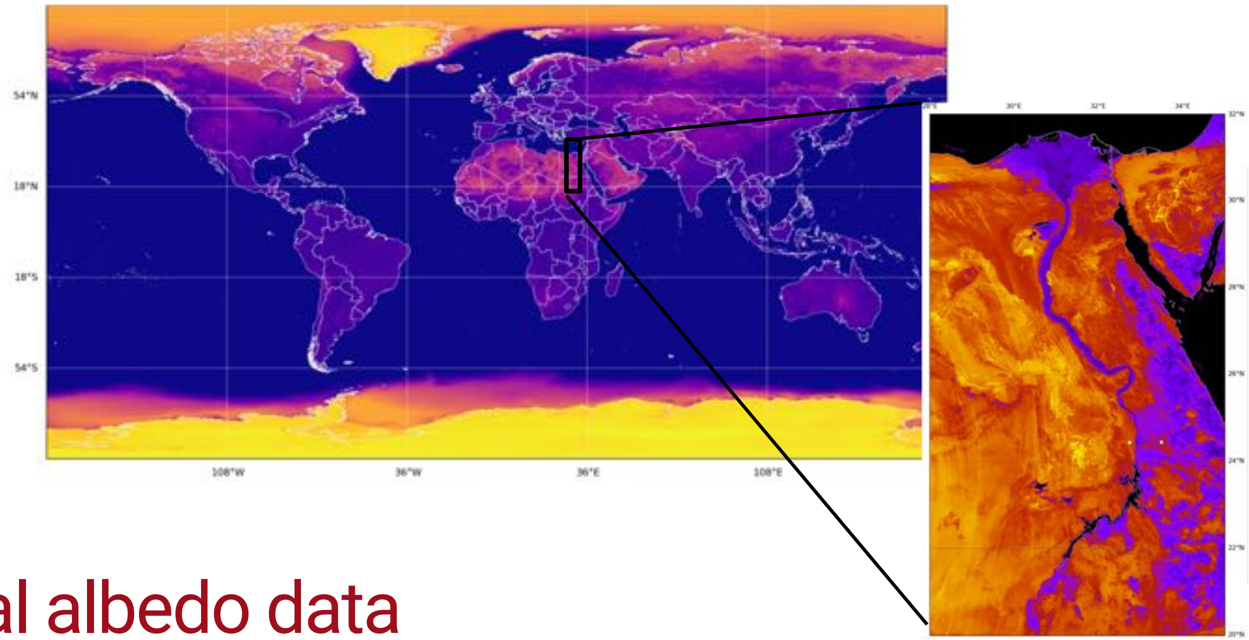

High resolution global albedo data and implications on simulation of monofacial PV

Vicente Lara-Fanego, Tomas Cebecauer, Artur Skoczek, Juraj Betak, Jose Antonio Ruiz Arias, Branislav Schnierer and Marcel Suri

Solargis, Slovakia

11th PV Performance Modeling and Monitoring Workshop, Weihai, China, December 2018

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About Solargis

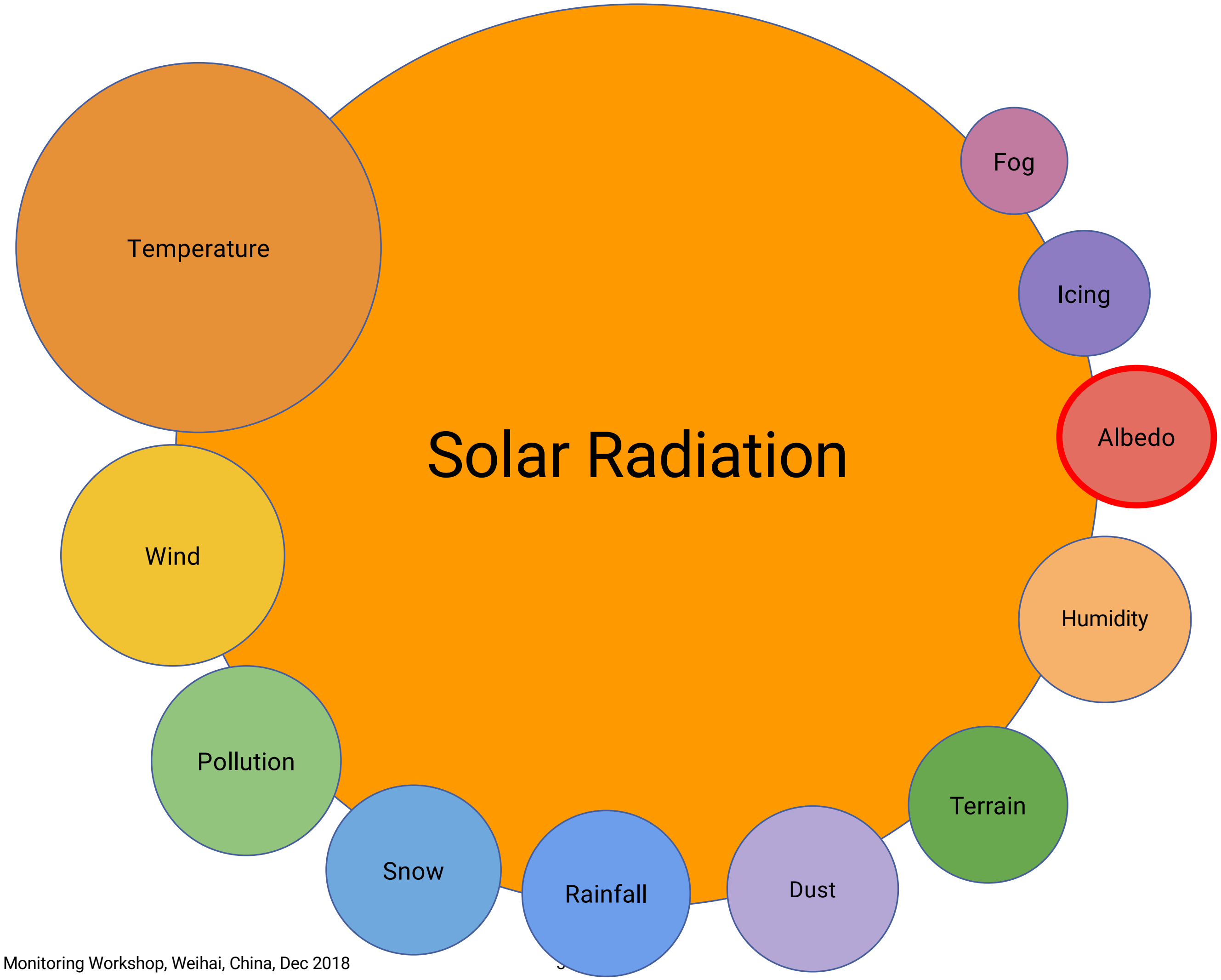
Solar resource, meteorological and photovoltaic simulation data, software and expert services for power industry

- Prospection
- Project development
- Monitoring
- Forecasting

700+ customers in 90+ countries

18+ year experience in solar energy

PV power depends on environment



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

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What is albedo

Surface albedo:

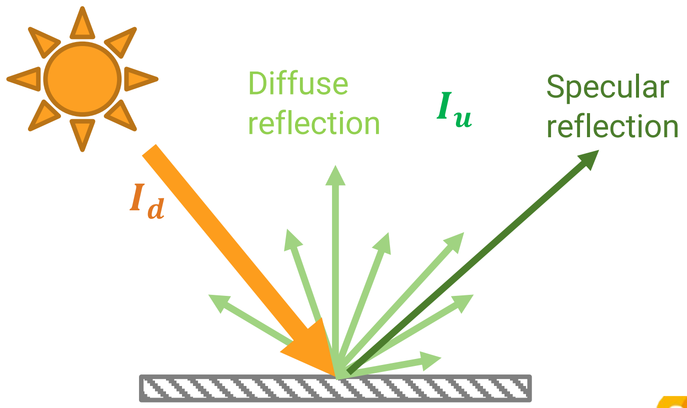
- Fraction of solar irradiance reflected by surface
- Ratio of upwelling (I_u) to downwelling (I_d) radiative fluxes at the surface

