Clim. Past Discuss., 10, C927–C934, 2014
www.clim-past-discuss.net/10/C927/2014/

Climate of the Past Discussions

Interactive comment on "Observations of a stratospheric aerosol veil from a tropical volcanic eruption in December 1808: is this the "Unknown" ∼1809 eruption?" *by* A. Guevara-Murua et al.

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Received and published: 25 June 2014

Dear Reviewers,

On behalf of myself and my co-authors, I would like to thank you all for your supportive comments and generous suggestions to assist us with improving our manuscript. Please see the following text for specific responses.

Response to R. Allan:

Reviewer comment: It would be very useful if the authors were able to provide some assessment of the potential that might exist for finding more documentary evidence for

the 1808/1809 eruption. As they note, it is quite surprising that no one has yet been able to conclusively identify the source of this event.

Authors response: We believe that it is possible that there is more information on the Unknown 1808 eruption in historical documents (e.g. in the various Latin American archives and/or in the Archivo General de Indias in Seville, Spain). A thorough search is time-consuming (and also involves an element of luck). Our findings narrow down the dates of interest significantly, which will aid the search.

Response to M. Toohey:

Comment 1: pg 1903, line 20: It might be worth noting here that these estimates of the sulfur loading and/or aerosol optical depth related to the 1809 UE (I'll call is 1809 UE, out of habit) are based on ice cores. Probably more weight should be given to multi-ice core composites, such as used by Crowley and Unterman but also Gao et al., (2007, 2008), than to single-ice core estimates like that from Zielinski (1995).

Authors response: We agree and have replaced the single ice core estimate of the sulfur loading of the Unknown eruption from Zielinski (1995) with the multi-ice core estimate from Gao et al. (2008).

Comment 2: The Crowley and Untermann (2013) data set is provided as AOD in 4 latitude bands. Calculating the global mean from these bands, I get a maximum global mean AOD for 1809 as 0.27-0.28, i.e., the same as quoted for the Crowley (2008) study.

Authors response: We have updated the AOD of the 1808 Unknown eruption with the Crowley and Unterman (2013) estimate. The global inferred AOD for 1809 is 0.198, according to the "Supplemental Table 3 - Inferred yearly global average aerosol optical depth (AOD) (at 550 nm)" as per link: ftp://ftp.ncdc.noaa.gov/pub/data/paleo/climate_forcing/volcanic_aerosols/crowley2013/crowle reff.txt

Comment 3: pg 1903, line 25: The comparisons of the magnitude of sulfur loading or AOD for 1809 UE vs. other eruptions check out with the estimates of Gao et al., (2007, 2008) except for Pinatubo, for which Gao et al. (2007) estimate a global sulfate aerosol load of 30 Tg, vs. 22 Tg for 1809 UE. So I don't think 1809 UE was "more than three times" the sulfate loading of Pinatubo.

Authors response: The global sulfate aerosol loading of the 1808 Unknown eruption was 53.74 Tg according to Gao et al. (2008). We agree that this value isn't "more than three times" the sulfur loading from the Pinatubo eruption and have corrected the relative comparison to "almost twice".

Comment 4: pg 1904, line 28: The explanation of the reason for stronger poleward aerosol transport in the winter hemisphere is not quite correct. Mixing and meridional transport in the stratosphere are driven by the breaking of planetary-scale Rossby waves in the midlatitude stratosphere, which occurs predominantly in the winter hemisphere since these waves cannot propagate upward through the easterly winds of the summer hemisphere stratosphere.

Authors response: We agree that we had oversimplified this explanation and have corrected this in the revised version of this manuscript. Thank you for bringing the studies Toohey et al., (2011) and Toohey et al., (2013) to our attention. These were very useful and are now included in the Discussion section of the manuscript.

Response to J. Cole-Dai:

Reviewer comment: 1. Page 1905, Line 15: Cooling is associated with atmospheric effects of volcanic eruptions. Therefore, it would be better to use words other than "extend beyond cooling" to refer to atmospheric effects. How about "In addition to cooling, large eruptions produce visibly observable global atmospheric effects"?

Authors response: We agree and have rewritten the sentence as suggested.

Reviewer comment: 2. Page 1905, Lines 21-23: This sentence seems to imply that the

Laki dry fog affected large parts of Europe, when in fact the dry fog was probably felt strongly only in Iceland.

Authors response: The implication of this sentence is correct; Iceland was severely affected by the 1783-4 Laki eruption, however, the resulting tropospheric dry fog also directly impacted large parts of Europe including Germany, UK, France and Denmark (Stothers, 1996). We have found (post-submission) an additional source commenting on Caldas' 1809 observations at a French Institute meeting in 1832 which, in making the comparison, confirms the geographic coverage of the Laki dry fog across Europe and into Africa. Of note is the attribution of the fog phenomena to the Icelandic eruption.

The New Monthly Magazine and Literary Journal, Part 3, Historical Register. London, published for Henry Colburn by Richard Bentley pg 170-171.

