CEOS-LPV Quarterly Meeting Q2 2026: Intro and feedback from CEOS-WGCV/LSI-VC

Fabrizio Niro
(Serco/ESA-ESRIN)

23 March 2026

CEOS
Committee on Earth Observation Satellites

Outline

- Upcoming CEOS-WGCV & LSI-VC Joint Meeting
- Update on Future CEOS-ARD
- Publication of LPV supersites V2
- Collaborations and Events
- Protocol and FA lead status

WGCV-56 & LSI-VC-19 Joint Meeting

- The **CEOS-WGCV and LSI-VC** Meetings will be held **jointly** from **20-24 April 2026** at EROS Center in Sioux Falls, South Dakota
- In addition to the individual WGCV and LSI meetings, a substantial portion of the week will be dedicated to **joint sessions**, to discuss around data quality and interoperability, with focus on **future CEOS-ARD**

https://ceos.org/ard/

CEOS Analysis Ready Data (ARD)

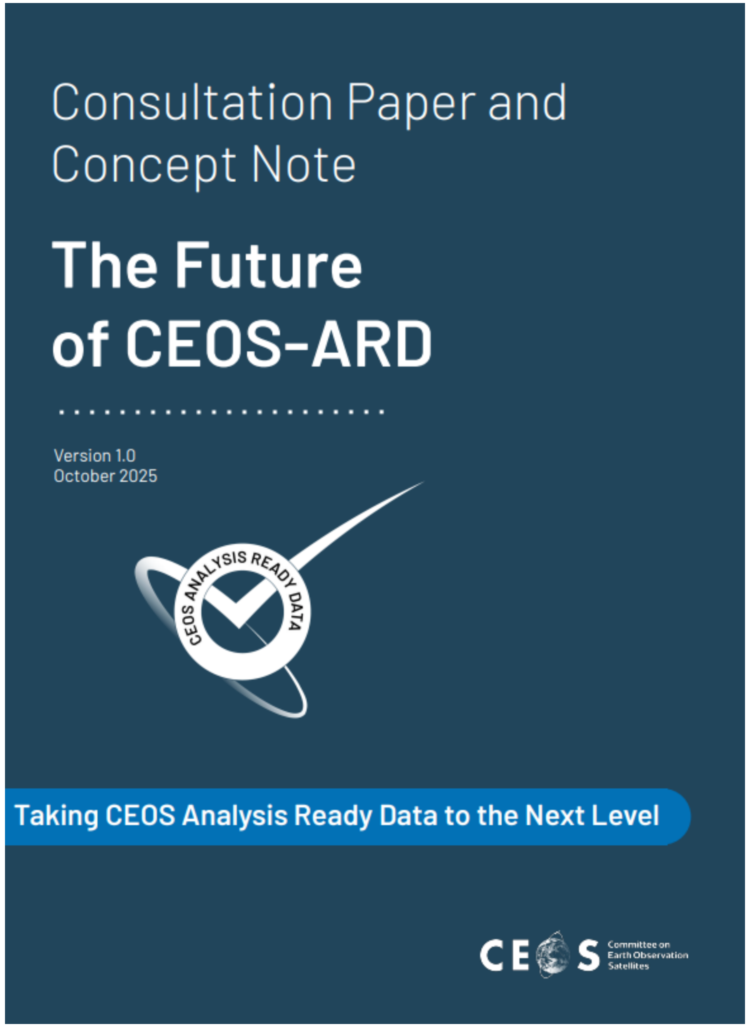
https://ceos.org/ard/

- CEOS-ARD are **satellite data** that have been processed to a **minimum set of requirements** and organized into a form that allows **immediate analysis** with a **minimum** of additional user effort
- **Aims**
  - **Reduce barriers** to the uptake of EO data
  - Enable **new applications** and users
  - Improve data **interoperability**
- Since 2016, nine CEOS-ARD Product Family Specifications (**PFS**) elaborated

