Papers

Influence of clouds on the broadband spectral irradiance at the Baltic surface

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Baltic atmosphere
Broadband spectral irradiance
Clouds

Anna Rozwadowska
Institute of Oceanology,
Polish Academy of Sciences,
Sopot

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Abstract

On the basis of downward irradiance data in the ultraviolet, visible and infrared spectral intervals as well as of meteorological observations collected during several cruises to the Baltic, the influence of clouds and solar zenith angle on the broadband spectral composition of solar radiation reaching the Baltic surface is analysed. The relation between the atmospheric transmittance of total irradiance and solar zenith angle, and the ratios of broadband spectral irradiance to the total for both visible and infrared radiation have been estimated by polynomials.

1. Introduction

The solar radiation flux reaching the Baltic surface undergoes constant variations due to both annual and daily changes in both solar altitude and meteorological conditions (*e.g.* Dera and Rozwadowska, 1991). Not only do these factors influence the total amount of incident solar radiation, they also modify its spectral composition.

As far as atmospheric gases are concerned, variability in the ozone content of the atmosphere plays a decisive role in the modification of the ultraviolet (UV) flux at the surface ($0.18 < \lambda < 0.36$ μm), especially the UV-B. Moreover, ozone has weak absorption bands in the visible light band (0.44–0.78 μm). Water vapour, another strong absorber present in the atmosphere in variable amounts, also has its main absorption bands in the infrared (IR) – at 0.72 μm, 0.82 μm, 0.94 μm, 1.14 μm, 1.38 μm, 1.87 μm, 2.7 μm, 3.2 μm, and weaker bands in the 0.54–0.7 μm range (*e.g.* Sivkov, 1968; Green *et al.*, 1988). The other atmospheric gaseous constituents, *i.e.* carbon dioxide, carbon monoxide, methane, nitrous oxide (N_2O), oxygen and nitrogen, are of minor importance to the variations of spectral absorption.

Rayleigh scattering by atmospheric gases acts mainly in the UV and blue parts of the spectrum.

The absorptive properties of an aerosol depend on its composition. Some types, *e.g.* urban or industrial aerosols, may noticeably affect the solar radiation spectrum (Lorente *et al.*, 1994).

Clouds influence the solar radiation spectrum at the surface owing to absorption by water droplets and/or ice crystals as well as water vapour. Like the absorption bands of water vapour, the main bands of ice and liquid water lie in the IR part of the spectrum. Light scattering in clouds, however, is spectrally almost neutral (Feygelson, 1981).

A knowledge of the spectrum of the incident solar radiation flux at the sea surface is indispensable in studies of *e.g.* solar radiation penetration into water and photosynthetic processes, as well as in the development of satellite methods of estimating the surface solar irradiance.

Many papers, *e.g.* Yang and Miller (1995); Shettle and Green (1974); Volkova and Chubarova (1995); Jokela *et al.* (1993); Frouin *et al.* (1989); Green and Chai (1988); Leckner (1978); Bird and Riordan (1986), deal with the spectral modelling of the solar radiation reaching the Earth's surface in various spectral ranges and for clear or cloudy atmospheres. Kano *et al.* (1978) have computed the ratios of the UV, VIS and IR irradiance to the total as a function of both the solar altitude and the total irradiance. The influence of an aerosol on the solar radiation spectrum is analysed by *e.g.* Lorente *et al.* (1994) and Bird *et al.* (1982). Measurements carried out in Russia have revealed that optically relatively thick clouds (Sc) modify the surface solar irradiance spectrum (Yevnevich and Shilovtseva, 1994; Izakova *et al.*, 1994), whereas attenuation of visible and infrared radiation by high-level clouds (Ci, Cc, Cs) (Barteneva *et al.*, 1994) is almost neutral. The papers by Słomka (1978); Słomka and Słomka (1972) and Abakumova *et al.* (1994) as well as the monograph by Feygelson (1981) also deal with this problem. Rodskjer (1983) related the spectral composition of the daily insolation to the relative total daily insolation and sunshine duration. Significant interannual trends in the spectral composition of both direct normal solar radiation (Sakellariou *et al.*, 1995) and total irradiance (Jacovides *et al.*, 1993b) have been found for the atmosphere near Athens (Greece). Seasonal changes have been described by Jacovides *et al.*, (1993a), Hansen (1984) and Rao (1984) and Kvifte *et al.* (1983).

Special attention has been given to the UV part of the solar spectrum. The influence of various meteorological parameters such as cloudiness, aerosols, visibility, ozone content or solar altitude on the ultraviolet radiation, based on model computations (Volkova and Chubarova, 1995; Jokela *et al.*, 1993) and/or experimental data (Kuik and Kelder, 1994; Frederick and Steele, 1995; Cartalis *et al.*, 1992; Van Weele *et al.*, 1995; Bordewijk *et al.*, 1995) has been investigated. Seasonal changes in the percentage of $UV\ A$ and B in the total radiation in Japan are presented by Sasaki *et al.* (1993).

