Photovoltaic system calibration with dynamic temperature model

James Barry[1], Dirk Böttcher[1], Klaus Pfeilsticker[1], Anna Herman-Czezuch[2], Stefanie Meilinger[2], Christopher Schirrmeister[2], Hartwig Deneke[3] and Jonas Witthuhn[3]

[1] Institute of Environmental Physics, University of Heidelberg,
[2] International Centre for Sustainable Development, Hochschule Bonn-Rhein-Sieg,
[3] Leibniz Institute for Tropospheric Research

UNIVERSITÄT HEIDELBERG ZUKUNFT SEIT 1386

MetPVNet

Introduction

An accurate characterisation of incoming solar radiation at the ground is not only important for climate and weather models – in the realm of energy generation, reliable forecasts of solar photovoltaic (PV) power production are becoming indispensable for grid operation. The proliferation of PV systems provides a unique opportunity to characterise global irradiance with unprecedented spatiotemporal resolution, which in turn will improve the accuracy and resolution of PV power forecasts. In order to use a PV plant as a sensor for atmospheric shortwave radiation, the first step is to model the generated power as a function of system-specific parameters, such as the array elevation and azimuth angles, conversion efficiency and temperature dependence (see for instance the review in Skoplaki and Palyvos (2009)). Once the PV system is "calibrated" under clear sky conditions one can use measured PV power to infer irradiance under all sky conditions and thus also atmospheric parameters such as aerosol or cloud optical depth.

PV forward model calibration

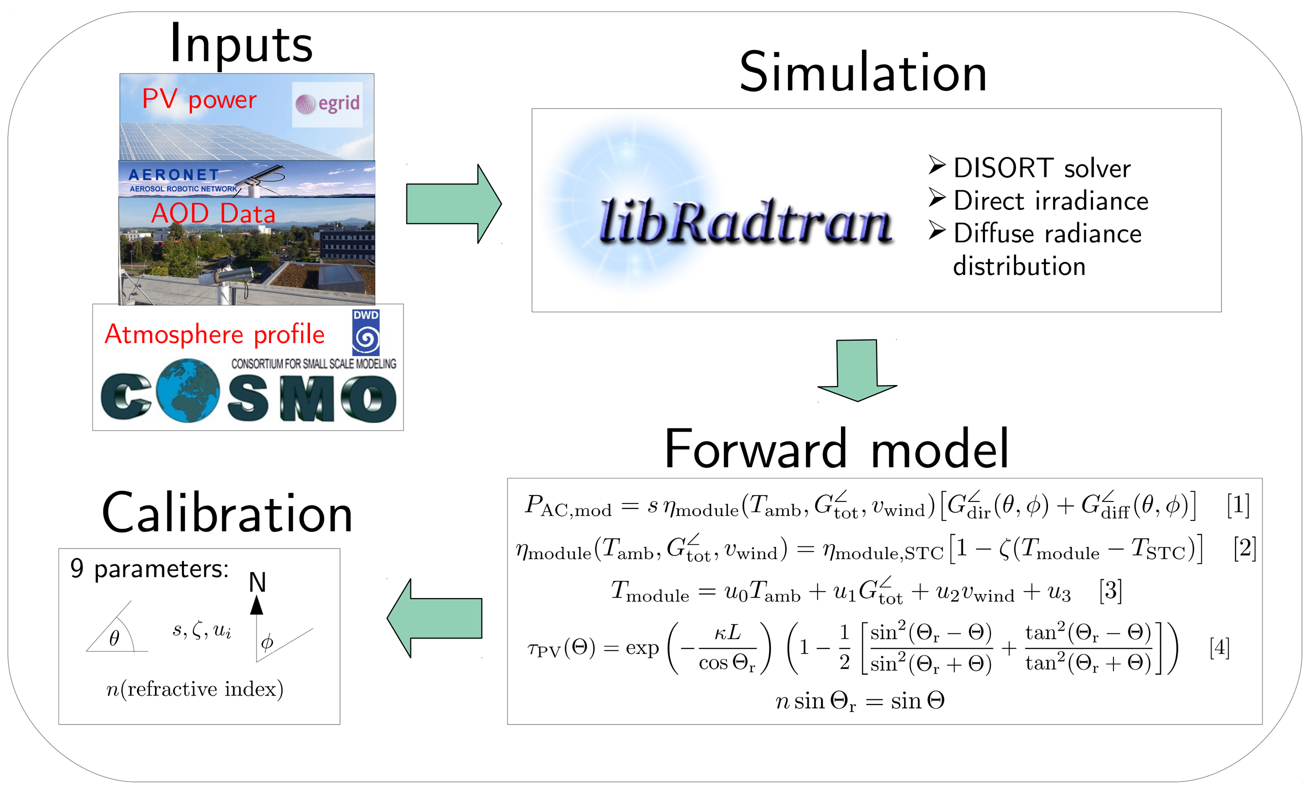

Figure 1: *Schematic diagram of forward model calibration.*

System calibration was performed using:

