A COMPARISON OF SCAPP RADIATION DATA WITH GLOBAL, DIFFUSE AND DIRECT SOLAR RADIATION

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Abstract

SCAPP is the abbreviation for SCAnning Pyrheliometer/Pyranometer. This instrument measures diffuse and direct short-wave radiation by a silicon receiver. Global radiation as well as sunshine duration are calculated within the instrument. That means one instrument is measuring all the downwelling short-wave quantities and sunshine duration. A short description of the SCAPP is given.For more than one year the measurements of the SCAPP have been measured nearby the pyranometers and pyrheliometers of the BSRN station at the Meteorological Observatory Lindenberg, Germany. The SCAPP results (time resolution is 1 minute means) were compared with the corresponding quantities of the BSRN station. Furthermore, hourly and daily totals are considered at different atmospheric conditions.

The results of these comparisons will be discussed. The daily totals of the quantities determined by the SCAPP deviate less than 10% from the direct by pyranometer and pyrheliometer measured totals.

1. Introduction

The radiation network of the German Weather Service consists of about 30 manned stations everyone of these is equipped with two ventilated and heated pyranometers CM11. One pyranometer is shaded by a shadow band measuring diffuse solar radiation while the other one is registering global radiation. Furthermore, at every station we have an electronic sunshine recorder from type SONIe.

Because of rising requests from several users for a higher spatial resolution of radiation data it was decided to increase the number of radiation stations.

The measurement of the diffuse solar radiation is only possible at a manned station because a daily check of the shadow band is demanded for high quality data. So, the realization of an extending radiation network at a stable number of manned stations is first of all an economic problem which calls for an instrument allowing the use at an automatic (unmanned) station.

In a study Bergholter and Dehne (1992) showed that it is possible to measure global, diffuse and direct solar radiation with one instrument, the **SCA**nning **P**yrheliometer/**P**yranometer (SCAPP). It fulfils the characteristics of operational pyranometers of “Moderate quality” (WMO, 1996).

In the German Weather Service the solution was found in having a basic radiation network as mentioned above consisting of about 30 manned pyranometer stations and an extending one consisting of about 130 automatic unmanned station applying the SCAPP as device measuring global, diffuse and direct solar radiation as well as sunshine duration.

In this paper the measurements of the SCAPP are compared with measurements made with pyrheliometer and pyranometer as reference instruments at the Meteorological Observatory Lindenberg (Germany) in 2004.

2. The Scanning Pyrheliometer/Pyranometer (SCAPP)

2.1. Technical description

The SCAPP was developed on the base of the SONIe sunshine recorder (Lindner, 1984). The prototype of the SCAPP was already presented at TECO-94 by Bergholter and Dehne (1994) but it was necessary to go further steps to get a stable working device.

Figure 1a shows the SCAPP as it is used for the measurements. The SCAPP consists of a head, a sensor module and an electronic board with power supply. An aluminium cylinder contains these parts.

The head with the entrance optics is protected by a glass dome against “the weather”. Figure 1b depicts a schematic drawing of head and sensor module.