None of these papers, however, addresses the Baltic atmosphere. The aim of the present paper is to analyse the influence of clouds and solar altitude on the variability of the broadband spectral composition of the solar radiation reaching the Baltic surface. Some preliminary results have already been included in the monograph by Dera (1995).

2. Material and methods

During 7 cruises to the Baltic Sea, which took place in October 1992, April and September 1993, and in May, August and September 1994, continuous registration of broadband spectral downward irradiance (global solar radiation) at the sea surface was conducted for the following spectral intervals:

- 295–2800 nm (during every cruise),
- 395–2800 nm (in 1994),
- 695–2800 nm (during every cruise).

Standard meteorological observations were made simultaneously.

The measuring system consisted of sensors and an electronic unit. The sensors were a Kipp and Zonen CM5 model pyranometer (total radiation), and 3 Eppley spectral precision pyranometers fitted with hemispherical Schott filters. WG295, GG395 and RG695 filters were chosen to divide the whole range of short-wave solar radiation reaching the sea surface into ultraviolet (295–395 nm), visible (395–695 nm), and near infrared (695–2800 nm) intervals.

The pyranometers were were mounted on Cardan suspensions to ensure that they were horizontal.

Pyranometer output voltages were amplified, converted to digital signals and transmitted to a PC computer. Irradiances were measured with a frequency of 5 s^{-1} and the mean values of 30 s were recorded. The data were converted to irradiance units in accordance with the following relations:

- for the Kipp and Zonen pyranometer and the Eppley pyranometer with a WG295 glass hemisphere:

$$E_d = \frac{V}{ec}, \tag{1}$$

- for Eppley pyranometers with colour filters:

$$E_d = \frac{V}{ec\Delta c}, \tag{2}$$

where

V – pyranometer voltage output, in mV,
e – amplification factor, $e = 200$,
c – pyranometer calibration coefficient, in mV W^{-1} m^2,
Δc – colour filter correction factor for c (the values given in the pyranometer calibration certificates).

Once a year the instruments were calibrated out of doors against Kipp and Zonen CM5 and CM7 pyranometers calibrated by the manufacturer. The measuring error ε_{E_d}, comprising all the error sources of the actinometric measurements on the ship, did not exceed $\pm 5\%$ for $\vartheta_S < 70°$ and $E_d > 100$ W m^{-2}. For irradiances lower than a dozen W m^{-2}, the error increases considerably.

Based on 5-minute mean spectral irradiances, the following were calculated:

- the total downward irradiance transmittance T_E with respect to the solar spectrum

$$T_E = \frac{\langle E_d(h=0)\rangle}{\langle E_d(h=\infty)\rangle}, \tag{3}$$

where $E_d(h = 0)$ and $E_d(h = \infty)$ are the respective total irradiances at the sea surface and at the top of the atmosphere

$$E_d(h=\infty) = S_o f \cos\vartheta_S, \tag{4}$$

where

ϑ_S – solar zenith angle,
S_o – the solar constant, equal to 1368 ± 7 W m^{-2} (Willson, 1993),
f – the factor describing seasonal changes in S_o due to changes in the Sun-Earth distance (*e.g.* Spencer, 1971; Paltridge and Platt, 1976),

- ratios of the irradiance from the designated wavelength interval to the total:

$$\begin{aligned} p(\lambda_1-\lambda_2) &= \frac{\langle E_d(\lambda_1-\lambda_2)\rangle}{\langle E_d(295-2800)\rangle} = \\ &= \frac{\langle E_d(\lambda_1-2800)\rangle - \langle E_d(\lambda_2-2800)\rangle}{\langle E_d(295-2800)\rangle}, \end{aligned} \tag{5}$$

where λ_1 and λ_2 cut-off wavelengths of the Schott filters.

The following notation was also adopted:

$$
\begin{aligned}
p(295-395) &= p_{UV},\\
p(395-695) &= p_{VIS},\\
p(695-2800) &= p_{IR}.
\end{aligned}
\tag{6}
$$

The absolute measuring error σ_p for a parameter $p(\lambda_1-\lambda_2)$, measured indirectly, was estimated:

$$
\sigma_{p(\lambda_1-\lambda_2)} = \sqrt{\begin{aligned} &\left(\frac{\partial p(\lambda_1-\lambda_2)}{\partial E_d(\lambda_1)}\right)^2 \sigma^2_{E_d(\lambda_1)} + \left(\frac{\partial p(\lambda_1-\lambda_2)}{\partial E_d(\lambda_2)}\right)^2 \sigma^2_{E_d(\lambda_2)} + \\ &\qquad + \left(\frac{\partial p(\lambda_1-\lambda_2)}{\partial E_d(295)}\right)^2 \sigma^2_{E_d(295)}, \end{aligned}}
\tag{7}
$$

where $\sigma_{E_d(\lambda_i)} = \varepsilon_{E_d(\lambda_i)} E_d(\lambda_i)$ and $E_d(\lambda_i) = E_d(\lambda_i - 2800)$. When $\vartheta_S < 70°$ and $E_d > 100$ W m^{-2} the absolute measuring errors are $\sigma_{p_{UV}} \le \pm 0.064$, $\sigma_{p_{VIS}} \le \pm 0.055$, and $\sigma_{p_{IR}} \le \pm 0.032$. Expressed as relative errors these amount to ± 80%, ± 12%, and ± 7% respectively. However, the errors rise considerably under conditions of low irradiance.

