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Main Author:

H.G. Beyer,
University of Applied Sciences Magdeburg-Stendal (FH)
Subcontractor to EHF

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Treatment of topics concerning the spatial statistics of cloud index and irradiance fields

Hans Georg Beyer
Dept. of Electrical Engineering
University of Applied Sciences (FH) Magdeburg Stendal

Jethro Betcke
Energy and Semiconductor Research Laboratory
Carl von Ossietzky University of Oldenburg

Antonio Ortégon Gallego
Renewable Energy Department
Canary Island Institute of Technology

Abstract

This report deals with two topics concerning the spatial structure of the cloud index and the irradiance field derived from Meteosat8 images using the Heliosat3 procedure.

The first topic concerns two intermediate steps of the procedure to derive the global irradiance and its direct and diffuse components. For these steps two different measures for the local spatial variability of the fields are applied: the local standard deviation and a specially defined variability index. Within the present report the relation of these measures is analysed and their mutual replaceability is discussed.

The second topic concerns the capability of the Meteosat8/Heliosat3 derived irradiance fields to represent the spatial cross statistics of the irradiance field. For this purpose the cross statistical properties of the satellite derived field are compared to the respective information derived from data of a ground station network. This comparison is performed a network of ground stations on the Canary Islands.

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1. Introduction

Within the development of the Heliosat3 method and work for the improvements of the Heliosat procedure based on Meteosat7 images as done within the PVSAT-2 project (Lorenz 2004) two different measures for the homogeneity of the cloud index field had been introduced: the standard deviation of the cloud index within a block of pixels centred around the pixel of interest and the variability as described by the average squared difference of all neighbouring pixels centred around the pixel of interest. The two measures are on one hand applied for deriving the clear sky index for the pixel of interest and on the other hand for the split of the global irradiance into its diffuse and direct irradiance fraction. In the present work package, it is analysed to what extend these two measures are statistically independent. From this it may be judged whether the use of these two different parameterizations is necessary.

As it concerns as well the spatial structure of the cloud or irradiance field, a second topic - however closely related to work packages 5000 and 6000 - is embedded in the present work package. Whereas the quality check of the Heliosat3 products as performed in the work packages 5000 and 6000 are concerned with single point statistics, i.e. the model accuracy for radiation components at a single location, in the present work package aspects of the spatial distribution of the cloud field or the irradiance field are under consideration. The motivation for the analysis of the spatial structure of the irradiance field stems from the needs for the respective information given e.g. by procedures for an optimal fusion of satellite derived data and ground based values or the application topic 'analysis large scale integration of solar energy into spatially distributed energy supply grids'. These topics are e.g. described by Beyer et al. (1997) and Reise (2004). In both fields, the representation of the spatial cross-statistics of the irradiance field as expressed by the cross-correlation function or the variogram play a key role. Therefore chapter 3 of this report are devoted to an exemplary check of the similarity of measures for the spatial statistics of the irradiance field as given by the Heliosat3/Meteosat8 procedure and the data from a ground station network. Within the Heliosat3 project data from a appropriate network of ground stations covering the Canary Islands operated by ITC is available. The results presented thus refer to this geographical region.

2. Comparison of the measures of the spatial variability used for the parameterization the local cloud index field

2.1 Description of the measures applied

As described in the previous work packages and the reports on the optimisation of the Meteosat7 based Heliosat method for both, the derivation of the clear sky index on the basis of the cloud index field and the subdivision of the estimated global irradiance into its components 'direct irradiance' and 'diffuse irradiance' the introduction of measures describing local homogeneity of the initial fields proved to be advantageous.

Within these procedures two separate measures are applied: the standard deviation of the data within a 5x5 block of pixels (applied for the diffuse/direct split) and a newly defined variability index (applied for a variability correction of the n-kt* relation). This variability index is defined by:

$$\mathrm{var} = \frac{1}{N}\sum_{i,j}(n_{i,j} - n_{i,j-1})^2 + (n_{i-1,j} - n_{i,j})^2$$

with the sum taken over a 5x5 neighbourhood around the pixel of interest.

These two measures a mathematically not identical, but are both aimed to separate data according to the local spatial homogeneity of the fields analysed. Thus it seems to be useful to analyse the degree of correlation of both measures in view of a possible interchange i.e. a possible reformulation of the correlations applied using a unique measure.

