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GNSS Radio Occultations for monitoring volcanic ash clouds

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Volcanic explosive eruptions affect economic, political and cultural activities. Major explosive eruptions, such as Mount Pinatubo in 1991, can also impact the Earth's climate. They inject huge amounts of gas, aerosol and ash into the upper troposphere and lower stratosphere (UTLS) causing increased reflection of solar radiation back to space and cooling the Earth's troposphere.
Measurements of atmospheric parameters, such as temperature and density, with high vertical resolution and accuracy are difficult during volcanic eruptions. Ongoing satellite missions do not provide suitable space-time coverage with adequate horizontal and vertical resolution and sensitivity. In-situ measurements are sparse and the acquisitions at UTLS altitudes are difficult and often not reliable. According to the statement of the International Union of Geodesy and Geophysics on "Volcanological and Meteorological Support for Volcanic Ash Monitoring", about 50% of the world's volcanoes that currently threaten air operations do not have any sort of ground based monitoring. Key parameters are the total erupted mass (total volume and maximum height of plume) and the cloud ash extent. The atmospheric height reached by a plume is fundamentally related to the flux of material ejected at the vent. The determination of the top height of the ash cloud and the monitoring of cloud movement and extent is important for characterizing the eruptive processes and for understanding the impact on climate due to the radiative interaction between the clouds, surface and atmosphere.
The Global Positioning System (GPS) Radio Occultation (RO) technique enables measurements of the atmospheric density structure in any meteorological condition, during day and night, with global coverage, high vertical resolution and high accuracy. Several ongoing RO missions provide a high density of vertical profiles with a good time and space coverage. With more than 10 years of GNSS RO availability, these acquisitions became important also for climatological studies thanks to the RO long-term stability and self-calibrated nature. RO data from different satellites can be combined to one consistent record with low structural uncertainty. All these reasons make RO well suited to study the structure of volcanic ash clouds and their impact on climate.
We investigated the Nabro eruption in June 2011 and monitored the ash cloud using GPS RO data. As reference for detecting the ash cloud we used sulfur dioxide data from the Ozone Monitoring Instrument (OMI). We found 250 co-located RO profiles and analyzed the vertical bending angle, density, and temperature structure. Results show that RO bending angle anomalies allow for detecting the volcanic ash cloud with good accuracy. RO temperature profiles give further detailed insight into the cloud's thermal structure. We also compared the cloud top altitude with the mean tropopause altitude in the areas of the volcanic plume to study its extension into the stratosphere. The results are very promising, showing significant capabilities of the RO technique for a potential future operational use for monitoring volcanic ash clouds.