Comments on *Multiresolution analysis of the spatiotemporal variability in global radiation observed by a dense network of 99 pyranometers during the HOPE campaign* by B.L. Madhavan et al. submitted for publication to *Atmospheric Chemistry and Physics*

Solar radiation at the surface varies considerably in time and space resulting from different factors including solar angle, atmospheric turbidity and surface albedo. At the regional/local scale extending from 0 to 10 km, clouds and other atmospheric constituents exert a strong influence on variability, raising questions on the representativeness of point measurements of solar radiation and the density of pyranometer networks that are needed for proper sampling. This variability also impacts on satellite estimates of solar radiation, since the technique usually relies on surface pyranometer measurements for validation. It is within this context that the authors have produced a thorough and timely study involving 99 pyranometers deployed in a 10 x12 km^2 area in Germany. A total of 19 days have been selected encompassing a range of cloud types and the data has been analysed using wavelet analysis at different spatial and temporal scales. In my view the analysis approach is appropriate, the quality of the work is good and the work makes a significant contribution to the literature.

It is good to note that the theory of wavelet analysis has been simplified in this revised version to make the document more readable to a general audience not familiar with the technique. I also note that more information on the pyranometer network is provided. I have some added comments that will hopefully help with the main focus of the study. I will organise my comments along the following topics:

- ***What is the analysis telling us regarding the contribution of different cloud spatial dimensions to the variability?***

I am aware that a more detailed study is planned involving cloud interactions. However there is still need to link your results with some of the published literature. There are considerable number of studies who have described properties of stratocumulus clouds using power spectral analysis. They usually involve liquid water content, liquid water path or solar radiation transmission with a power law relationship of the form:

$$Power(k) \approx k^{-C} \qquad \text{(a)}$$

Where k is wave number ($2\pi/\lambda$, λ being a distance unit in m or km) and C is a rregression constant. Studies involving aircraft, ground based, microwave radiometers and satellite data describe C as being around 5/3 but usually in a specific wavenumber range, equivalent to distances ranging from several tens pf km to less than 1 km (Boers, 1988; Cahalan and Snider, 1989; Davis et al., 1999; Gerber et al., 2001). Area distribution of broken Cu/Stcu clouds has also been studied Nunez et al. (2016), Koren et al., (2008), and Cahalan and Snider(1989) which describe a typical distribution of cloud area A in terms of a given number density N :

$$\ln(N) = \ln(A)^{-C1} \qquad \text{(b)}$$

And C1 is a least square fit. These studies point to the importance of low wave numbers or large cloud areas in dominating the variance of the time series of liquid water and solar radiation transmission, with a partly cloudy scene dominated by a few large clouds and many smaller ones (eq. 2).

The authors should relate some of their results to the considerable published literature on the subject as listed above. For example, in Figure 2, large fluctuations are observed in details D_3, D_4 and D_5. These must be related to changes in transmission resulting from longer-term changes in dominant cloud structure and composition (S12 in Figure 2), or the equivalent of low wave numbers in equation (a). Higher number details do not show this as they examine local-scale variability in cloud features (D_9 to D_{11}).

In Figure 5(a), wavelet variance for all cloud conditions is largest at long time periods, implying that large cloud structures with their associated transmissions are important at this scale. Similarly the power spectrum in Figure 8 shows high variance at high time periods and the importance of large scale cloud structures. The authors should examine a least square fit for a single point measurement in Figure 8 within the larger context of power spectrum measurements (equation (a)). Transformation from period or frequency to wavenumber space may be accomplished using the frozen turbulence hypothesis (Cahalan and Snider (1989; p. 104)).

