Assessing Ground Albedo in PV-Plants via Fisheye Camera and Satellite Images

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3 CIEMAT Energy Department, Renewable Energy Division

Agenda

- Motivation on ground albedo assessment
  - Relevance
  - State of the art
- Introduction of our approach
  - High-resolution (HR) satellite
  - Ground camera
- Experimental case studies
  - Validation of HR satellite albedo
  - Comparison of HR and Sentinel albedo
  - Camera-based albedo measurement
- Conclusion & Outlook



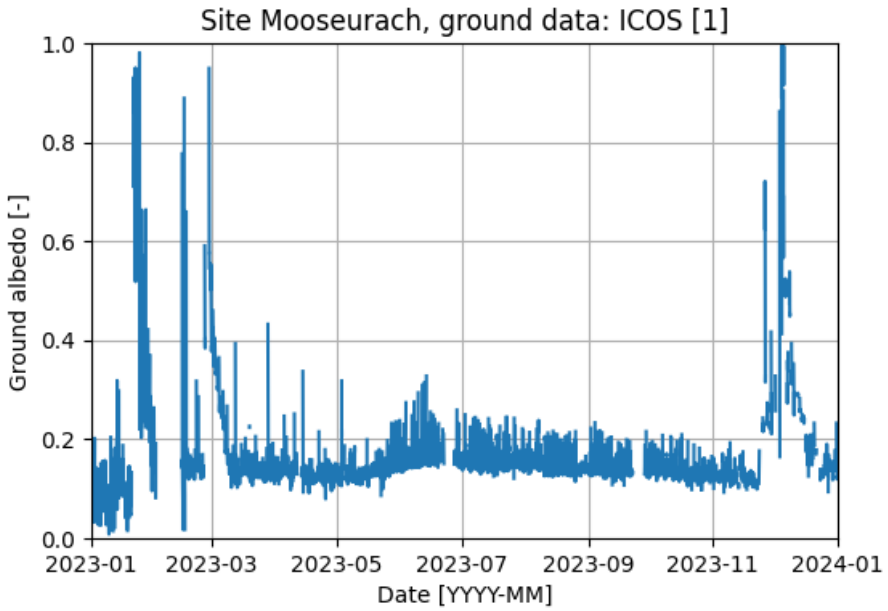
MOTIVATION

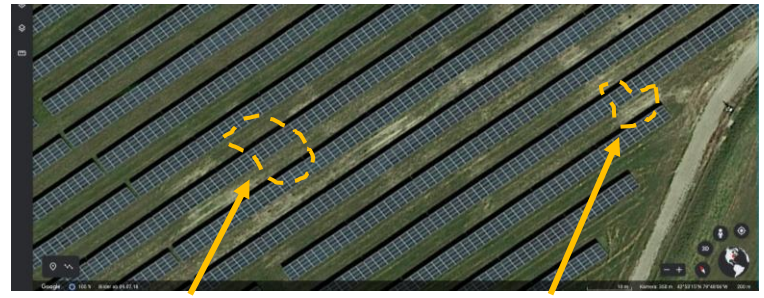
https://www.esa.int/Enabling_Support/Operations/Sentinel-2_teams_prepare_for_space

Motivation
Relevance of albedo information for bifacial PV



- Performance models for bifacial PV plants can exhibit notable deviations
- Inaccurate ground albedo contributes a considerable part to uncertainty
- Variations of ground albedo are frequent in PV plants:
  - temporally as vegetation recovers from construction works and seasonal changes
  - spatially with different surface types present in a PV plant:
    - Different soil types
    - Artificial/sealed surfaces
    - vegetation of different type, height and stage
    - …
- Estimation (Blum et al. 2025): Albedo variations >0.1 possible in PV plants and can lead to ±2% error in predicted annual yield





grass: albedo=? sand: albedo=?

1. Drösler, M., Eberl, J., Klatt, J., Meyer, H., Schlaipfer, M. (2026). ETC L2 ARCHIVE from Mooseurach, 2020–2025, ICOS RI, https://hdl.handle.net/11676/RqXJCin7S7YuLRqS9EdAqvYK

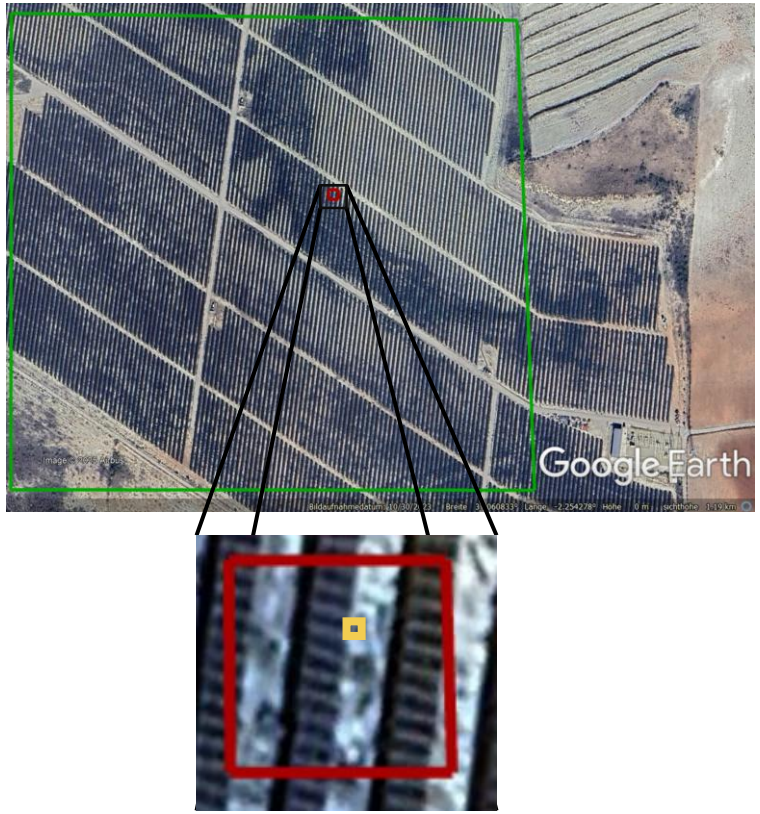
Motivation
State-of-the-art albedo data sources

- Ground measurements
  - Point-wise
  - High cost
  - Practical difficulty to find large unshaded space
  - IEC 61724-1 Class A: 2-5 measurement positions for PV plants up to 500 MW

- Alternative: Remotely sensed
  - MODIS
    - 500 m x 500 m resolution (**footprint** in image)
  - Sentinel, Landsat and other open access systems
    - Down to 10 m x 10 m resolution (**footprint** in image)
  - → To coarse to distinguish PV rows from ground



Image source: https://www.linkedin.com/posts/cfv-solar-test-laboratory_groundwork-joins-solaranywhere-by-clean-activity-7348728157979467778-dSYM (Accessed 18.09.2025)



