Modeling Climate Impacts of the 1783-1784 Laki Eruption in Iceland

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Introduction

The Laki eruption in Iceland, which began in June 1783, was followed by many of the typical climate responses to volcanic eruptions: suppressed precipitation and droughts, crop failure, and surface cooling lasting two to three years. In contrast to the observed cooling in 1784-1786, the summer of 1783 was anomalously warm in western Europe, with July temperatures reaching more than 3°C above the mean in some areas. While climate models can generally reproduce the surface cooling and decreased rainfall associated with volcanic eruptions, model studies have failed to reproduce the extreme warming in western Europe that followed the Laki eruption. As a result of the inability to reproduce the anomalous warming, the question remains as to whether this phenomenon was a response to the eruption, or merely an example of internal climate variability. Using the Community Earth System Model (CESM1) from the National Center for Atmospheric Research (NCAR), we investigate the role of the aerosol indirect effect of the "Laki haze," and the effect of the eruption on Europe's climate. Results indicate that the extreme summer temperatures may be attributed to natural variability. On the other hand, the unusually cold winter in Europe appears to have been due in part to the eruption, which forced a positive phase of the El Niño Southern Oscillation. Understanding the cause of this anomaly is important not only for historical purposes, but also for understanding and predicting possible climate responses to future high-latitude volcanic eruptions.

Methods and Experiments

- CESM1 Whole Atmosphere Community Climate Model
- 1° horizontal resolution
- 70 vertical levels, 6 x 10^{-6} hPa model lid
- Aerosol indirect effects
- Forced quasi-biennial oscillation
- Interactive middle atmosphere chemistry
- 25-year control run
- 40 simulations without Laki
- 40 simulations with Laki
- 94 Teragrams (Tg) of sulfur dioxide (SO_2) injected into stratosphere
- 28 Tg of SO_2 in surface emissions
- Initialized based on synoptics from *Thordarson and Self* [2003]
- Four sets of initial conditions; 10 runs from each

Results

In July 1783 northern, western and part of central Europe experienced an unusual heat wave [*Thordarson and Self*, 2003]. July 1783 is among the warmest on record in some parts of Europe. Figure 1 depicts the July 1783 temperature anomalies across Europe:

- Temperature reconstructions from *Franke et al.* [2017] show that in the western part of Europe the July 1783 surface temperatures are up to 1.5°C higher than the 5-year mean over 1778-1782 (Figure 1a).
- The noLaki ensemble (Figure 1b) shows a pattern that is qualitatively similar to Figure 1a, with significant warming north and west and cooling east and south.
- The Laki ensemble (Figure 1c) shows cooling over all of Europe. However, several ensemble members did show warming over Europe in spite of the cooling caused by the eruption (Figure 2).

