IEA PVPS Task 16

Subtask 1: Evaluation of Current and Emerging Resource Assessment Methodologies

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Participating countries:
AUS, DEU, CHE, CHL, DNK, ESP, EU, FRA, GBR, GRE, ITA, SVK, SWE, UAE, USA

Overview of Subtask 1

- Evaluates current and emerging resource assessment methodologies.
- Three categories:
  - Ground Measurements,
  - Numerical weather prediction models,
  - Satellite based methods.
- Develop best practices, guidelines and standards after analysis of various datasets and methods.

Activities in Subtask 1

- **Activity 2.1: Ground Based Method**

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- **Activity 2.2: Numerical Weather Models**

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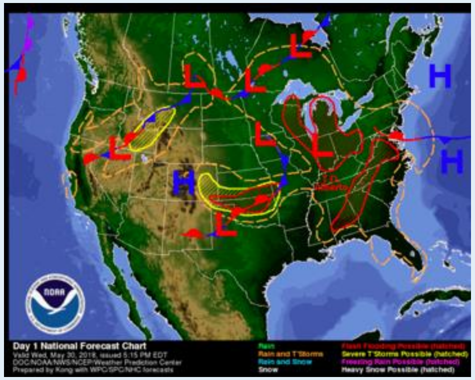
- **Activity 2.3: Satellite Based Methods**

Ian Grant, BOM, Australia, Ian.Grant@bom.gov.au

- **Benchmarking Framework (on hold)**



Activity 1.1: Ground Based Methods

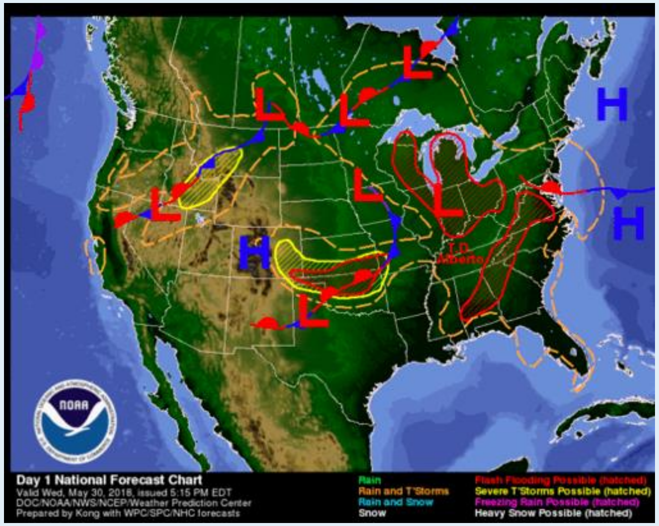
- Analysis and improvement of established measurement methods
- Analysis and improvement of advanced measurands
- Formulation of best practices and standards

Target Audience: Utilities, instrument manufacturers and users, and broader audience (economic and policy world)

Activity 1.2: Numerical Weather Models

- Solar radiation benchmarking of existing global and regional reanalysis
- Representation of resolved and non-resolved clouds in regional NWP
- Radiative transfer in NWP models

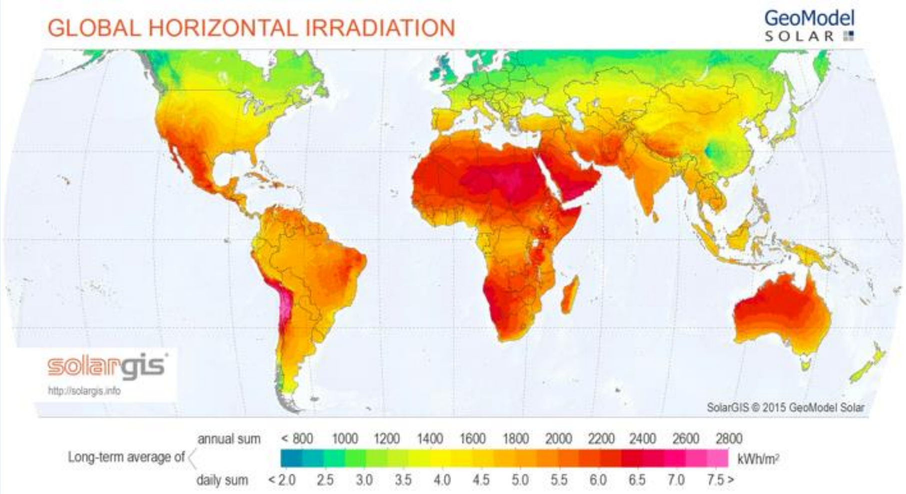
Target Audience: NWP data providers and users, weather services, utilities and broader audience (economic and policy world)



Activity 1.3: Satellite based methods

- Evaluation of recent and new methods
- Uncertainty dependence on local climate
- Methods improvement

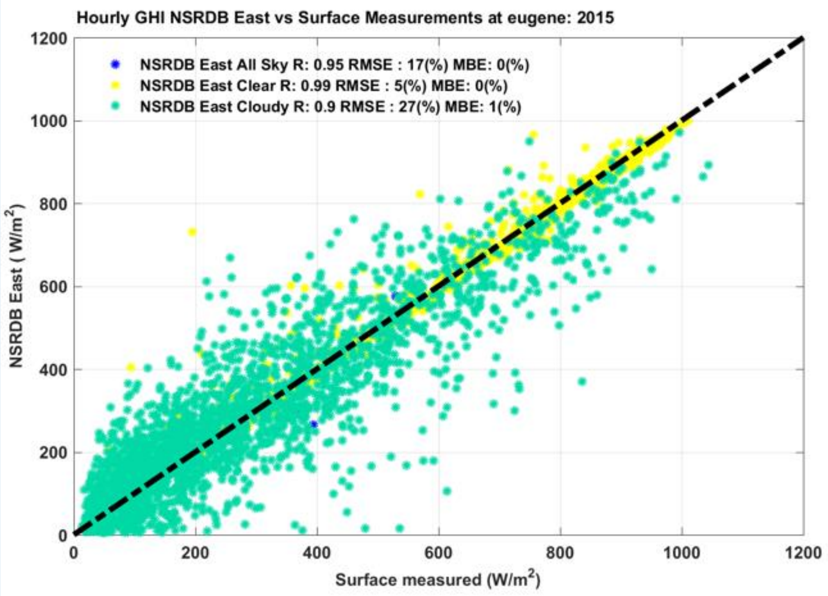
Target Audience: Satellite derived radiation data providers and users, utilities and broader audience (economic and policy world)



Activity 1.4: Benchmarking Framework

- Collection of qualified ground-measured data as reference
- Definition of data sets to be benchmarked
- Data infrastructure (databases, interfaces)
- Evaluation of software
- New evaluation criteria

Target Audience: NWP data providers and users, weather services, utilities and broader audience (economic and policy world)



