High resolution global albedo data and implications on simulation of monofacial PV

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About Solargis

Solar resource, meteorological and photovoltaic simulation data, software and expert services for power industry

- Prospection
- Project development
- Monitoring
- Forecasting

700+ customers in 90+ countries
18+ year experience in solar energy
PV power depends on environment

Solar Radiation

- Temperature
- Wind
- Pollution
- Snow
- Rainfall
- Dust
- Humidity
- Terrain
- Fog
- Icing
- Albedo
- Rainfall
- Fog
Topics

- Albedo: definition and relevance for PV
- Measuring and modelling albedo
- Solargis albedo database
- Effect of albedo in monofacial PV simulation
Albedo: definition and relevance to PV
What is albedo

Surface albedo:
- Fraction of solar irradiance reflected by surface
- Ratio of upwelling ($I_u$) to downwelling ($I_d$) radiative fluxes at the surface

Simple definition, but complex to determine:
- It is a coupled surface-atmosphere system
- It varies on a seasonal, daily or hourly basis (e.g. surface wet after rain)

Albedo is the directional integration of reflectance from a horizontal surface over all solar angles in a given period

$$\alpha = \frac{I_u}{I_d}$$
Calculating albedo

**Downwelling flux:** \( I_d = \text{direct} + \text{diffuse} \)

Albedo is defined as:
- Directional-hemispherical reflectance (black-sky albedo, \textit{BSA}), i.e. reflectance under direct illumination
- Bi-hemispherical reflectance (white-sky albedo, \textit{WSA}), i.e. reflectance under diffuse illumination

\( I_u \) is the \textit{upwelling irradiance}, i.e. irradiance reflected by the horizontal surface in all directions in a period of time

**General approach:**
\[
I_u = BSA \times DNI \times \cos(\theta) + WSA \times DIF
\]
Calculating albedo

For solar applications, **practical approach** based on white-sky albedo (WSA) is used for calculation of reflected irradiance $I_u$:

$$I_u \sim WSA \times GHI$$

Lambertian surface is assumed (isotropic albedo, WSA)
Relevance of albedo

Global irradiance on a tilted surface (GTI) of PV modules:

\[ GTI = \text{direct} + \text{diffuse} + \text{reflected} \]

Reflected irradiance is part of \( I_v \) that is projected by surface of a PV module. It can include reflected irradiance from surrounding horizon or objects.

Impact of albedo on calculation of reflected irradiation monofacial PV (monthly sums):

<table>
<thead>
<tr>
<th>PV modules</th>
<th>Standard conditions</th>
<th>Desert conditions</th>
<th>Snow conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fixed-mounting, trackers, standard PV power plants</td>
<td>0.1% - 0.5%</td>
<td>0.3% - 1.5%</td>
<td>1.5% - 8%</td>
</tr>
</tbody>
</table>
Albedo in PV calculations

Albedo has been widely considered as a constant value in PV solar industry (often $\alpha = 0.2$); in Solargis $\alpha = 0.12$ was used as a default value.

Difficult to obtain reliable long term values of albedo worldwide.

Secondary order of relevance in comparison to other parameters: GHI, DNI, TEMP.

Albedo varies considerably, even over relatively small areas.

<table>
<thead>
<tr>
<th>Surface type</th>
<th>Albedo (indicative values)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water</td>
<td>0.05 - 0.10</td>
</tr>
<tr>
<td>Forest</td>
<td>0.05 - 0.15</td>
</tr>
<tr>
<td>Grass</td>
<td>0.15 - 0.25</td>
</tr>
<tr>
<td>Sand</td>
<td>0.30 - 0.50</td>
</tr>
<tr>
<td>Snow</td>
<td>0.50 - 0.85</td>
</tr>
</tbody>
</table>
Albedo relevance for PV

Global tilted irradiance received by surface of a PV module (fix-mounted at 25°):

- Constant value (used by default when real albedo is not known): 0.20
- Correct value for Dubai: ~0.35

![Graphs showing the difference in global tilted irradiance (GTI) and reflected irradiance (REFLECTED) for different albedo values. The graphs illustrate that the difference in GTI is approximately 1%.](image)
Measuring and modelling albedo
Measuring and modelling albedo

**Local measurements**
- Very site specific (problem of representativeness)
- Recent time
- High resolution

**Data from satellites or numerical weather models**
- Large coverage
- Historical data
- Coarse resolution

![Huxeflux SRA20](image1)

![Kipp & Zonen CMP11](image2)

![Map of albedo](image3)
Measuring and modelling albedo

**Local measurements**
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- Recent time
- High resolution

Kipp & Zonen CMP11

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Huxeflux SRA20
Desirable characteristics of albedo dataset

- High spatial resolution
- Global coverage
- Long-term historical data, as close as possible to the present time
- No gaps (missing data)
- All kind of surfaces

Summary of the data sources with global coverage (non-exhaustive):