Future CEOS-ARD concept paper

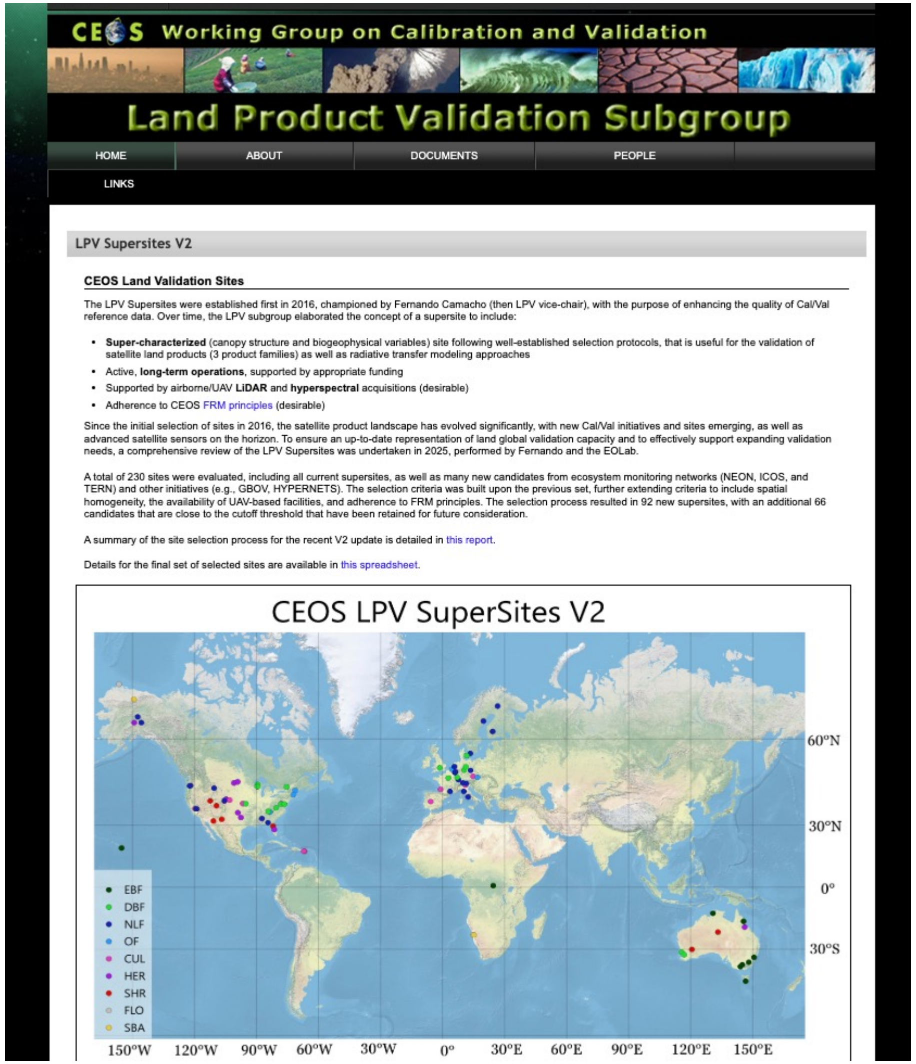
https://ceos.org/ard/

- Among the topics to be addressed in future CEOS-ARD, the LPV group can contribute to defining :
  - **Enhanced Metadata** Specifications
  - Data and Metadata **Quality**
  - **Thematic and Higher-level ARD Products**
- Feedback for LPV was requested, such as defining new PFS for land products, e.g., SM, AF, FRP,…
  - **Minimum processing steps**, **metadata** completeness, **quality** information



LPV Supersites V2 published

- **90 sites**, list and report published:
  - **Super-characterized** (canopy structure and bio-geophysical variables) following well-established protocols, useful for the validation of satellite land products (**3 product families**) and RTM approaches
  - Active, **long-term operations**, supported by appropriate funding
  - Supported by airborne/**UAV LiDAR** and **hyperspectral** acquisitions (desirable)
  - Adherence to **CEOS-FRM** (desirable)



https://lpvs.gsfc.nasa.gov/LPV_Supersites/LPVsites.html

Collaborations and events

- Collaboration with **GEOGLAM** on ET
  - First meeting with GEOGLAM held on 2nd Dec 2025, follow-up emails to define scope and agenda of an **ET Validation WS**
  - Joint LPV-GEOGLAM ET Workshop: **22-24 June, FAO** (Rome)
  - **Draft LPV ET protocol** will be presented aiming at gathering feedback and needs from GEOGLAM community, similar to what was done for the LC protocol
- Future events
  - Agreed to organise **LPVE 2027 WS in ESA/ESRIN** (Q2 2027 TBC)
  - **CEOS-LPV 2027 Plenary** will be held after the LPVE WS

