

Ground Albedo Measurements and Modeling

Bill Marion

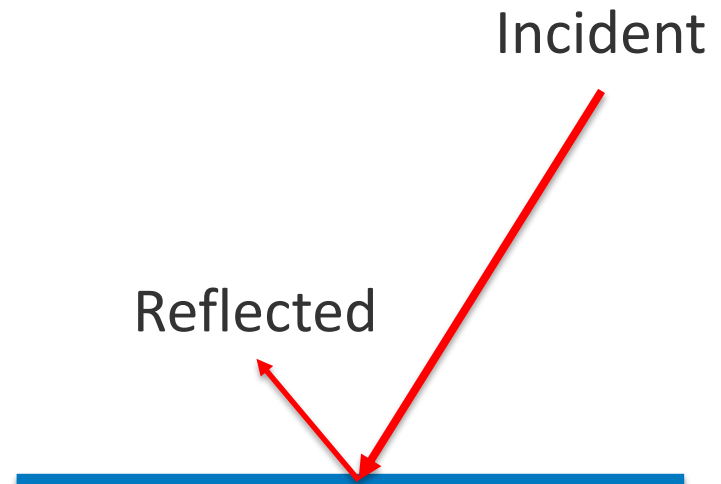
2018 Bifacial PV Workshop

September 11, 2018

Albedo

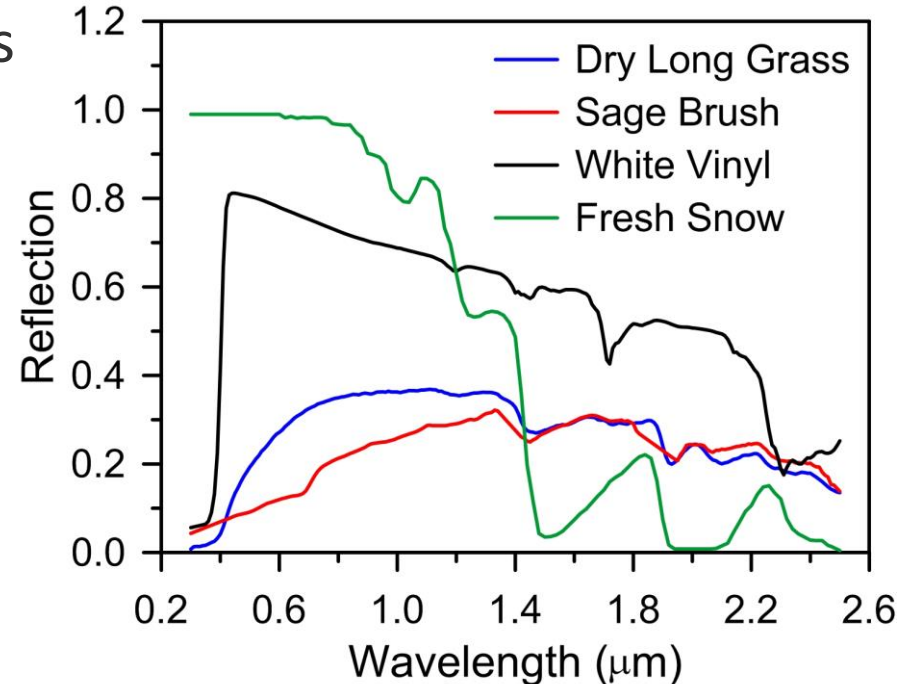
- Albedo of a surface is the fraction of the incident sunlight that the surface reflects
- Not a constant for a surface
- Varies with spectral and angular distribution of light
 - Cloudy versus sunny
 - Sun position (time of day, season, latitude)

