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Comparative analysis of albedo measurements (plane-of-array, horizontal, satellite) at multiple sites worldwide

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Albedo, that is, the diffuse reflectivity of a surface, is an important measurement in photovoltaic (PV) performance evaluation and simulation, especially for bifacial module technologies, which are rapidly gaining market share.[1] Yet many performance models assume albedo is constant over time for a particular substrate, even when evidence shows that albedo values can shift dramatically, based on sun angle, seasonal irradiance, type and seasonal variation in vegetative ground-cover, degree of backside shading, presence and degradation of snow, and prevalence of airborne particulates, such as soot, that absorb light[2]. Only by quantifying the temporal and spatial variation in albedo measurements can one accurately predict the performance of bifacial systems.

Equally concerning is the lack of standards for ground-based albedo monitoring. Typically, ground-based measurements rely on dual-pyranometer instruments, which consist of a class A pyranometer horizontal to the sky, and a "low cost" class C pyranometer horizontal to the ground, although sometimes combinations of pyranometer/reference cells or even reference cell/reference cell are employed. Most such instruments are fixed in place and their height can vary. Lacking a set of best practices or standards for measuring albedo creates data inconsistencies and introduces significant measurement uncertainty, with diurnal and seasonal changes in albedo and uneven backside shading rarely considered. As a result, the potential for measurement error can be as high as 30%, as reported by Bourne[3]. In addition, satellite measurements, as another data source, use different approaches to estimate albedo data, e.g., MODIS[4] - white- and black-sky method and are taken at a much higher resolution both spatially and temporally than ground-based measurements, thus making data comparisons difficult.

Technical Approach and Impact:

To enable the cross-site collection high-fidelity albedo data, we developed a replicable methodology and set of best practices, including common instrumentation and quality-assurance protocols. We will describe this methodology in detail and explain why we are confident not only in the accuracy of data collected from more than twelve field sites spanning the world's major climate zones but in drawing conclusions about global variations in albedo. Our study includes:

- Set of best practices for ground-based albedo measurement, information that is key to building an international standard. Best practices include requirements for ensuring data quality across multiple sites, including type and placement of instrumentation, and calibration and maintenance protocols;
- Quantified reduction in field-measurement uncertainty demonstrated by the above technical approach;
- Validation of the accuracy of satellite data relative to ground-based data;
- Greater accuracy of performance predictions of bifacial systems, facilitating their growth.

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[1] The market share of bifacial PV modules is expected to grow from 3% in 2018 to 40% by 2025, according to Bloomberg New Energy Finance, June 19, 2018.
[2] Bill Marion NEREL, BiFi Workshop, Denver, 2018
[3] Ben Bourne, BiFi Workshop, Denver, 2018
[4] Moderate Resolution Imaging spectroradiometer (MODIS)

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Explanatory page:

Measurement sites

Figure 1 shows a global albedo map based on satellite data[5] together with the field test sides of the members of PV CAMPER ("**P**hoto**V**oltaic **C**ollaborative to **A**dvance **M**ulticlimate **E**nergy **R**esearch,").
The map shows albedo on a scale from 0 (no incoming sunlight being reflected) to 0.9 (nearly all incoming light being reflected). Darker blue colors indicate that the surface is not reflecting much light, while paler blues indicate higher proportions of incoming light are being reflected. Highest albedos show brightest surfaces such as ice and snow-covered ground. Regions with deserts also have high albedos.
Our paper will include a comparative study of ground-measurements of our test sides and with satellite data.

