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Atmospheric Chemistry and Physics Discussions

Interactive comment on "The climatic effects of the direct injection of water vapour into the stratosphere by large volcanic eruptions" *by* M. M. Joshi and G. S. Jones

F. Prata (Referee)

fred.prata@nilu.no

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This is a very interesting and concise paper that discusses the important topic of the effects of volcanic eruptions on climate. The paper is well written and I think somewhat speculative: exactly for these reasons I think it should be published. The authors suggest that water vapour carried high into the stratosphere by volcanic eruptions, could provide a surface warming anomaly that is longer lasting than the well-known surface cooling due to sulphate aerosols, and could off-set that cooling by a few tenths of a degree or so. They suggest that differences in the amount of water vapour carried to the stratosphere in eruptions might explain why models overestimate the cooling due to the Krakatau 1883 eruption, but get the cooling “about right" for the Pinatubo 1991 eruption. The mechanism of extra warming due to stratospheric water vapour is demonstrated by their use of a good climate model and the results seem to support the idea. The paper is brief and the paper is well structured. I think that the idea is interesting but also very speculative. Thus I would encourage the authors to consider my comments below, and either address them in this paper or perhaps in a follow-up paper. Their paper raises interesting issues with regard to volcanic processes (water vapour transport to the stratosphere), climate model sensitivity, the role of stratospheric water vapour in climate (an important topic in its own right) and the surface temperature observational record (see below). I do hope this paper stimulates further work and discussion on this important topic.

The authors might like o consider the following comments:

1. **Water vapor and eruption columns.** There is no doubt that there are copious amounts of water vapour in eruption columns. The water can be entrained from the atmosphere (as vapour) or it could be derived from sea water (or from a caldera lake) during the explosive phase of the eruption. The authors do not actually say where the water vapour comes from in their modelling exercise and simply insert 500 Tg in the column from 0–40 km and spread this over 10°S to 0°N over 10 days. The purpose here is to anticipate the eruption style of Krakatau (8°S and column heights of 25-35 km). There is a discussion about Krakatau later. The problem I see with this is that the evidence for an explosive phreatomagmatic eruption at Krakatau is not that convincing. Self and Rampino (1981) give a detailed account of the chronology of the August 1883 Krakatau event. Their stratigraphic analyses and other evidence suggest that sea-water played only a minor role in the eruption. Since we don’t have any quantitative measures of the amount of water vapour in the eruption or for that matter how much SO_2 or ash were released it is possible to run a rather unconstrained modelling experiment. The authors do comment on the peculiar notion described in

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the paper by Schroder (1995) that noctilucent clouds were not observed prior to 1885, presumably hinting that Krakatau may have moistened the mesosphere. Noctilucent clouds occur at much higher altitudes (80 km) and so this would require a new transport mechanism, as there is no evidence that the Krakatau eruption reached heights greater than 35 km and they were probably closer to 25 km (the Pinatubo eruption columns reached 30–40 km).

2. **The amount and effect of water vapour.** The large eruption cloud from the Rabaul September 1994 event was associated with sea-water interaction with magma and the large umbrella shaped cloud that resulted was filled with ice (Rose *et al.*, 1996) that probably nucleated on ash particles or perhaps sea salt and efficiently prevented water entering the stratosphere (we know the height of this cloud ~15–18 km from satellite stereoscopic imagery). It is estimated that up to ~1000 Tg H_2O were released from the magma during the great Pinatubo eruption (Guo *et al.*, 2004a) and this does not count entrained water vapour or the effect of the co-ignimbrite cloud formation, which enhances entrainment. So it is difficult to sustain an argument that Krakatau released more water vapour into the stratosphere than Pinatubo. The evidence for increases in water vapour following large stratospheric eruptions is also not very convincing. There have been no reported measurements of significant water vapour anomalies through direct injection into the stratosphere following the stratospheric eruptions of El Chichón, St Helens, Pinatubo, Hudson, Soufrière Hills or the recent SO_2-rich plumes from Okmok and Kasatochi and the SO_2-poor Chaitén eruptions. Apart from the process of nucleation there is also chemical conversion which presumably uses up stratospheric water. Bekki (1995) has described a possible scenario where the erupted SO_2 gas may deplete the stratosphere of water vapour. In another study, referred to in this paper, Bekki *et al.* (1996) comment that inserting 2700 Gt of water vapour into the stratosphere, "... give very modest forcings compared to the aerosol negative forcing".

