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ILLUMINANCE/IRRADIANCE AT A HIGH LATITUDE IDMP STATION

by

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1. INTRODUCTION

Solar radiation records are most frequently of global radiation while data requests from the solar energy community frequently refer to sloping/vertical planes. The calculation of slope radiation from horizontal radiation is therefore frequently required.

Moreover, most radiation-driven processes are spectrally selective, like the photosynthesis or the erythemal response of human skin to ultraviolet radiation. Equally well-known is the concept of daylight, i.e. solar radiation evaluated in proportion to its capability of stimulating the human eye. Even though daylight data are in great demand, they frequently have to be estimated from prescribed luminous efficacies and observed or estimated beam and diffuse irradiance.

The present note deals with observed and modelled relationships between irradiances and illuminances measured on horizontal and vertical surfaces.

2. DATA

Data from the Swedish General class IDMP station Gävle-Brynäs (60E67'N, 17E16'E) were gratefully received from H. A. Löfberg at the Royal Institute of Technology, Department of Built Environment. Global and diffuse horizontal irradiances are measured by Kipp&Zonen CM11 pyranometers, while the following illuminances are measured by Licor LI-210 SZ sensors: Global, diffuse horizontal, north vertical, east vertical, south vertical, and west vertical. The sensors for diffuse radiation are shaded with suntracking shading disks (7 cm radius) at 70 cm distance. Ground reflected radiation is screened off from the vertical sensors by a black screen. The surrounding horizon is so low that it is neglected in this note. Since Gävle and Bergen are at the same latitude, the model is run with the same monthly water vapour amounts as those estimated for Bergen (0.8-1.9 cm).

3. MODELS

3.1 The luminous efficacy model.

The luminous efficacy model [1] is based on the CIE curve for photopic vision and spectral irradiances obtained by an interpolation between transmittance models for, respectively, cloudless sky [2] and unbroken cloud cover [3]. This interpolation decomposes the diffuse irradiance into "blue sky", "dark cloud", and "bright cloud" irradiance. For partly cloudy cases, the model was slightly tuned to hourly global illuminances and irradiances from Bergen. The parameterized version of the model requires solar elevation, day of year, and diffuse and beam clearness indices as input. In the case of beam irradiation, the model is slightly modified here to explicitly account for variation in column amount of water vapour, under the assumption that water vapour extinction takes place solely at visible wavelengths

3.2 The slope algorithm.

Given horizontal beam irradiance/illuminance, the beam irradiance/illuminance on a given slope is readily computed. To calculate the diffuse slope irradiance/illuminance requires additional information about surface reflectance and the horizontal diffuse irradiance/illuminance and its angular distribution.

We apply our slope algorithm [4] for diffuse irradiance even for diffuse irradiance. This algorithm assumes Lambertian ground reflectance and may account for local horizon effects. Sky radiance anisotropy for cloudless as well as overcast skies is parameterized as follows: One fraction, equal to the beam transmittance, of the horizontal diffuse irradiance is treated as circumsolar radiation [5]. Another fraction, decreasing from 0.3 at overcast to zero at beam transmittance = 0.15, is treated as collimated radiation from the zenith. The remaining horizontal diffuse irradiance is treated as isotropic sky radiance.

4. MODELLED VERSUS OBSERVED ILLUMINANCE.

"Modelled" vertical diffuse/beam illuminance is obtained by first transforming observed horizontal diffuse/beam irradiance into illuminance by the luminous efficacy model [1], and subsequently transforming these horizontal illuminances into their vertical counterparts by the slope algorithm [4]. Since we do no whether or not the screening of ground reflected radiation is 100% perfect, we apply the slope algorithm with foreground albedo 0.0 and 0.1.

"Observed" vertical diffuse illuminance equals observed total illuminance minus "observed" beam illuminance, where the latter is readily calculated from observed horizontal beam illuminance.

4.1 Bulk comparison

All hours in 1995 were first roughly classified with respect to cloudiness, according to the hourly horizontal illuminance ratio d/g = diffuse : global, as follows: "Clear" ($d/g < 0.25$), "Scattered" ($0.25 \leq d/g < 0.5$), "Broken" ($0.5 \leq d/g < 1.0$), and "Overcast" ($d/g \geq 1.0$). For the four vertical surfaces, the hours were even classified with respect to beam exposure, according to the illuminance ratio d/t = diffuse : total, as follows: "High beam" ($d/t < 0.25$), "Medium beam" ($0.25 \leq d/t < 0.5$), "Low beam" ($0.5 \leq d/t < 1.0$), and "No beam" ($d/t \geq 1.0$). Within each of these groups, hours were further subdivided into solar elevation groups 10-20°, 20-30°, 30-40°, and > 40°.

