Simplified method for monitoring of cumulus clouds by using global horizontal irradiance

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Abstract. A simplified method for monitoring of cumulus clouds which is based on a variational analysis of a time series of measured global horizontal irradiance is proposed. A distinctive feature of the technique is that it does not use an amplitude analysis of the time series and, as a result, there is no need to use any clear-sky model.

1. Introduction
Cumulus clouds have a significant impact on the formation of weather and climate of regions, because they are capable of carrying huge masses of water over considerable distances and heights. Besides, there is the need of continuous monitoring of cumulus clouds which, in turn, are the basis for the formation of cumulonimbus clouds that carry showers, thunderstorms, squalls, and hail. This paper describes an approach for the monitoring of cumulus clouds in the daytime using only a variational analysis of a time series of measured global horizontal irradiance (GHI).

The problem of automating observations of the sky state from the earth's surface is very difficult. One of the ways to replace the human observation of clouds could be analysis of operational actinometric information, in particular, analysis of global [1] or, separately, direct and diffuse irradiance [2]. In the standard approach measured solar irradiance is compared with the model values under clear sky, and then, using variance and amplitude analysis, the state of the sky is determined.

Variational analysis is carried out with the help of the standard deviation or the coefficient of variation (CV) of a time series. It shows how this series is variable in time. As applied to the measurement of solar irradiance, variational analysis gives an estimate of the frequency of changing the degree of coverage of the solar disk with clouds of different densities (at the analysis of direct irradiance) and the speed of movement of clouds in the zenith and near-zenith zones above the observation point (at the analysis of diffuse irradiance). In the process of analyzing the global irradiance, there is a combination of the influence of direct and diffuse irradiance and, accordingly, a combination of assessing the state of the solar disk and the state of the sky in the zenith and near-zenith zones.

According to the genetic classification of clouds, they can be stratiform, waveform, and cumuliform. Stratiform clouds (such as \textit{Cs}, \textit{As}, and \textit{Ns}), stratus clouds \textit{St} and the clear sky state have low variability in time and, accordingly, a small CV (close to zero). Waveform clouds (such as \textit{Cc}, \textit{Ac}, and \textit{Sc}) are more dynamic and have medium values of the CV. Cumuliform clouds (such as \textit{Ac cuf.}, \textit{Sc}}
cuf., and Cu) are capable of completely blocking direct solar radiation with some frequency, so they are characterized by large values of the CV.

The purpose of the amplitude analysis of a time series is to obtain a measure of the difference in the value of the measured solar radiation from its value under clear sky. This is usually done by calculating their ratio, and the result is a time series normalized in amplitude. The main problem in this case is the development of a clear sky model which should be correlated with the real state of the atmosphere.

2. Theory
If small segments of a time series are used for the analysis, for example, ± 10 minutes near the analysis point, the values of the measured GHI can be considered normalized and amplitude analysis will not be required. Figure 1 shows an example of daily variation of the global horizontal irradiance for clear sky (Ogurtsovo, WMO 29638), and Figure 2 shows its values for the analysis points 8:00, 12:00 and 17:00 GMT+6 (points A, B and C, respectively). It can be seen that these 21-min segments have small changes and, therefore, they can be taken as samples of the time series of the GHI with the same scale.

**Figure 1.** Daily time series of GHI for clear sky.

**Figure 2.** GHI in the range of ± 10 min for analysis points at 8:00 (A), 12:00 (B), and 17:00 (C).
That is, the 21-minute segments of the time series of global horizontal irradiance can be considered normalized, and the coefficient of variation can be used to analyze their homogeneity. Figure 3 shows typical variations of the GHI under clear sky and for some types of clouds and approximate values of the coefficient of variation $V_Q$ for a 21-minute moving window.

\[
\begin{align*}
\text{a) } & \\
V_Q &= 0.13 \div 0.31 \\
\text{b) } & \\
V_Q &= 0.05 \div 0.18 \\
\text{c) } & \\
V_Q &= 0.13 \div 0.31
\end{align*}
\]

Unlike other sky states, cumulus clouds clearly form a very inhomogeneous time series of global horizontal irradiance. Figure 4 shows a typical time series of global irradiance under cumulus clouds and the corresponding series of the CV. Values above the threshold of 0.33 correspond to moments of medium or large cumulus cloud amount. In this case, the task of monitoring of cumulus clouds can be reduced to the detection of such moments when the coefficient of variation for a 21-minute moving window of the measured GHI exceeds a certain threshold $V_Q > 0.33$. 

