Atmos. Meas. Tech. Discuss., 8, C2251–C2265, 2015
www.atmos-meas-tech-discuss.net/8/C2251/2015/

Atmospheric Measurement Techniques Discussions
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Interactive Comment

Interactive comment on "Shortwave surface radiation budget network for observing small-scale cloud inhomogeneity fields" *by* B. L. Madhavan et al.

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Received and published: 27 July 2015

Responses to anonymous referee # 1

We thank the reviewer for providing his/her valuable comments and suggestions on our article "Shortwave surface radiation budget network for observing small-scale cloud inhomogeneity fields" (amt-2014-313). In the process of revision, we have made the following changes in the original manuscript:

1. The title of the article was revised as "Shortwave surface radiation network for

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observing small-scale cloud inhomogeneity fields".

2. Section 3 (Data processing and initial quality control) from the old manuscript was revised to include the uncertainty estimation. The revised section 3 (Data processing, quality control and uncertainty estimation) excludes the statistical procedure completely and the quality control procedure was limited to observational flags. Accordingly, figure 4 and previously defined terminology for interpretation of results were removed. An uncertainty assessment of global horizontal irradiance (G) and corresponding derived global transmittance (T) measurements influenced by various operational sources was undertaken with the available observations during HOPE. These details were included in the revised manuscript as sub-section 3.3 with a more detailed report including figures as a Supplement.

3. Table 1 was updated and revised to include more information about ADC data logger and amplifier characteristics. Table 3 from old manuscript was labeled as table 4 in the revised manuscript. Uncertainty estimates of global horizontal irradiance and corresponding derived transmittance from various sources was included in Table 3 of the revised manuscript.

4. Minor corrections to figures 2 and 3 were done. Figures 5, 6 and 7 from old manuscript are renumbered as figures 4, 5 and 6 in the revised manuscript.

5. Following the revision of quality control procedure, the results and discussion section was revised accordingly retaining the same idea but with improved structuring.

Following are the responses to the referee comments (in *italicized* font):

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1 Specific comments

a) I have a lot of questions about the QC methods. In this regard, the data provider must demonstrate that the data are of sufficient quality for the analysis that is performed or intended. For the present preliminary work, the standard of proof is not as high as it would be for more explicit study of the effects of cloud structure on the surface SW irradiance field. Even so, a number of questions remain unaddressed.

The quality control procedure was revised by removing the entire statistical procedure and confining to the observational flags in the revised manuscript.

> *p. 2561, 20-25 – How were the cleanliness and level flags assigned? If contaminants or tilt in the instrument were found, were these situations corrected?*

- The cleanliness (on a scale of 1-10, with 1 representing perfectly clean condition while 10 corresponds to complete blocking of glass dome) and level (on a scale of 1-3, with 1 for perfect horizontal alignment while 2 and 3 correspond to the two possible orientations of misalignment, see figure S2 in supplement) flags were recorded with physical inspection once in a week when the battery replacement was undertaken. Cleanliness flags were assigned basing on the fraction of glass dome covered with either dust/soil, bird droppings etc.
- A spirit (or bubble) level was available on the leveling plate, which mounts the pyranometer sensor. The screws of the leveling plate were adjusted on the mounting rod such that the bubble in the spirit level is enclosed within the marked circle (i.e., indicator for perfect horizontal alignment). Figure S2 shows the picture of leveling plate adjusted with screws on the mounting rod with perfect horizontal alignment and other two possible misalignment positions (refer Supplement).

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- No corrections were applied to data. However, the uncertainty estimates due to soiling and horizontal misalignment were included in the revised manuscript.

p. 2563, 18-20 – The presence of birds, droplets, and shadows are physically observable. Do you just mean that you didn't observe them? Some of these can be (at least partly) accounted for. For example, observations that occur during periods when precipitation was falling can be eliminated; shadowing can be detected by looking for low irradiance values that occur for the same sun positions every day or by taking hemispheric photos at the station locations to determine the position of obstacles. A visit to or photograph of the site should allow one to make a rough estimate of where and when shading might occur, making the process of identifying shading in the data easier. In order for this data to be used in serious cloud research, at least the shading should be treated explicitly.

