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Interactive comment on "Changes in Surface Broadband Shortwave Radiation Budget during the 2017 Eclipse" *by* Guoyong Wen et al.

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The manuscript by Wen et al. discusses observations with pyranometers during the total solar eclipse of 21 August 2017. Pyranometer were located at two locations in the path of totality, at Casper, Wyoming, and Columbia, Missouri. Both locations were affected by clouds during the period of the eclipse. From their data, the authors reconstruct clear-sky measurements, i.e., they predict a time series of short wave (SW) irradiance at the two sites if there had been no clouds. In addition, they calculate the average reduction in SW irradiance for the two sites and the reduction of SW irradiance received by the Earth as a whole. The paper provides a quantification of the change in SW irradiance at two locations along the path of the solar eclipse of 21 August 2017. However, the findings are not generalized to be useful for the interpretation of the effect of solar eclipses in general. The topic of the paper is appropriate for publication in ACP.

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Discussion paper

General remarks

My main criticism of the paper is that the authors make many assumptions to simplify the problem at hand without estimating the impact of those assumptions on their results. Their findings are also not complemented with an uncertainty budget. For example, in Section 4.2., the effect of the eclipse on the reduction of global average irradiance is calculated based on the average SW flux within the area of the penumbral shadow "projected on Earth cross-section perpendicular to Sun-Earth line." According to Figure 6, a part of the perimeter of this area is outside the Earth. This circumstance is not even mentioned in the manuscript and will lead to errors when calculating the eclipse-induced relative reduction in SW flux according to Eq. (8.2) as changes in radiation outside the Earth's cross section are obviously inconsequential for the amount of energy received by Earth's surface.

Furthermore, the authors estimate the global surface effect of the eclipse from measurements at only two stations and do not take into account that the irradiance at Earth's surface does not only depend on the top of the atmosphere (TOA) reduction of irradiance resulting from the Moon's shadow but also on the path length of radiation traveling through the atmosphere. By basing their estimate only on two sites located in the path of totality, they neglect the fact that less radiation penetrates the atmosphere (both with and without eclipse) at high latitudes due to larger solar zenith angles (SZAs). Specifically, the authors assume in Eq. 8.3b that DeltaF is independent of azimuth angle phi but do not provide an estimate of the uncertainty caused by this assumption. While the effects of the difference in optical path at high and low latitudes partially cancel, the cancellation is not perfect because the change in atmospheric transmission depends exponentially on the optical path. The resulting uncertainty should be quantified.

In addition, the authors assert that the "temporal average of the observed surface SW flux from a local site is approximately equal to the spatial average of the surface SW flux" but do not try to estimate the uncertainty of this assumption. For example, uncertainties arise because the eclipse is not symmetric with respect to time. This is evident from Table 1, which shows that at Casper, the time difference between the first contact and totality is 1:21:33 while the difference between totality and forth contact is 1:25:34 - a difference of about 4 minutes. The effect may be small, but it should be quantified.

Lastly, estimating cloud optical depth from an instrument observing the direct Sun, like PANDORA, can lead to large errors, which are not discussed by the authors.

The PANDORA instrument has a relatively large field of view (FOV) of 2.2° (L101). This should work well for aerosol optical depth (AOD) retrievals if AODs are small, but could become problematic for estimating cloud optical depth, which are much larger. Ideally, the FOV of a radiometer looking at the direct beam for measuring optical depth should only be as large as the angular diameter of the Sun (~0.5°). (Of course, such a small FOV is not feasible due to tracking errors.) For large optical depths (e.g., tau > 4), the disk of the Sun is no longer clearly visible, and the radiation across the instrument's FOV is nearly uniform. In this case, the fraction of the instrument's signal that is contributed from the solid angle that contains the solar disk is only about (0.5°)ˆ2 / (2.2°)ˆ2 = 0.052 or 5.2%. As a consequence, the instrument "sees" much more light that it should and the resulting optical depth will be too small.

I suspect that the difference between the measured (green) and modeled (red) lines in Fig. 7 could be explained by values of cloud optical depth used in the model that are too small. If larger cloud optical depth were used, measurement and model should agree much better. The authors should provide an uncertainty estimate of the PANDORA-derived cloud optical depths and if necessary, apply a correction for the FOV effect. If my suspicion that systematic errors in the PANDORA cloud optical depth retrievals cause most of the difference between the measured and modeled results, the alternative explanation on line 356 ("Again, the cloud inhomogeneity is the main cause of the overestimation") may not be the dominating factor.

Specific comments:

L23: The sentence “The eclipse has a smaller impact on absolute value of surface flux reduction for cloudy conditions than a clear atmosphere; the impact decreases with the increase of cloud optical depth.” is trivial and could be deleted (see also my comment with respect to line 364 below).

L78: The Sun was not “nearly overhead” at the two sites. According to Table 1, the SZAs at the time of totality were 36° and 27°.

L119: Delete “collimated“

L144: The link http://aa.usno.navy.mil/data/docs/Eclipse2017.php does not work

L146: “the fact that the value of distance linearly correlated to time“ is not a fact but a crude assumption. If that were the case, the time between 1st contact and totality and totality and 4th contact would be the same, but it is not.

Eq. (1) and Figure 2: Beer-Lambert’s law only applies to monochromatic radiation. What wavelength is discussed here?

