Systematic Analysis of Meteorological Irradiation Effects

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Goals and Motivation

Since installation in 1997, the weather profile as well as the performance of a 1 MW PV system in Munich have been recorded in second intervals leading to interesting observations and determined effects. This study demonstrates the effect of cloud enhancements, which refer to increased solar irradiation values due to cloud reflection. This enables PV system manufacturers to optimise system performance to protect the system from the problems associated with the effect analysed here.

Background and Modeling with libRadtran

Increased irradiation values are mainly caused by reflection on cumulus clouds (cloud enhancements). Cumulus clouds form when warm air rises to altitudes up to 2 km where the moisture in the air condenses. Since these clouds mainly consist of tiny water droplets their contour is sharply defined. They are isolated and fully opaque. Parts that are exposed to sunlight glow deep white while the bottom area looks dark, due to the clouds own shading. Cumulus clouds can form in less than 10 min., dwell for up to 30 min. and dissolve as quickly as they came into being.

It is impossible to forecast the exact amount and location of cumulus clouds, only a probability for their formation can be given. The sharply defined edges lead to reflections and thus to cloud enhancement effects. Typical irradiation profiles, their specific characteristics concerning clear sky as well as cloud enhancements can be modeled using libRadtran (fig. 4).

Cloud Enhancement Effects in Daily and Annual Profiles for Various Locations

The effects of cloud enhancements are characterised in fig. 1. Regularly occurring spikes are visible. These spikes signify occurrences in which solar insolation values equal and even exceed those of the solar constant 1367 W/m². The peaks are predominantly due to cloud enhancements (fig 4). Moreover, module and ambient air temperatures were measured on site and are depicted in fig. 2 and 3. In the case of cloud enhancements, high irradiance values are associated with low module temperatures. Fig. 5 and 6 consider irradiation measurements above 900 W/m². Fig. 5 compares these measurements taken in 2008 and 2009 plotted against the frequency of incidents, the duration periods and the energy yield. Fig. 6 maps clear sky load profiles against those of cloudy days in 2009. Fig. 7 shows a comparison of the energy yield classified according to time periods for multiple locations. In Germany there seems to be a gradient from south to north, resulting in fewer long-lasting cloud enhancement effects in the north due to several reasons including different wind speeds. Loughborough benefits from lots of cloud enhancements but like Oldenburg has higher wind speeds than Munich. Fig. 8 exemplifies an entire course of a cloud enhancement incident on basis of spectral distribution in the range from 305 to 1640 nm (AgroSpec, tec5). The colour gradient represents the time flow. Fig. 9 displays the influence on the wave lengths.

Conclusions and Next Steps

Cloud enhancements is an underestimated effect in the field of photovoltaic. Accurate evaluation and analysis of its profiles allow identification of its impact. These irradiation enhancements usually correlate with low module temperature. This is caused by reflections at low hanging and sharply defined clouds. Cloud enhancement effects should be incorporated in PV system design for optimal performance. The next step of this project is to assure the previous results by evaluating additional locations on the European level. Therefore we are looking for further site data sets with highly resolved energy meteorological data to extend this research.