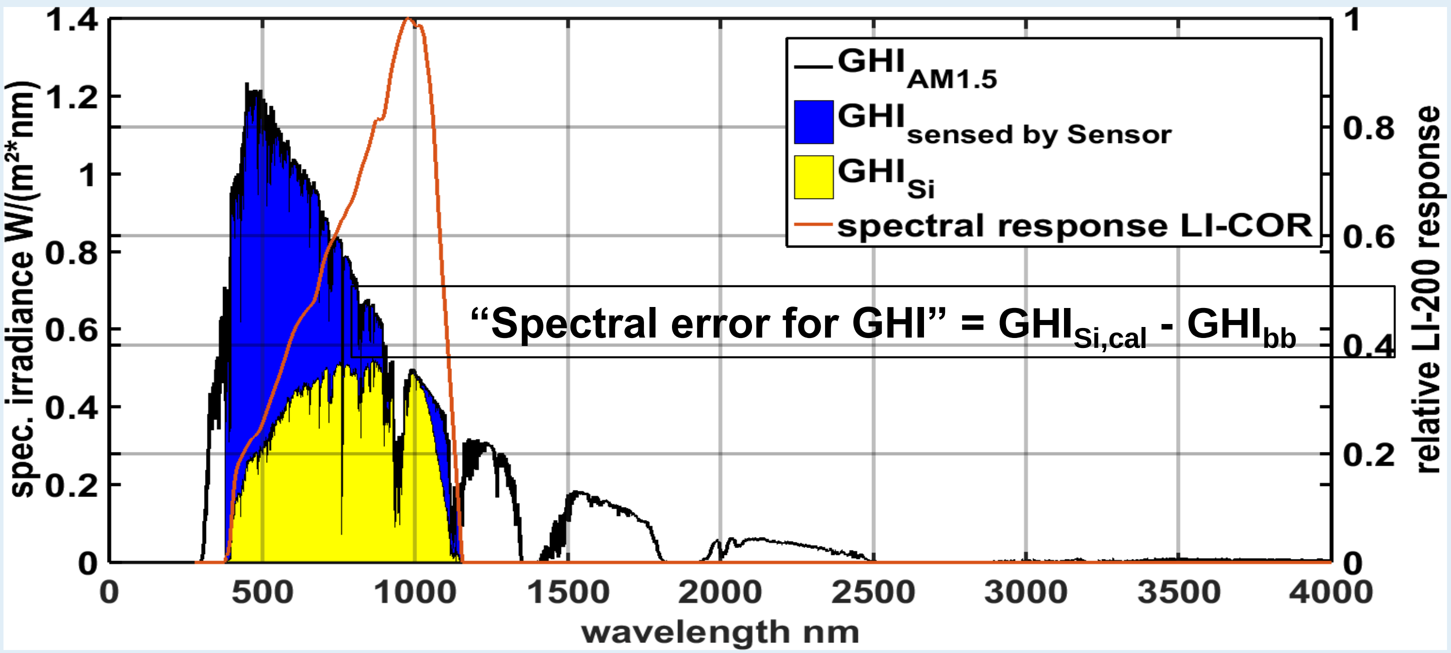
ON HOLD

REPRESENTATIVE RESULTS FROM 1ST AND 2ND TASK EXPERTS MEETING, MARCH 7-8, 2018

1.1: Ground Based Measurements

ISO 9060 standard for classification of pyranometers and pyrheliometers is under development.

- **Includes both thermal and photodiode sensors.**
- **Spectral error is included.**



If no other errors occur

$GHI_{Si,cal} = GHI_{bb}$ for ONE spectrum with "perfect" calibration!

$GHI_{Si,cal} \neq GHI_{bb}$ for OTHER spectra and this calibration factor!

1.1: Ground Based Measurements

- **New ASTM standard "Guide for Evaluating Uncertainty in Calibration and Field Measurements of Broadband Irradiance with Pyranometers and Pyrheliometers".**

INTERNATIONAL

Designation: G213 – 17

https://www.astm.org/Standards/G213.htm

Standard Guide for Evaluating Uncertainty in Calibration and Field Measurements of Broadband Irradiance with Pyranometers and Pyrheliometers[1]

This standard is issued under the fixed designation G213; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This guide provides guidance and recommended practices for evaluating uncertainties when calibrating and performing outdoor measurements with pyranometers and pyrheliometers used to measure total hemispherical- and direct solar irradiance. The approach follows the ISO procedure for evaluating uncertainty, the Guide to the Expression of Uncertainty in

2. Referenced Documents

2.1 *ASTM Standards:*[2]

E772 Terminology of Solar Energy Conversion

G113 Terminology Relating to Natural and Artificial Weathering Tests of Nonmetallic Materials

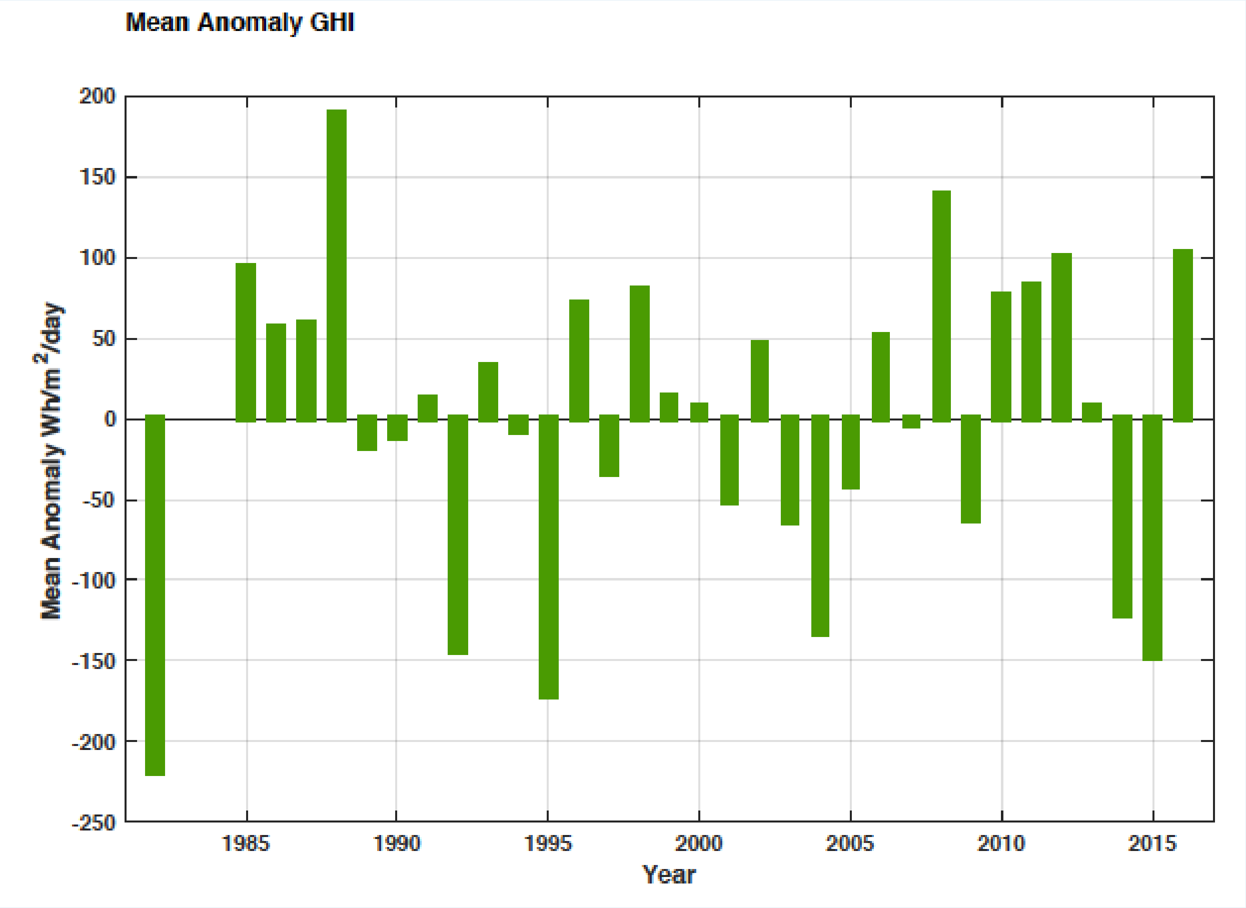
G167 Test Method for Calibration of a Pyranometer Using a Pyrheliometer

NATIONAL RENEWABLE ENERGY LABORATORY

IEA T16 PVPS

1.1: Ground Based Measurements

Analyzing trends using long-term measurements: challenges



GHI measurements using PSP from 1981.

