WGCV Interoperability Demonstrator: Surface Reflectance

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Committee on
Earth Observation Satellites

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Vniversitat de València

I2R

ReSe
APPLICATIONS

TELESPAZIO
a LEONARDO and THALES company

UMass Boston

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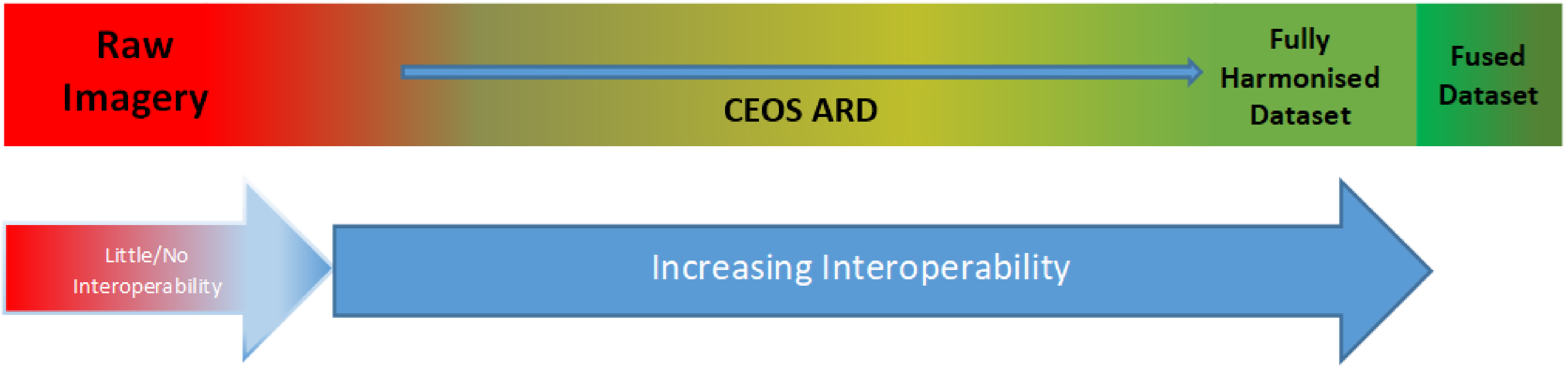
Background

- The CEOS-Analysis Ready Data Product Family Specification (PFS) provides a **strong basis for interoperability**.
- However, it **tolerates** different approaches for deriving the ARD, Surface Reflectance (SR) in particular. This affects the harmonisation of **multi-sensor products**, limiting their utility for applications requiring **time-series data** from several sources.
- Need to continue **building on the CEOS-ARD effort and developing approaches** to achieve better harmonisation of multi-sensor data.
- Proposal to **take the next steps** to support **better harmonisation of CEOS-ARD Surface Reflectance products** from multiple sources.
- Status update on the initiative – **work in progress.**