- As maintenance of each station was performed weekly once, the presence of birds or droplets at intermediate periods cannot be identified physically at a particular station unless continuous physical monitoring of the station is available. Short-term fluctuations in the global irradiance measurements can be observed due to the presence of birds on the pyranometer sensor. However, we can only attribute this signal to resting of birds if the sky is completely clear (or homogeneous) along with perfect cleanliness and horizontal alignment of pyranometer sensor. Measurements influenced by precipitation can be identified through sky images or rain gauge, but we cannot generalize that precipitation has occurred at all other stations simultaneously.

- We agree that shading can be identified by capturing photographs of surroundings at each station. The contribution of diffuse sky radiation for solar elevation angles < 5 is less than 1% and can be neglected. On contrary, the shadowing objects subtending angles of 10 or more and those that might intercept the solar beam at anytime requires attention. The correction to shadowing can be obtained from diffuse irradiance measurements on perfect cloudless days. The fraction of the sky which is obscured should not be computed but rather the fraction of the irradiance coming from that part of the sky which is obscured should be computed in order to correct the shadowing. Once the diffuse sky irradiance is corrected, the global irradiance adjusts subsequently. However, absence of diffuse sky radiation measurements constrain the application of this procedure for accurate determination of shadowing effect on pyranometer measurements specifically at each station. So, we have assumed that pyranometer measurements until elevation angles of 15 (or solar zenith angles $>$ 75) may have possible shading effects on the measurements due to close by or farther structures. While almost all stations concurred well in excluding the shading effects, there were 4–5 stations which showed the influence of shading above solar elevation angles $>$ 15.

p. 2563, 21-23 – Could bad data not also be characterized as good by these procedures?

- We agree that the chance of bad data being characterized as good through statistical procedure cannot be ignored. So, we have removed the statistical procedure in the revised manuscript.

p. 2564, 18-22 – ". . .. the possibility of small-scale cloud induced fields from a few stations being classified as outliers is high. So, the pyranometer stations with more than 50% measurements classified as outliers or minima or maxima on a given day were ignored completely considering the chance of sensor malfunctioning." In other words, you eliminated data points because they might be correct? Overall – A clearer presentation of how the operational and statistical flags were applied should be given. For that matter, it would be helpful to have the full procedure described on the same page instead of the operational checks two pages before the statistical methods.

- Statistical procedure was removed in the revised manuscript.

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p. 2566, ll. 12-15 – It's unclear where the estimate of 10% error came from. Previously, error was specified only in terms of the values in Table 1, not as a combined value. This possible error is then ignored. Is it not possible that this level of error could affect the measured "small-scale spatial and temporal variability"?

- The 10% error was an approximate estimate from table 1 (old manuscript). The current study is not based on the measurements from a single pyranometer station and the focus was mainly to assess the small-scale variability of cloud induced global irradiance measurements within the spatial domain by including measurements from all stations as a function of time. Even if a single station is assumed to have 10% error in the measurements, then the same uncertainty exist for all the other sensors under the same operational conditions. When the spatial inhomogeneity in the irradiance measurements from all the stations in the observation domain are considered, then the individual sensor uncertainties being the same cancels out for same measurement conditions.

Fig. 7 – Why are there so many more missing or malfunctioning stations on the overcast day?