- ***Treatment of direct radiation***

Figure 4 shows that the power spectra of transmittance is determined by the power spectra of direct beam transmittance, which is also stated in the text at page 15, line 18. The statement is reasonable with cirrus, thin altostratus or partly cloudy liquid water clouds, but it is unlikely to hold for overcast liquid water clouds. Using a radiative model such as Libradtran-1.7 will show that direct irradiance is only around 4% of the global irradiance for liquid water clouds of optical depth 3. Given these conditions, it would be difficult to make a general statement that direct irradiance dominates the global irradiance spectrum. My advice is to restrict the study to liquid water clouds or provide a detailed cloud breakdown in Table 1 and state that the spectral results for direct irradiance refers to the specific set of conditions used.

- ***Treatment of clear skies***

It is interesting to see that the clear case in Figure 5(a) also exhibit a similar distribution with high variance at long time periods. It is unclear to me why this should be. Would aerosols and water vapour exhibit the same behaviour as clouds with regards to their transmission spectrum, with high variance at high time periods? Or perhaps it might be an artefact of the transmission calculation (G/G0, G is measured clear sky global radiation, G0 is the extra-terrestrial radiation)? At high zenith angles transmissions would be low due to higher air mass, imposing a strong diurnal change in clear sky transmission.

Table 4 shows that the variance between an point measurement and 1 km x 1 km average (wavelet smooth S3?) is uncorrelated after six minutes (decorrelation time) for clear conditions. In my opinion, this is a remarkably low figure. Again as in the above paragraph, what features of clear sky turbidity or instrumental errors are causing this behaviour?

- ***How widely applicablke are the results?***

The sections on autocorrelation and spatial representativeness are very good and should provide useful data when planning a pyranometer array. However the authors should provide a word of caution, probably in the Conclusion, that conditions sampled are typical of mid-latitude systems and that the results may not be applicable to other regions such as the tropics typified by local convection, large cumulonimbus clouds and weaker regional winds.

- ***Minor corrections***

Page 2, line 7: replace “up” by “updrafts”

Page 2, line 24: replace “…could show that especially…” by “…reported that spatially…”.

Page 6, line 20: replace “… zenith angle below 75°” by “…zenith angle above 75°”. Is this correct?

Page 8, line 21: replace “…wavelet-based spectra…” by “…wavelet-based spectral power density…”.

Page 8, line 22: delete “ The quality of fit…been found to increase linearly with decreasing frequency” to “The root mean square error (rmse) which measures the quality of fit has been found to decrease linearly with decreasing frequency”.

Page 11, line 25: Side reflection from clouds is strongly enhanced in broken cloud conditions and could be important in lowering the correlation (Nunez et al., 2016).

Page 26, Table 3. It might be appropriate in the table to include averaging period used in the various studies (10 minutes, hourly, daily, etc.)

- ***References***

Boers, R., J. D. Spinhirne, and W. D. Hart, Lidar observations of the fine-scale variability of marine stratocumulus clouds, *J. Appl. Met.*, *27*, 797–810, 1988.

Cahalan, R. F., and J. B. Snider, Marine stratocumulus structure, *Remote Sens. Environ.*, *28*, 95–107, 1989.

Davis, A., A. Marshak, H. Gerber, and J. W. Wiscombe, 1999; Horizontal structure of marine boundary layer clouds from centimeter to kilometer scales, *J. Geophys. Res.*, *104*, 6123– 6144

Gerber, H., J.B. Jensen, A.B. Davis, A. Marshak, W.J. Wiscombe, 2001: Spectral density of cloud liquid water content at high frequencies, *J. Atmos. Sci.*, 497-503.

Koren, I., L. Oreopoulos, G. Feingold, L. A. Remer, and O. Altaratz (2008), How small is a small cloud?, *Atmos. Chem. Phys*., 8, 3855–3864.

Nunez, M., M.J. Marin-Fernandez, D. Serrano, M. P. Utrillas, K. Fienberg, J.A. Martinez-Lozano, 2016: Sensitivity of UV enhancement to broken liquid water clouds: a Monte Carlo approach as applied to Valencia, Spain, *J. Geophys. Res, Atmos*., 121, 949–964.