2.2 Data set used for the analysis of the correlation of the spatial measures

For this analysis a 10-day sample of cloud index images with a section of 660 * 480 Meteosat8 pixels covering Germany. Fig. 2.2.1 shows one of these images.

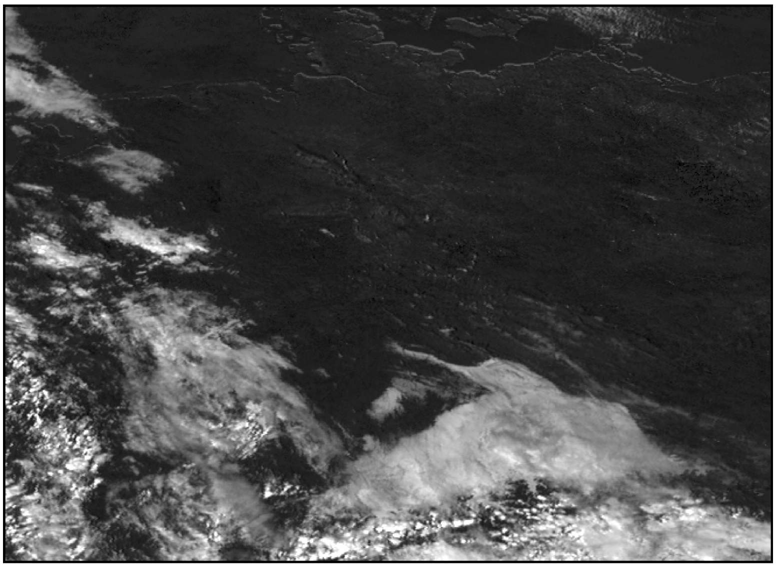

Fig. 2.2.1: Cloud index image covering Germany. The scene refers to the October 12th 2004, time: 12:15.

2.3 Analysis of maps of the different variability measures

For this scene the two variability measures - local standard deviation and the variability index as defined above are calculated. The results are shown in the figures 2.3.1 and 2.3.2. It has to be noted that the grey values of these images are subject to a linear scaling to ease perception.

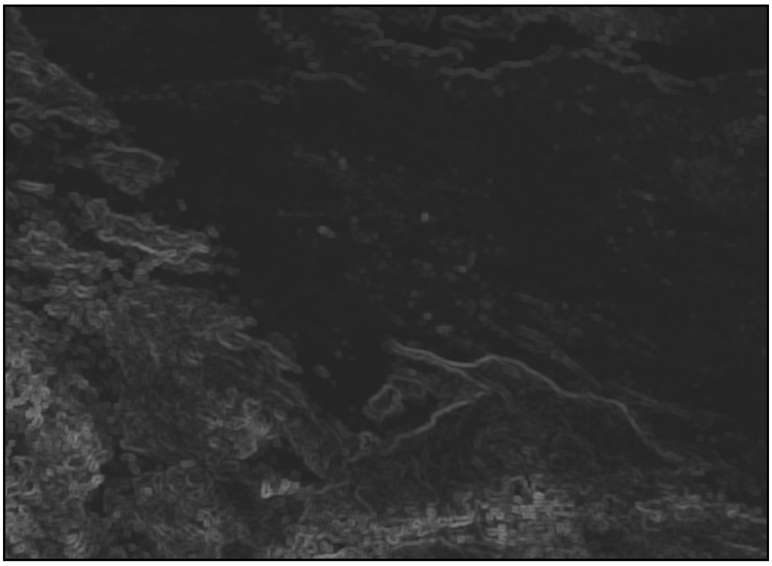

Fig. 2.3.1: Image representing the variability measure 'local standard deviation' applied to the image of the clear sky index given in fig. 2.2.1. Bright pixels refer to a height value of the standard deviation.

