Holistic assessment of the impacts of an enhanced stratospheric aerosol layer

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Background

Volcanic eruptions can inject vast quantities of sulphur dioxide and ash into the upper atmosphere, which cools the Earth's surface by scattering incoming solar radiation back to space. Major tropical eruptions such as Mt Pinatubo in 1991 are particularly effective at forcing climate in this way, with the timescale for decay back to quiescent conditions taking several years (see Figure 1).

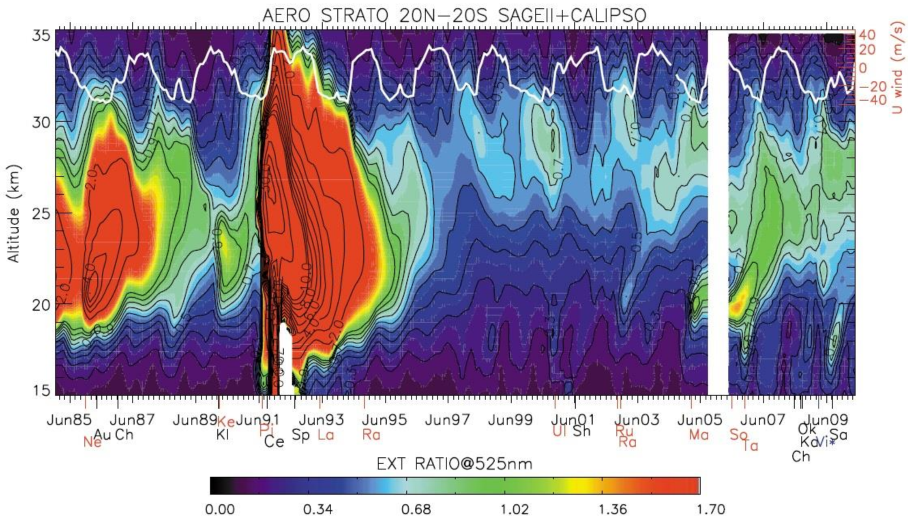

Figure 1: 15-year satellite record of tropical stratospheric aerosol combining vertical profiles measured by SAGE-II and CALIOP instruments (from Vernier et al., 2011).

While increased solar scattering from the optically thick stratospheric aerosol layer is the principal mechanism for volcanic radiative forcing, the large multi-year perturbation also affects climate in many other ways (see Figure 2):

- The volcanically enhanced aerosol can also absorb terrestrial radiation, offsetting some of the cooling from the additional solar scattering. The balance of these long-wave and short-wave radiative effects is closely associated with how large the aerosol particles grow (i.e. their size distribution).
- Volcanic aerosol also accelerate heterogeneous chemistry leading to stratospheric ozone loss via changes in NOy partitioning and chlorine activation (e.g. Solomon, 1999).
- Major tropical eruptions warm the stratosphere, causing circulation changes. The tropical stratosphere heating increases the equator-pole temperature gradient and causes a stronger and colder polar vortex.
- An increase in diffuse radiation was observed after Pinatubo (e.g. Blumenthaler and Ambach, 1994), and likely contributed to the observed pause in CO2 growth rate at that time (Gu et al. 2003), opposing the effects from surface cooling.

Quantifying these volcano-climate interactions, and reducing their uncertainty, also has direct implications for the efficacy and potential environmental risks from hypothesized solar radiation management via stratospheric particle injection.

