In-Situ Comparison of Five Soiling Measurement Systems

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PVPMC
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• Accelerate solar adoption by reducing solar resource uncertainty
• Solar industry leader for onsite reference measurements
• Contributed to over 25GW
• Early entrant working with NREL in 2008
• Outdoor R&D lab in operation since 2015
• US, Mexico, LatAM and Canada
• 39 staff + 140 technicians
PRESENTATION OUTLINE

- Introduce GroundWork Renewables (GR) R&D site
- Technology and data outputs
- GR soiling data processing methods
- Soiling measurement system data
- Next steps
## SOILING MEASUREMENT DEVICES

<table>
<thead>
<tr>
<th>Device</th>
<th>Manufacturer</th>
<th>Method</th>
<th>Outputs</th>
<th>Measurement Rate</th>
<th>Data Collection Period</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eclipse</td>
<td>GroundWork</td>
<td>Short-circuit Current (I_sc)</td>
<td>Isc, G, BOM Temp, SR, SLF</td>
<td>Three-second</td>
<td>May 2018 – May 2020</td>
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<tr>
<td>PVSoil</td>
<td>GroundWork</td>
<td>Isc</td>
<td>Isc, G, BOM Temp, SR, SLF</td>
<td>Three-second</td>
<td>May 2018 – May 2020</td>
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<tr>
<td>RDE300</td>
<td>Atonometrics</td>
<td>Isc &amp; Max Power Point (MPP)</td>
<td>Isc, Voc, G, BOM Temp, SR, SR_{ISC}, SR_{Pmax}</td>
<td>One-minute</td>
<td>May 2018 – May 2020</td>
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<tr>
<td>Mars</td>
<td>Atonometrics</td>
<td>Optical</td>
<td>TL, SR</td>
<td>Daily</td>
<td>May 2019 – May 2020</td>
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<tr>
<td>Dust IQ</td>
<td>Kipp &amp; Zonen</td>
<td>Optical</td>
<td>2xTL, 2xSR, BOM Temp</td>
<td>Instantaneous</td>
<td>May 2019 – May 2020</td>
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</tbody>
</table>

## OTHER INSTRUMENTATION

<table>
<thead>
<tr>
<th>Sensor</th>
<th>Manufacturer</th>
<th>Measurement</th>
<th>Data Collection Period</th>
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<tbody>
<tr>
<td>SR20</td>
<td>Hukseflux</td>
<td>Plane of Array Irradiance (26.5-degree tilt)</td>
<td>May 2018 – May 2020</td>
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<tr>
<td>WS500</td>
<td>Lufft</td>
<td>Wind speed &amp; direction, ambient temperature, relative humidity, barometric pressure</td>
<td>May 2018 – May 2020</td>
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<tr>
<td>TE525WS</td>
<td>Texas Instruments</td>
<td>Rainfall</td>
<td>May 2018 – May 2020</td>
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OPTICAL SOILING SYSTEMS

MARS


DustIQ

https://www.kippzonen.com/Product/419/DustIQ-Soiling-Monitoring-System#.Xu_28kVKhPY
• Two modules per measurement system: Clean and Soiled
• IEC 61724-1
  − Method 1 = Pmax
  − Method 2 = Isc
• Soiling ratio, $SR = \left( \frac{\text{Soiled Module Output}}{\text{Clean Module Output}} \right)$
• Measurements are based on transmission loss through a window due to the accumulation of soil
• Soiling ratio, \( SR = (1 - \text{Transmission Loss}) \)
• No regular cleaning
• The window should be cleaned (soiling system reset) when foreign substances block transmission
METHODS

- Matched 72-cell modules
- Calibration or normalization was performed for all module-based systems
- Daily maintenance
  - Maintain clean module
  - Measure and log module angular displacement N/S & E/W
  - Reset as necessary
- All data aggregated on one logger to eliminate time offset issues
DATA PROCESSING

• NREL Stochastic Rate and Recovery (SRR) Method*
  − Developed to quantify power loss due to PV degradation and soiling from PV yield data
  − Built into RdTools, an open source Python library for PV degradation analysis

• GroundWork Data Processing Method
  − Rooted in the SRR method
  − Unique attributes of the GroundWork method:
    ▸ Utilizes concurrent and co-located, ground-based irradiance measurements
    ▸ “Turns the dials” to optimize the SRR method for soiling measurement system outputs
    ▸ Sets a moving, site-specific and time-specific GHI irradiance threshold
    ▸ Factors in soiling system reset events and overlays rain and regular maintenance events using high quality maintenance logs

Figure 1A: Graph showing daily and 15-day median SR.