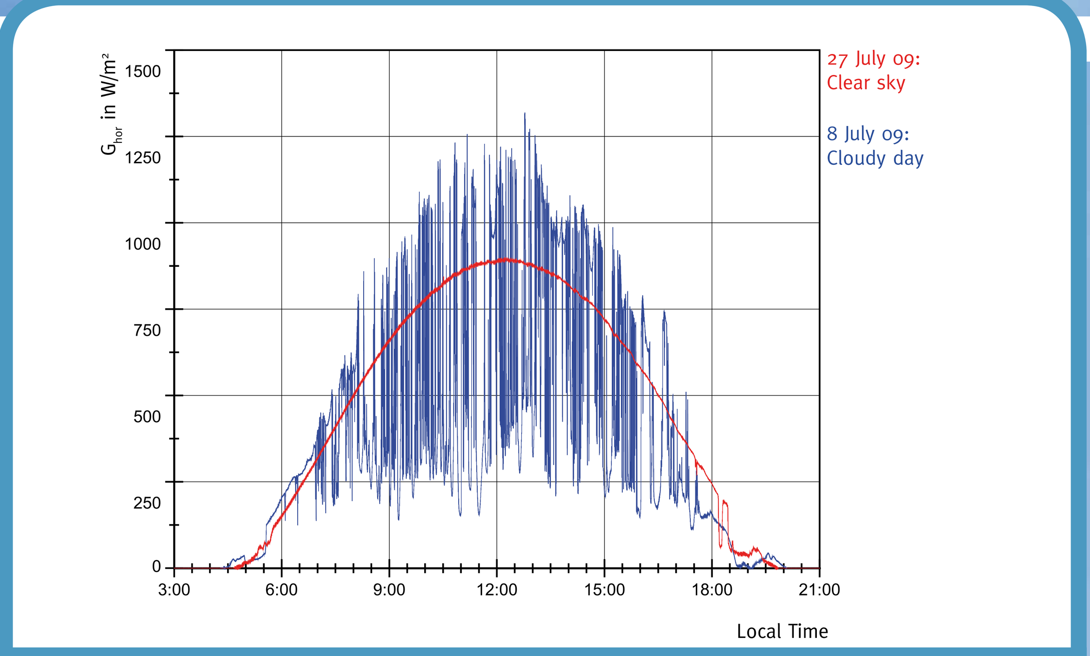

Figure 1: The chart depicts daily insolation values on a clear (red) and cloudy (blue) day. Measurements were taken at the horizontal using the CMP 21 from Kipp & Zonen.

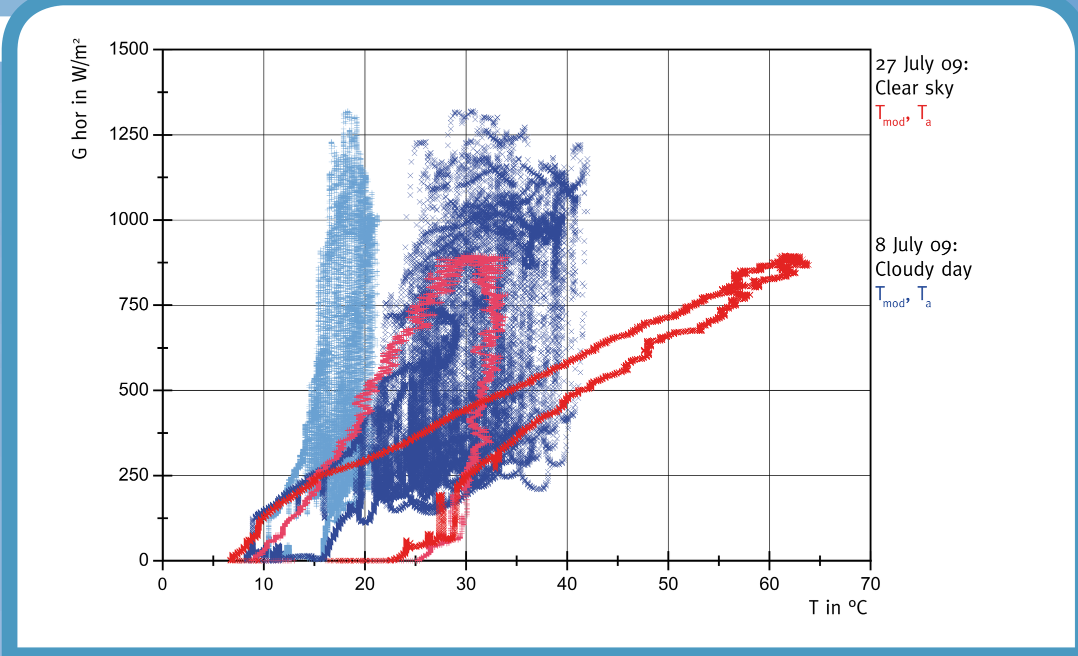

Figure 2: Module temperatures corresponding to the daily energy yield profile as in figure 1. The lighter shades of each colour represent ambient air temperature values. These were recorded using well ventilated air temperature sensors from Thies Klima. Module temperatures were determined by using reference modules containing PT100 sensors.

