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# Satellite observations of lightning-generated $NO_x$ in volcanic eruption clouds

Simon Carn (1), Nickolay Krotkov (2), Ken Pickering (2), Dale Allen (3), and Eric Bucsela (4)

(1) Michigan Technological University, Geological and Mining Engineering and Sciences, Houghton, United States (scarn@mtu.edu), (2) Atmospheric Chemistry and Dynamics Laboratory, Code 614, NASA Goddard Space Flight Center, Greenbelt, MD, USA, (3) Department of Atmospheric and Oceanic Science, University of Maryland, College Park, MD, USA, (4) SRI International, Inc., Menlo Park, CA, USA

The generation of $NO_2$ by lightning flashes is known to be an important source of $NO_x$ in the free troposphere, particularly in the tropics, with implications for ozone production. Although UV-visible satellite observations of lightning-generated $NO_x$ ($LNO_x$) in thunderstorms have been previously reported, here we present the first satellite observations of $LNO_x$ generated by lightning in explosive volcanic eruption clouds ($vLNO_x$) from the Ozone Monitoring Instrument (OMI) aboard NASA's Aura satellite. To date we have identified $vLNO_x$ in operational OMI $NO_2$ measurements ($OMNO_2$) during the high-latitude eruptions of Okmok (Aleutian Is; July 2008), Kasatochi (Aleutian Is; August 2008), Redoubt (Alaska; March 2009) and Grimsvötn (Iceland; May 2011), although analysis of $OMNO_2$ data for other eruptions is underway. We use World Wide Lightning Location Network (WWLLN) observations to verify the occurrence and location of lightning flashes in the volcanic eruption clouds. All the $vLNO_x$ anomalies are associated with strong UV Aerosol Index (UVAI) signals due to volcanic ash. Preliminary analysis shows that the maximum $vLNO_x$ column detected by OMI decreases linearly with time since eruption, and suggests that the $vLNO_x$ signal is transient and can be detected up to ~5-6 hours after an eruption. Detection of $vLNO_x$ is hence only possible for eruptions occurring a few hours before the daytime OMI overpass. Based on the number of lightning flashes detected by WWLLN in each eruption cloud, we also estimate the $vLNO_x$ production efficiency (moles $vLNO_x$ per flash). Preliminary estimates for the 2008 Kasatochi eruption suggest that this is significantly higher than the production efficiency in thunderstorms, but may be biased high due to the low detection efficiency of WWLLN (<10-50% of flashes detected over most regions). The measured $vLNO_x$ columns also require adjustment using an algorithm designed to retrieve $LNO_x$ from OMI, which takes the total OMI slant column $NO_2$ and removes the stratospheric contribution and tropospheric $NO_2$ background and applies an appropriate air mass factor to convert the slant column $LNO_2$ to a vertical column of $LNO_x$. However, OMI measurements of $LNO_x$ in thunderstorms suggest that any $NO_x$ below the cloud optical centroid pressure (OCP; ~350-500 hPa) is not detected. We speculate that the OCP may be lower (i.e. at higher altitude) in fresh volcanic clouds due to higher optical depths. The observation of $vLNO_x$ in volcanic clouds is significant since it implies active convection and plume electrification close to the satellite overpass time, with implications for aviation hazards due to volcanic ash. Furthermore, the $vLNO_x$ observations may provide information on air entrainment in volcanic eruption columns, which is required for some volcanic ash dispersion models. Although $vLNO_x$ is undoubtedly a very minor fraction of global $LNO_x$ production, explosive volcanic eruptions may inject $NO_x$ into the stratosphere where it has implications for ozone chemistry.