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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) have suggested that deep convection associated with the Asian monsoon played a critical role in transporting sulfur dioxide associated with the Nabro volcanic eruption (13 June 2011) from the upper troposphere (9 to 14 kilometers) into the lower stratosphere. An analysis of the CALIPSO lidar data indicates, however, that the main part of the Nabro volcanic plume was injected directly into the lower stratosphere during the initial eruption well before reaching the Asian monsoon deep convective region.

On 13 June 2011, the Nabro volcano (Eritrea, East Africa) injected large amounts of sulfurous material into the atmosphere (*1*). Due to its location and the prevailing circulation in East Africa and Asia, the plume was subsequently transported by the Asian anticyclone (*2*). More than 2 weeks after the eruption, on 1 July, the Cloud Aerosol Lidar and Infrared Pathfinder Satellite Observation satellite (CALIPSO) lidar detected an enhancement in aerosol backscatter in the lower stratosphere (~18 km) above the Asian monsoon [figure S3 in (*2*)]. Based on reports of an initial plume height between 9.1 and 13.7 km (*3*) and a single CALIPSO browse image 3 days after the eruption showing a plume near 9 to 12 km, Bourassa *et al.* (*2*) concluded that the main volcanic SO_2 plume was injected into the upper troposphere. They have then used Optical Spectrograph and Infra-Red Imaging System (OSIRIS) observations, available only above the tropopause, to indicate that the plume could have been lofted into the lower stratosphere by convection associated with the Asian monsoon.

The initial altitude range of the ash cloud reported by the Smithsonian Institution (9.1 to 13.7 km) (*3*) corresponds simply to the broad cruise-level range 30,000 to 45,000 feet for commercial aircraft at which the plume was reported by the Toulouse Volcanic Ash Advisory Center (VAAC). Those reports are based mainly on pilot observations and infrared imagery for air traffic corridors below 13 km. Bourassa *et al.* used data from a CALIPSO overpass on 16 June 2011 to identify a volcanic plume below 13 km. They note only in passing, and without explanation, a "stratospheric feature" at 18 to 19 km in the same transect [figure S2c in (*2*)]. Here, we present a more complete analysis of CALIPSO observations that shows that the volcanic plume was injected directly into the lower stratosphere and that, consequently, convection in the Asian monsoon was not required for the plume to reach stratospheric levels.

Two days after the eruption, the CALIPSO lidar crossed the main part of the volcanic SO_2 cloud. Figure 1A shows a map of SO_2 index from brightness temperature (BT) differences assembled from nighttime hyperspectral AIRS (Atmospheric InfraRed Sounder)/Aqua data on 15 June 2011. Tails of BT difference less than –7 K (*4*) extending from eastern Africa to the Middle East and turning east toward central Asia show an enhancement of SO_2 originating from the Nabro volcano (orange triangle). Figure 1, B and C, shows profiles of scattering ratio (SR) and volume depolarization ratio (VDR) at 532 nm from the CALIPSO lidar for an orbit crossing the SO_2