3. Results and discussion

In order to analyse the influence of clouds on the spectral variations in the solar radiation flux at the Baltic surface, three types of meteorological situation were distinguished, with respect to the types of clouds predominating in the sky:

- cloud class L – predominantly cumulus (Cu, Cb), low-level clouds (St, Sc, Ns) or middle-level layer clouds covering a considerable part of the sky (n $\ge$ 0.7),
- cloud class H – high-level clouds (Ci, Cs, Cc) or middle-level cloud cover n $<$ 0.5,
- cloudless sky – cloud cover n $\le$ 0.1 and horizontal visibility range $VIS > 4$ km.

Such a classification combines high- and middle-level clouds, because the latter type, when their cover is small, are usually optically thin and often accompany high-level clouds. An exception is the situation when the edge of a thick Ac or As cloud sheet appears over the observation point (Rozwadowska, 1991). Fig. 1 illustrates the numbers of observations for each cloud situation and various intervals of the solar zenith angle.

Under a clear sky and $\vartheta_S < 55°$, the respective mean values of the ratios of the broadband spectral irradiance to the total, *i.e.* p_{UV}, p_{VIS}, p_{IR}, are equal to 0.067, 0.419 and 0.516 (Tab. 1). Although the p_{UV} ratio has been included in the present analysis, the poor precision of its measurement must be borne in mind. The mean values of p_{UV}, p_{VIS}, and p_{IR} are comparable

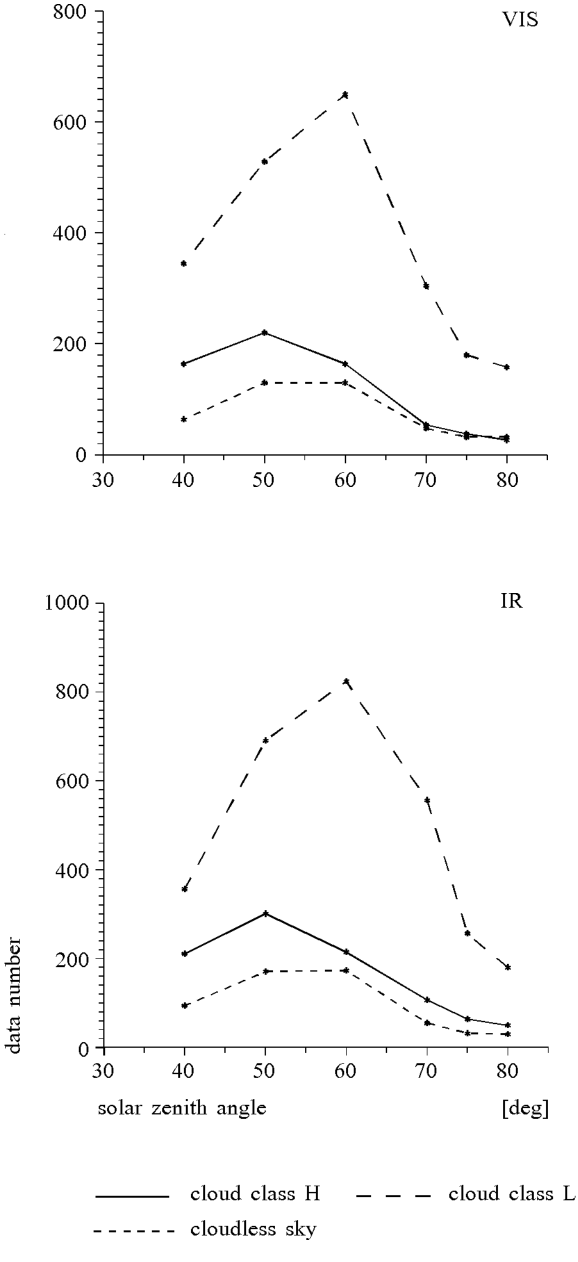

Fig. 1. Numbers of observations for each cloud situation and solar zenith angle interval analysed in this paper

with the corresponding results obtained by other authors shown in Tab. 2. Slight discrepancies may stem from the different wavelength intervals analysed by the investigators as well as from the fact that none of these authors

Table 1. The influence of solar zenith angle on the proportions of radiation from designated spectral intervals to the total solar irradiance at the Baltic surface, under cloudless conditions. The numbers in each table's cell are mean value, standard deviation and number of observations respectively

