

Global and diffuse radiation estimated from METEOSAT data at Bergen, Norway

by

Arvid Skartveit and Jan Asle Olseth*

**Geophysical Institute, University of Bergen
Allégaten 70, N-5007 Bergen, NORWAY**

*** In the SATEL-LIGHT project also at
The Norwegian Meteorological Institute**

Abstract

2 years (1996-1997) of hourly observations of global irradiance at Bergen, Norway, show a negligible mean bias deviation compared to data derived from METEOSAT by the Heliosat procedure. There is, however, a slight tendency that satellite data exceed ground truth under overcast sky while the opposite is true under approximately cloudfree sky. These minor deviations in global irradiance propagate, via a diffuse fraction model, into the Heliosat diffuse irradiances which at any solar elevation show mean bias deviations relative to ground truth amounting to some 5-10% of the average observed global irradiance.

1. INTRODUCTION

Images taken from geostationary satellites are a valuable source to retrieve solar irradiance data with an almost continuous spatial coverage (Beyer et al., 1996). With increasing latitude, however, the accuracy of such retrievals declines due to the fact that geostationary satellites see the earth's surface at an increasingly unfavourable angle. This limitation is not shared by the sun-synchronous polar orbiting satellites, but the retrieval of solar irradiation from these satellites is hampered by their incomplete temporal coverage (Karlsson, 1994, 1996).

The present paper compares hourly ground observations at Bergen with global and diffuse radiation estimated from the geostationary satellite METEOSAT. In addition to looking at mean bias errors, our paper focuses on how well frequency distributions of hourly irradiance observed at the surface are reproduced by corresponding data retrieved from METEOSAT data.

2. DATA

2.1 METEOSAT/Heliosat data

The Heliosat procedure, originally proposed by Cano et al. (1986) and recently modified by Beyer et al. (1996) and by the SATELLIGHT project (Fontoynt et al., 1998), yields surface global irradiance from pixel counts in the VIS-channel (0.5 - 0.9 μm) of the geostationary METEOSAT satellite. For each satellite image, these pixel counts are "adjusted" for instrument offset, backscatter from the cloudless atmosphere, solar zenith angle, and Sun-Earth distance to yield a relative apparent albedo ρ for 3 X 5 pixels centred around each of our ground truth stations. A cloud index n is subsequently defined:

$$n = (\rho - \rho_0) / (\rho_c - \rho_0) . \quad (1)$$

The reference values ρ_0 and ρ_c are extracted from a series of images, and refer to the albedo of the cloud-free pixels and that of a compact cloud cover, respectively. Note that a snow cover makes ρ_0 increase by an amount which may vary strongly both in space and time. Cloud indices are therefore a particularly inaccurate measure of cloudiness in case of snow cover.

The surface global irradiance is subsequently obtained from the following relation between global clear sky index k_g and cloud index n :

$$k_g = 1.20 , \quad \text{for } n \leq -0.2 , \quad (2a)$$

$$k_g = 1 - n , \quad \text{for } -0.2 \leq n \leq 0.8 , \quad (2b)$$

$$k_g = 2.0667 - 3.6667 n + 1.6667 n^2 , \quad \text{for } 0.8 \leq n \leq 1.1 , \quad (2c)$$

$$k_g = 0.05 , \quad \text{for } n \geq 1.1 . \quad (2d)$$

The global clear sky index k_g is here defined as the ratio between the actual global irradiation H_g (observed or satellite-derived) and an average cloud-free irradiation H_0 :

$$k_g = H_g / H_0 = H_g / (H_{b0} + H_{d0}) . \quad (3)$$

H_0 is the sum of clear sky beam irradiation H_{b0} (Kasten 1996) and clear sky diffuse irradiation H_{d0} (Dumortier 1995), both for Linke turbidity coefficient appropriate for the station in question.

Furthermore, the diffuse irradiance H_d is estimated from H_g obtained by the Heliosat procedure along with ratios H_d/H_g obtained by the diffuse fraction model of Skartveit et al. (1998).

