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Reply to comment by Cole-Dai et al. on "Climatic impact of the long-lasting Laki eruption: Inapplicability of mass-independent sulfur isotope composition measurements"

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Here we respond to the comments by *Cole-Dai et al*. [2014] on our article *Schmidt et al*. [2012]. Specifically, in response to section 2 of their reply, we argued in *Schmidt et al*. [2012] that based on previously published estimates of the volatile release height during the 1783–1784 C.E. Laki eruption, the lack of a sulfur mass-independent fractionation (MIF) anomaly is expected. In other words, no previous study on Laki ever argued that this eruption emitted SO_2 into altitudes $>$13–15 km. In section 2.3, *Cole-Dai et al*. [2014] argue that the nonzero $\Delta^{33}S$ value of their Laki sample 1 may be explained by a short-lived explosive phase at Laki during which volatiles reached the stratosphere. In *Schmidt et al*. [2012] in section 2, we argued in agreement with *Cole-Dai et al*. [2014] (section 3.1) that for a MIF anomaly to be preserved, the Laki volatiles would have had to be emitted in $>$20 km altitude. Our main point is that eruption column heights $>$20 km are unlikely based on the historical accounts and plume-rise modeling for the Laki eruption [*Stothers et al*., 1986; *Woods*, 1993; *Thordarson and Self*, 2003].

In *Schmidt et al*. [2012], we argued that to deduce a short-lived climatic impact of the Laki eruption based on the lack of a MIF anomaly and the length of the sulfate deposition in Greenland ice cores may be misleading because the climatic impact will outlast the radiative forcing of the Laki aerosol cloud. *Cole-Dai et al*. [2014] acknowledge the latter in their reply in section 4.2.

We agree with *Cole-Dai et al*. [2014] in that the magnitude and length of the climatic impact during the winter of 1783–1784 depends on the altitude of the volatile release during the eruption (sections 2.3 and 4.2). However, even if we assumed that during Laki all sulfur dioxide (SO_2) would have been released in the troposphere, then the aerosol cloud would still be present in the upper troposphere during March 1784, as is evident from independent model simulations of this "tropospheric-only" scenario [*Stevenson et al*., 2003]. We acknowledge that there is uncertainty on the volatile release height for Laki; however, it is worth considering that those climate model simulations that used an injection altitude between 9 km and 13 km for the Laki SO_2 [*Highwood and Stevenson*, 2003; *Oman et al*., 2006a, 2006b; *Schmidt et al*., 2012] best match the observed temperature changes during summer of 1783 [*Angell and Korshover*, 1985; *Brázdil et al*., 2010; *Briffa et al*., 1998; *D'Arrigo and Jacoby*, 1999; *Jacoby et al*., 1999; *Kington*, 1988; *Manley*, 1974; *Parker et al*., 1992; *Thordarson and Self*, 2003]. Based on these model simulations, a climatic impact during the winter of 1783–1784, albeit weaker than during the climactic phases of Laki, is expected (and our argument here does not exclude the role of natural variability in contributing to the cold winter of 1783–1784 as discussed in *Schmidt et al*. [2012]). Therefore, we continue to argue that for high-latitude eruptions such as Laki, the applicability of sulfur isotopic measurements to interpret the climatic relevance has yet to be demonstrated. It may transpire that the interpretation of MIF signals for the climate-relevance of an eruption is valid and unambiguous only for short-lived explosive eruptions in the tropics. In terms of the processes producing a MIF anomaly (section 3.3 in *Cole-Dai et al*. [2014]), the works by *Hattori et al*. [2013] and *Ono et al*. [2013] suggest that there are remaining issues not discussed by *Cole-Dai et al*. [2014], for instance, self-shielding of SO_2 due to high column densities typical for eruptions of Pinatubo-scale and greater, and the preservation of the MIF signature in general.

In agreement with our 2012 article, *Cole-Dai et al*. [2014] also conclude in section 5 that model simulations of the sulfur MIF signature including its deposition and preservation in sulfates in ice cores after volcanic eruptions are a fruitful area of future research. In *Schmidt et al*. [2012], we specifically suggested using the

1912 Katmai eruption in Alaska as a test case in model simulations that parameterize isotopic fractionation [*Pavlov and Kasting*, 2002; *Pavlov et al*., 2005; *Hattori et al*., 2013]. In the 1912 Katmai eruption around 5 Tg of SO_2 was released into altitudes between 15 and 24 km [*Stothers*, 1996]; therefore, this eruption appears to be an ideal test case because its emissions reached altitudes at which photolysis of either SO_2 or SO_3 is expected, and a climatic effect can be expected [*Oman et al*., 2005, 2006b]. However, we suggest that a time-dependent MIF anomaly can only be detected if the volcanic aerosol cloud was sufficiently spatially separated over time. *Cole-Dai et al*. [2014] disagree with this statement in their section 3.2. We argue that it is questionable whether a sufficient spatial separation can be achieved for high-latitude eruptions because of the limited latitudinal dispersion of their volcanic aerosol clouds. Therefore, transport and deposition may alter the $\Delta^{33}S$ signal and its deposition pattern independently of the aerosol residence time. Model simulations of a range of volcanic eruptions in terms of the location of the vent and injection altitude will help to address whether transport alters the deposition pattern of the MIF anomaly.

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