Solar zenith angle [deg]	p_{UV}	p_{VIS}	p_{IR}
80	**0.075** 0.019 32	**0.369** 0.034 32	**0.557** 0.027 30
75	**0.071** 0.013 32	**0.397** 0.027 32	**0.531** 0.023 32
70	**0.065** 0.009 48	**0.411** 0.019 48	**0.524** 0.019 55
60	**0.070** 0.010 130	**0.412** 0.015 130	**0.520** 0.012 173
50	**0.069** 0.009 130	**0.416** 0.012 130	**0.517** 0.012 171
40	**0.063** 0.009 64	**0.421** 0.007 64	**0.513** 0.008 94

dealt with a marine atmosphere. Although the atmosphere over the Baltic, an enclosed sea, is affected by land (urban, industrial and rural aerosols), the marine aerosol usually predominates. Compared to the aerosols of continental origin, the marine aerosol displays considerably weaker attenuation in the UV and VIS parts of solar spectrum (*e.g.* McClatchey *et al.*, 1984).

The occurrence of clouds noticeably modifies the spectral composition of the solar radiation, which is reflected in changes in the proportions of UV, VIS and IR radiation in the total irradiance (Tab. 3, Fig. 2). With the increase in low- and middle-level cloud cover, p_{UV} and p_{VIS} rises, whereas p_{IR} decreases. For n = 1 these proportions take respective values of 0.093, 0.480 and 0.428. The observed tendencies and values are in agreement with those given by other researchers, shown in Tab. 2, as well as with the papers by Abakumova *et al.* (1994), Yevnevich and Shilovtseva (1994) and Izakova *et al.* (1994).

Table 2. Proportions of radiant energy from designated spectral intervals to the total solar irradiance at the Earth's surface – comparison of data by different authors. The upper lines give definitions of the respective spectral intervals given by the authors of the source papers. FS denotes fractional sunshine

Author	p_{UV} : interval [nm] ratio	$p_{VIS/PAR}$: interval [nm] ratio	p_{IR} : interval [nm] ratio	Total irradiance interval [nm]	Conditions
Lorente *et al.*, 1994	300–400 0.0458	400–700 0.4438	700–1100 0.5104	300–1100	cloudless sky, $\vartheta_s = 60°$ rural aerosol (near Barcelona), ($\tau_a(550) < 0.230$)
Lorente *et al.*, 1994	300–400 0.0438	400–700 0.4387	700–1100 0.5175	300–1100	cloudless sky, $\vartheta_s = 62°$ urban aerosol (Barcelona), $0.345 < \tau_a(550) < 0.460$
Rao, 1984		385–695 0.443		295–2800	cloudless sky, annual means of daily values, $\phi = 44.5°$N
Hansen, 1984	295–385 0.046	385–695 0.448	695–2800 0.506	295–2800	cloudless sky, July, $\phi = 59.7°$N
Hansen, 1984	295–385 0.042	385–695 0.431	695–2800 0.529	295–2800	cloudless sky, March, $\phi = 59.7°$N
Blackburn and Proctor, 1983		300–700 0.45		295–2800	cloudless sky, $\phi = 43.5°$N
Yevnevich and Shilovtseva, 1994	300–380 0.05	380–710 0.45	710–4000 0.50	300–4000	$\vartheta_s = 80°$, n = 1, Sc, Moscow
Yevnevich and Shilovtseva, 1994	300–380 0.05	380–710 0.50	710–4000 0.46	300–4000	$\vartheta_s = 35°$, n = 1, Sc, Moscow

Table 2. continued

Author	p_{UV} : interval [nm] ratio	$p_{VIS/PAR}$: interval [nm] ratio	p_{IR} : interval [nm] ratio	Total irradiance interval [nm]	Conditions
Kano *et al.*, 1978	300–395 0.076	395–710 0.425	710–2700 0.499	300–2700	$\vartheta_s = 50°$, average value for various meteorological conditions
Rao, 1984		385–695 0.483		295–2800	cloudy sky, FS < 0.15, annual means of daily values, $\phi = 44.5°$N

The influence of high-level clouds (cloud type H) on the solar spectrum is weaker and for n = 1 the respective proportions of UV, VIS and IR in the total irradiation are 0.096, 0.412, 0.492. These confirm the findings of Barteneva and her co-workers (1994), who analysed the optical depth of high-level clouds in some narrow spectral bands (0.400, 0.550, 0.800, 1.0, 2.20 and 3.65 μm) and found its spectral characteristic close to neutral. On the other hand, according to Abakumova *et al.* (1994), the spectral transmittance of Ci + Cc + Ac was higher for the UV band than for VIS and IR.

In the case of a cloudless sky, the increase in the solar zenith angle (Fig. 2, Tab. 3) results in a decrease in the p_{VIS} ratio for the visible solar radiation, and for $\vartheta_S = 80°$ and n = 0 is equal to 0.369, and causes the IR p_{IR} ratio to increase up to 0.557. The above tendencies are pronounced for zenith angles higher than 70° and stem from the strong scattering of the short-wave (blue) part of the solar spectrum by the optically thick atmosphere near the horizon. A cloudy sky maintains this tendency. Certain deviations from these regularities, which can be seen in the data presented here, are probably due to the relatively small number of data. In the case of p_{UV}, a large measuring error could also account for them.