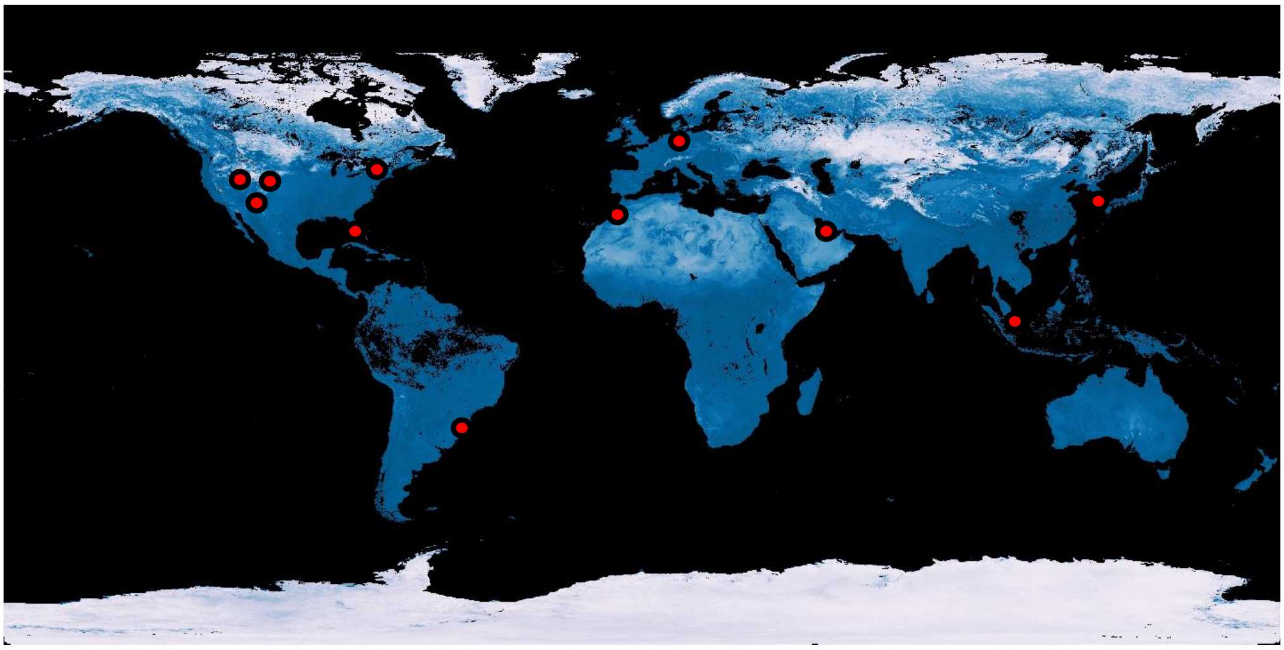

Figure 1: Global albedo data of February 2017 based on satellite measurements together with PVCAMPER's test (Sandia with 3 test sides in USA, Fraunhofer CSP, Anhalt University, Yeungnam University KIER, KTL, IRESEN, QEERI, UFSC and SERIS), are represented on the map by circles.

Technical details / experimental set-up

PV CAMPER has created a common technical approach and set of best practices to ensure our global research platform maintains high standards for data quality and availability, enabling data comparisons across multiple sites. For this study, our technical approach covers instrumentation for albedo ground-based measurements, mounting approaches (see Figure 2) and instrumentation uncertainty. Albedo ground-based measurements are deployed as follows:

- Pyranometers mounted horizontally, with one inverted to measure the ground-reflected irradiance;
- Pyranometers mounted in plane-of-array (site specific optimum) with one inverted to measure the ground-reflected irradiance;
- Portable albedo measurement set-up to investigate, e.g., different reflecting materials and inhomogeneity of albedo due to shading;
- Comparable study of pyranomerter and reference cell use and there influences on measurement uncertainty.

[5] NASA Earth observations: https://neo.sci.gsfc.nasa.gov/

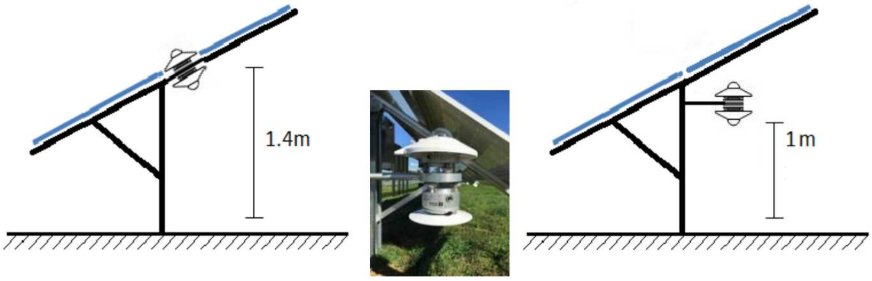

Figure 2: Measurement setup in-plane with site specific optimum tilt angle (left) and measurement setup with horizontal mounted pyramoneters (right)

