

Ground Albedo Measurements and Modeling

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2018 Bifacial PV Workshop

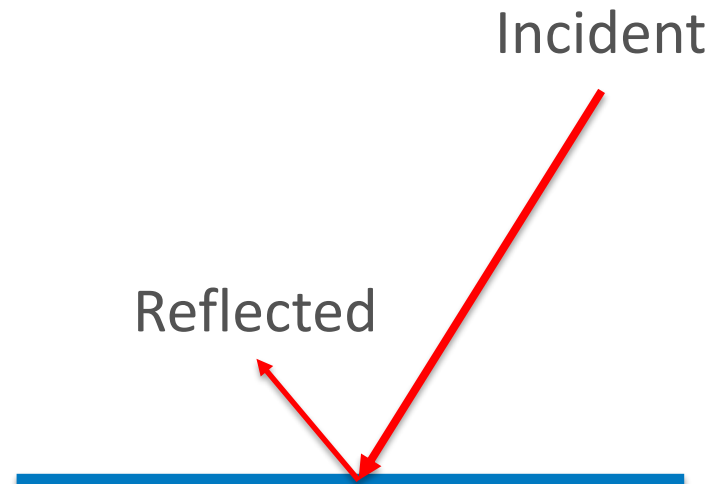
Lakewood, Colorado

September 11, 2018

Albedo

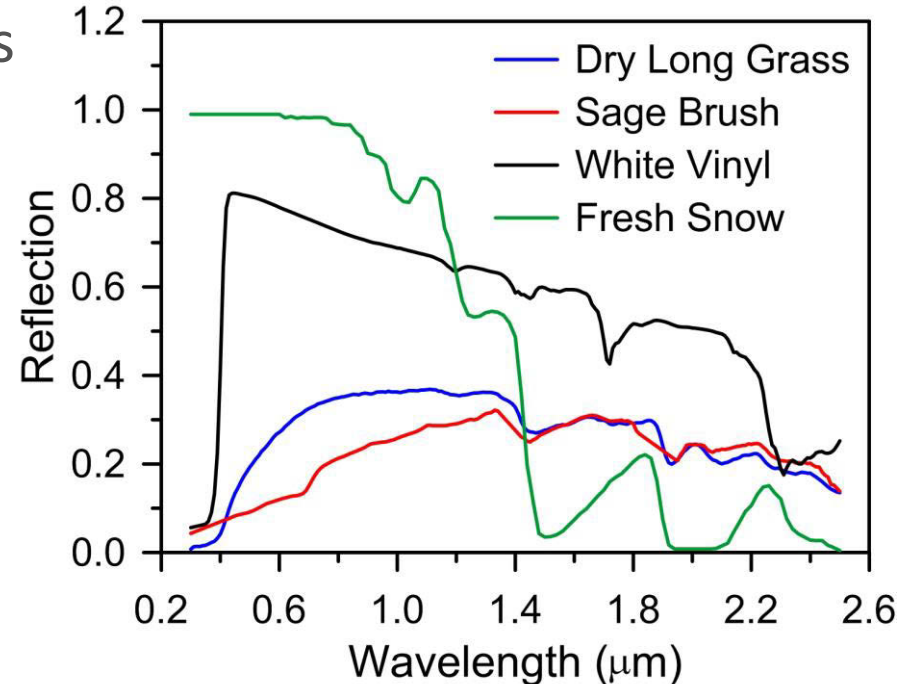
- Albedo of a surface is the fraction of the incident sunlight that the surface reflects
- Not a constant for a surface
- Varies with spectral and angular distribution of light
 - Cloudy versus sunny
 - Sun position (time of day, season, latitude)

