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Comment on "Large Volcanic Aerosol Load in the Stratosphere Linked to Asian Monsoon Transport"

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Comment on "Large Volcanic Aerosol Load in the Stratosphere Linked to Asian Monsoon Transport"

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Bourassa *et al*. (Reports, 6 July 2012, p. 78) report on the 13 June 2011 eruption of the Nabro volcano and satellite observations of stratospheric aerosol that they attribute to troposphere to stratosphere ascent via the Asian monsoon. They claim (citing another source) that the 13 June top injection height was well below the tropopause. We will show that the 13 June Nabro eruption plume was clearly stratospheric and contained both volcanic gases and aerosols. Moreover, we will show height-resolved stratospheric sulfur dioxide and volcanic aerosol enhancements 1 to 3 days old, unaffected by the Asian monsoon, precisely connected to the volcano. The observed stratospheric aerosols and gases are fully explained by the 13 June eruption and do not require a monsoon vehicle.

The Nabro volcano in Africa (13.37°N, 41.7°E) erupted explosively in the night from 12 to 13 June 2011 (*1*). Bourassa *et al.* (*2*) studied satellite observations of stratospheric aerosol after this eruption and characterized the stratospheric impact as the largest since the 1991 Mount Pinatubo eruption. However, unlike Pinatubo's super-Plinian eruption, Bourassa *et al.* characterize Nabro's 13 June injection as strictly tropospheric. The arrival of aerosols and/or precursors into the stratosphere is attributed to tropospheric meteorological processes associated with the Asian monsoon circulation [references in (*2*)]. There is no precedent in the scientific literature for this or similar process causing such a sizable—and indirect—volcanic impact on the stratosphere, hence its relevance to a general science audience.

However, there is satellite evidence that the Nabro 12 to 13 June 2011 eruption was explosive and penetrated above the tropopause. Moreover, there also is satellite evidence of stratospheric volcanic gases and particles, not only during the eruption but daily after the eruption as well. Here is the evidence, from publicly available and easily accessible data sources.

About 2 hours after eruption onset, thermal infrared (IR) brightness temperature (BT) imagery of the eruption at 22:15 UTC on 12 June by the Moderate Resolution Imaging Spectroradio-

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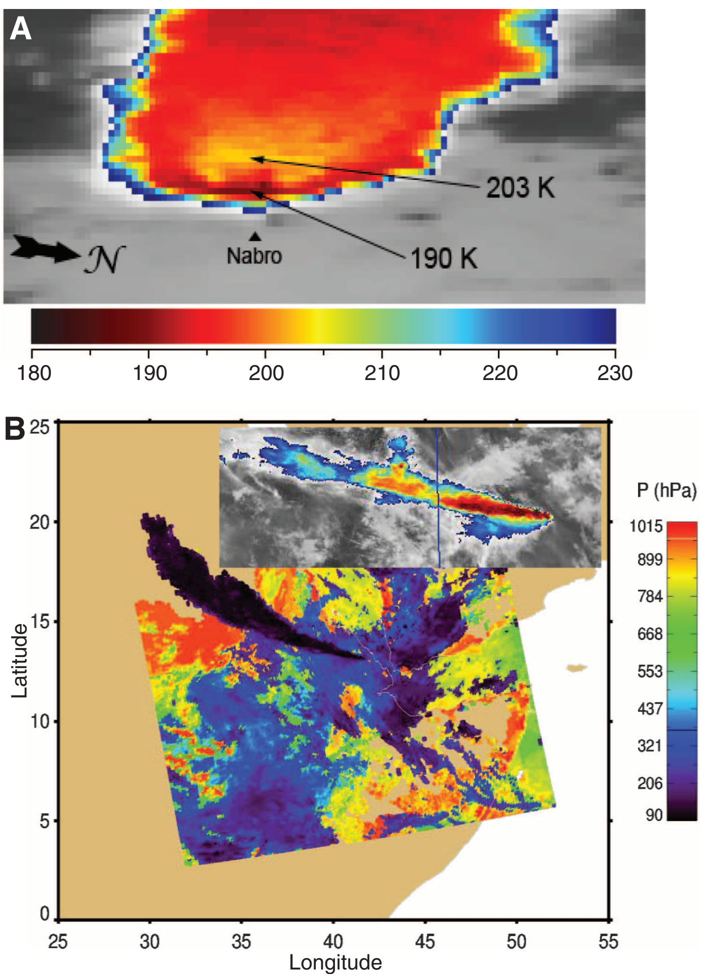