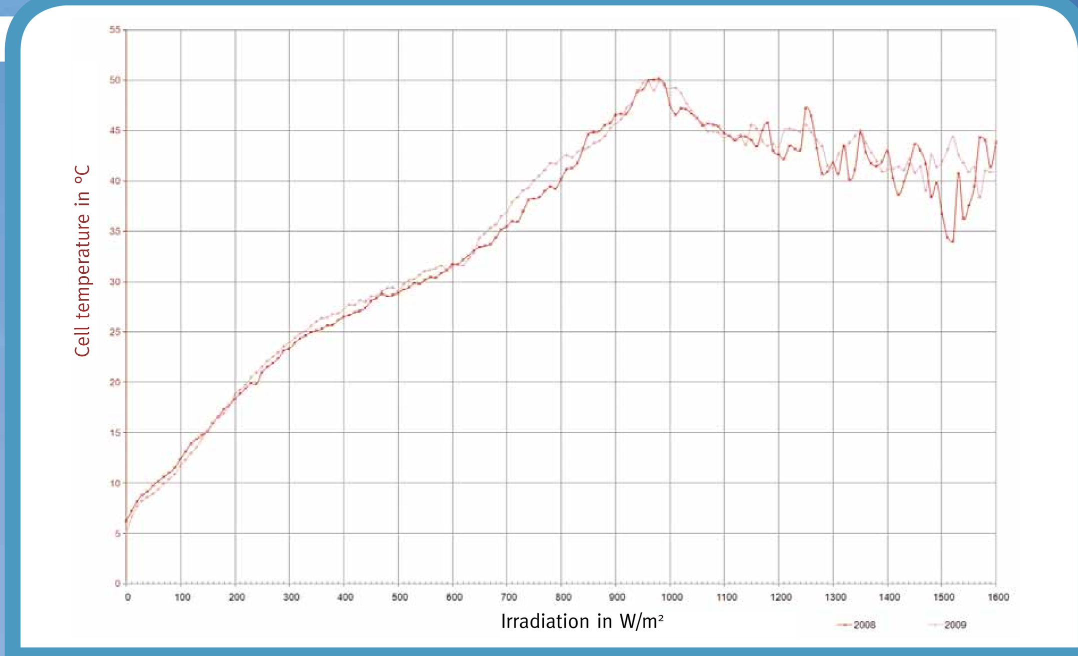

Figure 3: After a linear correlation between irradiation and module temperature, the curve of the module temperature above about 900 W/m² declines and even slightly decreases while irradiation continues to rise. This is due to the short intensive input of the cloud enhancement effect and the inert thermal mass of the modules.

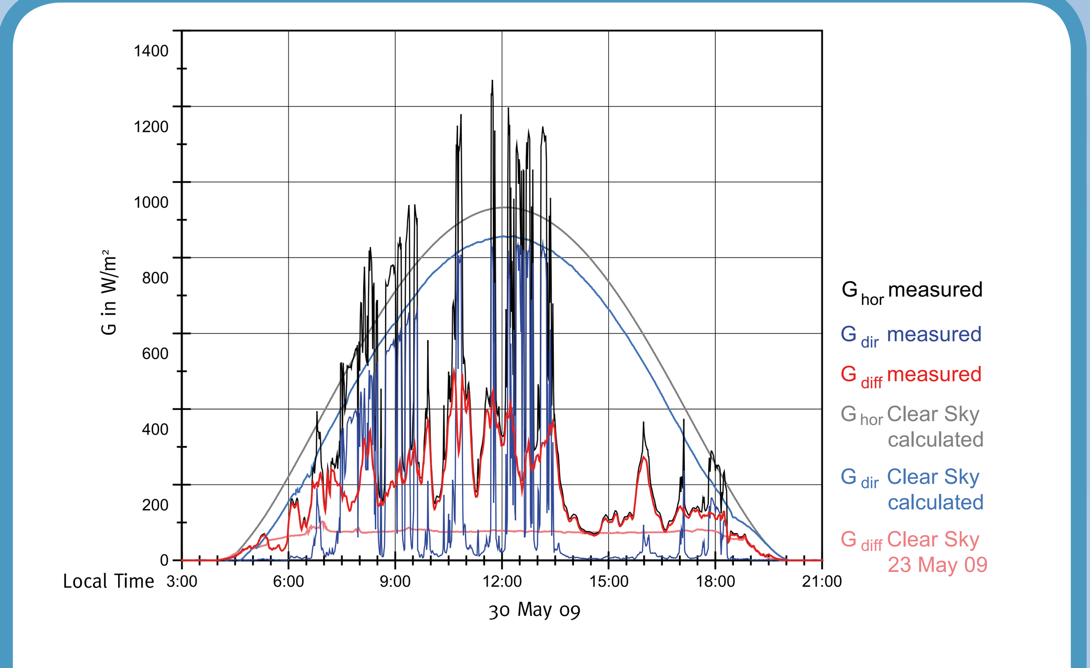

Figure 4: The black curve illustrates the daily profile of the global irradiation on the 30th of May 2009. Given in light grey (light blue) is the computed (rectified) profile of the clear-sky day. The corrected clear-sky profile is also envelope for the direct radiation fraction (dark blue). The peaks of the cloud enhancement incidents become visibly in the measured values of the diffuse radiation (red).