- In figures 5, 6 and 7, we have ignored the missing or malfunctioning stations. A missing station implies that non-availability of observations from that particular station. Non-availability can arise mainly if a particular station was not switched on after weekly maintenance or removal of a particular station temporarily for some additional maintenance or missing observational flags. Malfunctioning stations were identified based on the criteria that if a particular station repeatedly measures either minimum or maximum values in the spatial distribution of global-horizontal irradiance as time goes on over the day ($>$ 50% values), then these stations were assumed to be malfunctioning or resulting in spurious data. Also, missing of the intermediate measurements were resulting from the missing (or

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skipped) time records by GPS. On 4/5 May, we have observed one malfunctioning station and four missing stations. On 30 May, there were around ten missing stations due to one of the above reasons.

b) The purpose of the thermopile radiometers in this study is unclear.

Since there exist collocated thermopile pyranometer measurements from other research groups (e.g., FZJ, KIT1, KIT2), they were included as additional sources of information in addition to our pyranometer network measurements. As these thermopile pyranometers are categorized as first-class radiometer instruments with high accuracy, we have attempted to validate our close by EKO pyranometer measurements to enhance the reliability of our measurements, specifically on homogeneous sky days. Note that thermopile pyranometer measurements from FZJ were available as 1-minute averages while those of KIT1 and KIT2, they are obtained at 1 Hz resolution. Note that global horizontal irradiance measurements from these thermopile pyranometers are not corrected for zero offset, which may result in additional bias from 1:1 line of linear regression.

- *If it is as a check of the measurements from the silicon detectors, differences should be computed in terms of irradiance or derived transmittance. Correlation is a very weak indicator of agreement. For one thing, it depends highly on meteorological conditions: if the sky is reasonably uniform (clear or overcast), both signals will be highly correlated because the main feature of the day is the sun rising and setting; if broken clouds are present, correlation depends on factors such as the separation of the instruments and the size of the clouds. For another, bias does not affect correlation and, when signals are large, noise doesn't have much effect either.*

- In addition to the correlation coefficient (r), we have included additional measures

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of variability, namely, the root mean square error (rmse), slope and y-intercept (or bias) of linear regression for the time series global transmittance measurements of collocated thermopile pyranometer and the close by EKO pyranometer in the network. These details were included in Table 4 of revised manuscript. Note that table 3 in old manuscript was revised as table 4 in the revised manuscript.

- *In the array configuration that is described, it is not possible to use the thermopile radiometers to assess the accuracy of more than a few of the silicon detectors, because of the spacing. I'm wondering why the typical procedure of setting out all of the instruments over a small area and comparing their measurements over a couple of weeks before deploying them wasn't undertaken. This would at least help in estimating how much the range of estimated transmittances at any given time is affected by instrument biases.*

- We have undertaken an inter-comparison experiment among all EKO pyranometers (95 nos.) with continuous operation for an entire day before deploying them to HOPE Jülich campaign. As the prevailing atmospheric conditions were not favorable for prolonged operation due to snow forecast, we could not continue the measurements for a week or more time. However, we have conducted a similar inter-comparison experiment with 50 pyranometers in the recent Melpitz-Column experiment. The results of these inter-comparison were included in the detailed uncertainty analysis as supplement with the revised manuscript. Altogether, the uncertainty arising from inter-comparison of all EKO pyranometers was $< 5\%$ under variable sky conditions.

- *At several points, it looks like the thermopile radiometer measurements are being used to corroborate the range of transmittance values derived for the silicon detector array: "transmittance from thermopile pyranometers always lie within the limits of spatial variability from pyranometer network. This indicates that our pyranometer network is well capturing the cloud inhomogeneity fields at the surface."*

I don't see how the fact that the transmittance values from the thermopile detectors fall within the range of those from the silicon detectors indicates that the network is capturing the variability accurately. Transmittance from the thermopile detectors could range from 0.5 to 0.52 and would fall within the range from the array whether that range was 0.49-0.52 or 0.1-0.9.

- The statements along with the presentation of results was revised in the manuscript.

c) Other

- *Title. The title is overstated, since only one component of the radiation budget is considered.*

- The title is revised as "Shortwave surface radiation network for observing small-scale cloud inhomogeneity fields".

