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Comparison of two methods for cloud flagging of spectral UV measurements

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Abstract

This paper compares two methods of cloud flagging that were developed at the Deutscher Wetterdients (DWD) and at the Laboratory of Atmospheric Physics, University of Thessaloniki (LAP). The two methods are applied to the same data set to uncover their similarities and differences. The LAP method aimed at flagging the quality of global UV irradiance spectral measurements with respect to the purity of their spectral characteristics, while the DWD flags describe the sky conditions and their effects on the radiation field in an absolute sense as well as their short-time variability. In this respect, the two methods appear to have distinct differences, and also similarities, in describing when the sun's disk is occluded or not. © 2001 Elsevier Science B.V. All rights reserved.

Keywords: Clouds; Cloud flagging; Spectral ultraviolet radiation; Quality control

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1. Introduction

Among the atmospheric constituents that attenuate solar ultraviolet radiation, the most effective are clouds. Their role in modifying the spectral irradiance received at the earth's surface has been extensively studied (e.g. Frederick and Snell, 1990; Bais et al., 1993; Blumthaler et al., 1994; Li et al., 1994; Bordewijk et al., 1995; Estupinan et al., 1996; Josefsson and Landelius, 2000). In addition to the attenuation of solar irradiance, clouds may significantly distort the shape of spectra recorded by scanning spectrora-

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diometers, most of which still require a few minutes for the completion of a full scan. This effect becomes more significant when the clouds move fast and their optical depth is variable within extent. For quality control purposes, it is essential to characterize UV spectral measurements, both global and direct, according to the conditions of the sky at the time of the measurement. Use of distorted spectra for retrieving integrals of spectral irradiance or column abundances of atmospheric species may lead to erroneous estimates. Similarly, other research studies based on comparisons of spectral measurements at different wavelengths may significantly be affected and lead to unreasonable results. The need for flagging the spectra according to the effects introduced by clouds has been already recognized and included in the recommendations of international UV databases (e.g. Seckmeyer, 1999).

Regular cloud information exists mainly at meteorological stations, but its use for flagging spectral measurements is rather limited for various reasons. Most importantly, the frequency of observation is usually small (once every half hour in the best case), and hence they cannot be matched with the time frame of a spectral scan, which is typically between 2 and 10 min. Some of the stations measuring solar spectral UV irradiance do not conduct collocated cloud observations, and the closest to them location with such observations might be several kilometers away. Finally, cloud observations are very coarse and subjective, lacking detailed information for the actual cloud patterns. Apparently, it is almost impossible to link exactly such cloud information with their effects on radiation measurements, and the development of other methodologies would be required for more effective cloud flagging.

A cloud flagging method, based on radiometric measurements, was presented by Feister and Gericke (1998a,b). It is regularly used to flag the UV spectral measurements taken by the Brewer spectroradiometers Mk II, and Mk IV and Mk III as well as by the Bentham spectroradiometers of Deutscher Wetterdienst (DWD) at the Meteorological Observatories of Potsdam, Lindenberg and Hohenpeissenberg in Germany. Another method was developed at the Laboratory of Atmospheric Physics, of the Aristotle University of Thessaloniki, Greece (Vasaras et al., 1998), and is presented in detail in this study. In the present study, both methods, which are based on somewhat different concepts, were applied to the same data set and the results are compared to assess their effectiveness and their differences.

2. Methodologies and data

2.1. The method of LAP

The underlying idea of the cloud flagging method that was developed at the University of Thessaloniki, hereafter denoted as LAP method, is the utilization of the variability of short-wave solar radiation, which is induced by the corresponding variability of clouds. It is considered that the effects of changing clouds, both in area and optical depth, on the solar radiation field at ground are directly reflected pyranometer data, which can be easily sampled with frequencies sufficient to match the sampling frequency of a spectroradiometer. Assuming that the attenuation of clouds is independent of wavelength, then the variability of the radiation field during a spectral measurement can be quantitatively derived from synchronous, collocated pyranometer measurements. This assumption does not introduce significant errors, because cloud attenuation is expected to be a smooth function of wavelength (Seckmeyer et al., 1994) and here we are interested only on high frequency variability.