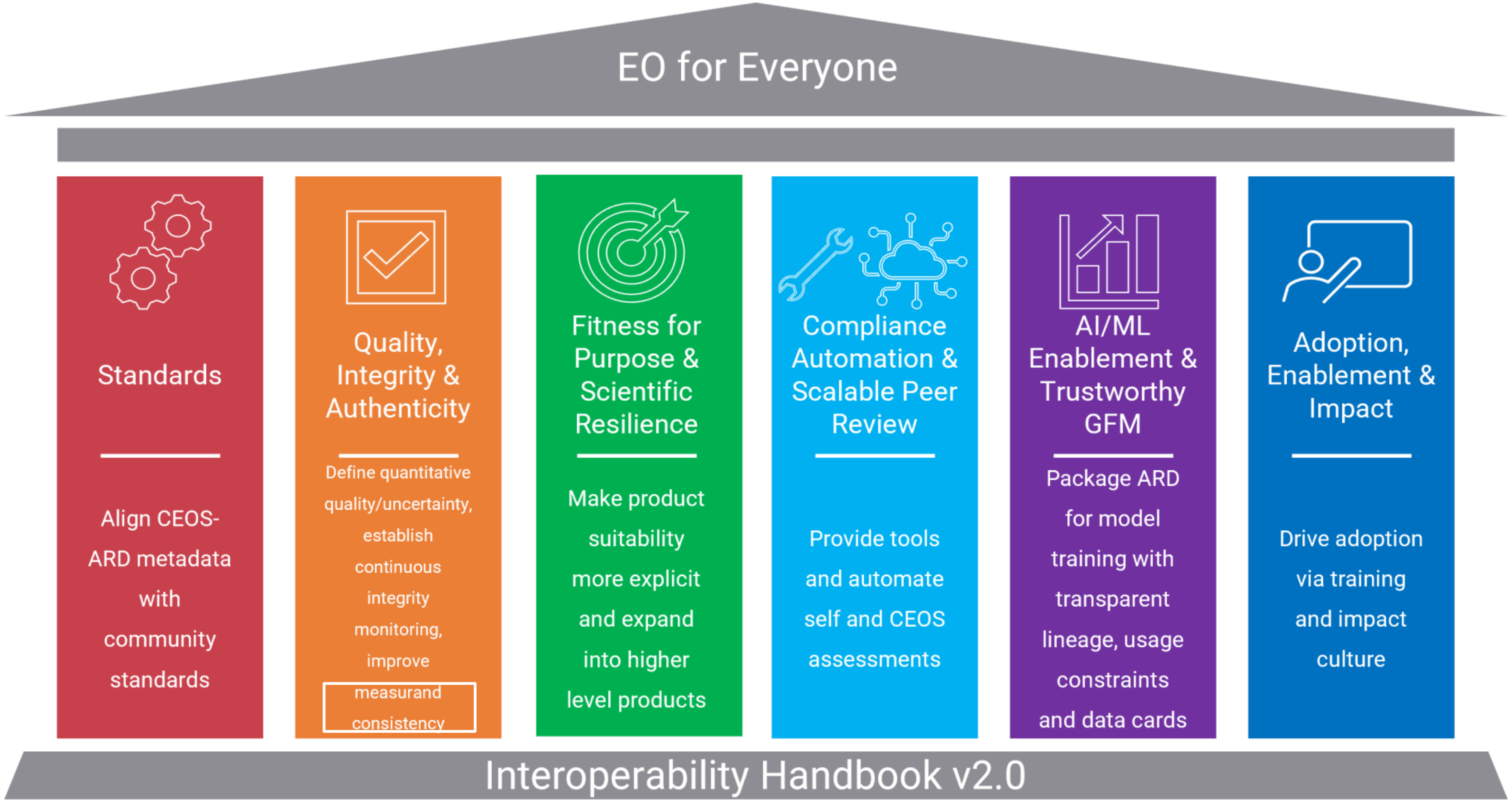
Correction and Inputs	ESA S2 L2A Sen2Cor	USGS L2 LASRC	GA Lambertian	GA NBAR	GA NBART
BRDF Model	-	-	-	Ross Thick, Li Sparse	
BRDF Parameters	-	-	-	MCD43A1 / VNP43	
BRDF: solar angle	-	-	-	✓	✓
BRDF: view angle	-	-	-	✓	✓
Atmospheric: solar angle view angle	-	✓ ✓	✓ ✓	✓ ✓	✓ ✓
Terrain illumination (slope/aspect/shadowing)	✓	-	-	-	✓
Adjacency	✓	-	-	-	-
Pressure	default	Internal based on DEM	MODTRAN default atmospheric profile - DEM altitude adjusted		
Air Temperature	default	MODIS/VIIRS CMG	MODTRAN default atmospheric profile - DEM altitude adjusted		
Aerosol Optical Thickness	DDV / CAMS	Internal algorithm	AATSR Climatology		
Water Vapor	Atmospheric Pre-corrected Differential Ab sorption	MODIS/VIIRS CMG	NOAA NCEP – DEM altitude adjusted		
Ozone	ECMWF	MODIS/VIIRS CMG	OMI/TOMS		
Atmospheric Correction	LibRadTran LUT	Internal algorithm/6S	MODTRAN 6		
Sun and Sky glint correction	-	-	-	-	-
DEM	Planet DEM COP DEM since 3.01	ETOPO5 (CMGDEM)	-	-	SRTM 1 sec (modified)

Why do we care?

- Inconsistency in surface reflectance products from different providers limits combined use of multi-sensor data, performing impactful analyses and gaining deeper insights.
- CEOS agencies' efforts in producing NASA HLS and ESA Sen2Like demonstrate the need to improve the compatibility of SR measurements across providers.
- Planned major Collection upgrades (e.g. USGS – Landsat C3) provide an opportunity for input in support of better alignment and harmonisation of SR products.
- CEOS-ARD is only the first step in the 'interoperability continuum', we need to plan the next steps to advance CEOS interoperability objectives.