Factory calibration used initially.

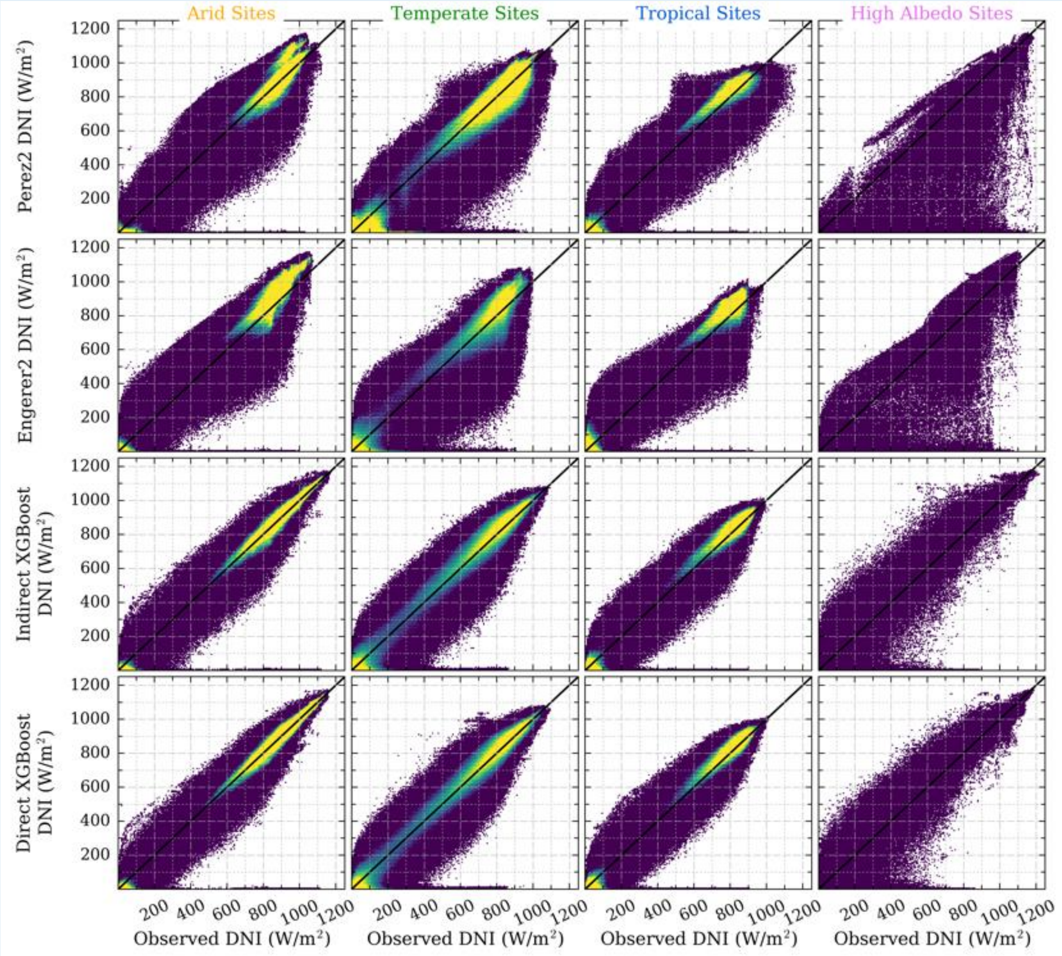
NREL calibration process changed over the years.

Thermal offset correction needed for this instrument but was only used in later years.

1.1: Ground Based Measurements

Improving separation models for GHI

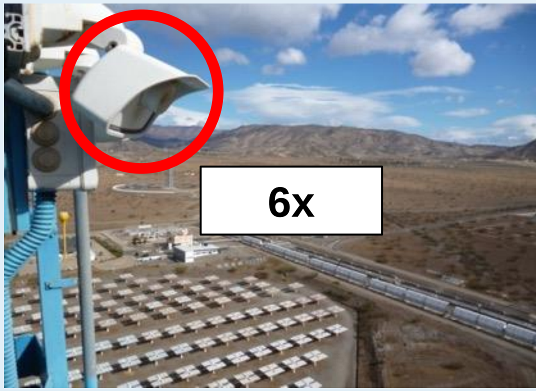
- Gradient Boosting improves significantly over the best individual models in current use
- High-albedo situations still inaccurate

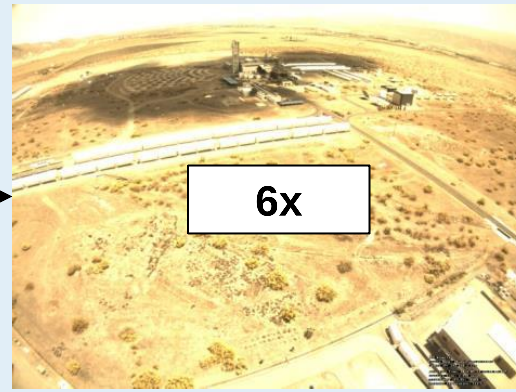


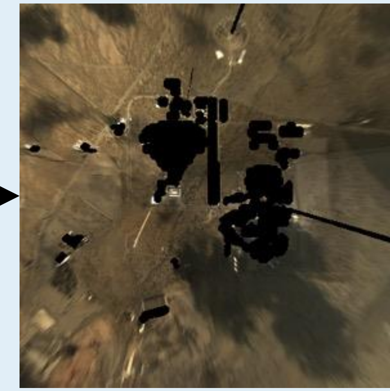
Ricardo Aler, Inés M. Galván, Jose A. Ruiz-Arias, Christian A. Gueymard, 2017. Improving the separation of direct and diffuse solar radiation components using machine learning by gradient boosting, Solar Energy, Volume 150, Pages 558-569, https://doi.org/10.1016/j.solener.2017.05.018.

