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Digital elevation models of volcanic plumes

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The routine retrieval of both height and velocity of volcanic clouds is a key issue in volcanology. The injection altitude is a crucial parameter that controls the ash/gas dispersion in the atmosphere and their impact and lifetime around the globe. Plume height information is critical for ash dispersion modelling and air traffic security. Moreover, the understanding of the volcanic system itself greatly relies on the knowledge of the volcanic cloud height, as ash/gas emission rates are related to the state of pressurization of the magmatic chamber. (e.g. Hreinsdottir et al., 2014). The height reached by a volcanic eruption column, together with the atmospheric wind regime, controls the dispersal of tephra. Column height is itself a function of vent radius, gas exit velocity, gas content of eruption products, and efficiency of conversion of thermal energy contained in juvenile material to potential and kinetic energy during the entrainment of atmospheric air (Wilson et al., 1978). Conventional photogrammetric restitution based on satellite imagery using MISR has been proposed to precisely retrieving volcanic clouds heights by removing the the plume own velocity that induces an apparent parallax. Recent approaches, based on photogrammetric analysis of image pairs, use the observation of parallax shifts (apparent movement in the projection plane). Photogrammetric methods can have a substantial advantage over other techniques for measuring cloud top heights due to requiring fewer metadata and assumptions about atmospheric conditions Merucci et al. (2016). However, clouds can move very rapidly (e.g. >50 ms) and so, if images are not acquired simultaneously, additional estimates of cloud motion are also required (de Michele et al., 2016; Nelson et al., 2013; Urai, 2004). The Multi-angle Imaging Spectro Radiometer (MISR) has been utilized to retrieve volcanic clouds top height, optical depth, type, and shape of the finest particles for several eruptions (e. g. Flower and Kahn, 2017).

When the along-track disparity includes contributions from parallax due to height and from real displacement due to along-track wind, the wind-corrected plume height can still be retrieved by inputting the wind direction, which is easily recognizable on a volcanic cloud. These pioneering methods apply to one particular instrument at medium resolution (275m for MISR). de Michele et al. (2016) pushes this methods forward by generalizing a complementary solution that virtually applies to all high

resolution satellites that present a lag between two spectral bands (figure 1).

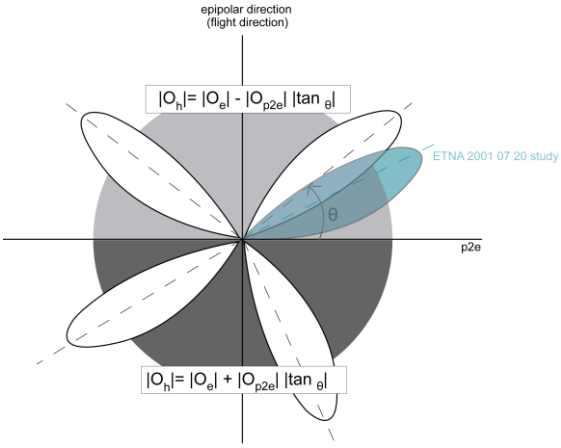

Figure 1. Geometrical considerations and formulas. O_h = pixel offsets due to height ; O_e = epipolar offset ; O_{p2e} = perpendicular-to-epipolar offset; θ = angle between the plume and the satellite azimuth direction.

Their method practically multiplies the number of possible repeat-time measurements, opening the door to infra daily, high resolution, volcanic cloud height monitoring from space. In this study, we apply the method developed for Landsat-8 in de Michele et al. (2016) to the CNES SPOT1-5 family on the Etna 2001-2002 flank eruptions (figure 2). Given the high resolution of the input images (from 5 to 10 meters), we practically extract Digital Elevation Models of volcanic plumes or Plume Elevation Models (PEMs, figure3). By using this SPOT legacy, we demonstrate the joint use of multiple satellite platforms to extract PEMs up to twice a day. This study is a hint for current available missions such as the Copernicus Sentinel 2.

Figure 2. SPOT image of Mt. Etna flank eruption, 20 July 2001.

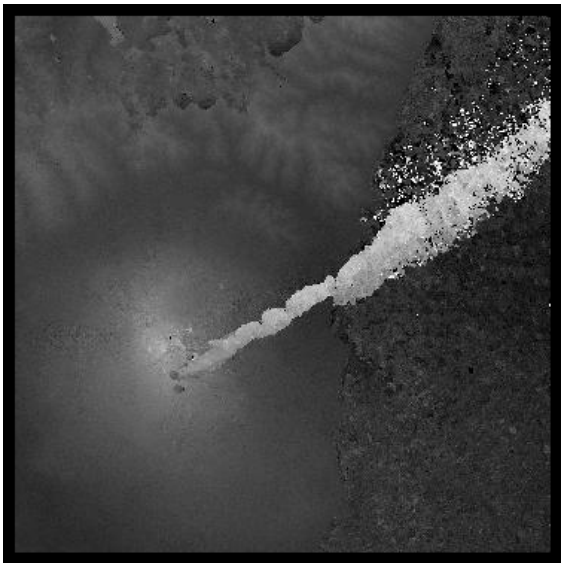

Figure 3. Plume Elevation Model of the Mt. Etna flank eruption, 20 July 2001. The grey scale indicate the height. It goes from zero (black) to 6 km (white).

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