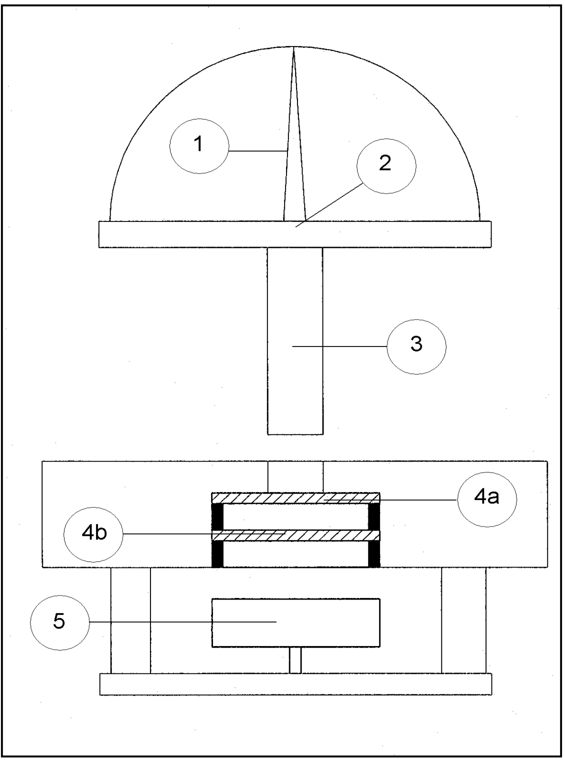


Fig. 1a: The **Sca**nning **P**yrheliometer/**P**yranometer (SCAPP) as it is used for measuring direct, diffuse and global solar radiation as well as sunshine duration.

Fig. 1b: Head and sensor module of the SCAPP consist of a spherical sector diaphragm (1), a diffuser (2), a beam-guide (3), two filter slides KG4 (4a), BG34 (4b) glass and a photodetector (5).

The head, consisting of a spherical sector diaphragm (1), a diffuser (2) and a beam-guide (3), is rotating and scans the whole sky 30 times per minute. The radiation from sky and Sun falls through the spherical diaphragm (1) and the diffuser (2) into the beam guide (3). Then the light goes via two filters slides, a white KG4 glass (4a) and a blue BG34 glass (4b), direct onto a photodetector (5). Because of the use of a photodetector as receiver only the spectral region between 0.3 to 1.1 µm is measured, which is typically for photodetectors, while shortwave radiation reaching the ground covers the region between 0.3 to 3.0 µm.

A pyranometer which is using a thermopile as detector converts, because of its spectral sensitivity, all the energy in this entire region. So, a photodetector and a thermopile never deliver the same results.

The weight of the SCAPP is about 5 kg. The height is about 260 mm and the diameter of the case is 185 mm. This device needs an electrical power of maximal 30 W.

The data transmission between SCAPP and computer happens via RS232 or RS422/485 interfaces.

2.2. The calibration of the SCAPP

The calibration of the SCAPP was made outside with the Sun as source of radiation. Measurements of direct and diffuse solar radiation by a pyrheliometer and a shaded pyranometer have to be made in parallel with the registration of the voltage of the SCAPP.
In Figure 2 schematic courses of the SCAPP signal during one rotation are shown in the case of different altitudes of the Sun, atmospheric conditions and other influences. It is visible, that the signal of the direct beam has, depending on the different factors, a more or less width. The different conditions here are generalized as signal (a) and (b). This width has to be fixed in the microprocessor and is strictly examined only valid for a special case.