1.1: Ground Based Measurements

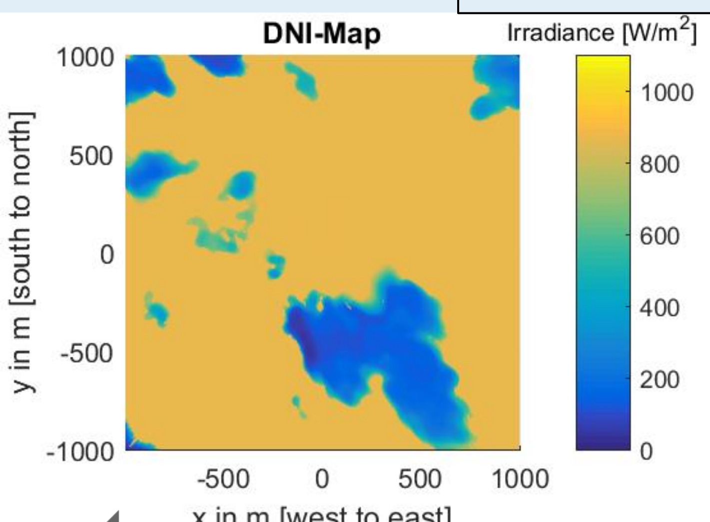
Benchmarking: Radiometer and ShadowCam-system
Ground-filming cameras provide irradiance maps as reference for All Sky Imager

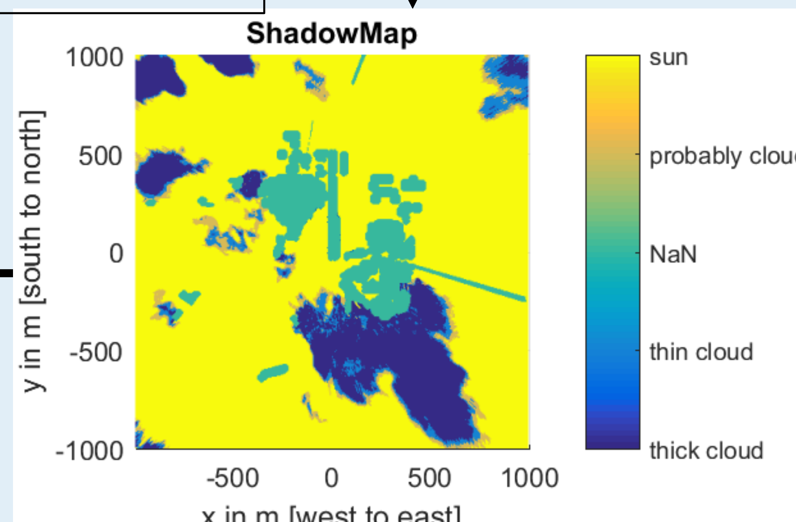






>30 radiometers (optional)





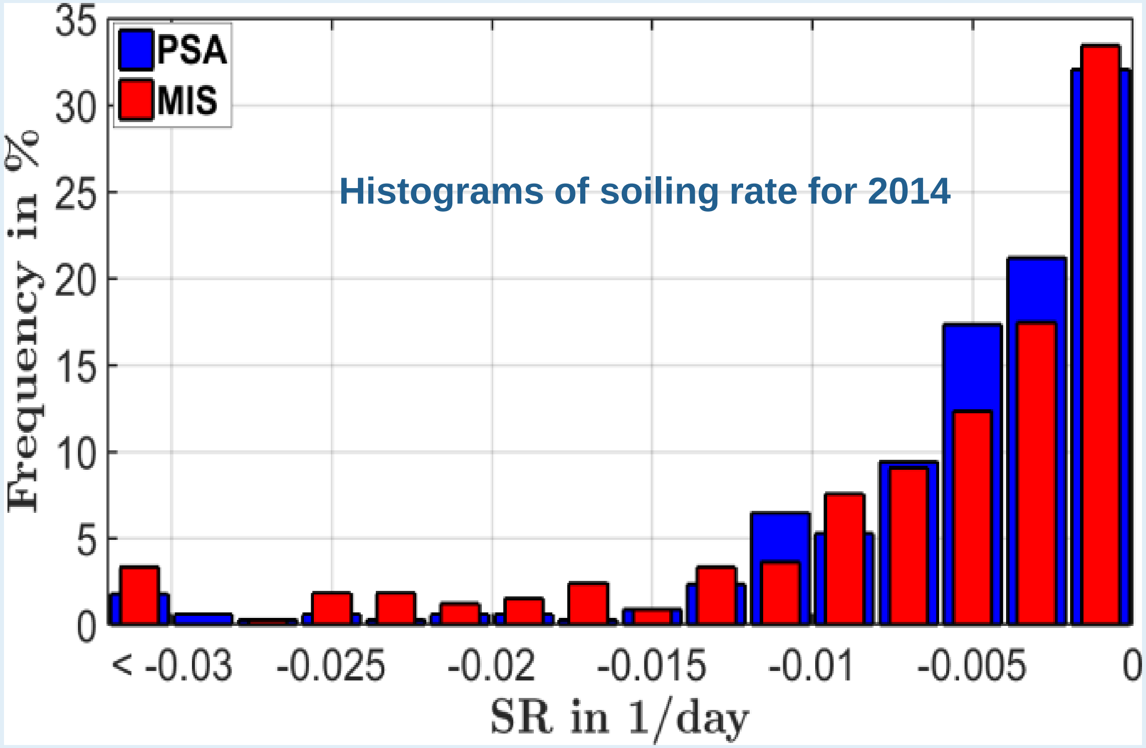
sunny + shaded reference image for nearly the same solar position

1.1: Ground Based Measurements

Physical Model for CSP soiling rate

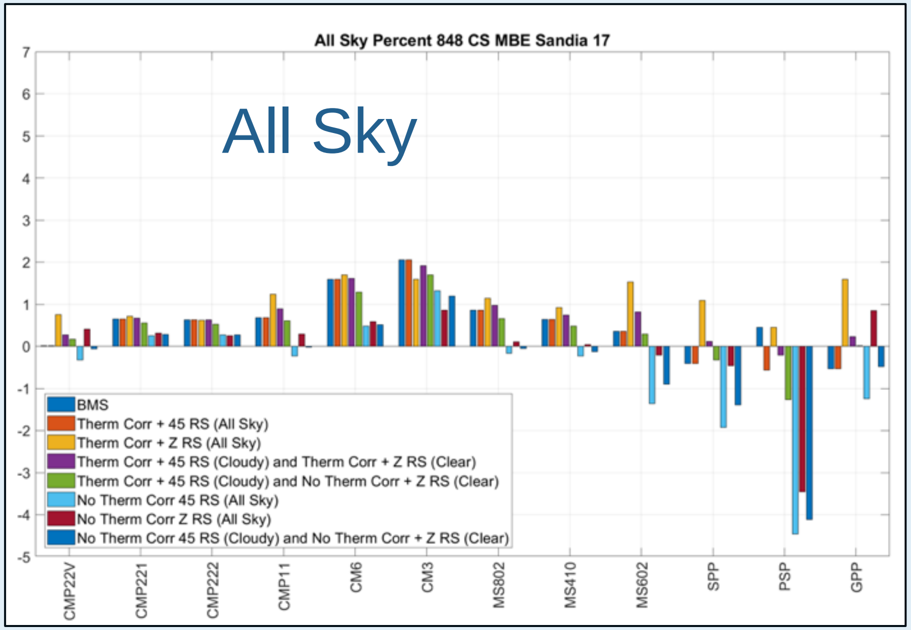
Has been developed by DLR using several years of data.

