validate CO and ozone.

2. DATA AND PROCEDURE

To explain the Ozone Wave-One this study used OMI Tropospheric Column Ozone (Ziemke et al. 2006). Lightning location data was obtained by the Worldwide Lightning Location Newowrk. The fir areas displayed are from MODIS (Giglio 2010). The AEROSE 2010 ozonesonde and radiosonde weather data are stored at Howard University Program in Atmospheric Science and at the National Environmental Satellite, Data, and Information

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Service (Nalli et al., 2011). The SHADOZ data is archived at NASA (Thompson et al. 2003a). The NOAA IASI ozone and CO data are obtained from www.class.noaa.gov.

3. SCIENCE APPLICATION FINDINGS

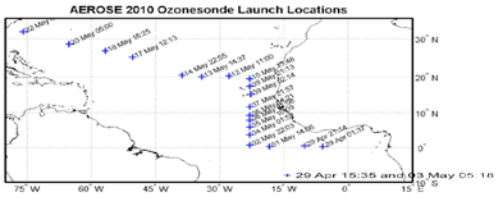

Figure 2. AEROSE 2010 and SHADOZ ozonesondes launch times and locations in blue crosses.

Between 29 April and 11 May 2010 the AEROSE Campaign on the Ronald H. Brown launched ozonesondes downwind of West Africa. The NCEP/NCAR Reanalysis (Kalnay et al., 1996) shows that the any nitrogen oxides or other constituent detrained out the convection and westward. The ship sailed along the Equator and then turned north along 23°W longitude before it made a westward turn further into the Atlantic Ocean. There were two SHADOZ launches at Ascension Island (14.42°W and 7.98°S) during the AEROSE period: 29 April and 3 May 2010. All of these launches were downwind of 114,398 lightning flashes along the ITCZ, over the Gulf of Guinea. There were 11,651 MODIS fire areas. Many of them are concentrated on the Guinea-Bissau Coast. There are a growing number of fire areas in the SH, particularly over the northern Angola, and the Democratic Republic of Congo (DRC)

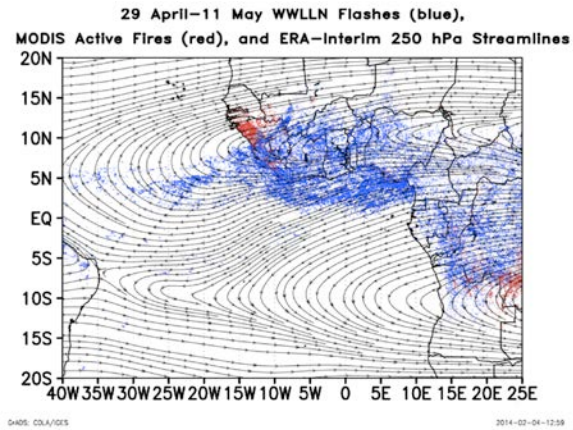

Figure 3. WWLLN lightning flashes (blue), MODIS biomass burning fire areas (red), and NCEP/NCAR Reanalysis streamlines between 29 April and 11 May.

The AEROSE 29 April and SHADOZ 3 May ozonesonde mixing ratios and relative humidity profiles in Figure 4a and b display considerable variability. The AEROSE ozone mixing ratios exceed 80 ppbv at 500 hPa and approach 80 ppbv at 275 hPa for SHADOZ. What is clear in these profiles is that generally, when there is maximum in ozone, there is a minimum in relative humidity. The SHADOZ case in Fig. 4b is particularly abrupt. The RH drops to 10% above 775 hPa simultaneous with a 30 ppbv rise in ozone at that pressure height. The dry air correlated with the ozone increases suggests that the ozone is generated from either LNO_x or stratospheric/tropospheric intrusions.