<table>
<thead>
<tr>
<th>Source</th>
<th>Agency</th>
<th>Max. spatial resol.</th>
<th>Max. temp. resol.</th>
<th>Period</th>
<th>Type</th>
<th>Observations</th>
</tr>
</thead>
<tbody>
<tr>
<td>MODIS (*)</td>
<td>NASA</td>
<td>500m</td>
<td>1 day</td>
<td>2001 - 2015</td>
<td>Satellite</td>
<td>Multiple products</td>
</tr>
<tr>
<td>CLARA-A2-SAL</td>
<td>EUMETSAT</td>
<td>0.25°</td>
<td>5 days</td>
<td>1982 - 2015</td>
<td>Satellite</td>
<td>BSA</td>
</tr>
<tr>
<td>(CMSAF)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ETAL (LSA SAF)</td>
<td>EUMETSAT</td>
<td>1km</td>
<td>10 days</td>
<td>2015 - present</td>
<td>Satellite</td>
<td>--</td>
</tr>
<tr>
<td>NSRDB</td>
<td>NREL</td>
<td>4km</td>
<td>1 day</td>
<td>2001 - 2014</td>
<td>Satellite</td>
<td>MODIS based</td>
</tr>
<tr>
<td>MPT</td>
<td>MINES Paris-Tech</td>
<td>5.6km</td>
<td>Monthly averages</td>
<td>2004 - 2011</td>
<td>Satellite</td>
<td>MODIS based</td>
</tr>
<tr>
<td>ERA-5</td>
<td>ECMWF</td>
<td>0.28125°</td>
<td>1h</td>
<td>2000 - present</td>
<td>NWP</td>
<td>--</td>
</tr>
<tr>
<td>MERRA2</td>
<td>NASA</td>
<td>0.5°x0.625°</td>
<td>1h</td>
<td>1980 - present</td>
<td>NWP</td>
<td>--</td>
</tr>
</tbody>
</table>

(*) This is an example of a specific MODIS product. Other MODIS products could have different parameters.
Surface albedo data sources

Numerical weather models

Advantages:
- Global coverage
- Long-term historical data
- No gaps
- All kind of surfaces

Disadvantages:
- Coarse spatial resolution, not enough to capture specific surface features considering a typical size of a PV power plant
Surface albedo data sources

Satellites

Advantages:
- Better spatial resolution (MODIS up to 500 m)
- Global coverage
- Long-term historical data
- All kind of surfaces

Disadvantages:
- Gaps (clouds, snow)

Example of missing data in the MODIS product MCD43C3 in Sechura Desert (Peru)
Surface albedo data sources

Effect of spatial resolution: example of Kumps (India)
Solargis albedo database
## Sources of surface albedo

**Numerical weather models and satellites**

**Conclusion:** none of them meet completely the required characteristics

--> therefore a compilation is needed

<table>
<thead>
<tr>
<th>Source</th>
<th>Comments</th>
</tr>
</thead>
</table>
| MODIS (NASA)                  | • MCD43GF gap-filled product. Ephemeral snow cover removed  
                                    • Other products: data gaps                                                                                           |
| CLARA-A2-SAL (CMSAF)          | • Coarse spatial resolution                                                                                                         |
| ETAL (LSA SAF)                | • Historical data period: 4 years                                                                                                   |
| NSRDB (Maclaurin et al. 2016) | • Snow cover based on IMS. Constant value of snow albedo: 0.8669. This could be valid for fresh snow in open land. It is too high for old snow, snow in forests, etc.  
                                    • No global coverage                                                                                                      |
| MPT (Blanc et al., 2010)      | • Monthly averages. Last year 2011                                                                                                 |
| ERA-5 (ECMWF)                 | • Coarse spatial resolution                                                                                                         |
| MERRA2 (NASA)                 | • Coarse spatial resolution                                                                                                         |
Solargis ground surface albedo database

- Albedo (snow-free) (gap-filled)
- MODIS MCD43G v5
  - Sun et al. (2017)

Innovative part

- Snow albedo (gap-filled)
  - MODIS albedo products
  - MODIS snow products
  - ERA5

1km

Solargis albedo
Solargis surface albedo database: Features

Database implemented in Solargis
- Parameter: WSA
- Geographical coverage: global
- Temporal resolution: 12 monthly + 1 annual data layers (long-term average)
- Time coverage: 10 years (2006 to 2015)
- Spatial resolution: 1 km
- No data gaps
Solargis ground surface albedo database: Validation

Validation
  • MODIS (MCD43) products are in validation stage 3
    • For 500 m albedo, accuracy < -5%
      (10% for low quality data)
    • Wang et al. (2012, 2014), Sun et al.
      (2017)
    • Inter-comparison with other sources
    • Internal evaluation against ground stations is in progress

Future steps
  • Incorporate new MCD43G when available
  • Extend time coverage by adding recent data
Solargis ground surface albedo database
Arabian peninsula
Natural processes and human activities can modify the surface albedo. Expert knowledge is needed when using albedo in solar modelling.

Example of drying process in Aral Sea region
Same day (15 July) for years 2007, 2011 and 2015
Ground surface albedo: Time changes

Change of land surface albedo due to forest clear-cut
Effect of albedo in monofacial PV simulation
Solargis ground surface albedo database

China

Difference between yearly GTI (optimum angle) calculated using new Solargis albedo vs. use of default value 0.12

Difference of yearly GTI:
Typically 0 to 2%
In extremes 8%
Seasonality of albedo in China

Difference between monthly GTI (optimum angle) calculated using new Solargis albedo compilation vs. default value of 0.12. Difference of monthly GTI: 0 to 8%
Seasonality of albedo

Highest variation in monthly albedo is in snow regions

(Maps shows standard deviation of monthly averages)

Monthly PV power production: Difference between calculation output based on high resolution monthly albedo vs. fixed albedo value of 0.12
Geographical variability of albedo

Percent difference in monthly PV power output when considering real high resolution albedo vs. default value of 0.12 (0.4 to 1.5%)
Conclusions

Harmonised and validated global albedo database ready to use in PV simulations
1-km spatial resolution, no spatial gaps
Long term average values (12 monthly + 1 yearly) representing 2006 to 2015
Available in Solargis Prospect app

Impact of albedo calculation on monofacial PV:
• Low (0.1 to 0.5%)
• Medium in deserts (0.3 to 1.5%)
• High in snow conditions (1.5 to 8%)

Impact on production of bifacial PV modules much larger
Thank you for attention!

Solargis
http://solargis.com

Albedo accessible from Solargis Prospect online application
Launch: Jan 2019