Figure 1B: Graph showing SR changes and rainfall amount with daily SR deviation and threshold.

Figure 1C: Graph showing SR over time with natural cleaning events and maintenance events.

Figure 1D: Graph showing dates with events marked.
TIME-SERIES COMPARISON: DAILY SOILING RATIO FROM ALL 5 DEVICES
MONTHLY SOILING LOSS: ALL 5 DEVICES

Graph showing monthly soiling loss from May 2019 to May 2020 for different devices, including Eclipse, RDE300 ISC, RDE300 MPP, PVSoil, DustIQ, and MARS.
## UDAQ PARTICULATE DATA

**2018**

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<th>March</th>
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**2019**

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Note: A plus sign (**) following a value indicates that the computed average includes one or more raw data values affected by a special event.
REAL WORLD CHALLENGES
SNOW TEST: PRE-CLEANING
EFFECTS OF SNOW ACCUMULATION AND MELTING

Snow is cleaned off of clean panel

Snow melts off of soiled panel or optical measurement window
AUGUST 2019 SOILING EVENT: LINEAR REGRESSION ANALYSIS

- **Eclipse Median Daily SR**
  - Slope = -2.3E-03
  - $R^2 = 0.9634$

- **RDE300 ISC Median Daily SR**
  - Slope = 2.3E-03
  - $R^2 = 0.9439$

- **RDE300 MPP Median Daily SR**
  - Slope = -2.0E-03
  - $R^2 = 0.8906$

- **PVSoil Median Daily SR**
  - Slope = -1.9E-03
  - $R^2 = 0.9412$

- **DustIQ Median Daily SR**
  - Slope = -1.6E-03
  - $R^2 = 0.9063$

- **MARS Median Daily SR**
  - Slope = -1.9E-03
  - $R^2 = 0.5763$
## AUGUST 2019 SOILING EVENT: ANALYSIS COMPARISON

<table>
<thead>
<tr>
<th>Linear Regression Slope</th>
<th>Eclipse</th>
<th>RDE Isc</th>
<th>RDE MPP</th>
<th>PVSoil</th>
<th>Dust IQ</th>
<th>Mars</th>
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</thead>
<tbody>
<tr>
<td>-2.3E-03</td>
<td>-2.3E-03</td>
<td>-2.0E-03</td>
<td>-1.9E-03</td>
<td>-1.6E-03</td>
<td>-1.0E-03</td>
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<table>
<thead>
<tr>
<th>Median Daily Soiling Rate</th>
<th>Eclipse</th>
<th>RDE Isc</th>
<th>RDE MPP</th>
<th>PVSoil</th>
<th>Dust IQ</th>
<th>Mars</th>
</tr>
</thead>
<tbody>
<tr>
<td>-2.3E-03</td>
<td>-2.2E03</td>
<td>-2.0E-03</td>
<td>-1.7E-03</td>
<td>-9.2E-04</td>
<td>-1.9E-03</td>
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• Variations in monthly soiling rate of module-based systems were on average < 1% while optical-based soiling rates were shown to deviate by a maximum of 2% when compared to the module-based data.

• The optical systems tended to underestimate the soiling at the Utah R&D site in the summer of 2019 as well as during snow events.

• The Eclipse and RD300 agree the best out of the 5 soiling measurement systems. This could be due to full-size high quality modules and similar measurement methods.

• The soiling tool results have a tight correlation with the linear regression calculation method. This helps to verify the accuracy of the soiling tool.

• Optical soiling measurement systems have promise due to the fact there is minimal maintenance and price but the measurements aren’t quite as accurate as using the short circuit current method with full size modules.

• Interannual variability is hard to measure over smaller intervals. The Utah R&D site experienced different weather and environmental conditions over two years. These include, but are not limited to, a bad fire season causing increased particulates, a snowy winter, and bird migrations causing droppings and frequent resets in the spring months.
WHAT’S NEXT?

- Uncertainty analysis
- Bifacial soiling
- Improved normalization techniques and optical sensor data processing
- Assess impact of light soak on normalization stability
- Historical dataset coupling
  - Rain