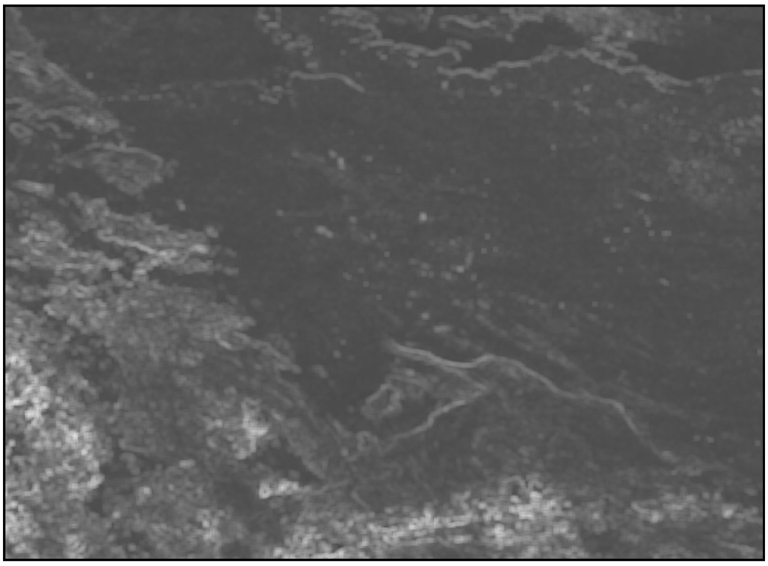

Fig. 2.3.2: Image representing the variability index for the image of the clear sky index given in fig. 2.3.1. Bright pixels refer to a height value of the standard variability index.

As may be noticed, the visual appearance of the two variability maps is quite similar. A quantitative analysis results in a cross correlation coefficient of 0.96 for this pair of images.

Repeating this analysis for the 12:15 clear sky index images for all 10 days analysed gives the results as given in table1.

day	cross correlation coefficient
12.10	0.96
13.10	0.94
14.10	0.95
15.10	0.94
16.10	0.92
17.10	0.92
18.10	0.94
19.10	0.95
20.10	0.94
21.10	0.97
Average:	0.94

Table1: Cross correlation coefficient of the images with the variability measures 'local standard deviation' and the 'variability index'. The data refer to the scenes taken at 12:15.

2.3 Conclusions on the comparison of the two measures

The analysis reveals that the measures 'local standard deviation' and 'variability index' mainly render the same information for the cloud index images analysed. Thus it may be expected, that the procedures using these measures, the variability correction of the n-kt* relation and the split of the global radiation to its direct and diffuse components may as well be based on a unique measure.

3. Analysis of the capability of Heliosat3 maps to reflect the spatial statistics of 15min irradiance data

The knowledge of the spatial structure is of importance for both, the merging of satellite and ground station data to gain optimal knowledge and the application of solar irradiance data for applications that involve networks i.e. spatially distributed structures. The topic of optimal data fusion is addressed e.g. Zelenka et al. (1992), Beyer et al. (1997), Bethke and Beyer (2004). The explicit discussion of the spatial structure of the irradiance field for network studies e.g. addressed by Beyer et. al. (1995) and Reise (2004). Treating these topics, the representation of the spatial cross-statistics of the irradiance field as expressed by the cross-correlation function or the variogram play an important role. In the following, data from the network of ground stations installed on the Canary Island and the Heliosat3 derived irradiance data for respective pixels are used to compare the satellite derived cross-statistics with their ground station derived counterparts.

3.1 Description of the dataset analysed

ITC operates a network of in total 21 solar radiation stations on the Canary Islands. The data cover in total period of 10 month. For the present study 15min averages of radiation data from 8 stations located on the Islands of Fuenteventura (3 stations), Gomera, El Hierro, Lanzarote (1 station each) and Tenerifa (2 Stations) for the month of December 2004 have been selected. The distances of these stations range from 20km-400km. This selection of data shows a high basic accuracy, i.e. good agreement of the satellite derived monthly means irradiation with the ground measured data. Thus the analysis of the cross-statistics is not obscured by offsets due to model inaccuracies or data failures caused by other effects. The satellite data are produced with the Heliosat3 methods based on the Meteosat8 images.

3.2 General quality of the irradiance data

For the inspected month the clear sky indices for both, satellite derived and ground station data are calculated with respect to the clear sky radiation as calculated wth Heliosat3. Fig 3.21 depicts the scatter of the ground based and satellite derived mean monthly clearness indices.

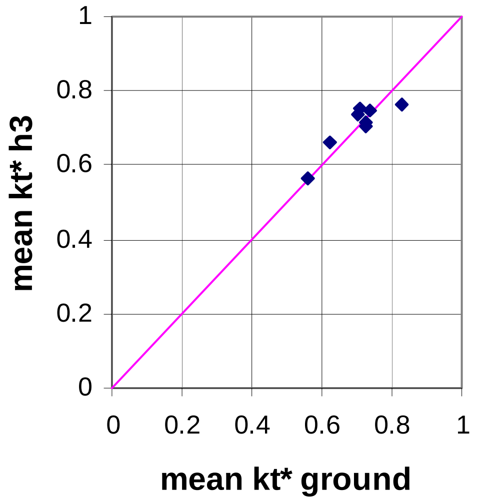

Fig. 3.2.1 Scatter diagram of satellite derived and ground based mean clear sky indices for a selection of the stations from the Canary Island network. Data refer to the month of December 2004.