- *Section 2.1.ii and Appendix A. Please state whether the accuracy specifications given here are operational values or manufacturer's specifications. These can differ significantly. It is the operational accuracy that we are interested in.*

- The accuracy details for the temperature and RH sensors are based on manufacturer specifications. We assume that these specifications agree well for operational conditions. So, we have not evaluated the same as the current study focuses on shortwave surface radiation measurements.

- *p. 2562, l. 4. How far apart were the thermopile pyranometers from each other? Based on this, is there any reason to expect the variability of estimated transmittance among these radiometers to be similar to that from the more extensive array of silicon-based instruments?*

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- The close by EKO pyranometers are spatially apart by 29.5, 227.5 and 343.5 m from the corresponding thermopile pyranometers of FZJ, KIT1 and KIT2 respectively (see page 2562, lines 3-5 old manuscript). In the revised manuscript, our comparisons were limited to the thermopile pyranometer with the nearest EKO pyranometer.

- *p. 2563, 11-12. GHI is not equal to DNI unless the sun is directly overhead.*

- The statement is corrected as "If there is no atmosphere, then the transmittance will be unity and the global-horizontal irradiance equals to the cosine of solar zenith angle weighted direct-normal irradiance (i.e., no diffuse component)".

- *p. 2569, ll. 2-6. The fact that something is difficult to model doesn't mean that it's significant.*

- Several studies emphasized the significance of solar radiation absorption due to broken clouds through both observational and modeling techniques. Solar absorption by clouds of about 25 Wm^{-2} more than global-mean absorption in cloudy atmosphere than predicted by theoretical models was observed using collocated satellite and surface measurements of solar radiation at five geographically diverse locations (Cess et al., 1995). Over western Pacific warm pool, absorption by the entire atmospheric column in the presence of clouds exceeded model predictions of absorption by about 35 Wm^{-2} (Ramanathan et al., 1995). These discrepancies between measured and calculated absorption by clouds were attributed to various factors, namely, cloud inhomogeneity (assumption of plane-parallel homogeneous cloud layers in models), cloud morphology and inadequacy of current models to predict scattering and absorption of real clouds (Pilewskie and Valero, 1995). Further, Cess et al. (1996) indicated that the enhanced shortwave cloud absorption was macrophysical rather than microphysical nature. Using a simple model with numerical stochastic radiative transfer calculation, Byrne et al. (1996) showed that broken clouds cause average photon path lengths to be greater than those predicted by homogeneous radiative transfer calculations of cloud-atmosphere ensemble with similar albedos, especially under and within the cloud layer. This bias was inferred to anomalous absorption.

- *p. 2570, l. 10-12. This is backwards. See, for example, Chow et al., Solar Energy, 2011. This statement, as given, is superfluous because it's not discussed in the context of the experiment. However, it is relevant to the measurements because of the limited spectral response of the silicon detectors.*

\- The statement is corrected as "An overcast sky is characterized by relatively lower global irradiance than that of a clear sky situation at any wavelength".

- *p. 2571, ll. 10-15. Please brush up on the principles of 3D radiative transfer. Side exit of scattered photons from clouds is an important component of increased irradiance in the areas between the clouds. Also, multiple scattering is not required to produce the observed effect. These phenomena have been known for some time, so an older reference should be cited.*

\- The sentence was corrected along with inclusion of older references.

- *p. 2573, ll. 16-21. It is unclear how the measurements from the array can be used in a 3D radiative transfer model or how radiative transfer through cloud fields from an LES model can be used to explain the measurements.*

\- The 3-D cloud fields (e.g., volume extinction coefficients in m^{-1}, single scattering albedo and phase function indices) from Large Eddy Simulations (LES) are input into 3-D Monte Carlo radiation transfer code (Macke et al., 1999) to simulate the shortwave global transmittance measurements within the observation domain of HOPE campaign. The probability density functions (PDFs) of these simulated global transmittance fields are compared with those from the pyranometer network to understand the differences in small-scale variability of cloud

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inhomogeneity fields. Understanding such small-scale variability will help assess what is the best agreement that can be reached in validation studies when comparing point measurements with satellite area estimates (linked to pixel size), when comparing point measurements to model cell results or when comparing satellite area estimates to model cell results.

