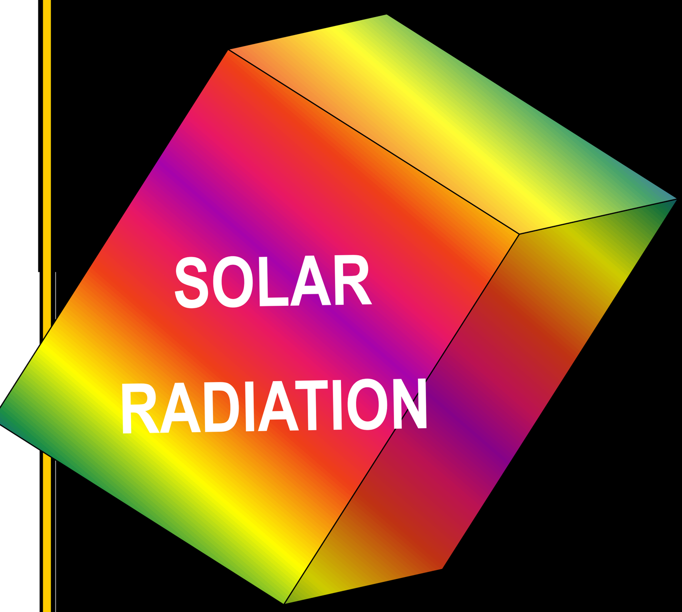
Investigation of spectral variability under outdoor conditions on the energy yield of a-Si, c-Si and CdTe Modules



Wagner J.E.[1], S. Hasel[1], W. Laube[1], P. Weihs[1], M. Rennhofer[2], R. Leidl[2], K. Berger[2], D.J. Baumgartner[3]

[1]Institute for Meteorology, University of Natural Resources and Life Sciences (BOKU), Vienna, Austria

[2]Austrian Institute of Technology (AIT), Vienna, Austria

[3]Kanzelhöhe Observatory for solar and environmental research, Karl-Franzens-University Graz, Treffen, Austria

contact: jochen.wagner@boku.ac.at

I. ABSTRACT

Within the scope of the project PV-SPEC, funded by the Austrian Science Foundation FFG, we investigate the performance of different types of photovoltaic (PV) modules as a function of global and spectral incident irradiance. For the investigation of the influence of the orientation and inclination on solar irradiance on inclined planes, we performed pyranometer measurements with different orientations (horizontal position, oriented towards east, south and west with an inclination of 35 degrees, see figure 1). Spectral measurements were performed at a horizontal position in the wavelength range from 350 to 1100 nm with 1 nm wavelength intervals. The aim of the project is the exact estimation of the potential energy yield of three module types (a-Si, c-Si and CdTe). We used the spectral measurements to improve the agreement between modelled and measured short curcuit currents (which is proportional to energy yield). Therefore we were able to quantify the spectral impact on short curcuit current as a function of the meteorological conditions, solar zenith angle, module type and module orientation.

Figure 1: Outdoor test facility on the roof of AIT, Vienna. Three module types are mounted towards east west, south and west with an inclination of 35 degrees.

II. METHODS

In the experiment three module types are tested under outdoor conditions. Every minute the short circuit current of each module, spectral irradiance (horizontal), global radiation (in the module plane), sunshine duration and module temperature is recorded.

Each module has a different spectral response – see figure 2.