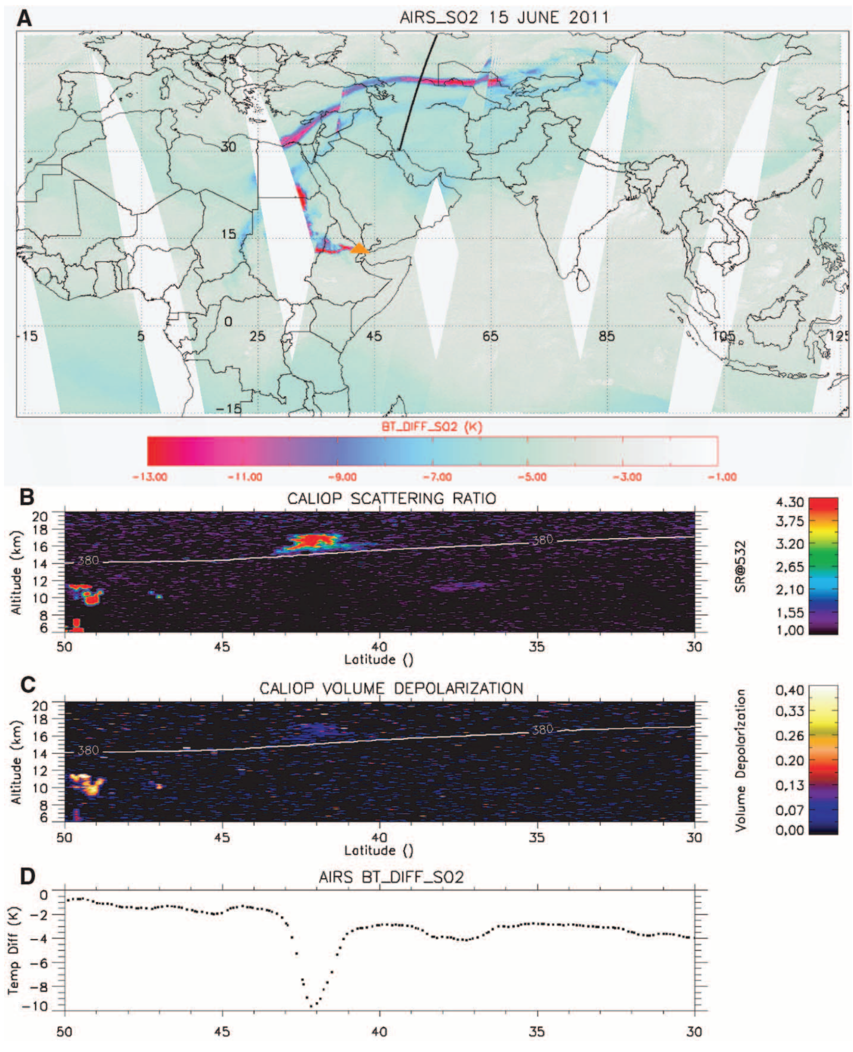

Fig. 1. (**A**) Map of SO_2 index based on BT differences assembled from AIRS/Aqua observations on 15 June 2011, 2 days after the Nabro eruption in Eritrea (orange triangle). The black line is the CALIPSO-collocated nighttime orbit track on 15 June 2011 at 22 h 39 min UTC that have crossed the volcanic SO_2 cloud (magenta). The corresponding CALIPSO lidar level-1 SR at 532 nm (**B**) and VDR (**C**) profiles along the same orbit are shown. The BT differences extracted along the lidar track from AIRS/Aqua is also displayed (**D**). Negative BTs between 41° and 43°N indicate the presence of a large amount of SO_2 collocated with a low depolarizing cloud near 15 to 17 km, consistent with the signature of sulfuric acid droplets and ash from the Nabro volcanic cloud. The volcanic cloud is in the lower stratosphere above the 380 K isentropic level, which characterizes the tropopause.

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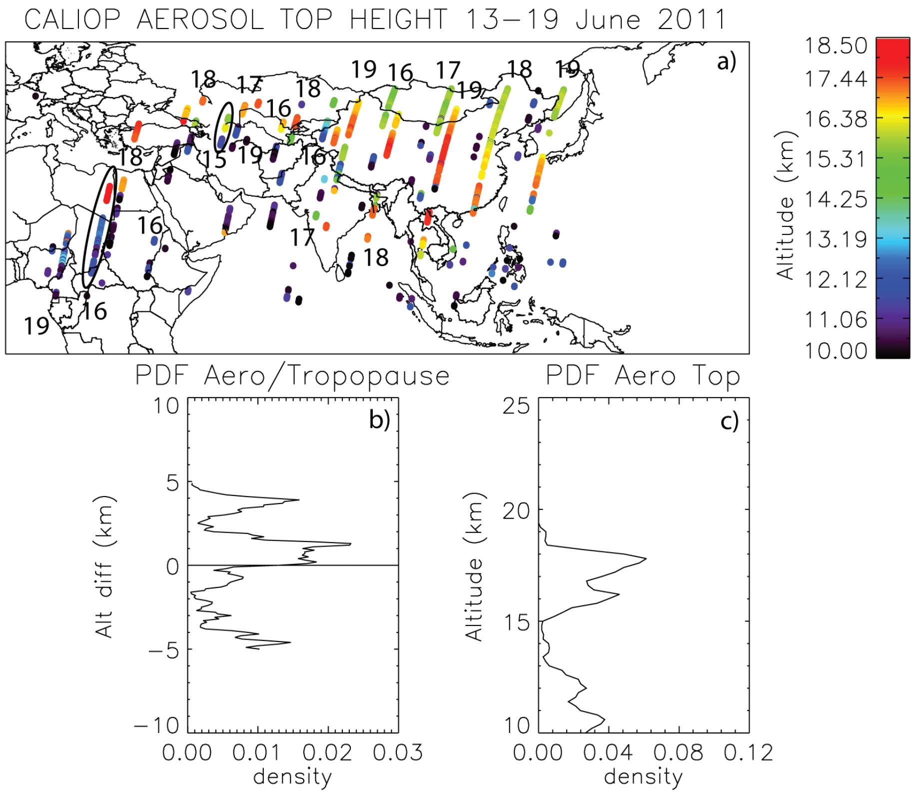

Fig. 2. (**A**) Map of top height of the highest aerosol layer detected in the CALIPSO lidar level-2 5 km aerosol data during the first 7 days after the Nabro volcanic eruption between 13 and 20 June 2011. Probability density function of absolute (**B**) and relative-to-tropopause (**C**) aerosol top height within this area. The tropopause altitude was taken from version 5 of the Goddard Earth Observing System Model meteorological analysis. Encircled in black is the piece of volcanic plume displayed in Fig. 1. Encircled in red is the plume described in figure S2 of Bourassa *et al*.