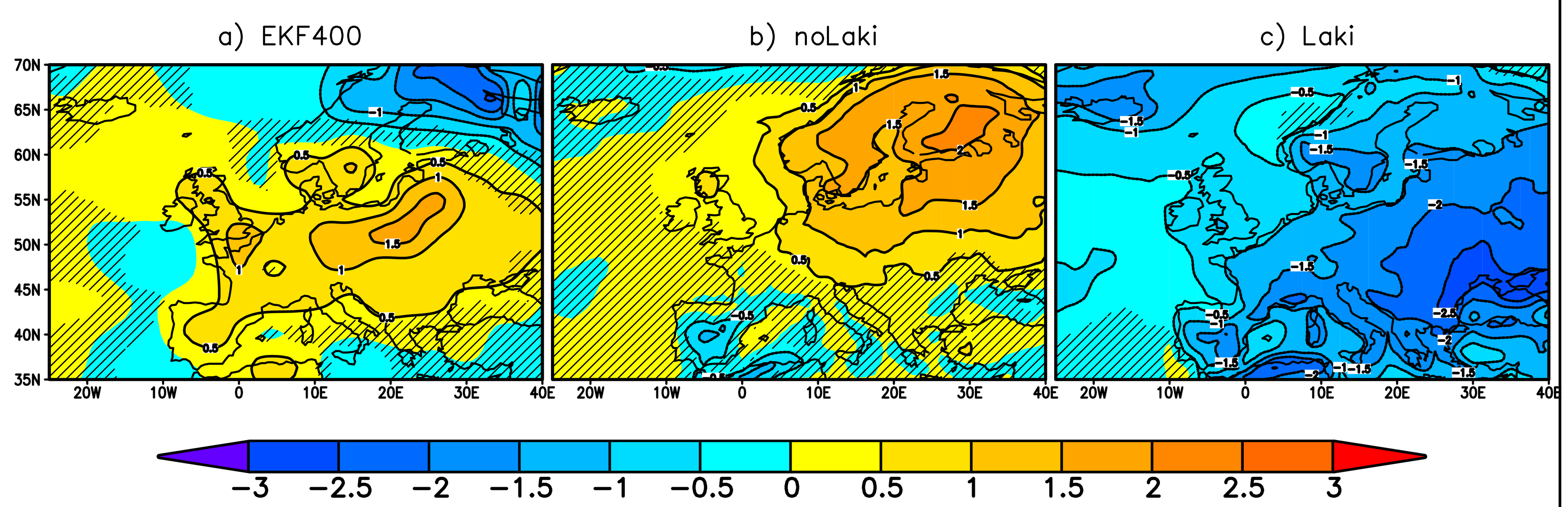

Figure 1. July 1783 European surface temperature anomalies (K) for (a) reconstruction from Franke et al. [2017], (b) average of noLaki ensemble, and (c) Laki ensemble average. Anomalies are calculated with respect to the five years before the eruption. Hatching represents areas < 95% significance using a two-tailed Student's t-test.

