Global and diffuse radiation estimated from METEOSAT data at some Nordic stations

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by

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Abstract

For snow-free ground, hourly observations of global irradiance at 9 Scandinavian ground stations (58 - 64°N) show a negligible mean bias deviation compared to data derived from METEOSAT. The satellite data nicely reproduce the spatial variation between the ground truth stations. Moreover, if time specific hourly data are required at a specific snow-free location, the satellite data for that location are probably more accurate than data from a ground station more than some 30 km away. However, snow cover reduces the agreement between surface observations and satellite derived data.

The overall average and even the hour to hour variation of diffuse irradiance at the two stations Bergen and Gävle is nicely reproduced by the satellite data.

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 some high latitude hourly ground observations 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 (Fontoynont 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:

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

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:

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

$$k_g = 1 - n \ , \qquad \text{for } -0.2 < n \le 0.8 \ , \qquad (2b)$$

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

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

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

$$k_g = H_g / H_0 = H_g / (H_{b\,0} + H_{d\,0}) \ . \qquad (3)$$

H_0 is the sum of clear sky beam irradiation $H_{b\,0}$ (Kasten 1996) and clear sky diffuse irradiation $H_{d\,0}$ (Dumortier 1995), both for Linke turbidity coefficient 3.0 (Hammer 1996). This composite clear sky model and the McMaster model (Davies & McKay, 1989) with estimated climatological water vapour and turbidity as input, yield nearly identical cloud free global irradiances (Olseth & Skartveit, 1997). These modelled values also agree nicely with observed cloud free irradiances at Bergen.

In a similar way, we define the diffuse clear sky index k_d by:

$$k_d = H_d / H_0 \ , \qquad (4)$$

where H_d is the diffuse horizontal irradiation, either observed or derived from METEOSAT data. In the latter case, H_d is estimated from H_g obtained by the Heliosat procedure (Hammer 1997) along with ratios H_d/H_g obtained by the diffuse fraction model of Skartveit et al. (1998).

2.2 Ground truth data

Hourly global radiation measured by CM11 pyranometers are available from the nine stations (6 to 525 m above sea level) plotted in Fig. 1. For Bergen and Gävle, even hourly horizontal diffuse radiation data, measured by CM11 pyranometers with shading disk, are available.

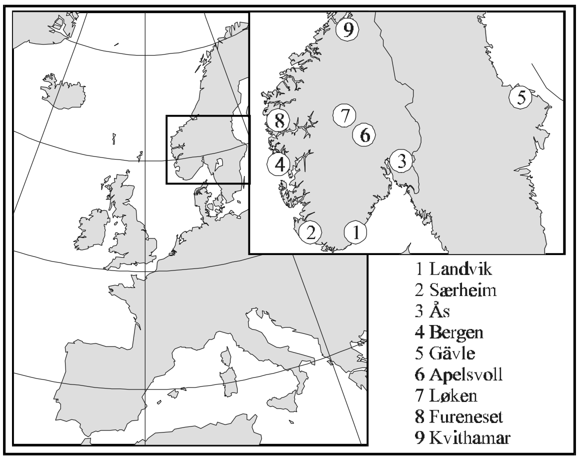

Fig. 1 Map with 9 ground stations plotted.

The difference with respect to time schedule of the various observations was approximately resolved as follows: For stations run according to GMT, the ground observation for e. g. the hour 11^{00} - 12^{00} GMT is compared to a weighted average of Heliosat estimates at 10^{54}, 11^{24}, and 11^{54} GMT (with weights 0.25, 0.5, and 0.25). For Bergen, which is run according to Local Apparent Time (5°19'E), the ground observation for e. g. the hour 11^{30} - 12^{30} LAT is compared to the average of Heliosat estimates at 11^{24} and 11^{54} GMT. Note that the impact of the remaining minor time shifts is substantially reduced by comparing averages and distributions of actual global / clear sky global irradiation rather than comparing individual pairs of corresponding hourly irradiations (see below).

METEOSAT and ground truth data from the period April - December 1995 are used in this paper.