LAP operates two UV spetroradiometers, a single- and a double-monochromator Brewer, which record global and direct UV scans at 0.5 nm steps from 290–330 and 286–366 nm, respectively. On the average, the sampling rate is about 3 s for one spectral measurement. Although a pyranometer could be sampled at this frequency, to associate one short-wave radiation measurement to each spectral measurement, the sampling frequency of the available long-term pyranometer record at LAP is one recording per minute. The variability of the radiation field within this minute can be inferred from the standard deviation of all the samples recorded during this minute, which is also available in the LAP record. To be able to flag all the past UV spectra of the Thessaloniki station. The development of the flagging method was founded on the 1-min pryanometer measurements. The pyranometer that is used at LAP is Kipp and Zonen CM 11, collocated with the two spectroradiometers at the roof of a four-stories building. All three instruments have similar exposure to solar radiation field.

For the time interval of each UV scan (8 min), the corresponding pyranometer data (eight points) are averaged and the standard deviation of the eight measurements as percentage relative to the average is calculated (coefficient of variation). These two quantities are used to assess quantitatively the variability of the radiation field, and hence the effect of clouds. The first is used mainly to detect the presence of a cloud, by comparing the absolute level of the measured irradiance with that expected under clear skies, and the latter to assess the degree of the introduced spectral distortion.

The clear sky irradiance that would be used as “reference” was determined from the existing pyranometer data set as a function of solar zenith angle. Two and a half years of data were used spanning from 1/1/1995 to 31/7/1997. The clear sky measurements were determined from the hourly regular cloud observations conducted by the National Meteorological Service at “Macedonia” airport of Thessaloniki. The attenuation of short-wave irradiance can be caused not only by clouds but also from aerosols, which may vary significantly during the year. Thus, it should be expected that the clear sky data would include some variability caused by aerosols. From measurements at LAP, it appears that the aerosol optical depth in the UV-A ranges during the year between 0.2 and 0.8 (Kazadzis et al., 2000), which may introduce variability in the short-wave irradiance of the order of about 10% (Kylling et al., 1998). In addition, some uncertainty in the determination of the “reference” is expected due to the distance of the pyranometer site from the airport (about 10 km) and from the small frequency of cloud observations relative to the 1-min measurements of the pyranometer. Unfortunately, there is no supporting information to help quantifying this uncertainty, but we believe that its overall contribution to the determination of the “reference” is rather small. Finally, to compensate for the effect of the variation of the sun–earth distance during the year, the measurements of short-wave irradiance were adjusted to the mean sun–earth distance by applying the appropriate correction factor.

The "reference" was formed from averages calculated at steps of 1° solar zenith angle, which were then smoothed by applying a third degree polynomial fit. Thus the clear sky irradiance $I_{\mathrm{ref}}(z)$ at a given solar zenith angle z can be derived from the relation:

$$I_{\mathrm{ref}}(z) = 1045.26 - 1.558\,z - 0.178\,z^2 + 6.36\,10^{-4} z^3\,[\mathrm{W\,m^{-2}}] \qquad (1)$$

According to the magnitude of the differences of the measured short-wave irradiance from the "reference" and of the coefficient of variation, four different flags were defined, represented by numbers ranging from 0 to 3. More specifically, the conditions that define each flag (see also Table 1) and the corresponding magnitudes of the two quantities are as follows.

Flag 0 (sun not occluded). It corresponds to cases where the sun's disk is not occluded from clouds, and the clouds that might be present do not reduce significantly the radiation field. This flag is set when the mean short-wave irradiance (the average of the eight measurements) is greater than 80% of the corresponding "reference" value, and the coefficient of variation is less than 0.75%. The low variability ensures that the recorded spectra are not distorted. This case includes mainly the clear sky conditions, but also cases where the presence of clouds does not introduce any measurable effect on the spectral irradiances recorded by the spectroradiometer.

Flag 1 (stable-cloudy). It defines conditions where, although the sun's disk is occluded from clouds, the radiation field is stable. The flag is set when the mean short-wave irradiance is smaller than 80% of the corresponding "reference" value, but the coefficient of variation is still less than 0.75%. The case actually corresponds to homogeneous cloud conditions, where the radiation filed remains rather stable and the spectral measurements are not distorted.