The METEOSAT data used in this paper are taken from the SATEL-LIGHT server at <http://arbois.entpe.fr>

2.2 Ground truth data

Global and diffuse (shading disk) radiation measured by CM11 pyranometers at Bergen are available for the years 1996-1997. Only hours during which the sun is above the natural horizon during the entire hour are used. These hourly ground truth data are compared to hourly averages obtained by adequate weighting of half-hourly Heliosat estimates.

3. RESULTS

Observed hourly global and diffuse irradiances are plotted against their Heliosat counterparts in Fig. 1. For global irradiance, the Heliosat versus ground truth mean bias deviations are only some $2\text{-}3 \text{ Wm}^{-2}$, which for solar elevations above 15° amounts to less than 1% of the average global irradiance. The root-mean-squared-deviations, however, range from 22% of average global irradiance for solar elevation $>30^\circ$ to 38% of average global irradiance for solar elevation $<15^\circ$ (Table 1). Moreover, it is seen that the Heliosat irradiances tend to slightly exceed their ground truth counterparts under cloudy sky (low irradiances) while the opposite is true under approximately cloudfree sky.

Heliosat yields diffuse irradiances with some $8\text{-}20 \text{ Wm}^{-2}$ mean bias deviations relative to their ground truth counterparts, which amount to some 5-10% of average global irradiance. The corresponding root-mean-squared-deviations are, however, some 2.6-2.9 times these mean bias deviations (Table 1). It is noteworthy that, in spite of small mean bias deviation in global irradiance, the major part of the diffuse mean bias derives from deviations in Heliosat global irradiance. This is inferred from the fact that the diffuse mean bias deviations are reduced to 1-2% of average global irradiance by running the diffuse fraction model directly on ground truth global irradiance (Table 1).

The above hourly data are even compared by plotting "percentile match curves" (Fig. 3) from accumulated duration curves (Fig. 2) as follows: the highest ground truth global or diffuse irradiance against the highest Heliosat irradiance, the second highest ground truth against the second highest Heliosat irradiance ..., the lowest ground truth against the lowest Heliosat irradiance. These curves quantifies the tendency, already seen from Fig. 1, that Heliosat overestimates ground truth global irradiance for low irradiances and underestimates it for high irradiances. Corresponding curves for diffuse irradiance reveal the same tendency (Fig. 3b-c).

Acknowledgments

This work is a part of the project SATEL-LIGHT in the JOULE Programme JOR3-CT950041, supported by the European Commission. We thank our project colleagues for valuable advices.

4. REFERENCES

- H.G. Beyer, C. Costanzo and D. Heinemann** (1996): Modifications of the Heliosat procedure for irradiance estimates from satellite images. *Solar Energy* **56**, 207 - 212.
- D. Cano, J. M. Monget, M. Albuissou, H. Guillard, N. Regas, and L. Wald** (1986): A method for the determination of the global solar radiation from meteorological satellite data. *Solar Energy* **37**, 31-39.
- D. Dumortier** (1995): Mesure, Analyse et Modélisation du gisement lumineux Application à l'évaluation des performances de l'éclairage naturel des bâtiments. Thesis, Laboratoire Génie Civil et Habitat, ENTPE, Lyon, France.
- M. Fontoynt, D. Dumortier, D. Heinemann, A. Hammer, J. A. Olseth, A. Skartveit, P. Ineichen, C. Reise, J. Page, L. Roche. H. G. Beyer, and L. Wald** (1998): SATELLIGHT: A www server which provides high quality daylight and solar radiation data for western and central Europe. 9th Conference on Satellite Meteorology and Oceanography in Paris, May 25-28, 1998.
- K.-G. Karlsson** (1994): Satellite-estimated cloudiness from NOAA AVHRR data in the Nordic Area during 1993. SMHI Reports Meteorology and Climatology No. **66**.
- K.-G. Karlsson** (1996): Cloud classifications with the SCANDIA model. SMHI Reports Meteorology and Climatology No. **67**.
- F. Kasten** (1996): The Linke turbidity factor based on improved values of the integral Rayleigh optical thickness. *Solar Energy* **56**, 239-244.
- A. Skartveit, J.A. Olseth and M.E. Tuft** (1998): An hourly diffuse fraction model with correction for variability and surface albedo. *Solar Energy* Vol. 63, No. 3, pp. 173-183, 1998.