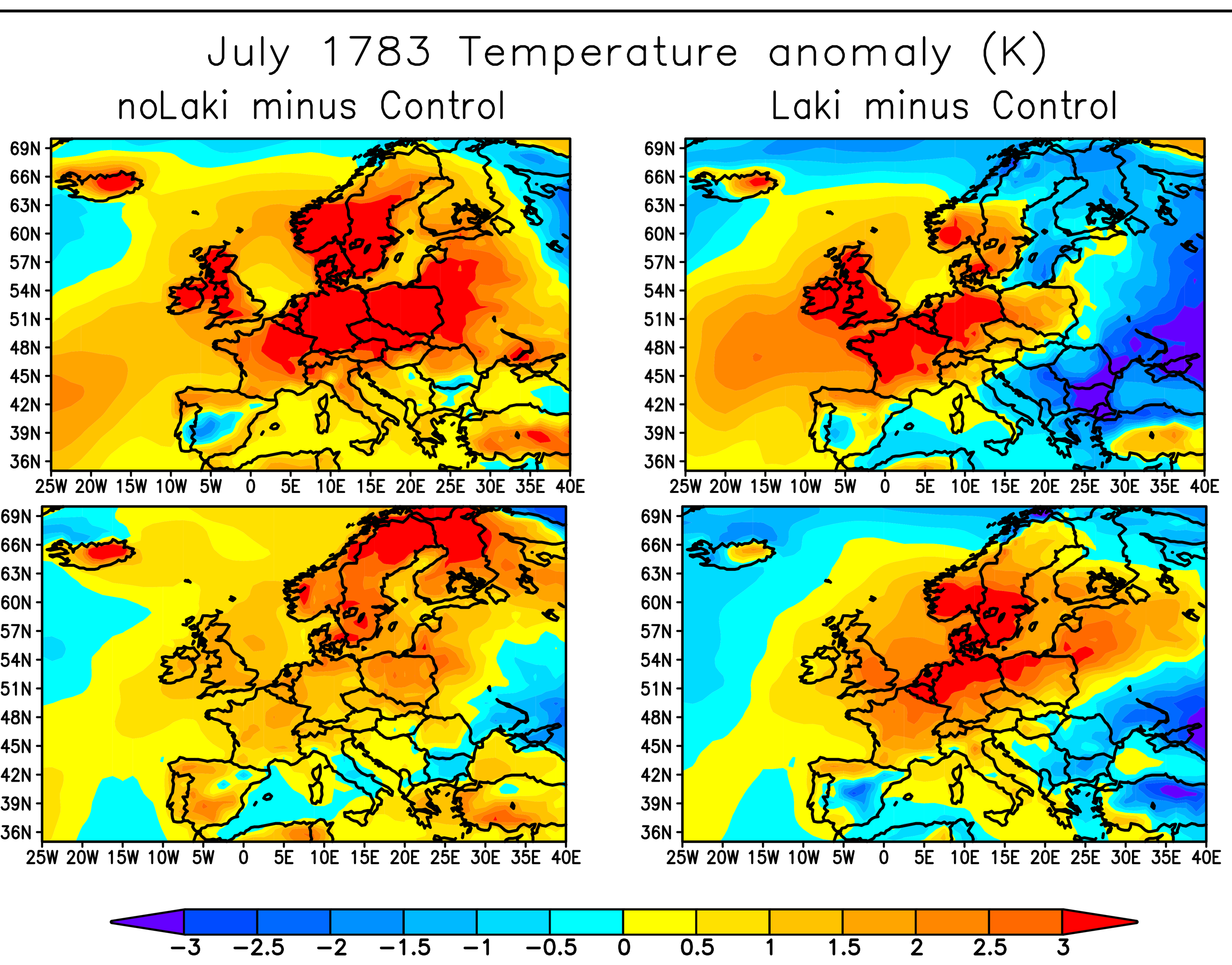

Figure 2: Examples of warm July simulations without (left) and with (right) the Laki eruption.

In contrast to the warm summer of 1783, records show that winter 1783-1784 was cold and harsh [e.g., *Thordarson and Self*, 2003]. Benjamin Franklin wrote "perhaps the winter of 1783-4, was more severe, than any that had happened for many years" [*Franklin*, 1784]. *D'Arrigo et al.* [2011] attributed the cold season to a combination of a negative phase of the North Atlantic Oscillation (NAO) and a positive phase of the El Niño Southern Oscillation (ENSO). *Pausata et al.* [2015, 2016] showed that high-latitude eruptions can increase the likelihood of an El Niño in the winter following the eruption. Figure 3 shows the sea level pressure anomalies for the winter after the Laki Eruption for the two ensembles, while Figure 4 shows the Niño 3.4 index for each of the simulations in the year after the Laki eruption:

- The EKF400 reconstruction (Figure 3a) shows a strong negative phase of the NAO
- A positive phase of the NAO is observed in the both of the model ensembles (Figure 3b-c).
- Ensemble members with the eruption show an increased likelihood of an El Niño in the winter after the eruption (Figure 5), in agreement with *Pausata et al.* [2016].