Preliminary results

Figure 3 (a) shows the front and rear-side irradiance at one test site. The two pyranometer are mounted in-plane with a tilt angle of 35° as shown in Figure 2 - left. The groundcover is grass and the measurement period is from June to July'18. We selected typical summer days, indicated as clear, partial cloudy and overcast. *'Clear'* sky days are days with a low diffuse irradiance and no clouds, *'partial cloudy'* days have direct and high diffuse light due to bright/white clouds and *'overcast'* days have a closed cloud cover.
For each single day type we selected different front-side irradiances levels of interest (100, 200, 400, 700, 1000 and 1200W/m²) and defined the corresponding rear-side irradiance.
Figure 3 (a) shows the rear-side irradiance (Gr) as function of the front-side irradiance (Gf) - grey dots. For each day type defined Gf levels of interest are highlighted. Blue diamonds represent the *clear* sky day, red rectangle the *partial cloudy* day, and green triangle the *cloudy* day.
While analyzing the measured Gf we see an average value of about 145 W/m² at 1000 W/m² for clear and partial cloudy days. At clear days and Gf < 300W/m² Gr is rather stable with values around 50 W/m². However, at days with a higher diffuse irradiance such as partial cloudy and cloudy days Gr is decreasing constantly down to 25 W/m².
Figure 3 (b) shows the albedo (ratio of rear- and front-side irradiance). At clear sky days the albedo is 0.14 and rather constant over the day. Only in the early morning and late evening the albedo rises due to high sun azimuth angles. While for partial cloudy and overcast days the ratio is 0.15-0.25 and 0.2, respectively. The albedos show fluctuations over the days.
The study will include further data of all PVCAMPER test sides including different measurement and mounting structures.

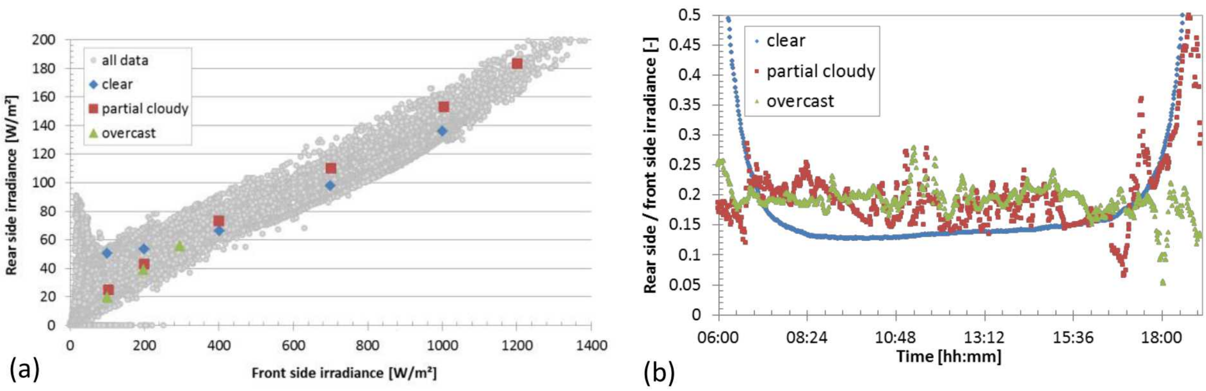

Figure 3: (a) Outdoor front and rear-side measurements (grey) in open-rack configuration with grass subsurface. Blue diamonds represent the defined irradiance levels of interest for the clear day, red rectangle the partial cloudy day, green triangle the cloudy day, (b) ratio of rear- and front-side irradiance for three different day types.