$$\text{Albedo} = \text{Reflected} \div \text{Incident}$$



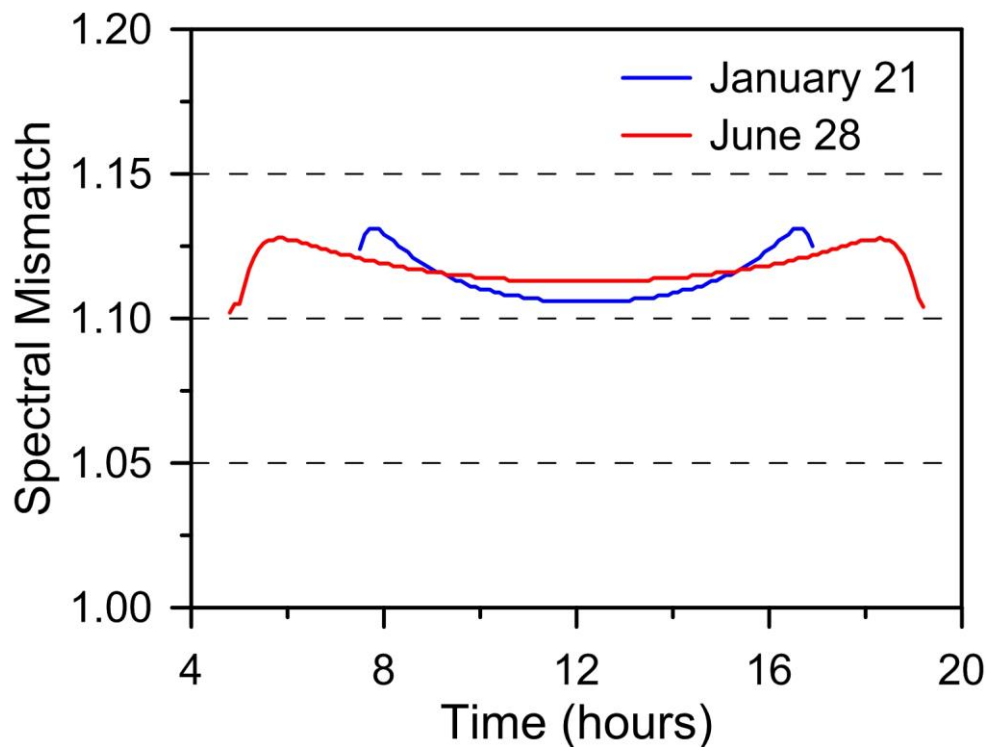
Spectral Reflectance

- Spectral reflectance is a surface property
- Can use with spectral irradiance data (SMARTS modeled) to calculate ground-reflected radiation and albedo
- Data sources
 - USGS, <https://pubs.er.usgs.gov/publication/ds1035>
 - SMARTS has ~ 130 files



Ground Reflected Spectral Mismatch

- SMARTS modeled ground-reflected spectral irradiance
- Dry Long Grass spectral reflectance data
- For x-Si cells, clear skies



Albedo Data Sources

- Averages from studies (climate and latitude sensitive)

Item	Values
Grass	0.15 – 0.26
Black earth	0.08 – 0.13
White sand, New Mexico	0.60
Snow	0.55 – 0.98
Asphalt pavement	0.09 – 0.18
Concrete pavement	0.20 – 0.40

- Satellite-Derived
 - Albedo is an essential parameter for determining the earth's energy balance and climate change
- Measurements – SURFRAD, AmeriFlux, BSRN networks

Satellite-Derived Method

- Ground reflection measured from a changing satellite viewpoint over several days
- Multi-angle data for clear skies used to determine the Bidirectional Reflectance Distribution Function (BRDF)
 - BRDF describes mathematically the changes in reflectance observed when an illuminated surface is viewed from different angles.



Sun behind observer.



Sun opposite observer.

Moderate Resolution Imaging Spectroradiometer (MODIS) Data

- A primary source of albedo products, sensors onboard Terra and Aqua satellites beginning in 2001
- MODIS product MCD43GF - Cloud and snow-free, gap-filled
 - World-wide coverage with 30 arc-second (~ 500 m) spatial resolution, 8-day temporal resolution.
 - 7 bands ($0.47\ \mu\text{m}$, $0.55\ \mu\text{m}$, $0.67\ \mu\text{m}$, $0.86\ \mu\text{m}$, $1.24\ \mu\text{m}$, $1.64\ \mu\text{m}$, and $2.1\ \mu\text{m}$)
 - 3 broadbands (shortwave 0.3 to $5.0\ \mu\text{m}$; visible 0.3 to $0.7\ \mu\text{m}$; and near-infrared 0.7 to $5.0\ \mu\text{m}$)
 - BRDF parameters, and albedos determined from the BRDFs

MODIS Albedos

- White-sky - Albedo in the absence of a direct component when the diffuse component is isotropic (cloudy skies).
- Black-sky - Albedo in the absence of a diffuse component and which is a function of solar zenith angle (at solar noon for MODIS product)