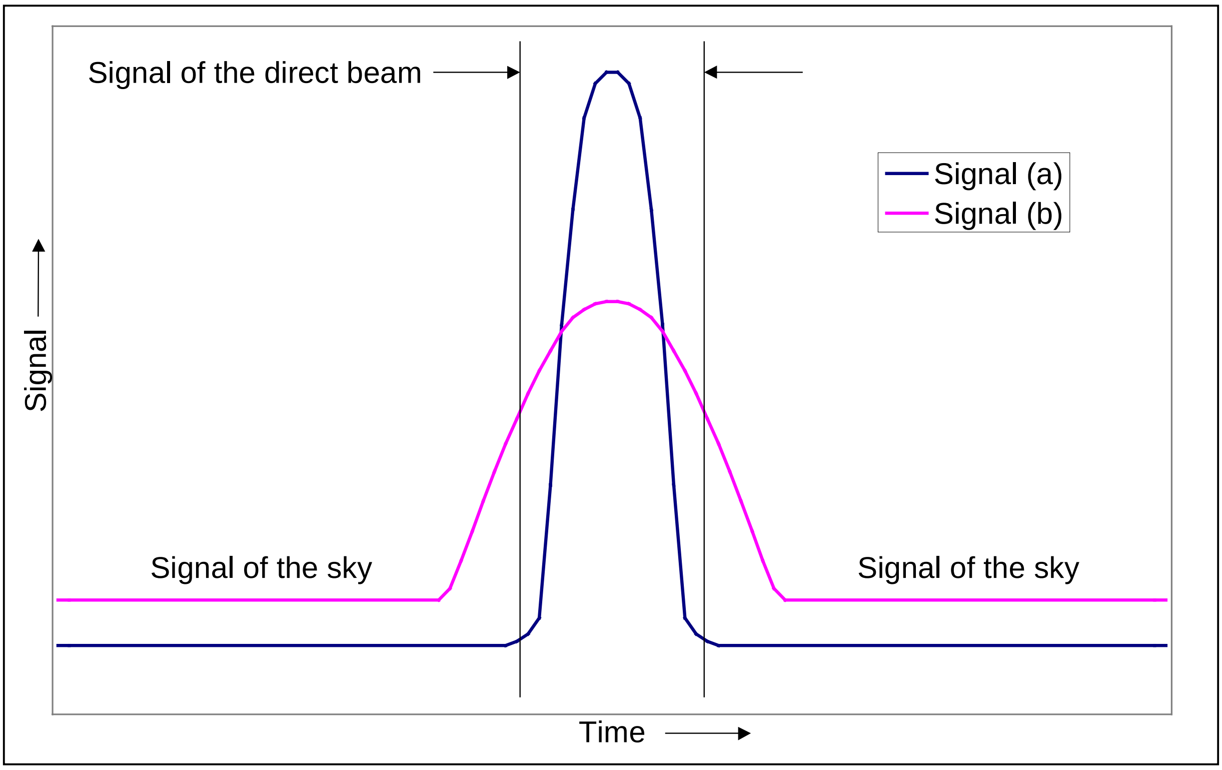


Fig. 2: Schematic courses of the SCAPP signal during one rotation of the head describing different conditions (a) and (b).

The result is, that the SCAPP needs because of the above described set up and the different pattern of the solar radiation more than one factor for the calculation of the correct radiation quantities. Therefore, at first a basic sensitivity of the diffuse solar radiation has to be determined. This is made for irradiances of the direct radiation < 2 W/m² and if the elevation of the Sun is >10°.
Because the diffuse solar radiation received within the SCAPP depends on direct radiation it is necessary to determine correction factors for the diffuse radiation. These correction factors are calculated in steps of 20 W/m² of the direct radiation. Furthermore, the sensitivity of the direct solar radiation has to be calculated depending on the solar zenith angle for every two degrees. Those factors are only calculated if the irradiance of the direct radiation is > 50 W/m² to get stable results.
This set of factors is given into the microprocessor of the SCAPP to calculate the direct and diffuse solar radiation and as sum of these the global radiation.

3. Comparisons of SCAPP, pyrheliometer and pyranometer measurements

3.1. Instruments and data

The comparisons between the SCAPP and the reference instruments were made in 2004. The data of totally 316 days were compared. In five months the data of all days were available but in May for instance only about 50% of the days could be used because of different reasons. The comparison was made at the radiation platform of Meteorological Observatory Lindenberg