In the marine atmosphere, clouds (consisting mainly of water droplets and water vapour), the marine aerosol (also containing a high proportion of water), and atmospheric water vapour are the principal factors influencing the spectral composition of the solar irradiance in both the VIS and the IR

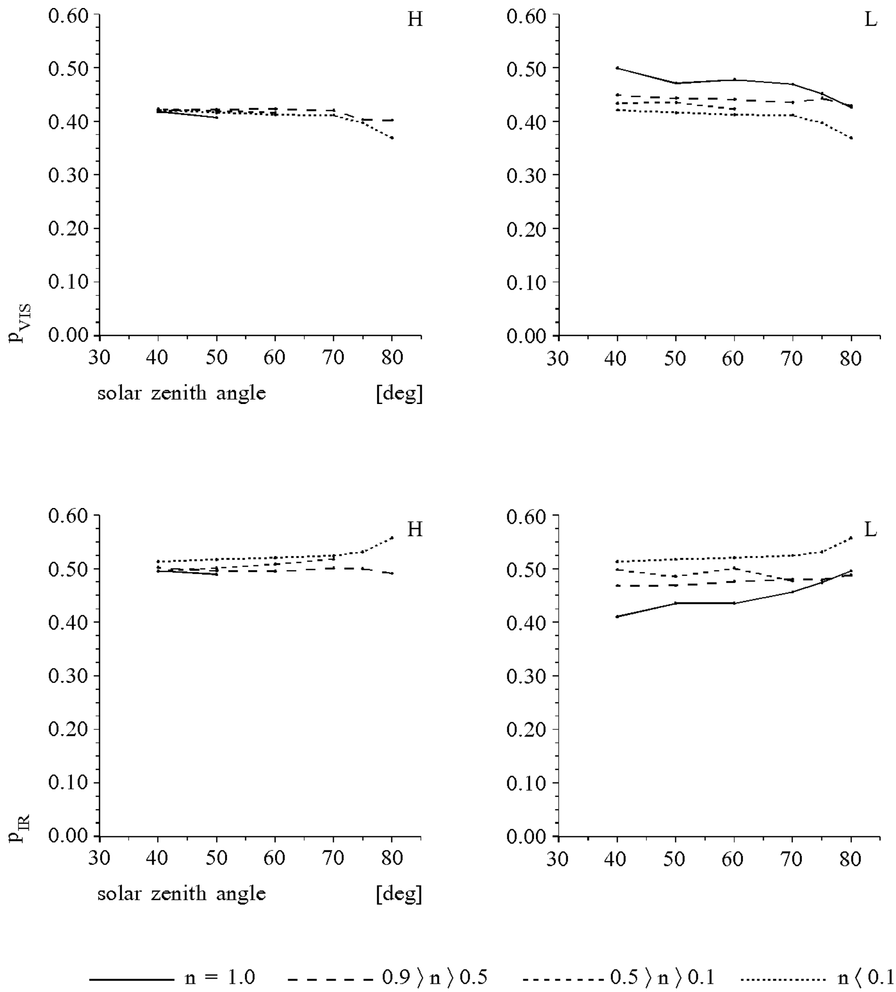

Fig. 2. The influence of solar zenith angle, cloud class (H, L) and cloud cover on p_{VIS} and p_{IR} ratios

parts of the spectrum. These allow to suppose that for all the cloud types (cloud classes) and cloud covers the p_{VIS} and p_{IR} ratios should be well correlated with the transmittance of the total irradiance T_E for constant ϑ_S. Such an approach would also eliminate the impact of cloud optical thickness variations within each cloud class, which can be considerable (Rozwadowska, 1991). Fig. 3, which illustrates the influence of T_E on p_{VIS} and p_{IR} for $45° < \vartheta_S < 55°$, confirms this supposition.

The relations between the total irradiance transmission T_E and ϑ_S on the one hand, and the p_{VIS} and p_{IR} proportions on the other can be described by means of the following polynomial:

Table 3. The influence of both cloudiness and solar zenith angle, on the proportions of radiation from designated spectral intervals to the total solar irradiance at the Baltic surface. The numbers in each table's cell are mean value, standard deviation and number of observations respectively

Cloud class:		H			L		
n	ϑ [deg]	p_{UV}	p_{VIS}	p_{IR}	p_{UV}	p_{VIS}	p_{IR}
0.6	82–73	**0.075** 0.014 30	**0.404** 0.027 30	**0.521** 0.025 30	**0.084** 0.020 33	**0.444** 0.040 33	**0.472** 0.056 33
	72–56	**0.072** 0.009 56	**0.431** 0.018 56	**0.491** 0.029 64	**0.076** 0.011 64	**0.430** 0.022 64	**0.486** 0.032 77
	55–35	**0.073** 0.004 77	**0.440** 0.011 77	**0.504** 0.015 81	**0.074** 0.009 43	**0.449** 0.016 43	**0.469** 0.023 77
1.0	82–73	–	–	–	**0.080** 0.017 224	**0.439** 0.030 224	**0.483** 0.035 289
	72–56	–	–	**0.462** 0.025 33	**0.085** 0.013 520	**0.475** 0.029 520	**0.445** 0.030 698
	55–35	**0.096** 0.014 60	**0.412** 0.007 60	**0.492** 0.010 60	**0.093** 0.011 375	**0.480** 0.037 375	**0.428** 0.035 402