"Atmospherical Phenomena in New Grenada. At a recent sitting of the French Institute, M. Roulin communicated some curious particulars relative to an unusual condition of the atmosphere observed in New Grenada [Granada]. From the 11th of December, 1808, to the end of January 1809, the disk of the sun at his rising appeared pale, and totally divested of its dazzling splendour, so that it was often mistaken for the moon. However, after gaining a slight elevation, it reassumed its ordinary aspect. Both in the morning and evening, it often appeared tinged with a slight shade of rose colour or light green, and sometimes of a bluish grey, nearly resembling the hue of steel. The cold, during the whole of this time, was more sensibly felt than general; and frequently in the morning the plains in the neighbourhood of Bogota were covered with a hoar frost, which nipped the tender shoots of plants, a circumstance before unknown in this district within the memory of man. The sky was constantly clothed with a transparent haze, uniformly extended, and continuing during the day as well as the night. This produced none of those coloured halos, which are generally served on such occasions surrounding the sun and moon. It concealed all stars below the fourth magnitude. The air was constantly free from moisture, and generally calm; and the winds which blew at short intervals, came always from the South. This phenomenon was observed at Pasto

Popayan, Neyba [Neiva] Tunja, and Santa Martha [Marta]; that is, from the first to the twelfth degree of south latitude. M. Arago remarked that the mist of 1784 was not less extensive, since it was observed at the same time at Napoli di Romania and in Africa, and that its duration was still longer. This mist was remarkable for the absence of moisture; and the observations of Sennebier show that the hygrometer, when exposed to its influence, advanced towards the point of dryness. Some persons considered it as the tail of a comet, while others attributed its appearance to the eruption of a volcano, which took place about that time."

Reviewer comment: 3. Page 1905, Line 28 to Page 1906, Line 13: I think such detailed description of the observations of the Krakatau aftermath is not necessary. Maybe a concise summary is sufficient.

Authors response: We disagree with this suggestion. The detailed descriptions given in the extracts from personal observations of atmospheric effects following the Krakatau 1883 event allow the reader to make a direct comparison with what observers chose to record about the phenomena they were observing in 1808-09, reinforcing the close similarities in descriptions used. In addition, the chronology and geographic distribution of the observations following Krakatau are valuable for our analysis of the timing and location of the 1808 eruption.

Reviewer comment: 4. Page 1913, Lines 9-13: This description is almost identical to that in Page 1910, Lines 22-27.

Authors response: In our Results section (pg. 1908-1911), we describe Caldas' meteorological readings and observations (including frost events), and place these in the context of modern records in order to demonstrate Caldas' experience and knowledge in relation to all the climate anomalies he described. In our Discussion section (pg 1910) we present the case that the anomalous frequency of frost days recorded by Caldas, when combined with observations of a constant upper level haze, demonstrate that the frosts were most likely the consequence of a volcanic aerosol veil that

reduced incoming shortwave radiation. At this point of the Discussion it is important to revisit the modern meteorological observations of frosts because these are, by contrast, always associated with clear skies since they are caused by increased outgoing longwave radiation.

Reviewer comment: 5. Page 1914, Lines 6-8: I don't quite understand this. Why is it significant that the twilight glows seen in Lima were not seen in Bogota?

Authors response: The 'twilight glow' phenomenon is associated with optical effects through the leading edge of a volcanic aerosol cloud as it spreads; the glow is no longer observed at a particular latitude when the overlying aerosol layer becomes too thick. This observation is based on a detailed analysis of the chronology and geographic extent of 'twilight glow' observations following the Krakatau eruption in the chapter of the Royal Society Report (Ed. Symons, 1888) 'On the unusual optical phenomena of the atmosphere 1883-1886, including twilight effects, coronal appearances, sky haze, coloured suns, moons, etc.' by Russell and Archibald (1888). Russell and Archibald (1888) reported the appearance and then disappearance of the observed glows occurred over a timescale of several months at any one location, and how later reports of the phenomenon were from increasingly higher latitudes. That Caldas in Bogotá (4°N, Colombia) made no mention of this phenomenon, while listing other detailed observations consistent with aerosols overhead, suggests that the aerosol layer released by the Unknown eruption of 1808 was, from the outset, too thick at this equatorial latitude to produce a twilight glow, as expected for a tropical volcanic eruption. At the same time, at a site just south of the 'tropical pipe' region (Lima, Peru; 12°S), Unanue reported a twilight glow over the 3-month period of December 1808 until February 1809. The fading of optical effect after February 1809 suggests thickening of the aerosol optical depth over Lima as the aerosols spread poleward. Together the two reports support our interpretation that both accounts are consistent with an aerosol layer of tropical origin and aerosol optical depths thickest over the Equator.

We have rewritten this section of the manuscript to clarify the significance of this ob-

servation in our hypothesis that the 1808 eruption was of tropical origin.

Reviewer comment: 6. Page 1914, Lines 22-24: Would such a large eruption in Central America be expected to be recorded in the Spanish colonial archives?

Authors response: Colonial documents held by the Archivo General de Centro América (the AGCA, or Central American Archives) contain numerous reports of much smaller eruptions and of their consequences. While we cannot entirely rule out the possibility that a large eruption took place in Central America, we have so far found no evidence and believe it unlikely that an eruption of magnitude VEI6 would not have been recorded by the local authorities. We would also note that Feldman (1993) published a chronological record of volcanic and seismic events drawn from the colonial archive, and that no significant events were recorded anywhere in Central America for 1808 or 1809.

Reviewer comment: 7. Page 1918, Lines 12-22: I like this analysis of the possible social and political reasons why the 1808/1809 eruption was not documented in European and Western Hemisphere written historical records. However, as this is likely the opinion of the authors (I am guessing this, based on the lack of cited work for this part) and therefore quite speculative, I suggest to move this to the Discussion section.

Authors response: We agree that the analysis of the possible social and political reasons for why the 1808 eruption was not documented in the historical record is our opinion. It is also the case that there is no cited work: our interpretation is based on the absence of specific evidence, and of our reading of the kinds of preoccupations that informed writings of the period. However, since the Conclusion section typically allows for a nod to future research directions, we hope that the likelihood of finding more reports and observations about the eruption can be considered in this regard (particularly now that we have narrowed the possible dates and locations).

Response to C.S. Zerefos:

Thank you for your supportive comments.

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Interactive comment on Clim. Past Discuss., 10, 1901, 2014.