E D U C E

Cloud flagging and diagnostic tools for spectral UV measurements

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This document presents a summary of two methods (LAP and DWD)[1] for cloud flagging that have been developed from partners of EDUCE and are available to data originators and users of the EDUCE database. It also includes a description of the work plan of NPI towards the finalization of a diagnostic tool, which will be used for flagging of spectral UV measurements for different effects.

1. Cloud flagging method developed at the University of Thessaloniki (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 in 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 and here we are interested only on high frequency variability.

The global spectral measurements performed at LAP with a Brewer MK III spectroradiometer cover the range 286-366 nm in steps of 0.5 nm. On the average, the sampling rate is about 3 sec 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 one-minute pyranometer measurements. The pyranometer that is used at LAP is a Kipp & Zonen CM 11, collocated with the two spectroradiometers. All three instruments have very similar exposure to solar radiation field.

For the time interval of each UV scan (8 min), the corresponding pyranometer data (8 points) are averaged and the standard deviation of the 8 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

[1] The two cloud flagging methods have been compared and applied to a common data set. The results are published in:
Vasaras, A., A. F. Bais, U. Feister, C. S. Zerefos, Comparison of two methods for cloud flagging of spectral UV measurements, **Atmos. Res.**, (in press) 2000.

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 one-minute 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 $I_{ref}(z)$ at a given solar zenith angle z can be derived from the relation:

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

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:

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 8 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.

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.

References:

Kylling, A., Bais, A.F., Blumthaler, M., Schreder, J., Zerefos, C.S., and Kosmidis, E., 1998. Effect of aerosols on solar UV irradiances during the photochemical activity and solar Ultraviolet radiation campaign. J. Geophys. Res. 103, D20, 26,051-20,060.

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.

2. Cloud flagging method developed at Deutscher Wetterdienst (DWD)

The cloud flagging method uses radiation and cloud data independent of the measurement of spectral solar UV irradiance. Its application is, therefore, not restricted to spectral UV irradiance, but can be used to derive cloud flags for any kind of atmospheric parameters. Input data to the method are solar irradiance measurements as well as cloud and visibility observations that are usually available at weather stations equipped with pyranometers measuring global and diffuse irradiance. There are 27 of the weather stations in the German Weather Service that measure the input data needed to derive cloud flags. The time resolution of the cloud flags is determined by the time resolution of the pyranometer data, e.g. one minute intervals.

The input parameters to perform cloud flagging are

- solar global irradiance (global and either diffuse or direct) measured by pyranometers (for global and diffuse irradiance) or pyrheliometers (for direct irradiance)
- total cloud cover
- horizontal visibility
- sunshine duration (optional).

Solar global and diffuse irradiance are measured by pyranometers. Diffuse irradiance is measured by a pyranometer, with the sun occluded by a shadow disk, sphere or ring and with a subsequent correction, if the shadowing device occludes part of the sky. As an alternative, diffuse irradiance can be derived as the difference between global irradiance measured by a pyranometer and direct irradiance measured by a pyrheliometer.

Total cloud cover, i.e. the fraction of the sky covered by clouds, and horizontal visibility are observed at weather stations according to WMO guidelines usually at hourly time steps. They are needed as input to the cloud flagging method to discriminate between cloudless sky and those clouds (usually thin clouds), the effect of which is not easy to discriminate from atmospheric aerosols without additional measurements. Cloud heights derived from ceilometer measurements can be used as an alternative to visual cloud observations, if the latter are not available. However, the information they provide is somewhat different from visual cloud observations, because ceilometers usually scan the sky overhead and they miss to detect some of the high, thin clouds (Cirrus).

Sunshine duration is measured at one minute time intervals using sunshine recorders. Their use in the cloud flagging method is optional, because most of the information they contain is provided by direct solar irradiance.