The overall offset of the satellite derived data is 1%, maximum absolute deviation is 8%. This may be considered as typical for the Heliosat3 procedure.

As second measure for the quality of single point data the variance of the clear sky index is inspected. The result is given in fig. 3.2.2.

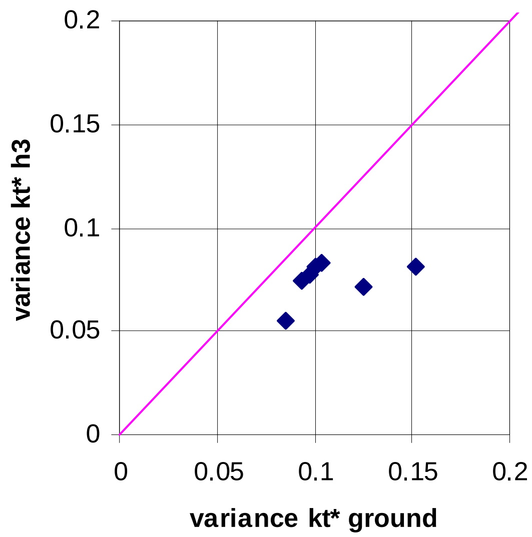

Fig. 3.2.2 Scatter diagram of satellite derived and ground based variance clear sky indices. Same data base as fig. 3.2.1. .

It has to be concluded, that the satellite data underestimate the variance of the ground data in the time scale of 15min. This fact has to be considered in the following discussion of the spatial characteristics of the quality of the satellite derived irradiance field.

3.3 Analysis of spatial structure

As first the measure 'cross correlation' is compared for satellite derived and ground data. For the selection of stations analysed the cross-correlation coefficient for the clear sky indices is calculated for all pairs of stations / pairs of the respective pixel values. The coefficients are calculated according to:

$$r_{1,2} = \frac{\frac{1}{N}\sum (x_1(n) - \bar{x}_1)(x_2(n) - \bar{x}_2)}{\sigma_1 \sigma_2} \qquad (3.3.1)$$

As the coefficients are normalized by the values of the standard deviation σ (the square root of the variance) the unequal amplitudes of the variability of the clear sky index in the satellite and ground data should not effect the this measure.

Figure 3.3.1. gives the scatter of the correlations coefficients as calculated from the ground and satellite derived data.

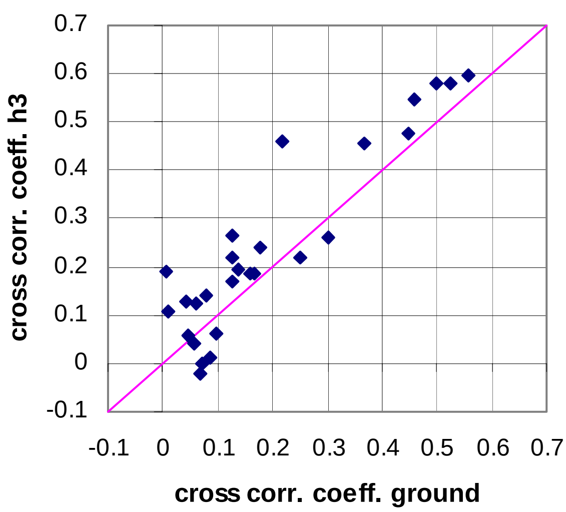

Fig.3.3.1. Cross correlation coefficients for the clear sky index calculated for pairs of ground station data and the respective pixel values.

It may be recognized, that the cross correlation given by the satellite data is in general somewhat higher than the values given by the ground data (average overestimation of the coefficients: 21%). In the same time this plot indicates, that the general spatial structure of the field is well reflected by the satellite derived data as the relative sorting of the coefficients is in general preserved.

As a second measure for the spatial structure of the clear sky index fields, the average squared difference of the clear sky index is inspected. This measure is selected due to its importance in calculating the variogram of the field (see e.g. Zelenka et al 1992). Figure 3.3.2. gives the results for the sets inspected.

