Authors' response to Anonymous Reviewer #1

General comments:

This is a well written and interesting study on the origin of numerous observations of blue/green suns in 1831. There will certainly always be some uncertainty, but in my opinion this is a convincing study and according to the evidence presented in the manuscript it seems indeed highly plausible that the 1831 eruption was the one of Ferdinandea. The paper is well suited for Climate of the Past and I recommend publishing the article after considering the following (mainly minor) comments.

[R1,1] Thank you. We are grateful for your helpful and detailed comments.

Apart from the specific comments below it would be good if the paper would also briefly address the following points:

- Were there reports of wildfires in Europe in August 1931?

[R1,2] Although it was not a primary focus of the literature search, no reports of very large forest or bush fires in southern Europe in July or August 1831 were identified.

How does the time lag between the eruption and the occurrence of colored suns differ between Ferdinandea and other eruptions, e.g. Krakatoa?

[R1,3] Please see response 2 to Reviewer #3.

Specific comments:

Lines 77 – 80: Perhaps you can here already refer to the appendices. When reading these sentences I was asking myself: How many newspapers and journals were searched and which ones? This information is provided later, but it would also fit here.

Line 122: "These observations have accordingly not been included in the present analysis."

Probably because Fig. 1 is right below this sentence I was asking myself, whether the point in China refers to the observations of this Mandarin compendium (which is not the case, as I learned later).

Figure 5: what is the meaning of the color of the circles. This is not explained as far as I can tell. In particular: What is the black circle in the "no blue sun" area?

[R1,4] We had indeed neglected to specify the meaning of the colour of the points in Figure 5. We have revised the caption to read:

> **"Figure 5. Locations of observations of a blue$^{(+)}$ sun (black points) and of null observations (red points) reported in August 1831 (see Appendices A and B). The boundary between the region where a blue$^{(+)}$ sun was observed and the region where it was not is delineated approximately with curve A – A'."**

The apparently exceptional case of the single black point in the 'no blue$^{(+)}$ sun' area represents observation [A7], reported from Odessa on 9 August 1831. As discussed at

manuscript lines 441 *et seq*, it may be that this observation represents the transport of aerosol from the eruption site at a different altitude and in a different wind direction from the others in the connected sequence.

Fig. 6: I think this Figure is appropriate for this manuscript, but I would add a disclaimer that this is only a very crude depiction of the plume extent and motion.

[R1,5] We have revised the manuscript at lines 174 and 186 (Figure 6) so that the word 'reconstruction' is qualified with the word 'approximate'.

Line 194: "yields a transport rate of about 0.97 deg hour^-1"

This refers to longitude, right? I suggest mentioning this explicitly to avoid confusion.

[R1,6] The y-axis in Figure 7 does specify degrees longitude but, to avoid any doubt, we have revised the manuscript at lines 195 and 196, as well as at lines 467 and 468 so that the term '(long.)' is added between the terms '^{o}' and 'hour^{-1}'.

Section 3.5: I would add that zonal winds in the stratosphere at mid-latitudes depend on the seasons and are easterly (westward) in summer and westerly (eastward) in winter. In August the winds would be easterlies, i.e. westward winds, which supports your hypothesis. The zonal wind reversal in the middle atmosphere typically occurs in September. This information can be found in a standard text book on atmospheric dynamics.

[R1,7] We have revised the manuscript at line 219 such that it now reads:

> **"…aerosol plume must have been transported in the stratosphere. An easterly stratospheric wind direction at around 40^{o} N in July is also supported by zonal mean wind fields derived from twentieth century data (Randel, 2003)."**

Equation (1): what are the limitations of this equation? What assumptions is it based on? There must be limits to the parameter ranges in which the equation is applicable, e.g. if Delta M ist very small, tau may be negative, which does not make sense.

[R1,8] Equation [1] is derived by Stothers (1984a, 1984b). The basic principle on which it is founded is that the optical path length through the atmosphere ('air mass') varies with zenith angle (z) as sec z (see, for example, Schaefer 1993). This simple relationship is no longer true at high zenith angles where, for example, atmospheric refraction effects become important (Stothers 1984a, Schaefer 1993). Accordingly, we delimit the use of equation [1] to values of solar elevation angle (α) $> 15^{o}$. Thus sin $\alpha > 0.26$ and, yes, you are correct, for a physically realistic $\tau>0$, in theory ΔM>0.77. In the context of our paper, however, the very lowest discernible change in solar magnitude that we could consider analytically is much larger, ΔM = 3.4 (manuscript line 238). We do take the point but trust that the combination of our references to Stothers (1984a, 1984b) and our delimited parameter ranges ($\alpha > 15^{o}$ and ΔM > 3.4) should provide adequate assurance regarding the valid use of equation [1]. We have nevertheless revised the manuscript at line 231 to read that:

> **"Atmospheric refraction can be neglected for $\alpha > 15^{o}$ (Stothers, 1984b; Schaefer, 1993)."**

Line 242: “These three observational phases”

It’s not entirely clear which three phases you mean here.

