1 Overview and general recommendation

This manuscript describes the inference of equations depicting how the electric signal of the Absolute Cavity Pyrgeometer (ACP) can be related to the incoming irradiance at the entrance of the instrument considering the different fluxes within the instrument. The ACP was first described by Reda et al. (2012) and is considered as one of two types of instrument that can be used for providing the World primary reference for terrestrial radiation in the future. The description given by Reda et al. (2012) included assumptions that strongly restricted the conditions when the instrument can be used. In any case, the ACP having no dome, it can only be used during fair weather nights, which is already a restriction, but the further added restrictions by Reda et al. (2012) complicated its use. Thus, this manuscript is an important contribution to the description of an instrument that may participate in the definition of the next primary reference for terrestrial radiation and its scope is appropriate for publication in Atmospheric Measurement Techniques.

I find the manuscript of good quality and most of my comments concern minor points where I think that clarifications are needed or I find some formulation unclear where I usually suggest reformulation that I hope to be clearer. I have two more important comments, the first being that I believe all elements are present in the manuscript for computing a full uncertainty budget, which I recommend to add. The second is that the manuscript is overly long, and I recommend suppressing one part that I find can be omitted. I think the manuscript can be published after my main comments are addressed and the minor points are resolved.

I detail my comments below starting with my two most important comments followed by minor points. Some of the minor points still emphasize questions that need clarification, while some other are just corrections of typos.

2 Major Comments

1. Because the ACP is considered as a potential instrument for a group providing the future primary reference for terrestrial radiation, it is important that its uncertainty budget is well defined. The manuscript provides improved equations for describing the physics of the ACP. With these, it should be possible to better determine the uncertainty budget than was possible for Reda et al. (2012), and the resulting uncertainty for the ACP may also be smaller than the one given by Reda et al. In addition, sections 7.1, 9.1 and 9.3 already contain most of the elements that should be considered for the uncertainty budget. I am aware that the authors recommend further work, especially concerning the influence of the convection term when it varies, for instance, when humidity is high, but I believe the authors can already give estimates. I strongly recommend including a full uncertainty budget computation just before the conclusion. I think this would not be too overwhelming an effort given how valuable it would be.

2. While the manuscript is extremely thorough, it is also very long. It is valuable to compare several methods for determining the characteristics of the ACP, especially detailing how the new determinations differ from those of Reda et al. (2012). This partially explains the length of the manuscript. However, I do not find the part describing the calibration using solar irradiance very helpful, especially since generic values had to be used for the thermopile calibration because no solar calibration of an ACP was performed. I would recommend suppressing the parts of the manuscript referring to the calibration using solar irradiance and eventually let it for a further publication when such calibrations could actually be performed.

3 Minor Points

Note: assuming the authors used LaTeXto format their manuscript, I used LaTeXformatting for the minor comments allowing me to use the corresponding mathematical typesetting. I also include the PDF file (available as supplement) obtained by processing the LaTeXdocument to facilitate reading the mathematical formulas.

1. Eq. 5 (line 67) should be $KV = \varepsilon_r (W - W_r)$. The different equation in the manuscript is most likely a typo because the equation given here is consistent with both the previous and next equation in the manuscript.

2. Eq. 7 (line 72). The first term of the right-hand side should be $T_b(t)$, not $T_{rb}(t)$.

3. Lines 90-91: is the concentrator absorptance a consequence of the scattering on the walls because some radiation is again scattered toward the concentrator wall where it can again be absorbed? Please, clarify.

4. Line 92: Replace "at one end of the symmetrical concentrator" with "at the lower end of the symmetrical concentrator affixed to the body part of the ACP pyrgeometer", so that there is no possible confusion.

5. Lines 98-100 and derivation from Eq. (11) to Eq. (12): Eq. (11) is the same as Eq. (4), and it can be suppressed while simply mentioning that Eq. (4) is also valid for the outgoing flux from the receiver when the concentrator is present. It may be more useful to replace Eq. 11 from the manuscript with an equation that results from solving Eq. (4) and Eq. (10):

$$F_{\downarrow} = \frac{\tau W + \varepsilon_c W_c + \beta \varepsilon_r W_r}{1 - \beta(1 - \varepsilon_r)} \tag{11}$$

   Which then easily leads to Eq. (12) in the manuscript.

6. Line 112: Replace "... dependent on several factors such as water vapur content" with "... dependent on several factors such as water vapor content."