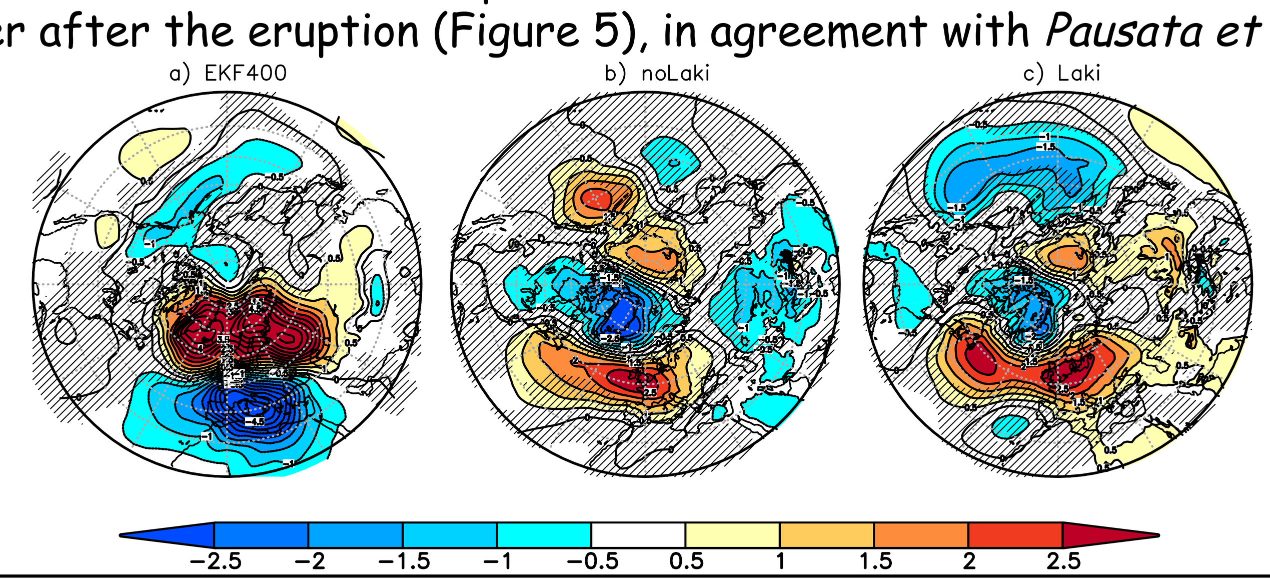

Figure 3: DJF 1783-1784 Northern Hemisphere sea level pressure anomalies (hPa) for (a) reconstruction from Franke et al. [2017], (b) average of noLaki ensemble, and (c) Laki ensemble average. Anomalies are calculated with respect to the five years before the eruption. Hatching represents areas < 95% significance using a two-tailed Student's t-test.

Figure 4: Niño 3.4 index with and without the Laki eruption.

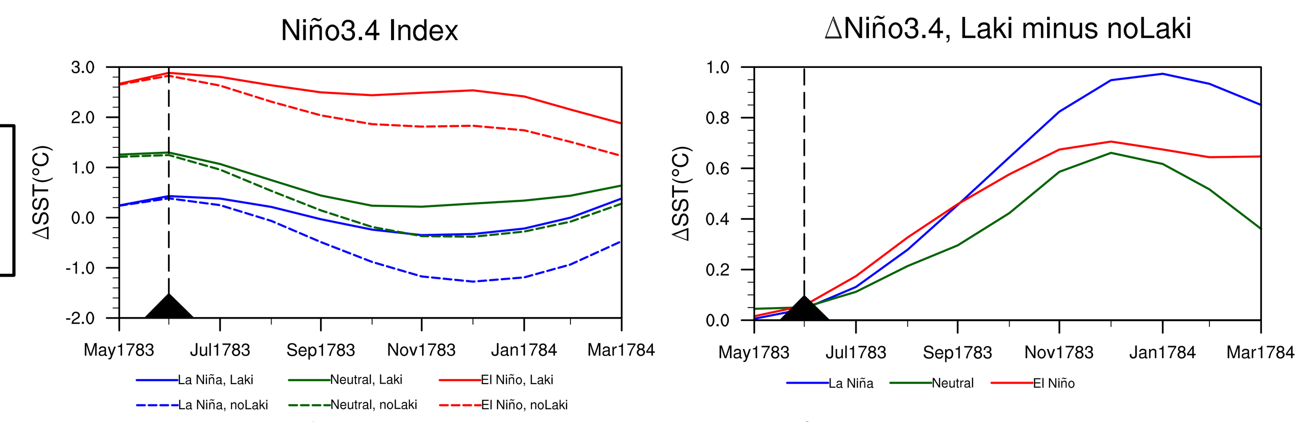

Figure5 shows the DJF 1783-1784 surface temperature anomalies:

- The *Franke et al.* [2017] reconstruction shows extreme cooling over most of Europe, and anomalies below -3 K covering a large area of Central Europe (Figure 5a).
- The Laki ensemble (Figure 5c) shows some cooling, but the anomalies are indistinguishable from those of the noLaki ensemble (Figure 5b).