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

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



Calculating albedo

Downwelling flux: I_d = direct + diffuse

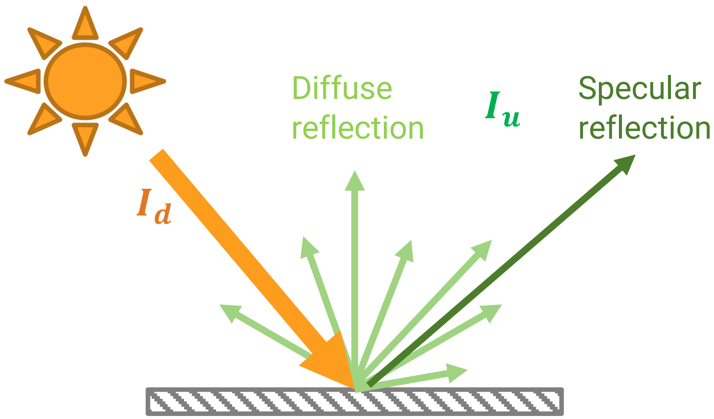
Albedo is defined as:

- Directional-hemispherical reflectance (black-sky albedo, **BSA**), i.e. reflectance under direct illumination
- Bi-hemispherical reflectance (white-sky albedo, **WSA**), i.e. reflectance under diffuse illumination

I_u is the upwelling irradiance, i.e. irradiance reflected by the horizontal surface in all directions in a period of time

General approach:

$$I_u = \boldsymbol{BSA} * DNI * cos(\theta) + \boldsymbol{WSA} * DIF$$

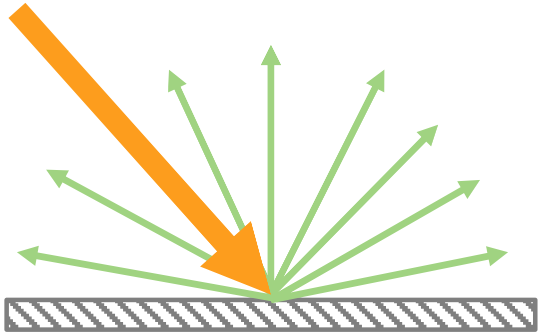


Calculating albedo

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

$$I_u \sim \boldsymbol{WSA} * GHI$$

Lambertian surface is assumed (isotropic albedo, WSA)



Relevance of albedo

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

GTI = direct + diffuse + reflected

Reflected irradiance is part of I_u 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):

PV modules	Standard conditions	Desert conditions	Snow conditions
Fixed-mounting, trackers, standard PV power plants	0.1% - 0.5%	0.3% - 1.5%	1.5% - 8%

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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

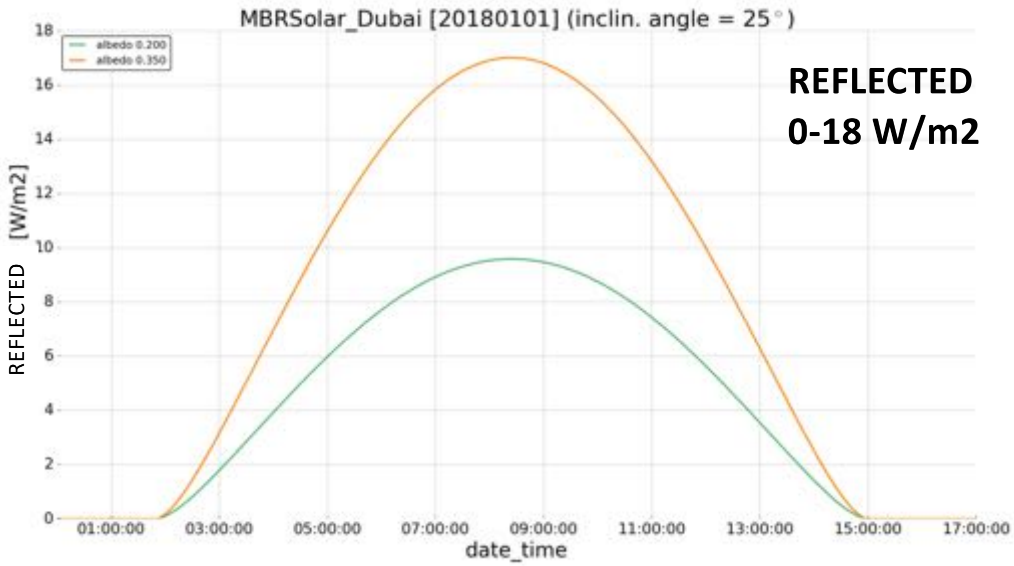
Albedo varies considerably, even over relatively small areas

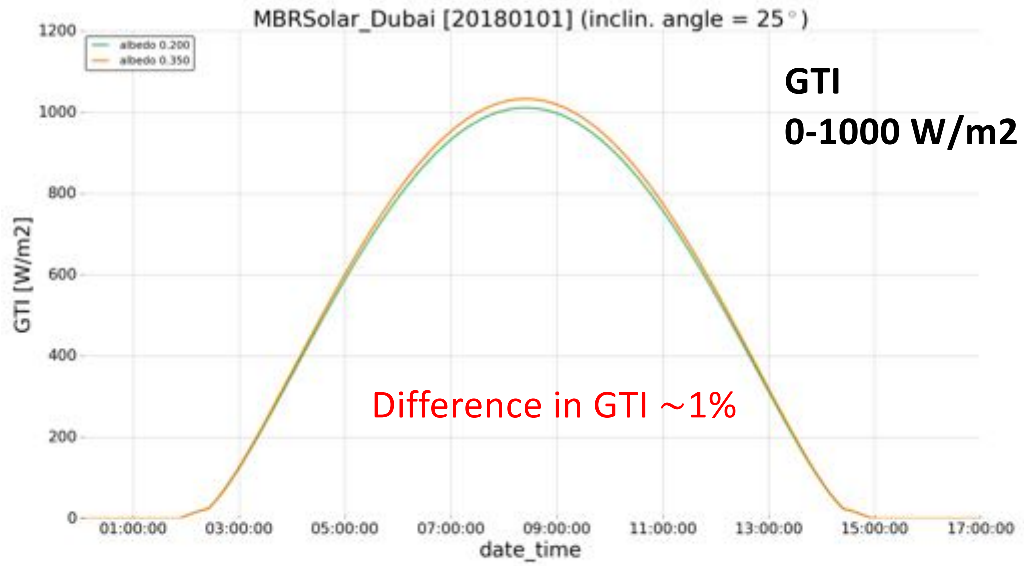
Surface type	Albedo (indicative values)
Water	0.05 - 0.10
Forest	0.05 – 0.15
Grass	0.15 - 0.25
Sand	0.30 - 0.50
Snow	0.50 – 0.85

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





Measuring and modelling albedo

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Measuring and modelling albedo

Local measurements

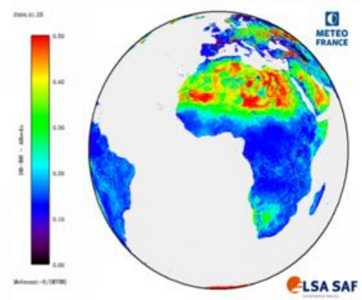
- Very site specific
  (problem of representativeness)
- Recent time
- High resolution

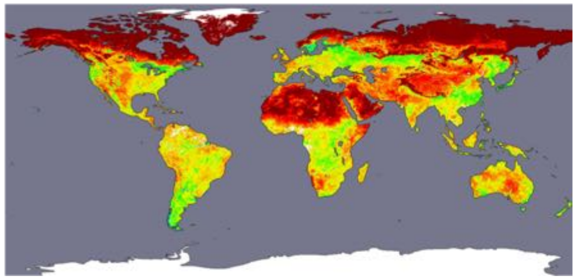
Kipp & Zonen CMP11

Huxeflux SRA20

Data from satellites or numerical weather models

- Large coverage
- Historical data
- Coarse resolution





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Measuring and modelling albedo

