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Ultraviolet Polarised light for Detection of volcanic ASH – UP-DASH

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Instructions

- Please limit the report to max 3-5 pages, including tables and figures.
- The report should be sent as pdf document and include the subheadings listed below. Please make sure to address any comments made by the reviewers (if applicable, you were informed in this case beforehand).
- The report will be made available on the ENVRIplus website. Should any information be confidential or not be made public, please inform us accordingly (in this case it will only be accessible by the EC, ENVRIplus project partners, and the reviewers).

- **Introduction and motivation**

Volcanic ash is emitted from active volcanoes when fragmentation occurs during magma ascent. The processes which produce fragmentation are complex and non-linear, and rapid variations in ash emission rate are often qualitatively observed. Detection and quantification of ash emissions would open the possibility of new insights into the processes which initiate and inhibit fragmentation, through integration of multiparametric datasets. This would allow improved numerical modelling of the magma ascent process and improved risk mitigation, as the ash emissions directly impact local populations due to ash fall on roads and roofs, and closure of airspace to air traffic.

Current methods of ash detection require expensive, bulky equipment such as LIDARs. Here, we propose using the depolarizing behaviour of volcanic ash to allow discrimination from liquid aerosols. Mt. Etna offers the ideal location to perform this research, as Etna regularly produces ash emissions which affect local populations and air space, and is probably the most well-monitored volcano in the world, allowing the critical integration of our new ash data with multiparametric data required to decipher the processes controlling ash production.

We would focus on ultraviolet wavelengths, as these are both strongly scattered and extensively monitored on Etna using the FLAME network of scanning UV spectrometers and UV cameras, used to measure SO2 flux from Etna. We would also perform developmental work on nearby Stromboli, which is also monitored with a FLAME network and extensive geophysical instrument networks by the Etna observatory.

Our research spans the domains of solid earth and atmosphere, applying atmospheric remote sensing techniques to volcanic threats. It also strongly resonates with Theme One of the ENVRIplus mission of technical innovation, specifically the development of new sensor technologies. Our work would strongly support INGV Etna observatory in its collaboration with Catania International Airport to mitigate the risk to aircraft from volcanic ash produced by Etna.

- **Scientific objectives**

Atmospheric molecular scattering of solar radiation polarises light, with maximum polarisation found when viewing the sky at 90 degrees from the sun's azimuthal position. Single scattering from spherical liquid aerosols has no effect on polarisation, whilst non-spherical particles will depolarise light. Using two UV

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spectrometers/cameras, with and without a linearly polarising filter, we will quantify depolarisation and identify ash, and then use LIDAR data from Etna to calibrate ash quantification from UV data.

- **Methodology and experimental set-up**

Our first access visit in September 2017 had two main aims – to discuss in depth plans and aims for the project with the project members at INGV, and to perform preliminary fieldwork to assess the use of depolarisation of scattered sunlight from ash as a detection method.
The first part of the trip consisted of a two day stay in Catania working at INGV. During this time meetings were held with Simona Scollo and Tommaso Caltabiano (unfortunately Giuseppe Salerno was away at the time). One primary point of discussion was the use of the LiDAR at INGV Catania as a method of validation of the ground based UV measurements, and it was discussed as to how we would achieve this.
We also spent some time on Etna performing UV camera and spectrometer measurements. We tested the ash depolarisation method using the spectrometers (two UV spectrometers deployed side by side, one with a polarising filter and one without) using ash re-suspended by passing vehicles on the road to the summit of Etna. This removed any other volcanic product (e.g. gas or other aerosols) to focus purely on the ash.
The second part of the visit was spent on Stromboli, where observations of explosions from the volcano were made from a position called "Punta Labronzo", which offers good views of the activity from the volcano. Here the spectrometers were deployed again, and measurements of the depolarisation, denoted ϕ here, from the ash produced in explosions were made. Figure 1 shows an example of the response in depolarisation from one explosion, in which a sharp change in ϕ is seen. The onset of the explosion can be seen by the sharp drop in intensity, which agrees with timings recorded in the field. These results show that the depolarising effect of ash can be measured passively using ground based UV spectrometers. Unfortunately the weather made solar measurements difficult, leading to the variability in the background signal seen, however this shows that a signal can be seen even under poor conditions.
The results from this visit will be presented at the upcoming EGU meeting in Vienna, where the ideas, results and implications will be shown:

In July 2018 a futher visit was carried out and the primary aim of this visit was to run AshCam beside an SO2 camera to investigate the effect of ash on SO2 retrievals from ash rich explosions from Stromboli volcano. To do this AshCam and an SO2 camera were deployed at the location "Punto Labronzo".