Table 1 Ground truth (observed at surface) averages along with corresponding mean-bias-deviation (MBD) and root-mean-square-deviation (RMSD) of hourly global and diffuse irradiance derived from METEOSAT. Corresponding data are even given for hourly diffuse irradiance derived directly from ground truth global irradiance. In all three cases, data are given for three solar elevation intervals (h) along with number of hours (N).

Solar elevation	N	Surf. Obs. (Wm ⁻²)	MBD (Wm ⁻²)	RMSD (Wm ⁻²)
Global				
h > 30°	2491	376.7	2.0	84.7
15° < h < 30°	1973	201.0	1.7	55.0
h < 15°	543	87.2	3.3	33.4
Diffuse (from METEOSAT global)				
h > 30°	2486	178.5	19.4	56.0
15° < h < 30°	1968	98.6	14.6	37.7
h < 15°	543	51.4	8.5	23.5
Diffuse (from surface global)				
h > 30°	2568	177.9	8.2	41.5
15° < h < 30°	2345	95.7	4.5	23.0
h < 15°	972	45.8	1.0	12.8

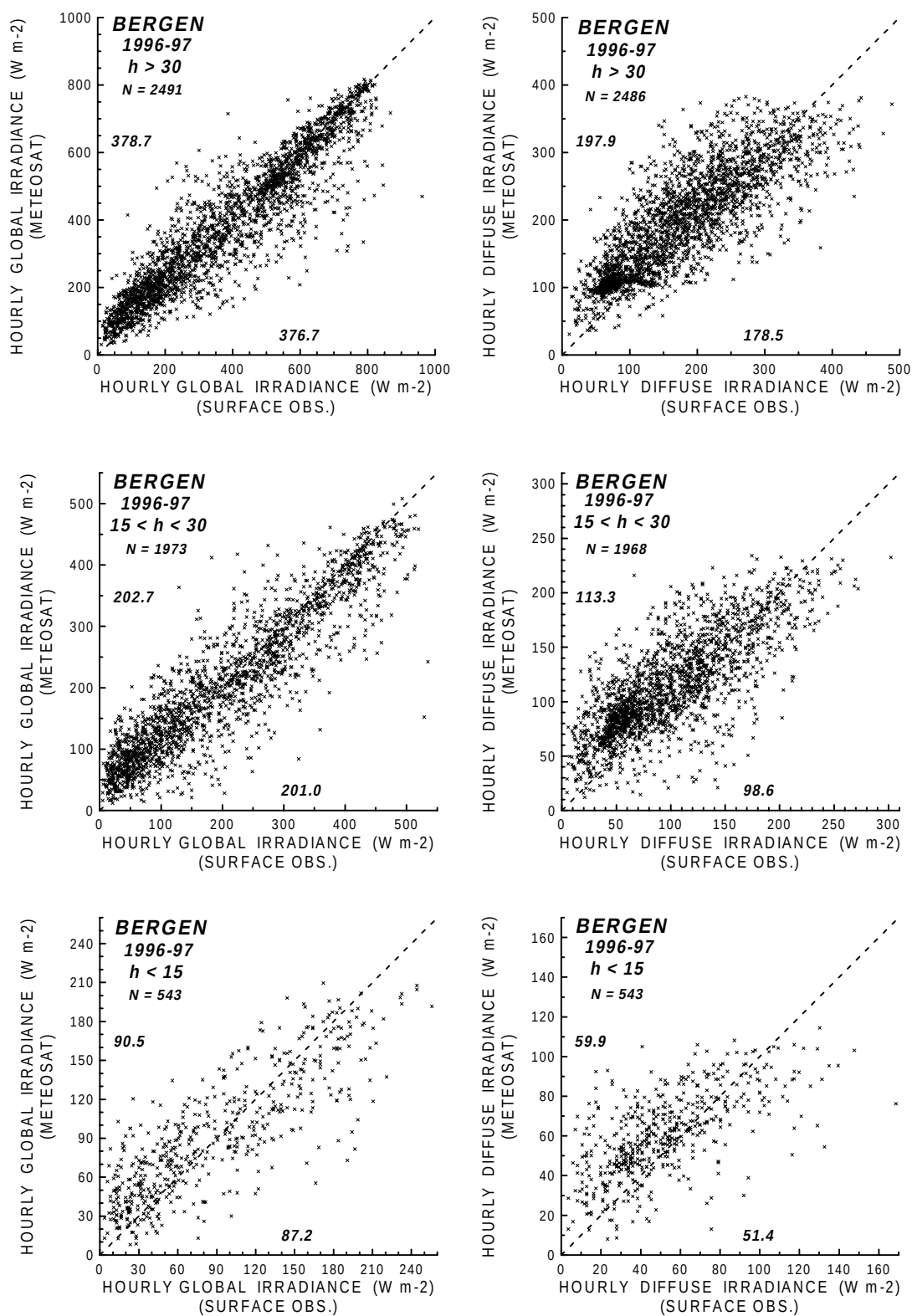


Fig. 1 Global (left column) and diffuse (right column) hourly irradiances derived from METEOSAT, plotted versus their ground truth counterparts. Data are plotted within three solar elevation (h) intervals at Bergen during 1996-1997. Number of hourly values are plotted as N , while average values are printed on the respective axes.