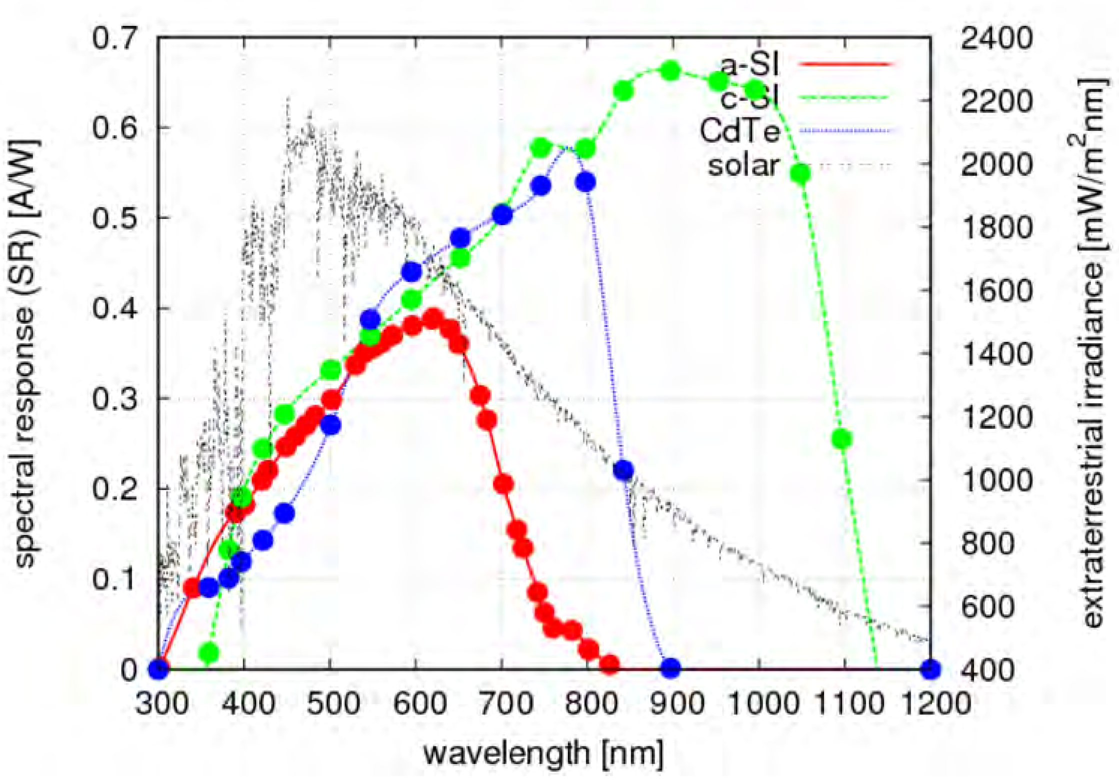


Figure 2: Spectral response for the three investigated module types (amorphous double junction thin film silicon – aSi, single-cristalline silicon – cSi and cadmium-tellurium – CdTe) is shown (left ordinate). Extraterrestrial irradiance is shown additionally (right ordinate).

To estimate the impact of spectral variability, we calculated the short circuit current using AM1.5 spectrum (see following formula). Additionally we used the modified[1] measured spectra instead of the AM1.5 spectrum.

[1]ASHRAE incidence angle modifier (Duffie and Beckman (1991)) to take into account reflection losses and conversion of the spectrum from the horizontal plane to the tilted planes according to Klucher (1979).

$$I_{SC} \approx I_{ph} = \frac{E_{pyr(j)}}{E_{AM1.5}} \cdot A_{cell} \int_{300nm}^{1200nm} E_{AM1.5}(\lambda) \cdot SR_k(\lambda) d\lambda$$

with:

I_{SC} - short circuit current [A]

I_{ph} - photocurrent [A]