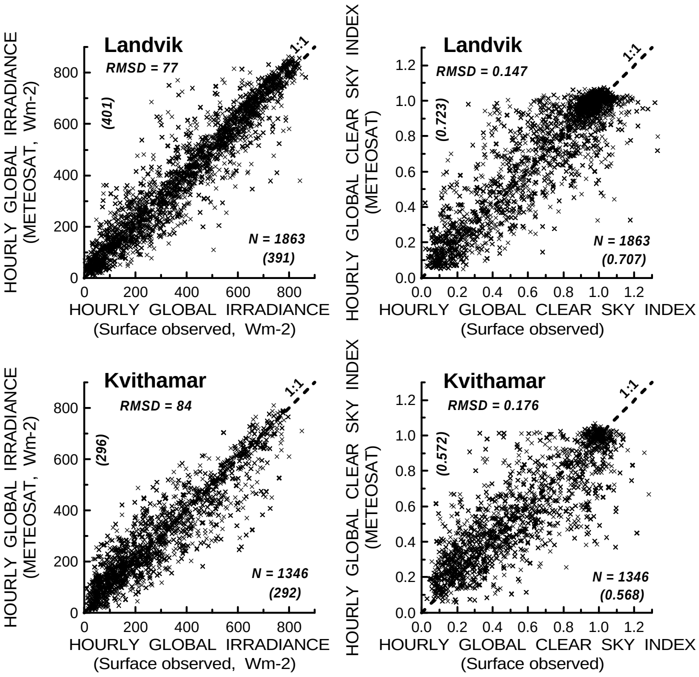

Fig. 2) Surface observed vs modelled (METEOSAT) hourly global irradiance and hourly global clear sky index for the snow free periods at Landvik and Kvithamar, together with the 1 to 1 lines. The root-mean-square-deviations (RMSD) and the number of hours (N), together with observed and modelled averages (in parentheses along the axes) are also given.

3. RESULTS

As examples, observed hourly global clear sky indices and hourly global irradiances are plotted (Fig. 2) against their Heliosat counterparts for snow-free ground at the southernmost (Landvik) and the northernmost (Kvithamar) of our 9 stations, which happens to have the highest and lowest irradiation, respectively. The Heliosat versus ground truth mean bias deviations are less than 2.5 % of the observed average at both these stations, and even at 7 of our 9 stations (Table 1). For the 9 stations collectively, the Heliosat versus ground truth residual root mean square deviation is 82 Wm^{-2}, which is 24% of the observed overall average. This hourly deviation is similar to those observed between stations some 30 km apart within a ground truth network in southeastern New York State and Massachusetts (Perez et al., 1996). That is, if time specific hourly data are required at a specific snow-free location, the satellite data for that location are probably more accurate than data from a ground station more than some 30 km away. A similar break-even distance (27 km) was reported by Perez et al. (1996).

Table 1 Average global clear sky indices (ratios between irradiation sums) observed at surface and derived from METEOSAT data for the snow-free period and the period possibly affected by snow. (MBD = METEOSAT - Observed).

	No snow			**″Snow″**		
Station	**Observed**	**METEOSAT**	**MBD**	**Observed**	**METEOSAT**	**MBD**
Landvik	0.720	0.737	0.017	0.867	0.564	-0.303
Særheim	0.666	0.672	0.006	-	-	-
Ås	0.643	0.671	0.028	0.724	0.700	-0.024
Bergen	0.596	0.616	0.020	-	-	-
Gävle	0.682	0.678	-0.004	0.716	0.584	-0.132
Apelsvoll	0.636	0.645	0.009	0.706	0.651	-0.055
Løken	0.636	0.646	0.010	0.689	0.671	-0.018
Fureneset	0.618	0.622	0.004	-	-	-
Kvithamar	0.567	0.571	0.004	0.650	0.631	-0.019
Overall	0.640	0.651	0.011	0.725	0.634	-0.092

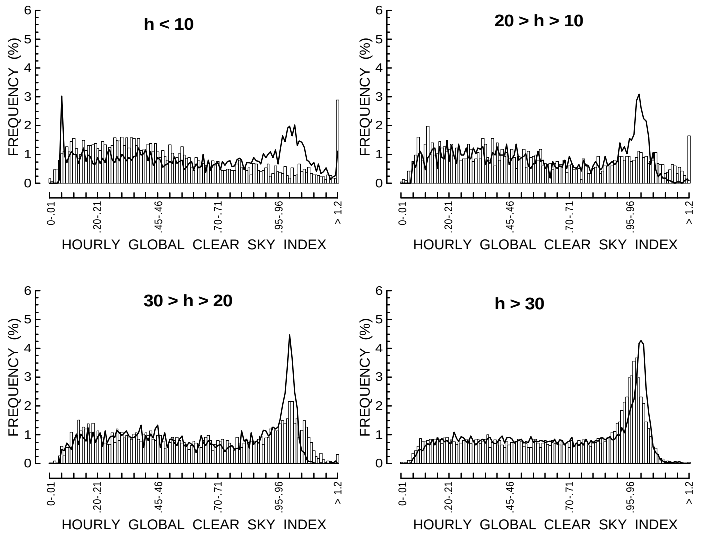

Fig. 3 Observed (histograms) and modelled (METEOSAT, curves) frequency distributions of hourly clear sky indices for snow-free period at the 9 northern stations in Table 1 collectively for different solar elevation (h) intervals.