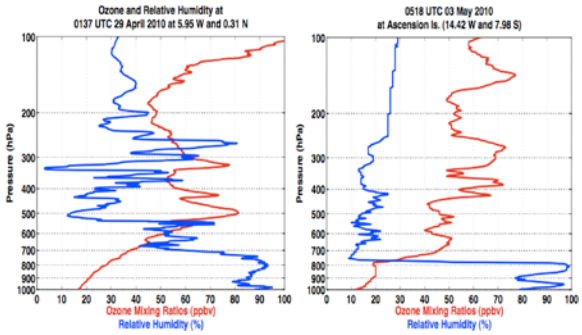

Figure 4 Vertical profiles of ozone mixing ratio (red) and relative humidity (blue) for a) AEROSE 0137 UTC 29 April 2010 and b) SHADOZ 0518 UTC 3 May 2010.

There were two AEROSE ozonesonde launches on 29 April and 1 SHADOZ (Figure 5a). Each of these ozonesondes are downwind of the biomass burning and LNO_x enhancement which could lead to ozone increases. Figures 5a-b show ozone from 273 hPa for the NOAA IASI descending (Fig. 5a) and ascending (Fig. 5b) orbits. The pressure level 273 hPa was chosen because NOAA IASI is sensitive to ozone in the upper troposphere. In the vicinity of the ozonesonde launches ozone mixing ratios are 35-45 ppbv which is only a slight underestimate of the AEROSE 29 April observations (see Fig 4a) of approximately 50 ppbv. This is the case for the ascending orbit (see Fig 5b).

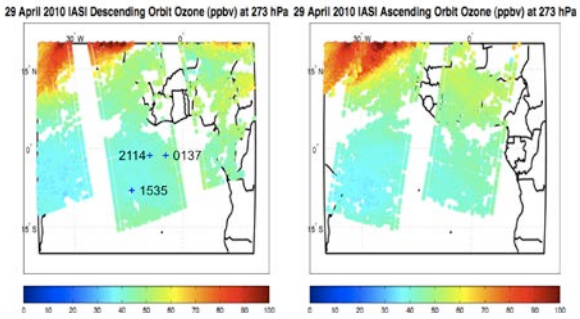

Figure 5. Scatter plots of NOAA IASI ozone mixing ratio (ppbv) at 273 hPa for the a) descending and b)

ascending overpass. The blue crosses in a) depict the ozonesonde launch times.

Since IASI is sensitive to CO in the middle troposphere, hence we use a pressure level of 639 hPa. Carbon monoxide is a good tracer. What is interesting is that beginning at the Guinea-Bissau coast and extending westward is a plume of CO greater than 115 ppbv. This aligns with the biomass burning fire areas from Figure 2.

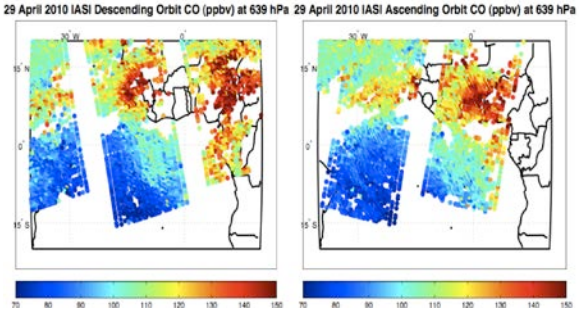

Figure 6. Scatter plots of NOAA IASI CO mixing ratio (ppbv) at 639 hPa for the a) descending and b) ascending overpass.

Figure 7 depicts the June 2006 MODIS biomass burning fire areas. They are wide spread over northern Angola and the DRC (Smith et al., 2014a). Figure 8 displays CO from the June 2006 biomass burning simulation in Smith et al., (2014a, in prep). A plume of CO greater than 100 ppbv originates from the burning region. Figure 9 shows the difference in CO mixing ratios between the control (baseline) simulation with biogenic and anthropogenic emissions and the biomass burning simulation (see Fig. 8) that adds fire emissions. Figure 9 suggests CO mixing ratios were 65-80 ppbv without biomass burning. The CO plume in Figure 8 similar to the CO mixing ratio plume depicted by NOAA IASI (see Fig. 6b). The June 2006 case suggests that the model can predict similar values and physical structure to the NOAA IASI CO product.