L169: irradiance > spectral irradiance at a wavelength of xxx nm

L200 - 201: This paragraph is a misrepresentation of the paper by Koepke et al. (2001) and focuses on a small detail of that paper. I would say: Amongst others, Koepke et al. (2001) estimated ...“ Also, change “normalized radiance“ to “the ratio of spectral irradiance at 310 nm calculated for eclipse and non-eclipse conditions“.

L202: delete “radiance and”. (Radiance (e.g., from the sky) are neither discussed by Koepke or in this paper).

L266 - 270: The value of DeltaF depends greatly on the cloud condition at the time of the eclipse. If I understand the text correctly, F2 (i.e., the denominator of Eq. (8.2)) was multiplied by factor of 0.55 to account for the average global transmission of the atmosphere. If clouds and other atmospheric absorbers and scatterers within the area of the eclipse would attenuate the TOA irradiance by the same factor, Delta F would provide a good estimate of the “mean” global consequences of the eclipse. However, if the area affected by the eclipse were either clear-sky or shrouded by an optical thick cloud, DeltaF could greatly deviate (either up or down) from this average value. While this issue is discussed to some extend later when results for Casper and Columbia are presented, the limitations of estimating the global consequences of an eclipse should already be introduced here. The authors should keep in mind that their paper would be more useful if their results could also be applied to future eclipses occurring at different locations and cloud conditions. A generalization of their findings would be appreciated by readers.

L271: The link http://aa.usno.navy.mil/data/docs/geocentric.php does not work.

L280: In line 259, F_eclipse was defined as the average flux in the 2D area of the Moon’s shadow. Here F_eclipse is defined as the average of F along the totality path. This is not the same. The equation should be deleted here because only the definition on L259 (and the calculations in Eq. (8.3)) are relevant here.

L292: As mentioned in my general comment, the assumption that fluxes at Earth’s surface are independent of the azimuth angle is rather crude and the uncertainty of this assumption should be quantified.

L296-297: Change “F_non-eclipse(r) is derived from F_non-eclipse(r) (Eq. 6.2).” to “F_non-eclipse(r) is derived from F_eclipse(r) according to Eq. (6.2).” (Note that the original sentence includes “non” twice.)

L303: Why does more cloud cover lead to more realistic atmospheric conditions? Do you mean that the conditions at Columbia are more representative for the average attenuation of radiation, e.g., as expressed earlier by the factor of 0.55?

L314-317 & L324: While it is true that clouds can lead to irradiances at the ground exceeding the clear-sky limit, an enhancement of about 22% near the time of totality (as indicated in Fig. 7a) that is caused by “thin cirrus clouds” seems to be rather large. I suspect that systematic errors in the conversion of the observed measurements (black line in Fig. 7a) to the “derived non-eclipsed” dataset (green line) may have also contributed to this large enhancement. The uncertainty of this conversion should be given or at least it should be acknowledged that systematic errors in the conversion could have contributed to the large enhancement effect.

L330: As mentioned earlier, I suspect that systematic errors in the cloud optical depth data from the PANDORA spectrometer are the main cause of the discrepancies between the modeled (red) and derived (green) surface SW irradiance at time where clouds attenuate (i.e., when the Sun is behind the cloud). The authors should quantify systematic errors in PANDORA-derived cloud optical depths.

L356: The sentence “the cloud inhomogeneity is the main cause of the overestimation” is just an assertion without basis. As mentioned above, I think the large FOV of the PANDORA spectroradiometer is the main cause of the overestimation. If the authors disagree, they should provide quantitative evidence that cloud inhomogeneity is really the main culprit.

L364-375, Figure 8, Figure 9: It is rather trivial that the effect of the eclipse leads to smaller *absolute* changes during cloudy than clear conditions. I am not sure why this is discussed in such detail here, and even mentioned in the abstract.

L380: Please delete “rigorously”. As mentioned above, there are many assumptions and simplifications going in these calculations. I would not consider them “rigorous”.

L382-393, Figure 10: My take-home message from this paragraph and the figure is that the global effect of an eclipse on SW irradiance is between about 4 and 10%, and depends on a lot of factors, including SZA and cloud optical depth. Such a wide range of reductions is not very useful. It would be nice if the authors could generalize their results to make them more applicable for other eclipses.

L409: I disagree with the conclusions that “clouds play a unique role in modifying the surface flux reduction during an eclipse". As correctly concluded in the paper, clouds attenuate the incoming radiation by about the same percentage during a partial eclipse and during a normal day, except of the red-shift effect (Fig. 5), which is smaller than 5%. So I don't see anything "unique" about clouds (with the exception that they are a nuisance when interpreting measurements during an eclipse.)

Figure 2: Specify wavelength. In the caption, change "radiances" to "irradiance" (The optical depth refers to the attenuation of the direct solar beam.)

Figure 3: Explain color scale of panels (d) and (e).

Figure 4: Change "nearest station in Springfied" to "Springfield, the nearest station to Columbia".

Figure 5: The font size is the insert of panel (a) is too small. Define the term "spectral transmittance" (make clear that transmittance refers to the global (sun and sky) irradiance at the surface, not just the solar beam).

Technical corrections:

L23: on absolute > on the absolute

L34: arctic > Arctic

L192: error cloud inhomogeneity > error in cloud inhomogeneity

L230: slight > slightly

L368: optical depth > optical depths

L473: The paper by Ockenfuß is now published.

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