Future CEOS-ARD strategy



CEOS-ARD Strategy 2026 will be developed throughout 2026 by the CEOS-ARD Oversight Group in collaboration with various CEOS entities and in consultation with external stakeholders.

Proposal

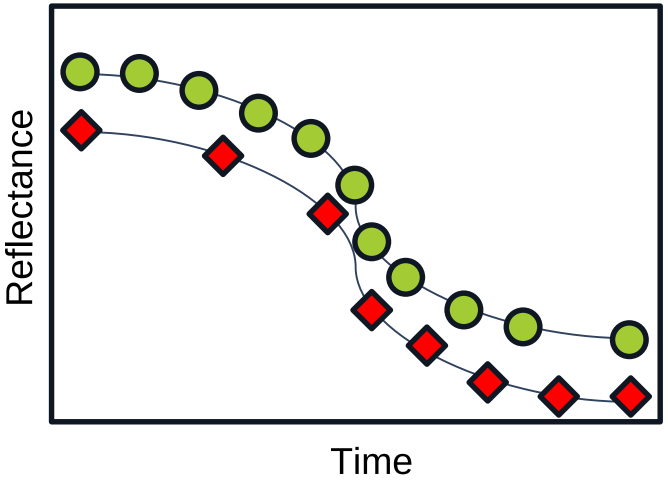
- Build on CEOS-ARD achievements so far, take next steps to achieve multi-sensor interoperability.
- Unambiguous characterisation of the SR measurand in the context of CEOS-ARD products.
- Identify a set of corrections for achieving better SR consistency in support of harmonised CEOS-ARD SR products.
- Develop guidance for achieving consistency in SR from multiple sources to support interoperability.

Benefits

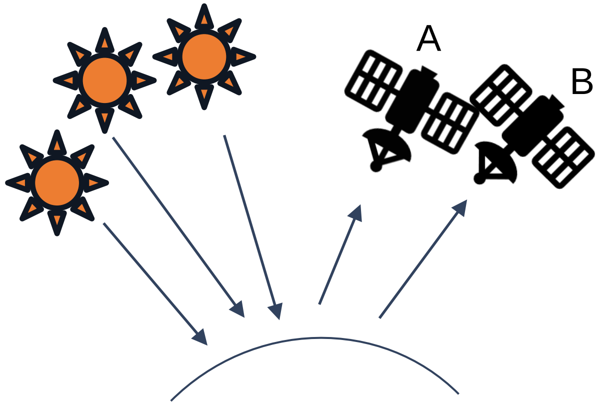
- Consistent time-series across sensors, steps towards enhanced harmonisation amongst CEOS-ARD SR products.
- Focused effort on value-adding with a common foundational measurand, improved results from multi-sensor analyses, and better insights.
- Reduced duplication of effort, cost savings, increased global applicability of algorithms, higher return on investment.

Conceptual model (current)