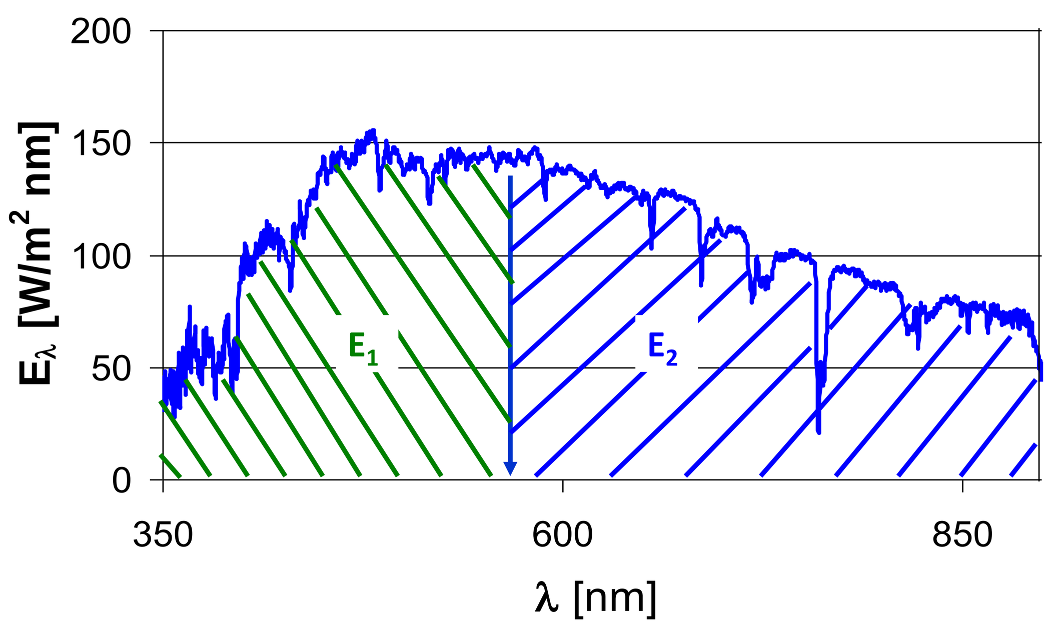
$E_{pyr(j)}$ - irradiance measured with pyranometers j - east, south, west [W/m2]

$E_{AM1.5}$ - integrated irradiance from AM1.5 spectra (1000.2078) [W/m2]

$A_{cell(k)}$ - effective cell area k - aSi,CdTe,cSi [m2]

SR_k - spectral response (see Figure 2) k - aSi, CdTe, cSi [A/W]

A frequently used measure to characterise spectra is the average wavelength λave – see figure 3. We calculated λave for every spectrum to investigate the influence of sun elevation on the module plane, time of the day and meteorological conditions. An example is shown in figure 4.



$\lambda_{ave} \Leftrightarrow E_1 = E_2$ λ_{ave}(AM1.5) = 597 nm

Figure 3: Calculation of the average wavelength λave according to Minemoto (2007). Both areas E_1 and E_2 have to be equal. λave is the corresponding wavelength.

