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# Nitrogen oxides in the global upper troposphere interpreted with cloud-sliced $NO_2$ from the Ozone Monitoring Instrument

Eloise A Marais (1), Daniel J Jacob (2,3), Sungyeon Choi (4), Joanna Joiner (4,5), Maria Belmonte-Rivas (6), Ronald C Cohen (7,8), Thomas B Ryerson (9), Andrew J Weinheimer (10), and Andreas Volz-Thomas (11)

(1) University of Birmingham, School of Geography, Earth and Environmental Sciences, Birmingham, UK, (2) John A. Paulson School of Engineering and Applied Sciences, Harvard University, Cambridge, MA, (3) Earth and Planetary Sciences, Harvard University, Cambridge, MA, (4) Science Systems and Applications Inc., Lanham, MD, (5) NASA Goddard Space Flight Center, Greenbelt, MD, (6) Royal Netherlands Meteorology Institute, De Bilt, the Netherlands, (7) Department of Chemistry, University of California at Berkeley, Berkeley, CA, (8) Department of Earth and Planetary Science, University of California at Berkeley, Berkeley, CA, (9) Chemical Sciences Division, Earth System Research Lab, National Oceanic and Atmospheric Administration, Boulder, CO, (10) National Center for Atmospheric Research, Boulder, CO, (11) IAGOS-AISBL, Brussels, Belgium

Nitrogen oxides ($NO_x \equiv$ NO + $NO_2$) are long lived in the upper troposphere (UT), and so have a large impact on ozone formation where ozone is a powerful greenhouse gas. Measurements of UT $NO_x$ are limited to summertime aircraft campaigns predominantly in North America. There are year-round $NO_x$ measurements from instruments onboard commercial aircraft, but $NO_2$ measurements are susceptible to large interferences. Satellites provide global coverage, but traditional space-based $NO_2$ observations only provide one piece of vertical information in the troposphere. New cloud-sliced satellite $NO_2$ products offer additional vertical information by retrieving partial $NO_2$ columns above clouds and further exploit differences in cloud heights to calculate UT $NO_2$ mixing ratios. Two new cloud-sliced $NO_2$ products from the Ozone Monitoring Instrument (OMI; 2004 launch) provide seasonal UT $NO_2$ data centered at 350 hPa for 2005-2007 (NASA product) and 380 hPa for 2006 only (KNMI). Differences between the products include spectral fitting to obtain $NO_2$ along the viewing path (slant column), the air mass factor calculation to convert slant columns to true vertical columns, treatment of the stratospheric $NO_2$ component, and the choice of cloud products. The resultant NASA $NO_2$ mixing ratios are 30% higher than KNMI $NO_2$ and are consistent with summertime aircraft $NO_2$ observations over North America. Comparison between NASA $NO_2$ and the GEOS-Chem chemical transport model exposes glaring inadequacies in the model. In summer in the eastern US lightning $NO_x$ emissions are overestimated by at least a factor of 2, corroborated by comparison of GEOS-Chem and MOZAIC aircraft observations of reactive nitrogen ($NO_y$). Too fast heterogeneous hydrolysis of dinitrogen pentoxide ($N_2O_5$) leads to an underestimate in UT $NO_2$ in winter across the northern hemisphere. Absence of interannual variability in lightning flashes in the lightning $NO_x$ parameterization induces biases in UT $NO_2$ in the tropics due to anomalous lightning activity linked to the El Niño Southern Oscillation. Ongoing work is to use GEOS-Chem to investigate the implications of updated representation of UT $NO_x$ on ozone.