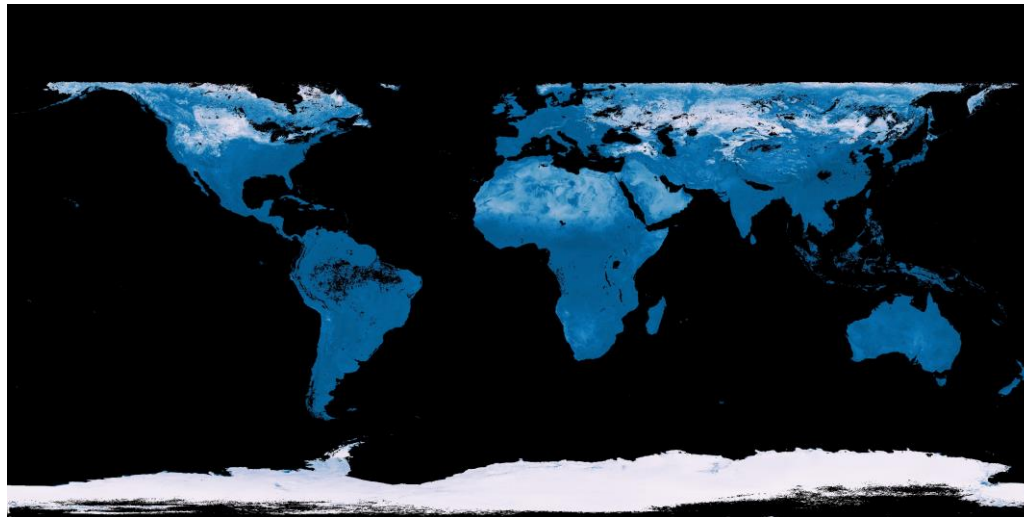
Note: Actual or blue-sky albedo may be estimated by weighting white-sky and black-sky albedos by their respective proportions of diffuse and direct radiation.

Available MODIS Derived Albedo Products

NASA Earth Observations

https://neo.sci.gsfc.nasa.gov/view.php?datasetId=MCD43C3_M_BSA

- 8-day and monthly values with spatial resolution from 0.1 to 1.0 degree
- Black-sky albedo at local solar noon
- Persistent cloudiness may result in “no data”



December, 2016

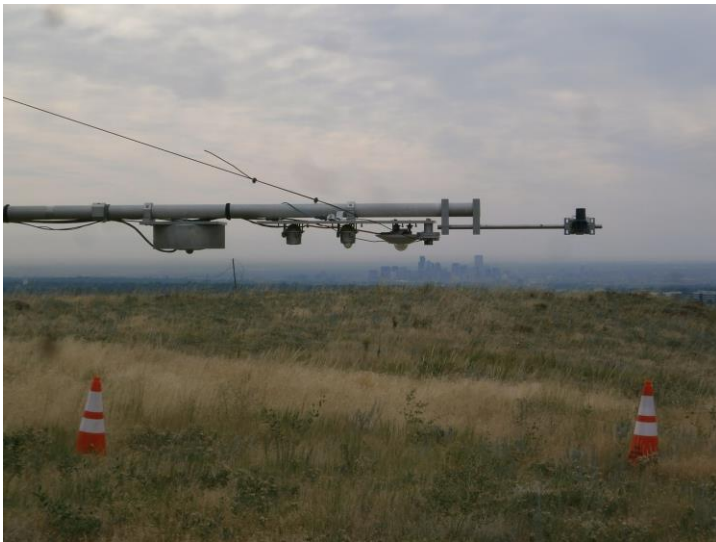
Available MODIS Derived Albedo Products

NREL's National Solar Radiation Data Base (NSRDB)