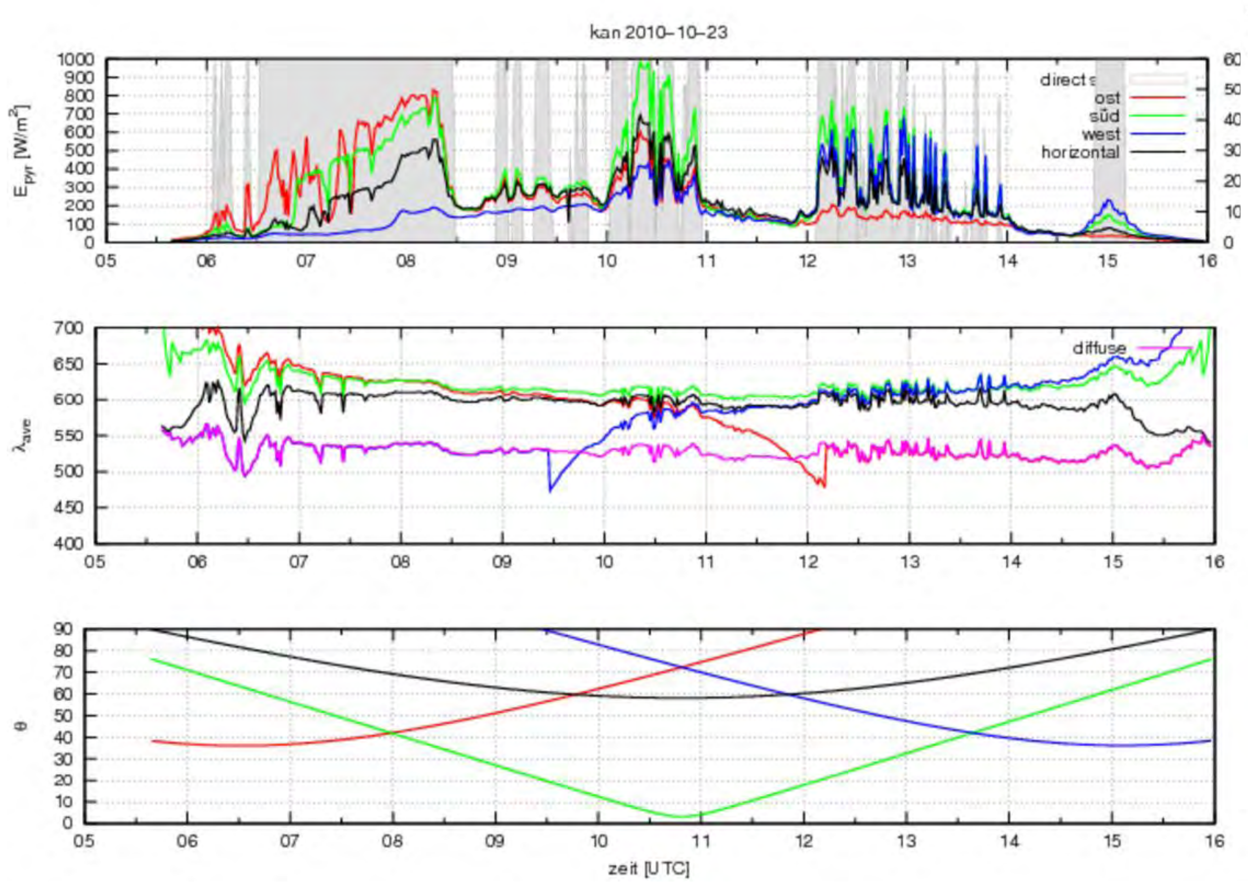


Figure 4: The daily course of global radiation (on a horizontal surface and the three tilted surfaces) is shown (top) together with sunshine duration (grey area). Furthermore average wavelength of the measured or converted spectra (see text) is shown during the course of the day (center) and finally the daily cycle of the solar elevation with respect to the four different planes is displayed for October 23rd 2010 at KanzelhÖhe.

III. RESULTS

Deviations between state of the art model results (no spectral variability, AM1.5 spectrum) and measurements is in the order of 10 per cent (figure 5, black lines and numbers). Model with spectral variability differ only up to 5 per cent in this particular case (figure 5, red lines and numbers). However, model performance strongly depends on module type, weather situation and orientation of the module.