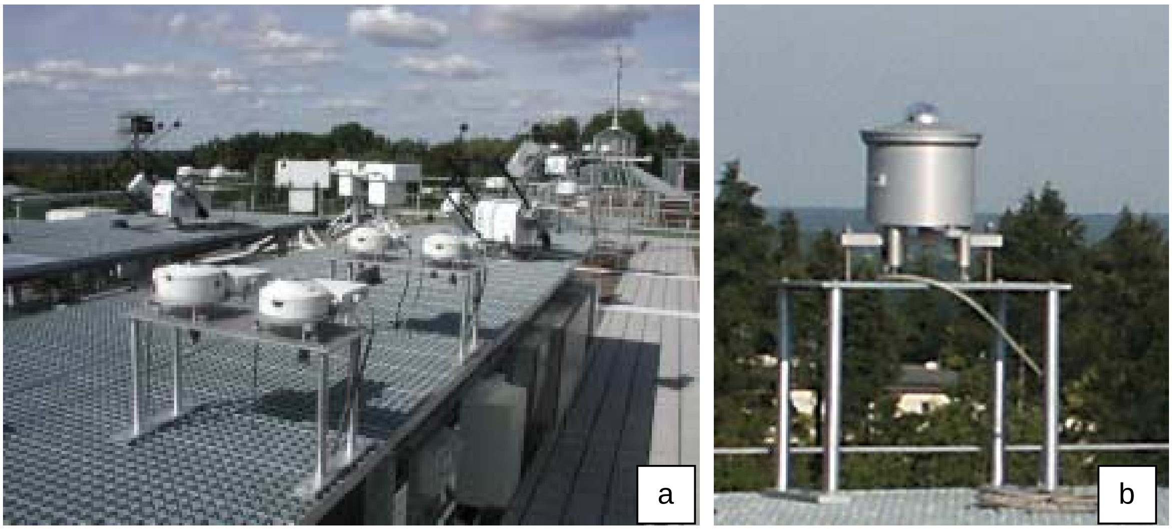


Fig. 3a: Radiation platform at the Meteorological Observatory Lindenberg with the reference instruments from the BSRN station for the comparison with the SCAPP.
Fig. 3b: The SCAPP at the radiation platform during the comparison.

(Fig. 3a and b). The instruments of the BSRN station Lindenberg were used as a reference. The pyrheliometer CH1 960129 measuring the normal direct solar radiation and the CM22 020073 for obtaining the diffuse solar radiation are mounted on a 2AP solar tracker. Global radiation was measured by the CM22 020074. All these instruments are produced by Kipp & Zonen, the Netherlands. The voltages of the pyrheliometer and pyranometers were recorded by the COMBILOG data logger (manufacturer Fa. Th. Friedrichs, Germany) and then converted into irradiances while the data of the SCAPP were already converted by its own microprocessor. All data are stored as 1 minute means. Hourly means and daily totals were calculated on this basis.

3.2. Hourly means

Mainly, user apply hourly totals. Therefore, these values of the SCAPP and the reference instruments will be compared in the following. Scatter diagrams with the hourly means from March, July and December are shown as examples for typical months at the equinox, as well as highest and lowest sun altitude.