Flag 2 (unstable-cloudy). This flag is set when none of the above conditions are met, and defines situations with the sun occluded from inhomogeneous, broken clouds. These clouds are characterized by significant and rapid changes in their optical depth, producing high variability in the spectral measurements belonging to the same scan. Such spectra are usually unusable.

Flag 3 (unknown). Finally, the last flag is used to identify the spectra for which no information is available, mostly due to breaks in the record of the pyranometer data. Other methods, possibly not automated, could be used to flag those spectra, which are in principle too few.

Table 1
Definition of cloud flags by the LAP and DWD methods

LAP flag	Description	DWD flag	Description
0	Sun not occluded	0	Cloudless sky
1	Stable-cloudy	1	Cloudy, dim sky, sun not occluded
2	Unstable-cloudy	2	Cloudy, bright sky, sun occluded
3	Unknown	3	Cloudy, bright sky, sun not occluded
		4	Cloudy, dim sky, sun occluded
		5	Unknown sky conditions

The limits of the average irradiance (80%) and the coefficient of variation (0.75%) that are used for the definition of the flags were determined from a series of trial applications of the method to a number of cases representative of different cloud patterns and effects.

The application of the method for flagging spectra recorded by other instruments with different scanning time, such as the Mk II type Brewer spectrophotometers, can be done with slight adjustment of the limit of the coefficient of variation. The use of pyranometer data only for the determination of the flags, makes the method applicable to almost every UV monitoring station, since pyranometer (or similar other) data are available in most of them, and in any case the installation of a new pyranometer to an existing station is rather inexpensive compared to the cost invested for the operation of a spectroradiometer.

2.2. The method of DWD

The method developed at DWD is described in detail in the papers of Feister and Gericke (1998a,b). Cloud flags are derived from 1-min values of global irradiance, diffuse or direct irradiance measured by pyranometers with shade ring or shade disk or by pyrheliometers, as well as from hourly values of observed cloud cover and horizontal visibility for solar zenith angles of less that 85°. All the input values are available at meteorological stations that perform a program of solar radiation measurements such as the three Observatories of DWD as well as 27 out of the 42 weather stations measuring both global and diffuse irradiance in Germany.

Two parameters were selected as the most effective to derive cloud flags: sky brightness and ratios between direct and diffuse irradiance. The sky brightness K_D (Perez et al., 1993) is derived from the measured 1-min solar radiation components

$$K_D = m(E_D/E_o) \tag{2}$$

where E_D is the diffuse component of solar irradiance, E_o is the extraterrestrial solar radiation and m is the relative optical air mass (Kasten and Young, 1989). The ratio between the direct and diffuse irradiances R_{ND} is defined as

$$R_{ND} = E_N/E_D \tag{3}$$

where E_N is the direct solar irradiance at normal incidence (Hulstrom et al., 1989).

Six different flags between 0 and 5 are defined (see also Table 1). It should be noted that the concept of this method is different from the LAP method, as it aims not only to characterize the quality of the spectral measurements, but also the general sky conditions. Furthermore, the stability of the sky conditions over certain time intervals, e.g. the time of a spectral scan, can be assessed by looking at the maximum changes or standard deviations of the two parameters during the time interval considered. The six flags and their definitions are as follows.

Flag 0 (cloudless sky). It corresponds to cases to completely clear sky, and it is set when $5 < R_{ND} \leq 15$.

Flag 1 (cloudy, dim sky, sun not occluded). This is a variation of flag one, with relatively low sky brightness. While R_{ND} varies between 0.5 and 5, K_{D} now takes values between 0.01 and 0.25.

Flag 2 (cloudy, bright sky, sun occluded). It corresponds to cases where clouds obscure the sun, but the sky brightness is relatively high. This flag is set when direct irradiance becomes negligible (R_{ND} is smaller than 0.5) while the sky brightness is still quite high ($0.25 \leq K_{\mathrm{D}} < 0.55$).

Flag 3 (cloudy, bright sky, sun not occluded). It defines conditions where the sun's disk is not occluded and the sky brightness is relatively high, due to the presence of clouds. The flag is set when R_{ND} is in the range 0.5 to 5, and K_{D} is between 0.25 and 0.55.