The main aim of access 3 in October 2018 was to deploy AshCam again besides the SO2 camera to improve the data quality of the results from access 2. To address the issues of access 2 (results limited to a select number of frames due to small explosions and low image acquisition frequency) two changes were planned to how the data were collected. Firstly the cameras were deployed closer to the vents at a view point at an altitude of 400 m instead of 100 m to increase the spatial resolution of the imagery, and secondly the acquisition frequency of the cameras was increased from 0.2 Hz to 2 Hz.

- **Preliminary results and conclusions**

After access 1 a new instrument named AshCam was developed based on the technology of the SO2 camera and using the depolarisation measurements performed during access 1. This camera was successfully deployed on a separate field trip to Santiaguito volcano, Guatemala, during January 2018. The results of this trip are detailed by Esse et al. (2018) (DOI: 10.1038/s41598-018-34110-6) in which the contribution of ENVRIPLUS was acknowledged.

Although weather conditions were favourable for data collection in access 2 (clear blue sky behind the plume) image acquisition was hampered by the position of the sun relative to the viewing direction. This impacted measurements as the intensity of the skylight changed rapidly, requiring frequent changes in integration time to avoid saturating the camera sensors. This was also an issue for AshCam as it uses the polarised skylight as a light source and the degree of polarisation of the skylight decreases as the viewing angle nears the position of the sun. This means that even though several good sized explosions were measured, the ash did not give a strong depolarisation signal. Although this access did not achieve its aims, it did show that the sensitivity of AshCam depends strongly on the position of the sun relative to the viewing direction. This will influence future deployments of AshCam to ensure that the viewing angle is sufficiently far from the position of the sun.

Figure 1 shows the side by side results for the SO2 camera and AshCam for both an ash rich explosion and an ash poor explosion (identified by visible imagery). Unfortunately during the access the activity of the volcano was less intense than during previous visits to Stromboli, with only very small explosions occurring so the signal is small, however during the ash rich explosion it can be seen that the presence of ash identified by AshCam corresponds to an area of negative SO2 measured by the SO2 camera. For the ash poor explosion there is no clear signal from AshCam and no apparent area of clearly negative SO2 read by the SO2 camera.

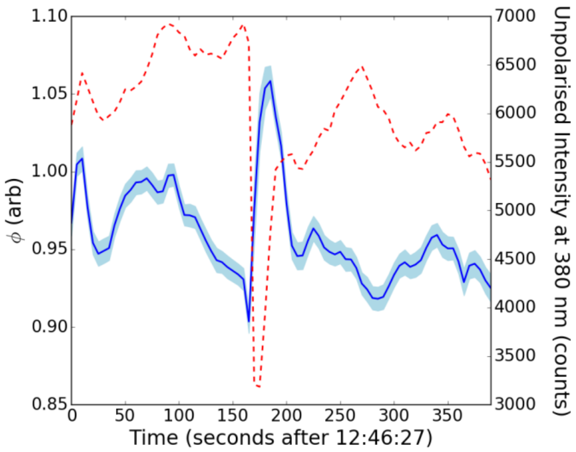

Figure 1 Depolarisation response (labelled ϕ) and intensity change over one explosion from Stromboli. The shaded region denoted the standard deviation in response across the spectrum

During access 2 we successfully deployed AshCam besides an SO2 camera and showed that areads of ash identified by AshCam corresponded to areas of negative SO2read by the SO2 camera, suggesting that AshCam can be used to identify ash contaminated pixels in the SO2 camera that can then be ignored during analysis. However, due to the low level of the activity of Stromboli during the access the collected data is comprised of only a few frames and so more work is required to fully test this. This was the main aim of the third access.

Figure 2

Although weather conditions were favourable for data collection during access 3 (clear blue sky behind the plume) image acquisition was hampered by the position of the sun relative to the viewing direction. This impacted measurements (Figure 2) as the intensity of the skylight changed rapidly, requiring frequent changes in integration time to avoid saturating the camera sensors. This was also an issue for AshCam as it uses the polarised skylight as a light source and the degree of polarisation of the skylight decreases as the viewing angle nears the position of the sun. This means that even though several good sized explosions were measured, the ash did not give a strong depolarisation signal.