Motivation

State-of-the-art albedo data sources and our approach

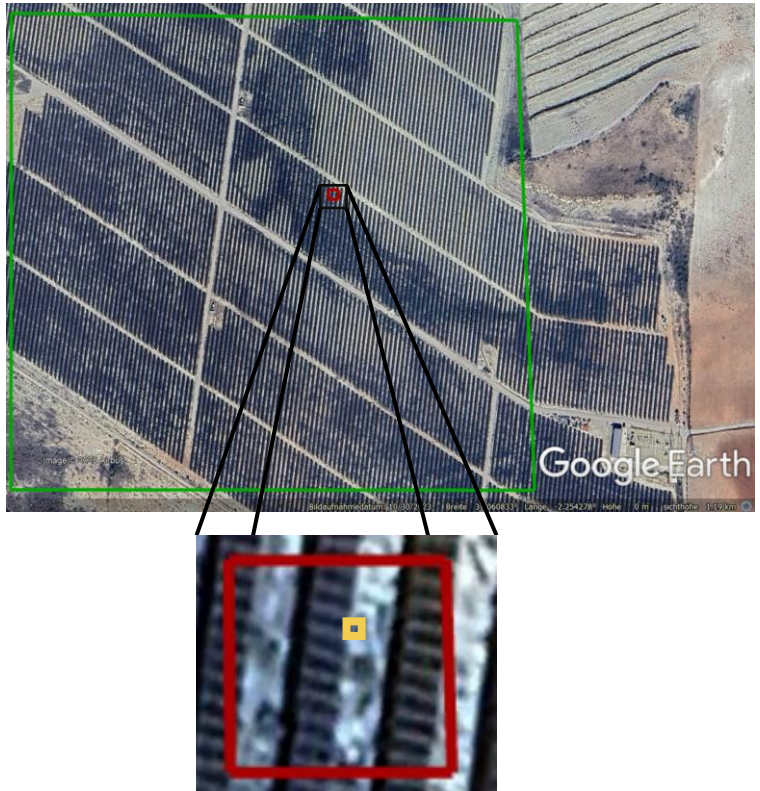
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  - Point-wise
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- Our approach
  - Novel, more practical ground measurement within power plant
  - Spatial variations from highly-resolved remote sensing data
    - Down to 30 cm x 30 cm resolution (**footprint** in image)
  - Combination of both for a highly accurate spatially and temporally resolved and locally calibrated ground albedo



Image source: https://www.linkedin.com/posts/cfv-solar-test-laboratory_groundwork-joins-solaranywhere-by-clean-activity-7348728157979467778-dSYM (Accessed 18.09.2025)