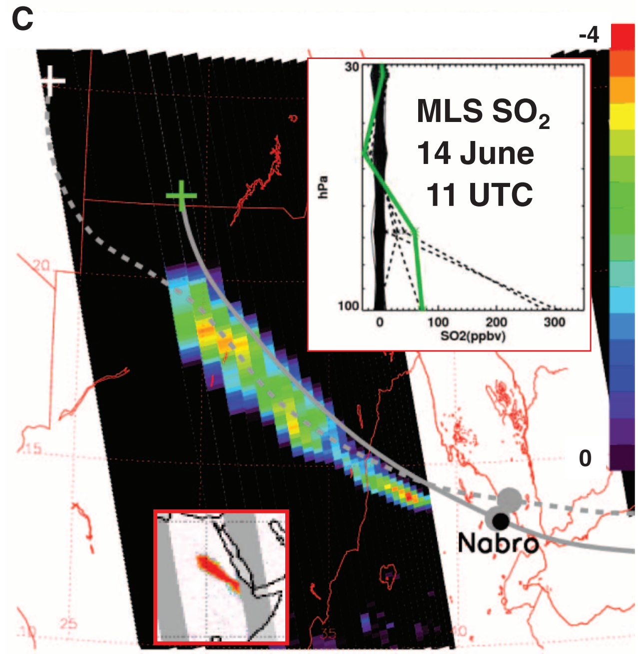

Fig. 1. (**A**) MODIS 11 μm BT, 22:15 UTC 12 June 2011. Nabro is marked by the black triangle. The color bar applies to (A) and the inset of (B). (**B**) MODIS level 2 CTP. (Inset) MODIS 11 μm BT, 10:45 UTC 13 June 2011. (**C**) OMI AI, scaled from 0 to minimum value, 13 June 2011. (Inset below plume) OMI SO_2 (*8*). (Inset right) MLS SO_2 profiles for 14 June between 20° and 30°N. Dashed profiles have stratospheric enhancements at 68 and 100 hPa. Back trajectory from the green profile, launched at 88 hPa, terminating at 00 UTC 13 June. The gray dot is the closest pass to Nabro, at 7 UTC 13 June. The gray dashed line is the back trajectory from the Cloud Aerosol Lidar and Infrared Pathfinder Satellite Observation satellite (CALIPSO) 18.5 km layer on 16 June ["small" layer reported by (*2*); location is white + sign]. The gray dot shows the closest Nabro pass, at 18 UTC 13 June.

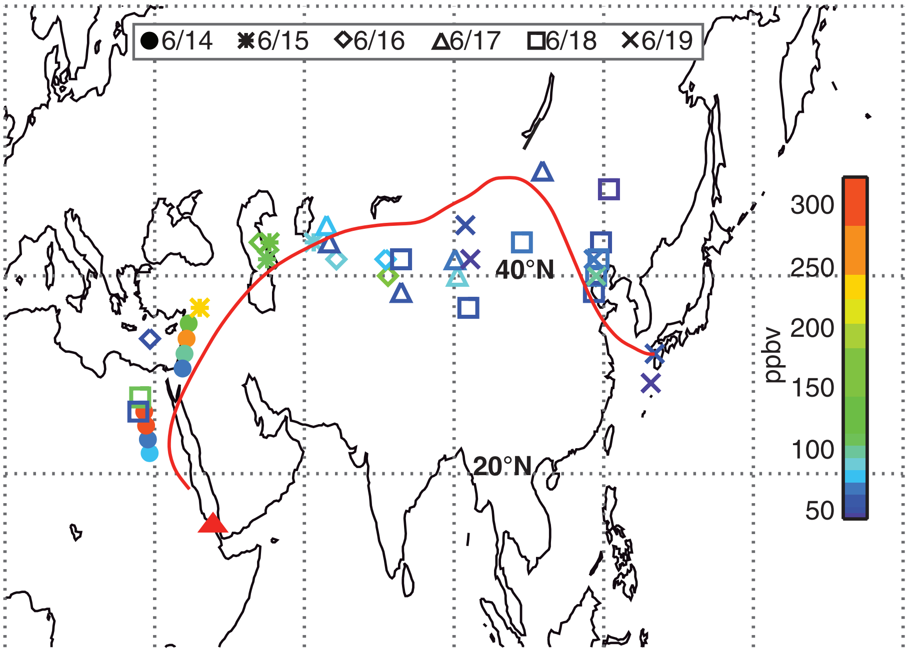

Fig. 2. Locations of MLS SO_2 stratospheric enhancements, 14 to 19 June 2011. Isentropic back trajectory (red line) from 19 June observation over Japan, launched at 16.5 km (390 K), to 13 June. Much of the parcel path, and MLS stratospheric enhancements, are north of 40°N; i.e., in mid-latitude extratropics.