Flag 4 (cloudy, dim sky, sun occluded). It corresponds to cases where clouds obscure the sun's disk and the sky brightness is low. This flag is set when R_{ND} is less than 0.5 and K_{D} varies between 0.01 and 0.25.

Flag 5 (unknown sky conditions). Similarly to the LAP method, this flag represents cases with no information about the sky conditions.

Since the DWD method is based on the absolute levels of the two quantities R_{ND} and K_{D}, flags can be computed at any time resolution, defined only by the availability of input data. Since the radiometric data are recorded at 1-min intervals, the flags are available every minute. The flags as defined by the two methods are summarized in Table 1, from which their differences and similarities can be deduced.

Not only cloudiness, but to a smaller extent also atmospheric aerosols can affect both ratios of solar radiation components (2) and (3). Their effect is accounted for by setting a threshold value for RND that depends on horizontal visibility (see Feister and Gericke 1998a,b). Using a "decision tree", every minute of the day is classified as "cloudy", "cloudless" or "unknown". The additional input data of visibility and cloud cover are used then to convert a statement that flag "0" represents either cloudless sky or a sky with clouds having the same effect on global irradiance as the blue sky into a "clear statement" that the sky was cloudless indeed during that time interval.

3. Discussion and conclusions

As it appears from the description of the two methods (Table 1), the results from the application of the two methodologies cannot be compared directly, as the LAP flags may correspond to a combination of more that one flag of the DWD definition. For comparing the two methods, they were both applied to a common data set. Since the information required for the definition of the DWD flags were not available at the UV station of Thessaloniki, data sets from Potsdam for the time period 1996 through 1997 were used, although the spectral measurements were done by Mk II Brewer instrument having a smaller spectral range from 290 to 325 nm, because a Brewer instrument of the type Mk II with an extended spectral range up to 363 nm was installed at Potsdam later in 1997.

As already mentioned, the DWD flags can be calculated at 1-min intervals, while the LAP flags can be defined only at larger intervals (e.g. 8 min). Thus, for the comparison, the LAP method was applied to consecutive intervals of 8 min, starting at sunrise, using the data measured at Potsdam, and these flags were related to the DWD flags only when during the 8 min the DWD flag was the same. Fig. 1, presents the application of the two algorithms on four characteristic days with different sky conditions. The solid curve represents the diurnal course of measured short-wave irradiance, and the solid and open circles refer to the calculated cloud flags following the two methods of LAP and DWD, respectively.

April 1, 1997 was almost clear, with the sun continuously visible. Both methods provided the cloud flag of 0 almost for the entire day, except during a period of a few hours in the morning, where the DWD cloud flag was set to 1, indicating the presence of clouds, which however did not change the radiation field adequately to force a change of the LAP cloud flag. One can also notice two short periods close to sunrise and sunset were the LAP cloud flag changed to 2. At such large zenith angles with low intensities, the LAP method seems to become uncertain. However, under such conditions the uncertainties introduced to UV spectra from various sources are already high, so that flagging of these spectra might not be extremely important, especially when spectral measurements are used to derive daily integrals, where the contribution of irradiances at low solar elevations is small.

The second example, 25 May 1997, is a bright but cloudy day, with moving, inhomogeneous, broken clouds. The DWD method indicates that until late afternoon hours the sun was always visible, which suggests that the evident variability of the short-wave irradiance is caused only by the reduction of the diffuse sky light from the clouds. Only when sharp decreases occur in the irradiance (around 1500 h) the method reports full coverage of the sun's disk. Similarly, the LAP method suggests that the sun is not occluded for most of the day, with the exception of single short periods coinciding with the distinct decreases of the short-wave irradiance signal. Thus, with regard to the quality of the spectra that would be measured during this day, it appears that only in these few cases the spectra may have been distorted by clouds. Apparently, the LAP flag was set to 2 even when the DWD flag indicated that the sun was not occluded, suggesting that the clearness of the sun's disk solely is not enough to warrantee the purity of the measured spectra. It is noted here that the DWD cloud flagging method allows a decision to be made whether a measured spectrum may be distorted by a moving cloud. This information is derived from the change of 1-min values of K_D and K_{ND} over the time of the spectral measurement (Feister and Gericke, 1998a).

