

Interactive comment on “On the phenomenon of the blue Sun” by Nellie Wullenweber et al.

Nellie Wullenweber et al.

csavigny@physik.uni-greifswald.de

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Reply to comments by referee #1

Referee comments:

Overall I expect that the authors will adequately deal with my comments, therefore I assume that the paper will be acceptable after a revision.

So my official recommendation is: some amendments needed

The paper presents an extensive theoretical study of how aerosol and Rayleigh scattering can modify the perceived color of the sun. It does so using aerosol layers of given optical thickness containing aerosol size distributions with variable mean size and width, as defined by log normal distributions. As expected, the results indicate that anomalous scattering (σ increases with λ , which can give rise to blue suns or

C1

moons) are rather rare phenomena and require special conditions such as sometimes happening after volcanic eruptions or intense forest fires. The authors nicely describe the effects of optical depths including Rayleigh scattering which was previously mostly neglected when explaining blue suns. Overall the paper is well structured and serves its purpose. I have however several suggestions and questions which should be dealt with.

Reply: We thank the reviewer for his/her very constructive comments. As described in more detail below, we essentially followed all the suggestions by the reviewer.

First general comment: Starting to read I immediately missed a reasoning why absorption by aerosols is neglected. I had to wait for Sect. 4 where – in a more or less vague and qualitative manor – it was discussed that absorption has been dismissed due to results of several studies. I cannot help but think that instead of qualitatively arguing, you should compute maybe just one example for typical imaginary parts from the literature and compare the results to the absorption free case. Then any reader would accept your arguments. Right now I have just to believe them which is unsatisfactory.

Reply: This is a very good idea and we now included a new subsection on the importance of absorption by aerosols and discussed one example with a typical absorption signature of aerosols.

Second general comment: Color perception is more than just the xy-coordinate in a chromaticity diagram. It is very helpful to plot the color, however, in real observations the influence of attenuation is dramatic when moving for 30° SZA to 90° SZA and one must consider the influence of changing contrast. The least I would expect is to not only show the color of the sun, but also how it's relative brightness changes. Even better would be to add a short discussion of how color perception is expected to be influenced by the variation in brightness and contrast.

Reply: This is a good point, too, and in the submitted version of the manuscript

C2

we didn't really discuss this aspect. The irradiance variations are actually shown in some of the Figures (3, 4, 6, 8 of the discussion paper), but we didn't discuss them. We now added paragraphs on possible effects of brightness changes and on potential contrast effects to the discussion section.

Third general comment: I missed a discussion concerning the influence of ozone absorption (Chappuis bands) on the color, in particular for large SZA. It had been shown e.g. for lunar eclipses that blue color during totality can be influenced by ozone (Appl. Opt. 47, No. 34 / H149 (2008)). The effect of ozone has also been briefly discussed for blue moons (see literature). I assume that your model does also allow to assume an ozone distribution and check how / if results change.

Reply: Thank you for this suggestion. Yes, we can easily test the effect of ozone (ozone is considered in the results in the submitted version of the paper) and we have performed a series of new simulations with varying amounts of ozone.

If an aerosol layer with an OD of 1 is considered (as in Fig. 4 of the online manuscript) the effect of changing the total ozone column between 100 DU (unrealistically low except for ozone hole conditions) and 500 DU is very minor. The transmission spectra are certainly affected – also in an aerosol-free case – but the overall shape of the transmission spectra is not changed to the extent to cause a significant change in the colour of the sun. We also tested unrealistically large ozone columns (1000, 2000 and 5000 DU) that lead to large differences in the transmission spectra, and also the colour of the sun. For Ozone columns up to 500 DU differences are difficult to identify visually.

We added a new subsection (3.8) to the manuscript discussing the effect of ozone absorption on the transmission spectra and the resulting colours of the sun. A few sample simulations results will be included, too.

In the following I mention some additional thoughts which I had when reading the text.

