The University of Oxford Department of Earth Sciences

EARTHSCIENCES

Onset behaviour of volcanic eruption plumes

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Overview

This studentship is jointly funded by the Centre for Observation and Modelling of Earthquakes, Volcanoes and Tectonics (**COMET**) and the British Geological Survey (**BGS**). The project will explore the factors which control the initial height of 'starting' volcanic plumes, and test the hypothesis that the height is related to the initial power of the eruption. The novelty of the work will be the focus on starting plumes, and on plumes from short-lived or unsteady eruptions.

This work is important, because the rates of plume rise, the three-dimensional form of the plume, and the initial plume height are all parameters that can be determined from satellite data; and these physical parameters that are considered to place important controls on the injection height and injection history of volcanic ash and gases into the atmosphere; and thereby on the subsequent evolution and impact of the volcanic umbrella cloud.

Background

The January 2022 eruption of Hunga Tonga – Hunga Ha'apai challenged our understanding of the dynamics of volcanic plumes. The eruption involved multiple events, with the first injecting material to record-breaking heights (~57 km; Carr *et al.* 2022; Proud *et al.* 2022). This raises interesting questions about what caused the column to reach these heights. The scientific literature contains many papers on the equilibrium height of sustained volcanic plumes (e.g. Sparks et al., 1997), much less is known about the initial or transient stages of volcanic plume development; and on plume behaviour during unsteady volcanic eruptions (e.g. Clarke et al., 2002; Chojnicki et al., 2015).

Transient volcanic ash plume from an explosion at Lokon-Empung, Indonesia.

Methodology

Initially the student will review the relevant literature on explosive volcanic eruptions and plume dynamics, to understand the state-of-the-art both of observations of eruptive parameters, and also of the different models that are currently used to simulate volcanic plume dynamics, and their different approaches, assumptions and limitations (e.g. Aubry et al., 2023).

In parallel, the student will make new measurements and gather new observational datasets on rising volcanic plumes from selected recent explosive volcanic eruptions, with a particular focus on satellite data. The most relevant datasets initially will be those acquired by broadband instruments onboard geostationary satellites (e.g., GOES-East, GOES-West, Himawari, MTG) operated in super rapid scan mode. This mode provides observations at up to 1-minute intervals at a spatial resolution of about 2 km. The La Soufriere, St Vincent eruption of 2021 was observed in this mode and enabled the recognition of a minimum of 35 distinct paroxysms in the 14 day eruptive sequence (Taylor et al. 2023).

The infrared channels can be used to estimate plume top height in each frame and so determine volcanic column vertical velocity. Additionally, the plume rise can be studied from side viewing instruments on these geostationary platforms (e.g., Horvath et al. 2022). These satellite observations will be combined with measurements of the sulfur dioxide (SO_2), water vapour and ash emission from the Infrared Atmospheric Sounding Interferometer (IASI) which will help to fully characterise the plumes studied.

The next phase of the work will be to explore the extent to which current plume models are able to adequately simulate the observations, or otherwise. Based on these cross-comparisons, we expect that there will be scope for the student to develop, or extend, a computer model which incorporates the energetics of a volcanic blast, and which can predict the height of an eruption given the volcanic power, atmospheric temperature profile and so on. In due course, the model will include relevant physical processes such as entrainment, droplet condensation and freezing (which release latent heat) as well as atmospheric wave generation (which transports energy away from the volcano). The student will implement time-step models so that the plume is not assumed to be in equilibrium. A sensitivity study will identify the critical parameters needed to describe an event. To develop and validate the model it is anticipated the student will build upon the observational techniques used for 'overshooting tops' – this is where the vertical motion of convective clouds results in a cloud top temperature colder (and so not in equilibrium) than the surrounding atmosphere (Mikus and Mahovic, 2013).

A particular focus will be to see if the model can explain the height reached by the Hunga-Tonga – Hunga Ha'apia explosion, where additional data will come from lightning (Briggs et al. 2022), trace gas (Sellitto et al., 2022) and atmospheric wave measurements (Wright et al., 2022). The model could be tested further by estimating the height of clouds formed from atmospheric nuclear testing (where the power of the explosion is known); and could, of course, be tested against any other new observational datasets that arise during the course of the project.

The supervisory team brings together expertise in Earth Observation, physical volcanology, and modelling of volcanic plumes, from diverse perspectives. This will provide the candidate with a rich and stimulating training environment, and with varied opportunities for developing their project in one or more directions.

Timeline

Year 1: Training, literature review and refining the project proposal. Data gathering, and investigation of existing models.

Years 2 and 3: Data analysis and interpretation. Development of ideas for model development, testing and analysis. Completion of papers; observational and modelling.

Year 4: Integration and testing of new data, and new model outputs.

Training & Skills

We encourage applications from candidates from groups that are underrepresented at the University of Oxford and within the geosciences.

This project would suit a student with a strong maths, physics or computational background, and a keen interest in studying volcanic plumes. Programming experience (such as python/IDL) and experience with Linux is an advantage.

The student will become a skilled user of Earth Observation data related to volcanoes and a proficient user and developer of models of different complexity. The project will contribute towards a better understanding of the hazards and forecasting of volcanic plumes which falls within the remits of both COMET, and the British Geological Survey.

Selected references & Further Reading

T.J. Aubry, S. Engwell et al., (2023). New insights into the relationship between mass eruption rate and volcanic column height based on the IVESPA dataset. Geophysical Research Letters

I.A. Taylor et al., (2023), Satellite measurements of plumes from the 2021 eruption of La Soufrière, St Vincent, Atmospheric Chemistry and Physics, acp-2022-772

Further Information

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