April 2, 1997 is an example of a day with two different patterns; clear in the morning and almost completely cloudy afterwards. The large reduction of the pyranometer signal, particularly between 1000 and 1400 h, suggests the presence of optically dense clouds that are capable of reducing the radiation down to about 20%. Despite the dense clouds, according to the LAP method it would be still possible in some periods to acquire global irradiance spectra of sufficient quality. Apparently, during these periods the clouds were rather homogeneous with quite stable optical thickness, leaving the radiation field almost unaltered.

Finally, on May 30, 1997 the cloud pattern is highly variable with fast-moving broken clouds, which occlude the direct sunlight periodically during the day. During most of the day, the DWD method sets the cloud flag to 2, and the LAP method reports unstable cloudy conditions, which prevent the acquisition of good quality spectra.

From the above examples, it appears that although the DWD method is more detailed (based on more than one sources of information), only the flag 0 (cloudness sky) can be used directly to flag global irradiance spectra. However, the method is also capable of classifying stable or unstable cloud conditions by use of maximum changes or standard deviations of the parameters K_D and K_{ND}, but this information was not considered in the present study. The LAP method was developed to be used exclusively for flagging the quality of spectra, whereas the DWD method is a more general, but detailed, flagging method that aims to categorize the sky conditions and the resultant effects on the radiation filed mostly in an absolute sense. Possibly, the two methods may be used to supplement each other, hence increasing the confidence of the produced flags.

In Fig. 2, some characteristic examples are presented, showing the spectral behavior of UV irradiances recorded under conditions characterized by different flags. Ratios between spectra marked with different flags and spectra recorded under clear skies are shown. The different pairs of spectra were recorded under the same or very similar solar zenith angles and total ozone columns, in order to minimize their effect in the produced ratios. Under such circumstances, ratios of spectra taken under clear skies should be

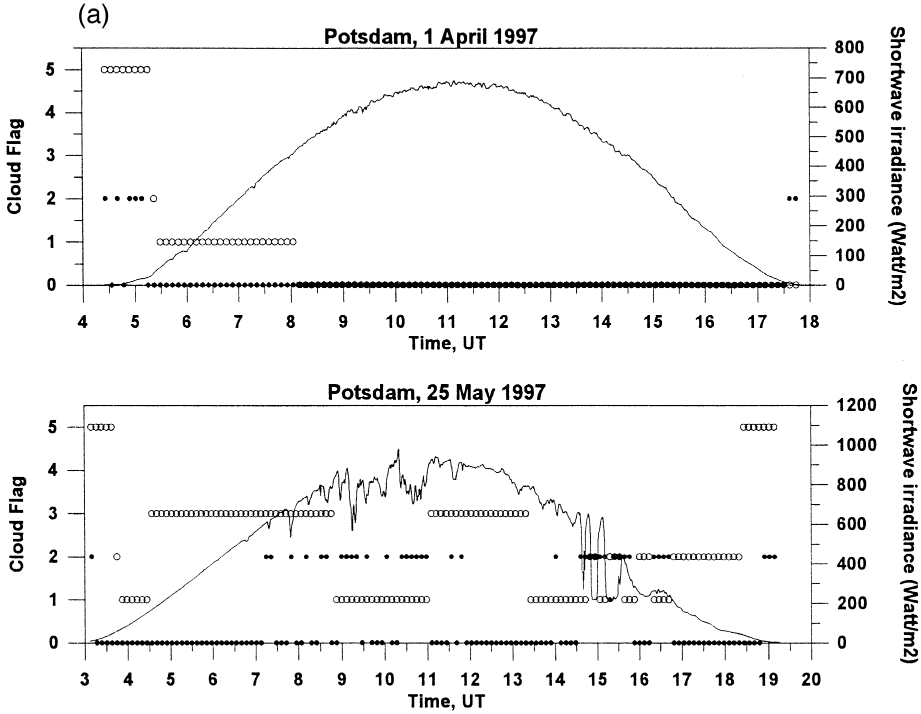

Fig. 1. Application of the two flagging methods on days with different sky conditions. Open and solid circles correspond to flags derived by the DWD and LAP methods, respectively (note that the superposition of the two flags results to a solid circle of larger diameter). The solid line represents short-wave irradiance measured by a pyranometer.