For horizontal surfaces, Fig. 1a shows the nice correspondence between group mean values of, respectively, observed global illuminance and global illuminance modelled from beam and diffuse irradiance by the luminous efficacy model [1].

For non-zero beam exposure on verticals, Figs. 1b,c show group mean values of, respectively, observed total illuminance and total illuminance modelled from horizontal diffuse and beam irradiance. It is seen that the assumption of foreground albedo 0.1 apparently fits the observations better than does the assumption of zero foreground albedo.

For zero beam exposure on verticals, Figs. 1d,e show group mean values of, respectively, observed illuminance and illuminance modelled from horizontal diffuse and beam irradiance. Even in this case the assumption of foreground albedo 0.1 apparently fits the observations better than does the assumption of zero foreground albedo.

4.2 Diurnal variation

The period May 19. - July 26. 1995 (noon hour solar elevation = $50.4 \pm 2°$) was selected for a model vs. observation comparison of the diurnal illuminance variation. For this purpose, each day was roughly classified as "nearly cloud-free", "partly cloudy", and "overcast", as outlined below.

4.2.1 Nearly cloud-free days

14 days with daily diffuse : global illumination ratio less than 0.35 were found during the selected summer period.

The vertical beam illuminance is lower on west vertical in the afternoon than it is on east vertical in the morning, obviously due to the occurrence of afternoon convective clouds (Fig. 2a). Moreover, the modelled vertical beam illuminances are slightly lower than the observed ones, merely reflecting a slight discrepancy between observed and modelled horizontal beam luminous efficacy.

In these nearly cloud-free days, the diffuse illuminance observed on verticals depends significantly on azimuthal direction, and this dependency is reasonably well reproduced by the model (Figs. 3a,b).

Since there is abundant beam illuminance to reflect onto the vertical surfaces, the modelled vertical diffuse illuminances depends significantly on the foreground albedo in these nearly cloud-free days (Figs. 3a,b). Note, in particular, that the observed diffuse illuminance on north vertical is approximately twice that modelled for zero foreground albedo, while it is close to that modelled for foreground albedo 0.1.

Inspection of the individual nearly cloud-free days indicates, however, that the model tends to overestimate the circumsolar fraction at low solar elevations under an entirely cloud-free and low turbidity sky.

Figs. 4a,b show the nice correspondence between modelled and observed diurnal variation of vertical total illuminances under a nearly cloud-free sky.

4.2.2 Partly cloudy days

25 days with daily diffuse : global illumination ratio in the range 0.35 - 0.85 were found during the selected summer period.

As in the nearly cloud-free days, the vertical beam illuminances are significantly affected by the prevalence of afternoon convective clouds, and the effect of a slight discrepancy between observed and modelled horizontal beam luminous efficacy is seen (Figs. 2c,d).

Even in these partly cloudy days, the diffuse illuminances observed on verticals depend significantly on azimuthal direction, and this dependency is reasonably well reproduced by the model (Figs. 3c,d). However, the observed differences between east and west (Fig. 3c) and between south and north (Fig. 3d) exceed the corresponding modelled differences, indicating that the model moderately underestimates the circumsolar fraction under a partial cloud cover.

Figs. 4c,d show the nice correspondence between modelled and observed diurnal variation of vertical total illuminances under a partial cloud cover.

4.2.3 Overcast days

Only one overcast day (no beam recorded) was found during the selected summer period.

Our slope algorithm yields no circumsolar diffuse radiation under an overcast sky, and the modelled vertical diffuse illuminance is therefore independent of azimuthal direction. This independency is corroborated by the observations, which for the overcast day (Figs. 3e,f) differ substantially less between azimuthal directions than they do in nearly cloud-free and partly cloudy days (Figs. 3a-d). Note, however, that the observed diffuse illuminance increase at 14 hr is accompanied by a moderate azimuthal dependency (maximum on south, minimum on north) which is not reproduced by the model (due to zero beam).