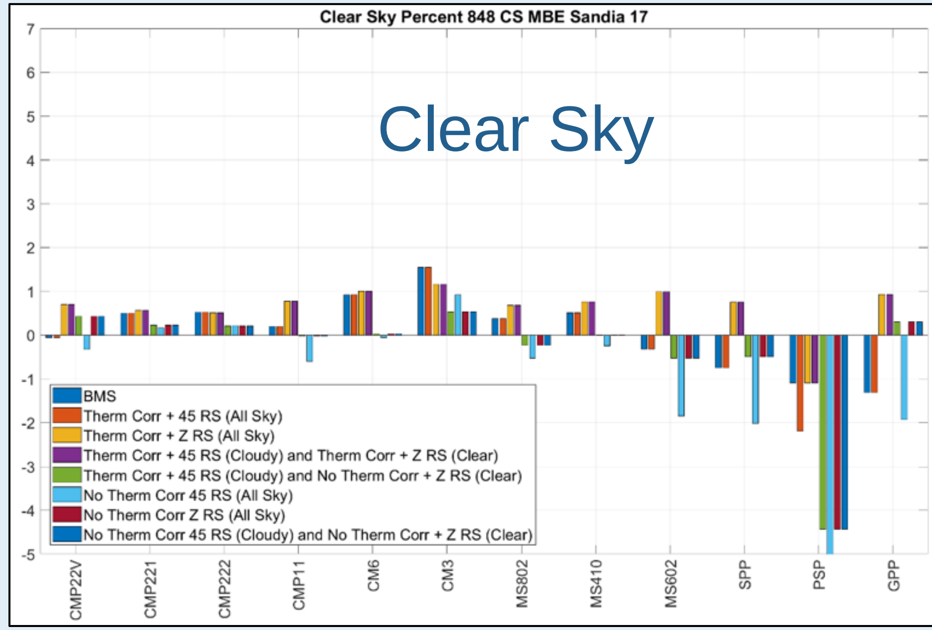
- Test of further parameterizations for turbulent regime.
- Include particle properties.
- Test for typical cleaning intervals (1 to 2 weeks).
- Test with more measurement data.



1.1: Ground Based Measurements

Evaluation of radiometer biases using various calibration methods



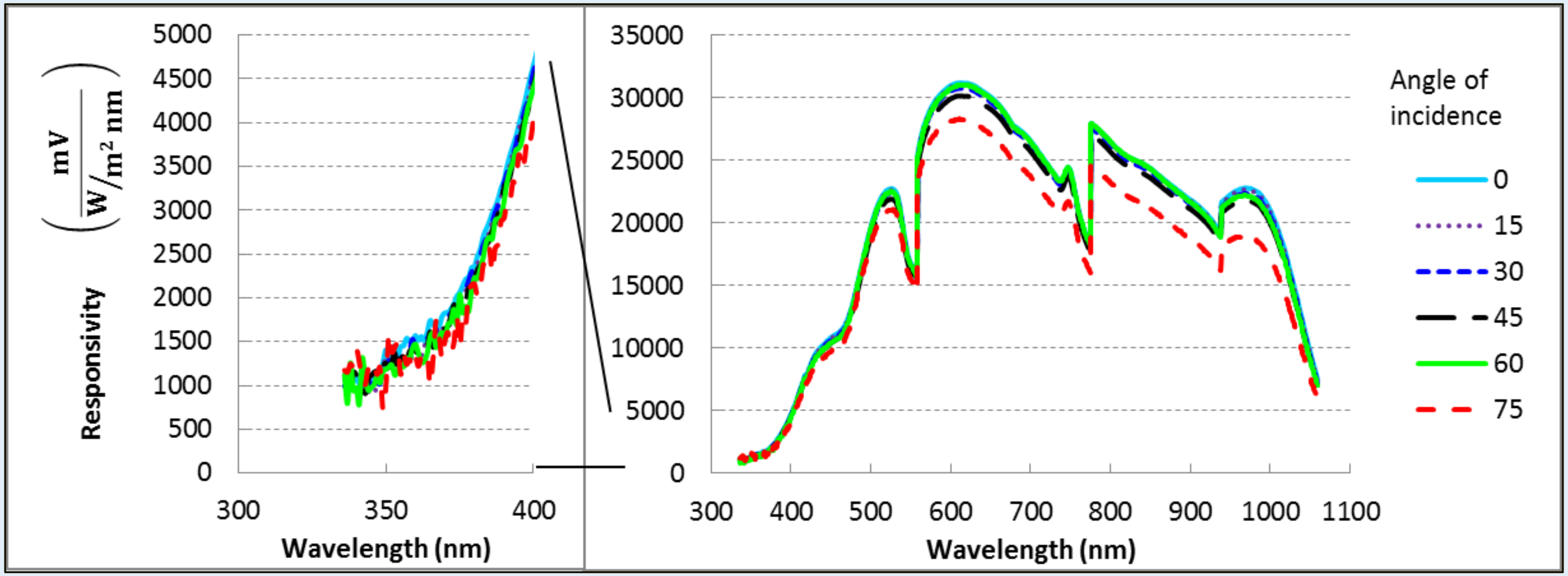


Newer radiometer designs have low cosine response and thermal offset and might not require correction.

1.1: Ground Based Measurements

Uncertainty in spectroradiometer calibration and measurement.

Methodology to determine the uncertainty of a spectroradiometer that is consistent with the Guide to the Expression of Uncertainty in Measurement (GUM) method.

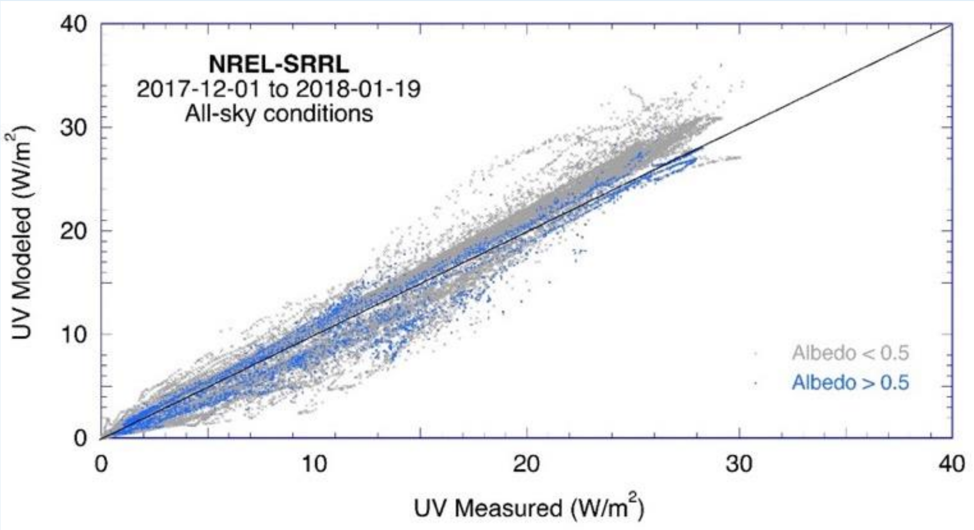


Responsivity compared to wavelength for various angles of incidence. The responsivity is nearly constant as the angle of incidence changes. Only when the angle of incidence is increased to 75º is there a noticeable change in the responsivity compared to the other angles. A detailed view of the wavelengths from 300–400 nm is shown in the left panel.