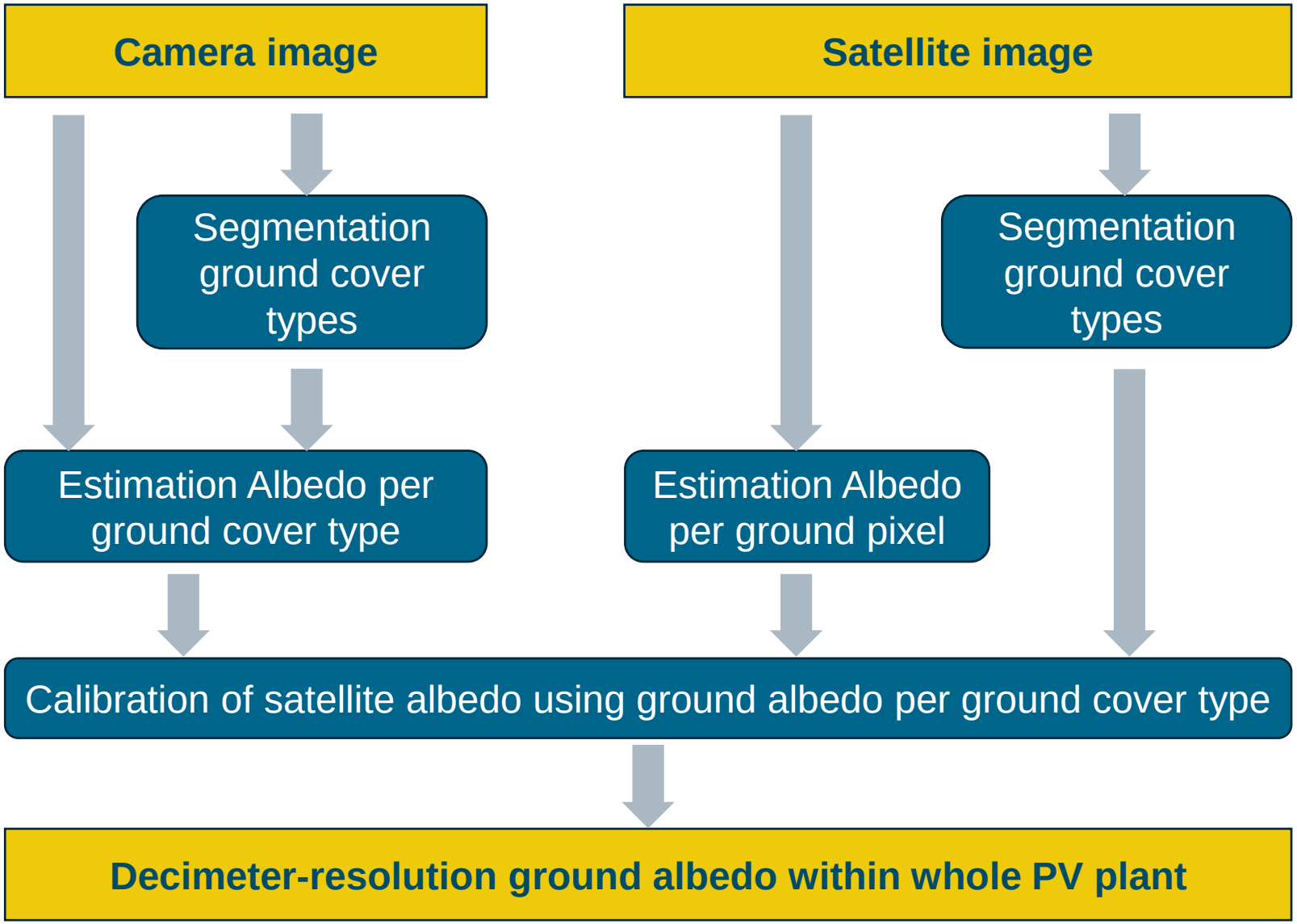




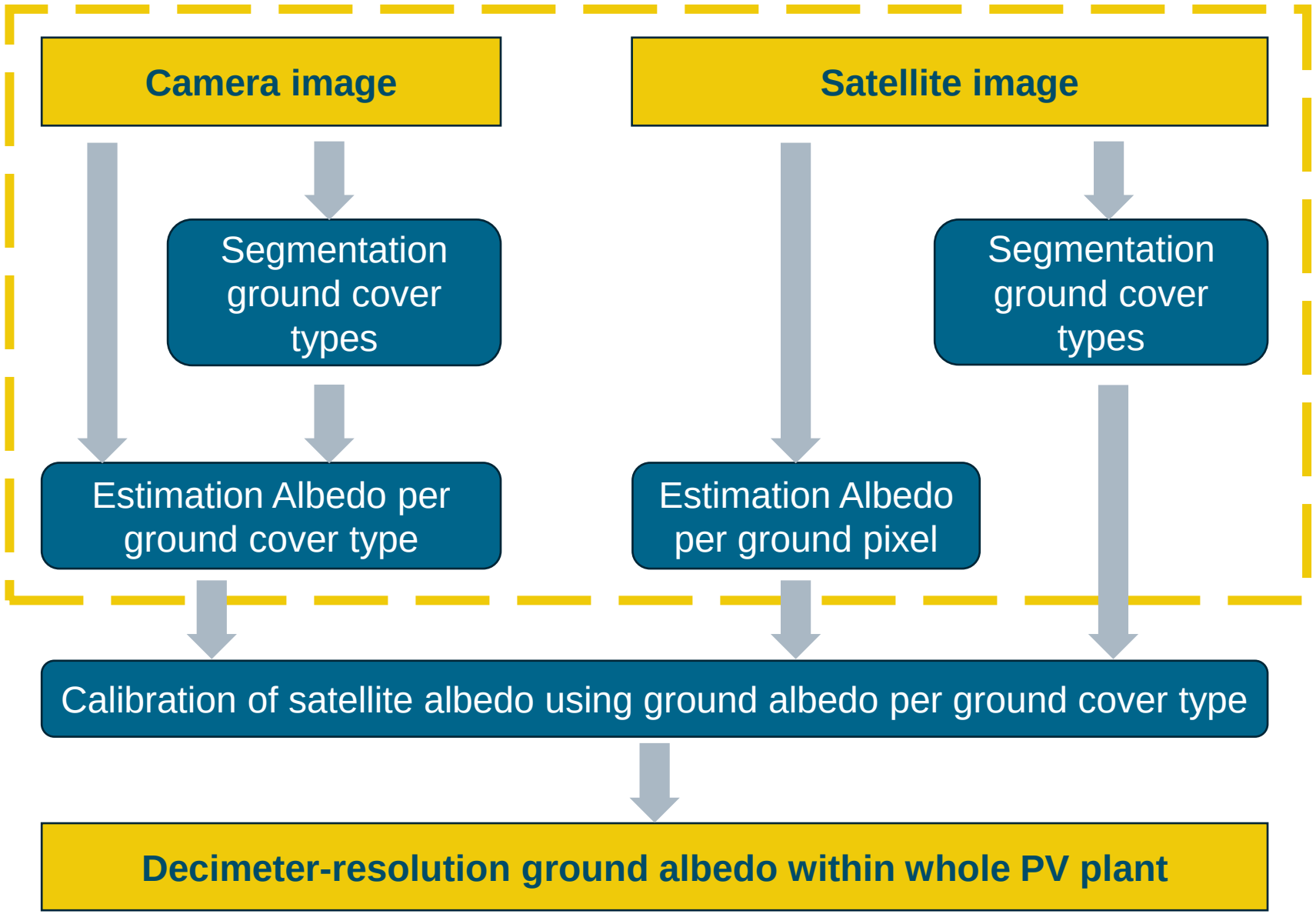
METHOD

https://www.esa.int/Enabling_Support/Operations/Sentinel-2_teams_prepare_for_space