Illumination conditions

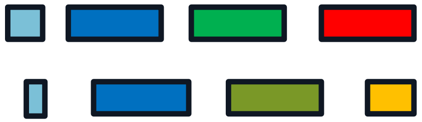


Surface Reflectance Profiles



Target characteristics

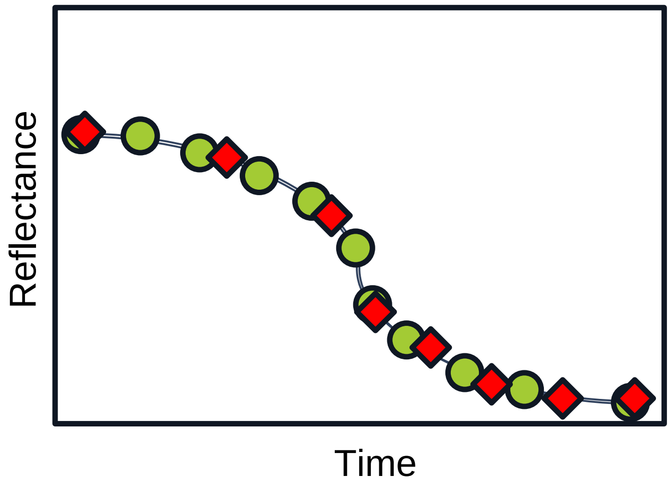
A
B



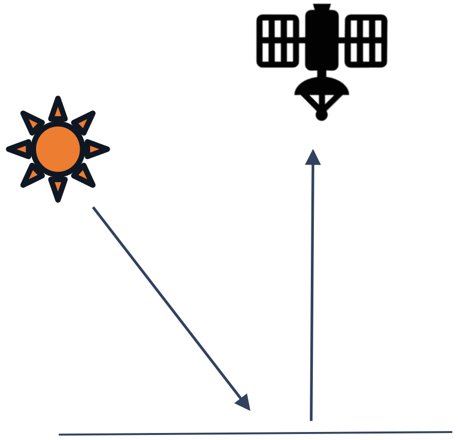
Datasets A and B

	A	B
Atmospheric correction	✓	✓
BRDF correction	✓	✗
Terrain Illumination correction	✓	✓
Adjacency correction	✓	✗
Solar angle normalization	✓	✗

Conceptual model (desired)



