Validation and benchmark of a novel low-cost measurement system of direct and diffuse irradiance at six sites worldwide

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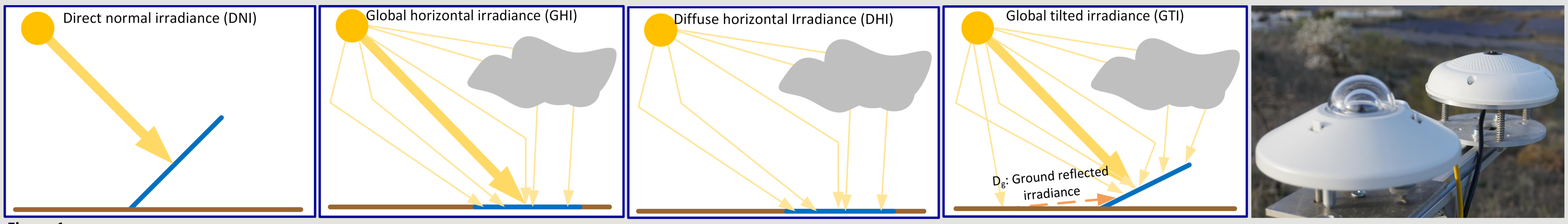

Figure 1

Motivation

Accurate, robust and cost-efficient measurements of global, direct and diffuse irradiance (Figure 1, left) in various planes are of great interest for meteorological applications. Several measurement systems for DNI, DHI or GTI are available on the market.

These measurement techniques exhibit at least one of the shortcomings: need for intensive maintenance, high acquisition cost, low accuracy or restrictions to single planes (e.g. one pyranometer per plane).

We developed the novel PyranoCam system [1,2]. We expect it to be comparably robust and inexpensive. In this work, which has been partly presented previously in [3,4], we demonstrate PyranoCam's benefit by an experimental evaluation at six sites on 4 continents.

Overview of the PyranoCam method

The PyranoCam measurement system (Figure 1, right) uses a thermopile pyranometer (ISO 9060:2018 class A) and an all-sky imager (ASI) to measure GHI, DHI, DNI and GTI (for any arbitrary plane) [1]. The PyranoCam method can be divided into two main sections, as depicted in the flowchart (Figure 2).

- Physical model [1]
- Machine-learning-based corrections [2]

Approach of our study

PyranoCam is benchmarked against commercial systems (Rotating Shadowband Irradiometer (RSI), Delta-T SPN1, EKO MS-90) at 2 sites with distinct climates (Table 1). Each sensor is calibrated at the respective site.

At these 2 sites we also analyze the influence of atmospheric conditions on the measurement accuracy of each sensor.

Further, we validate PyranoCam at four additional sites (Table 1).

Our benchmark focuses on DHI and DNI as the superior performance of PyranoCam for GTI against transposition-based models was already shown in [1]. Transposition models based on DNI and DHI measured by ISO 9060:2018 class A pyrheliometer and shaded pyranometer were outperformed by PyranoCam.

Our high-quality reference measurements are provided by sun trackers equipped with sun sensor and ISO 9060:2018 Class A pyrheliometers (DNI) and shaded pyranometers (DHI).

