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

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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.