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



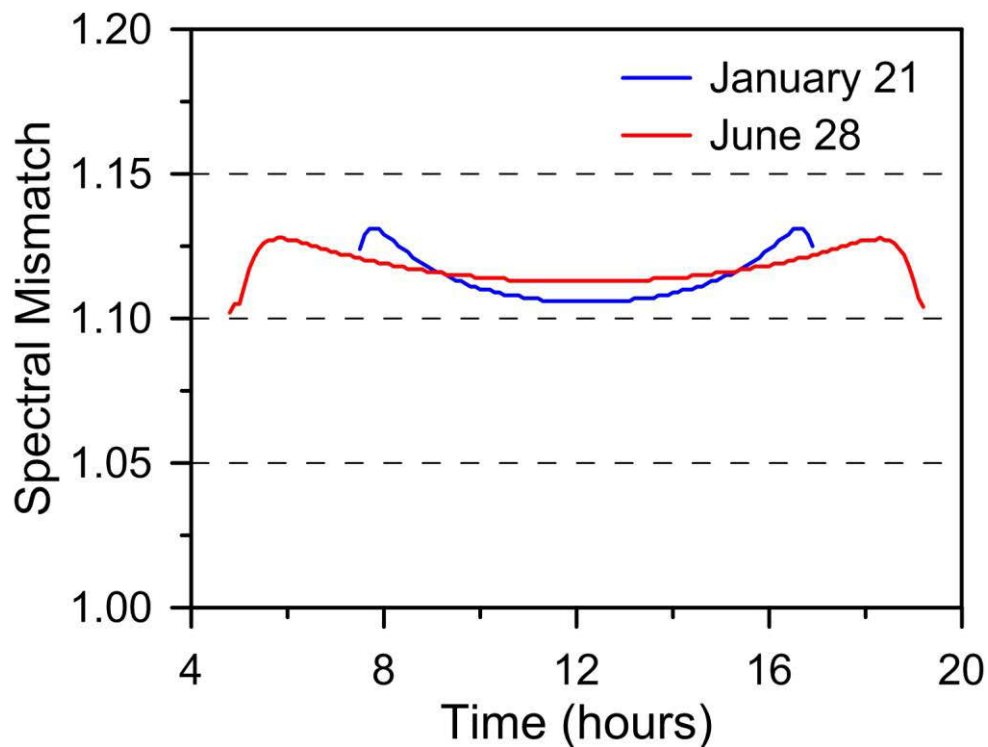
Spectral Reflectance

- 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)

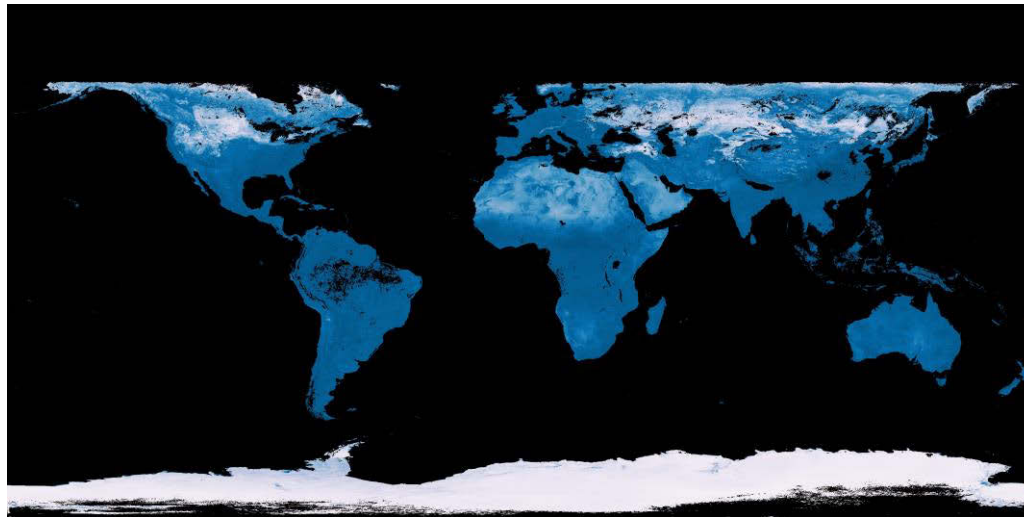
Note: Actual or blue-sky albedo may be estimated by weighting white-sky and black-sky albedos by their respective proportions of diffuse and direct radiation.

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

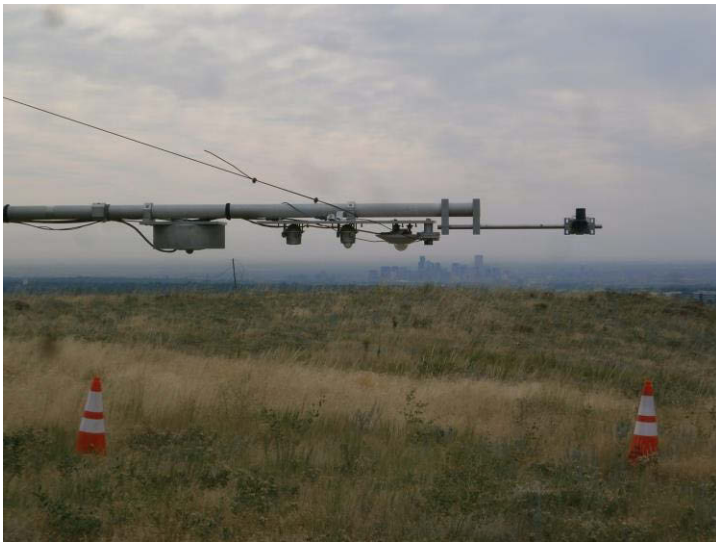
Available MODIS Derived Albedo Products

NREL's National Solar Radiation Data Base (NSRDB)