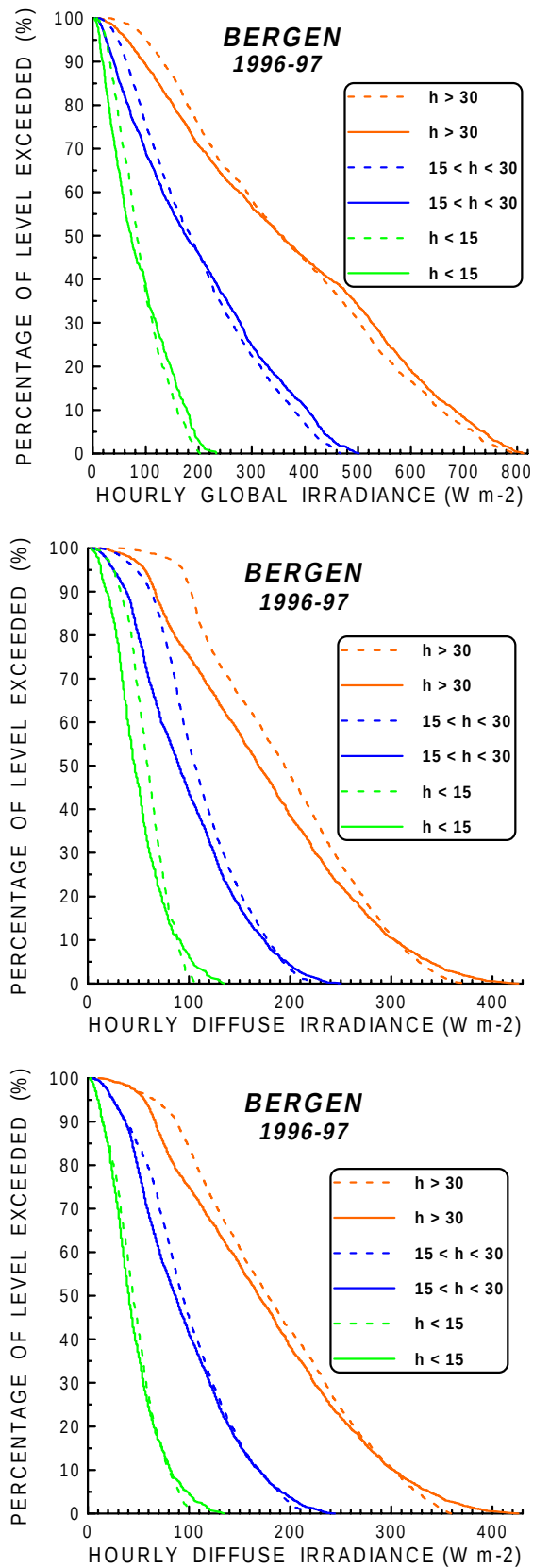


Fig. 2 Accumulated duration curves for global and diffuse irradiance for three solar elevation intervals at Bergen 1996-1997. Fully drawn curves are ground truth data. The broken curves in the two upper panels show METEOSAT derived data, while those in the lowest panel represent diffuse irradiances obtained by running the diffuse fraction model on ground truth global irradiance (not on Heliosat global as in the central panel).