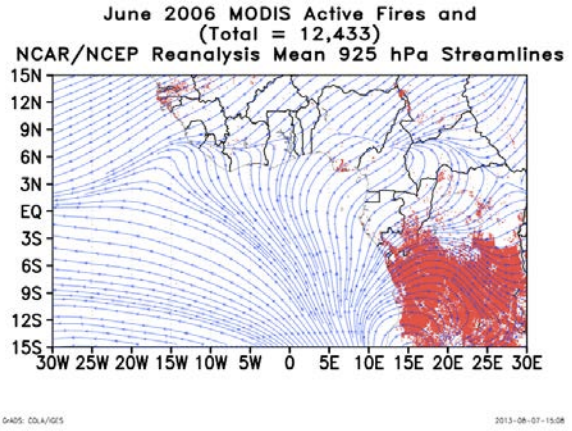

Figure 7 Scatter plot of WRF-Chem Model biomass burning simulation CO mixing ratio (ppbv) at 650 hPa.

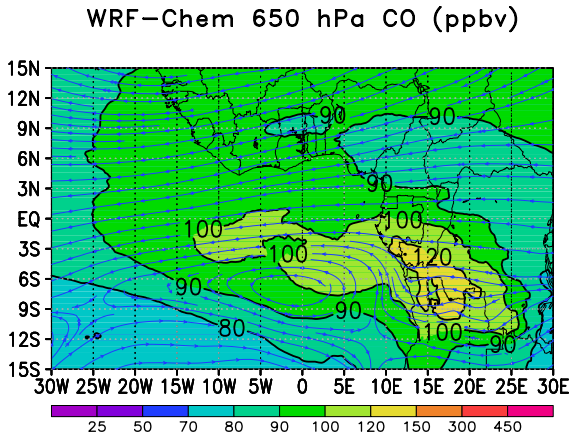

Figure 8. Contour plots of WRF-Chem Model biomass burning simulation CO mixing ratio (ppbv) at 650 hPa.

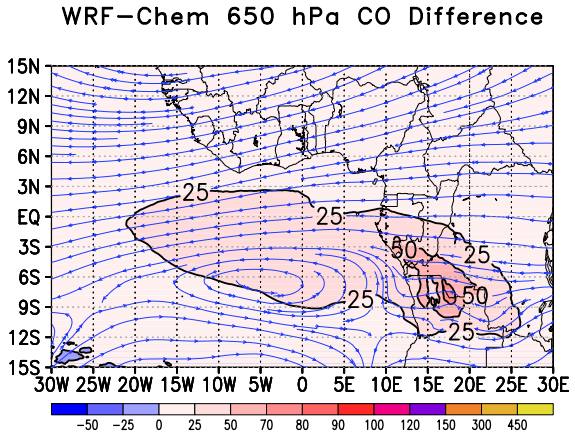

Figure 9. Contour plots of WRF-Chem Model biomass burning simulation and control simulation CO mixing ratio differences (ppbv) at 650 hPa.

4. FUTURE WORK

To our knowledge models have rarely been used to validate sounder trace gas products, particularly combined meteorology/chemistry mesoscale models like WRF-Chem. This provides many opportunities for future work for validation and science applications such as the Ozone Wave-One eastern Equatorial Atlantic Ocean ridge. Specifically, this study will use Version 3.5 of the WRF-Chem Model as a validation tool for NOAA IASI ozone and CO and NOAA CrIS CO mixing ratios and eventually the NOAA-Unique products to validate the model. The model parameterization will include the Regional