meter (MODIS) (Fig. 1A) shows the deep convective umbrella cloud, with locally cold BT in a peripheral arc and warmer BT near the cloud-top center. This is a signature of violent convection; warm-core BT in volcanic plumes has been associated with overshooting into the warmer lower stratosphere (*3*).

The cold, high, opaque volcanic cloud was considerably larger by mid-day 13 June. NASA's A-Train constellation of quasisimultaneous nadir and limb viewing measurements (*4*) includes several instruments we use to characterize the 13 June Nabro plume, roughly 14 hours after onset. Two IR-based methods indicate opaque, tropopause-level cloud. MODIS cloud-top pressure (CTP) (Fig. 1B), retrieved with the CO_2-slicing technique (*5*), is very low in the expansive Nabro plume, as low as 95 hPa. The minimum IR BT of this cloud is –78°C. This implies an opaque cloud as high as 16 km (120 hPa), considering the environmental temperature profile. Figure 1C shows the aerosol index (AI) from the Ozone Monitoring Instrument (OMI). Negative AI values indicate scattering aerosols such as liquid sulfate droplets (*6*). The scattering aerosol index corroborated independently sensed stratospheric sulfate particle observations in the Hekla (Iceland) eruption plume of February 2000 (*7*). The footprint of negative AI is similar to the OMI SO_2 feature on 13 June (Fig. 1C, inset) and the MODIS high cloud. Ultraviolet backscatter sensors such as OMI cannot "see through" optically thick cloud (*6*). Hence, the signal of scattering aerosols (and SO_2) is originating from above the high cloud top. The opaque cloud surface also guarantees that no information from the troposphere below is obtainable.

One day later, the Microwave Limb Sounder (MLS) (*4*) retrieved height-resolved SO_2 (Fig. 1C, inset). Five contiguous profiles exhibited strong stratospheric SO_2 enhancements, up to ~19 km. A backward trajectory launched in this plume follows a path to the volcano, intersecting at ~07 UTC 13 June while the eruption was ongoing. A second trajectory, launched from the 16 June aerosol layer at 18.5 km pointed out by Bourassa *et al.* in figure S2 also goes back to the volcano on 13 June. Hence, these aerosol and SO_2 profile data corroborate the high injection heights suggested by the combined OMI/MODIS imagery on 13 June.

Figure 2 shows the MLS 100 hPa SO_2 mixing ratio for stratospheric enhancements from 14 to 19 June. We define a stratospheric enhancement as any point where 100 hPa SO_2 > 40 parts per billion by volume (ppbv) and either the potential temperature at 100 hPa >380 K or SO_2 at 68 hPa >10 ppbv. This stratospheric SO_2 plume, of which there is no evidence before 13 June, moves from the Mideast and Africa on 14 June through mid-latitude Asia to the Pacific Ocean, never encountering the Asian monsoon. This progression is consistent with the prevailing winds, as shown by the back trajectory launched from a 19 June MLS SO_2 observation. Back trajectories from this point at lower altitudes do not trace back to Nabro.

Bourassa *et al.* claim that a tropospheric injection on 13 June 2011 was responsible for the eventual stratospheric aerosol abundance that surpassed all previous eruptions since Mount Pinatubo. They presented no height-resolved data from 13 June that showed a strong tropospheric abundance of sulfates or precursors in the plume. Here, we provided direct evidence of the 13 June plume's horizontal footprint and constrained its altitude effectively above the tropopause. The plume height was corroborated by height-resolved measurements of SO_2 and aerosol 1 to 3 days later. MODIS IR imagery 2 hours after eruption onset manifests a signature of explosive volcanic convection breaching the tropopause. These data show that the 12 to 13 June eruption of Nabro was above the tropopause and directly deposited volcanic gas and particles into the lowermost stratosphere and that the Asian monsoon was not responsible for their transport into the stratosphere.

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