7. Line 130, citation of Jinan et al. (2010). I think Jinan is the given name and Zeng is the surname, which is a rather common Chinese surname. Thus, I believe this reference should be Zeng et al. (2010) and not Jinang et al., (2010). This also applies at lines 134, 139, 144, 215, 265, 548, 555-556, 675, and at line 691 where the reference is given that should be "Zeng, J., Hanssen L., Reda I., Scheuch J." and not "Jinan, Z., Hanssen L., Reda I., Scheuch J."

8. Eqs. 19 and 20 (line 131-138): The derivation by Zeng et al. (2010) does not use the same terminology as this manuscript. I believe it is assumed in the manuscript that Zeng et al. described the relationship between the thermopile signal and a reference irradiance signal S when the concentrator is not present as $K_1 V_0 = S_0 - W_{r0}$, while the relationship with the concentrator present was taken as $K_1 V_c = \tau S_c - W_{rc}$. Dividing the latter by the former allows obtaining Eq. 19. If these assumptions were made, it would help the reader stating them in the manuscript. I also believe this manuscript includes corrections for convection and emission by the concentrator wall in these two relationships as $K_1 V_0 = S_0 - W_{r0} + \gamma(T_{air0} - T_{r0})$ (without concentrator) and $K_1 V_c = \tau S_c - W_{rc} + \varepsilon_c W_{cc} + \gamma(T_{airc} - T_{rc})$. Again, dividing the latter by the former allows obtaining Eq. 20. It would also help stating it in the manuscript.

9. Eqs. 19 and 20 (line 131-138): I wonder if other subscripts than "0" and "c" could be used for the situation with and without concentrator. Subscript 'c' is also used for describing characteristics of the concentrator itself such as its emissivity, temperature, thermal emission, etc. Also using it to denote measurements taken with and without concentrator makes it confusing for the reader: in this case, W_{rc} is the thermal emission from the receiver (not the concentrator), when the concentrator is in place.

10. Lines 183-184: I am not sure what the authors meant with "Using Eq. (22) these results implied data selection generates..." The authors may have meant "Using Eq. (22), the data selection implied by these results generates $\langle K_1 \rangle$ that are approximately 6% less than the Reda et al. (2012) implementation."

11. Line 185: Replace "... the difference between the results from Reda et al., 2012 and the use Eq. (18) could be..." with "... the difference between the results from Reda et al. (2012) and results using Eq. (18) could be..."

12. Line 190: Replace "the base temperature of the pyrgeometer, and its dome, and the blackbody output irradiance are changed..." with "the base and dome temperatures of the pyrgeometer, and the blackbody output irradiance are changed..."

13. Lines 206-207: I am not sure how to understand the end of the sentence. With "α_c is not required but given Kirchhoff's law indicates it would not be independent of ε_c" did the authors mean "Kirchhoff's law allows relating α_c to ε_c, reducing the number of concentrator properties to determine"?

14. Line 211: "For ACP95 the concentrator emissivity ... was found to be 0.0225..." is already mentioned at the beginning of section 5.

15. Line 225: A range for γ is given at the end of the paragraph. In addition, there is an estimation of the impact of γ uncertainty on W_{atm} in the third paragraph of section 8 (starting at line 250). I would suggest to move this estimation here after line 225 (section 7.1 is about impact of uncertainties on W_{atm}) and refer to it later in section 8.

16. Lines 247-249: "but α_c the absorption fraction..." It is unclear to me if α_c is different from α in eq. 9. By analogy with ϵ_c (that I understand as the emissivity of the concentrator walls), α_c may be the absorptivity of the walls and not the concentrator as a whole. If they are the same, this sentence only expresses Kirchhoff's law in words or is a rewording of the fact that the backscatter is assumed insignificant. Please clarify.

17. Lines 252-253: Replace "convection coefficient γ divided by concentrator transmission of..." with "convection coefficient divided by concentrator transmission (γ/τ) of..."

18. Lines 276-278: Replace "... and for ACP96 a 1 s measurement sequence every 10 seconds" with "... and a 1 s measurement sequence every 10 seconds for ACP96."

19. Line 282: Replace "... instrument expanded (k=2) of 2 Wm^{-2}..." with "... instrument expanded uncertainty (k=2) of 2 Wm^{-2}..."

20. Line 303: Replace "One we will assume..." with "We will assume..."

21. Line 314: "Using the new equation..." Do the authors mean "Using Eq. 18 with τ estimated with Eq. 20? Please be more specific.

22. Line 355: Replace "... the average differences were much smaller in magnitude" with "... the average differences were smaller in magnitude when using the data from both IRIS instruments to derive single C and τ values."

23. Line 371: "in the new equation..." Again, I think the authors are referring to Eq. 18. Please refer to it by its number.