Local measurements

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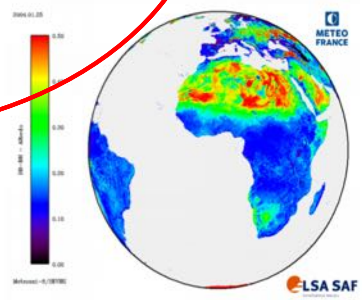

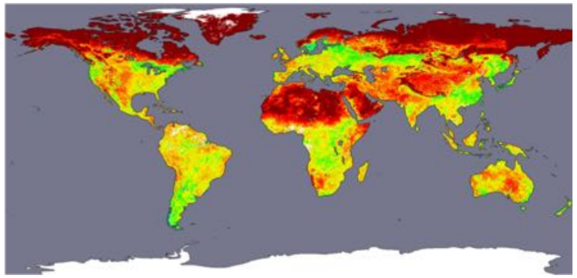

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Surface albedo data sources

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):

Source	Agency	Max. spatial resol.	Max. temp. resol.	Period	Type	Observations
MODIS (*)	NASA	500m	1 day	2001 - 2015	Satellite	Multiple products
CLARA-A2-SAL (CMSAF)	EUMETSAT	0.25⁰	5 days	1982 - 2015	Satellite	BSA
ETAL **(LSA SAF)**	EUMETSAT	1km	10 days	2015 - present	Satellite	--
NSRDB	NREL	4km	1 day	2001 - 2014	Satellite	MODIS based
MPT	MINES Paris-Tech	5.6km	Monthly averages	2004 - 2011	Satellite	MODIS based
ERA-5	ECMWF	0.28125⁰	1h	2000 - present	NWP	--
MERRA2	NASA	0.5⁰x0.625⁰	1h	1980 - present	NWP	--

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

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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

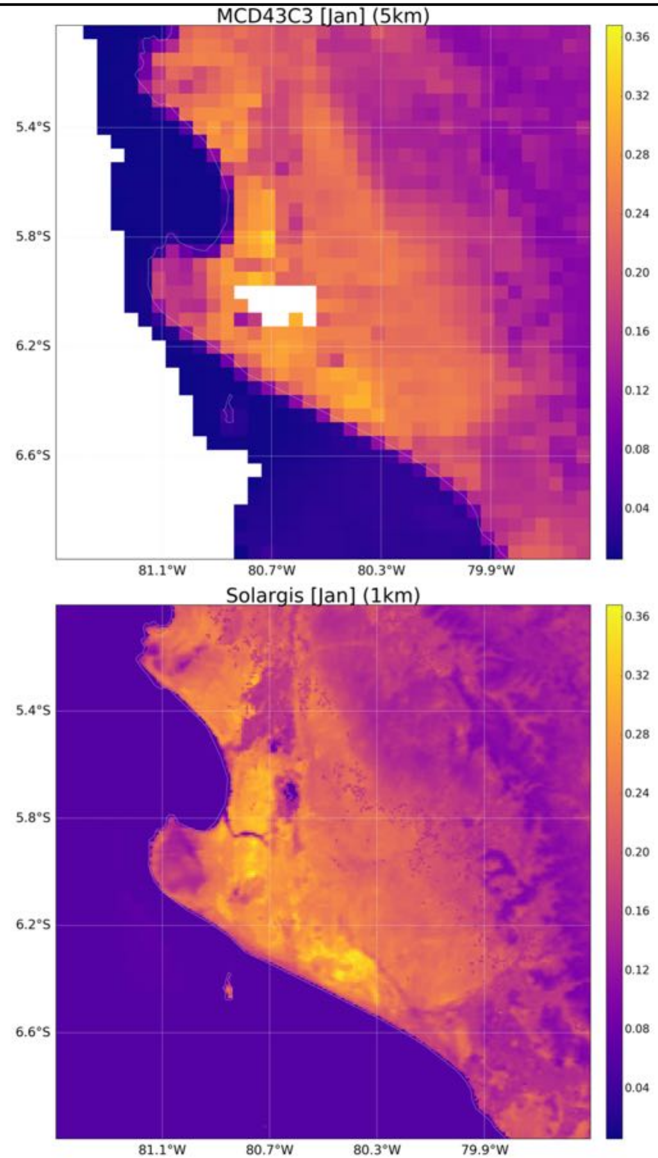
Advantages:

- 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)



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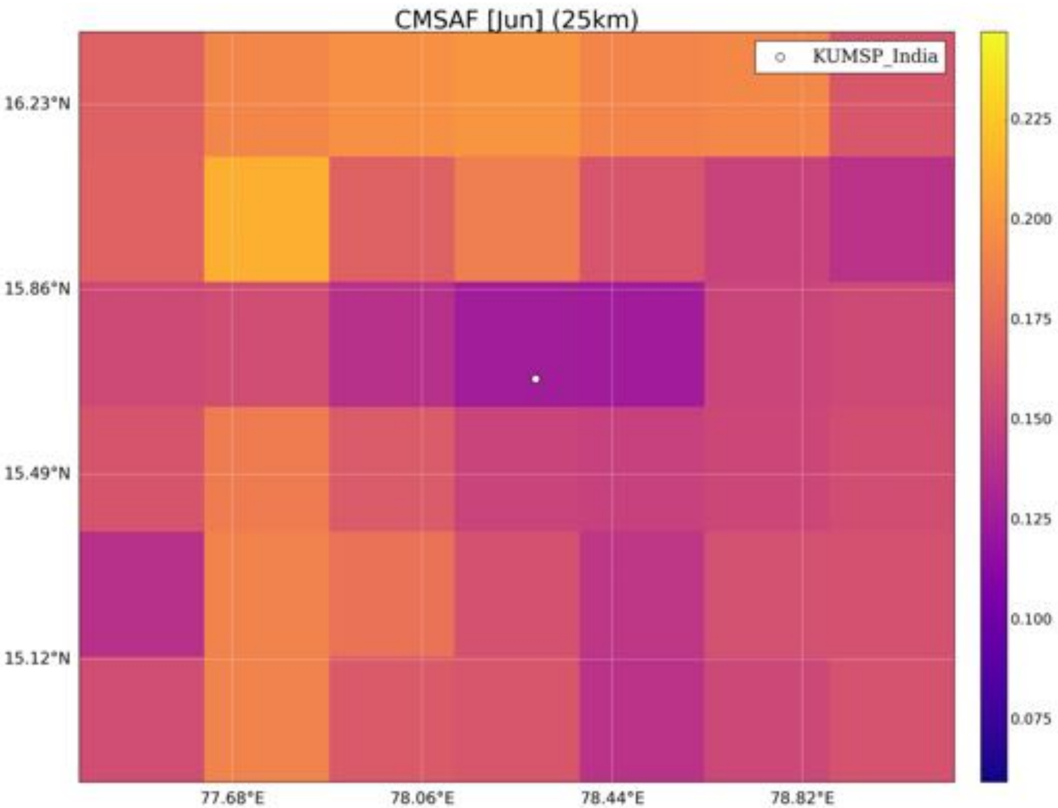
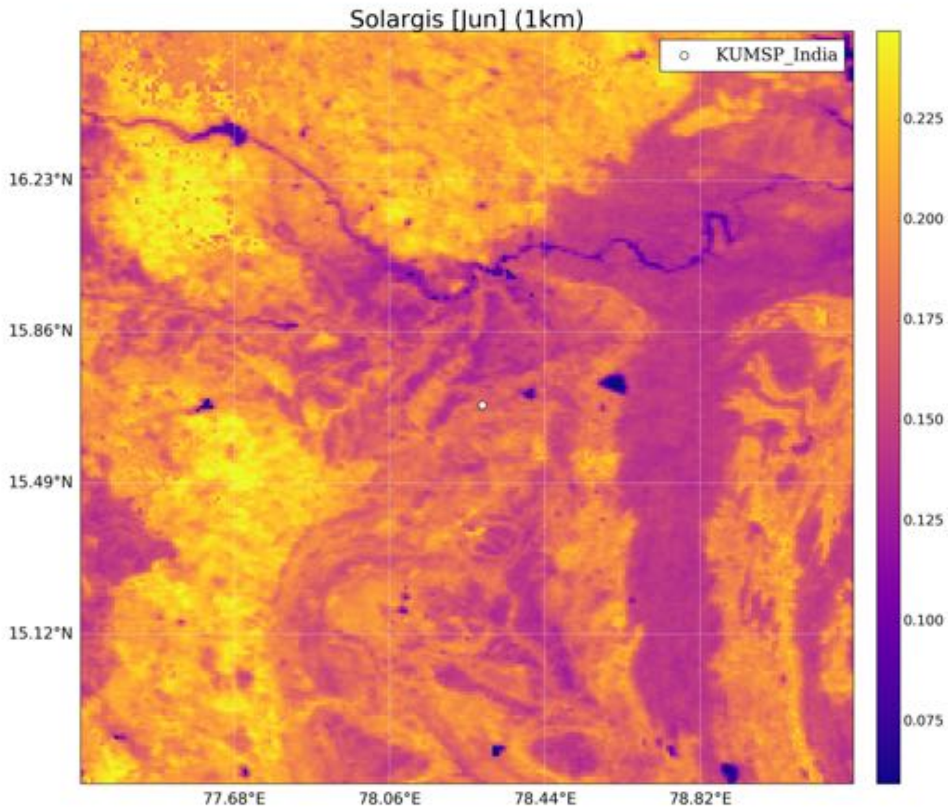
Surface albedo data sources