- 15 minute PV power data from twenty systems in the Allgäu region in Germany, recorded over four weeks in autumn 2018, with up to 12 clear sky days
- Forward model [1] as detailed in Buchmann (2018), with efficiency model [2] taken from Evans and Florschuetz (1977), temperature model [3] from TamizhMani et al. (2003) and optical model [4] from De Soto et al. (2006)
- LibRadtran (Emde et al., 2016) simulation; inputs from AERONET and COSMO model
- Non-linear optimisation (Bayesian inversion) with Levenberg-Marquardt method

Dynamic temperature model

The module temperature was modelled dynamically as a function of irradiance, ambient temperature and wind speed, in order to take into account (i) the heat capacity of the PV system and (ii) the time shift between irradiance and ambient temperature during the day. In order to capture the effect of the heat capacity of the PV system, the linear model (TamizhMani et al., 2003) was "regularised" so that the temperature at time t_i is also dependent on past values up to t_{i-n}. Each term in the model [3] was multiplied by the matrix

$$M_{ij} = \exp\left(-(i-j)\frac{\Delta t}{\tau}\right) \quad \text{for} \quad 0 \le i-j \le n\,,$$

and the measured module temperature was used to retrieve the time constant τ with non-linear optimisation. As shown in Figure 2, one expects a time lag in module temperature of roughly 5 minutes after a rapid change in irradiance.

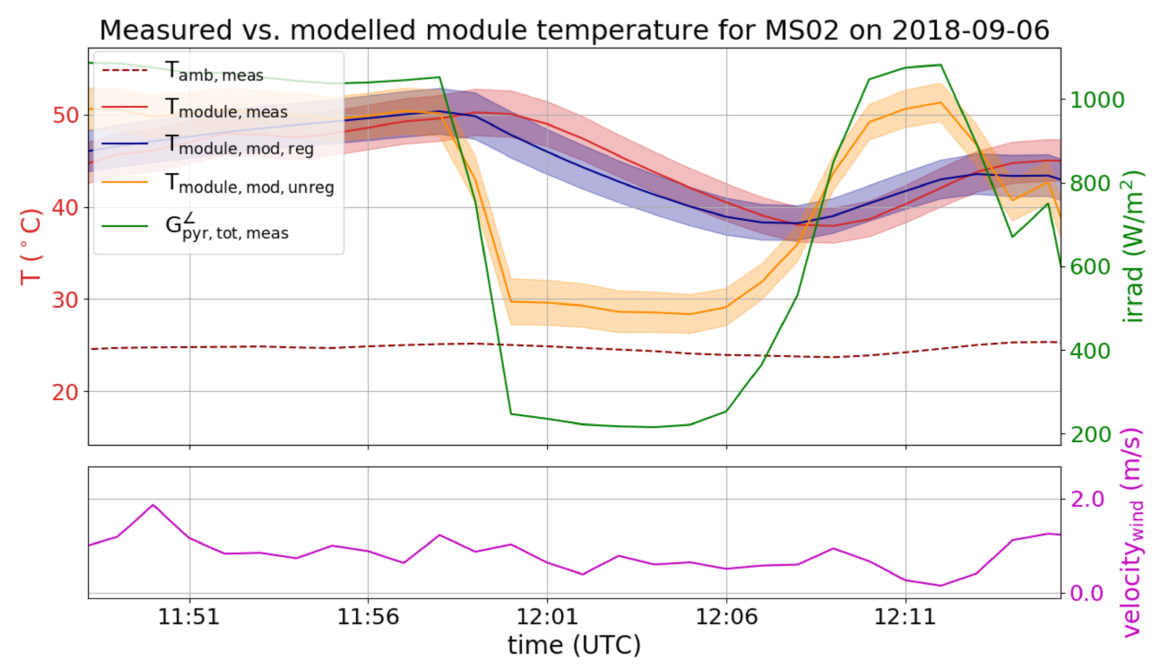

Figure 2: *Comparison of static and dynamic modelling of PV module temperature.*

Validation

Figure 3 shows an example of the modelled PV power from the non-linear fit using data corresponding to a solar zenith angle of up to 80°, a limit enforced by the pseudo-sphericity of the DISORT solver in libRadtran.