Moreover, since there is no beam illuminance to reflect onto the verticals, the modelled diffuse illuminances (Figs. 3e,f) depend far less even on the foreground albedo than they do in nearly cloud-free and partly cloudy days (Figs. 3a-d).

For this overcast day, the model yields a fraction 0.3 of circumzenithal illuminance which is not seen by vertical surfaces. An assumption of isotropic overcast sky luminance would therefore increase the vertical diffuse illuminance by a factor 1.43. Such an increase is clearly contradicted by the observations, which reasonably well corroborate a circumzenith fraction 0.3 along with a some 0.0 - 0.1 foreground albedo.

5. CONCLUDING REMARKS

One year of radiation data from the general class IDMP station Gävle-Brynäs indicates:

- The observed beam luminous efficacy slightly exceed that of the luminous efficacy model [1].
- The observed azimuthal dependency of vertical diffuse illuminance indicates that the assumption circumsolar fraction = beam transmittance [4] sligthly underestimates the circumsolar fraction under a partial cloud cover, while the circumsolar fraction may be sligthly overestimated at low solar elevation under a cloud-free and low turbidity sky.
- There are indications that the vertical diffuse illuminances are sligthly affected by reflection from the foreground, i.e. that the ground reflected radiation is not completely eliminated by the black screen.
- The vertical diffuse illuminances corroborate a circumzenith fraction 0.3 under overcast sky.

6. REFERENCES

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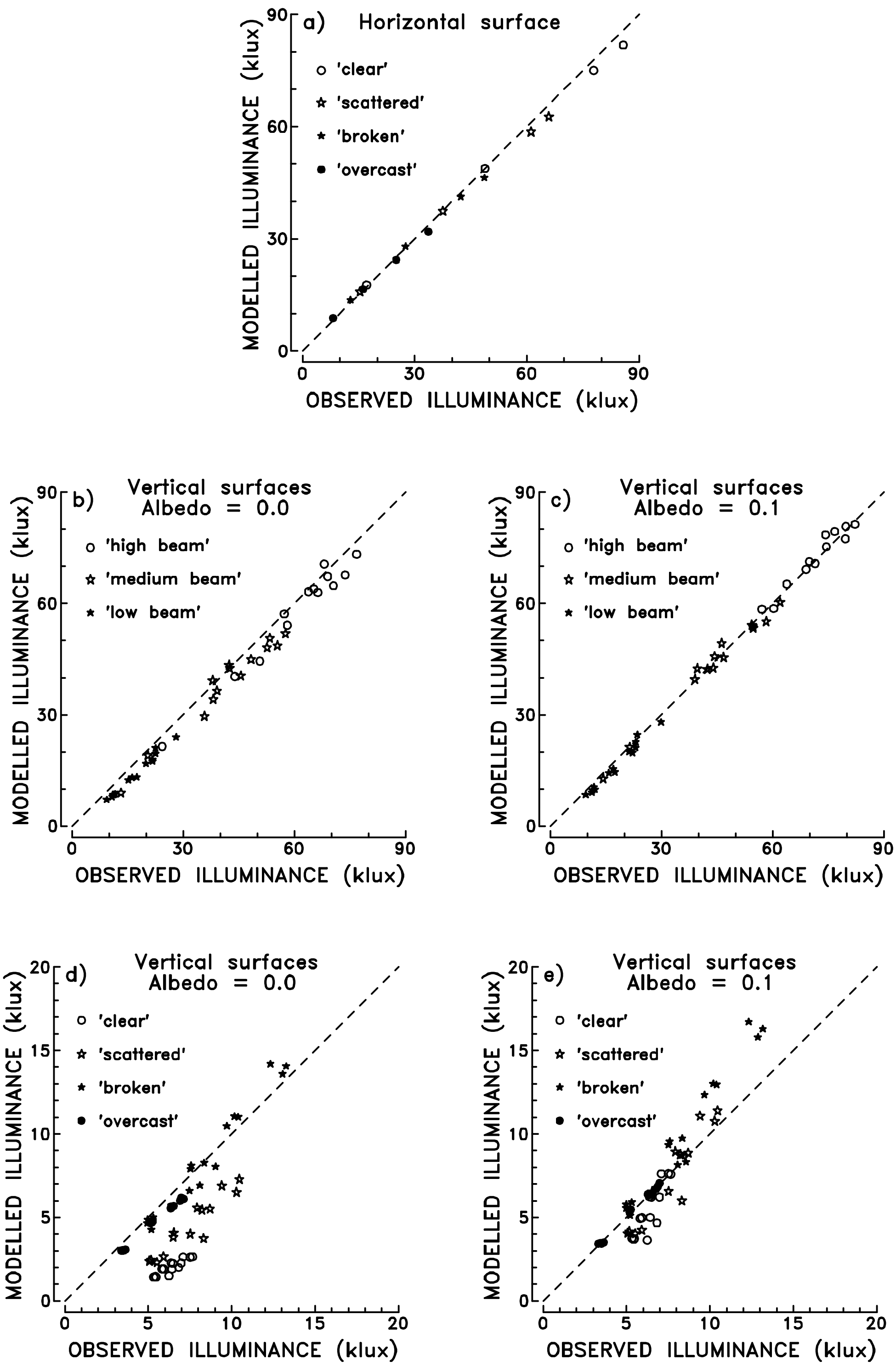