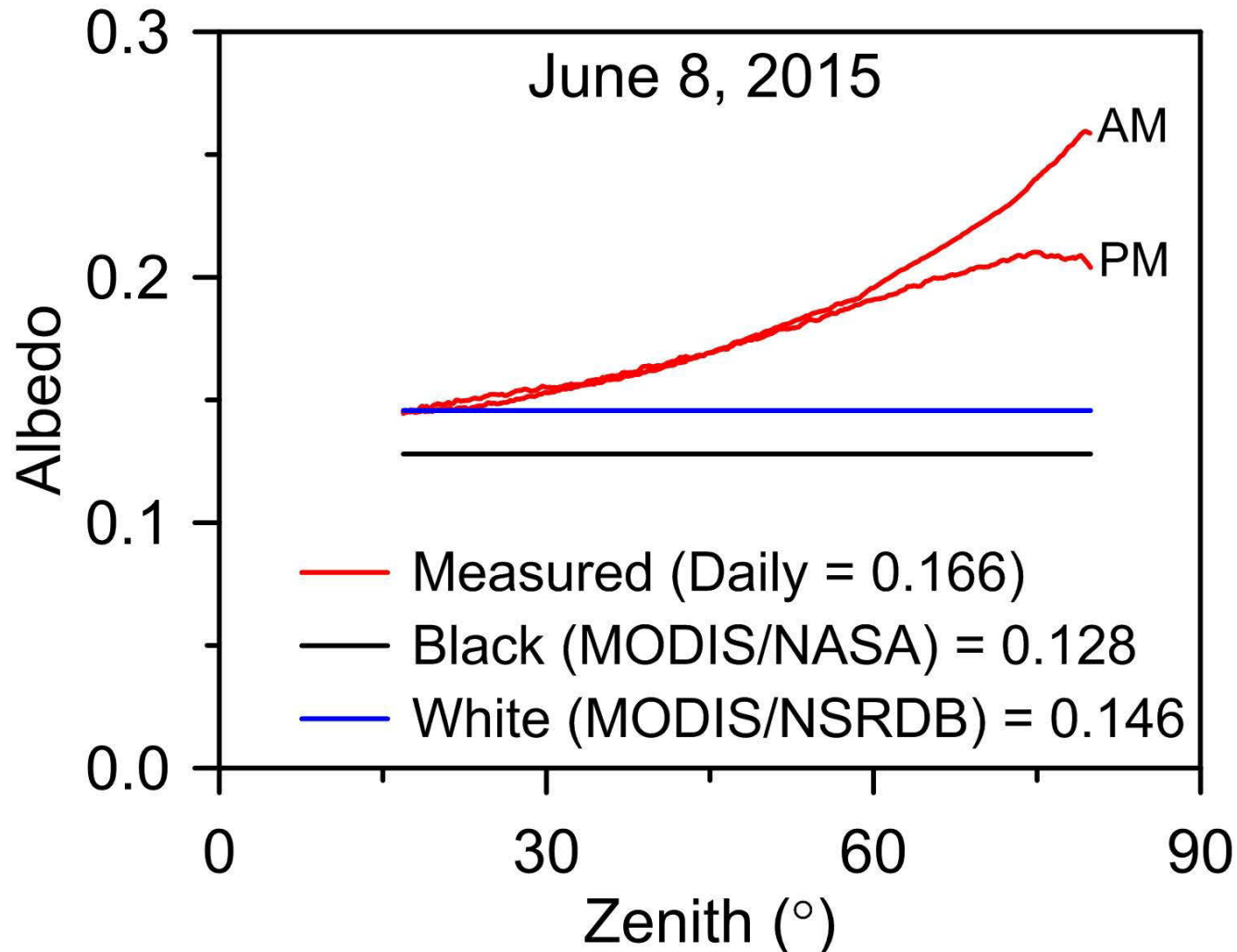
- MCD43GF plus missing snow days filled using a snow-day product from NOAA
- White-sky albedo data in shortwave band (0.3-5.0 μm) reprocessed to match NSRDB 4-km grid.
- When snow cover present, albedo set to 0.8669
- Daily albedo values (for changing snow cover)
- Reference: <https://www.nrel.gov/docs/fy17osti/67306.pdf>

