Direct stratospheric injection or uplift by the Asian Monsoon?

Tracing the Nabro 2011 eruption plume using trajectory ensembles and satellite data

Volcanic eruptions are the largest source of stratospheric aerosol, which affects the Earth's energy balance by scattering part of the incoming solar radiation back to space and provides surfaces for heterogeneous reactions that influence the chemistry of the stratosphere. It is commonly believed that in order to affect the stratospheric aerosol load significantly, eruption plumes need to extend into the stratosphere. In contrast, Bourassa et al. (2012) linked an observed enhancement of stratospheric aerosol – the strongest since Pinatubo – to sulfur emitted by the Nabro volcano and transported to the stratosphere via the Asian summer monsoon anticyclone. The role of this transport pathway has been questioned by Sawamura et al. (2012), Fromm et al. (2012) and Vernier et al. (2013), who all present convincing evidence for direct injection into the stratosphere during the eruption.

Using ensembles of forward trajectories initialized from AIRS satellite images of the early plume, it can be shown that both pathways – direct injection and uplift by the Asian monsoon – supplied visible amounts of aerosol to the stratosphere. The relative contributions of both pathways are quantified using a Lagrangian inverse modelling approach constrained by CALIOP observations and validated by independent ground-based lidar observations.

Long term simulations and satellite observations show the aerosol plume to spread throughout the lowermost stratosphere over the entire northern hemisphere after the breakup of the anticyclone. This initial meridional transport is confined to the lower branch of the Brewer Dobson circulation. However, a sizeable fraction of the trajectory ensemble rises further when upwelling intensifies with the onset of boreal winter. This delayed transport from the Asian monsoon region into the upper branch of the BD-circulation is supported by the observation of stronger aerosol signatures above 20 km in the tropics in winter 2011/12 compared to other years. This has implications for the transport of anthropogenic SO_2 and other pollutants that accumulate in the TTL over the Asian monsoon region virtually every summer.

Bourassa, A. E., et al.: Large Volcanic Aerosol Load in the Stratosphere Linked to Asian Monsoon Transport, *Science*, 337, 78-81, 2012.

Fromm, M., et al.: Comment on "Large volcanic aerosol load in the stratosphere linked to Asian Monsoon Transport" by Bourassa and co-authors. *Science*, 339, 647c, 2013.

Sawamura, P., et al.: Stratospheric AOD after the 2011 eruption of Nabro volcano measured by lidars over the Northern Hemisphere, *Environ. Res. Lett.*, 7, 2012.

Vernier, J.-P., et al.: Comment on "Large volcanic aerosol load in the stratosphere linked to Asian Monsoon Transport" by Bourassa and co-authors. *Science*, 339, 647d, 2013.