[R1,9] In the interests of brevity, we had compressed the discussion in sect. 3.6. but we appreciate that it might have lacked a degree of clarity as a result. We have therefore revised the manuscript at line 241 to add the following sentence:

> **“For suitable aerosol optical depth values (τ), three observational phases may therefore be distinguished: at higher solar elevations, a sun of normal or near-normal appearance (for $\Delta M < 3.4$ and likely for some part of the range $\Delta M = 3.4$ to $\Delta M = 12$); at lower solar elevations, a pale sun able to be viewed with the naked eye (for the remaining part of the range $\Delta M = 3.4$ to $\Delta M = 12$); and at lower solar elevations still, a blue$^{(+)}$ sun able to be viewed with the naked eye (between $\Delta M = 12.5$ and $\Delta M = 16.5$). ”**

Line 258: “and using the corresponding magnitude range (either 8 < \Delta M < 12 or 12.5 < \Delta M < 16.5)”

Which range is used in which case?

[R1, 10] Likewise we have revised the manuscript at lines 249 *et seq.* to read as follows:

> **“Nine of the sources (Appendix A) report the local time at which a blue$^{(+)}$ sun was observed. The corresponding solar elevation angle (α) can be recovered from this local time, for example, using the National Oceanic & Atmospheric Administration (NOAA) Solar Calculator (available at: https://gml.noaa.gov/grad/solcalc/) (Appendix A, col. 6). Using this solar elevation angle (α) and the range of reduction in solar magnitude associated with a blue$^{(+)}$ sun observation ($\Delta M = 12.5$ to $\Delta M = 16.5$), expression [1] therefore yields a corresponding range of instantaneous aerosol optical depth values (τ) in each case (Fig. 8).**
>
> **Five of the sources (Appendix A) report the local time at which the sun was observed with the naked eye after having been observably blue$^{(+)}$ in the morning or before becoming observably blue$^{(+)}$ in the afternoon. The qualitative descriptions of the appearance of the sun in these latter reports, for example, as a ‘crystal globe’ (source [A8]) or as ‘moon-like’ (source [A10]), suggest the upper end of the $3.4 < \Delta M < 12$ range in magnitude reduction, *i.e.* $8 < \Delta M < 12$. Likewise, recovering solar elevation angle (α) from local time and using this solar elevation angle (α) with the range of reduction in solar magnitude associated with a naked eye sun observation ($\Delta M = 8$ to $\Delta M = 12$), expression [1] yields a corresponding range of instantaneous aerosol optical depth values (τ) in each case (Fig. 8).”**

and accordingly:

> **Figure 8. Estimated instantaneous aerosol optical depth ranges. Those marked with a circle represent ranges derived from observations of a blue$^{(+)}$ sun whereas those marked with a square represent ranges derived from observations of a naked eye sun (either after having been observably blue$^{(+)}$ in the morning or before becoming observably blue$^{(+)}$ in the afternoon). (See sect. 3.6).**

Figure 8 and related explanations in the text: I don't fully understand, how the optical depths and their error bars are estimated. You use equation 1 and obtain information on the solar zenith (or elevation angles), but how is \Delta M determined for each case? This seems highly arbitrary and should introduce significant uncertainties.

[R1,11] Please see [R1, 10].

Please also explain, how the error bars in Fig. 8 were determined.

[R1, 12] Please see [R1, 10].

Line 289: "extinction co-efficient Q"

Q needs to be dimension-less for equation (2) to yield the correct units. This already implies that Q is the "extinction efficiency", not an "extinction co-efficient". Coefficients typically have units of 1/length, X-sections of length^2 and the Mie efficiencies (scattering or extinction) are dimension-less.

[R1, 13] We have revised the manuscript at line 289 (and correspondingly in Table 2) to read 'extinction efficiency'.

Line 340: "The eruption has been assigned a VEI of 3, which is associated with a total volume of erupted tephra of the order of 0.1 km^3."

This amount of erupted tephra is certainly probably associated with large uncertainties, right? I suggest mentioning this.

[R1, 14] Estimating the amount of tephra erupted by a particular eruption can indeed be associated with large uncertainties. However, we say that this eruption has been assigned a VEI of 3 (which it has) and that a VEI of 3 is associated with a volume of erupted tephra of the order of 0.1 km^3 (which it is). We do take the point but we trust that 'of the order of' should be sufficient to flag this uncertainty *i.e.* it is unlikely to have been 0.01 km^3 or 1 km^3 but somewhere in-between.

Line 364: "This hypothesis"

Which hypothesis do you mean here? That Ferdinandea was the source of the aerosol leading to the blue sun observations? Or your hypothesis on the additional release of sulfur?

[R1, 15] We have revised the manuscript to refer to hypothesis 'H1' (relating to the release of sulphur from sedimentary deposits) at lines 348, 364, 555 and 562 and hypothesis 'H2' (relating to the sulphur enriched aerosol having reached the stratosphere) at lines 376, 390, 421, 436, 557 and 562.

Line 421: „This hypothesis"

Again, which hypothesis?

[R1, 16] Please see [R1, 15]

Line 441 – 443: As mentioned above, the zonal winds in the stratosphere in July/August will most likely have been easterly/westward, in good agreement with your hypothesis.

Citations (occurs many times in the paper): “et al” -> “et al.”

[R1, 17] We have revised the manuscript to read ‘et al.’ where-ever the term is used.