Atmospheric Deposition Model (RADM2, Stockwell et al., 1990) chemical mechanism, four bins of the Model for Simulation Aerosol Interactions and Chemistry (MOSAIC, Zaveri et al., 2008) aerosols, Grell et al. (2013) convective parameterization, Lin et al. (1983) microphysics scheme, and the new LNO_x parameterization. The model simulations will include Reanalysis of Ozone in the Troposphere (RETRO) anthropogenic emissions and Model of Pollution in the Troposphere (MOPITT) biogenic emissions. Test simulations will be done with model LNO_x emissions in the model originating from Worldwide Lightning Location Network (WWLLN) flashes. The lightning flash counts will be scaled up by a Tropical Rainfall Measuring Mission (TRMM)/Lightning Imaging Sensor (LIS) climatology from Allen, (2014, personal communication). This method was used in Smith et al., (2014, in prep). As part of this study we will need to have an estimate of where the gases originated from and their trajectory so we will use the WRF-Chem version of the Lagrangian Particle Dispersion Model (FLEXPART, Stohl et al., 2006).

This study will continue with the AEROSE 2010 (Nalli et al., 2011) and SHADOZ Ascension Island ozonesonde data. Direct comparisons of ozone and CO mixing ratios in terms of a horizontal slices and vertical profiles will be made. We can reverse the validation procedure and test NOAA IASI and NOAA CrIS data inside of the WRF-Chem. Preliminary tests of CO and ozone retrieval data can be used as CO and ozone initial or lateral boundary conditions. This will be an initial test of whether or not sounder trace gas products can validate the model. Specifically, CO and ozone would be replaced by the Model for Ozone and Related Tracers (Emmons et al., 2006) CO and ozone output.

April and May are transitional months (biomass burning fire areas increasing in the SH and ITCZ moving northward over West Africa as opposed to the ITCZ closer to the Equator and NH biomass burning. Both regimes will become more robust during the summer (i.e. greater areal biomass burning coverage and higher lightning flash counts) hence it will be advantageous to view more SHADOZ Ascension Island data and examine ozonesondes from Cape Verde and Dakar, Senegal during June/July 2010 (Jenkins et al. 2012 and 2013).

Once the initial model/validation tests are complete and the improvements to the model and data are defined, WRF-Chem model simulations for larger time periods will be completed. Ozone and CO from NOAA IASI and CO from NOAA Cross-track Infrared Spectrometer (CrIS) will be integrated and assimilated into WRF-Chem. The above steps would be repeated for the AEROSE 2011 and 2013a. The 2011 cruise contains ozonesonde mixing ratio data from both the Northern and Southern Hemispheres which will contribute to our understanding of the NH ozone enhancement from LNO_x and biomass burning and the SH ozone enhancement from primarily biomass burning. August is also the height of the areal coverage of the biomass burning fire areas. The AEROSE 2013a data will provide an opportunity for us to analyze the ozone generated from the NH biomass burning and LNO_x generated from the ITCZ convection along the Equator. In these future studies we will use Measurement of Ozone and Water Vapor by Airbus In-service aircraft (MOZAIC, Marenco et al., 1998) trace gas data. It is important to explore this vertical mixing ratio information as it could be an additional validation tool for CO.

5. IMPROVEMENTS AND CONCLUSIONS

Improvements in mixing ratio and spatial structure of the NOAA IASI CO and ozone and NOAA CrIS CO products through the model is desired. These improvements will benefit the Joint Polar Satellite System (JPSS). Examining the ozone products will also lead to improvements in meteorological data such as temperature and water vapor. Until there are more consistent temporal and spatial ozone and trace gas observations over the eastern Equatorial Atlantic Ocean, the validation of the trace gas products from the sounder with the model will help the atmospheric chemistry community feel more confident about the sounder data. This will eventually increase the visibility NOAA IASI and NOAA CrIS products that will subsequently entice more users. This study will provide a cultivate collaboration of the NOAA-Unique Sounder and numerical modeling communities.

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