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Atmospheric Chemistry and Physics Discussions

Interactive comment on "Atmospheric impact of the 1783-1784 Laki Eruption: Part II Climatic effect of sulphate aerosol" *by* E.J. Highwood and D.S. Stevenson

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Atmospheric impact of the 1783-1784 Laki Eruption: Part II Climatic effect of sulphate aerosol; Response to reviewer 2

E.J. Highwood and D.S. Stevenson

This response to the comments made by the anonymous referee is made on behalf of both authors. We thank the reviewer for their helpful comments. Many of the comments and queries have been resolved by clarifying the text of the paper and including additional references. We have made new calculations in response to a few points, and altered some of the figures for clarity. Our responses are given below in considerably more detail.

Detailed response to reviewer 2

Many of the clarifications that this referee demands can be answered by reference to the companion paper Stevenson et al, (2003). However, we accept that this is annoying to those only reading Part 2 and have therefore added a more full description in many places.

1. P1604, L19/20: How did you choose the "Lo" and "hi" scenarios? Please justify and add references. Also over which geographical area are these emisssions distributed?

We state clearly that the Lo and Hi scenarios are described in detail in Stevenson et al, 2003, and we also give in the paper the height of the emissions. The scenarios were chosen to give a range of emission heights, bearing in mind the controversy discussed in the Introduction regarding the height of emission for the Laki eruption. The Hi case is based on preliminary modelling from S. Self (pers. comm., 2002) while the Lo case should give a lower bound on the altitudes of SO2 emission. We do not wish to repeat the description of Stevenson et al., 2003 but have added a sentence for clarification. The emissions were added to a single model grid square over Iceland.

2. P1604, L26; Why is the sulphate aerosol lifetime longer for the Laki cases?

The longer sulphate lifetime for Laki, compared to the lifetime of sulphate in 1990 simulation is also explained in Part 1; it is simply because more of the Laki sulphate resides in the upper troposphere and lower stratosphere compared to 1990 sulphate. Removeal processes are slower at upper altitudes and so lifetime is longer (see Part 1, section 4.3, p 565, l.24 to p.566, l7). The sentence will be altered to reflect this.

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3. P1605, l8-13: Why did you have to use different e-folding times? Couldn't you just have extended the IGCM run for another 2 years?

The e-folding times were necessary in the IGCM after the first year post-eruption since the input aerosol fields generated by the chemical transport model were only available for one year. It is prohibitively expensive to run the chemical transport model (it is this model and not the IGCM that must be run to produce the aerosol fields) for longer and in any case, most of the aerosol had been removed as quickly as one year from the start of the eruption. The two different e-folding times were used to bracket the possible range. Our results show that this part of the forcing is not important. Sentence added for clarification.

4. P1606,l23: Why did you have to assume that the aerosol is dry? Don't you have relative humidity in the CTM and IGCM?

The CTM and the IGCM of course both have relative humidity, but neither have aerosol microphysics. We completed a sensitivity test with wet (80%) aerosol described clearly in section 5 in order to establish the effect of this limitation of the model.

5. P1607,l2: Why does only the mixing in STE03 have a resolution comparable to T21? What is the horizontal resolution of all the other process? Why can't the CTM be run at t21 resolution for all the processes?

STOCHEM is a Lagrangian model that maps to a 5x5 degree Eulerian grid, which is also used for mixing, emissions, deposition, output etc. Reference to mixing has been dropped to avoid confusion.

6. p1608,l2: Why do you use monthly climatologies of meteorological parameters for *the input of the radiation if it's called every day? Doesn't the IGCM provide meteorological data on a much finer temporal resolution? What is the timestep of the IGCM?*

There appears to be some confusion here between the IGCM climate calculation which has 64 timesteps per day, and the off-line radiative forcing calculation. The latter requires that the same atmospheric profiles are used in two runs of the radiation code, one with and one without the aerosol. In this calculation only a mean climatological profile is used.

7. p1608,l4: Why do you use fixed dynamical heating? I seem to be lost, is the IGCM not a GCM that calculates dynamical transport and heating itself?

Again there is some confusion regarding the off-line radiative forcing calculation as opposed to the IGCM runs themselves. The IGCM of course has dynamical transport and heating as in any other GCM. To calculate (off-line) the radiative forcing (the change in net flux at the tropopause) we must include any flux change resulting from the stratosphere returning to equilibrium quickly. The fixed dynamical heating approximation is a standard method of doing this.

8. What causes the secondary maximum in the tropics?

As stated in the paper, this maximum is a result of slow (and small) aerosol transport to lower latitudes in later months. Sulphate aerosol over the dark ocean will have a higher magnitude radiative forcing than would the same amount of aerosol over the larger proportion of land in the Northern Hemispehre mid and high latitudes. In addition, during Northern Hemispehre winter the negative radiative forcing due to the scattering of solar radiation is limited since insolation is weak. The tropics and subtropics therefore appear as a relative maximum in negative radiative forcing.

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9. p1611: T21 model simulations differ quite a bit in the dynamics from higher resolution simulations. Even though you point that out in the "Uncertainty" section , I would suggest to repeat at least the "Hi/Long" IGCM simulations in T30 resolution or better.