Proposed model chain

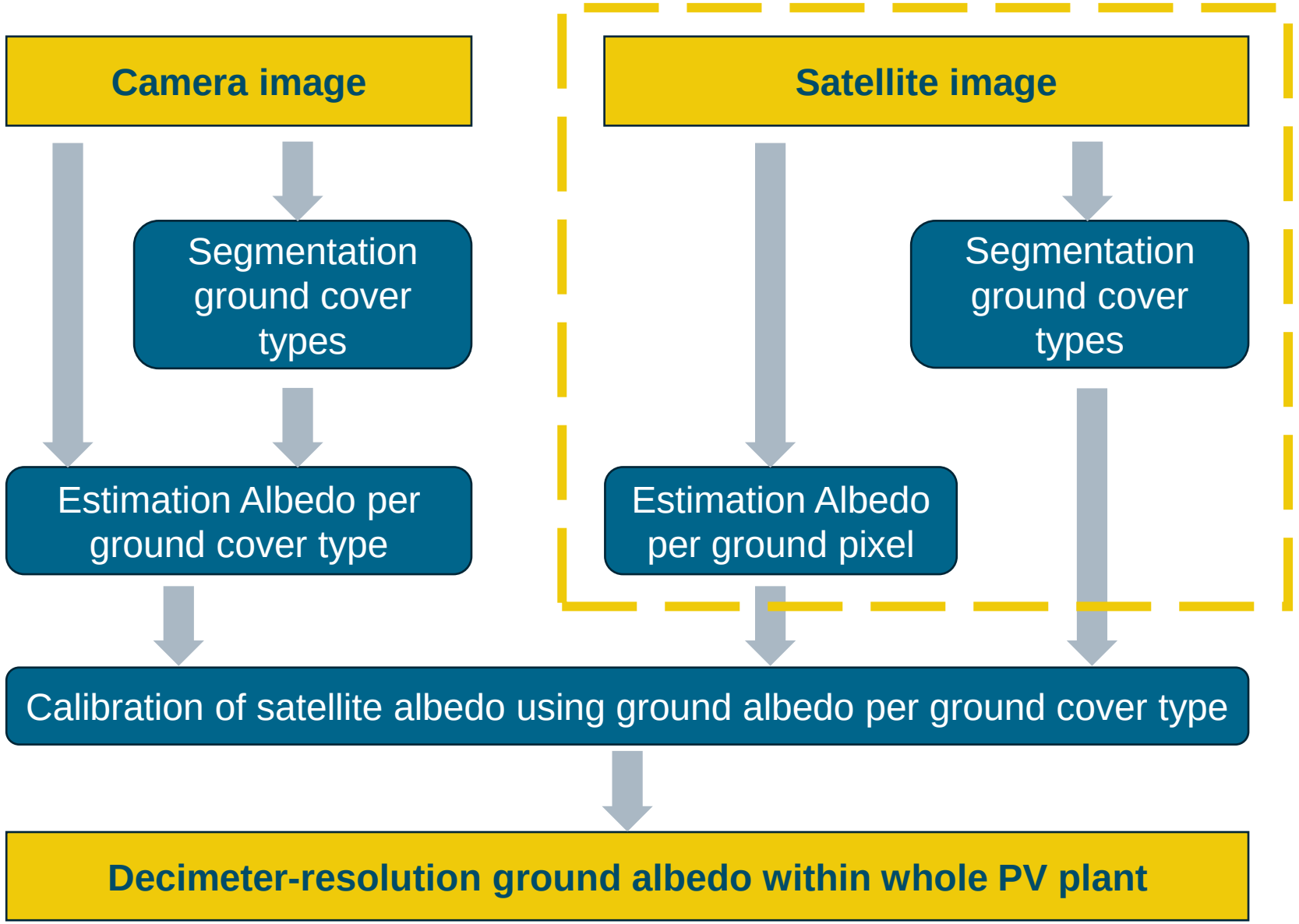


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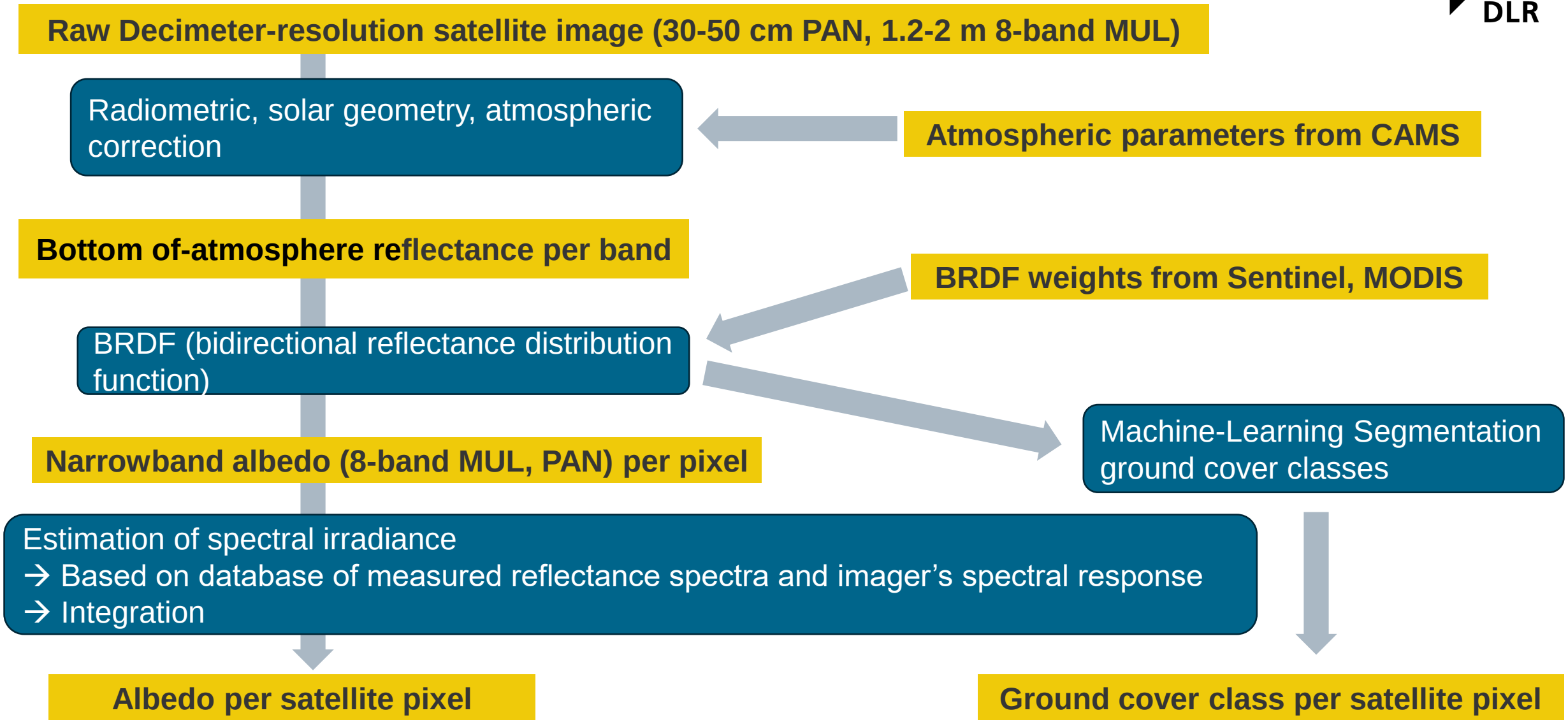


Focus today

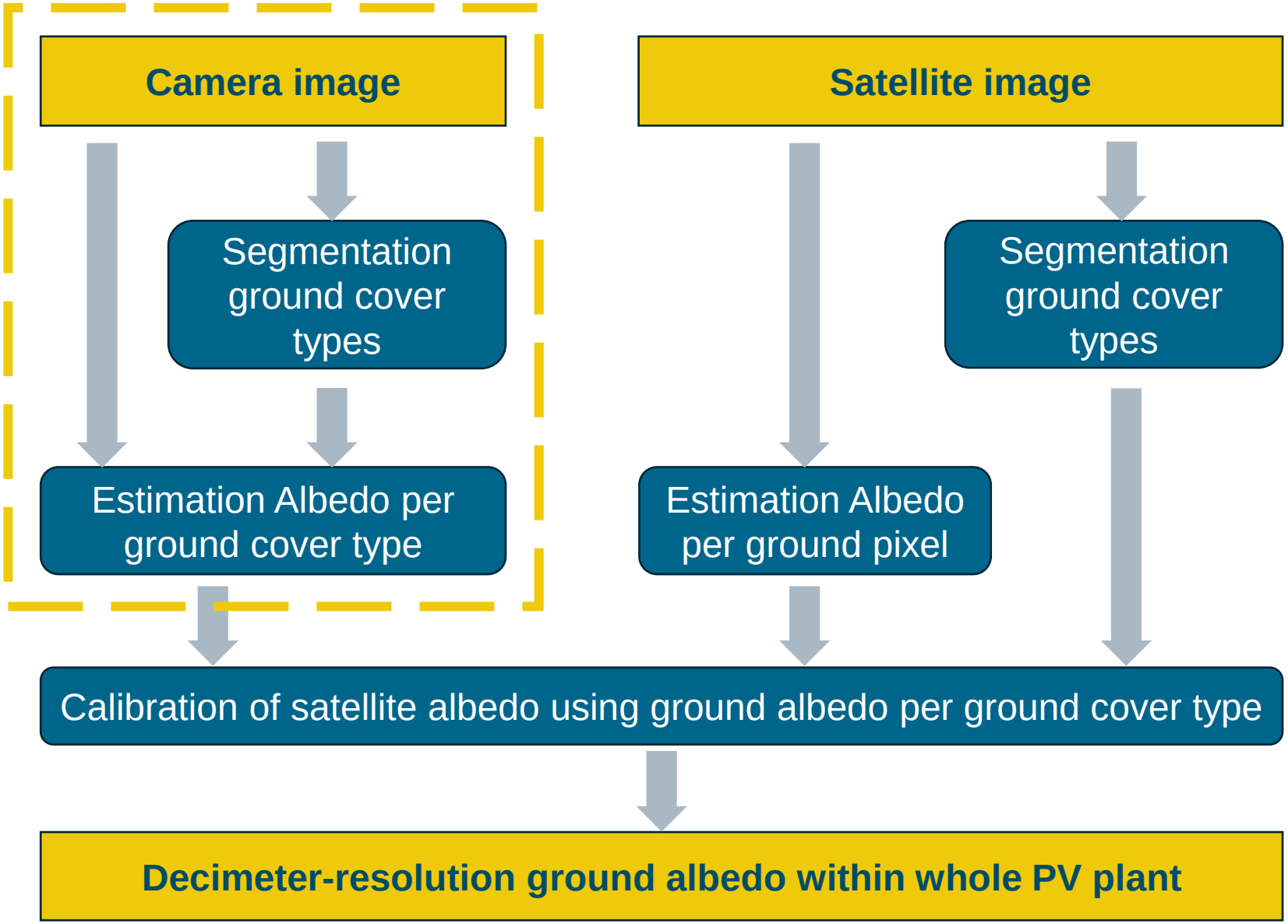
Proposed model chain



Estimating ground albedo from satellite images



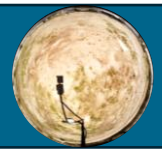
Proposed model chain



Albedo measurement in solar field and per ground cover class

Ground camera within solar field





R,G,B image

Radiometric camera model
→ resolves irradiance information spatially

R,G,B image

Machine-Learning Segmen-tation ground cover classes

Radiance image per R,G,B

Radiance image split by class

BRDF
→ Estimated from observations of the same ground cover type under different viewing and sun angles
→ Hemispheric radiance image modeled & integrated

Narrowband irradiances (R,G,B) per ground cover type

Estimation of spectral irradiance from R, G, B narrowband irradiance and ground cover type
→ Based on a database of measured reflectance spectra and camera's spectral response
→ Integration