C3

line 77, see first general comment

Reply: As mentioned in our reply to the first general comment above, we followed the reviewer's suggestion and simulated the effect of aerosol absorption on the resulting colors of the solar disk. Line 77 was adjusted correspondingly.

line 91 Sect. 2.2: of course this depends on the physics/optics knowledge of the general reader of the journal, but to my opinion, the topic of color as treated in the section is basic textbook knowledge. This section can be shortened appreciably including deleting Fig. 1. I suggest to just quote respective textbooks. Reason: those who are not familiar with chromaticity diagrams and respective definitions will not get a better knowledge when reading this condensed textbook knowledge and those familiar with the topic do not need it. I would just keep the last sentences, i.e. lines 110-117

Reply: We followed the reviewer's suggestion and reduced this section significantly and referred to a standard text book and some other sources. We did not delete the lines before 110 entirely, because it is our experience that many colleagues have problems interpreting the chromaticity diagram without additional information.

line 128; discussion of figure 2: Maybe I am old fashioned here, but I personally think looking at Fig. 2 alone makes it harder to see the point. I suggest that you should add the classic diagram of extinction efficiency versus size parameter which explains anomalous extinction at one glance. Having this in mind greatly helps to understand your admittedly nice representation of the same content in Fig. 2.

Reply: OK, we added an additional plot as suggested by the reviewer.

Line 147: you mention standard atmospheric trace gases are used, is ozone included ? see third general comment

Reply: Yes, ozone is included and we now mention the considered trace gases explicitly in the manuscript.

C4

Line 161: have you used the exponent 4.00 for Rayleigh scattering or averaged 4.08 which includes dispersion effects of air (e.g. Young, Phys Today Jan 1982, p2-8)?

Reply: We used the Bates (1984) formula of the Rayleigh scattering cross section. We determined the spectral exponent by fitting a power law to the spectral dependence of the Rayleigh extinction cross section in the 400 nm – 700 nm and obtained the value: 4.0836 ± 0.0067 . We now mention explicitly in the paper that the Bates formula is used.

Reference:

D.R. Bates, Rayleigh scattering by air, Planetary and Space Science, Volume 32, Issue 6, Pages 785-790, [https://doi.org/10.1016/0032-0633\(84\)90102-8](https://doi.org/10.1016/0032-0633(84)90102-8), 1984.

Line 172: question: is the vertical optical depth of 1 only the aerosol or the total optical depth ? please clarify!

Reply: The vertical optical depth of 1 refers to the aerosols only. We replaced “optical depth” by “ aerosol optical depth” to make this clear.

Line 152: Starting Sect. 3.2, discussion of diagrams 3-6 and 8: see second general comment.

Reply: We added a discussion of brightness and contrast effects to the manuscript.

Line 220: from fig. 7 I estimated a change in attenuation from 400 nm to 630 nm from around 10^{-4} to $4.3 \cdot 10^{-5}$ i.e. a factor of 2.3 between blue and red. You describe the change in depth as only being 10%, that is true, but misleading. It is the factor of 2.3 difference for the radiometric quantities entering the eye of an observer which is relevant. Maybe you could amplify the change by plotting from 8 to 11 rather than 6 to 12. And of course, the attenuation of more than 10,000 also means that sun is not very bright, though still bright enough for color perception. One may compare this to totality of a solar eclipse where attenuation with regard to daylight is around 10^{-5} .

C5

Reply: You are certainly correct that the change in radiance is relevant, not the change in OD. We adjusted the statement and plotted the Figure again with the y-range suggested by the reviewer.

Line 222: “were” only available (you refer to Wilsons data)

Reply: changed.

Line 223: maybe better to write . . . variation with about 10% change is not . . .

Reply: this statement was already corrected following the comment by reviewer 1.

Line 265: see general comment 1

Reply: We included a new subsection on the effect of absorption by aerosols and included sample results of transmission simulations with aerosol absorption, as suggested by the reviewer.

references:

I propose that the authors carefully check all refs. I found e.g. one misspelling.

Reply: We proofread the references several times and corrected a few minor errors.

Line 325. Should probably be Dietze (e missing), as G. Dietze in his book on atmospheric optics from 1957 mentions blue suns.

Reply: Thank you for catching this, the correct spelling is “Dietze”.

I had expected some other general standard textbook refs. which at least shortly discuss blue suns in the context of Mie scattering such as Van de Hulst, Light scattering by small particles from 1957 or Bohren/Huffman, Absorption and scattering of light by small particles, Wiley 1983.

Reply: Okay, we now also cite Van de Hulst and Bohren & Huffman.

C6

In addition, Gedzelman / Vollmer Twice in a blue moon, Weatherwise Sept/Oct 2009, 28-35, discussed blue moons including the role of ozone and also a but of optical depth discussion.

Reply: Thanks for this suggestion, we were not aware of this article. It is now also cited in our manuscript.

Interactive comment on Clim. Past Discuss., <https://doi.org/10.5194/cp-2020-117>, 2020.