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Did the Nabro volcanic eruption directly overshoot the tropopause?

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During the night of 12 to 13 June 2011 an explosive eruption occurred at the Nabro volcano located in Eritrea (13.4°N, 41.7°E). This has been recognized as the largest volcanic eruption since Pinatubo 1991, ejecting ash and sulfur dioxide (SO_2) into the atmosphere, spreading over more than 60 degrees in latitude and more than 100 degrees in longitude within a few days and lasting for more than 15 days. While there is agreement on the fact that the eruptive mass reached the stratosphere, the processes bringing the cloud to the lower stratosphere are still much debated. For solving this issue we used about 300 atmospheric profiles from Global Positioning System (GPS) Radio Occultation (RO) observations and analyzed the pre-eruption conditions and the impact of the eruption itself on the tropospheric and stratospheric thermal structure.
The GPS RO technique enables measurements of the atmospheric parameters in nearly any meteorological condition, with global coverage, high vertical resolution and high accuracy, making RO data well suited to study the thermodynamic structure of volcanic clouds and their impact on climate.
In the Nabro area there are no ground based measurements that can be used for such kind of studies and, in the period of the eruption, there are no acquisitions by the Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO) satellite.
By analyzing the RO bending angle anomaly in the volcanic cloud area, we evaluated the cloud top altitude and compared it to the tropopause altitude (also derived from RO) in the same area. Moreover, we analyzed the RO temperature profiles before and after the eruption.
Our results show that the volcanic cloud directly overshoot the tropopause and that the injected SO_2 warmed the lower stratosphere in an area of about 10x10 degrees in latitude and longitude for 6 months, which is consistent with the effect found on a larger scale for the Pinatubo eruption in 1991.
This study shows the capabilities of GPS RO data for improving the detection and monitoring of volcanic clouds. The global coverage allows monitoring any volcano of the Earth and determining the tropopause altitude with high accuracy at any latitude. The independence from weather conditions and the high vertical resolution help to understand whether the eruptions overshoot into the stratosphere and contribute to short-term climate variability.