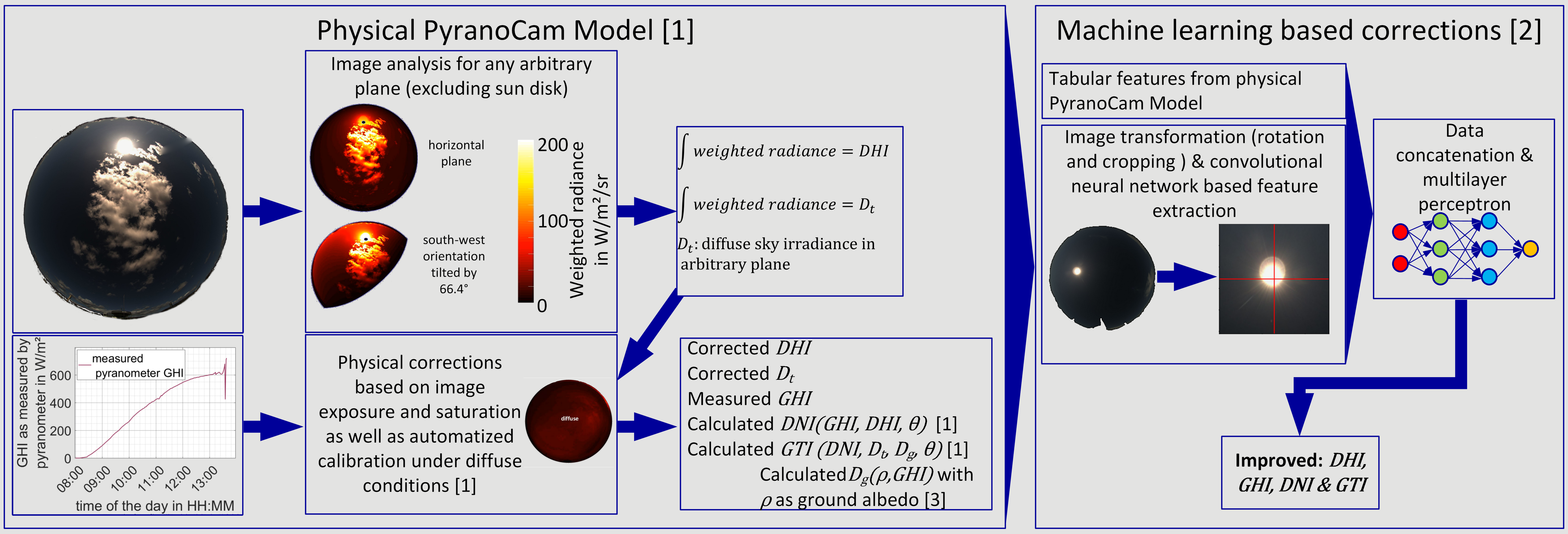

Figure 2

Table 1

Parameter	Tabernas	Oldenburg	Benguerir	Golden	Patras	Perth
Latitude	37°N	53°N	32°N	40°N	38°N	32°S
Special characteristics	High clouds, wide range of turbidities	High cloud coverage	Very turbid	High in mountains, frequent snow		
Köppen climate class	Cold desert climate	Temperate oceanic climate	Hot semi-arid climate	Warm-summer humid contin. climate	Hot-summer mediterranean climate	Hot-summer mediterranean climate
Mean DHI; DNI (dataset)	144 W/m²; 541 W/m²	135 W/m²; 269 W/m²	537 W/m²; 165 W/m²	157 W/m²; 481 W/m²	137 W/m²; 503 W/m²	134 W/m²; 421 W/m²
Evaluated period	2022-08-01…2023-06-30	2022-09-01…2023-07-31	2022-07-12…2023-08-14	2023-05-04…2023-08-29	2022-07-12…11-29; 2023-05-05…12-11	2023-04-04…2023-09-22

Results

- Benchmark in Tabernas and Oldenburg on 11 months data set
- Used error metrics:
  - Root mean square deviation (RMSD)
  - Mean absolute deviation (MAD)
  - Bias
- RSI and PyranoCam show a similar performance and both clearly outperform the remaining radiometers at both sites
- Metrics of SPN1 and MS-90 vary notably between the sites, indicating impact of the prevailing atmospheric conditions
- The influence of atmospheric conditions on the observed relative deviations is evaluated by spearman coefficient of correlation (r)
  - Atmospheric parameters have strong influence on the accuracies of MS-90 and SPN1
  - Atmospheric parameters have rather small influence on accuracies of RSI and PyranoCam

Summary & Outlook

- PyranoCam is operational
- Benchmark showed best performance in terms of DNI and DHI for PyranoCam and RSI
- PyranoCam's accuracy was additionally confirmed at four independent sites
- For GTI, PyranoCam outperforms transposition models
- The PyranoCam hardware can be used to derive cloud coverage/classification and short-term deterministic and probabilistic forecasts of the solar irradiance [5,6]

Table 2

Sensor	Strongest influence on measurement error (DNI, DHI)	
	DNI (Situations with DNI > 100 W/m²)	DHI (All-sky conditions)
RSI	Sun azimuth angle, r=0.44	Reference DHI, r=0.42
PyranoCam	Sun elevation angle, r=0.32	Reference DNI, r=0.41
MS-90	Reference DNI, r=-0.73	Reference DNI, r=0.86
SPN1	Circumsolar contribution to DNI, r=0.80	Circumsolar horizontal irradiance, r=-0.63

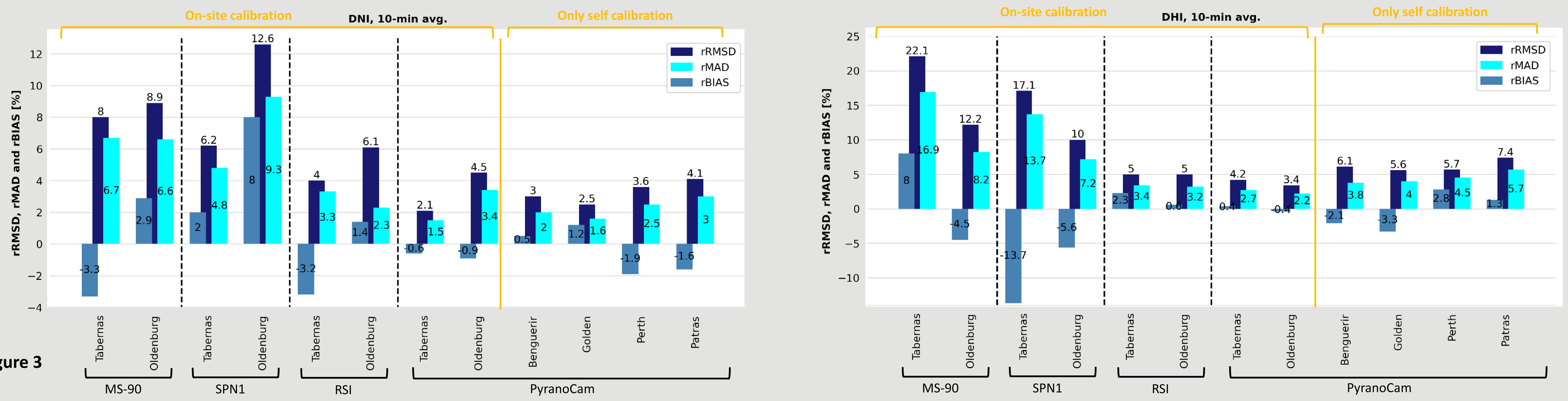

Figure 3

References

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