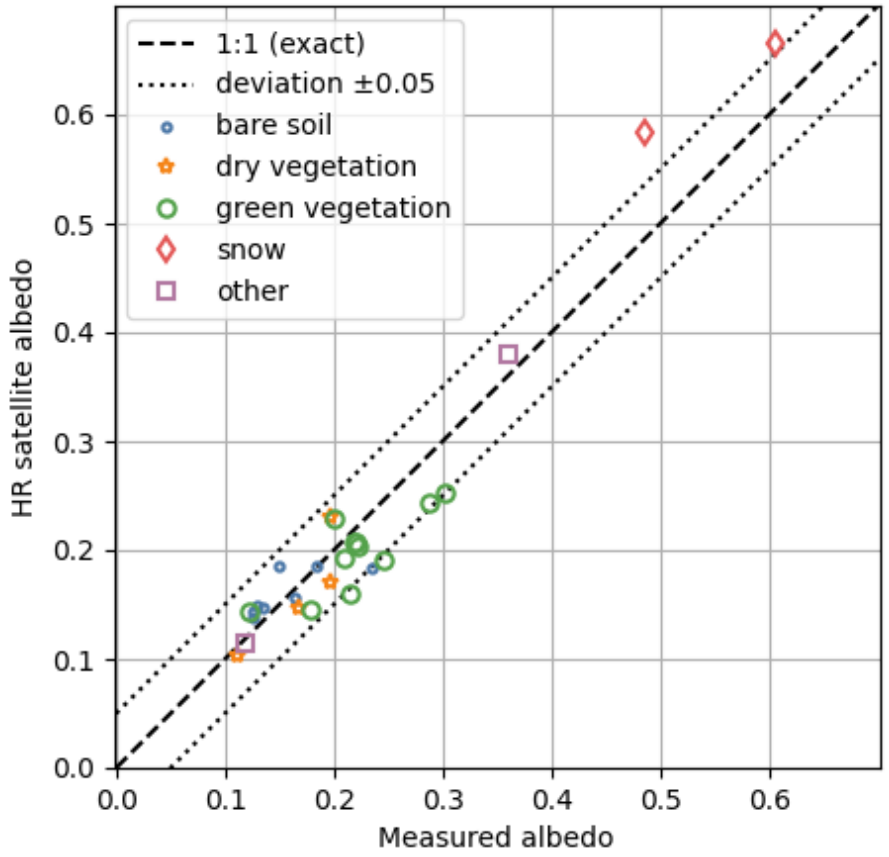
Albedo per ground cover class



EXPERIMENTAL RESULTS

https://www.esa.int/Enabling_Support/Operations/Sentinel-2_teams_prepare_for_space

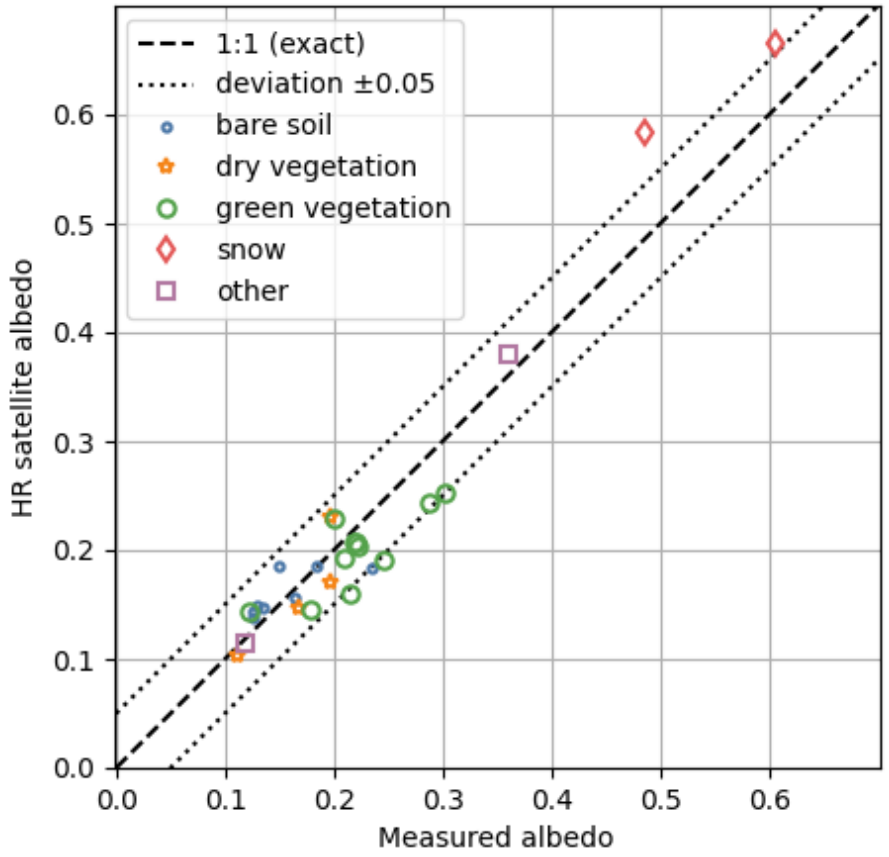
Estimating albedo from HR satellite images
Accuracy evaluation



The evaluation includes measurement data of DLR, CIEMAT, ICOS [1] and BSRN [2]

1. ICOS RI et al., ICOS ETC, 2026. Ecosystem final quality (L2) product in ETC-Archive format - release 2026-1. https://doi.org/10.18160/S6TB-567H
2. Driemel et al., 2018, Baseline Surface Radiation Network (BSRN): structure and data description (1992–2017), Earth Syst. Sci. Data, 10, 1491-1501, doi:10.5194/essd-10-1491-2018

Estimating albedo from HR satellite images
Accuracy evaluation



Ground Cover	RMSD	MAD	Bias	Pearson-r
all	0.036	0.029	-0.002	0.965
snow	0.081	0.078	0.078	1
no snow	0.029	0.025	-0.008	0.889

The evaluation includes measurement data of DLR, CIEMAT, ICOS [1] and BSRN [2]

1. ICOS RI et al., ICOS ETC, 2026. Ecosystem final quality (L2) product in ETC-Archive format - release 2026-1. https://doi.org/10.18160/S6TB-567H
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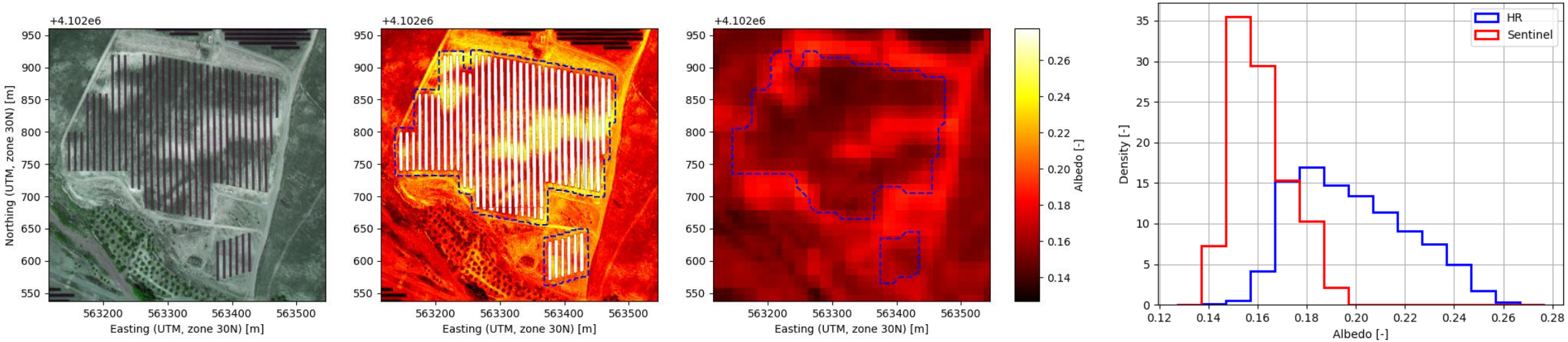
- Albedo based on HR satellite sufficient to detect variations of ground albedo
- Calibration with ground data advisable