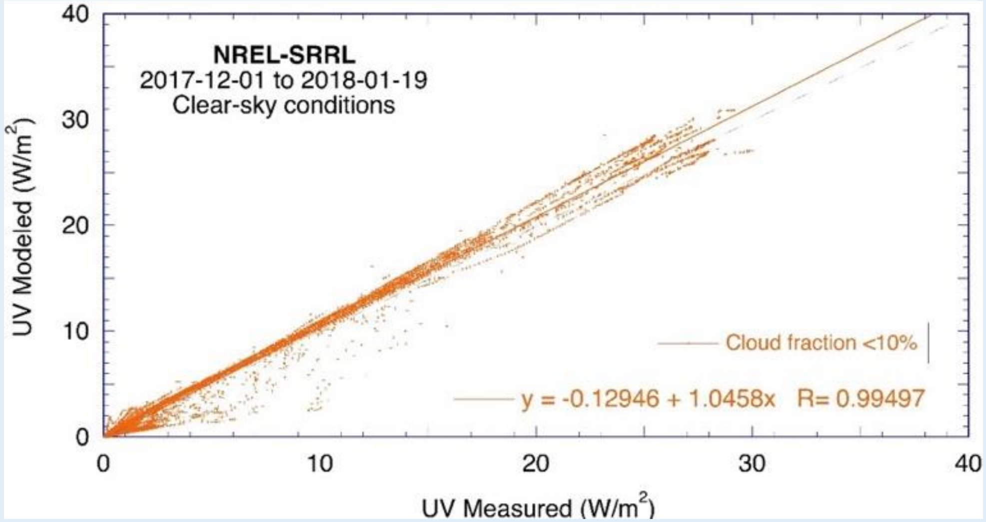
Josh Peterson, Frank Vignola, Aron Habte, Manajit Sengupta, (2017) Developing a spectroradiometer data uncertainty methodology, Solar Energy,Volume 149, Pages 60-76, https://doi.org/10.1016/j.solener.2017.03.075.

1.1: Ground Based Measurements

Modeling UV from broadband for PV reliability applications



Modeled vs. measured 1-min UV global irradiance under all sky conditions at SRRL for low and high surface albedo conditions.

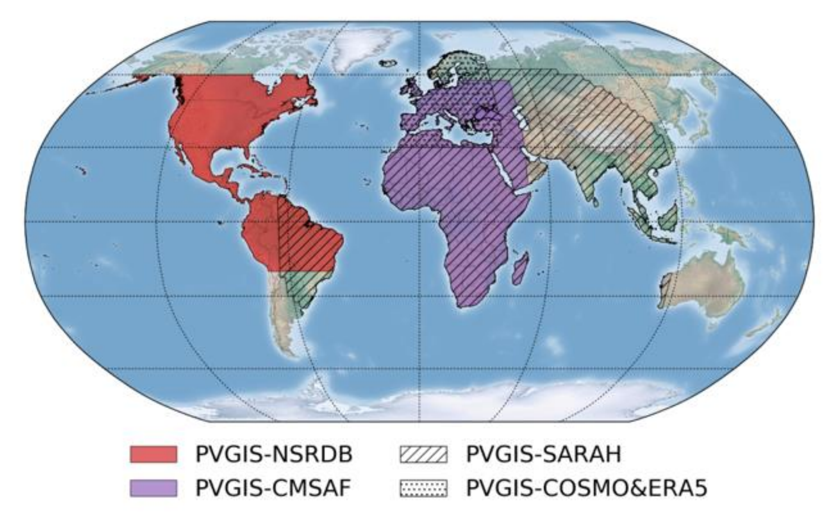


Modeled vs. measured 1-min UV global irradiance under clear-sky winter conditions at SRRL.

The correlation between the modeled and measured UV irradiance is highly significant (R^2 = 0.995), which provides confidence in the simple clear-sky model developed here.

1.2: Numerical Weather Models

Validation of different reanalysis products against ground measurements and satellite retrieved data



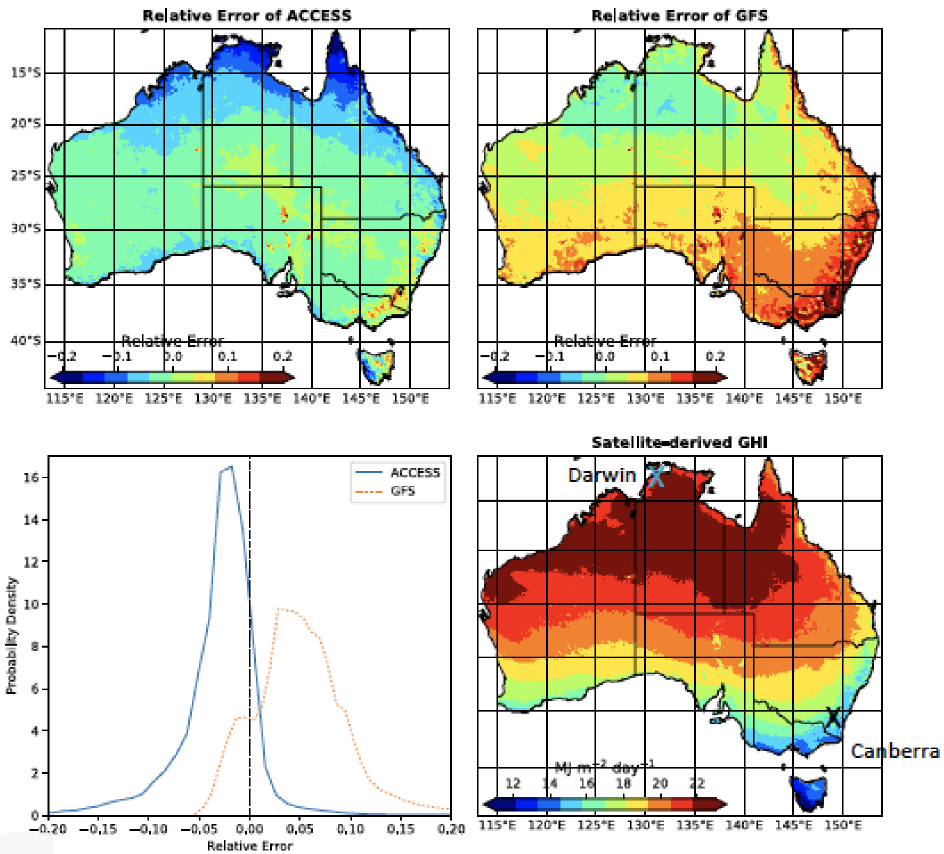
- ✓ **ERA-5 and COSMO have substantially improved** the quality of the solar radiation estimates of previous reanalyses.
- ✓ Yearly bias of **ERA-5 is similar to satellite** based products.
- ✓ Remaining limitations: **cloud prediction and spatial resolution** (ERA5).

- ✓ When available, **satellite data is preferable.**
- ✓ Solar radiation estimates from ERA-5 and COSMO are a valid option when satellite is not available and may be used to **fill gaps** of missing satellite data.