Effect of spatial resolution: example of Kumps (India)





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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

Source	Comments
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

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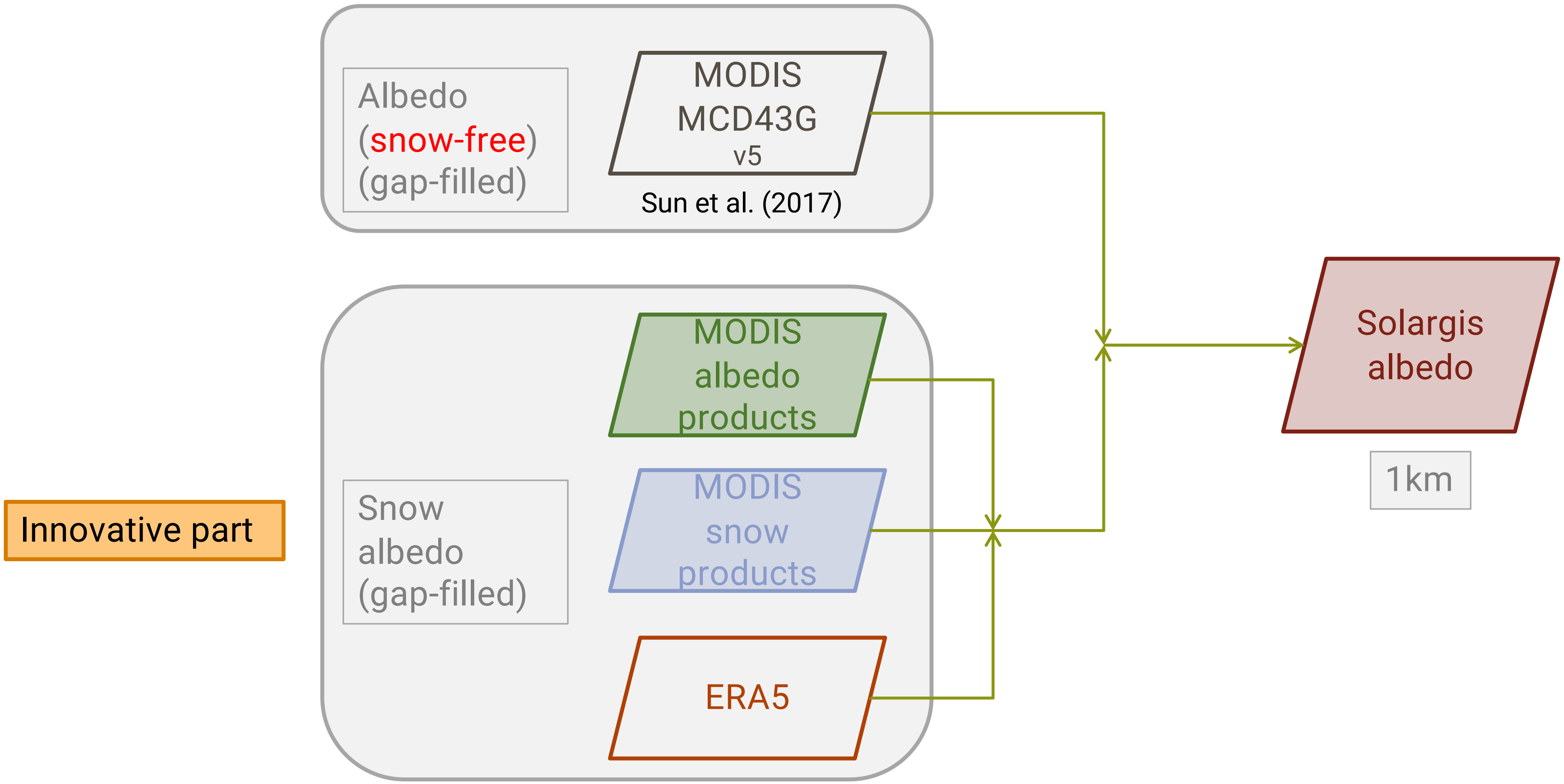
Solargis ground surface albedo database



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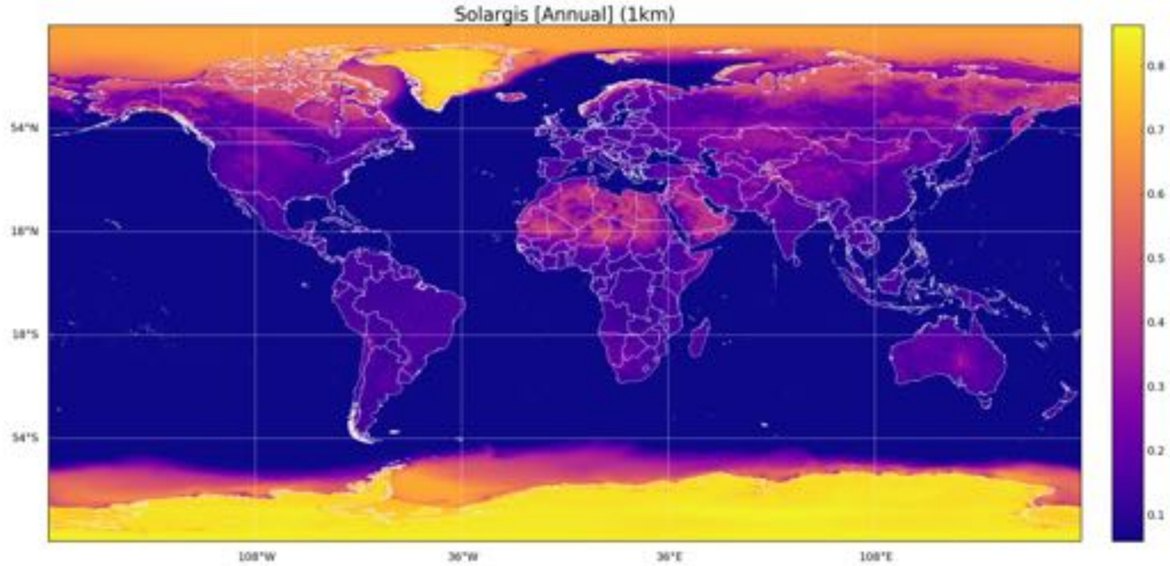
Solargis surface albedo database: Features