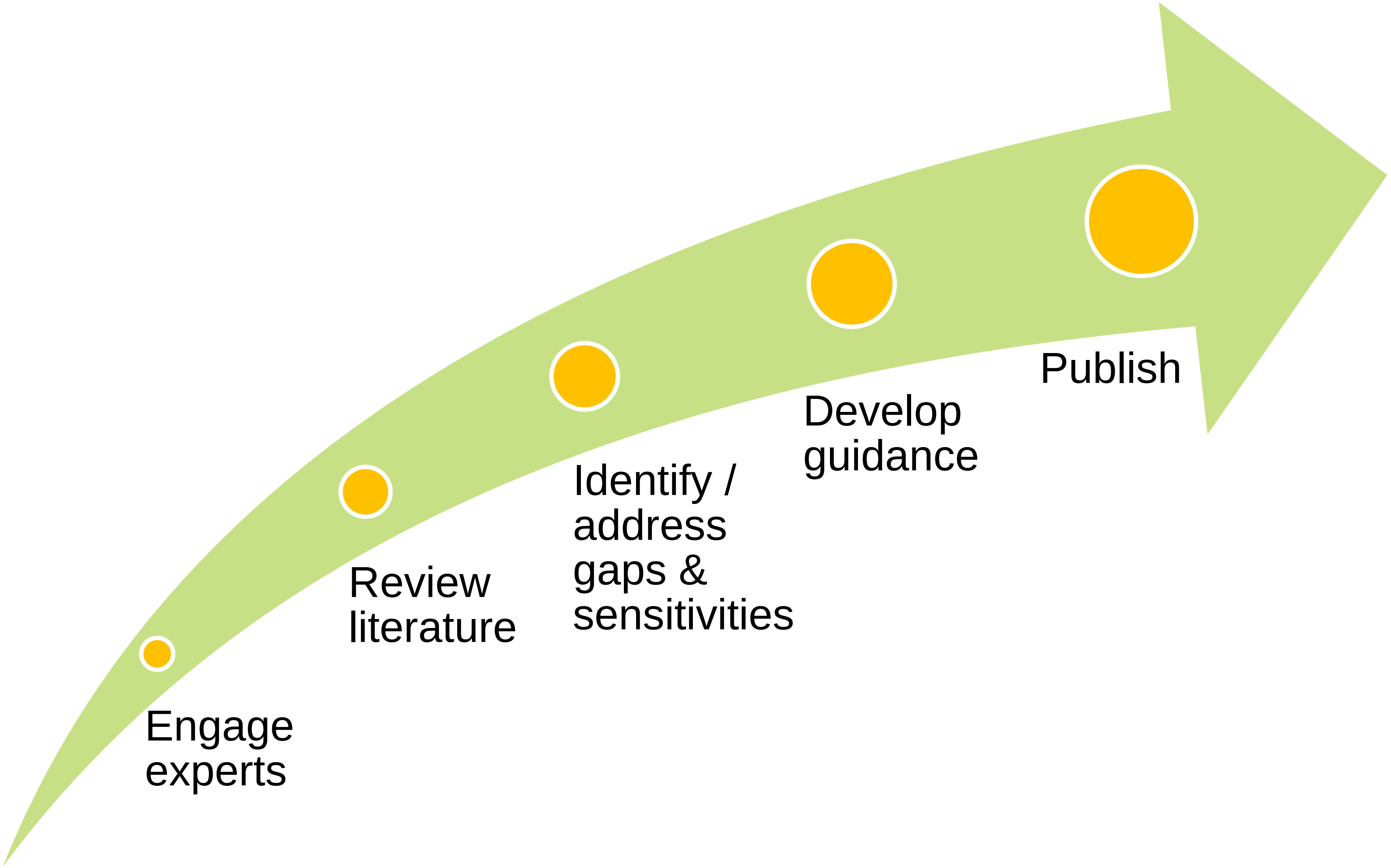
Surface Reflectance Profile



A+B  Harmonised datasets

	A	B
Atmospheric correction	✓	✓
BRDF correction	✓	✓
Terrain Illumination correction	✓	✓
Adjacency correction	✓	✓
Solar angle normalization	✓	✓

Process


Engage
experts
Review
literature
Identify /
address
gaps &
sensitivities
Develop
guidance
Publish

Status of activities

- Original concept first presented at ARD23 Workshop, exposure document of the concept presented at WGCV-52 in June 2023, then at LSI-VC 14 in October 2023, revised concept paper presented at WGCV-53 in March 2024.
- Following feedback, engaged the expert community after a call for 'Expressions of Interest' to participate in the Surface Reflectance Quality, and Consistency initiative.
- Fortnightly meetings of the expert group continue, initial discussions focussed on terminology to enable shared understanding of objectives for the work.
- Subsequent effort to document the discussions that could support interoperability initiatives within CEOS (Interoperability Framework, Handbook 2.0, led by WGISS).
- A guidance document on the SR quality and consistency initiative is in development with contributions from the expert group.

SR literature review

Retrieval of Pseudo-BRDF-Adjusted Surface Reflectance at 440 nm from GEMS	Lee, W., Kim, J., Park, S. S., et al. (2024). Retrieval of pseudo-BRDF-adjusted surface reflectance at 440 nm from GEMS: Surface reflectance retrieval using a hybrid approach. Atmospheric Measurement Techniques, 17(9), 5601–5616. https://doi.org/10.5194/amt-17-5601-2024	Integrating BRDF-based surface reflectance retrievals into operational environmental satellite algorithms to enhance the accuracy of satellite-derived surface reflectance products, and performance of level 2 atmospheric composition retrievals.
Evaluation of Surface Reflectance Products Based on Optimized 6S Model	Li, H., Liu, Y., & He, H. (2022). Evaluation of surface reflectance products retrieved from Landsat-8 OLI and Sentinel-2 MSI based on an optimized 6S model. Remote Sensing, 14(1), 83. https://doi.org/10.3390/rs14010083	Optimized 6S model reduces the mean percent absolute error (MPAE) by 32.20% for Landsat-8 OLI and 33.56% for Sentinel-2 MSI compared to the original 6S model

Retrieval of Ground Surface Reflectance from MODIS Satellite Data	Zhukov, V. N., & Mishin, D. Y. (2023). Retrieval of ground surface reflectance from MODIS satellite data using a correction model accounting for rugged terrain. Atmospheric and Oceanic Optics, 36(2), 203–211. https://doi.org/10.1134/S1024856024701604	Neglecting rugged topography can underestimate reflectance values, findings suggest that incorporating topographic effects can improve the accuracy of surface reflectance retrievals in rugged terrains
Uncertainty Quantification of Surface Reflectance for Satellite Hyperspectral Remote Sensing	Yan, B., Zhang, H., & Li, D. (2024). Uncertainty quantification of surface reflectance for satellite hyperspectral remote sensing in mountainous regions. In Proceedings of SPIE 13511, Remote Sensing of Clouds and the Atmosphere XXIX (Vol. 13511, p. 135112L). https://doi.org/10.1117/12.3056765	The uncertainty of at-sensor radiance and the uncertainty of direct solar irradiance are the two major sources of reflectance uncertainty. Provides a per-pixel, per-band uncertainty estimate, enhancing the reliability of