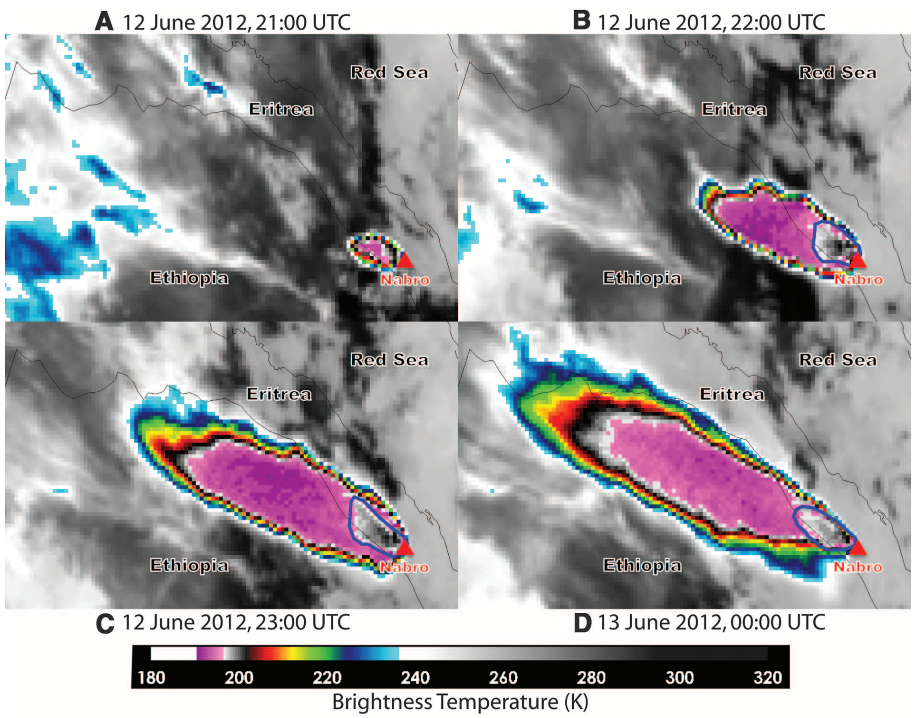

Fig. 3. Snapshots of cloud-top infrared brightness temperature (BT) from SEVIRI/Meteosat-9 on 12 June 2011 at 21:00 (**A**), 22:00 (**B**), and 23:00 (**C**) and 13 June at 00:00 UTC (**D**) around the Nabro volcano (see black box in Fig. 2). Area of enhanced BT (~203 K, encircled in blue) surrounded by very cool cloud top (~192 K) is the signature of stratospheric intrusion (*8*) by the Nabro volcanic plume.

cloud; extracted SO_2 BT differences from AIRS within 25 km along the CALIPSO track are shown in Fig. 1D. The layer depicted near 15 to 17 km, between 42° and 43.5°N in Fig. 1, B and C, is associated with a minimum of BT differences lower than –7 K, consistent with its volcanic origin. The CALIPSO data, combined with the SO_2 map, indicate that the Nabro volcanic cloud is in the lower stratosphere (between 15 and 17 km) and above the 380 K isentropic surface, which characterizes the tropopause. Given the low VDR, compared with pure volcanic ash [0.36 (*5*)], it is very likely that the plume is a mixture of ash and recently formed sulfuric acid droplets.

CALIPSO observed the volcanic cloud at these altitudes several times during the first week after the eruption. Figure 2A shows a map of aerosol top height constructed from the CALIPSO nighttime level-2 aerosol layer product (*6*) for 13 to 19 June 2011, together with a probability density function of the absolute (Fig. 2B) and relative-to-tropopause (Fig. 2C) aerosol top height. The map shows the main part of the volcanic plume extending from the eastern Mediterranean to eastern China at altitudes of 15 to 19 km in the northern part of the Asian anticyclone above the tropopause. The main plume was clearly not yet affected by deep convective activity that characterizes the southeast part of the Asian anticyclone (*7*).

Finally, Fig. 3 shows an analysis of Spinning Enhanced Visible and Infrared Imager (SEVIRI)/Meteosat-9 imagery near the Nabro volcano during the first few hours after the eruption on 12–13 June 2011. The maps of cloud-top brightness temperatures (BT) show a cloud umbrella of extremely low BT (192 K) spreading northwest from the volcano. Enhanced BT near the volcano (~203 K) surrounded by those very cold clouds indicates a signature of stratospheric intrusion by the volcanic plume during the initial eruption (*8*). The nearest temperature profile from a sounding at Abha (Saudi Arabia) (*9*) shows that a temperature of 203 K corresponds to an altitude near 19.5 km, 1.5 km above the local cold-point tropopause. Thus, BT imagery provides other evidence that the initial eruption of Nabro injected materials directly into the lower stratosphere.

To conclude, observations from CALIPSO and other data sources show the volcanic plume from Nabro already in the low stratosphere well before any encounter with deep convection associated with the Asian monsoon. Thus, the conclusions of Bourassa *et al*., connecting transport of the Nabro plume to the stratosphere with convective lofting in the Asian monsoon, are incorrect. Although convective transport may well loft volcanic SO_2 into the lower stratosphere, Bourassa *et al.* cannot be used as evidence for this process.

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