Corrigendum: Small volcanic eruptions and the stratospheric sulfate aerosol burden

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In my original perspective piece (Pyle 2012), I mistakenly suggested that both Sawamura et al (2012) and Bourassa et al (2012) had attributed the lofting of the Nabro plume into the stratosphere to the strong Asian summer monsoon. In fact, while the ash clouds that accompanied the most explosive phases of the Nabro eruption were reported by the Toulouse VAAC to have reached 9–14 km on 13–14 June (Smithsonian Institution 2011), the Micro Pulse Lidar profile from Sede Boker, Israel, for the same date (14 June) shows a strong peak in the scattering ratio at around 17 km elevation. This was interpreted by Sawamura et al (2012) as being potentially due to ash and sulfate particles, and would suggest that the initial phase of the eruption injected material to this altitude. Sawamura et al (2012) also showed that the transport of the volcanic plume to Sede Boker was consistent with forward air-trajectory models, which for that time period showed a strong anticyclonic vortex due to the Asian summer monsoon, but they did not suggest that the monsoonal circulation was responsible for lofting of the plume. Bourassa et al (2012) identified a stratospheric enhancement of aerosol optical depth across eastern Asia beginning in early July 2011, which they attributed to the vertical transport of volcanic SO$_2$ from the eruption plume into the lower stratosphere. Further work, using other techniques that can resolve altitude, is required to fully understand the time-history of the volcanic ash and gas plumes, and the sulfate aerosol that subsequently developed.

References

Bourassa A E, Robock A, Randel W J, Deshler T, Rieger L A, Lloyd N D, Llewellyn E J and Degenstein D A 2012 Large volcanic aerosol load in the stratosphere linked to Asian monsoon transport Science 337 78–81

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Sawamura P et al 2012 Stratospheric AOD after the 2011 eruption of Nabro volcano measured by lidars over the Northern Hemisphere Environ. Res. Lett. 7 034013

Smithsonian Institution 2011 Nabro. First historically observed eruption began 13 June 2011 Bull. Glob. Volcanism Netw. 36 (9) (www.volcano.si.edu/reports/bulletin/contents.cfm?issue=3609)
Understanding of volcanic activity and its impacts on the atmosphere has evolved in discrete steps, associated with defining eruptions. The eruption of Krakatau, Indonesia, in August 1883 was the first whose global reach was recorded through observations of atmospheric phenomena around the world (Symons 1888). The rapid equatorial spread of Krakatau’s ash cloud revealed new details of atmospheric circulation, while the vivid twilights and other optical phenomena were soon causally linked to the effects of particles and gases released from the volcano (e.g. Stothers 1996, Schroder 1999, Hamilton 2012). Later, eruptions of Agung, Bali (1963), El Chichón, Mexico (1982) and Pinatubo, Philippines (1991) led to a fuller understanding of how volcanic SO$_2$ is transformed to a long-lived stratospheric sulfate aerosol, and its consequences (e.g. Meinel and Meinel 1967, Rampino and Self 1982, Hoffman and Rosen 1983, Bekki and Pyle 1994, McCormick et al 1995).

While our ability to track the dispersal of volcanic emissions has been transformed since Pinatubo, with the launch of fleets of Earth-observing satellites (e.g. NASA’s A-Train; ESA’s MetOp) and burgeoning networks of ground-based remote-sensing instruments (e.g. lidar and sun-photometers; infrasound and lightning detection systems), there have been relatively few significant eruptions. Thus, there have been limited opportunities to test emerging hypotheses including, for example, the vexed question of the role of ‘smaller’ explosive eruptions in perturbations of the atmosphere—those that may just be large enough to reach the stratosphere (of size ‘VEI 3’, Newhall and Self 1982, Pyle 2000). Geological evidence, from ice-cores and historical eruptions, suggests that small explosive volcanic eruptions with the potential to transport material into the stratosphere should be frequent (5–10 per decade), and responsible for a significant proportion of the long-term time-averaged flux of volcanic sulfur into the stratosphere (Rampino and Self 1984, Pyle et al 1996, Self and Rampino 2012). But as yet, there is little evidence for the consequences of this scale of eruption for the climate system (Miles et al 2004), and few data against which to test simulations of stratospheric sulfur-injection ‘geoengineering’ scenarios of a similar scale and frequency (e.g. English et al 2012).

A hint of the new volcano-observing capability came during the eruption of Eyjafjallajökull, Iceland. For a few days in April 2010 meteorological conditions, coupled with a dramatic increase in volcanic ash production, led to the wide dispersal of fine volcanic particles across northern Europe; an event which was widely tracked by ground-based and satellite-borne instruments, augmented by in situ measurements from balloons and aircraft (Bennett et al 2010, Flentje et al 2010, Harrison et al 2010, Stohl et al 2011). Despite the interest in Eyjafjallajökull at the time, this was, geologically, only a very modest eruption with limited sulfur emissions and an impact restricted mainly to the regional troposphere (e.g. Thomas and Prata 2011, Walker et al 2012).

Then, in June 2011, a previously dormant volcano in north-east Africa began to erupt violently. Little is known about Nabro, which is a partially collapsed volcano that straddles the Eritrea–Ethiopia border, and has had no known historical activity (Wiart and Oppenheimer 2005). Despite the remote location,
and lack of prior warning, the event and its aftermath were remarkably well captured by remote-sensing instruments, as demonstrated in the new letter by Sawamura et al (2012). Using both ground-based and satellite-borne laser-ranging (lidar) data, Sawamura et al (2012) were able to extract detailed information about the nature of the volcanic aerosol layer, and its spread around the globe. The eruption started strongly, with substantial ash plumes for the first 48 h, rising to 9–14 km altitude (Smithsonian Institution 2011, Bourassa et al 2012), that carried at least 1.3–1.5 Tg of SO$_2$ (Krotkov et al 2011, Clarisse et al 2012). This was probably the largest sulfur yield from an explosive eruption since Pinatubo and Hudson in 1991 (Deshler et al 2006, Krotkov et al 2010). Within two weeks, volcanic aerosol had been detected at elevations of 15–20 km within the upper troposphere/lower stratosphere above north Africa and southern Eurasia; and within a month, the aerosol had been detected by lidar instruments on every continent in the northern hemisphere, from 20°–45°N. The aerosol, presumed to be dominated by sulfate, persisted for the period of observation (June–September 2011), and led to a small but significant stratospheric aerosol optical depth (AOD) perturbation (average $\sim$0.02). While this is an order of magnitude lower than global AOD perturbations following the most significant eruptions of the 20th century (e.g. Stothers 1996), it is nonetheless substantially larger than estimates of the typical ‘nonvolcanic’ stratospheric aerosol background ($<0.01$, Deshler 2008).

The Nabro eruption was a particularly interesting event, partly because it was unremarkable. Without remote-sensing measurements, this eruption would probably have passed with little notice; and the geological record of this event is likely to be modest. But now we know that events of this scale still have the potential to have a hemispheric impact on the stratosphere. In this case, as both Sawamura et al (2012) and Bourassa et al (2012) show, the strong Asian summer monsoon was probably responsible for the rapid lofting of the SO$_2$ plume into the lower stratosphere, where it was able to react to form a fine sulfate aerosol with the potential to persist for some months. Similar arguments will pertain to other geological small—but sulfur-rich—volcanic events in the past, and this calls for a reassessment of our assumptions about the potential impact of small volcanic eruptions on the stratospheric sulfate aerosol burden.

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