Protocol Status

- **LC** protocol

  Will be presented at **CEOS-SIT Meeting** (April 14th - 16th, 2026, Irvine) for endorsement

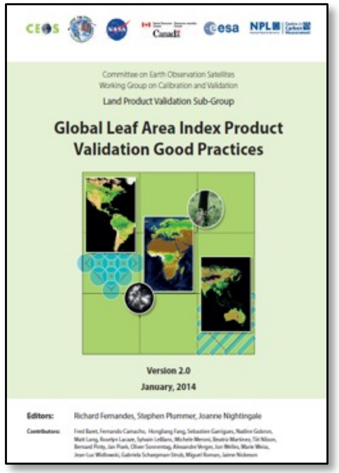
- On-going efforts

  Update of **fAPAR/LAI**, draft paper in preparation

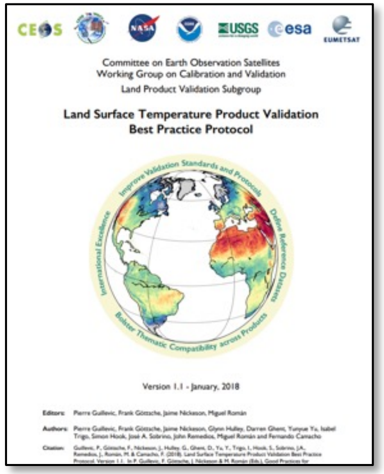
  VI and **LSP**: consolidated draft ready to be finalised

