

18 OCTOBER 2000 : VOLCANOES, AEROSOLS AND CLIMATE

**Alan Robock (Rutgers University, New Jersey, USA) - Volcanic Eruptions and Climate: Winter Warming and Summer Cooling**

Large volcanic eruptions inject sulfur gases into the stratosphere, which convert to sulfate aerosols with an e-folding residence time of about 1 year. Large ash particles fall out much quicker. The radiative and chemical effects of this aerosol cloud produce responses in the climate system. By scattering some solar radiation back to space, the aerosols cool the surface, but by absorbing both solar and terrestrial radiation, the aerosol layer heats the stratosphere. For a tropical eruption, this heating is larger in the tropics than in the high latitudes, producing an enhanced pole-to-equator temperature gradient, especially in winter. During the winter in the Northern Hemisphere following every large tropical eruption of the past century, surface air temperatures over North America, Europe, and East Asia were warmer than normal, while they were colder over Greenland and the Middle East. This pattern and the coincident atmospheric circulation correspond to the positive phase of the Arctic Oscillation. In spite of the decrease in surface solar heating, surface air temperature increases in high and midlatitudes of the Northern Hemisphere in the winter because of changes in tropospheric circulation caused by stratosphere-troposphere dynamical coupling. Using the Max Planck Institute ECHAM4 and the Geophysical Fluid Dynamics Laboratory SKYHI GCMs, we have successfully simulated this response following the 1991 Mount Pinatubo eruption. This result will allow us to produce better seasonal forecasts for the Northern Hemisphere winter following the next large tropical eruption. It also shows that stratospheric forcing of the climate system must be considered along with sea surface temperature anomalies when making seasonal forecasts, especially in mid and high latitudes in the winter.

**Clive Oppenheimer, Marie Edmonds, Hayley Duffell (University of Cambridge), Matt Watson (Michigan Tech.), Lisa Horrocks (Open University), Mike Burton (Sistema Poseidon, Italy) - Remote sensing of tropospheric volcanic gas and aerosol plumes**

Volcanoes emit carbon, hydrogen, sulfur and halogen-bearing gases, and various kinds of aerosol, to the atmosphere both during and between eruptions. Surveillance of plume composition is essential for interpretation of volcanic activity and modelling of environmental impacts of downwind deposition. It also supports assessment of the role of volcanic gases and aerosols in modifying atmospheric chemistry and dynamics. The atmospheric and climatic effects of volcanic emissions depend critically on emission altitudes and magnitudes of SO<sub>2</sub>. Intermittent explosive eruptions can pump > 10<sup>10</sup> kg of S into the upper atmosphere against a background of continuous fumarolic and "open-vent" emission into the troposphere. Thanks to Pinatubo's 1991 eruption, understanding of the atmospheric chemistry and radiative and climatic impacts of volcanic gases and aerosols in the stratosphere is well-developed. In the troposphere, the picture is less clear but recent analyses suggest that 18-40 % of the global tropospheric sulfate burden is volcanogenic. These figures exceed the fraction of the sulfur source to the atmosphere that is volcanogenic (approx. 10 %) because of the generally higher altitudes of

entrainment of volcanic sulfur compared with biogenic and anthropogenic sources. One barrier to study of tropospheric volcanic emissions is the limited information that can be obtained from satellite remote sensing, because of the plumes' smaller magnitude and lower altitude compared with stratospheric emissions. We have focused, therefore, on ground-based remote sensing methods, including sun photometry for retrieval of aerosol properties, and open-path Fourier transform spectroscopy for measurement of gas ratios and emission rates. This presentation will review preliminary results obtained with both techniques at several strongly degassing volcanoes.

**Eleanor J. Highwood (University of Reading), David Stevenson (University of Edinburgh)** - Modelling the effect of the Laki eruption of 1783 on tropospheric chemistry and climate

Volcanic explosions that affect climate for extended periods of time are usually explosive, such as Pinatubo in 1991. However, the effusive eruption of Laki, Iceland, in 1783 has been held responsible for the cold winters of 1783/84 and subsequent years. The eruption released a huge quantity of sulphur dioxide (122 Tg), a large fraction of which was converted into sulphuric acid aerosol, creating a dry fog over much of Europe for several months. The consensus opinion of recent years is that there was not much stratospheric penetration by the volcanically produced aerosol. The climatic impact of such an eruption would be expected to be limited to small temporal and spatial scales. Most of the previous studies relating to this eruption have been based on documentary or ice core evidence. We now use a global tropospheric chemistry model to simulate aerosol formation and transport, together with radiative forcing codes and a climate model (Reading Intermediate General Circulation Model) to explicitly calculate the effect of this volcanic eruption on tropospheric chemistry and climate.