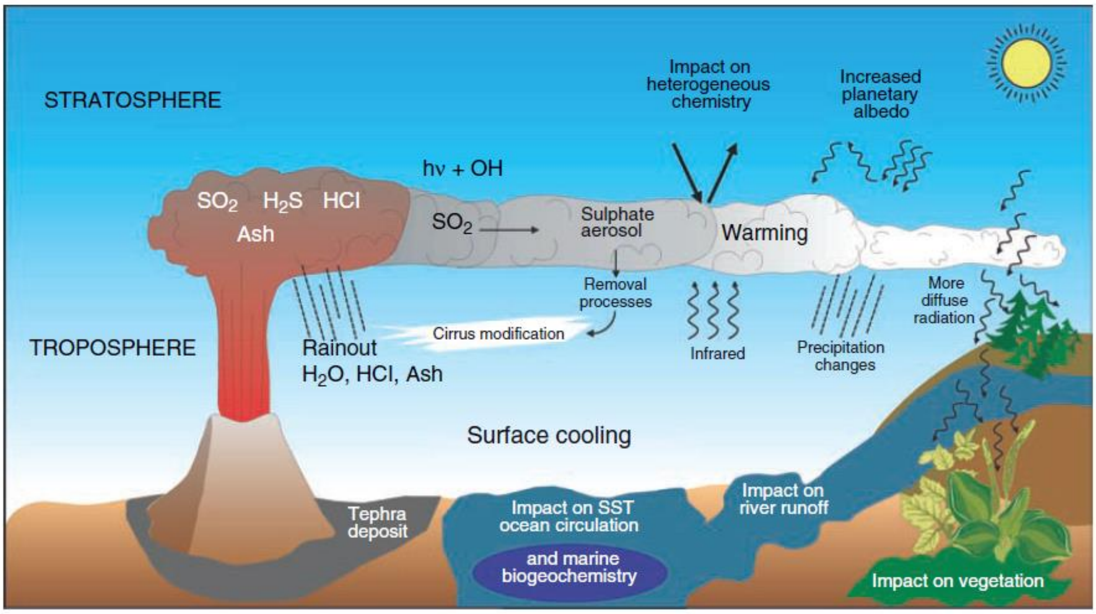

Figure 2: Schematic illustrating the different ways volcanoes influence climate

Project Overview

This project will investigate the impacts of tropical eruptions on stratospheric composition and the magnitude of the associated radiative effects. The research will involve global composition-climate model experiments to quantify the different volcanic aerosol-chemistry and aerosol-radiation interactions described above, and thereby provide an integrated assessment of the effects of volcanic eruptions.

The potential research strands within the PhD studentship are:

1. Volcanic aerosol-chemistry interactions assessing impacts on stratospheric NOy species and subsequent effects on ozone in mid- and high-latitudes.
2. Exploring how the stratospheric warming within major tropical volcanic plumes influences ozone changes via composition-dynamics interactions.
3. Investigating the impacts of major eruptions on the terrestrial carbon cycle through changes in surface diffuse radiation, temperature and precipitation.
4. Predicting the effects from a hypothetical future major eruption in a low chlorine stratosphere, and contrasting with the 1963 Agung eruption

Research at Leeds has adapted the joint NERC-Met Office Earth System Model UKESM to simulate stratospheric aerosol interactively (UKESM-strat). UKESM-strat simulations will be combined with offline analysis to better understand the drivers and sensitivity of these different "volcano-climate indirect effects".

Potential for high impact outcome

Fully understanding the impacts of volcanoes on climate remains an important research area, and accurately charactering their effects is key to attributing anthropogenic influences on historical climate change. Through ongoing collaboration with other scientists in the UK and internationally through the SPARC initiative on stratospheric sulphur, this project can answer important unresolved questions about how volcanoes influence stratospheric composition and climate. The Leeds team are involved with a NASA-initiated activity to co-ordinate international modelling and observational capabilities to prepare for monitoring the effects from a future major volcanic eruption. The research in the project will likely lead to several papers, with the potential for submission to high impact journals.

Training

The student will be supervised by Dr. Graham Mann, Prof. Martyn Chipperfield and Dr. Alex Rap within the ICAS stratospheric aerosol, atmospheric chemistry and physical climate research groups. This project provides a high level of specialist scientific training in: (i) State-of-the-science application and analysis of global atmospheric composition-climate models; (ii) techniques to analyse and compare with satellite measurements of atmospheric composition; (iii) numerical modeling and use of cutting-edge supercomputers. The student will have access to a broad spectrum of training workshops in Leeds including extensive training workshops in numerical modelling and generic skills (http://www.emeskillstraining.leeds.ac.uk/).

UK collaboration and international context

The project is aligned with a range of projects on stratospheric/volcanic aerosol research at Leeds, which include collaborations with the UK Met Office. The research for this project will improve the joint NERC/MO UK Earth System Model, more realistically representing how volcanic eruptions influence simulated stratospheric composition and surface climate. The experiments and research findings also align with the international VolRes initiative which seeks to co-ordinate activity among climate modelling centres, national science agencies and Universities to respond effectively to monitor, and predict the impacts from, future major volcanic eruption.

Key References

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