24. Eq. 26 (line 383): To strictly follow Eq. 18, the term $\langle K_1 \rangle V(t)$ should be preceded by a minus sign.

25. Lines 413-421: It is not clear whether there are three or four conditions. One condition states that a cooling sequence does not start before $(T_r - T_c)(t_i) - (T_r - T_c)(t_{i+1}) < 0.04$ or that it ends when this condition is not anymore fulfilled. On the other hand, there is also a condition that $(T_r - T_c)(t_i) - (T_r - T_c)(t_{i+1}) < 0.02$. Does this mean that, within a cooling sequence, only measurements satisfying the latter condition are kept? Is there also a condition on the minimum number of valid point in a cooling sequence? Please clarify. I also think it will help the reader if the paragraph started with a general statement on the conditions then listed the conditions explicitly. In case the authors have three conditions (adapting to four conditions is straightforward), I suggest introducing the paragraph as follows. "Three conditions were used to select measurements sequences acceptable for the LSQ calibration, limiting the voltage difference between two successive measurements, the change in the temperature difference between the receiver and the concentrator between two successive measurements, and the total voltage increase over a full cooling sequence. Explicitly, the conditions were:" After this introduction, the authors can include a numbered list with the conditions explicitly detailed.

26. Lines 415-416: Replace "... the voltage difference between two consecutive voltage was least than or equal to +3.5 μV" with "... the voltage difference between two consecutive voltage was less than or equal to +3.5 μV."

27. Lines 425-426: "... the slopes for $(T_r - T_c)$, and $\langle A_{dT} \rangle$, shows an upwards shift between days 200 and 255 that recovers when data collection recommenced on day 312." It is difficult to see such an upwards shift on Figure 4. There are three groups of points between days 200 and 255. For these groups, the green points have extremely similar values, except maybe for the last day in the period where there is some dispersion, but it is not larger than the dispersion in the group of point between day 0 and 30. I am not sure this statement can be upheld and I would suppress it.

28. Line 433: Only a single short sentence mentions Figure 6, just saying what parameter is displayed on the figure. If this figure is not discussed, it should be suppressed as well as this sentence. I think Tables 5 and 6 are sufficient for the discussion.

29. Table 5 caption (lines 441-443): The caption of Table 5 is confusing for me. I think the authors meant, and should indicate as caption "ACP $\langle C \rangle$ determined using linear LSQ calibrations and using IRIS measurement as reference irradiance (section 8.3). LSQ calibrations use all 244 periods regardless of the stability of W_{atm}. When IRIS measurement are used as reference, values of $\epsilon_c = 0.0225$, $\gamma = 6.5$ and $\tau = 0.977$ are chosen and only periods with a standard deviation of W_{atm} from the IRIS less than 0.4 Wm-2 are used, including 115 periods for IRIS2 and 63 periods for IRIS4".

30. Table 6 caption (lines 445-447): In relation to the change suggested for Table 5 caption, I suggest to replace the caption of Table 6 with "Same as Table 5 for the determination with IRIS as reference, but with values of $\epsilon_c = 0.0225$, $\gamma = 8.4$ and $\tau = 0.977$".

31. Lines 449-450: Replace "... are shown in Figure 7 with the convection coefficient used value is 6.5" with "... are shown in Figure 7 (computations use a convection coefficient $\gamma = 6.5$"

32. Line 453: I do not understand what the authors meant with "give consistent < C > values about a mean".

33. Lines 474-475: Replace "... is a consequence of net irradiance based on the temperature difference of the base of the thermopile to the top of the thermopile" with "... is a consequence of net irradiance inducing a temperature difference between the base and the top of the thermopile."

34. Lines 505-506: Replace "... over the cooling and heating period was below 0.6 Wm-2" with "... over the cooling and heating period to be below 0.6 Wm-2."

35. Lines 514-515: Replace "... provided irradiances compared well" with "... provided irradiances that compared well."

36. Line 580: Replace "The Reda et al., 2012 and the new equation are dependent..." with "The equation from Reda et al., 2012 and the new equation are dependent..."

37. Line 582: Replace "... provided the other coefficients in new equation are known" with "... provided the other coefficients in the new equation are known."

38. Line 615: Replace "... this is complicated by needing to divide by the transmission" with "... this is complicated by the need to divide by the transmission."

39. Lines 653-654: Replace "Further work is required to ensure that confirms the ACP..." with "Further work is required to confirm the ACP..."

40. Lines 668-669: Replace "... were reduced but not eliminate" with "... were reduced but not eliminated."