Fig.1 a) Hourly data from Gävle-Brynäs (1995) grouped according to cloudiness and solar elevation (see text): Global illuminance modelled from observed horizontal beam and diffuse irradiance plotted vs observed global illuminance.

b-c) Hours of non-zero vertical beam exposure grouped according to azimuthal orientation, solar elevation, and vertical beam exposure (see text): Group mean values of total illuminances modelled from horizontal diffuse and beam irradiances plotted vs observed total illuminances.

d-e) Same as b-c), but for hours of zero vertical beam exposure grouped according to azimuthal orientation, solar elevation, and cloudiness (see text).

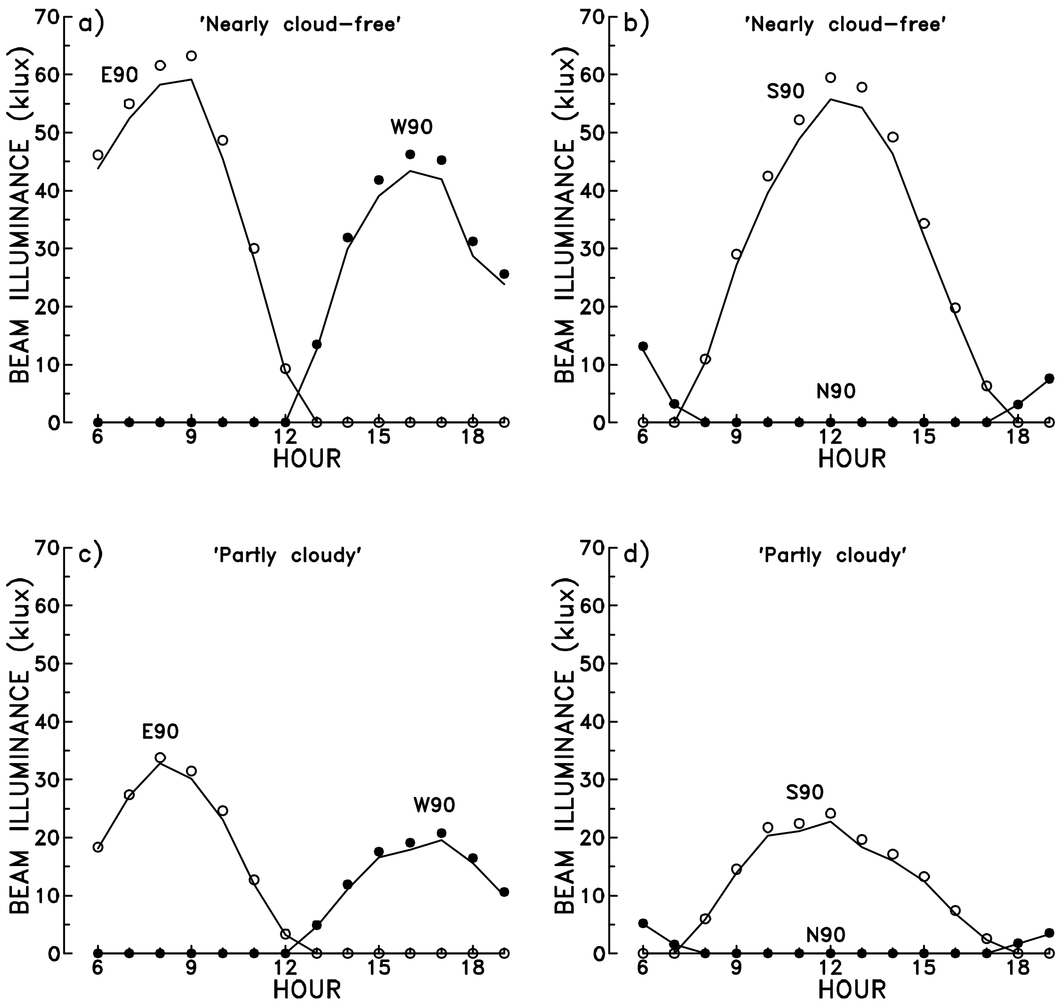

Fig.2 Vertical beam illuminance calculated from horizontal beam illuminance ("observed" - dots) and from horizontal beam irradiance (modelled - curves). Hourly mean values for summer days grouped as "nearly cloud-free" and "partly cloudy" (see text).