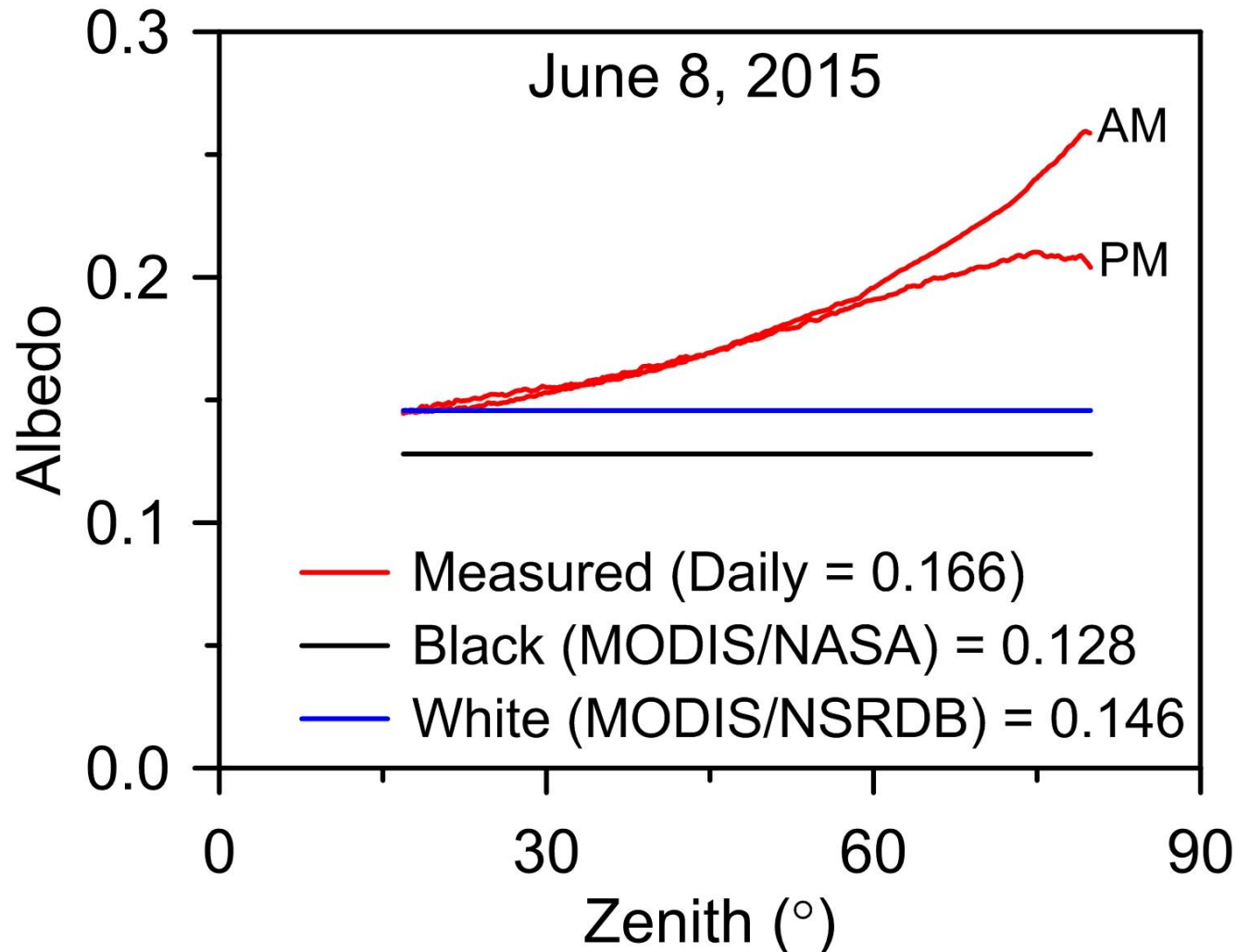
- MCD43GF plus missing snow days filled using a snow-day product from NOAA
- White-sky albedo data in shortwave band (0.3-5.0 μm) reprocessed to match NSRDB 4-km grid.
- When snow cover present, albedo set to 0.8669
- Daily albedo values (for changing snow cover)
- Reference: <https://www.nrel.gov/docs/fy17osti/67306.pdf>