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



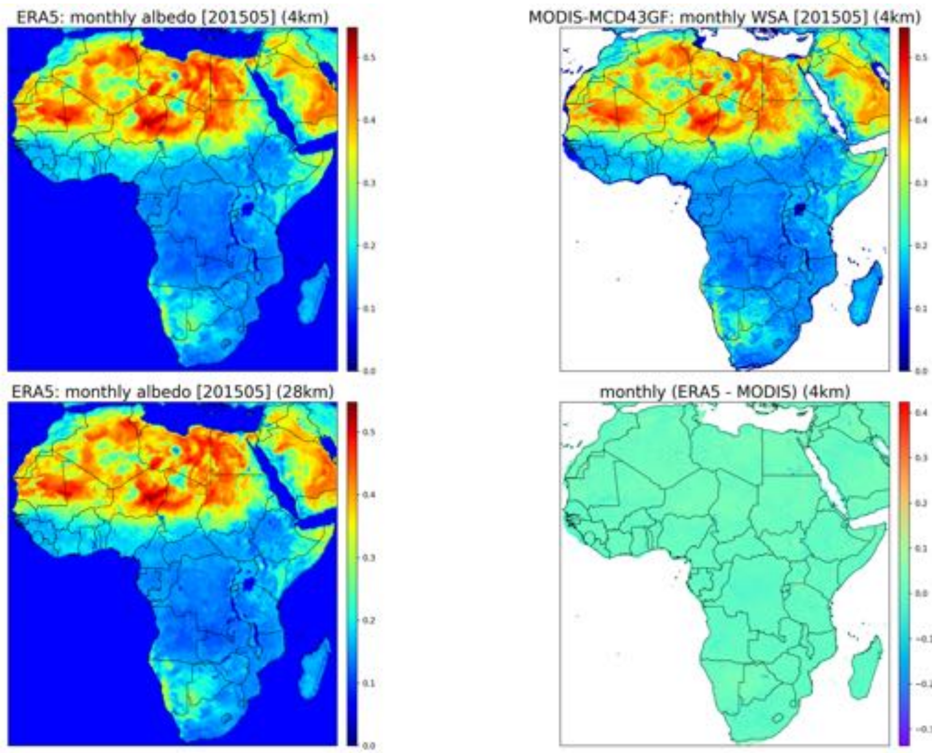
Solargis ground surface albedo database: Validation

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



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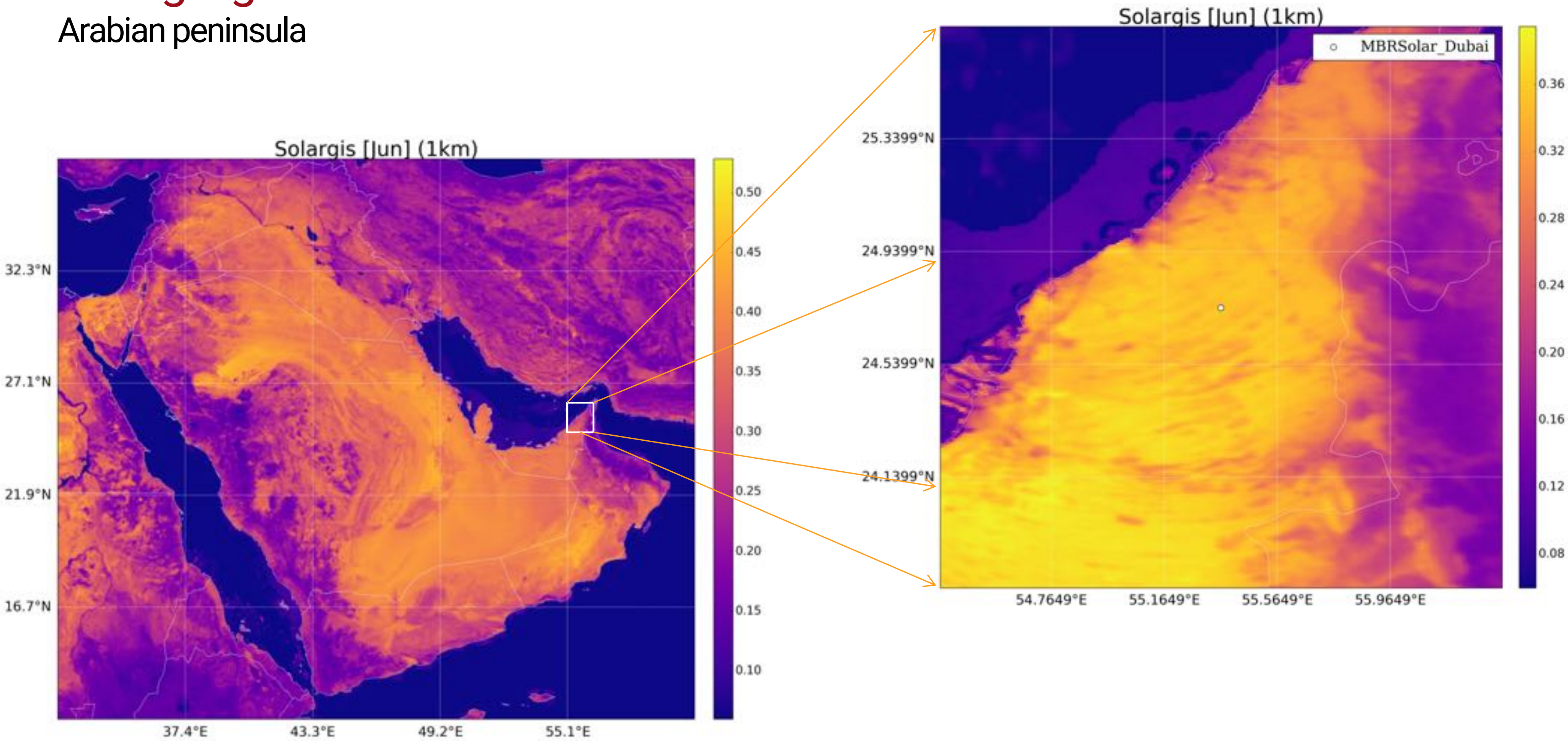
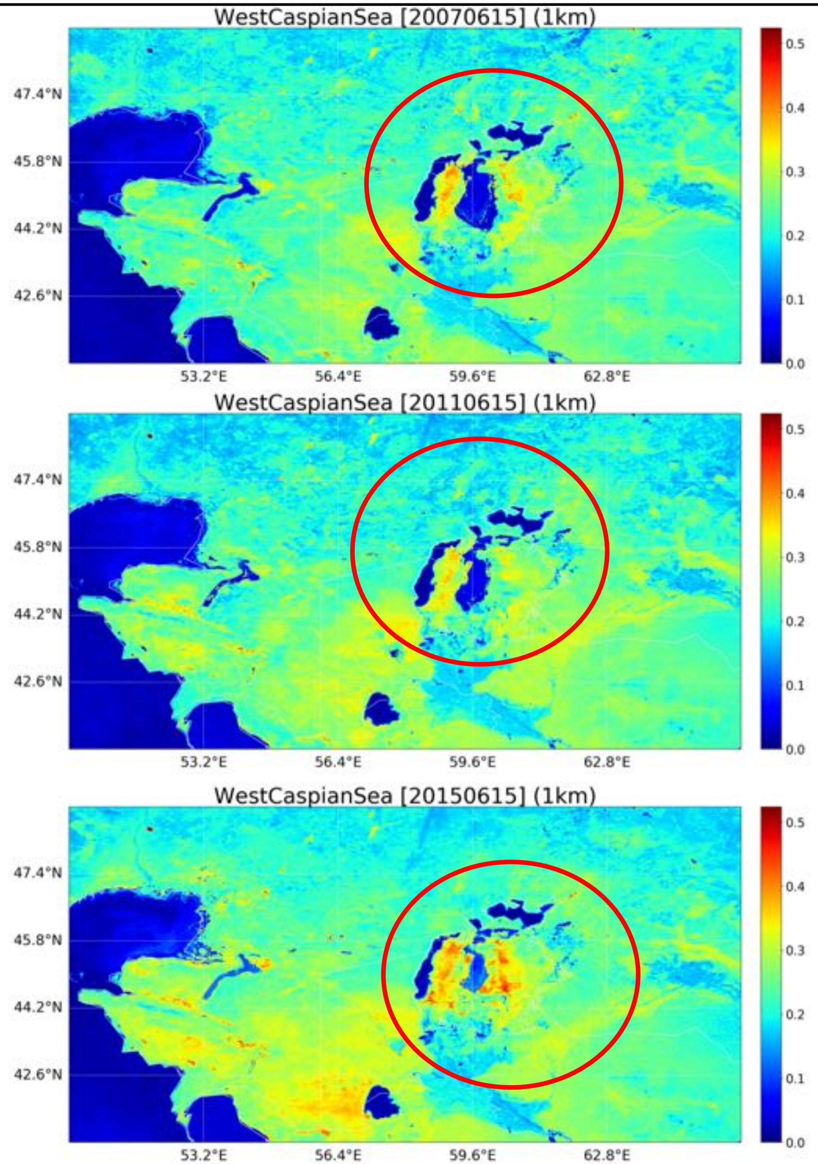
Solargis ground surface albedo database