$$p_i = \sum_{j=0}^{2} \left[\sum_{k=0}^{4} a_{i,j,k} (\cos \vartheta_S)^k \right] (T_E)^j, \tag{8}$$

where i and ϑ_S denote the spectral interval (VIS, IR) and solar zenith angle respectively. The coefficients of the polynomials matched to the experimental data for the VIS and IR parts of the solar radiation surface spectrum are given in Tabs. 4 and 5 respectively. The relations obtained are shown in Fig. 4. The UV interval was omitted in polynomial fitting because of the considerable measurement error in the p_{UV} data.

To evaluate the polynomial formulas $p_{VIS}(\vartheta_S, T_E)$ and $p_{IR}(\vartheta_S, T_E)$ described by eq. (8) with the polynomial coefficients from Tabs. 1 (VIS) and 2 (IR), the following error estimators have been computed (Stone, 1993):

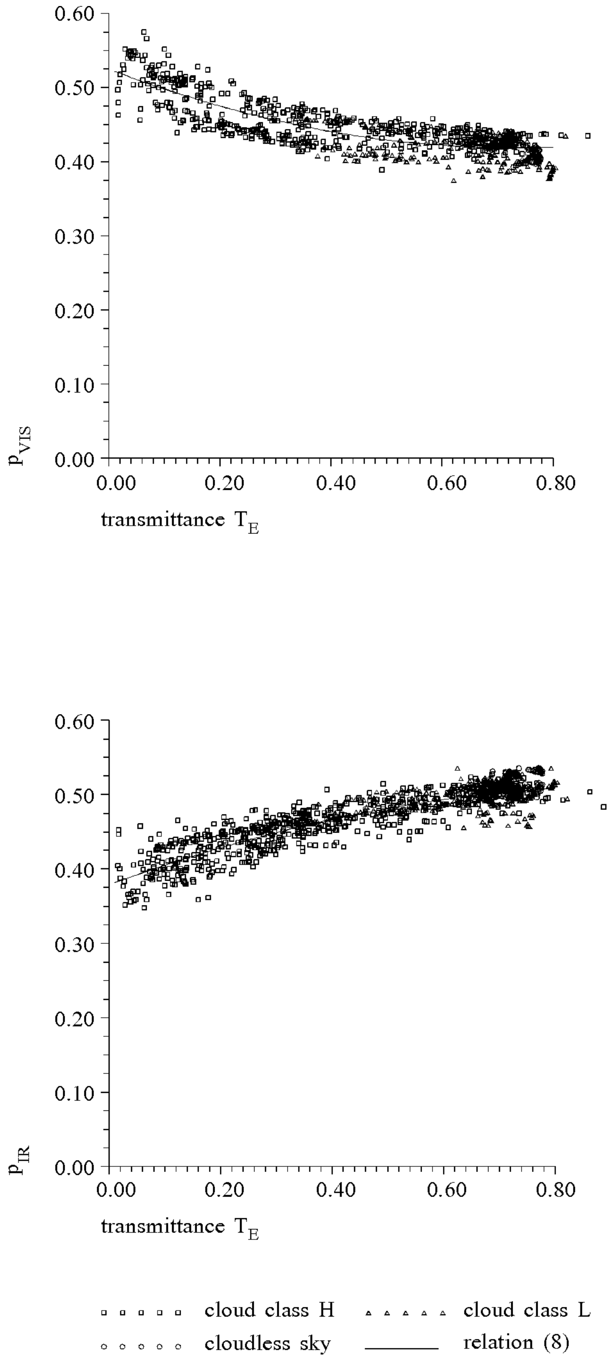

Fig. 3. The relations between the ratios of broadband spectral irradiance to the total, *i.e.*, p_{VIS}, p_{IR}, and transmittance of the total irradiance for $45° < \vartheta_S < 55°$. The points denote experimental data