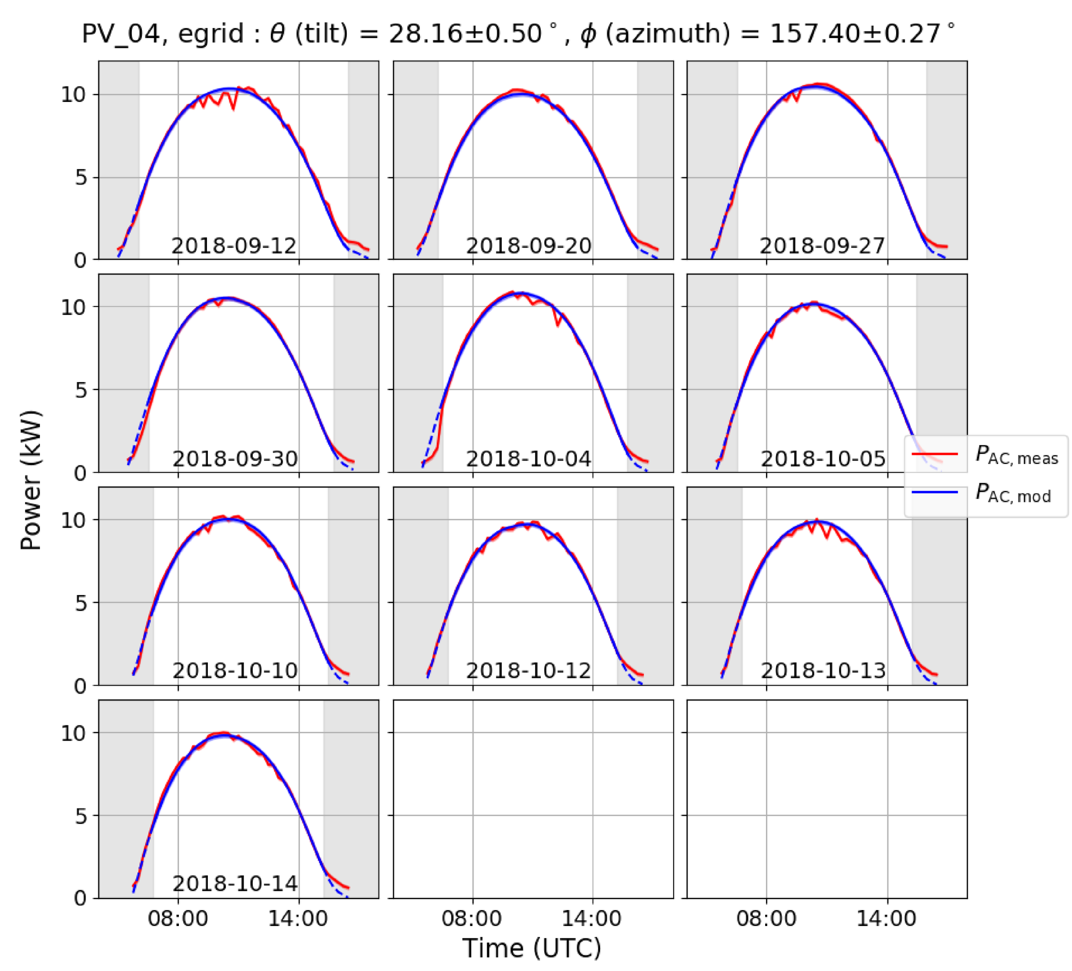

Figure 3: *Measured and modelled PV power for the station PV_04, along with retrieved orientation angles.*

The results from the optimisation algorithm were compared to data on orientation angles from airborne laserscanning, as shown in Figure 4. The azimuth angle retrieval is relatively accurate, whereas the modelled elevation angle is often incorrect. This is due to the large correlation with other parameters such as module area and efficiency.