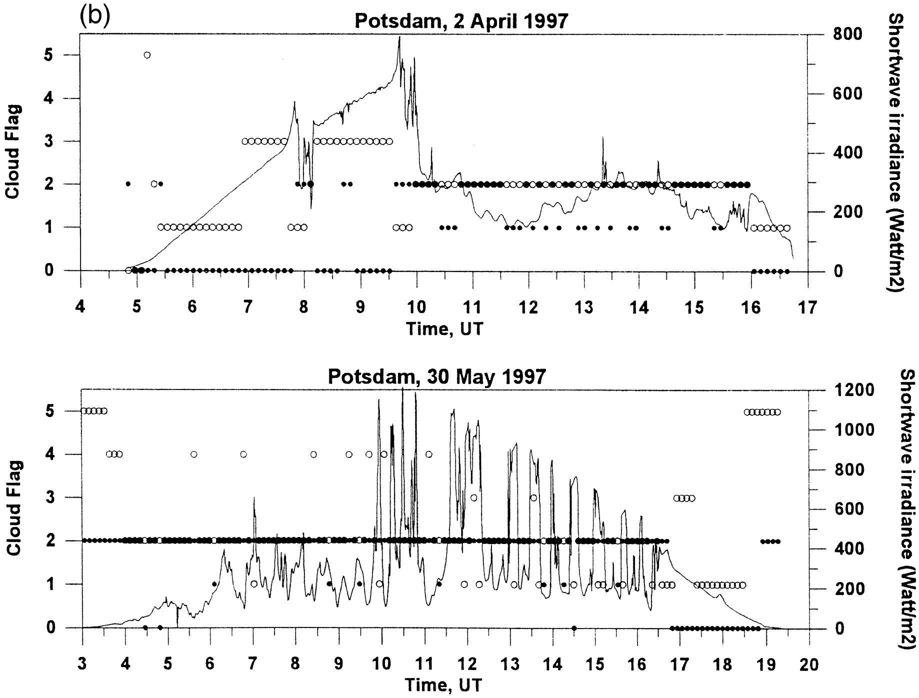

Fig. 1 (*continued*).

very smooth and flat. On the contrary, if one of the spectra were recorded under cloudy conditions, the ratio would be significantly distorted. Fig. 2a shows 4 ratios of spectra corresponding to 4 different solar zenith angles marked with flags 0 and 1, using respectively the LAP and DWD method. Despite the deviation of the ratio from unit, which may be due to differences in the aerosols between the two measurements or to changes in the absolute calibration, all ratios seem quite smooth, confirming that the spectral characteristics of the recorded irradiances were unaffected by clouds. The opposite conclusion can be derived from Fig. 2b, which shows four other ratios between spectra marked by both methods with flag 2 and clear sky spectra. The significant impact of changing clouds on the spectral UV irradiances is apparent.

Concerning now the relation between the results of the two cloud flagging methods, a statistical analysis was conducted using the flags derived in 35,368 cases. These cases correspond to 8-min intervals of measurements conducted in Potsdam within about 2.5 years. The flags following the DWD method were determined as usually (Feister and Gericke, 1998a) and the pyranometer data were used to derive the flags corresponding to the LAP method. Table 2, summarizes those statistical results, presenting for each flag derived by the DWD method during the above-mentioned period the occurrences (n) of the various flags according to the LAP method and the corresponding percentages relative to the total number of cases. To avoid the weaknesses of the two methods at low intensities only data corresponding to solar zenith angles smaller than 75° were used.