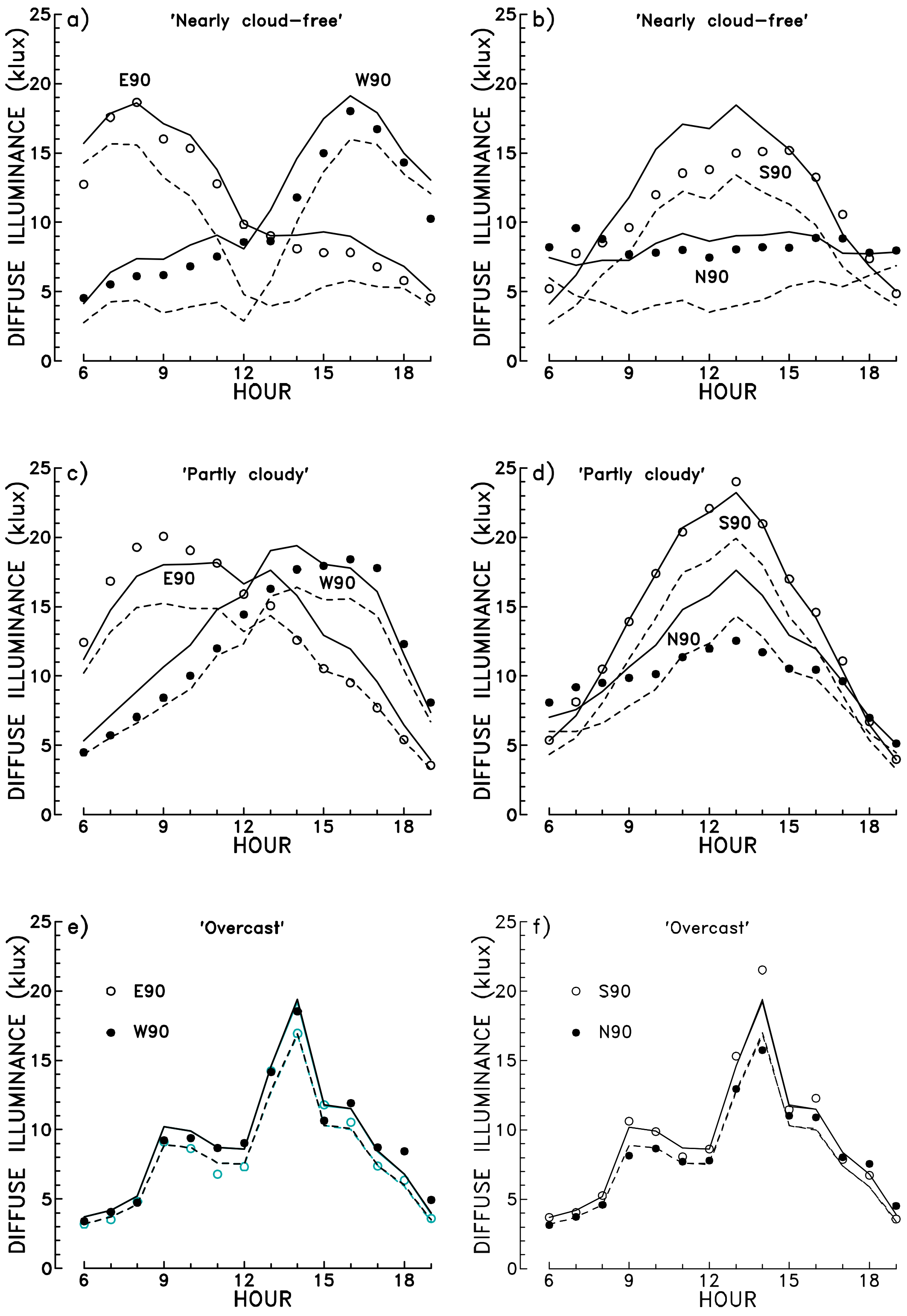

Fig.3 Vertical diffuse illuminance observed (dots) and modelled (curves) from horizontal beam and diffuse irradiances. Hourly mean values for "summer" days grouped as "nearly cloud-free", "partly