Estimating albedo from HR satellite images

Case studies estimating albedo in PV plants – Tabernas

HR satellite

Sentinel



Site	Sentinel mean	Sentinel std	HR mean	HR std
Tabernas I	0.161	0.011	0.189	0.029

- HR satellite albedo unaffected by presence of PV arrays
- Sentinel albedo in part biased as PV and ground albedo mixed
- Sentinel underestimates spatial variations (std) of ground albedo within PV plant

Estimating albedo from HR satellite images

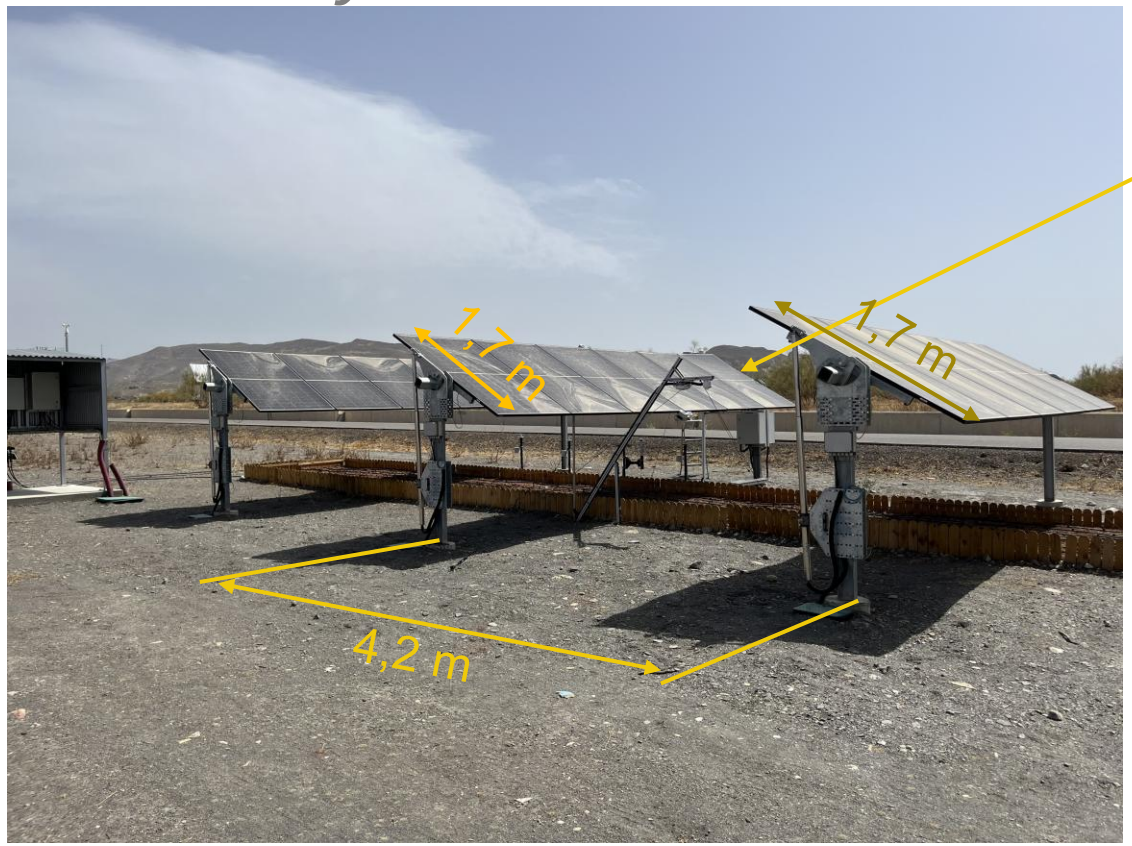
Case studies estimating albedo in PV plants

Site	Sentinel mean	Sentinel std	HR mean	HR std
Tabernas	0.161	0.011	0.189	0.029
Turillas	0.181	0.017	0.235	0.022
Huerup	0.137	0.014	0.214	0.028
Freienwill	0.129	0.014	0.235	0.024

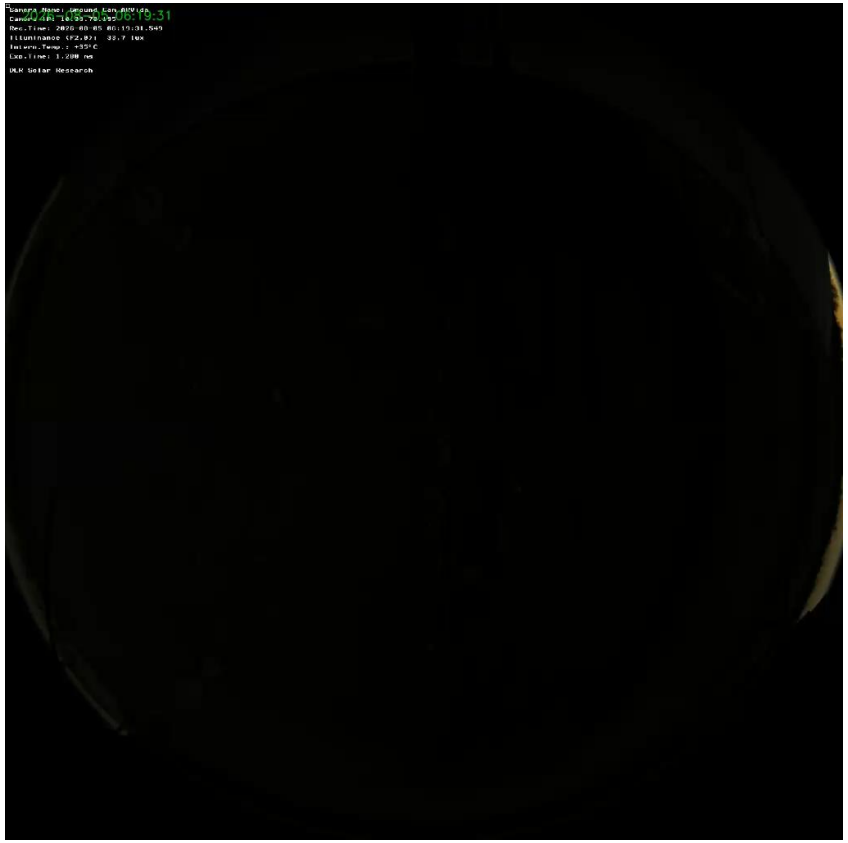
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Estimating albedo from camera images

