Response to RC2 (Anonymous Referee #4)

Revealing Halos Concealed by Cirrus Clouds

Yuji Ayatsuka

I would like to thank the reviewers for their kind and useful comments and constructive suggestions on our manuscript. We have modified the manuscript according to the comments as possible. The modifications in our revised manuscript are listed below.

Main comment

- *The major revision I would like to see is a quantitative assessment of the Boyd (or other) method using the four image processing techniques described here. To save time, the Boyd training set (presumably available online or from the authors) could be used as a benchmark. Can you show quantitatively that there is an advantage to the new approach?*

Thanks for the insightful comment. Boyd and Foster's algorithms are designed to detect halos in an image, while ours is designed to process images into ones in which we can easily detect halos, making it difficult to compare them directly at this time. Although our algorithm is able to make Boyd and Foster's algorithms more efficient, I think this will be one of our future studies. Instead of the comparision to their algorithms, as a quantitative evaluation of the algorithms presented in the manuscript, I have added Fig. 12, which shows histograms of the processed images and some explanations of them.

Applying our algorithm to Total Sky Image datasets will also be an interesting future study, but we may need some more parameter optimization of the algorithm, since we mainly tuned parameters for images taken with standard cameras and lenses. I have also added some descriptions about this.

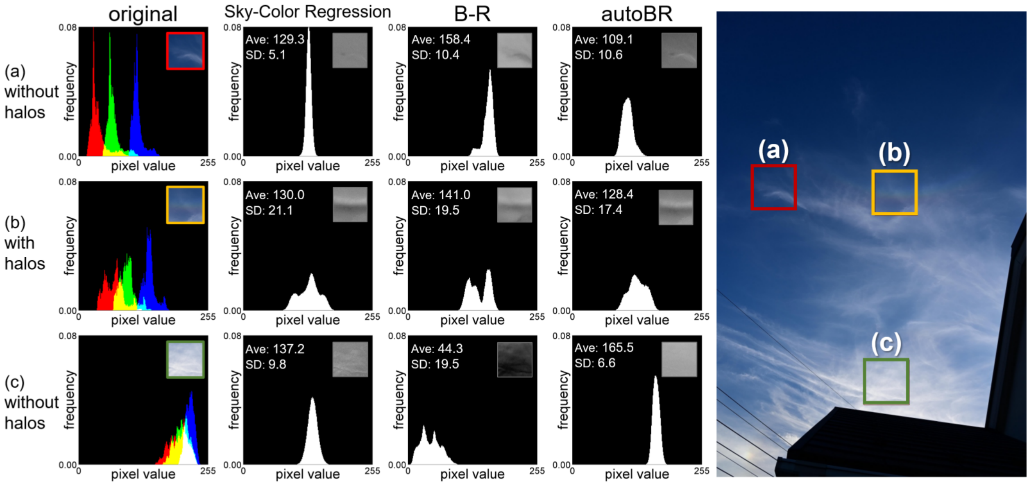

Figure 12: Histograms of Processed Image Parts: (a) and (c) are areas without halos, while (b) is an area with circumzenithal and supralateral arcs.

Line 152: 6.1 Evaluation

Fig. 12 displays histograms of processed image parts by the sky-color regression, B−R processing and autoBR. Rows (a) and (c) show areas without halos, while row (b) shows an area with circumzenithal and supralateral arcs.

With the sky-color regression and autoBR, distributions of pixel values for areas (a) and (c), without halos, are simple standart distributions, while there are two or more peaks in distributions with B−R processing. Standard deviations are also smaller with the sky-color regression than with B−R processing. For area (a), the standard deviation is smaller when using the sky-color regression compared to autoBR. Conversely, for area (c), the standard deviation is smaller with autoBR than with the sky-color regression. It shows that the sky-color regression is not always the most effective method for canceling out cloud, and to be refined in future studies.

For area (b), all algorithms produced a histogram with three peaks corresponding to the clouds, reddish parts, and bluish parts of the halos. However, the peaks are most clearly separated with the sky-color regression. The standard deviation is also the largest with the sky-color regression.

The average values for the areas are maintained around 128, which is the midpoint value of the range 0 to 255, with the sky-color regression. It shows that the local adaptive processing works.

next to Line 158: The sky-color regression algorithm has been developed and optimized mainly for the images captured by standard digital single-lens reflex (DSLR) cameras equipping lenses with focal length 24 mm to 100 mm. Adjusting parameters may be necessary for other types of images, such as total sky images. Optimizing and evaluating the algorithm for total sky images is an area for further study.

- *More justification of the relevance of detecting halos is needed. Many studies, perhaps some by Alexei Korolev (ECCC), Greg McFarquhar (Univ. Oklahoma), Ben Murray (Leeds), Sergey Matrosov (Univ. Colorado), Knut Stamnes (SIT), Ping Yang (Texas A&M), and others could be used to motivate the importance of information about ...*

Thanks for listing related researches. I have added some references and description in the introduction.