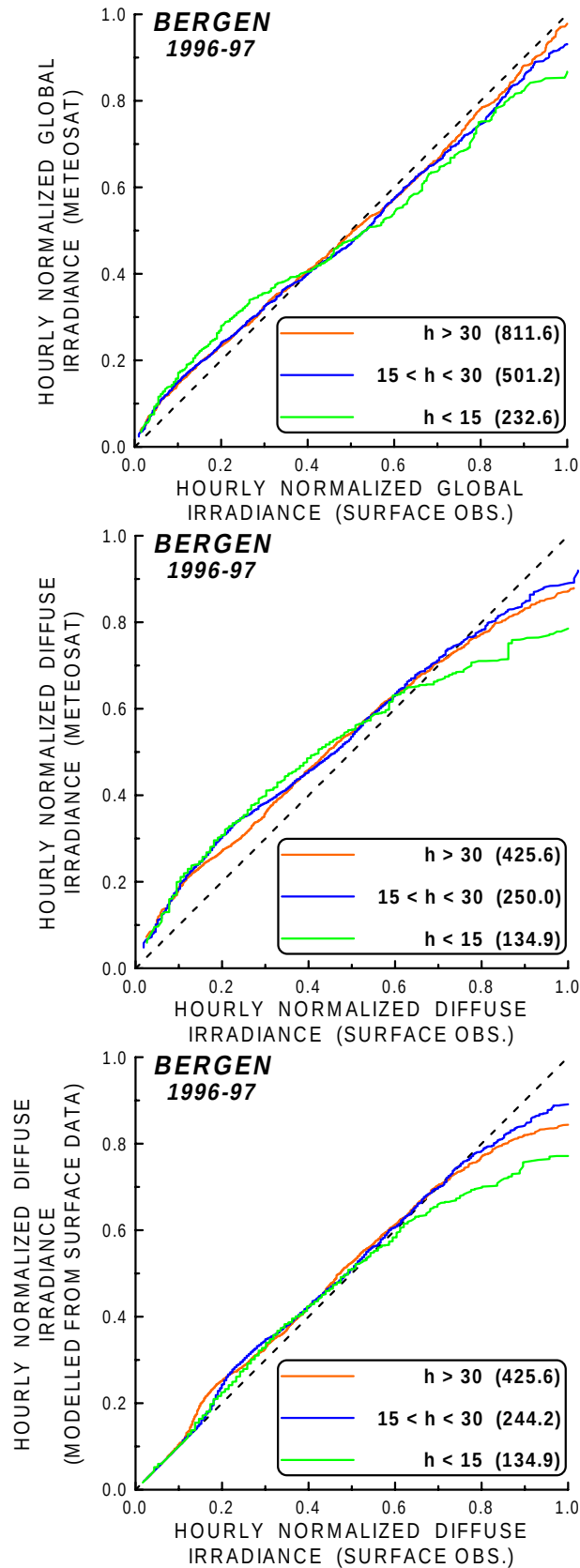


Fig. 3 Same as Fig. 2, but now plotted as "Percentile match curves" (see text) between modelled values and ground truth values. In all cases, the hourly irradiances are normalized to the 99.5% percentile point of the corresponding distribution. These numbers (Wm^{-2}) used for normalization are given in parentheses for each case.