Arabian peninsula



Solargis ground surface albedo database

Aral sea



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

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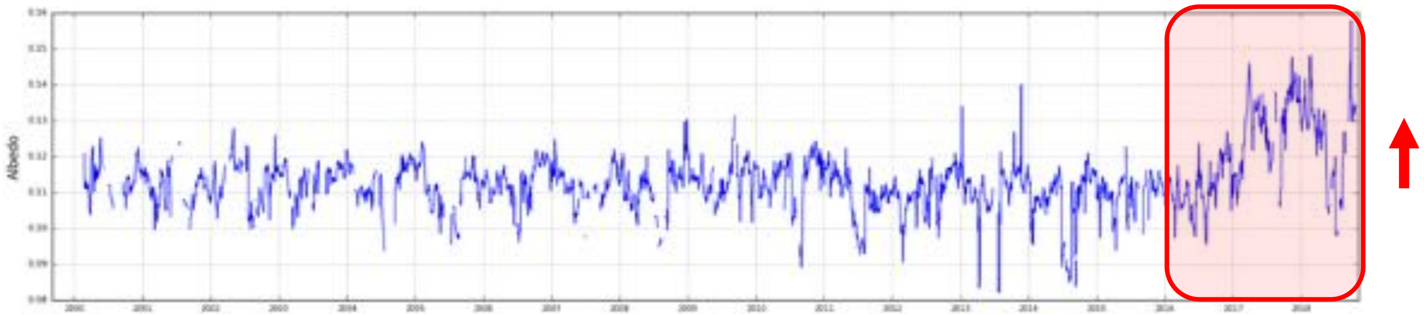
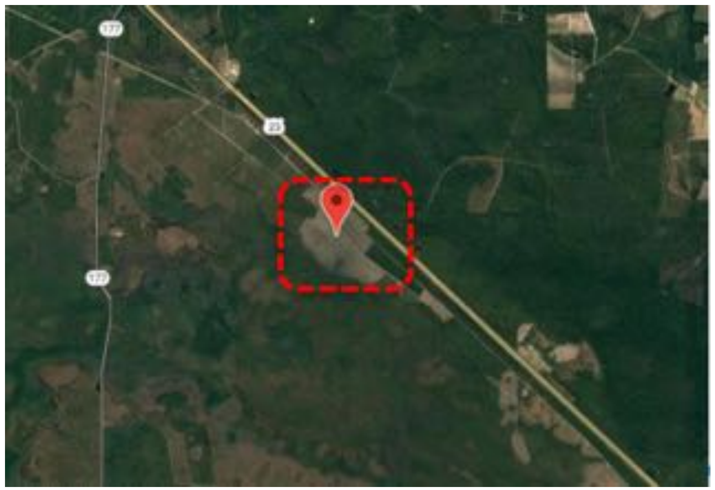
Ground surface albedo: Time changes

Change of land surface albedo due to forest clear-cut



2016

2018



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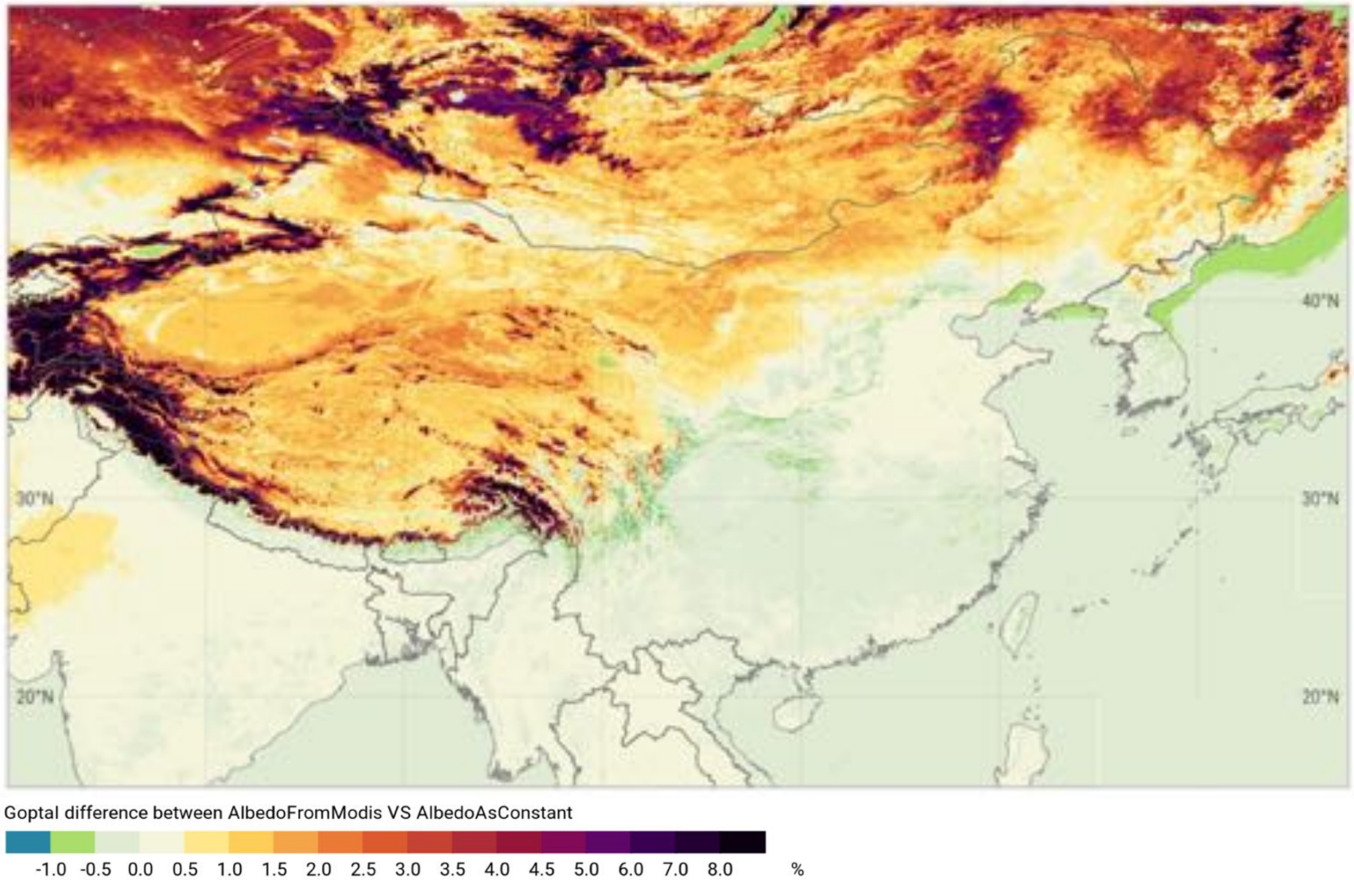
Effect of albedo in monofacial PV simulation