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3. **How big were Krakatau and Pinatubo?** The dust veil index (DVI) and the volcanic explosivity index (VEI) are two measures of the size of an eruption, but neither assess the S-loading that governs the amount of sulphate aerosol produced and the magnitude of the surface cooling. Dynamics are very important too (Robock, 2000); as is the location of the eruption and even the timing–the season seems to be important. Pinatubo and Krakatau were both assessed as VEI=6 eruptions, and the amount of fine ash sent into the atmosphere has been estimated as ~4–5 km^3 (Guo *et al.*, 2004a) and ~5–8.5 km^3 (Self and Rampino, 1981), respectively. The amounts of SO_2 for Pinatubo, even with modern satellite estimates is uncertain by ~20% (Guo *et al.*, 2004b) and we can only guess how much Krakatau inserted. Sato's (1993) AOD record suggests that Krakatau and Pinatubo were not that different: peak global AOD's of 0.164 (1884.29) and 0.149 (1992.12), respectively. Since the climate forcing by volcanoes is supposed to scale linearly with AOD (Hansen *et al.*, 2005), the forcings should be quite similar. The point I am making is that Krakatau's cooling effect may have been comparable to Pinatubo's, within all of these uncertainties.

4. **How big was the cooling?** I am a little puzzled by Figures 5 and 6 which seem to show that Krakatau only had a 0.12 K cooling effect, globally. Biffra *et al.* (2000) and Robock (2005) show that this was more like 0.3–0.4 K cooling, although the different domains–Biffra *et al.* and Robock refer to NH anomalies, and differencing techniques make direct comparisons difficult. Is it significant that the reference period is the 4 years prior to the eruption? How anomalous were those years? Robock (2005) also suggests that the tree-ring record on which the proxy NH land temperature record is based, may be biassed because of the effect of diffuse radiation on tree-ring growth. So maybe Krakatau produced a stronger cooling than the analysis of the observational record suggests? An additional forcing also occurred just after Pinatubo from the eruption of Hudson (14–15 August, 1991) and enhanced AODs in the SH can be seen in Sato's record in

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mid-1992. This would have made the global cooling following Pinatubo smaller, had Hudson not erupted, perhaps by 10%.

5. **A complex problem.** At the heart of this paper is an attempt to reconcile some very uncertain observations with a discrepancy arising from simulations of very complex and unconstrained climate models. It seems the discrepancy may also be illusory. Was the cooling from Krakatau that much smaller than Pinatubo? And if it was, are there other reasons why this is so? For example do we really know how much SO_2 was released by Krakatau? Do we know that other factors, such as dynamical effects, natural variability (ENSO, AO etc.) or other processes (enhanced cloud albedo from ash particle nucleation), chemistry (there were no CFCs in the stratosphere when Krakatau erupted–the effects on ozone depletion may have been different), the effects of location (Krakatau at 6°S, Pinatubo at 15°N) and timing (Krakatau in late August, Pinatubo in mid-June) were the same for Krakatau and Pinatubo? Could these differences account for a possible small difference between the cooling effects of the two eruptions?

Additional references

Bekki, S. (1995) Oxidation of volcanic SO_2: a sink for stratospheric OH and H_2O, *Geophys. Res. Lett.*, **22**(8), 913–916.

Biffra *et al.* (2000) Influence of volcanic eruptions on Northern Hemisphere summer temperature over the past 600 years, *Nature*, **393**, 450-455.

Guo *et al.* (2004a) Particles in the great Pinatubo volcanic cloud of June 1991: The role of ice, *Geochem, Geophys. Geos.*, **5**, Q05003, doi:10.1029/2003GC000655.

Guo *et al.* (2004b) Re-evaluation of SO_2 release of the 15 June 1991 Pinatubo eruption using ultraviolet and infrared satellite sensors, *Geochem, Geophys. Geos.*, **5**, Q04001, doi:10.1029/2003GC000654.

Hansen *et al.* (2005) Efficacy of climate forcings, *J. Geophys. Res.*, **110**, D18104, doi:10.1029/2005JD005776.

Robock, A. (2005) Cooling following large volcanic eruptions corrected for the effect of diffuse radiation on tree rings, *Geophys. Res. Lett.*, **32**, L06702, doi:1029/2004GL022116.

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Rose, W. I. *et al.* (1996) Ice in the 1994 Rabaul eruption cloud: implications for volcano hazard and atmospheric effects, *Nature*, **375**, 477–479.
Sato, M., *et al.* (1993), Stratospheric aerosol optical depth, 1850-1990. *J. Geophys. Res.*, **98**, 22987–22994 (Updates available from http://data.giss.nasa.gov/modelforce/strataer/).
Self, S., and M. R. Rampino (1981) The 1883 Krakatau eruption, *Nature*, **294**, 699-704.

Fred Prata, 17 March 2009.

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