\[\text{Figure 3. Typical time series of GHI under a) clear sky, b) cirrus clouds } Ci, \text{ and c) altocumulus clouds } Ac \text{ cuf.}\]
3. Practical results

To test the proposed method, we used the measured GHI of an unshaded pyranometer CM11 (Kipp & Zonen) of the meteorological observatory of the IMCES SB RAS for the warm season of 2018 (at the Sun altitude $h > 30^\circ$). Verification of the results was carried out using a binary classifier by visual comparison of color panoramic images of the sky from the All-Sky camera installed next to the pyranometer. Comparison of Precision and Recall of the $Cu$ classification was performed for $V_Q > 0.30, 0.33, \text{ and } 0.36$ by using the $F$-measure. For these values of $V_Q$, no significant differences were found.

![Figure 4. Typical time series of GHI $a)$ and CV $b)$ under cumulus clouds $Cu$.](image)

| Month   | Number of analysis points ($h > 30^\circ$) | Threshold $V_Q$ | Number of $Cu$ points (True positive) | Precision | Recall | $F$-measure | Number of $Cu$ error points (False positive) | Error rate, % |
|---------|------------------------------------------|-----------------|----------------------------------------|-----------|--------|-------------|---------------------------------------------|--------------|
| May     | 14806                                    | 0.30            | 3225                                   | 0.82      | 0.92   | 0.87        | 694                                         | 51 37        |
|         |                                          | 0.33            | 2821                                   | 0.86      | 0.90   | 0.88        | 445                                         | 55 44        |
|         |                                          | 0.36            | 2387                                   | 0.88      | 0.81   | 0.85        | 331                                         | 54 46        |
| June    | 13255                                    | 0.30            | 2182                                   | 0.69      | 0.79   | 0.73        | 1002                                        | 31 49        |
|         |                                          | 0.33            | 1885                                   | 0.72      | 0.74   | 0.73        | 723                                         | 31 55        |
|         |                                          | 0.36            | 1679                                   | 0.77      | 0.69   | 0.73        | 498                                         | 33 44        |
| July    | 16913                                    | 0.30            | 2847                                   | 0.82      | 0.85   | 0.84        | 614                                         | 37 31        |
|         |                                          | 0.33            | 2628                                   | 0.85      | 0.82   | 0.84        | 452                                         | 33 39        |
|         |                                          | 0.36            | 2370                                   | 0.88      | 0.77   | 0.82        | 332                                         | 32 31        |
| August  | 14784                                    | 0.30            | 2970                                   | 0.81      | 0.79   | 0.80        | 706                                         | 48 38        |
|         |                                          | 0.33            | 2610                                   | 0.83      | 0.74   | 0.78        | 537                                         | 49 38        |
|         |                                          | 0.36            | 2262                                   | 0.85      | 0.68   | 0.76        | 395                                         | 51 36        |
As a threshold of $V_Q$, it is convenient to use a value of 0.33, which is usually used as a boundary to separate homogeneous and inhomogeneous time series. The results of verification of the simplified method for monitoring of cumulus clouds are shown in the table 1.

It should be noted that most cases of incomplete sampling are due to a small Cu amount. Errors of the classification accuracy (false negative and false positive) are mainly caused by the simultaneous presence of more than one type of clouds and errors of visual determination of the type and amount of clouds by All-Sky images. Stratocumulus Sc and altocumulus Ac clouds are most often mistakenly classified as cumulus clouds. Taking into account the difficulty of separating cumulus and cumulonimbus clouds over the observation point, the classification of $Cb$ as $Cu$ was taken as a positive result of the method (true positive).

4. Conclusions
The above-proposed simplified method allows, in the daytime (at the Sun altitude $h > 30^\circ$) and in almost real time, the monitoring of cumulus clouds of medium and large size, which are a basis for the formation of cumulonimbus clouds. First of all, it is necessary to prevent dangerous meteorological phenomena (showers, thunderstorms, squalls, hail) whose sources are just cumulonimbus clouds. There is no need to develop a clear sky model. This allows implementing the method by using small computational resources. This is very important for autonomous systems of measuring solar radiation, which are equipped, as a rule, with only one unshaded pyranometer for measuring global horizontal irradiance.

Acknowledgments
This research was carried out with financial support under project of fundamental research of the SB RAS No. IX.138.2.5 and assignment of the Ministry of Science and Higher Education of the Russian Federation No. 5.3279.2017/4.6.

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