SR literature themes

Theme	Description
Introduction and Definitions	Overview of surface reflectance, its significance for remote sensing applications, and key foundational terms.
Atmospheric Correction Algorithms and Inter-Comparisons	Studies on atmospheric correction methods, comparative evaluations of algorithms, and assessments of correction accuracy.
BRDF Normalisation and Topographic Correction	Research on bidirectional reflectance distribution function (BRDF) normalisation and terrain/topographic correction to mitigate angular and elevation-related effects.
Traditional Inter-Sensor Harmonisation (Landsat–Sentinel-2)	Literature on physics-based methods for harmonising surface reflectance between different satellite platforms, particularly Landsat and Sentinel-2.
Surface Reflectance Product Evaluations and Datasets	Analyses of global and regional SR products, including validation studies and assessments of consistency, reliability, and temporal coverage.
Validation and Uncertainty Quantification	Research focused on validating SR data using ground-truth (in situ) measurements and approaches for quantifying uncertainty in reflectance estimates.
Machine Learning and AI-Based Harmonisation	Studies leveraging machine learning and artificial intelligence to harmonise reflectance across satellite sensors, with a focus on non-physics-based techniques.
Other Topics (not covered above)	Additional or emerging topics in surface reflectance not covered in the above categories.

Literature grouping

1. Introduction and Definitions

- **Holben & Fraser (1984)**: *Atmospheric effects on remote sensing of surface reflectance*.
  — Early foundational work discussing the impact of atmospheric effects on reflectance data.

2. Atmospheric Correction Algorithms and Inter-Comparisons

- **Li et al. (2010)**: *Evaluation of atmospheric and BRDF correction to standardize Landsat data*.
- **Li et al. (2012)**: *Physics-based atmospheric and BRDF correction for mountainous terrain*.
- **Zhou et al. (2022) / Li et al. (2022)**: *Evaluation of surface reflectance using optimized 6S model*.
- **Vermote et al. (2016)**: *Preliminary performance analysis of Landsat 8 surface reflectance*.
- **Zhukov & Mishin (2023)**: *MODIS terrain correction model*.
- **Chen et al. (2024)**: *Global 30m seamless data cube using Landsat and MODIS* (includes atmospheric correction methods).
- **Lee et al. (2024)**: *Pseudo-BRDF-adjusted surface reflectance retrieval using hybrid approach*.

3. BRDF Normalisation and Topographic Correction

- **Li et al. (2013)**: *Issues in applying DSM data for terrain illumination correction*.
- **Li et al. (2016)**: *Evaluation of TanDEM-X DEM for terrain correction*.
- **Li et al. (2017)**: *Improving BRDF normalisation using MODIS BRDF-vegetation relationships*.
- **Li et al. (2012)**: (Also fits here due to combined BRDF/topographic correction).

4. Traditional Inter-Sensor Harmonisation (Landsat–Sentinel-2)

- **Claverie et al. (2018)**: *Harmonized Landsat–Sentinel-2 dataset*.
- **Ju et al. (2025)**: *Version 2.0 Harmonized Landsat–Sentinel-2 SR dataset*.
- **Chen et al. (2024)**: *Harmonisation across Landsat 5–9 and MODIS*.

5. Surface Reflectance Product Evaluations and Datasets

- **Feng et al. (2012)**: *Quality assessment using MODIS*.
- **Feng et al. (2013)**: *Global SR products from Landsat assessed with MODIS*.

Inference from themes (example)

Topographic and Terrain Illumination Correction

Key references:

Richter (1998); Sandmeier & Itten (1997); Li (2012, 2013, 2016); Schläpfer (2014); Jia et al. (2020)

Literature Conclusions:

- ✓ Illumination geometry and terrain-induced radiance anisotropy significantly bias surface reflectance in rugged terrain.
- ✓ Physically based approaches (radiative transfer + DEM-informed illumination modelling) outperform empirical cosine corrections in preserving spectral integrity (Sandmeier & Itten, 1997; Richter, 1998).
- ✓ Physics-based terrain correction (Li et al., 2012, 2013) improves reflectance consistency across slopes and aspects, particularly in heterogeneous landscapes.
- ✓ Use of high-resolution DEMs (e.g., TanDEM-X; Li et al., 2016) enhances correction fidelity.
- ✓ Operational BRDF-terrain coupling schemes (Schläpfer et al., 2014; Jia et al., 2020) demonstrate feasibility for airborne and satellite systems.