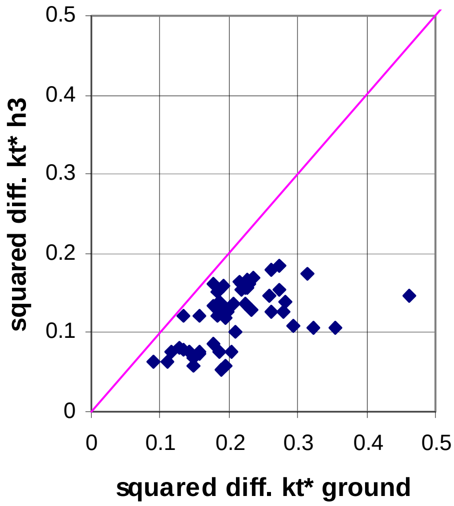

Fig. 3.3.2.: Scatter diagram of the average squared difference of the clearness index values for pairs of stations/pixels gained from ground and satellite derived data.

It is obvious, that the satellite data show a general underestimation of this value. This was to be expected taking into account the underestimation of the variances of the clearness index for individual points as indicated in Fig. 3.2.2..
Normalizing the values of the squares differences by the product of the standard deviations, a value that represents more purely the spatial information in the data may be gained. Figure 3.3.3 gives the scatter diagram for these data. The satellite derived data show an offset of -10%. The correlation coefficient of satellite and ground derived data is 0.84. The result that this normalized measure of the spatial information may reasonably be gained by the satellite data had to be expected, as the cross-correlation coefficient and the normalized squared difference may be

exchanged, taking into account the averages and the variances of the single point data.

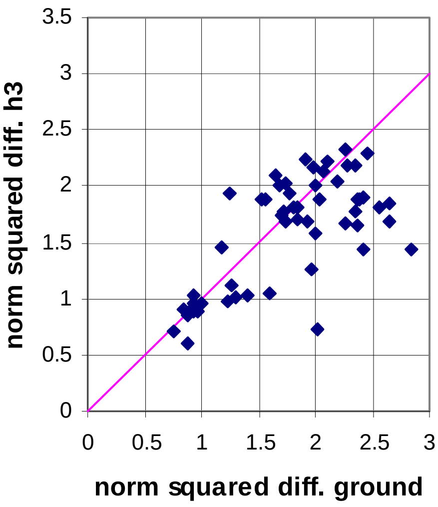

Fig. 3.3.3.: Scatter diagram of the normalized average squared difference of the clearness index values. Same data set as figure 3.3.2. .

3.4 Conclusions on spatial statistics of the irradiance field

Based on the example analysed it may be concluded that the basic spatial structure i.e. the co-occurrence of positive and negative deviations from the mean at two locations is well represented by the Meteosat8 based Heliosat3 data. As a shortcoming, it has to be stated that the satellite derived data are not able to cope with the variability of the 15 min means of the ground data. Even with the improved spatial resolution of the Meteosat8 images the dynamics of the satellite derived irradiance field are reduced. It may however be expected that that based on a higher number of ground data sets a correction procedure for the satellite derived variability measured could be identified.

References

Betcke, J. and H.G. Beyer (2004), Accuracy improvements of irradiation data by combining ground and satellite measurements, Report Work Package 4010, Project PVSAT-2, Contract No. ENK5-CT-2002-00631, Oldenburg University

Beyer, H.G., C. Costanzo, Ch. Reise (1995), Multiresolution analysis of satellite-derived irradiance maps - an evaluation of a new tool for the spatial characterization of hourly irradiance maps, Solar Energy **55**, 9-20

Beyer, H.G. G. Czeplak, U. Terzenbach, L. Wald (1997), Assessment of the methods used to construct clearness index maps for the new European solar radiation atlas (ESRA),Solar Energy **61**, 389-397

Lorenz, E. (2004), Improved diffuse Irradiance model, Report on deliverable D4.2 , PVSAT2 project, Contract No. ENK5-CT-2002-00631, Oldenburg University

Reise, Ch. (2004), Power Flow Estimation for Future Solar Electricity Grids, Proc. Eurosun 2004, Freiburg

Zelenka, A,, V.Agostino, W.Josephson, E.Maxwell, R.Perez, M.Noia, C.Ratto, R.Festa (1992) Techniques for supplementing solar radiation network data, A report to Task 9: Solar Radiation and Pyranometry Studies, IEA-report No IEA-SHCP-9D-1