Relaying volcanic plume measurements in real time by using a balloon-borne multi-gas and particles sensors system

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Volcanic emissions are composed of particles (ash, water droplets, sulphates) and gases (mainly H_2O, CO_2, SO_2, HCl and H_2S). Their presence in the atmosphere can produce serious implications on environment, climate, life on Earth, human society and aviation [Delmelle et al., 2002; Robock 2000; Casadevall, 1994]. The detection and retrievals of volcanic emissions is generally carried out by using satellite and ground based remote sensing systems that have advantages and drawbacks. The satellite systems are characterised by high density, large spatial coverage and are irreplaceable for volcanic monitoring on a global scale, while ground-based systems, offer real-time, continuous, high spatial and temporal coverage.

However, the composition of volcanic clouds is critical to assess due to physical limitations of the instruments' sensitivity, uncertainties of particles optical properties, particles size distribution (PSD) and uncertainties on altitude and thickness. Moreover, the presence of high concentration of some gases in the atmosphere (e.g. CO_2) makes challenging their estimation inside the volcanic cloud. Because of that, direct in-situ measurements into the volcanic cloud are required in order to make an accurate characterization of a volcanic cloud.

Considering that drones could be contaminated and damaged by ash particles and their measurements can be affected by the propellers, a less invasive and less expensive balloon-borne system equipped with a custom multi-gas and Optical Particle Counter (OPC) sensor package (named "Volcanosonde") have been developed in the framework of the VOLANDO (VOlcanic pLume chAracterization using sounNDing balloOns) project funded by European Union - Next Generation EU, Missione 4 Componente 1 CUP 1207.10.00. The volcanosonde is composed of a set of gas sensors (CO_2, SO_2, H_2S and HCl), an OPC (concentration and size distribution), and sensors of atmospheric parameters such as pressure, relative humidity and temperature, all integrated on a circuit board. The data packets are acquired with a frequency of 1 Hz, transmitted to a ground station for real-time visualization and stored onto an onboard memory.

In this work the preliminary results obtained from a field campaign carried out on Etna volcano in August 2024 and June 2025 will be presented. During the campaigns a thetered balloon configuration was adopted. From an altitude of 3100 m asl, with a 400 m cable, three volcanosondes, spaced by 50 m each, have been lifted from the balloon inside the Etna volcanic plume to provide time series of the different species at different altitudes.

The results obtained indicate high presence of water vapour, high correlation between CO_2, SO_2, HCl and particles concentration, high values of the CO_2/SO_2 ratio and a bimodal PSD with peaks centered around 0.4 and 1.5 μm.

The tests realized during the field campaigns indicate the feasibility of the thetered balloon configuration for the direct measurements of gas and particles in the volcanic plume. This configuration will provide a comprehensive view of the internal structure and composition of a volcanic plume, helping to validate remote sensing retrievals, contribute to understanding volcanic processes, improve dispersion models as well as mitigating risks to local populations and airspace.

References

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