All the input parameters go into a cloud flagging algorithm that assigns one out of six possible cloud flags to every minute of the day for solar zenith angles of less than about 85°:

- cf = 0: cloudless sky
- cf = 1: sun not occluded, bright sky

- cf = 2: sun occluded, bright sky
- cf = 3: sun not occluded, dim sky
- cf = 4: sun occluded, dim sky
- cf = 5: unknown sky conditions

Changes of cloud flags within time periods of more than 1 minute, which are typical for spectral UV scans taken with current types of spectroradiometers, can be interpreted as a measure of the "stability" of sky conditions during the respective time period. If sky conditions change during the time of the measurement, the spectrum may have been distorted by moving clouds.

The cloud flagging method has been applied to spectral irradiance measurements taken at the Meteorological Observatories Potsdam, Hohenpeissenberg and Lindenberg for the period 1995 through 1999 (Feister and Gericke 1998 a and b) and is being used to derive cloud flags for current data. All the resulting cloud flags were written into the files of the sites' pyrheliometer data archived at the Finnish Meteorological Institute in the SUVDAMA project. The method can be applied to any other site that has the input parameters needed. A software routine written in FORTRAN for application to measurements taken at other sites is available on request from the authors (uwe.feister@dwd.de).

References:

Feister, U, and K. Gericke (1998 a): Cloud flagging of UV spectral irradiance measurements. Atmosph. Res. 49, 115 – 138.

Feister, U. and K. Gericke (1998 b): Flagging global UV irradiance spectra for clouds. Conf. on Cloud Physics and 14th Conf. on Planned & Inadvertent Weather Modification. 17 – 21 August 1998, Everett, WA, AMS, Boston. MA. 71 – 74.

3. Outline of work associated with NPI task within WP 5 and 6

Current status:

A fast and easy simulation tool (http://www.itek.norut.no/~olae/fastrt/fastrt.html) is the central component in a quality indication of UV spectra. The QA tool (ftp://ftp.itek.norut.no/outgoing/olae/check_flextor_distr.tar.gz) bases its function on comparison of measured UV spectra with modeled UV spectra for cloudless sky under identical observation conditions. For the quality indicator program of submitted flextor files (check_spectrum.pl) the following output exist:

The diagnosis number (and message) is one of

- 0 (Predominantly clear sky)
- 1 (Wavelength incorrectly specified)
- 2 (Irradiance incorrectly specified)
- 3 (Broken clouds, high albedo or possible measurement error)
- 4 (Significant cloud/aerosol veil or possible measurement error)

0: OK

1: Something is wrong with the wavelength specification in the measurement input file

2: Something is wrong with the irradiance specification in the input file

For classification 3 and 4, the cumulative measured irradiance between 320 and 400 nm is compared to the corresponding modelled irradiance for clear sky.

3: the cumulative measured irradiance exceeds the modelled by 20% or more

4: the cumulative measured irradiance is 70% or less of the modelled irradiance

This very simple flagging will be improved in the EDUCE project.

1. Fastrt will be improved to account for some cloud, snow and aerosol scenarios.

2. More refined distance metrics with appropriate boundaries for atmospheric anomaly indication will be defined.

3. Design tool for indication of occurring clouds during scan time.

Benefits and motivation:

Atmospheric indicators will assist users in selecting

clear sky spectra

spectra which are most probably influenced by clouds, snow and aerosols

spectra which are most probably marred by instrument errors

Currently b) and c) are not separable in check_flexstor.pl. For different reasons, users want to separate the three types of spectra or use a) and b) together. In particular, most users would want to reject any spectra with obvious instrument errors from their analysis.

As most UV spectra are measured automatically, little ancillary metadata on atmospheric and surface conditions will usually be available. Furthermore, automatic unattended time series of UV spectra may be influences by circumstances like ice and snow, birds, dirt, calibration errors, etc. If such spectra escapes on site QC/QA, we hope that the new QA tool for the EDUCE database will detect most of the erroneous spectra.

Algorithms for cloud flagging exist for stations where diffuse/direct spectra (DWD) and pyranometer measurements (LAP) are available. The NPI work will focus on QA issues also related to other types of instruments, and thus complement existing cloud flagging methods.