Albedo Measurement

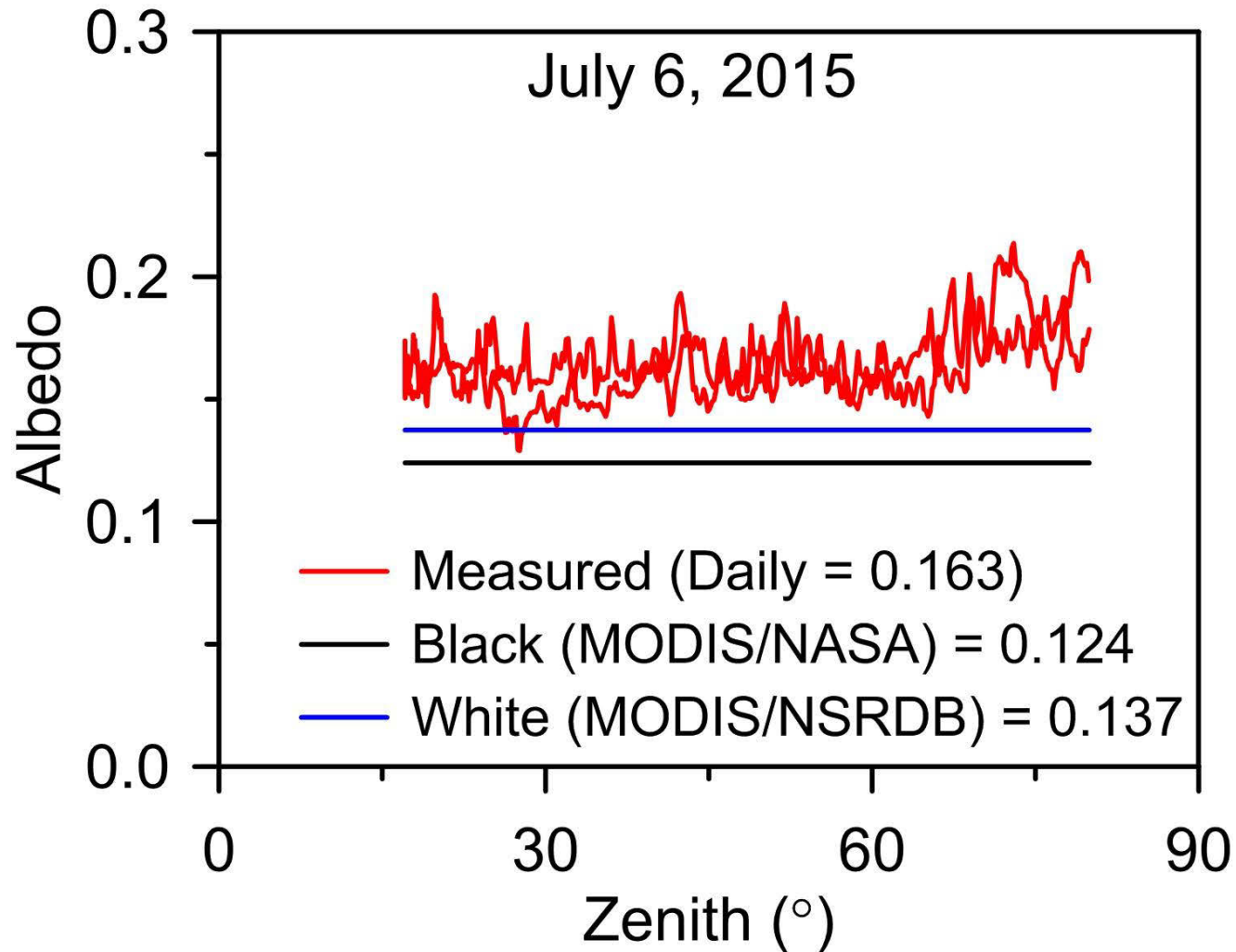
- Two pyranometers mounted horizontally, with one inverted to measure the ground-reflected radiation
- Mounting height is 1-2 meters for smooth surfaces
- Increased height for snow conditions, unchecked vegetation, and croplands.
- Height for SURFRAD sites is 9 meters.