- *Figures: 2: The red boxes are difficult to see. It would be nice to have a scale in m or km.*

- The red boxes were replaced with white boxes. A scale in meters was included in the revised figure 2.

- *Figures: 4-7: What do the grey areas in the time series represent?*

- The grey area represents the spread (or extent) of maximum and minimum values in the spatial distribution as time goes on.

Writing:

There are a few grammatical errors in this paper, however, poor phrasing and incorrect word usage are a greater problem because they create confusing or misleading statements. A native English speaker should read through and correct the text so that the authors' meanings are clear. While there are many instances of poor phrasing in the paper, I have listed some of the most egregious examples below.

We tried our best to correct the grammatical errors and improve the clarity in the revised manuscript.

- *p. 2556, l. 17 - What are "indirect interactions" between radiation and clouds?*

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- The incoming solar radiation reaching the Earth's surface is modulated by two ways: (a) first order (or primary) interaction with clouds (water droplets and ice), aerosols (mineral dust, soot etc.), water vapor and ozone, and (b) second order (or secondary) interaction with 3D cloud effects (i.e., cloud edge scattering with enhancement in surface reaching radiation) and aerosol-indirect effects. In our statement, the first order interaction associated with clouds was referred to 'direct interaction', while the second order interaction associated with clouds (i.e., 3D cloud effects) was referred to 'indirect multiple interactions'. With a view to avoid further confusion, we have revised the phase as "modulated by direct and multiple interactions with clouds".

- *p. 2560, l. 25 – "Serial" and "analog" do not represent conflicting properties. Aren't the meteorological values also reported as a function of time?*

- Yes. The meteorological parameters (RH and ambient air temperature) were measured as a function of time. The sentence was corrected.

- *p. 2563, l. 21 – "Nullified" is a rather strong word for this screening procedure.*

- The statement was removed in the revised manuscript.

- *p. 2565, l. 6 – What does "the time-series between the minimum and maximum values" mean?*

- Within the spatial domain, there exist minimum and maximum values of global horizontal irradiance measurements (or derived global transmittance) at each time step. These can be represented as two distinct time-series of minimum and maximum values from the spatial field. Note that these minimum and maximum values need not correspond to a single pyranometer station and varies within the spatial field. In the revised manuscript, entire statistical procedure was removed to avoid further confusion.

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- *p. 2567, l. 20 – What is meant by “background shadowing” (vs. “foreground shadowing”)?*

- Those objects that are stationed farthest from the field of view of pyranometer sensor and are said to influence their measurements were referred to be causing “background shadowing“. On contrary, any objects that are stationed in close proximity or exactly in front of the pyranometer sensor field of view can be assumed to be causing “foreground shadowing“.

- *p. 2567, l. 21 – Should say “spatial distribution,” not “spatial variability.”*

- Corrected.

- *p. 2567, l. 24 – How would you recognize “perfect” clear-sky conditions?*

- Based on the visual inspection of the sky images obtained from the sky camera located at LACROS supersite.

- *p. 2570, l. 5 – Do you see statistical significance? If not, avoid the word “significance.”*

- Corrected.

- *p. 2570, l. 16 – What does “the loss in significant digits” mean?*

- The sentence was removed in the revised manuscript.

Please find the revised manuscript with markups to highlight the corrections we have made. The following are the conventions adopted to show the markups in the revised manuscript:

- Original text in the manuscript is retained in **black** color.

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- Deleted original text is crossed and highlighted in **red** color.
- Added new text with an underline in **blue** color.

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