  Fires, **SM** update planned

  1st draft **ET** on-going

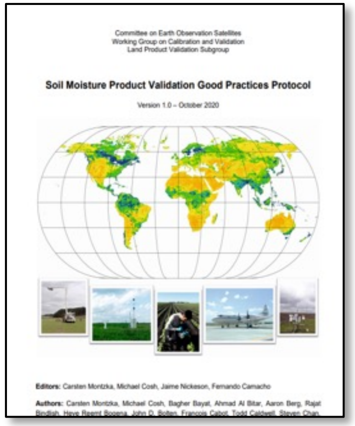


2014 - LAI



2018 - LST

2019 - Albedo



2020 - SM

2021 - AGB

2025 - LC

FA leads status

	First Name	Last Name	Institution	Country	End of Term
Admin	Fabrizio	Niro	ESA	Italy	Apr 2028
	Vacant				
	Jaime	Nickeson	GSFC	USA	
Land Cover	Alexandra	Tyukavina	University of Maryland	USA	Mar 2027 (2nd term)
	Nandika	Tsendbazar	Wageningen University	Netherlands	April 2027 (1st term)
	Sophie	Bontemps	Université Catholique de Louvain	Belgium	**ex-officio**
Biophysical	Richard	Fernandes	Natural Resources Canada	Canada	Apr 2027 (one term)
	Hao	Teng	University of Maryland	USA	April 2027 (1st term)
	Luke	Brown	University of Salford	UK	Jan 2026 (1st term)
Fire/Burn Area	Louis	Giglio	University of Maryland	USA	Sep 2026 (2nd term)
	Bernardo	Mota	National Physical Lab	UK	Jan 2026 (1st term)
Surface Rad	Zhuosen	Wang	GSFC	USA	**ex-officio**
	Angela	Erb	Leidos	USA	Jan 2026 (1st term)
	Jorge	Sanchez-Zapero	EOLab	Spain	Jan 2026 (1st term)
Soil Moisture	John	Bolten	NASA GSFC	USA	Apr 2026 (2nd term)
	Alexander	Gruber	TU Wien	Austria	Oct 2026 (1st term)
LST	Thomas	Holmes	NASA/GSFC	USA	Dec 2028 (1st term)
	Lluis	Perez Planells	Karlsruhe Institute of Technology	Germany	Sept 2026 (1st term)
Phenology	Joshua	Gray	North Carolina State University	USA	Jan 2025 (2nd term)
	Victor	Rodríguez-Galiano	University of Seville	Spain	Aug 2025 (2nd term)
	Qiaoyun	Xie	The University Of Western Australia	Australia	Sep 2028 (1st term)
Snow Cover	Carrie	Vuyovich	NASA GSFC	USA	Jan 2026 (1st term)
	Juha	Lemmetyinen	Finnish Meteorologial Inst.	Finland	Sep 2026 (1st term)
Veg Index	Tomoaki	Miura	University of Hawai'i	USA	**ex-officio**
	Simon	Kraatz	USDA	USA	Apr 2027 (1st term)
	Sarah	Gebruers	VITO	Belgium	Sep 2028 (1st term)
Biomass	Laura	Duncanson	UMD/GSFC	USA	**ex-officio**
	Kim	Calders	Ghent University	Belgium	Feb 2026 (1st term)
	Mikhail	Urbazaev	GFZ	Germany	Jan 2029 (1st term)
	KC	Cushman	ORNL	USA	Jan 2029 (1st term)
ET	Yun	Yang	Cornell University	USA	Jan 2027 (1st term)
	Carmelo	Cammalleri	Politecnico di Milano	Italy	Jan 2027 (1st term)
GPP/NPP	Arthur	Endsley	University of Montana	USA	Sept 2027 (1st term)
	Álvaro	Moreno	University of Valencia	Spain	Nov 2027 (1st term)

NEW co-lead in **Phenology**
Dr. Qiaoyun Xie
The University Of Western Australia

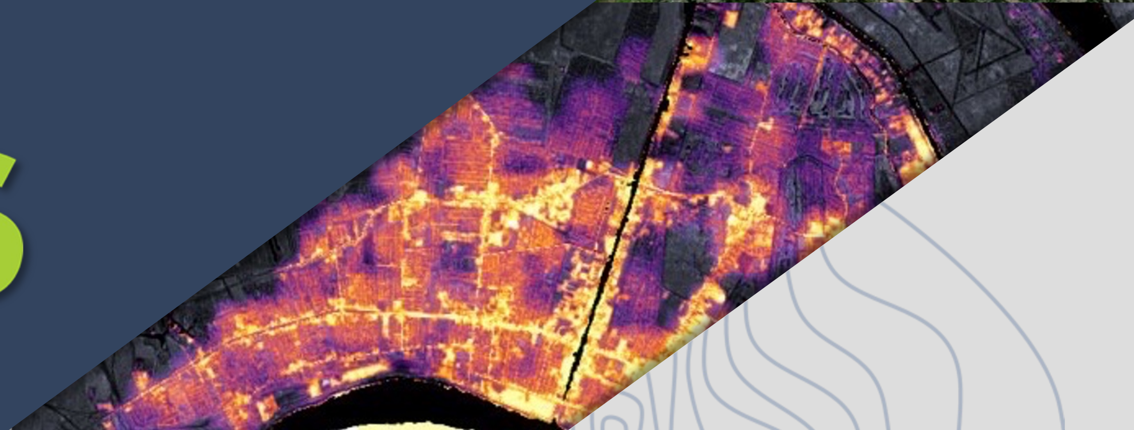
NEW co-lead in **VI**
Dr. Sarah Gebruers
VITO
Belgium

NEW co-lead in **Biomass**
Dr. Mikhail Urbazaev
GFZ
Germany

NEW co-lead in **Biomass**
Dr KC Cushman
ORNL
USA

Still vacant:
- Vice-chair

Reports from FA leads



Committee on
Earth Observation Satellites

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Land Cover Focus Area

Alexandra (Sasha) Tyukavina (U. Maryland, USA)
Nandika Tsendbazar (Wageningen University, Netherlands)

LPV – March 24, 2026

Land Cover updates (1/2)

Validation guidelines dissemination update:

- Presentation at CEOS Strategic Implementation Team (SIT) Meeting (Irvine, CA, April 15-16) – Sasha Tyukavina
  - 15-minute presentation highlighting the main updates of the guidelines;
  - Expected endorsement of CEOS.