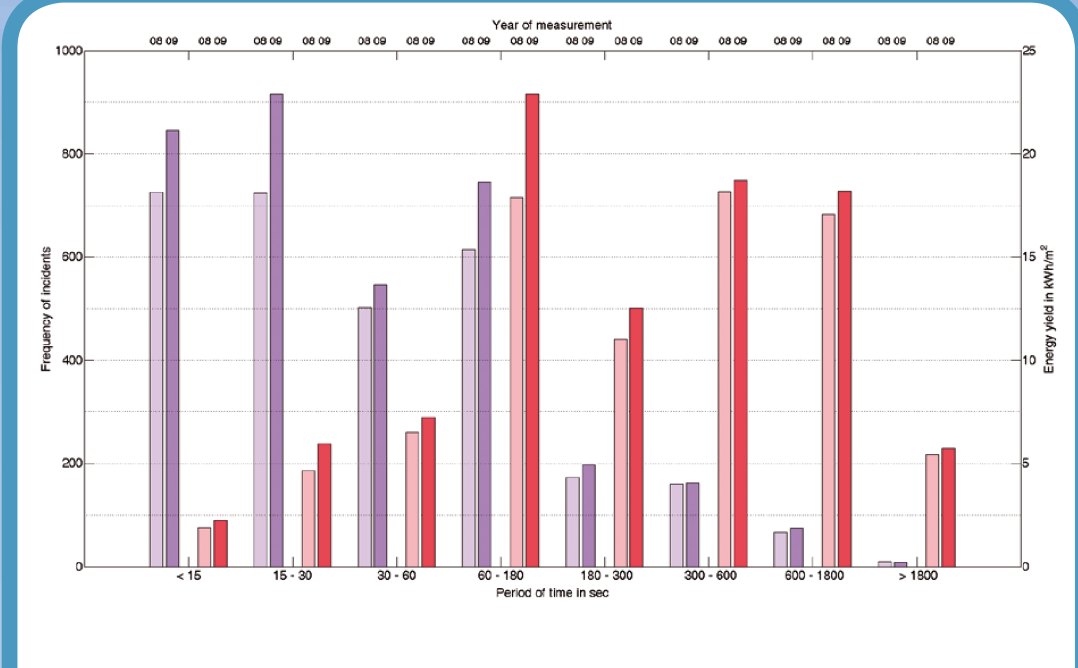

Figure 5: Insolation values above 900 W/m² (derived from figure 1), classified according to time period, frequency (blue, y-axis) and energy yield (red, y2-axis). The light and the dark colours represent values for the years 2008 and 2009 respectively.