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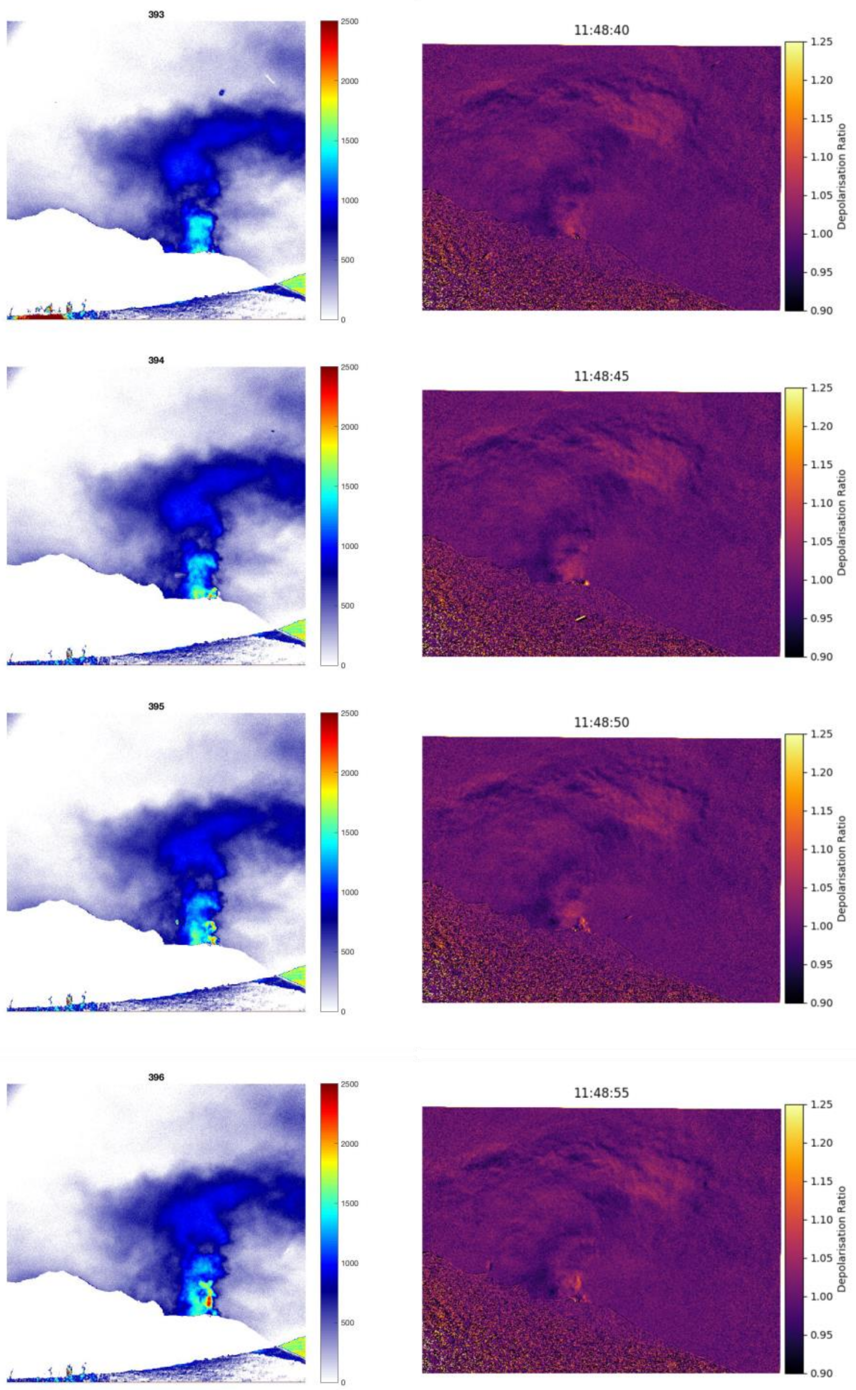

Figure 3: Synchronous images from the SO_2 camera (left column) and AshCam (right column) during an ash rich explosion. The ash signal in the AshCam image corresponds to a negative signal in the SO_2 camera.

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- **Multidisciplinary approach**

The combination of ash texture analysis and depolarisation is a powerful multidisciplinary tool to investigate ash sedimentation processes.

- **Outcome and future studies**

The successful publication in Nature scientific reports highlighted the combination of ash sedimentation velocity quantification which can now allow better constraints for models of ash evolution. This means we will be able to perform future studies to exploit the potential of the techniques developed in UP-DASH

- **References**

Esse, B., Burton, M., Varnam, M., Kazahaya, R., Wallace, P., Von-Aulock, F., Lavallée, Y., Salerno, G., Scollo, S. and Coe, H. (2018). Quantification of ash sedimentation dynamics through depolarisation imaging with AshCam. Scientific Reports, 8 (1).