- Oral presentation is accepted at StatEO2026 (Frascati May 5-7) – Nandika Tsendbazar
  - Good audience for disseminating the guidelines;
  - But was requested to combine with another presentation of Nandika.

CEOS WORKING GROUP ON CALIBRATION & VALIDATION

Biophysical (1/1)

<u>Good practices update</u>

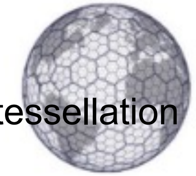
- 15+ responses received on draft paper – lots of useful feedback on methods which is being worked through

- Original timeline has proven challenging due to external circumstances affecting focus area leads
  - Consequently, *Remote Sensing of Environment* special issue deadline was unrealistic
  - Update sent to all contributors in February

- Focus area leads have agreed to instead target a regular issue of the new EGU *Earth Observation* journal (https://www.earth-observation.net/)
  - Not-for-profit and open review

Copernicus LCFM 10m LC validation (2/2)

- 2020 LC 10 validation report was published
(the map was published last year).
- It uses a systematic sampling design based on a hexagonal tessellation
- Primary sample unit is 10x10 pixels



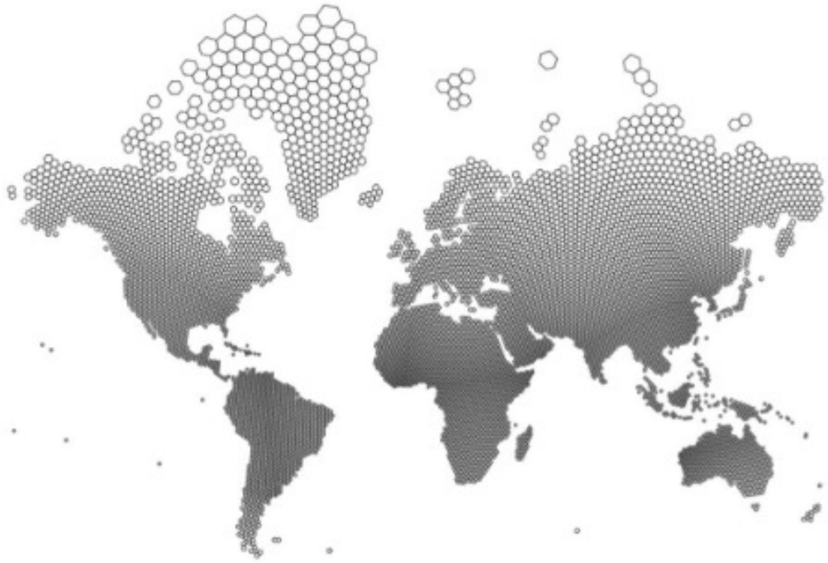
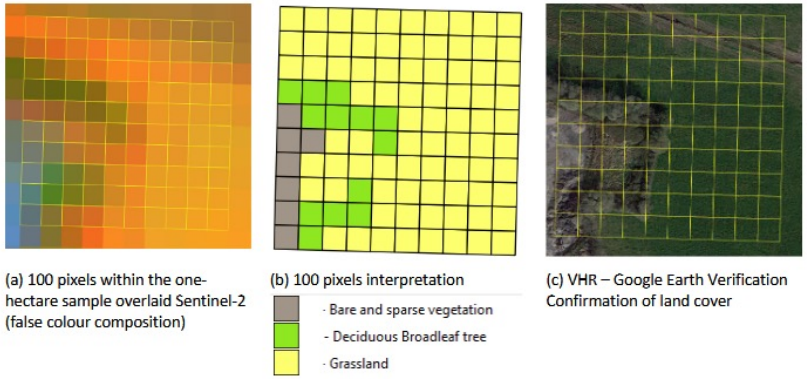


Figure 2: Hexagonal tessellation (Level 3) of the earth, based on a truncated icosahedron and single hexagon plot.