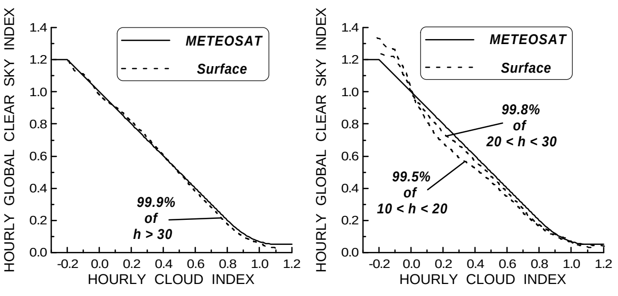

Fig. 4 "Percentile match curves" between hourly global clear sky index (surface observed and modelled from METEOSAT) and cloud index (modelled from METEOSAT) [see text] for different solar elevation (h) intervals collectively for the snow-free period at the 9 stations in Table 1. Curves are drawn for the central 99.5% to 99.9% of the distributions.

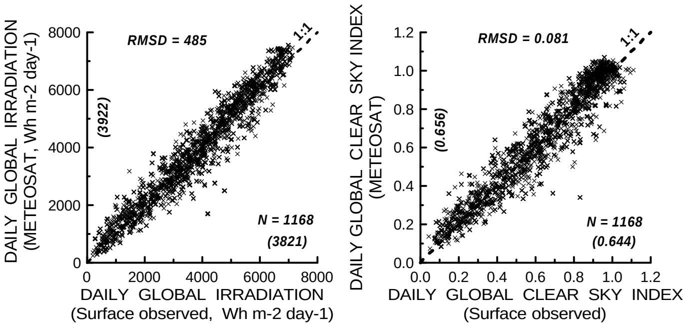

Fig. 5 Surface observed daily global irradiation and global clear sky index plotted against METEOSAT modelled values for snow-free periods at the 9 stations in Table 1, together with the 1 to 1 line. The number of days (N) together with observed and modelled averages (in parentheses along the axes) and root-mean-square-deviatons (RMSD) are also given.

Frequency distributions of hourly global clear sky indices (ground truth and satellite derived) at the 9 stations were formed for hours within solar elevation intervals. For solar elevations > 10°, the satellite derived distribution (Fig. 3) reasonably well reproduces the characteristic bimodal pattern (Skartveit & Olseth, 1992) of the ground truth distribution. Note, however, that the cloudless mode of the ground truth distribution is somewhat broader than its Heliosat counterpart, in particular at low solar elevations, and it is slightly shifted towards lower values. This is due to the fact that Heliosat is not explicitly designed to pick up the inherent variability (atmospheric absorption in particular) of cloud-free atmospheres.

We further compare the above hourly distributions, by plotting "percentile match curves" as follows: the lowest ground truth global clear sky index k_g against the highest Heliosat cloud index n, the second lowest k_g against the second highest n, ..., the highest k_g against the lowest n. For snow-free ground, these curves turn out to vary only moderately between stations. For the 9 stations collectively (Fig. 4), the "percentile match curve" for solar elevation > 30° almost exactly matches eqn (2), and the match is reasonable even for lower solar elevations. During the possibly snow affected periods, however, a significant number of high ground truth clear sky indices is not reproduced by the Heliosat-procedure, most probably because Heliosat tend to interpret cloud free scenes with snow cover as partly cloud covered scenes.

Observed daily irradiations and clear sky indices, for snow-free ground at all 9 stations collectively, are plotted in Fig. 5 against their Heliosat counterparts. For 1168 snow-free days, the average daily ground truth / Heliosat irradiation ratio is 0.974, while (not shown) the average ratio is 1.106 for 98 possibly snow affected days. The Heliosat versus ground truth residual root mean square deviation is 485 Wh m^{-2} day^{-1}, which is 13 % of the observed (snow-free) overall average. Most probably because days with snow cover are excluded in our case, these 13 % are less than the 17-22% daily deviation reported for a large number of ground truth sites in Europe (Zelenka et al., 1992). Our daily deviation is in fact similar to those observed between stations some 18 km