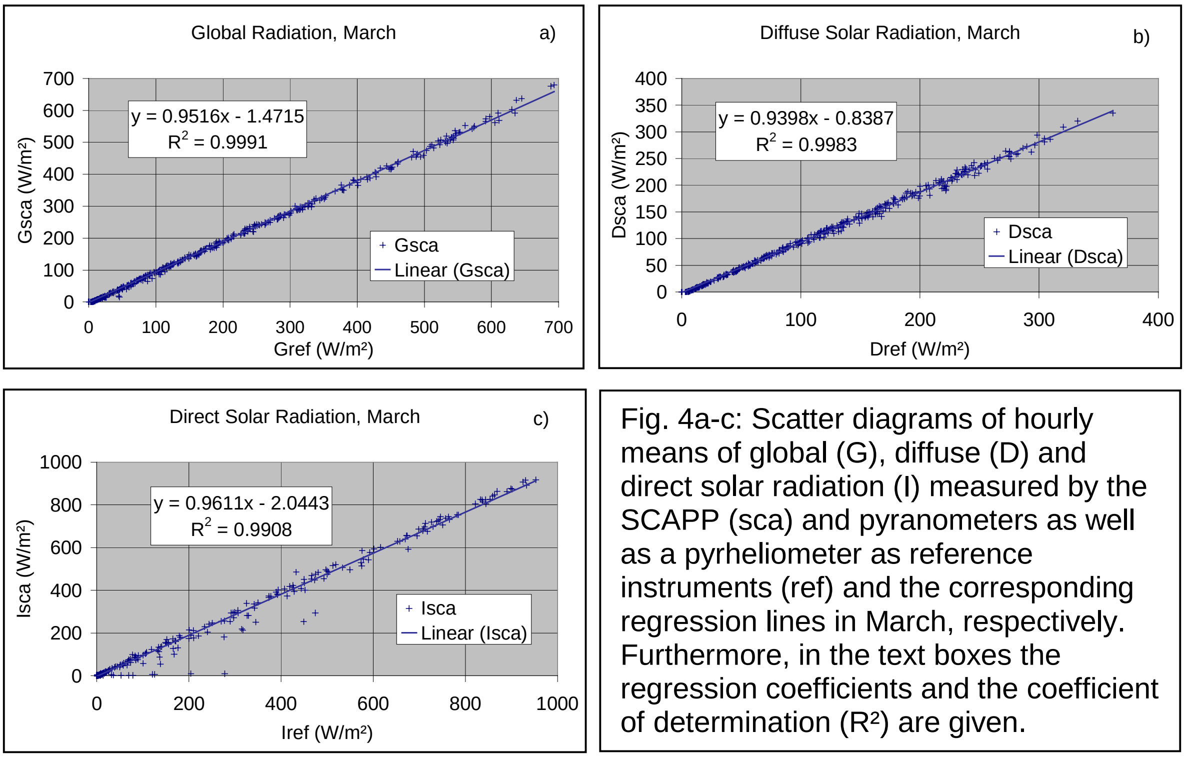
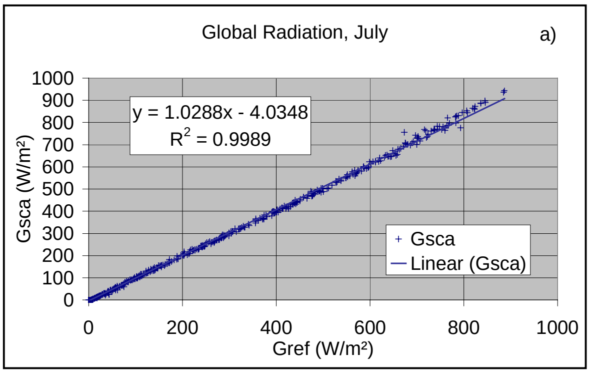
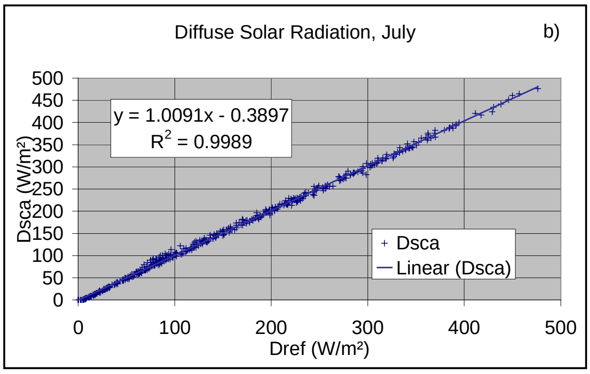


Fig. 4a-c: Scatter diagrams of hourly means of global (G), diffuse (D) and direct solar radiation (I) measured by the SCAPP (sca) and pyranometers as well as a pyrheliometer as reference instruments (ref) and the corresponding regression lines in March, respectively. Furthermore, in the text boxes the regression coefficients and the coefficient of determination (R²) are given.

The Figures 4a-c show that there is a good correlation ($R^2>0.99$) between the SCAPP data and the values from the reference instruments in March. The slope of the regression line is between 0.94 (Fig. 4b) in the case of the diffuse solar radiation and 0.96 (Fig. 4c) at the direct solar radiation. This means that the SCAPP values are to low in the average.