Table 2: Producer and user accuracy of LCM-10 given by Land cover classes - validation analysis LCM-10 V1 for 2020.

		Validation LCM-10 2020 V1 Raster product					
Code		PA (%)	ΔPA (%)	OE (%)	UA (%)	ΔUA (%)	CE (%)
10	Tree cover	90.90	0.04	9.10	83.39	0.44	16.61
20	Shrubland	67.90	0.33	32.10	56.39	0.93	43.61
30	Grassland	64.53	0.14	35.47	82.44	0.46	17.56
40	Cropland	86.22	0.09	13.78	87.04	0.63	12.96
50	Herbaceous wetland	73.62	0.58	26.38	77.20	2.23	22.80
60	Mangroves	100.00	0.00	0.00	100.00	0.00	0.00
70	Moss and lichen	83.66	0.36	16.34	61.34	1.88	38.66
80	Bare /sparse vegetation	86.79	0.06	13.21	89.33	0.46	10.67
90	Built-up	77.83	0.72	22.17	59.87	2.81	40.13
100	Permanent water bodies	92.23	0.09	7.77	89.13	1.12	10.87
110	Snow and ice	99.92	0.06	0.08	85.64	1.91	14.36
254	Unclassifiable	/	/	/	/	/	/
255	No data	/	/	/	/	/	/
Overall accuracy		80.10 ±0.20 %					



(a) 100 pixels within the one-hectare sample overlaid Sentinel-2 (false colour composition)

(b) 100 pixels interpretation

(c) VHR – Google Earth Verification Confirmation of land cover

Figure 6: Land cover maps interpretation procedure.

https://land.copernicus.eu/en/technical-library/product-validation-report-global-land-cover-10-m/@@download/file

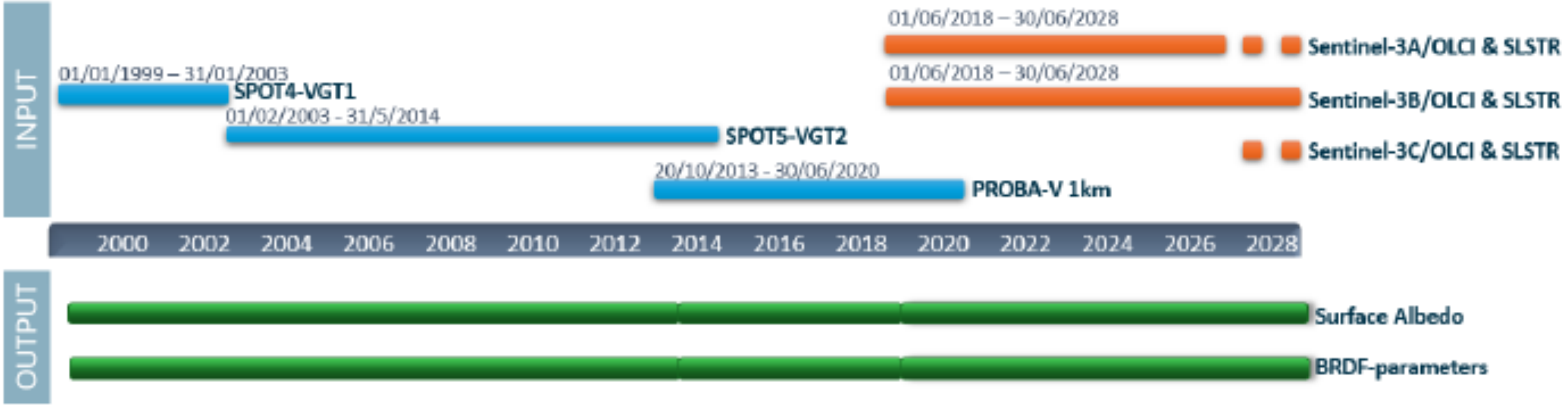
A set of 10,702 samples

Focus Area Reports

Surface radiation: Angela Erb, Jorge Sánchez-Zapero

- *Copernicus Climate Change Service*
- ***Surface albedo next phase → KOM 30/03/2026***