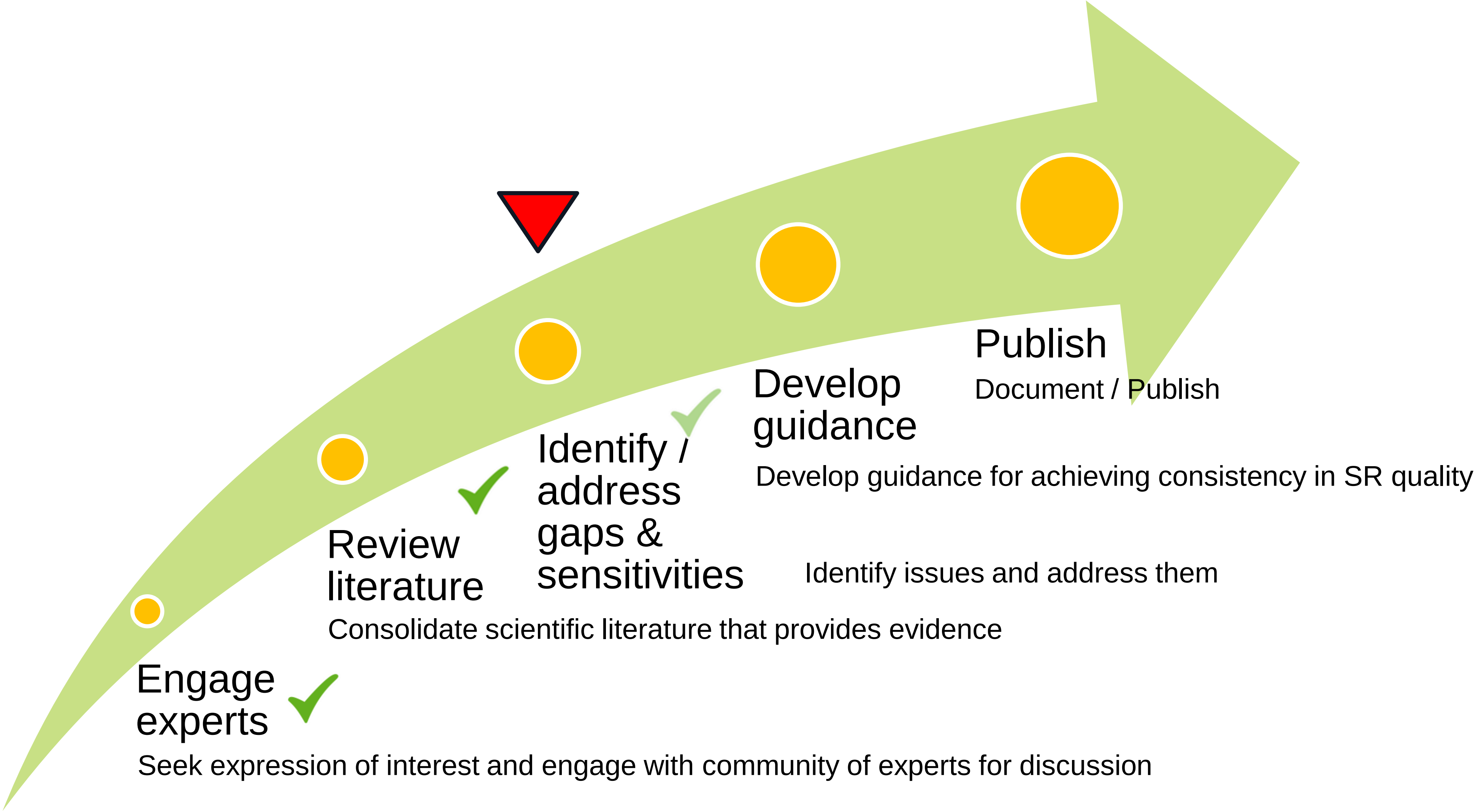
Impact on Cross-Sensor Consistency

- ✓ Uncorrected terrain effects introduce sensor-dependent biases due to differing overpass geometries and view angles.
- ✓ Physics-based terrain correction reduces directional artifacts, enabling more consistent reflectance retrievals across Landsat, MODIS, Sentinel-type and airborne systems.
- ✓ DEM quality becomes a limiting factor for harmonisation in mountainous regions.

Implications

- ✓ Terrain correction must be integrated with atmospheric and BRDF normalisation for ARD compliance.
- ✓ Harmonised global DEM standards are critical for multi-sensor product families.
- ✓ Terrain-BRDF coupling should be considered mandatory in high-relief environments for cross-mission consistency.

Where we are now



Upcoming meetings

JACIE 2026: 13–17 April, USGS Headquarters in Reston, Virginia

CEOS WGCV-56: 20-24 April, joint with **CEOS LSI-VC-19** Meeting at USGS EROS, Sioux Falls, South Dakota

40th CEOS Plenary, 3-6 November Hobart, Australia

Thank you

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