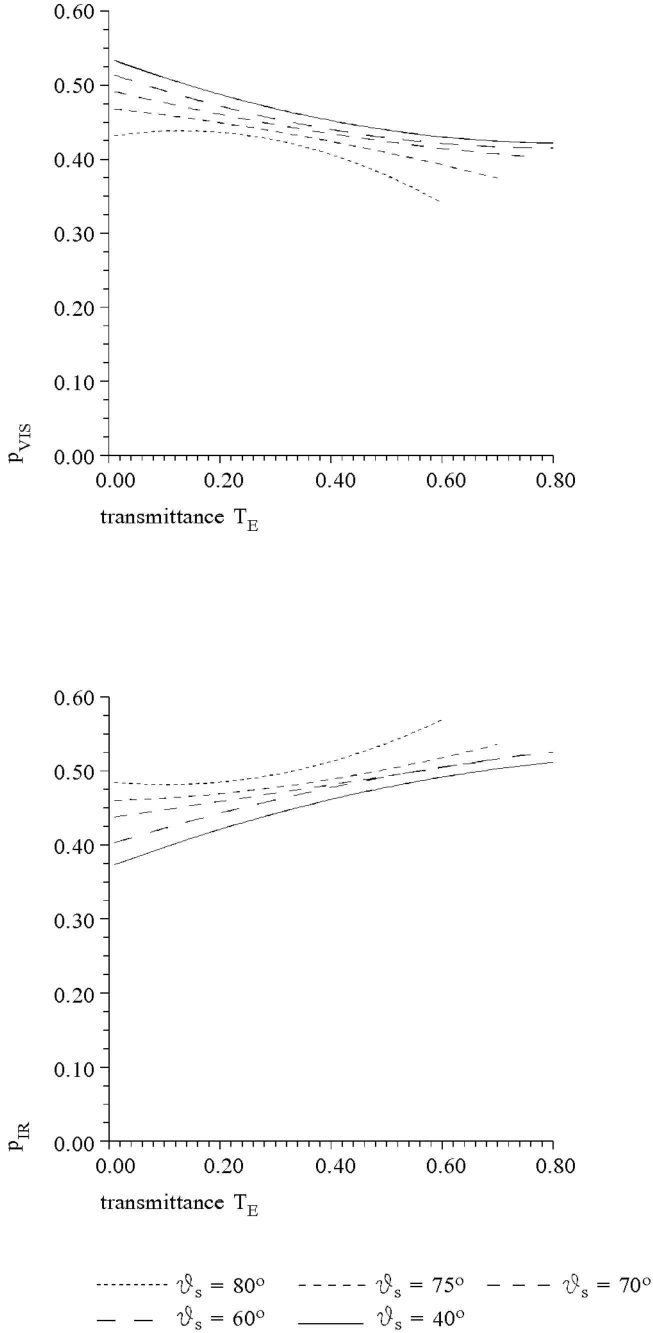

Fig. 4. The relations between the atmospheric transmittance of total irradiance and solar zenith angle ϑ_S, and the ratio of broadband spectral irradiance to the total for visible p_{VIS} and infrared radiation p_{IR}, estimated by the polynomials given by eq. (8) with the parameters from Tabs. 4 and 5 respectively

- the mean bias error:

$$MBE_i = \frac{1}{N}\sum_{j=1}^{N}(p_{i,j}^m - p_{i,j}^e), \tag{9}$$

- the root mean square error:

$$RMSE_i = \left(\frac{1}{N}\sum_{j=1}^{N}(p_{i,j}^m - p_{i,j}^e)^2\right)^{0.5}, \tag{10}$$

- the relative mean bias error (systematic error):

$$MBE_{1,i} = \frac{1}{N}\sum_{j=1}^{N}\left(\frac{p_{i,j}^m - p_{i,j}^e}{p_{i,j}^e}\right), \tag{11}$$

- the relative root mean square error:

$$RMSE_{1,i} = \left(\frac{1}{N}\sum_{j=1}^{N}\left(\frac{p_{i,j}^m - p_{i,j}^e}{p_{i,j}^e}\right)^2\right)^{0.5}, \tag{12}$$

where $i = VIS$ or IR. The indices m and e denote the modelled and measured (empirical) values respectively.

Table 4. The coefficients $a_{VIS,j,k}$ of the polynomial (8) representing the empirical relation $p_{VIS}(\vartheta_S, T_E)$

$_j\backslash k$	0	1	2	3	4
0	0.29726178	1.02281039	–1.62059646	0.90472005	0.0
1	1.13715378	–9.33218722	24.82282582	–30.57324270	14.26680562
2	–2.51248324	19.37894195	–53.69692852	66.67890364	–30.87036508

Table 5. The coefficients $a_{IR,j,k}$ of the polynomial (8) representing the empirical relation $p_{IR}(\vartheta_S, T_E)$

$_j\backslash k$	0	1	2	3	4
0	0.54379371	–0.35043272	0.06771906	0.12328117	0.0
1	–0.28432025	1.12009352	0.99746229	–3.15148685	1.55936803
2	1.57776328	–11.23762657	30.28422650	–37.96076168	17.99151073

Tab. 6 presents the estimation errors, calculated for the entire data sets of VIS and IR ratios. Their values are relatively low when compared to the measuring errors. For both spectral ranges, the systematic errors do not exceed 1%, and the root mean square errors are considerably lower than the corresponding measurement errors.