cloudy", and "overcast" (see text) . Fully drawn curves for foreground albedo = 0.1, and dashed curves for foreground albedo = 0.0.

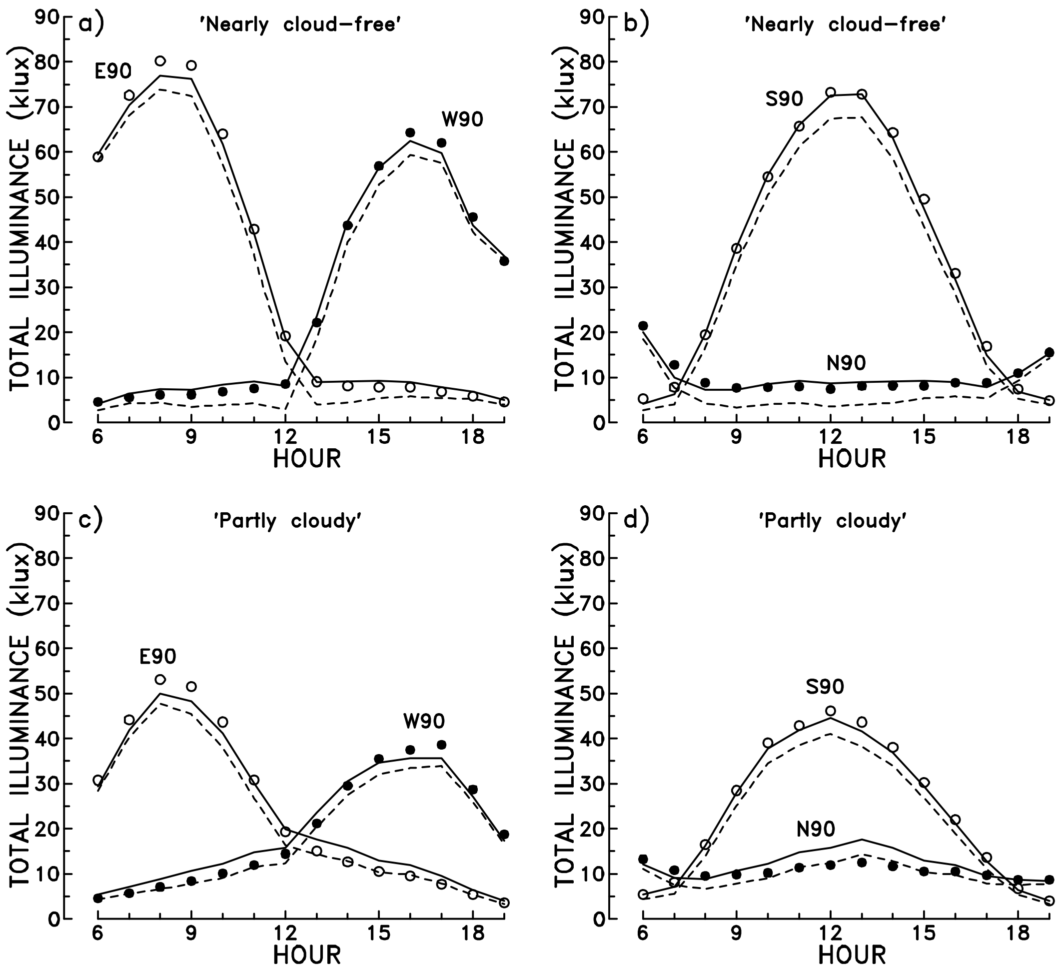

Fig.4 Same as Figs. 2-3, but for total illuminance.