Line 10: It is in an in situ and wide-area observation of ice crystals in clouds. For example, the difference in frequncy of appearance between 22° and 46° halos suggests the ratio of pristine to non-prestine crystals in clouds (van Diedenhoven, 2014). There are also several studies ice crystals and halo observations (Lynch and Schwartz, 1985; Sassen et al., 1994; Um and McFarquhar, 2015; Sassen, 1980; Lawson et al., 2006).

- *More review of how halo images are analyzed would benefit the paper.*

I have added references of the papers conatining images processed by some techiniques. (Updated references are listed at the end of this letter.)

Line 12: Image processing techniques can be used to observe even faint halos in photographs more clearly, which can greatly aid in these types of studies (Riikonen et al., 2000; Moilanen and Gritsevich, 2022; Großmann et al., 2011).

- *More review of how the older B-R technique is used would also benefit the paper.*

I would like to refer to papers that describe and analyze the B−R processing in detail, but I could not find them (it is one of the motivations for writing this manuscript). I have added quantitative comparizons of the B-R and other techiniques as Figure 12, and also added footnotes at the description of the B-R processing.

Line 59: B−R processing also referred as "color subtraction," is a widely used technique for enhancing and explaining halos and other atmospheric optical phenomena.
Footnote for it: See
https://atoptics.co.uk/blog/opod-helic-lowitz-arcs-france/ or
https://atoptics.co.uk/blog/opod-helic-lowitz-arcs-france/ for examples.

Minor comments

- *Line 8. Somewhat nitpicky, but halos refer to full circle displays (implying randomly oriented particles) and oriented displays are arcs; i.e., Fig. 1 includes both arcs and halos.*

Sorry for the ambiguous words, but a term "halos" sometimes includes arcs in papers on atmospheric optical phenomena such as "Atmospheric Halos" by Walter Tape. I have added description and a footnote that clearly define "halos" including arcs in this manuscript, in the abstract and in the main texts.

Line 1: ... halos (including arcs) appear in the sky.
Footnote for Line 8: 'Halos' are typically used to refer to sun-centered rings, while 'arcs' refer to the other type of atmospheric phenomena caused by ice crystals. However, in this manuscript, we will use 'halos' to refer to both.

- *Line 42, 165. The purpose isn't to detect halos, right? Rather, the purpose is to process images so as to enhance light associated with halos and increase the accuracy of detection algorithms. See Major comment (a).*

Thanks for the comment and sorry for the ambiguous notation. Of course, the purpose of the algorithms is to process image for easier halo detection. I have modified some descriptions.

Line 42: "to detect halos" → "to process the image for easier halo detection"
Line 165: "to extract halos from sky images" → "to process sky images for easier halo detection"

- *Lines 18-20: I can't tell if autoBR needs a citation or if it is being introduced in the present manuscript.*
- *Line 76: Explored heuristically where? Earlier you stated that you developed it but no reference was provided. Is this being introduced here or can it be referenced?*

Sorry for unclear descriptions. I implemented the autoBR algorithm in a tool (called Atmospheric Optical Image Enhancer (AOI, for short)) that was released two years ago, but details of the algorithm are explained first in this manuscript.

- *Line 26: It seems like this technique would work best for arcs that are refractive (i.e., disperse white light into spectral constituents like a 22 deg halo) but not for arcs that are reflective (i.e., are also white, like a parhelic circle). Is that true?*

It is almost true. However, the algorithms also work on some colorless arcs, such as a parhelic circle (see the images in the second row from the bottom in Figure 11). In another example not in this manuscript, a helic arc can be seen in the processed image. From these results we can know that such arcs are somehow bluer than the background clouds. It is an interesting point that the algorithms allow such an analysis.

I have added a description about it in the manuscript.

Line 149: While the algorithms mainly enhance colored halos, a colorless parhelic circle is also visible in the image at the second row from the bottom. It suggests that a parhelic circle appears slightly bluer than the background clouds.

- *Figure 5, Line 95: I'm having a trouble understanding what is being represented here. The annotation is ambiguous and the arrows aren't explained. Can you add information to the caption and add interpretation to the text?*

Sorry for the unclear explanations. The "colors" on the picture are some kind of vectors consisting of R, G and B values. The arrows represent the addition of vectors. I have added the explanations in the caption of Figure 5.

Figure 5: The arrows represent vectors, L_M and L_H, added to the vector L_R (in the B vs. R. space). The color of the sky at a given point in an image is the result of the summation of three vectors.

- *There are no photo credits. Were the photos all taken by the author? If they aren't, please add credits. If they are, congrats on the odd radius halos in the middle row of Fig 11. Outstanding capture!*

Yes, all the photographs in this manuscript were taken by the author. I have added the description in the caption of Figure 1. (Thanks for the comment, and I am glad you like the photo of the pyramidal halo display!)

Figure 1: (All the photographs in this manuscript were taken by the author in Tokyo, Japan.)

- *Typos*

Thanks for catching these typos. I have corrected them all.

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