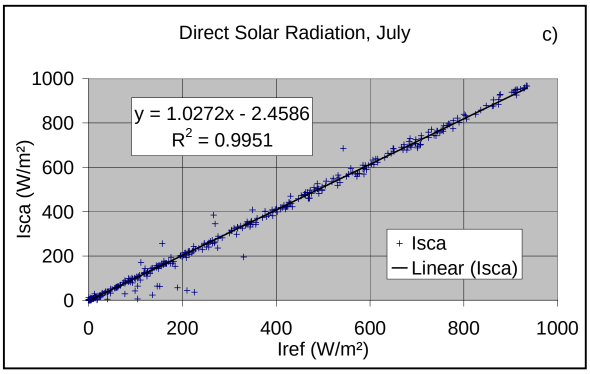
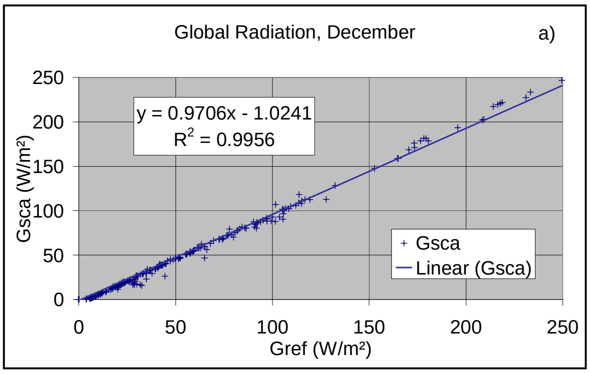
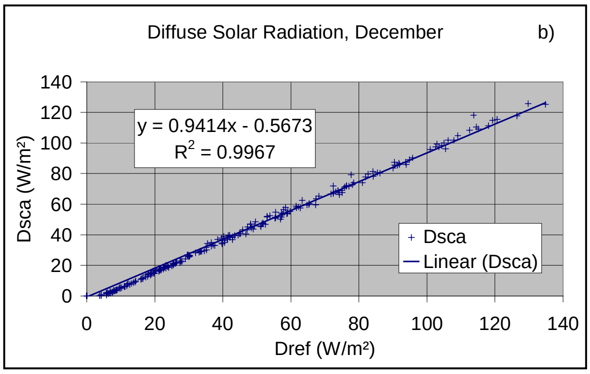


Fig. 5a-c: Scatter diagrams of hourly means of global (G), diffuse (D) and direct solar radiation (I) measured by the SCAPP (sca) and pyranometers as well as a pyrheliometer as reference instruments (ref) and the corresponding regression lines in July, respectively. Furthermore, in the text boxes the regression coefficients and the coefficient of determination (R^2) are given.

If we look at Figures 5a-c depicting the corresponding scatter diagrams for July we find only a small distinction in comparison to March. We detect the main difference in the slope of the regression lines. All three values are >1. Mainly, this is the result of a calibration which was done in June.

The Figures 6a-c show a similar picture like in the other above presented months. But especially in the Figures 6a and b it sticks out, that at a low irradiance the points are below the regression line while at the upper end the measured values above the line. This is typical for





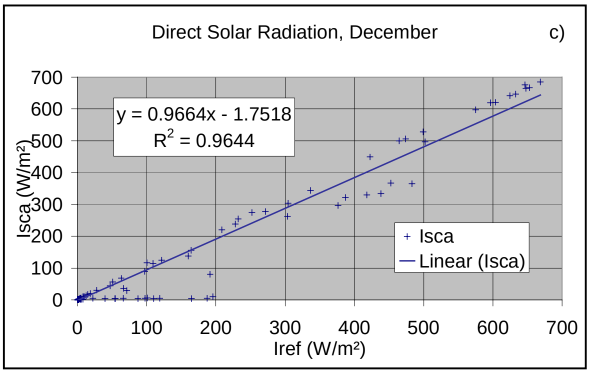


Fig. 6a-c: Scatter diagrams of hourly means of global (G), diffuse (D) and direct solar radiation (I) measured by the SCAPP (sca) and pyranometers as well as a pyrheliometer as reference instruments (ref) and the corresponding regression lines in December, respectively. Furthermore, in the text boxes the regression coefficients and the coefficient of determination (R^2) are given.

the Winter with low irradiances, while in the other seasons the points are equally distributed around the corresponding regression line.