1.2: Numerical Weather Models

Validating GFS and ACCESS forecasts using satellites

Annual Average Map of GHI for 2017

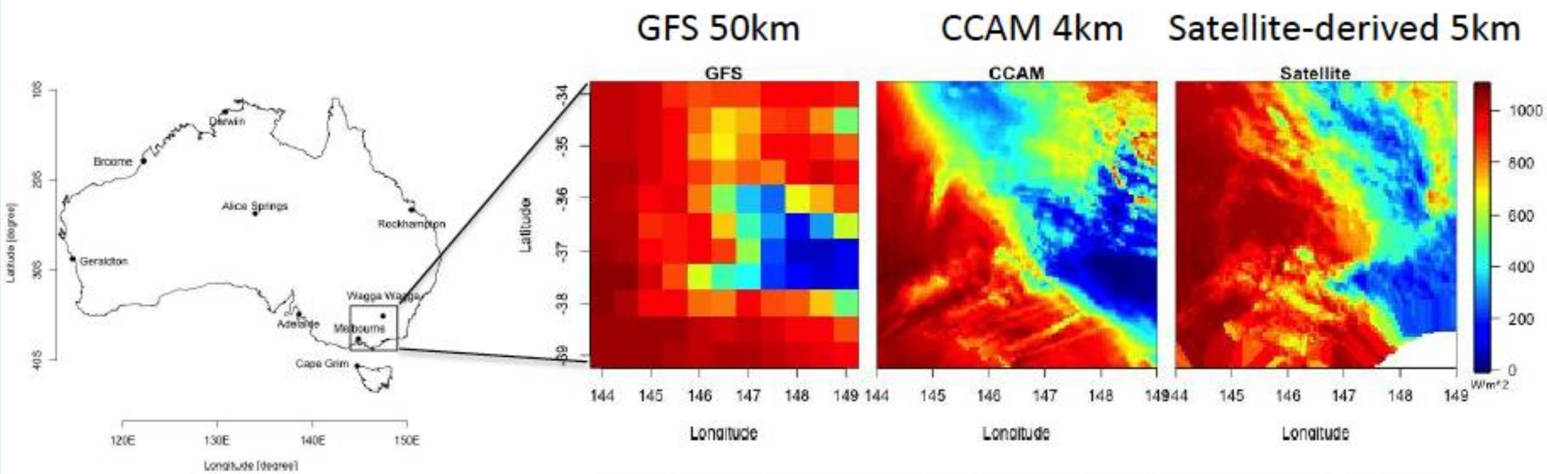


- Interpolating ACCESS and GFS results
- Relative error ≡ (Model - Satellite)/Satellite
- 1 MJ m^{-2} day^{-1} = 11.6 W m^{-2}
- Overall match of two models with satellite
- Error pattern is characterised by:
  - ACCESS – underestimation in northern Australia up to -0.2
  - GFS – overestimation in south-eastern Australia up to 0.2
  - GFS's PDF is more dispersed

1.2: Numerical Weather Models

Validating GFS and CCAM forecasts using satellites

Demonstration of simulated regional variability



GHI average for 10-13 in AEST on January 4, 2012

- GFS and CCAM match in large-scale patterns.
- CCAM simulates small-scale variability which does not exist in GFS.
- However, for specific locations, CCAM may not necessarily match satellite better than GFS.

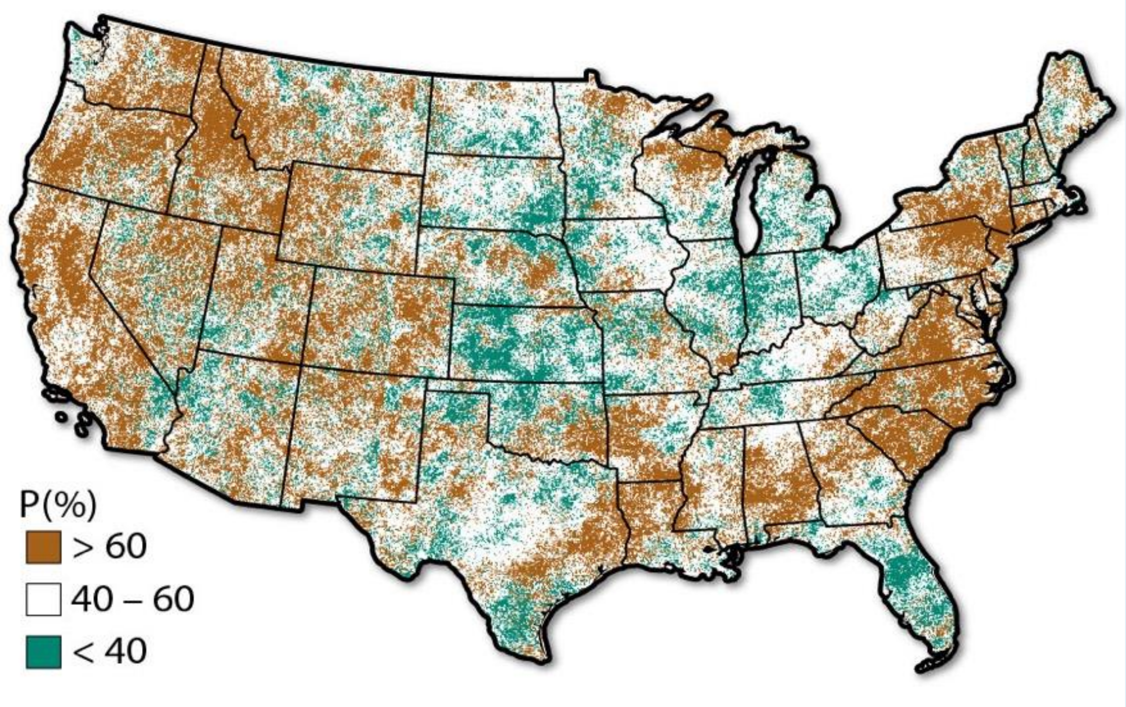
1.3: Satellite Based Methods

Probability of Exceedance using TMY

Calculation of PV generation using TMY after converting to single-axis tracking solar resource using Perez transposition model.

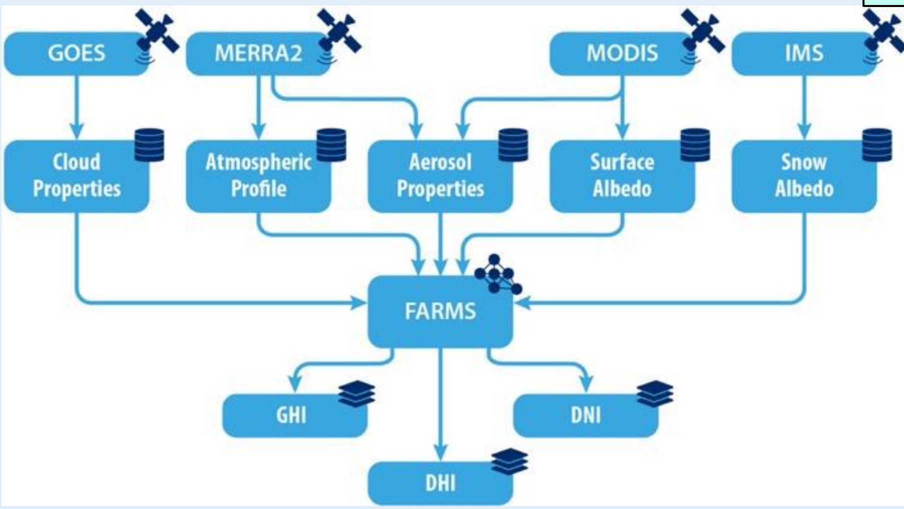
TMY represents median for horizontal but does not represent the median for other orientation.