Case study in a PV installation



Ground Cam



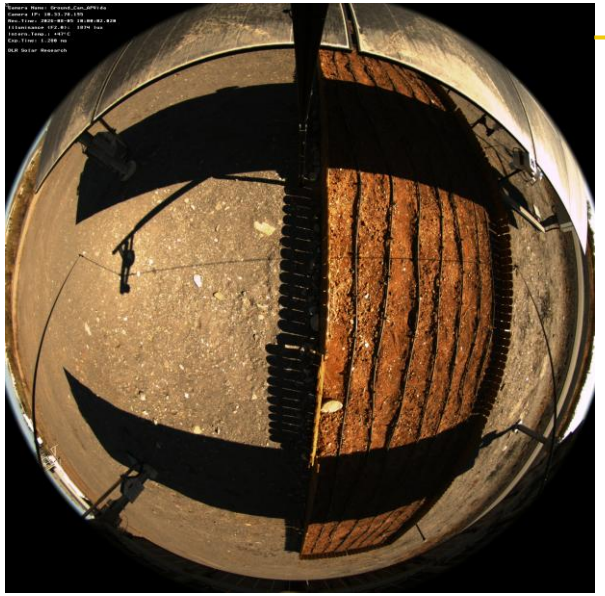
- South-facing PV array with small row distance
- Site unsuited for conventional albedo measurement (e.g. IEC 61724-1 requires 8-m radius always shadow-free at all times)
- Camera-based albedo measurement tested under these challenging conditions

Images taken at PSA. The research site Plataforma Solar de Almería (PSA) is owned and operated by the Spanish CIEMAT

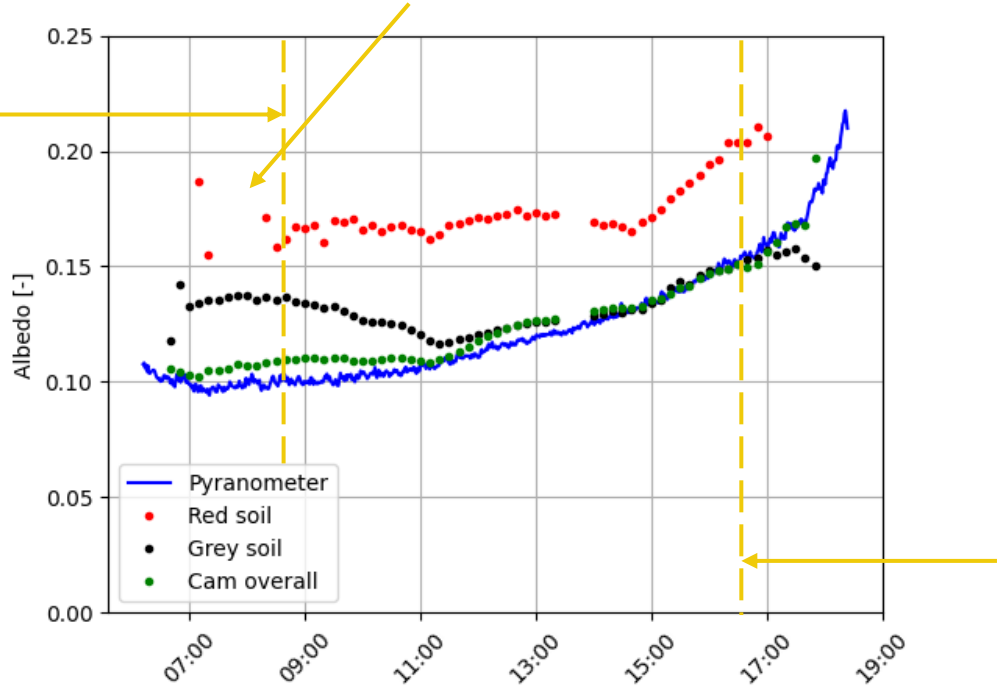
Estimating albedo from camera images

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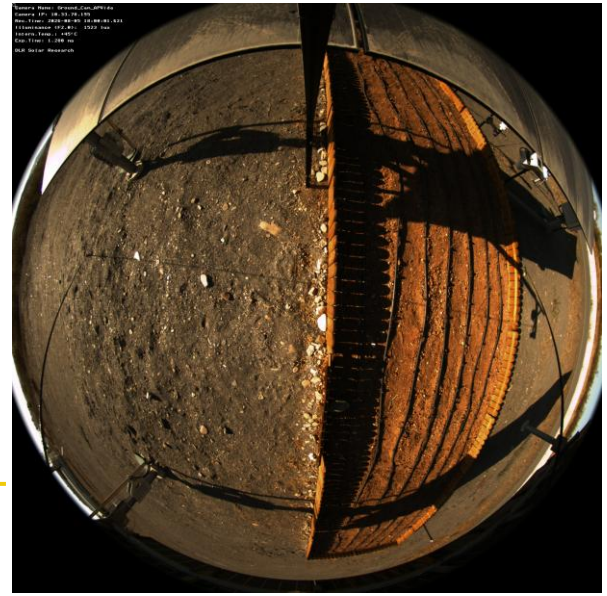
Strong shading in the morning



Insufficient number of valid pixels in some conditions



Less shading towards evening (edge effect)



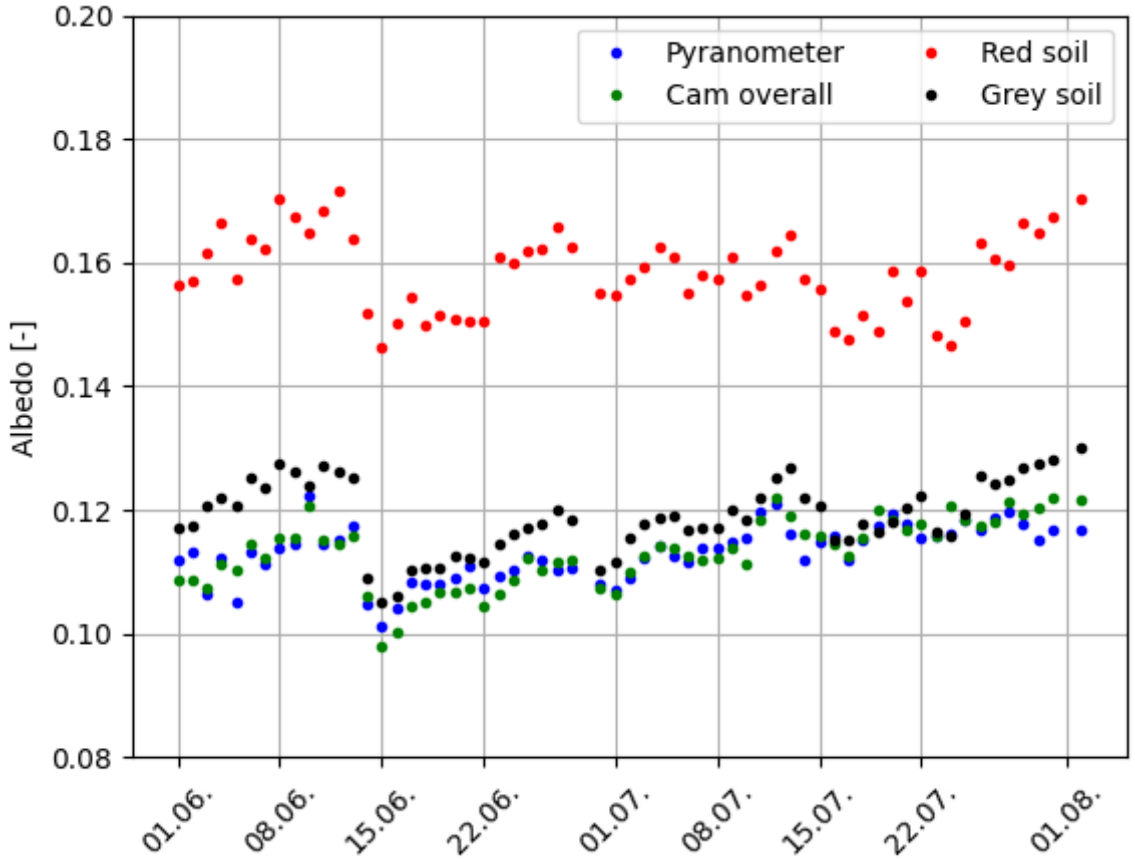
- Camera can reproduce pyranometer measurement well (green line)
- Shading strongly affects albedo from pyranometer → diurnal variation from 0.1 to 0.2
- Albedo of both ground cover types is reconstructed reasonably from camera image