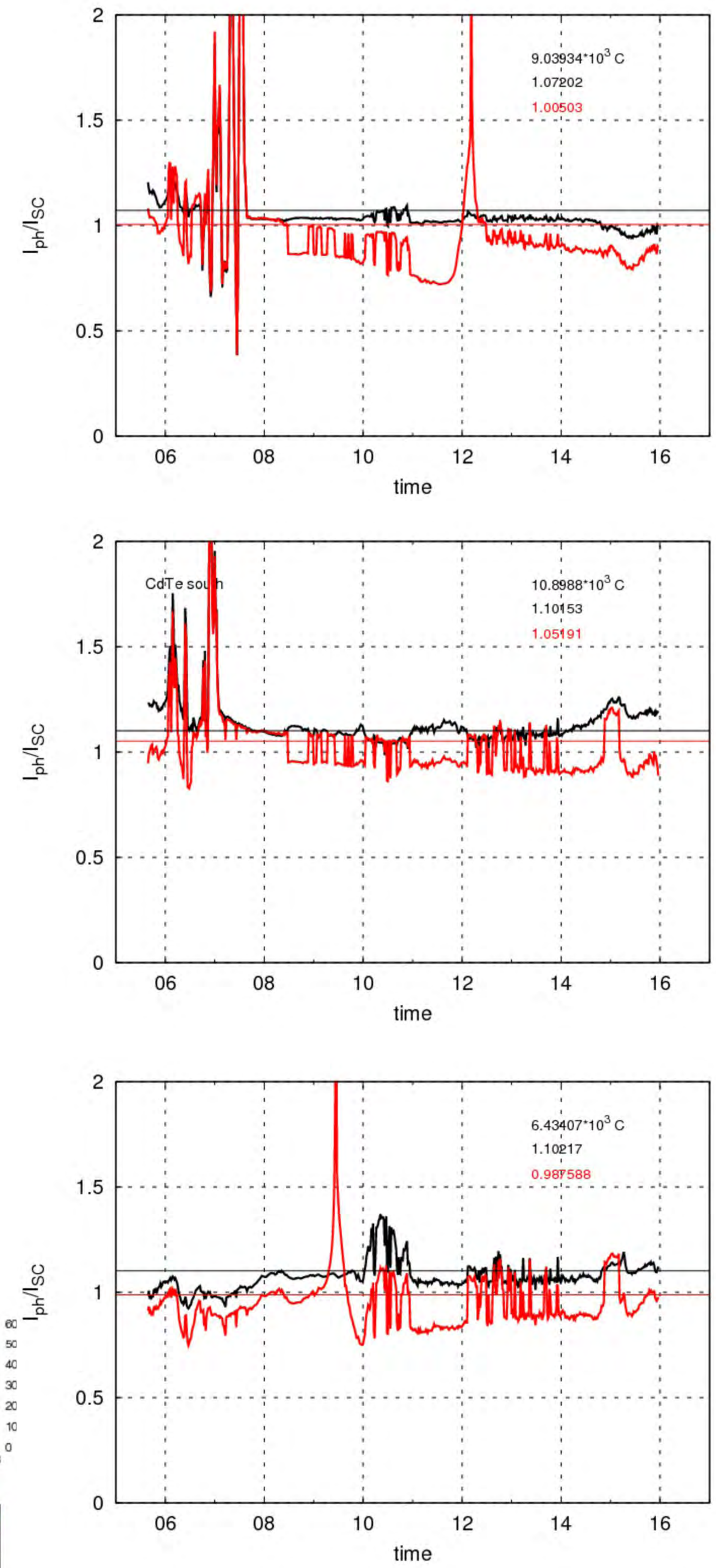


Figure 5: Daily course of the short circuit ratio (model/measurement) for one module type (CdTe) and the directions east (top), south (center) and west (bottom) for October 23rd 2010. Black line – model using AM1.5 spectrum, red line – model with observed spectra. Numbers indicate the average ratio for the day, conversion of the spectra into the module plane according to observed sunshine (see figure 4 top).

IV. CONCLUSIONS AND OUTLOOK

For the selected days a significant variability of the solar spectrum was observed. However an accurate quantification of the impact of spectral variability on short circuit current is difficult. The next steps towards a more accurate quantification of the effect of spectral variability on the energy yield are as follows:

- process large amount of data to derive mean values and temporal variability
- measure the characteristic curve in addition to short circuit current

ACKNOWLEDGEMENTS

Studies presented have been funded by Klima- und Energiefonds des Bundes, 2. Ausschreibung Neue Energien 2020. Project: „Einfluss von Sonnenspektrum und Klima auf die Performance von photovoltaischen Anlagen: Regionale Abschätzung des Sonnenenergiepotentials Österreichs"

REFERENCES

Duffie, J., Beckman, W., 1991: Solar Engineering of Thermal Processes. 2nd Edition 15. Wiley, New York, pp.309 pp.

Klucher, T. M., 1979: Evaluation of models to predict insolation on tilted surfaces. Solar Energy 23(2), 111–114.

Minemoto T., Nagae S. and Takakura H., 2007: Impact of spectral irradiance distribution and temperature on the outdoor performance of amorphous Si photovoltaic modules. Solar Energy Materials & Solar Cells 91 (2007) 919–923