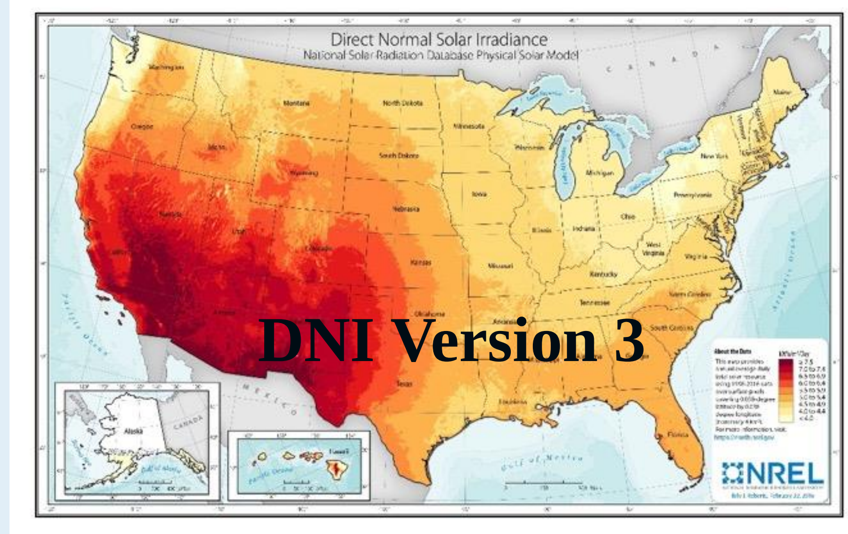
Points to the need for tilt-specific TMY

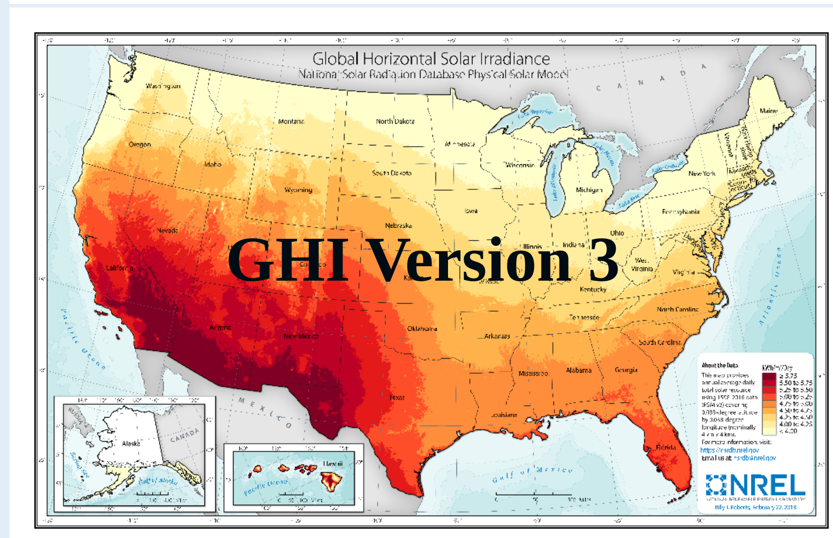


1.3: Satellite Based Methods

NSRDB update using PSM v3 – 1998-2016

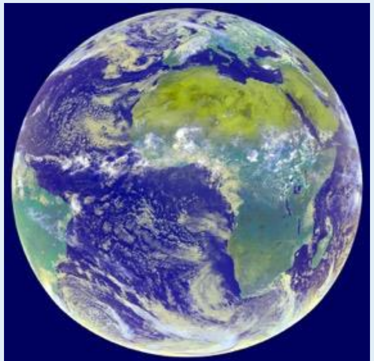


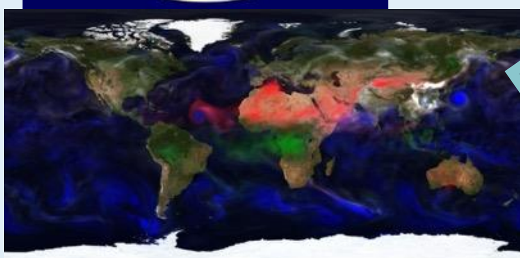


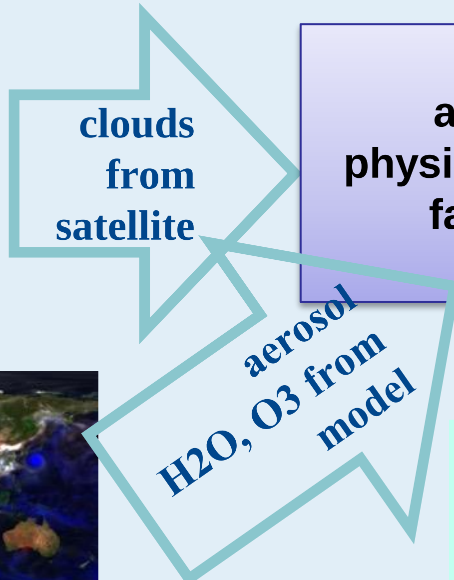


- Hourly aerosol optical depth (1998-2016) from Modern-Era Retrospective analysis for Research and Applications Version 2 (MERRA2).
- Snow-free Surface Albedo from MODIS (2001-2015) (MCD43GF CMG Gap-Filled Snow-Free Products from University of Massachusetts, Boston).
- Snow cover from Integrated Multi-Sensor Snow and Ice Mapping System (IMS) daily snow cover product (National Snow and Ice Data Center).
- GOES-East time-shift applied to cloud properties instead of solar radiation.
- Ancillary data (pressure, humidity, wind speed etc.) from MERRA2.

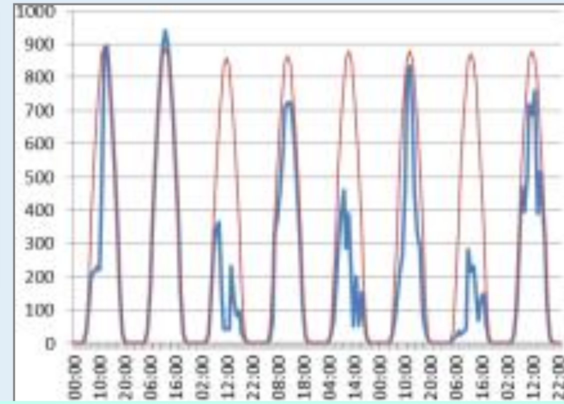
1.3: Satellite Based Methods







Heliosat-4 and McClear physical approaches, fast radiative transfer



CAMS solar radiation service

Marion Schroedter-Homscheidt (DLR)Armines (L. Wald, M. Lefèvre, B. Gschwind), Transvalor (E. Wey, L. Saboret) and FMI (A. Arola, W. Wandji) contributions within CAMS-72

News:

- new User Guide released
- quarterly validation reports now for hourly data
- removing several inconsistencies in McClear
- new scheme on how to use CAMS aerosol
- bias correction in implementation
- circumsolar ratio product under development
- APOLLO_NG (the probabilistic scheme) in scientific evaluation

1.3: Satellite Based Methods

Workshop on uncertainty from satellite and re-analysis products

- First "round table" of discussions of new protocols, criteria, analysis for a better understanding and modeling of the uncertainty of solar datasets from satellite & re-analysis products
- Discussion of uncertainty in ground measurements that are used as ground-truth. Proposed workshop at 3rd Experts meeting.
- Introduction of Committee of Earth Observation Satellites and work to define protocols and validation levels.
- Update to Mesor report on benchmarking of solar resource products.

1.4: Benchmarking

New evaluation criteria proposed for benchmarking of satellite and reanalysis products of Solar Irradiance.
Evaluate accuracy of temporal variability using Empirical Model Decomposition.

Correlations between model IMFs with WRDC

Lower representation capability of reanalysis products for the finest temporal variability

High correlation for (IMF: Intrinsic Mode Decomposition) IMF-7 corresponding to the yearly variability having the highest amplitudes (=> large global correlation)