Table 1
Regression constants (m: slope coefficient; c: point of intersection with the y-axis) and the coefficients of determination (R^2) of the hourly means of the SCAPP and the corresponding reference instruments for global, diffuse and direct solar radiation

Month	global			diffus			direct		
	m	c	R^2	m	c	R^2	m	c	R^2
Jan	0.931	-0.812	0.997	0.920	-0.584	0.998	0.932	-2.189	0.960
Feb	0.945	-1.043	0.999	0.933	-0.679	0.999	0.956	-1.629	0.983
Mar	0.952	-1.472	0.999	0.940	-0.839	0.998	0.961	-2.044	0.991
Apr	0.974	-2.658	0.998	0.951	-0.700	0.998	0.989	-4.542	0.992
May	0.995	-2.388	0.998	0.984	-1.347	0.999	1.028	-0.382	0.977
Jun	1.011	-2.364	0.999	1.012	-1.807	0.999	1.032	-2.108	0.994
Jul	1.029	-4.035	0.999	1.009	-0.390	0.999	1.027	-2.459	0.995
Aug	1.021	-3.344	0.999	1.002	-0.548	0.999	1.026	-3.923	0.996
Sep	1.013	-2.450	0.999	0.995	-0.331	0.998	1.006	-5.241	0.992
Oct	0.989	-1.355	0.999	0.979	-0.615	0.999	0.986	-2.929	0.982
Nov	0.976	-1.002	0.998	0.979	-0.735	0.998	0.985	-1.051	0.970
Dec	0.971	-1.024	0.996	0.941	-0.567	0.997	0.966	-1.752	0.964

Table 1 gives an overview about the regression constants and the coefficient of determination. In the case of the global and diffuse solar radiation the correlation between the SCAPP and the reference values is very strong in all months as visible in the corresponding R^2 column, while at the direct radiation the R^2 especially in Winter has lower values.

The slope coefficients m show at all radiation quantities a clear annual course with low values in Winter and high in Summer time.
As above mentioned in June a calibration of the SCAPP was made and the new coefficients were used from the beginning of June. The new and improved calibration constants led to a higher level of the slope coefficients at all radiation quantities showing a better agreement between the SCAPP and the reference values of the pyrheliometer and the pyranometers.

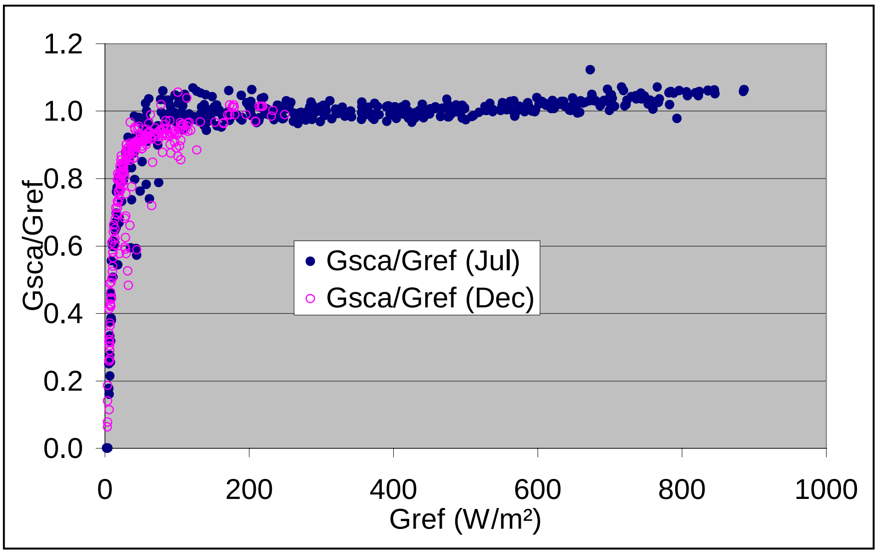


Fig. 7: Hourly ratios Gsca/Gref in dependence on Gref for July and December.

Figure 7 shows the hourly ratios Gsca/Gref in dependence on the corresponding global radiation Gref. The ratio Gsca/Gref is about 1.0 at values Gref > 75 W/m². In July these cases occur in about 78 % of the hours, while in December only 29 % exceed this bound. Therefore, the mean ratio Gsca/Gref in December is less then in July. This means that at a lower global radiation, this bound is about 75 W/m², the SCAPP values systematically to low. This is also the reason for the annual course of the slope coefficients of all quantities given in Table 1.