It is argued by many that in an ideal world, all climate simulations should be run at the highest technically possible resolution. However, the IGCM is designed to be suitable for doing the many ensemble runs necessary here in an inexpensive fashion. In T21 resolution, the IGCM has a climatology and climate sensitivity that is realistic and compares well with other models. While many studies of volcanic radiative forcing or influence on climate (mostly pertaining specifically to Pinatubo aftermath) have been run at T30 or higher resolution (e.g. Stenchikov, 1998; Graf and Timmreck, 2001 and Kirchner et al., 1999), the IGCM is in fact considerably higher resolution than some widely used climate models such as the Wonderland model used in Hansen (1992) for Pinatubo simulations and many other studies on climate impact (e.g. Hansen 1997). Additionally, IPCC (2001) found that it was not obvious that increased horizontal resolution produced any systematic improvement in regional patterns of climate change. Throughout the paper we make it clear that our study is to serve as a starting point for other simulations of this type of eruption and highlights the areas where particular improvements might be expected. As such, we defend the presentation of results along with discussion of the caveats.

p1613,l9: Why are you doing sensitivity tests for July 1983, when you show radiative forcing distributions for August 1783 in Figure 3? I suggest to use the same month for consistence, i.e. either July in Figure 3 or August for the sensitivity experiments.

This is a very good point. We have now shown both sensitivity tests and disrtibution for July.

p1614,l23; Everywhere else you use the 'hi; scenario. Even though you explain on the *next page that aerosols in the 'Hi; scenario would affect mixed and ice clouds more than low level clouds, I would still encourage you to calculate the indirect effect on water clouds for the 'hi' scenario here for consistency.*

We have recalculated the indirect effect on water clouds for both the Lo and Hi aerosol scenarios using the same empirical relationships as described in the paper but following the methodology of IPCC01. This resulted in a Northern Hemisphere mean indirect forcing of -8Wm^{-2} for the Lo scenario and -14 Wm^{-2} for the Hi scenario. This still only includes the first indirect effect but is a better estimate than previously made. If this is a real forcing in the atmosphere (see comments below) it means that our simulation would probably overestimate the observed temperature anomaly after the 1783-1784 Laki eruption and may suggest an increasingly important role for the anomalous circulation in warming Northern Hemisphere land masses. It also suggests that anotehr similar eruption without the anomalous circulation could result in a considerably larger negative temperature response.

p1615, l4/5: it's not true anymore that all the work on the indirect effect has examined only water clouds. The impact of volcanic aerosols on ice clouds was studied for instance, by Jensen and Toon, GRL, 1992; Kaercher and Lohmann, JGR, 2002; Luo et al., J. Climate, 2002

We thank the referee for pointing out these references. We were careful to say that "almost all" the work had been on ice clouds. We are aware that there have been recent advances in the impact of aerosol on ice clouds, and on the implementation of this effect in models, as discussed by Kaercher and Lohmann (2002). However, compared to the indirect effect on liquid water clouds, this is still at a very early stage and certainly beyond the capabilities of the present model, and feel that this justifies our statement that "almost all" the work has been on liquid water clouds. Interestingly, Luo et al (2002) found no evidence of changes in clouds following the Pinatubo eruption. Therefore we can do no more at this stage than point to it's potential importance, as discussed in section 5.

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Climate sensitivity parameter	peak temp. change	duration of event
0.3	-0.21	8 years
0.6	-0.21	20 years
1.0	-0.21	30 years

Table 1: Energy balance model results for a radiative forcing lasting 2 years and of similar magnitude to the global mean forcing calculated in this study. Table shows the impact of increasing the climate sensitivity parameter is more noticeable in duration than peak of event.

P161,p15: I seem to be lost again, why should the climate sensitivity parameter for a short duration forcing change the duration of the event rather than the magnitude? Shouldn't it affect both?

The referree is indeed correct. A change in climate sensitivity parameter will generally affect both the magnitude and duration of the temperature impact. As the climate sensitivity parameter is increased, the effectiveness of a given radiative forcing in producing a temperature change increases, however the timescale of response of the system also increases and the combination of these effects means that for a small magnitude and very short duration forcing there is very little change in the peak forcing reached. The increased response time is however noticeable in the duration of the event as shown in calculations with the energy balance model and a radiative forcing profile similar to that of the Laki eruption (referred to briefly in the paper):

We have dealt with the technical corrections that the referee pointed out as appropriate. In particular we have made the significant areas in Figure 5 clearer. We have checked the lines regarding point 10 and they are correct. The "Hi/Short" cooling rates are not consistently larger than the "Hi/Long" ones. In fact there is very little aerosol

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left in the atmosphere in either case after year 1 as is clear from Figure 1. The different heating rates are presumably a result of changes in the circulation in each case and it is therefore not obvious that either "Hi" scenario should be consistently cooler. The main result from this figure is that the "Lo" scenario does not produce any significant temperature changes. As far as the size of these images goes, they were each made individually, it is the size of the page that constrains the size of the image. We have relabelled them A,B and C so that they can if necessary be arranged horizontally.

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