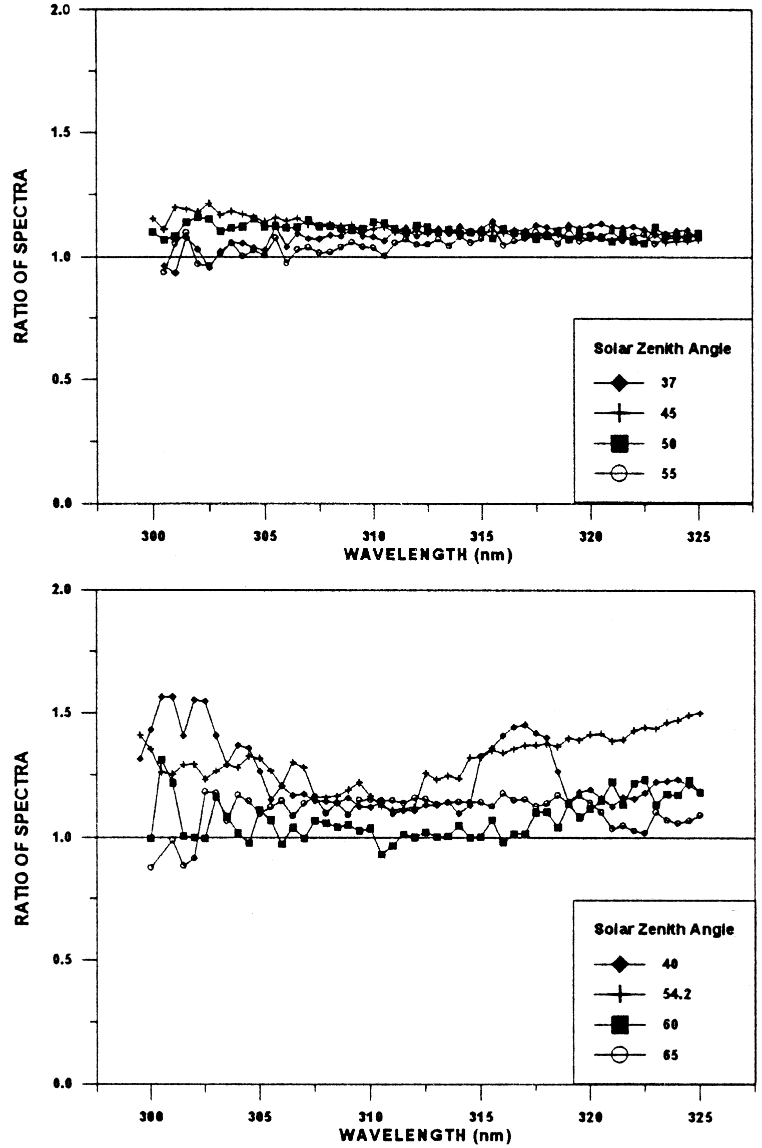

Fig. 2. Ratios of global UV spectra marked with different flags. (a) All spectra were recorded under clear-sky conditions. (b) Ratios are between spectra recorded under unstable-cloudy conditions and spectra under clear skies.

As mentioned already, the two flagging methods cannot be compared directly, but there are some relations, which are confirmed also from the results of Table 2. Thus, almost 99% of the occurrences of LAP flag 0 correspond to the three flags of DWD, which have in common the visibility of the sun's disk (0, 1 and 3). The UV spectra

Table 2
Statistical results for the comparison of the two flagging methods

DWD flag	LAP flag 0		LAP flag 1		LAP flag 2	
	n	%	*n*	%	*n*	%
0	1842	21.3	222	3.2	47	0.2
1	3985	46.0	654	9.3	3728	18.9
3	2745	31.7	222	3.2	320	1.6
2	82	1.0	4654	66.3	10764	54.7
4	6	0.1	1266	18.0	4817	24.5
5	9	0.1	0	0.0	6	0.1
Total	8669	100.0	7018	100.0	19681	100.0

recorded under such circumstances are expected to be pure since the dominant factor of the spectral distortion is the partial and changing with time coverage of the direct sun radiation by clouds. On the other hand, when the sun is completely occluded the radiation field is in most cases uniform, except when the sun is covered by optically thin clouds with variable optical depth. Thus, only 84% of the cases with LAP flag 1, which defines uniform cloudy conditions, coincide with the DWD flags 2 and 4 (sun occluded). The remaining 16% of the cases are distributed in the previous three categories, suggesting that even when the sun is visible, there might be cases with variable radiation field (e.g. from bright cumulus clouds) that may affect the spectral measurements. Finally, 79% of the cases marked with LAP flag 2 (unstable-cloudy conditions) correspond to the DWD flags 2 and 4 (sun occluded).

In general, the agreement of the results of the LAP and DWD flagging methods is rather satisfactory, especially in cases where the direct sun radiation is not blocked by clouds. For the other cases there are differences, which mainly arise from the different concepts of the two methods. The LAP method mainly aims in the variability of the radiation field that affects the purity of the spectral measurements, while the DWD method is used to derive both cloud flags to characterize sky conditions at time steps of 1 min as well as to determine the stability of optical sky conditions over selected time intervals, e.g. for the time periods of spectral UV scans.