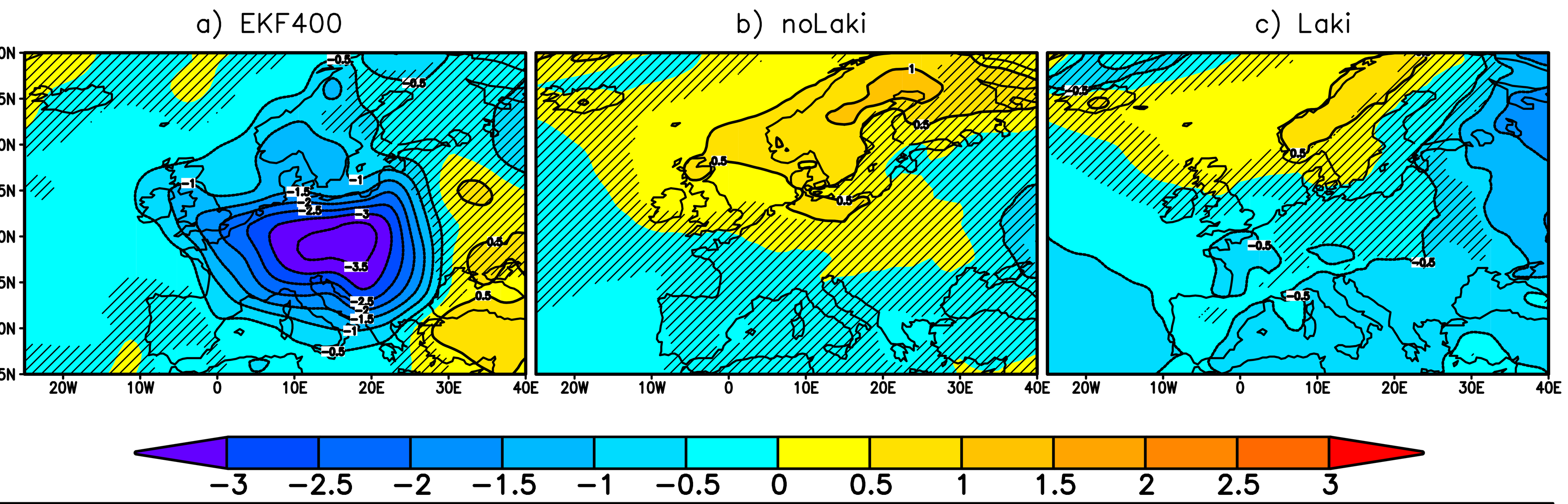

Figure 5: DJF 1783-1784 European surface temperature anomalies (K) for (a) reconstruction from Franke et al. [2017], (b) average of noLaki ensemble, and (c) Laki ensemble average. Anomalies are calculated with respect to the five years before the eruption. Hatching represents areas < 95% significance using a two-tailed Student's t-test.

Conclusions

1. Model simulations indicate that the warm European summer in 1783 was caused by natural variability, and not the Laki eruption. Some ensemble members indicate a warm summer in spite of the eruption, in agreement with temperature reconstructions.
2. The negative phase of the NAO was likely not forced by the Laki eruption.
3. There is a tendency toward an El Niño after the Laki eruption. This result is in agreement with recent studies.

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References

D'Arrigo, R., R. Seager, J. E. Smerdon, A. N. LeGrande, and E. R. Cook (2011), The anomalous winter of 1783–1784: Was the Laki eruption or an analog of the 2009–2010 winter to blame?, *Geophys. Res. Lett., 38*, L05706, doi:10.1029/2011GL046696.

Franklin, B. (1784), Meteorological imagination's and conjectures, *Manchester Lit. Philos. Soc. Mem. Proc., 2*, 122.

Franke, J., S. Brönnimann, J. Bhend, and Y. Bugnara (2017), A monthly global paleo-reanalysis of the atmosphere from 1600 to 2005 for studying past climatic variations, *Scientific Data*, *4*, doi:10.1038/sdata.2017.76

Marsh, D., M. Mills, D. E. Kinnison, and J. -F. Lamarque, (2013), Climate change from 1850 to 2005 simulated in CESM1(WACCM). *J. Clim.*, *26*, 7372-7391, doi:10.1175/JCLI-D-12-00558.1.

Oman, Luke, A. Robock, G. L. Stenchikov, and T. Thordarson, (2006), High-latitude eruptions cast shadow over the African monsoon and the flow of the Nile. *Geophys. Res. Lett.*, 33, L18711, doi:10.1029/2006GL027665.

Pausata, F. S. R., L. Chafik, R. Caballero, and D. S. Battisti (2015), Impacts of a high-latitude volcanic eruption on ENSO and AMOC, *Proc. Natl. Acad. Sci., 112*(45), 13784–13788.

Pausata, F.S.R, C. Karamperidou, R. Caballero, and D. S. Battisti (2016), ENSO response to high-latitude volcanic eruptions in the Northern Hemisphere: the role of the initial conditions, *Geophys. Res. Lett., 43*(16), 8694-8702.

Thompson, D. W. J., and J. M. Wallace (1998), The Arctic Oscillation signature in the wintertime geopotential height and temperature fields, *Geophys. Res. Lett.,* **25**(9), 1297–1300, doi:10.1029/98GL00950.

Thordarson, T., and S. Self (2003), Atmospheric and environmental effects of the 1783– 1784 Laki eruption: A review and reassessment, *J. Geophys. Res., 108*(D1), 4011, doi:10.1029/2001JD002042.