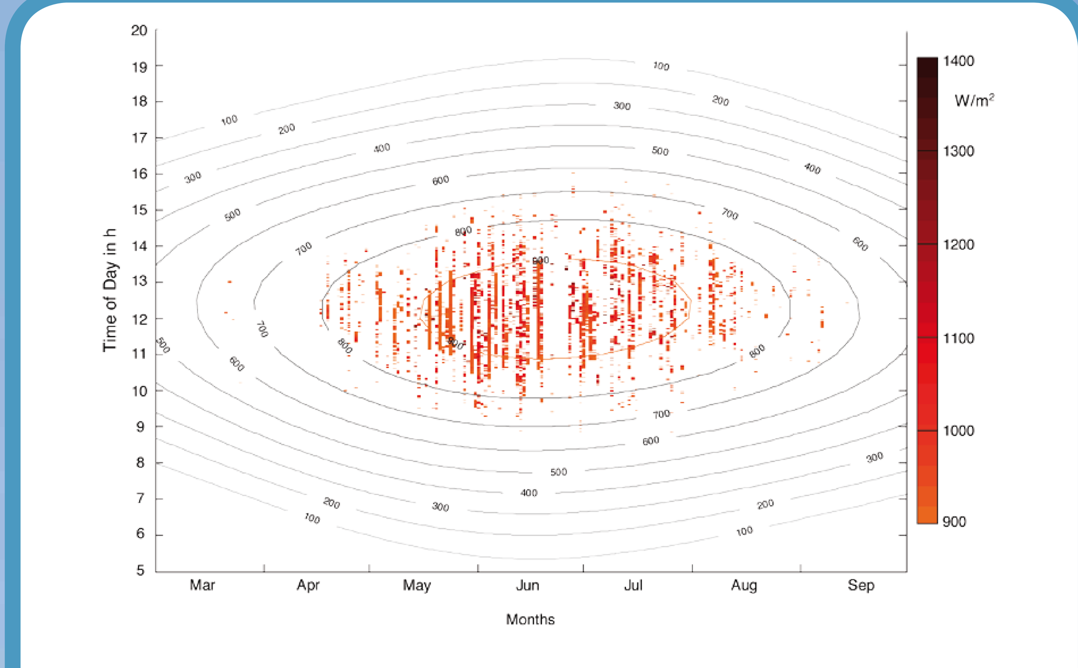

Figure 6: The isolines show the calculated daily irradiation values of a clear day in 2009. The incidents where the irradiation values lie above 900 W/m² are in red and are mapped against the time of day.

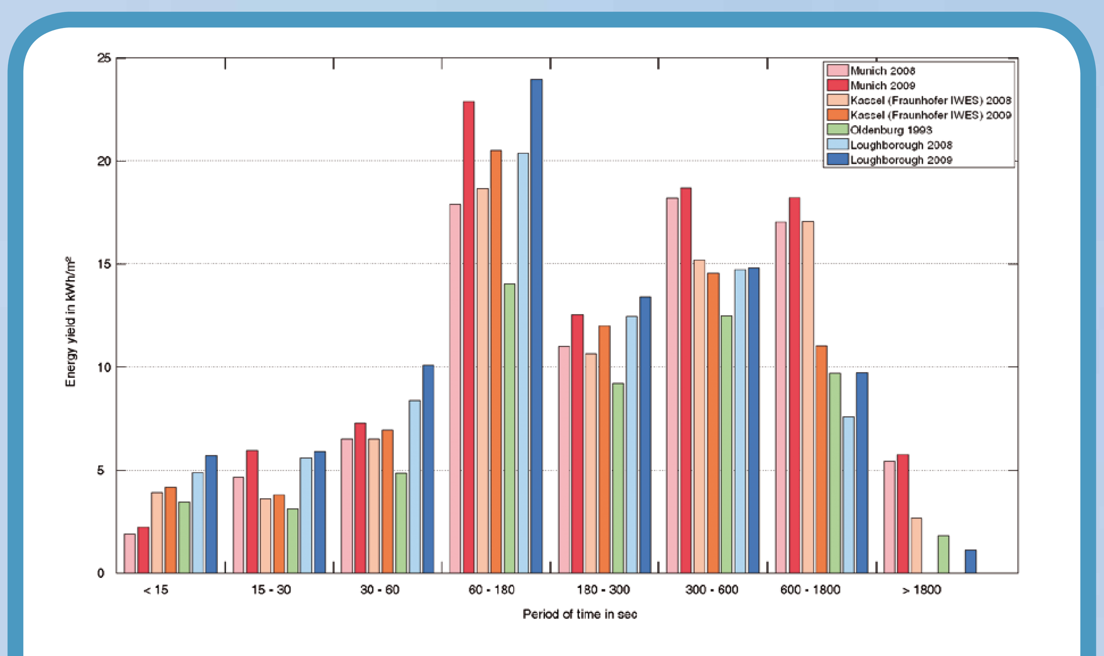

Figure 7: Comparison of the energy yield classified according to time periods at multiple locations. If available, data of the years 2008 and 2009 was taken. Other than the coastal Oldenburg, Munich benefits from lower wind speeds, resulting in more incidents lasting longer than 300 sec. In Germany there seems to be a gradient from south to north, resulting in fewer long-lasting cloud enhancement effects in the north due to several reasons including different wind speeds.