Table 6. The accuracy of estimation of $p_{PAR}(\vartheta_S, T_E)$ and $p_{IR}(\vartheta_S, T_E)$ by the polynomial (8) with the parameters from Tabs. 2 and 3 respectively

Error	VIS	IR
MBE	0.00091	−0.00038
$RMSE$	±0.01897	±0.02191
MBE_1	0.406%	0.137%
$RMSE_1$	±4.43%	±4.76%

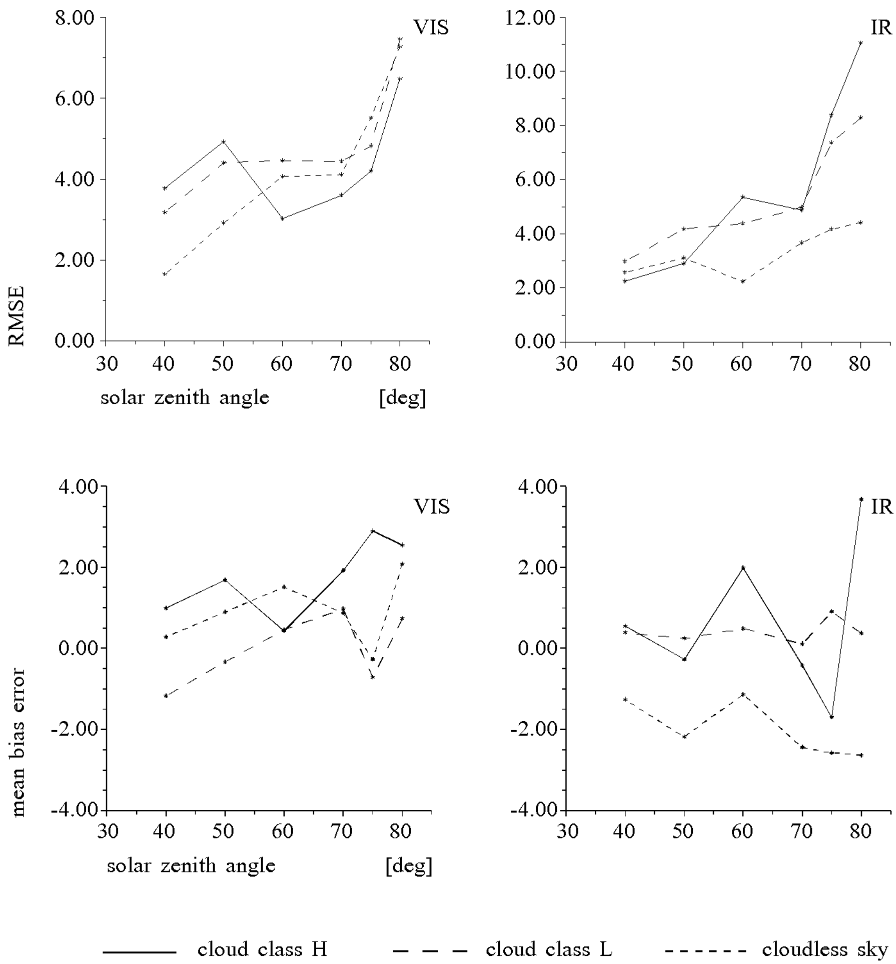

Fig. 5. The accuracy of estimation of $p_{PAR}(\vartheta_S, T_E)$ and $p_{IR}(\vartheta_S, T_E)$ by the polynomial (8) with the parameters from Tabs. 2 and 3 respectively

The estimation (fitting) errors calculated for each cloud class and solar zenith angle interval separately are depicted in Fig. 5. The relative $RMSE$s for all the cloud classes take similar values, lower than $\pm 5\%$, except when the solar zenith angle $\vartheta_S > 70°$, at which these errors rise considerably. These, however, can be justified by the rise in the measurement error under these conditions. The systematic errors do not reveal any significant discrepancies between the polynomial estimation quality for all the conditions under consideration.

4. Conclusions

- Under a clear sky and $\vartheta_S < 55°$ the respective mean values of the proportions of the global solar radiation from the UV, VIS and IR spectral intervals to the total, *i.e.* p_{UV}, p_{VIS}, p_{IR} are 0.067, 0.419 and 0.516. The impact of clouds on the spectral composition of the solar irradiance at the sea surface is strongest for the layer of low- or middle-level clouds (cloud class L), and for n = 1 the proportions p_{UV}, p_{VIS}, p_{IR} take values of 0.093, 0.480 and 0.428 respectively. These values are consistent with those obtained by other authors.
- The present research has confirmed that high-level clouds are optically too thin to change the spectral composition of solar radiation at the sea surface to a significant extent.
- The differences between the optical thicknesses of low- and high-level clouds are the main factor accounting for their different impact on the spectral composition of solar radiation at the sea surface.
- For a given solar zenith angle, the transmittance of the total irradiance T_E is a good indicator of the spectral composition of the global solar radiation at the Baltic surface under various cloud conditions.
- The relations between the atmospheric transmittance of total irradiance and solar zenith angle ϑ_S, and the ratios of the broadband spectral irradiance to the total for the VIS p_{VIS} and IR radiation p_{IR} can be estimated by the polynomials given in eq. (8) with the parameters from Tabs. 4 and 5 respectively.

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