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%

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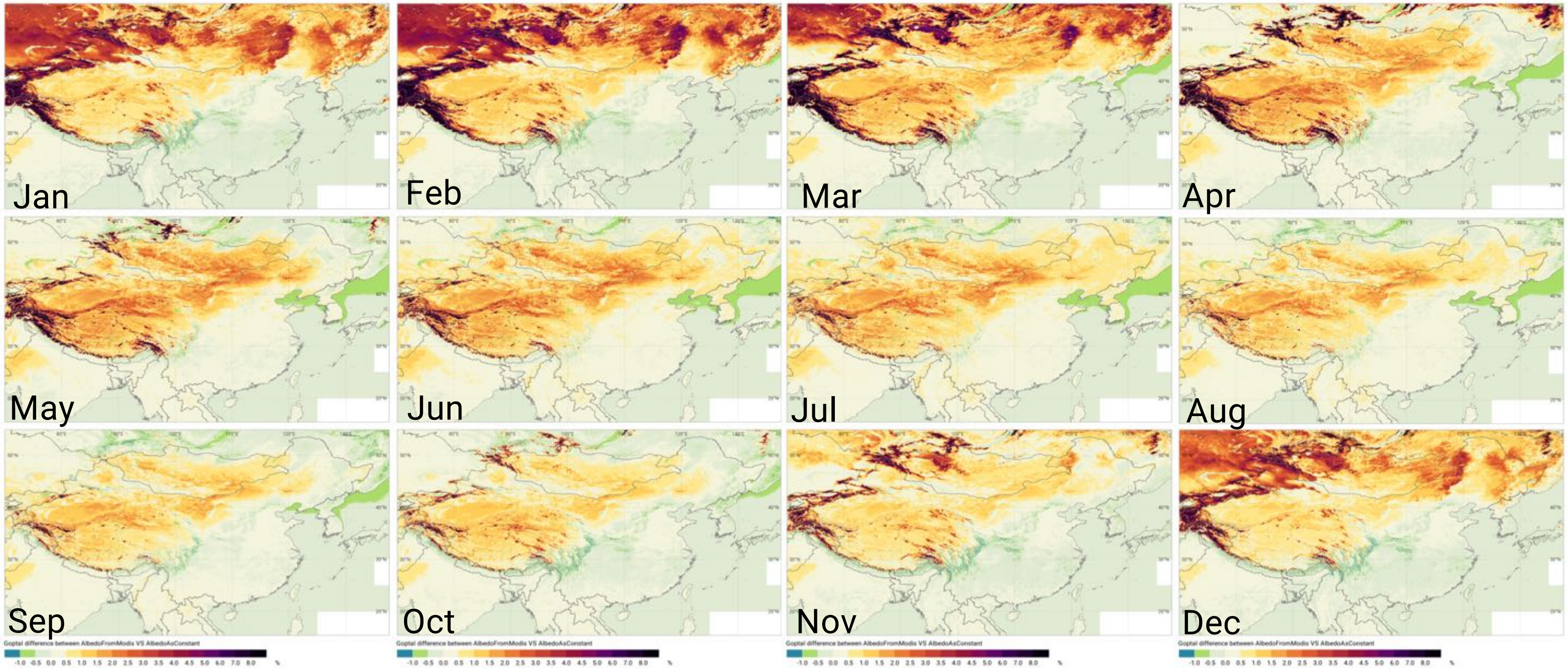
Seasonality of albedo in China

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%



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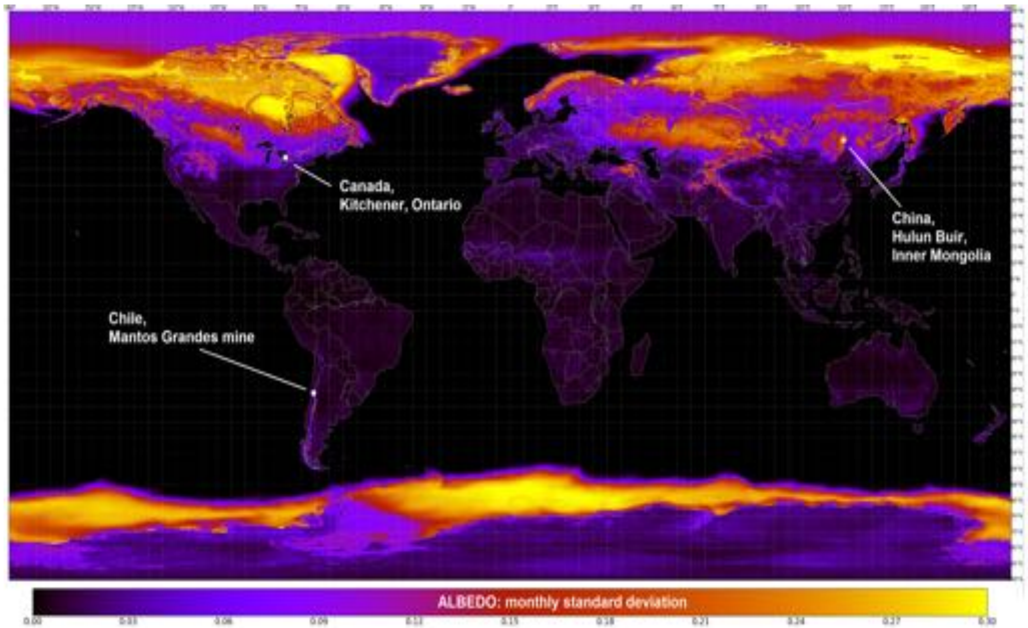
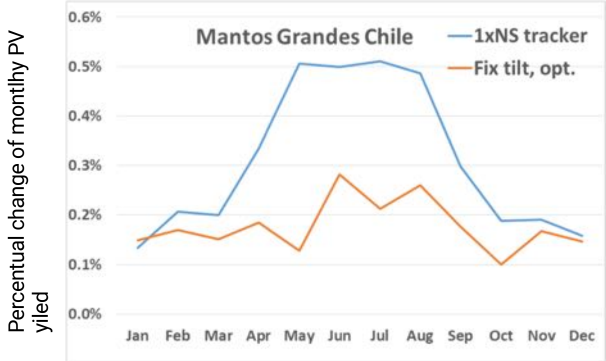
Seasonality of albedo

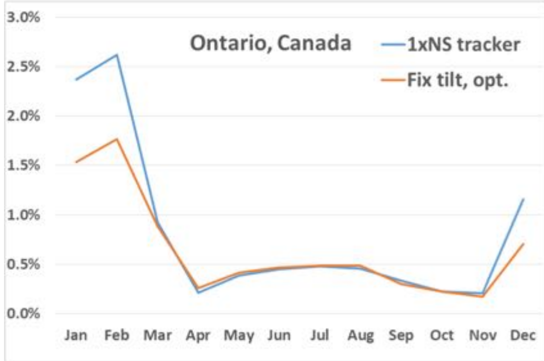
Highest variation in monthly albedo is in snow regions

(Maps shows standard deviation of monthly averages)