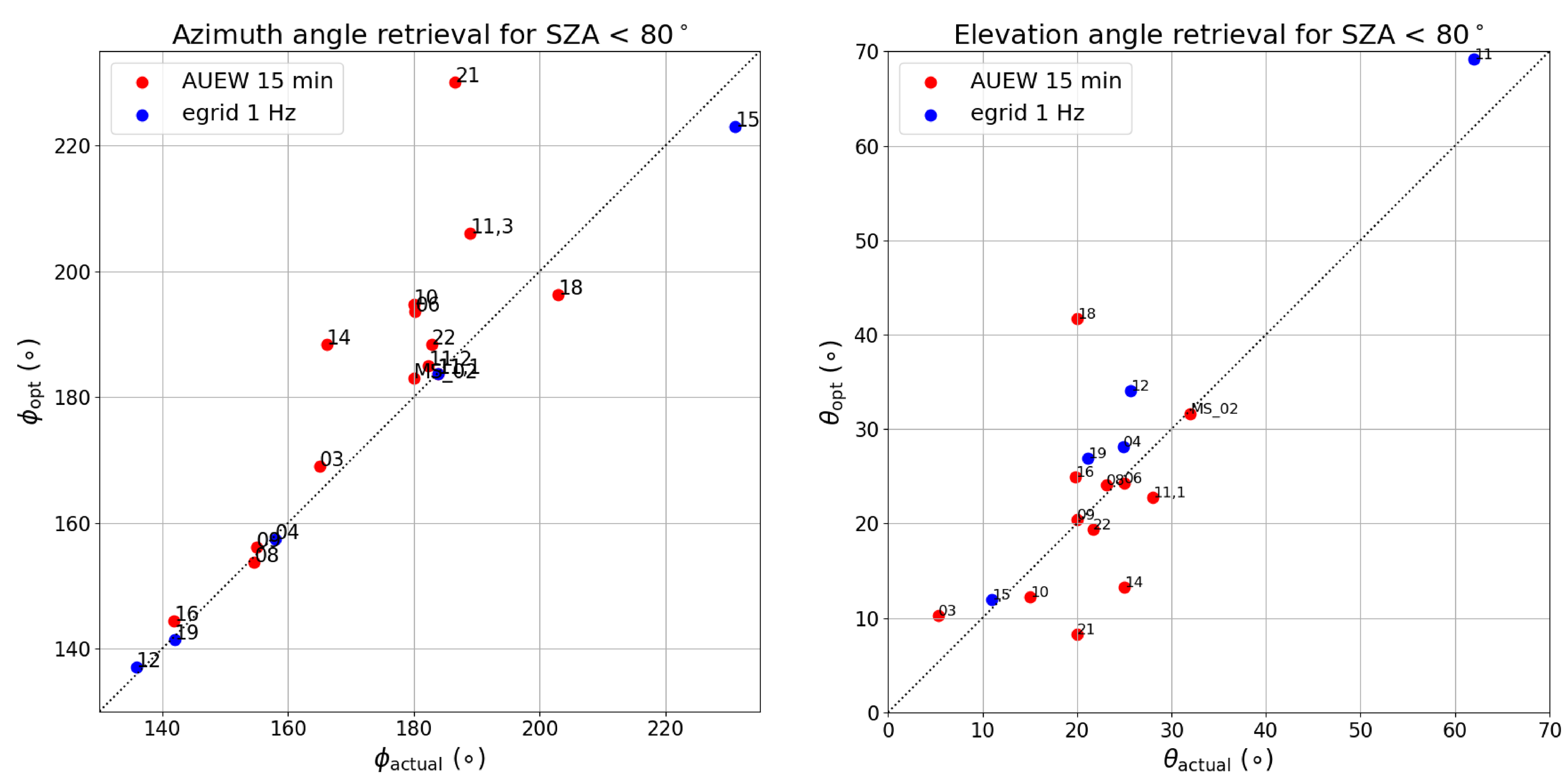

Figure 4: *PV system orientation angles: retrieval vs. ground truth values.*

Summary and Outlook

Further improvements to the model are required in order to better calibrate the systems:

- Longer simulation period to disentangle the elevation angle – area – efficiency correlations
- Non-linear temperature model; inclusion of dynamic model in PV power inversion
- MYSTIC solver for accurate spherical geometry, also valid for SZA $> 80°$
- Inclusion of diode model for accurate retrieval under low light conditions

Next step: inversion of all-sky observations in order to infer the optical properties of the atmosphere, using libRadtran with the MYSTIC solver and a non-linear retrieval.

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