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Detection and estimation of volcanic eruption onset and mass flow rate using weather radar and infrasonic array

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The explosive eruption of sub-glacial Eyjafjallajökull volcano in 2010 was of modest size, but ash was widely dispersed over Iceland and Europe. The Eyjafjallajökull pulsating explosive activity started on April 14 and ended on May 22. The combination of a prolonged and sustained ejection of volcanic ash and persistent northwesterly winds resulted in dispersal the volcanic cloud over a large part of Europe.

Tephra dispersal from an explosive eruption is a function of multiple factors, including magma mass flow rate (MFR), degree of magma fragmentation, vent geometry, plume height, particle size distribution (PSD) and wind velocity. One of the most important geophysical parameters, derivable from the analysis of tephra deposits, is the erupted mass, which is essential for the source characterization and assessment of the associated hazards. MFR can then be derived by dividing the erupted mass by the eruption duration (if known) or based on empirical and analytical relations with plume height.

Microwave weather radars at C and X band can provide plume height, ash concentration and loading, and, to some extent, PSD and MFR. Radar technology is well established and can nowadays provide fast three-dimensional (3D) scanning antennas together with Doppler and dual polarization capabilities. However, some factors can limit the detection and the accuracy of the radar products aforementioned. For example, the sensitivity of microwave radar measurements depends on the distance between the radar antenna and the target, the transmitter central wavelength, receiver minimum detachable power and the resolution volume. In addition, radar measurements are sensitive to particle sizes larger than few tens of microns thus limiting the radar-based quantitative estimates to the larger portion of the PSD.

Volcanic activity produces infrasonic waves (i.e. acoustic waves below 20 Hz), which can propagate in the atmosphere useful for the remote monitoring of volcanic activity. Infrasound associated with explosive eruptions is generally produced by the rapid expansion of the gas–particle mixture within the conduit and, in consequence, it is related to the dynamics of the volume outflow and thus to the intensity of the eruption. Infrasound is closely linked to the magma fragmentation process.

By combining data from ground surveys and remote sensing measurements, it is possible to gain more insights into tephra detection and distribution. Microwave scanning radars can be exploited to extract tephra spatial-temporal distribution in proximity of the volcano vent. Radar detection of ash clouds is a cumbersome problem, as their signature can be confused with that of hydrometeors. On the other hand, infrasonic arrays can provide a very accurate signal about the onset of a volcanic fountain, even though not necessarily discriminating between lava and ash eruptions.

In this work we illustrate the methodology to combine microwave radar data with infrasonic measurements using, as a case study, the eruption of 2010 Eyjafjallajökull. The probabilistic detection module of the Volcanic Ash Radar Retrieval (VARR) physically-based technique is illustrated. The ash detection methodology is based on the temporal analysis of radar volumes of reflectivity and geographical information for the considered specific area. The infrasonic array signal is coupled with radar data to enhance the VARR probability of ash detection. Moreover, mass flow rates estimated from radar measurements are compared with those retrieved from infrasonic arrays and derived from simplified analytical eruption models.