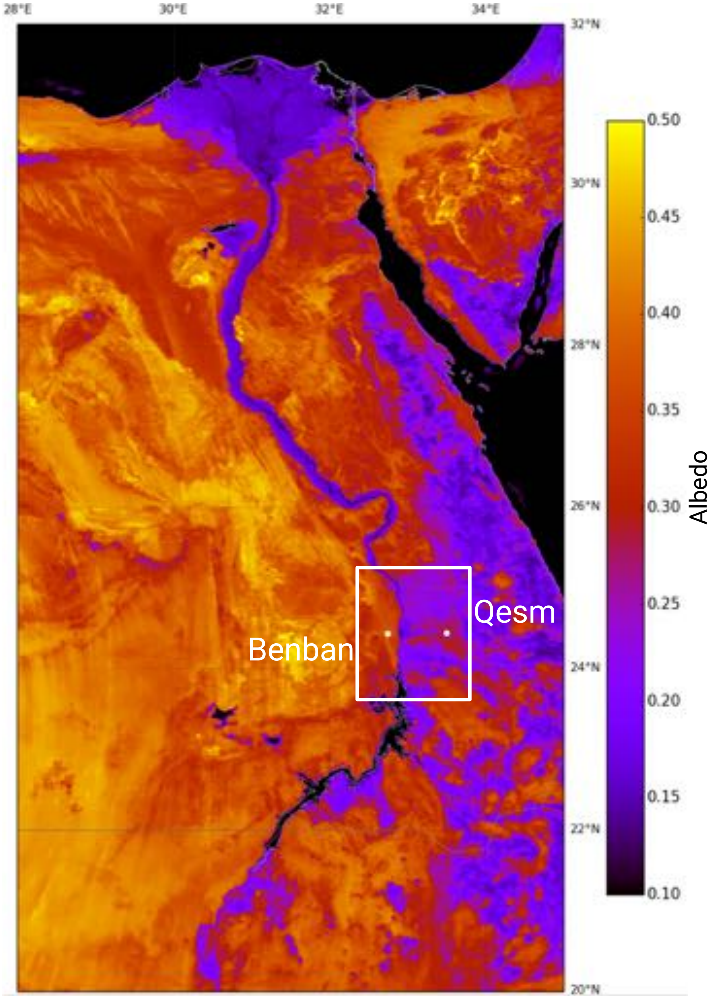


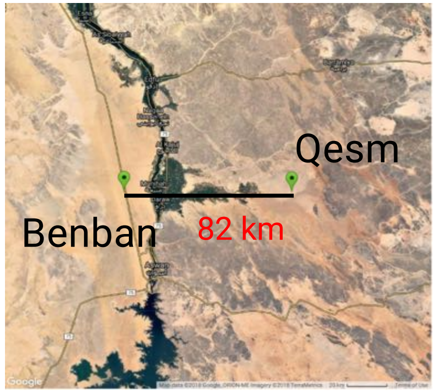
Monthly PV power production: Difference between calculation output based on high resolution monthly albedo vs. fixed albedo value of 0.12



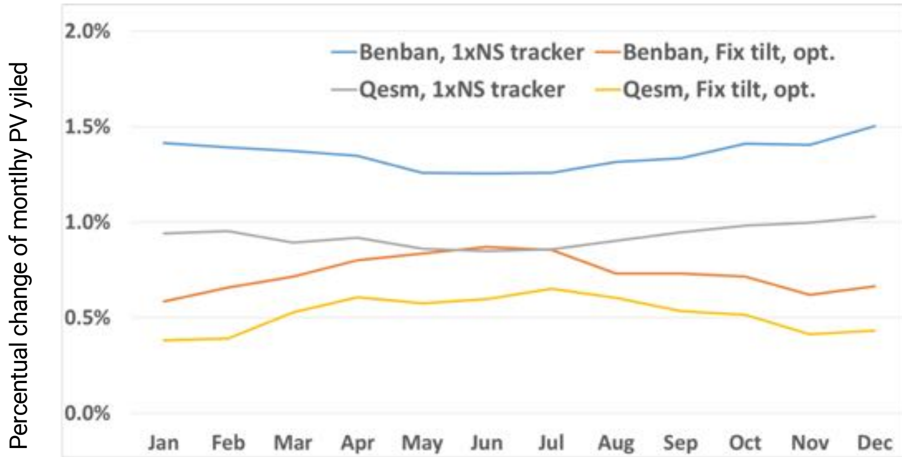


Geographical variability of albedo





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!

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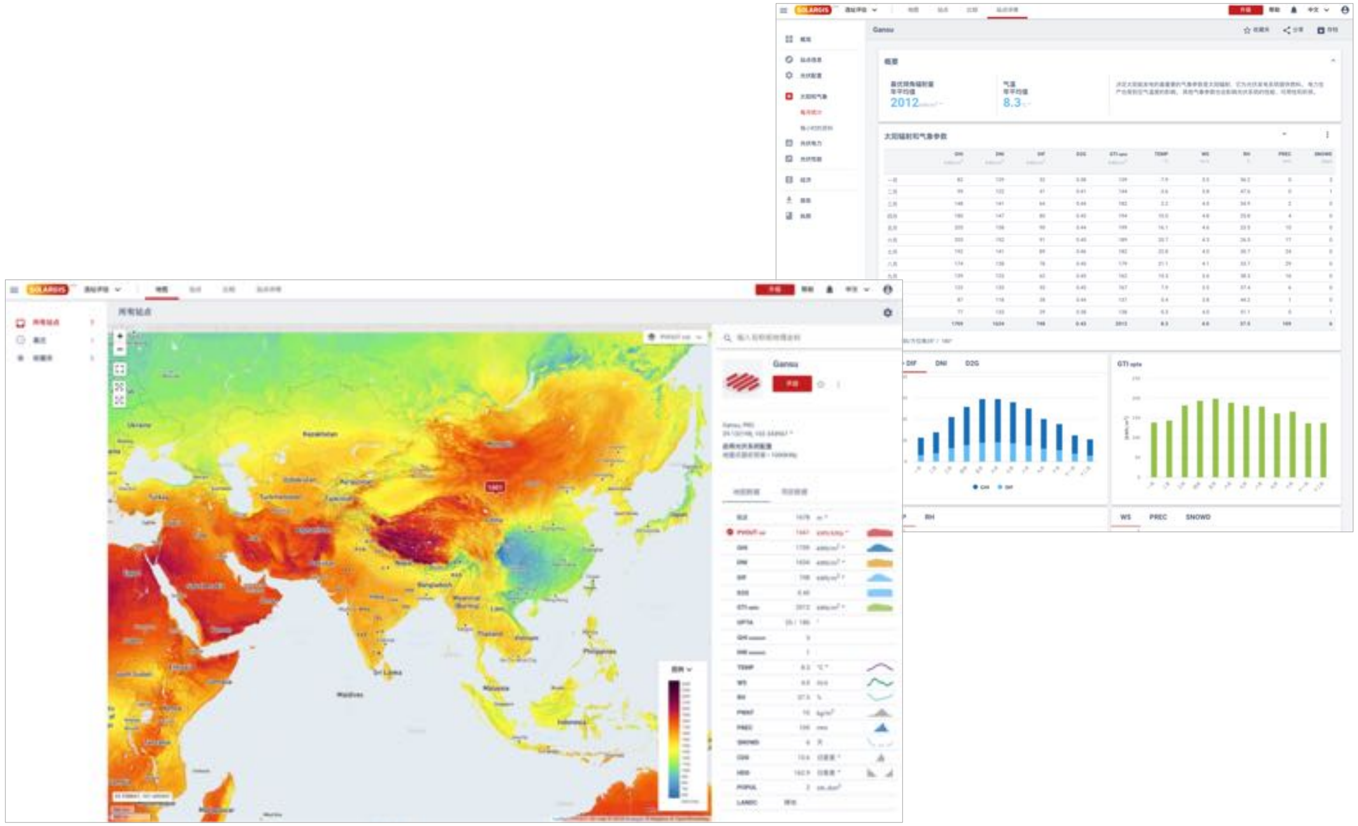
http://solargis.com



Albedo accessible from Solargis Prospect online application
Launch: Jan 2019