**Lionel Wilson (Lancaster University)** - Some Theoretical Perspectives on Volcano-Climate Interactions

Much has been learned in recent years about the effects of various kinds of volcanic eruption on the atmosphere, and hence the climate, and other contributors at this meeting will discuss specific, documented cases. I shall examine from a theoretical point of view the possible extreme ranges of conditions that could occur during eruptions of various kinds, and then try to relate these to the levels in the atmosphere, and the rates, at which particles, aerosols and gases could be injected. At first sight some of the results may appear rather alarmist, but it must be kept in mind that there has not been what volcanologists would regard as a large volcanic eruption of any kind (lava flow, high eruption cloud or pyroclastic flow) on Earth within the whole of recorded human history. Indeed, we have to look to some of the volcanic deposits preserved on other planets in the Solar System to get some insight into what is possible.

**Jeff Knight (UK Met. Office)** - Stratospheric heterogeneous chemistry - the 1991 Pinatubo eruption

The chemical loss of stratospheric ozone occurs by the catalytic cycling of reactive free radicals, which are themselves the photolysis products of more stable 'reservoir' chemicals. These are formed from the breakdown of source gases such as methane, nitrous oxide and CFCs, and are relatively unreactive in the gas phase. Some of these species, however, react readily on the surface of solid aerosol particles (such as found in Polar Stratospheric Clouds (PSCs)) or in solution in liquid aerosols. The latter scenario occurs in the lower stratospheric aerosol layer, which is mainly composed of droplets of aqueous sulphuric acid. Although the aerosol is very tenuous, as the stratosphere is both very dry and clean, heterogeneous reactions allow aerosols to have an influence on ozone chemistry, especially at low temperature. This influence is greatly increased when an explosive volcanic eruption injects large amounts of sulphur dioxide into the stratosphere, temporarily enhancing the aerosol amount by up to two orders of magnitude or more.

In this study, the effect of enhanced aerosol levels caused by the eruption of Mt. Pinatubo on the Antarctic Ozone hole is studied with seasonal integrations of a mechanistic three-dimensional model with fully coupled dynamics, radiation and chemistry. The model includes a treatment of PSC and aerosol chemistry, and is run with no aerosol as well as background and post-Pinatubo aerosol amounts. For the volcanic case, realistic aerosol amounts are derived from Improved Stratospheric and Mesospheric Sounder (ISAMS) data. The results for the background case show that the inclusion of aerosol chemistry increases the concentrations of active chlorine but decrease amounts of active nitrogen. These effects are enhanced in the volcanic case, especially at the edge of the polar vortex, where temperatures are low enough to cause efficient heterogeneous processing but are too high to allow the formation of PSCs, which incorporate the aerosol droplets as nuclei. Additional ozone depletion of the order of 20 DU results from aerosols, and the size and duration of the ozone hole are increased. The results support previous suggestions that the Mt. Pinatubo eruption caused a temporary increase in ozone depletion over Antarctica and elsewhere.

**Claudia Timmreck (Max-Planck-Institute for Meteorology, Hamburg) - GCM modeling of stratospheric aerosol**

Stratospheric aerosol has various effects on the global climate system. It changes the chemical composition of the stratosphere due to heterogeneous reactions, provides condensation nuclei for the formation of polar stratospheric clouds and cirrus and disturbs the radiative balance of the atmosphere in changing the albedo. These different atmospheric mechanisms are especially strong when the aerosol background layer is perturbed due to strong volcanic eruptions.

Right now, global model studies considering the various interactions between aerosol microphysics, radiation, chemistry and dynamics which are necessary to completely analyze the atmospheric effects of a volcanic eruption and of the stratospheric background aerosol are still missing.

In a first step towards a chemistry microphysics climate model we have successfully included a fully explicit size-resolving aerosol microphysics in the Hamburg climate

model ECHAM4. The fundamental basis of the microphysical model is the explicit description of the essential parameters of the binary H<sub>2</sub>SO<sub>4</sub>/H<sub>2</sub>O system dependent on temperature and partial pressure. The following processes are solved: Homogeneous nucleation, condensation, coagulation, and sedimentation. The microphysical model is therefore capable to describe the formation and the development of stratospheric background aerosol as well the temporal development of a volcanic disturbance. The microphysical model is combined with a tropospheric sulfur cycle which treats the natural and anthropogenic emissions, chemistry, dry and wet deposition of DMS, SO<sub>2</sub> and liquid sulfate aerosol. A multiannual GCM simulation show that the model could reproduce the stratospheric background aerosol quite well.

Furthermore we have investigated the radiative forcing of large volcanic eruptions by using the stratospheric mesospheric version of the Hamburg climate model MAECHAM4. In particular interactive and non-interactive simulations with prognostic volcanic aerosol were performed for the 1991 June eruption of Mt. Pinatubo (15.14° N, 120.35° E) and for the Laacher See eruption (52° N, 7.14° E), which occurred 11,000 ±50 BP, just before the onset of the Younger Dryas. The model results were carefully analyzed with respect to the global transport of the volcanic cloud, the radiative forcing, the lifetime of the disturbance in the stratosphere and temperature effects in the lower tropospher