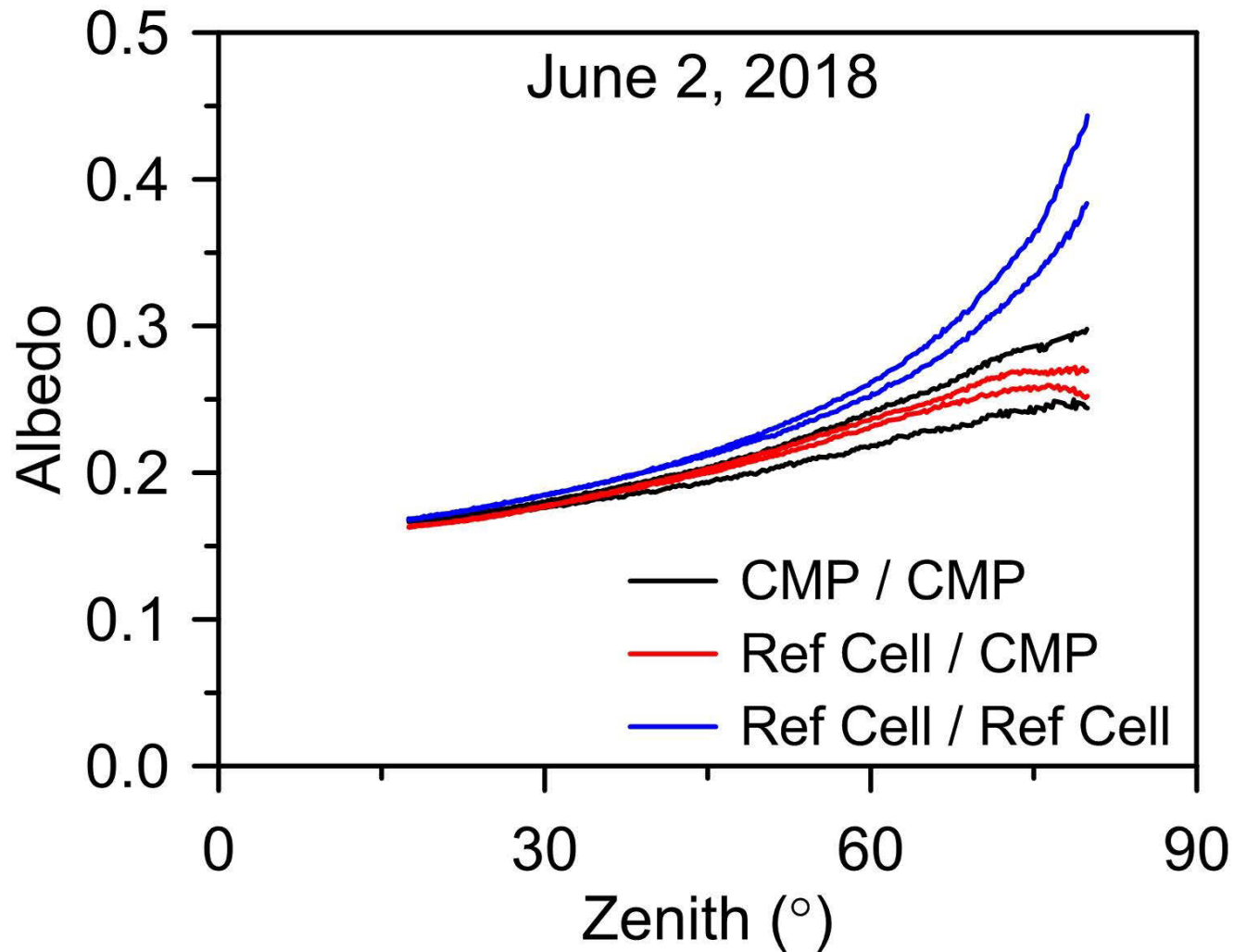
Sunny Day Albedo – Measured, Black, White



Cloudy Day Albedo – Measured, Black, White

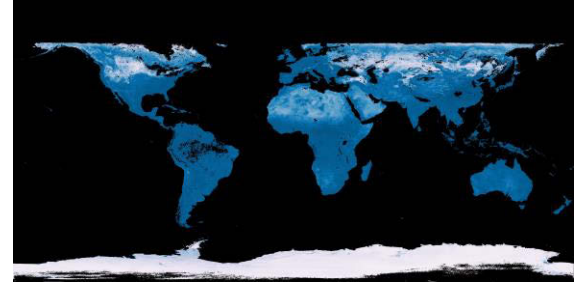


Sunny Day Albedo – Using Reference Cells



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

NREL/PR-5K00-72589

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