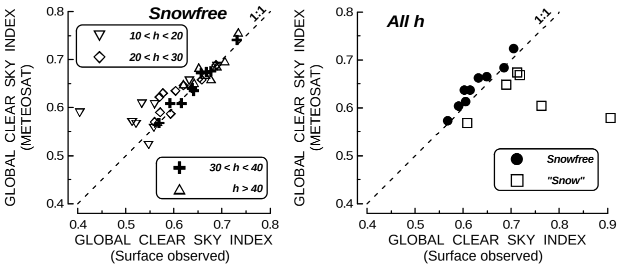

Fig. 6) Left: Group mean values of surface observed vs modelled (METEOSAT) hourly global clear sky index for different solar elevation intervals (h) for the snow free periods at 9 northern stations.
Right: Overall mean values for all hours for each of the stations for the snow-free (9 stations) and for the possibly snow affected (6 stations) periods.

apart within several European and North American ground truth networks (Zelenka et al., 1992). That is, if time specific daily data are required at a specific snow-free location, the satellite data for that location are probably more accurate than data from a ground station more than some 18 km away.

Fig. 6 shows satellite derived overall global clear sky indices at each of the 9 stations, plotted versus their ground truth counterparts. The spatial variation of ground truth data is reproduced remarkably well by the Heliosat data, both within solar elevation intervals and for all solar elevations collectively. The average global clear sky index for individual stations range from 0.567 to 0.720 for ground truth data, and from 0.571 to 0.737 for satellite data. The root-mean-square-deviation between ground truth and satellite averages is 0.014, which is only 9% of the range of ground truth averages.

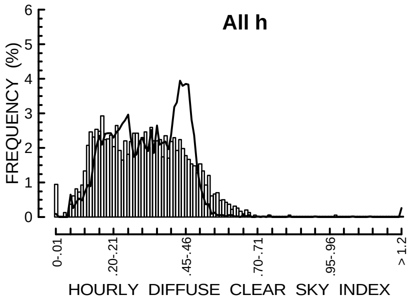

Fig. 7) Surface observed (histograms) and modelled (METEOSAT, curve) frequency distributions of hourly diffuse clear sky indices for snow-free period at Bergen and Gävle for all solar elevations h.

Frequency distributions of hourly diffuse clear sky indices (ground truth and satellite derived) at Bergen and Gävle are plotted in Fig. 7. Although a reasonable overall agreement between ground truth and satellite is seen, the Heliosat data cover a somewhat more narrow range and show a more pronounced bimodal distribution pattern than do the ground truth data. Hourly ground truth diffuse irradiances are plotted against their Heliosat counterparts in Fig. 8. For 3543 snow-free hours, the average ground truth / Heliosat ratio is 0.96, which is considered a satisfying overall agreement.

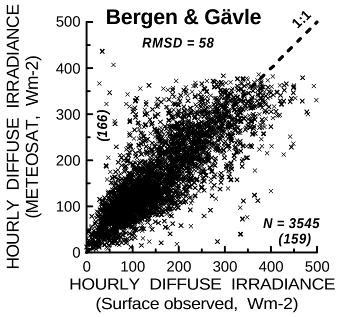

Fig. 8) Surface observed vs modelled (METEOSAT) hourly diffuse irradiance for the snow free periods at Bergen and Gävle, together with the 1 to 1 lines. The root-mean-square-deviations (RMSD) and the number of hours (N), together with observed and modelled averages (in parentheses along the axes) are also given.

4. CONCLUDING REMARKS

For snow-free days during the period April - December, 1995, hourly observations of global irradiance at 9 high latitude (58 - 64°N) ground stations show a negligible mean bias deviation compared to corresponding data derived from Meteosat by the Heliosat procedure. The Heliosat data nicely reproduce the day to day variation and even the observed spatial variation between our ground truth stations. The distribution of hourly ground truth data for solar elevation > 30° almost exactly matches that of satellite derived data, and the match is reasonable even for lower solar elevations. Moreover, if time specific hourly data are required at a snow-free location, the satellite data are probably more accurate than data from a ground station more than some 30 km away.

The overall average and even the hour to hour variation of diffuse irradiation at Bergen and Gävle is nicely reproduced by the Heliosat data. The hourly diffuse irradiances derived from Heliosat cover, however, a somewhat more narrow range and show a more pronounced bimodal distribution pattern than do the ground truth data. The latter discrepancy may probably be resolved by introducing a diffuse fraction model which, for given input parameters, predicts a diffuse fraction distribution rather than an expected average diffuse fraction.

The Heliosat-procedure derives surface global irradiance from actual satellite counts along with corresponding cloud-free, respectively overcast, reference counts. The success of Heliosat critically depends on an adequate predetermination of these cloud-free/overcast reference counts. Our data confirm that a variable snow-cover strongly hampers an adequate predetermination of cloud-free reference counts, particularly in rural areas. The occurrence of snow cover consequently reduces the agreement between surface observations and satellite derived data.

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