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References

Bais, A., Zerefos, C.S., Meleti, C., Ziomas, I.C., Tourpali, K., 1993. Spectral measurements of solar UVB radiation and its relations to total ozone, SO_2 and clouds. J. Geophys. Res. 98 (D3), 5199–5204.

Blumthaler, M., Ambach, W., Salzgeber, M., 1994. Effects of cloudiness on global and diffuse UV irradiance in a high-mountain area. Theor. Appl. Climatol. 50, 23–30.

Bordewijk, J.A., Slaper, H., Reinen, H.A.J.M., Schlaman, E., 1995. Total solar radiation and the influence of clouds and aerosols on the biologically effective UV. Geophys. Res. Lett. 22 (16), 2151–2154.

Estupinan, J.G., Raman, S., Crescenti, G.H., Streicher, J.J., Barnard, W., 1996. Effects of clouds and haze on UV-B radiation. J. Geophys. Res. 111 (D11), 16807–16816.

Feister, U., Gericke, K., 1998a. Cloud flagging of UV spectral irradiance measurements. Atmos. Res. 49, 115–138.

Feister, U., Gericke, K., 1998b. Flagging global UV irradiance spectra for clouds. Conf. On Cloud Physics and 14th Conf. On Planned and Inadvertent Weather Modification. 17 to 21 August, Everett WA, AMS, MA. pp. 71–74.

Frederick, J.E., Snell, H.E., 1990. Tropospheric influence on solar Ultraviolet radiation: the role of clouds. J. Clim. 3, 373–381.

Hulstrom, R.L., Maxwell, E., Riordan, C., Rymes, M., Stoffel, T., 1989. SERI Solar Radiation Resource Assessment Project: FY 1988 Annual Progress Report. Solar Energy Research Institute, Golden Colorado 80401-3393, SERI/PR-215-3500 DE89009456.

Josefsson, W., Landelius, T., 2000. Effect of clouds on UV irradiance: as estimated from cloud amount, cloud type, precipitation, global irradiation and sunshine duration. J. Geophys. Res. 105 (D4), 4927–4935.

Kasten, F., Young, A.T., 1989. Revised optical air mass tables and approximation formula. Appl. Opt. 28 (22), 4735–4738.

Kazadzis, S., Bais, A.F., Balis, D., Zerefos, C.S., Blumthaler, M., 2000. Retrieval of downwelling UV actinic flux density spectra from spectral measurements of global and direct solar UV irradiance. J. Geophys. Res. 105 (D4), 4857–4864.

Kylling, A., Bais, A.F., Blumthaler, M., Schreder, J., Zerefos, C.S., Kosmidis, E., 1998. Effect of aerosols on solar UV irradiances during the photochemical activity and solar Ultraviolet radiation campaign. J. Geophys. Res. 103 (D20), 26051–26060.

Li, J., Geldart, J.W., Chylek, P., 1994. Solar radiative transfer in clouds with vertical internal inhomogeneity. J. Atmos. Sci. 51 (17), 2542–2552.

Perez, R., Seals, R., Michalsky, J., Ineichen, P., 1993. Geostatistical properties and modelling of random cloud patterns fro real skies. Sol. Energy 51 (1), 7–18.

Seckmeyer, G. (Ed.), 1999. Scientific UV Data Management (SUVDAMA). EU project ENV4-CT95-0177. Final Report, Brussels, Belgium.

Seckmeyer, G., Thiel, S., Blumthaler, M., Fabian, P., Gerber, S., Gugg-Helminger, A., Hader, D.P., Huber, M., Kettner, C., Kolher, U., Kopke, P., Maier, H., Schafer, J., Suppan, P., Tamm, E., Thomalla, E., 1994. Intercomparison of spectral UV radiation measurement systems. Appl. Opt. 33, 7805–7812.

Vasaras, A., Bais, A., Meleti, C., 1998. Characterization of spectral UV measurements according to the cloud effects. IV Greek Conference of Meteorology–Climatology and Atmospheric Physics. Athens, 22–28 September. pp. 325–329.