Albedo Measurement

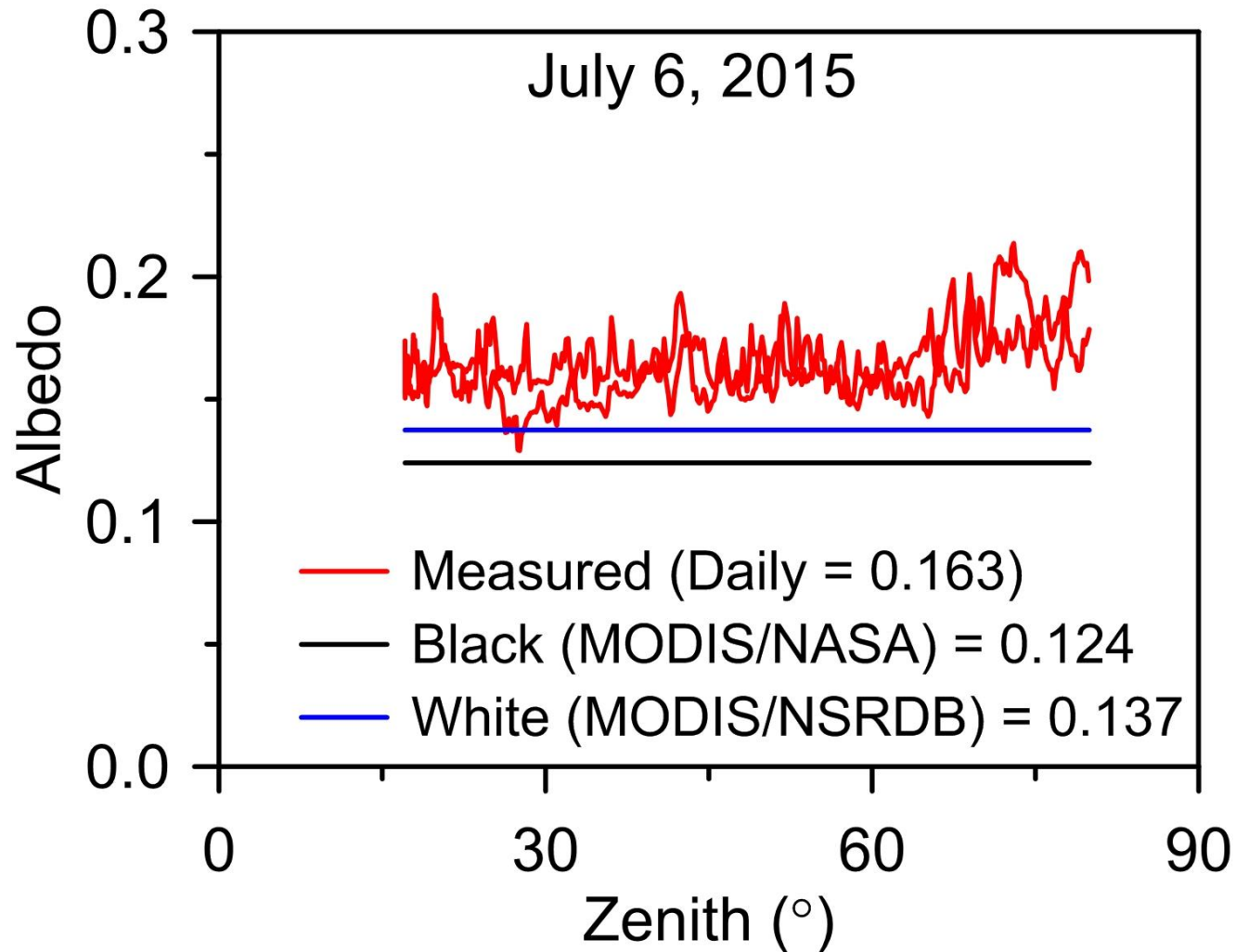
- Two pyranometers mounted horizontally, with one inverted to measure the ground-reflected radiation
- Mounting height is 1-2 meters for smooth surfaces
- Increased height for snow conditions, unchecked vegetation, and croplands.
- Height for SURFRAD sites is 9 meters.