Niklas Blum, Bijan Nouri et al., DLR Institute of Solar Research, 14.09.2026

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Estimating albedo from camera images

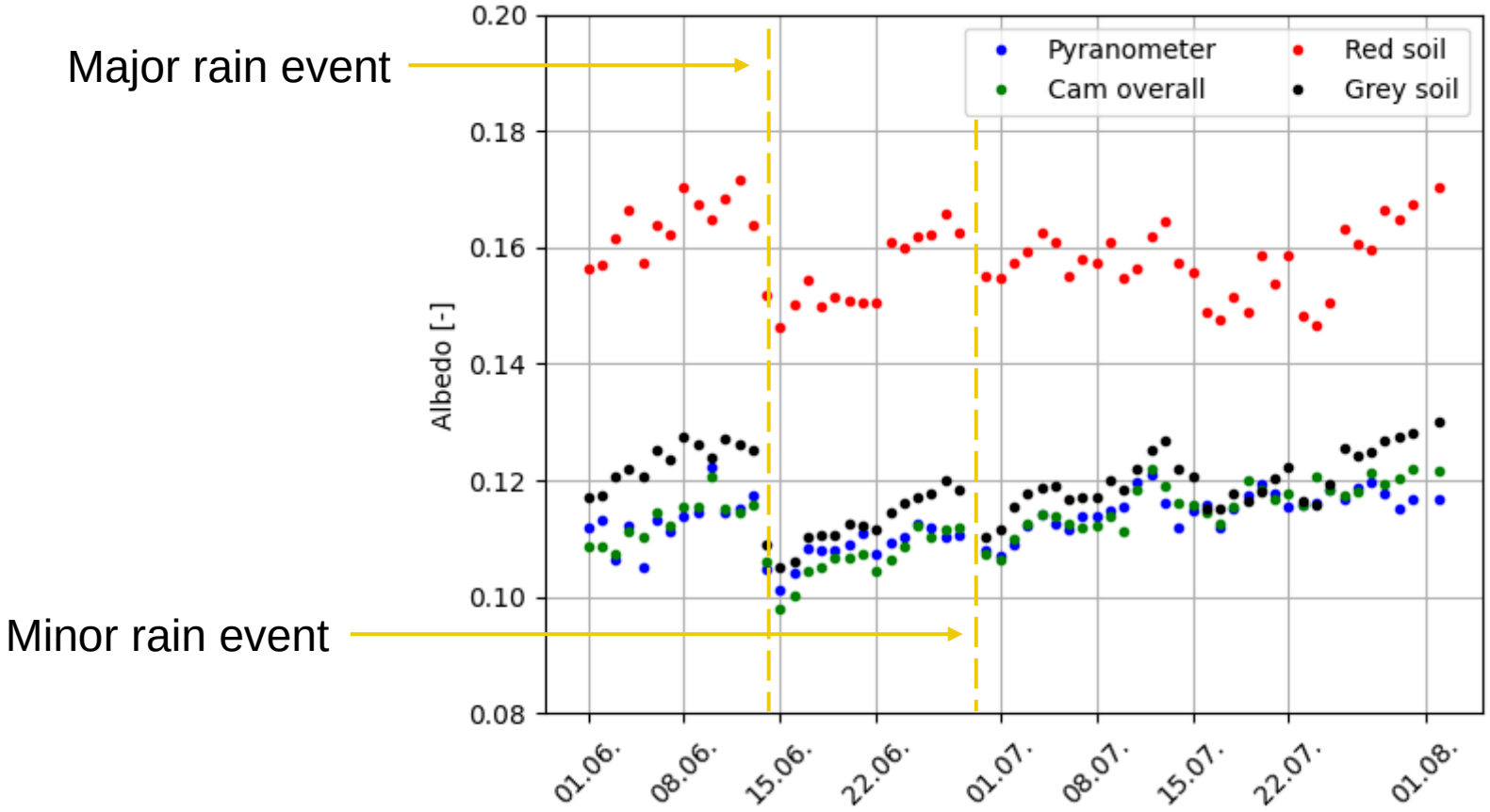
Case study in a PV installation – evaluation all-sky conditions (62 days)



- Camera reproduces ground-reflected irradiance from pyranometer well under all conditions
- Sky and environmental conditions (rain) influence albedo of all ground classes

Estimating albedo from camera images

Case study in a PV installation – evaluation all-sky conditions (62 days)



Comparison camera vs. pyranometer	
Mean cam	0.113
RMSE	0.002
Bias	1.8e-5 (One day used for calibration)

- Camera reproduces ground-reflected irradiance from pyranometer well under all conditions
- Sky and environmental conditions (rain) influence albedo of all ground classes



CONCLUSION

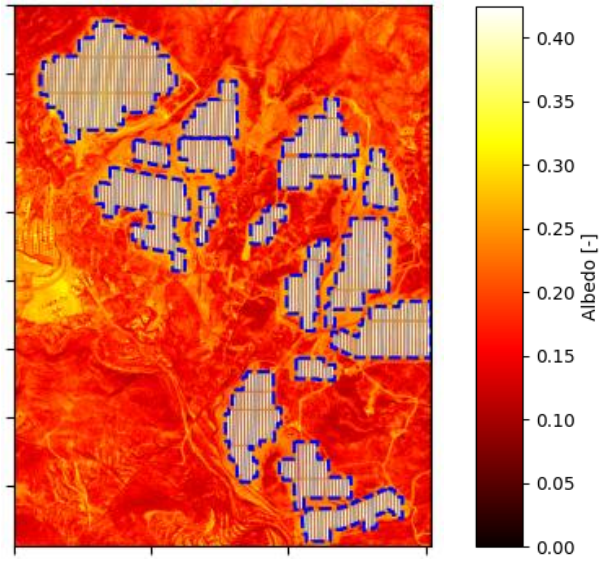
https://www.esa.int/Enabling_Support/Operations/Sentinel-2_teams_prepare_for_space

Conclusion

- A ground camera can measure ground albedo advantageously
  - Multiple ground cover types present in the camera image simultaneously
  - Also in the presence of high shares of shades ground
    - → No shadow-free space required
- Decimeter-resolution satellite images are suited to detect albedo variations within PV plants
- In combination satellite and camera can measure ground albedo more adequately than state-of-the-art approaches
  - Few measurement locations needed
  - No shadow-free space required as with state-of-the-art albedo measurements
  - Spatial variations of ground albedo resolved only in decimeter-resolution satellite images
- Accuracy increase of ground albedo expected to avoid ~2% error in PV yield assessment

Outlook

- Validations ongoing
  - Albedo and rPOA data from further demonstration sites will be presented
- Combination approach of ground measurements and remotely-sensed albedo will be presented







Images taken at PSA. The research site Plataforma Solar de Almería (PSA) is owned and operated by the Spanish CIEMAT



THANK YOU FOR YOUR ATTENTION!
QUESTIONS?

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