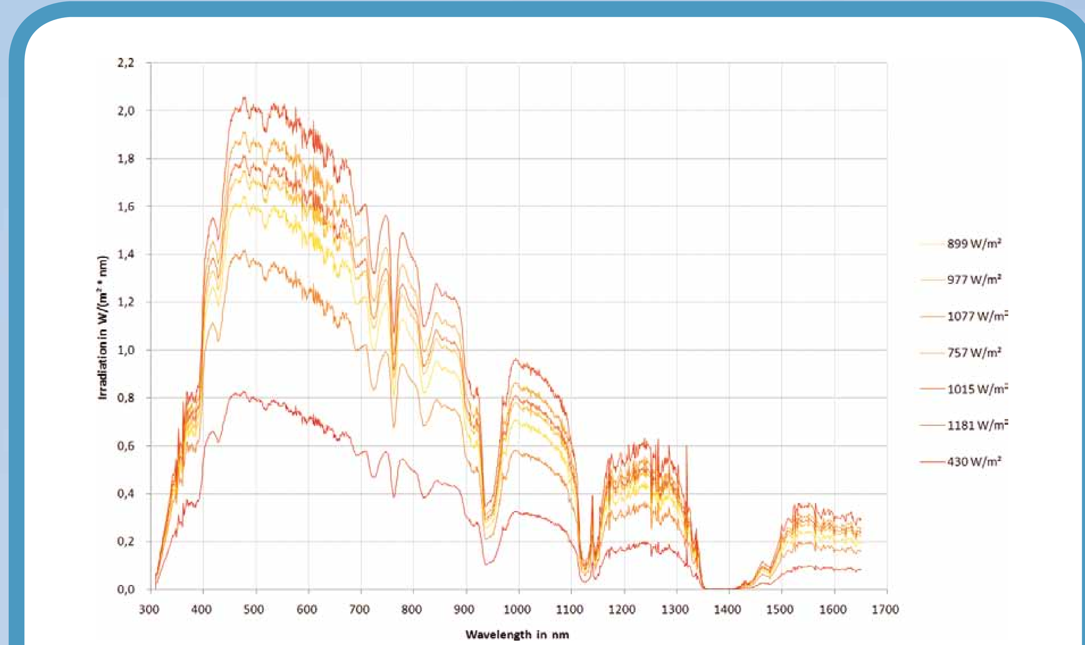

Figure 8: Using the AgroSpec (by tec5) the spectrum from 305 nm to 1640 nm was captured during an exemplary cloud enhancement incident. The first measurement (yellow) shows clear sky conditions, the last measurement (red) was taken with the sun being covered by a cloud. The colour gradient represents several snapshots that were sequentially taken in between. As the cloud draws nearer to the sun especially the short-wave part of the spectrum starts to rise (orange).

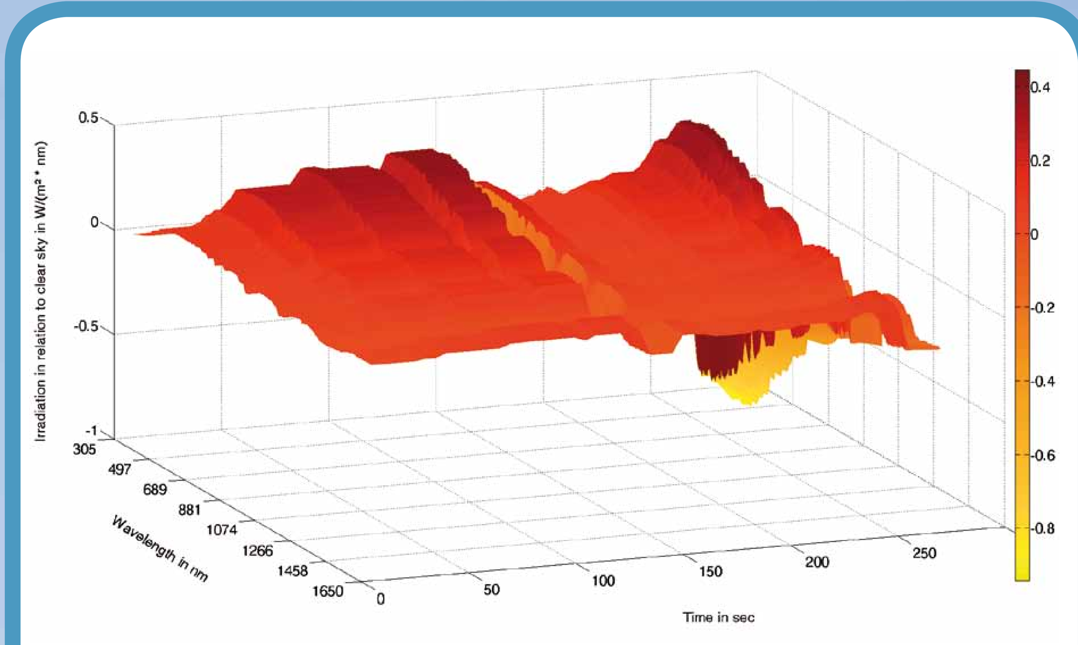

Figure 9: The graph displays the same data as figure 8, this time in relation to clear sky conditions and with constant time intervals. It shows that the peaks caused by cloud enhancement incidents mainly affect the short-wave range of the spectrum whereas the impact on wavelengths greater than 900 nm is rather weak.

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