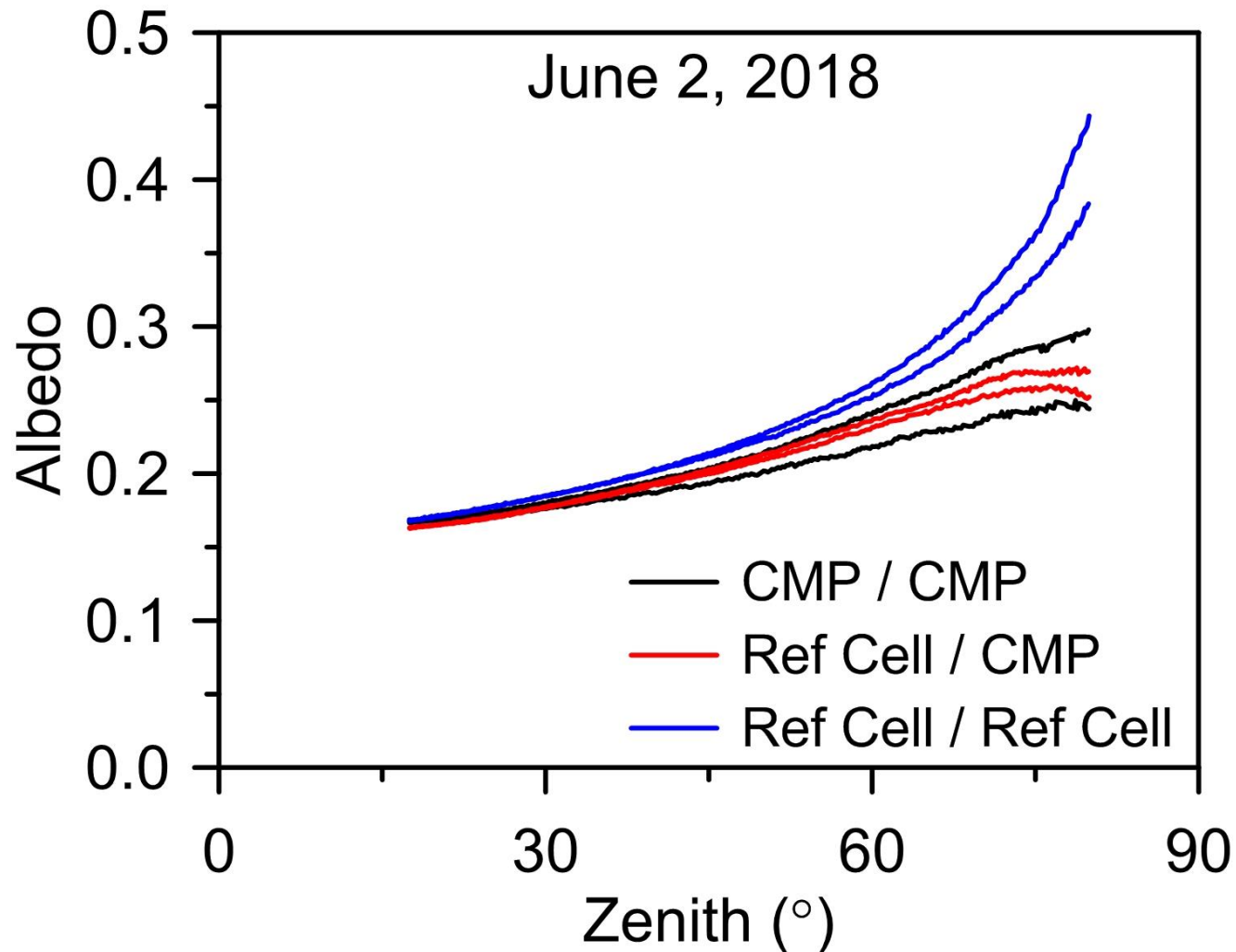
Sunny Day Albedo – Measured, Black, White



Cloudy Day Albedo – Measured, Black, White

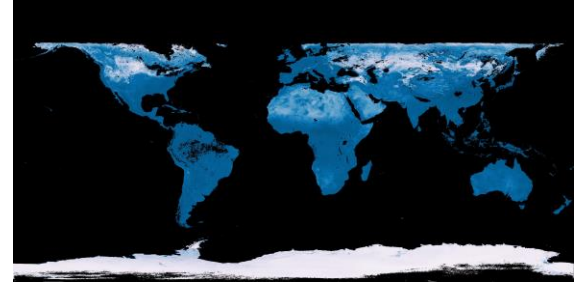


Sunny Day Albedo – Using Reference Cells



Albedo Data Uncertainty

- MODIS albedo: ± 0.02 absolute (but will need to adjust from black- and white-sky to blue-sky)
- Site measured: ± 0.02 absolute (difficulties due to spatial uniformity of surface, instrument spectral and angular response, calibrations, installation, shading of surface by instruments and support structure)



Albedo and Bifacial Modeling

- Current practice
 - Isotropic reflection
 - Monthly or daily albedo
 - No spectral considerations
- Potential improvements
 - Anisotropic reflection (with BRDF or other method)
 - Hourly albedos
 - Spectral correction of the reflected radiation
 - Accommodate installations on sloped surfaces (for correct shadow projections and calculations of reflected radiation from non-horizontal surfaces)

Thank You

www.nrel.gov

Publication Number

This work was authored by Alliance for Sustainable Energy, LLC, the manager and operator of the National Renewable Energy Laboratory for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308. Funding provided by the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy (EERE) under the Solar Energy Technologies Office (SETO) Agreement Number 30295. The views expressed in the article do not necessarily represent the views of the DOE or the U.S. Government. The U.S. Government retains and the publisher, by accepting the article for publication, acknowledges that the U.S. Government retains a nonexclusive, paid-up, irrevocable, worldwide license to publish or reproduce the published form of this work, or allow others to do so, for U.S. Government purposes.