3.3. Daily totals

In Figure 8 the annual courses for the daily ratios of Gsca/Gref and Dsca/Dref are shown.

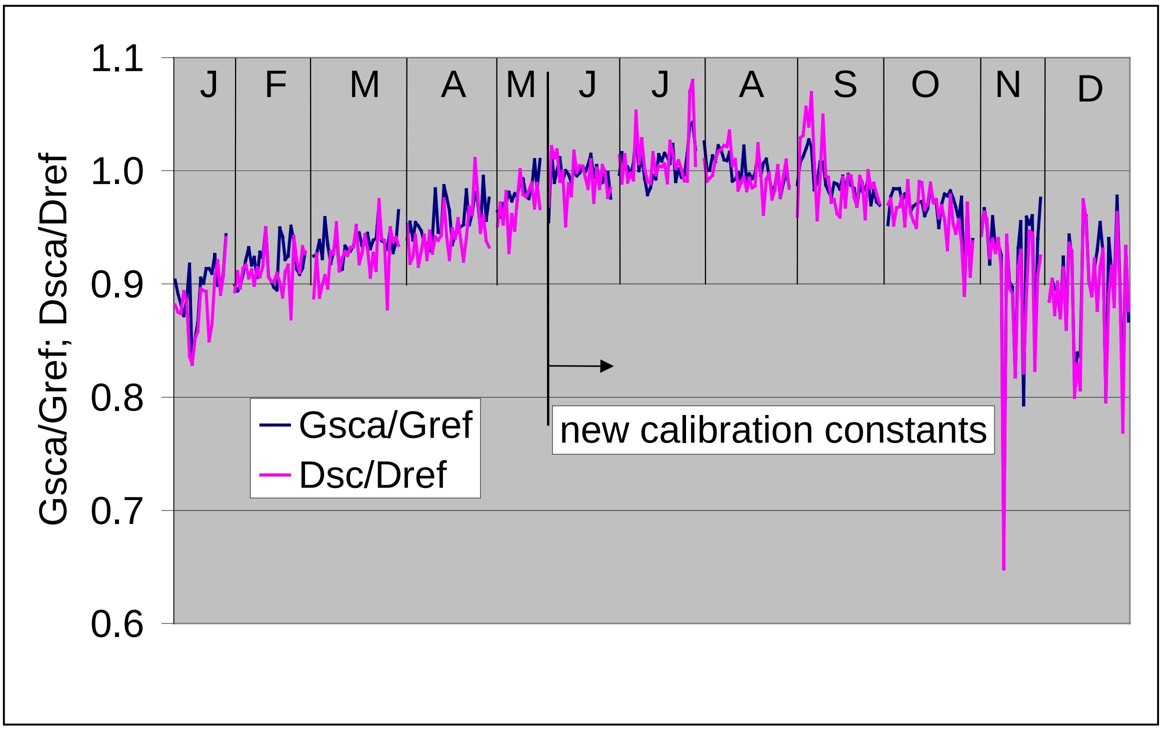


Fig. 8: Annual courses for the daily ratios Gsca/Gref and Dsca/Dref.

A look at Figure 8 shows a clear annual course of the investigated ratios with a very good agreement of the SCAPP and the reference values in Summer time, where the ratios of the daily totals within ± 5 %. Outside this time most of the values >0.9. Very small daily totals in November and December are the reason for the ratios <0.9. Especially, the daily total of only 36 J/cm² at the 9th of November led to the remarkable outlier.
The new calibration constants used with begin of June improved the results. This is visible, if we compare the level of the blue and pink line in months the a comparable altitude of the Sun, e.g. March and October or April and September, for instance. The ratios are closer to 1 in autumn then in the corresponding months in spring.

4. Conclusions

- The comparison showed that the measurements of the SCAPP in most cases are in good agreement with the results of the reference instruments.
- At lower global radiation (about <75 W/m²) the SCAPP results are frequently to low in comparison with the reference. In future this should be improved.
- The SCAPP is a multisensor of “Moderate quality”, which is suitable for radiation measurement where highest quality is not demanded.

5. Literature

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