- ***Current Status of the service: Different versions across sensors, algorithms, resolutions.***
  - ***V1.0, V2.0 for NOAA/AVHRR (4km), SPOT/VGT & PROBA-V (1km)***
  - ***V3.1 for Sentinel-3/OLCI&SLSTR (300m)→ The most accurate product***



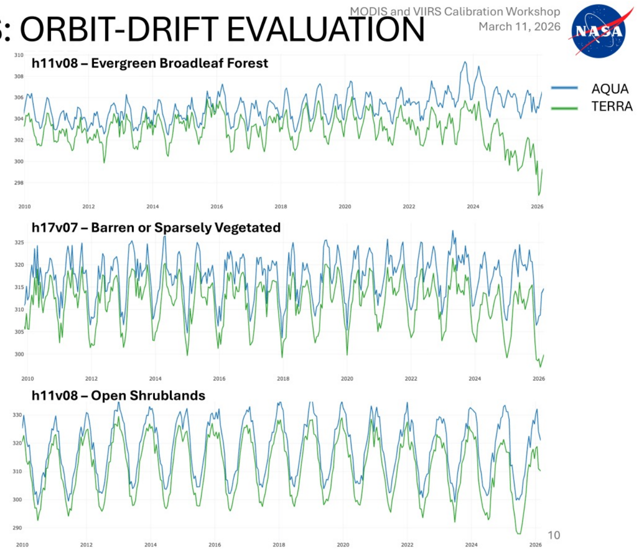
- ***Objective of this phase:***
  - ***Provide homogeneous V4.0 with same algorithm used in V3.1 (most accurate) and provide CDR at 1km spatial resolution from SPOT/VGT (1999-2014), PROBA-V (2014 – 2020) and Sentinel-3/OLCI&SLSTR (07.2018 – 2028).***
  - ***Include BRDF parameters in this new version.***

Focus Area Reports

- **Surface radiation:** **Angela Erb, Jorge Sánchez-Zapero**
- Terra MODIS and Aqua MODIS to be decommissioned in Feb and Sept 2027
- Suomi-NPP will proj. to stop collected science data in late 2026
- Continuity record continues through JPSS-1 and JPSS-2 (and future JPSS-4 and JPSS-3)
- MODIS/VIIRS Calibration/Validation workshop hosted at GSFC. LDOPE slides here show status of MODIS/VIIRS sensor calibration and consistency: https://modis.gsfc.nasa.gov/sci_team/meetings/202603/index.php

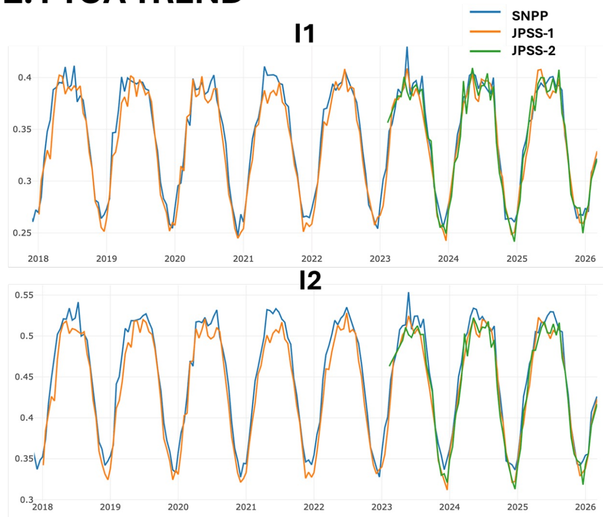
TERRA/AQUA - MODIS: ORBIT-DRIFT EVALUATION

- Land Surface Temperature (LST) Trends Observed Over Dominant Land Cover Types (Averaged) shows trend in the LST from drift.
- Aqua MODIS with later afternoon overpass-time and hotter condition exhibiting stable/slightly upward trend.
- Terra MODIS with earlier morning overpass-time and cooler condition exhibiting downward trend.



C2 SNPP/JPSS-1/JPSS-2.1 TOA TREND

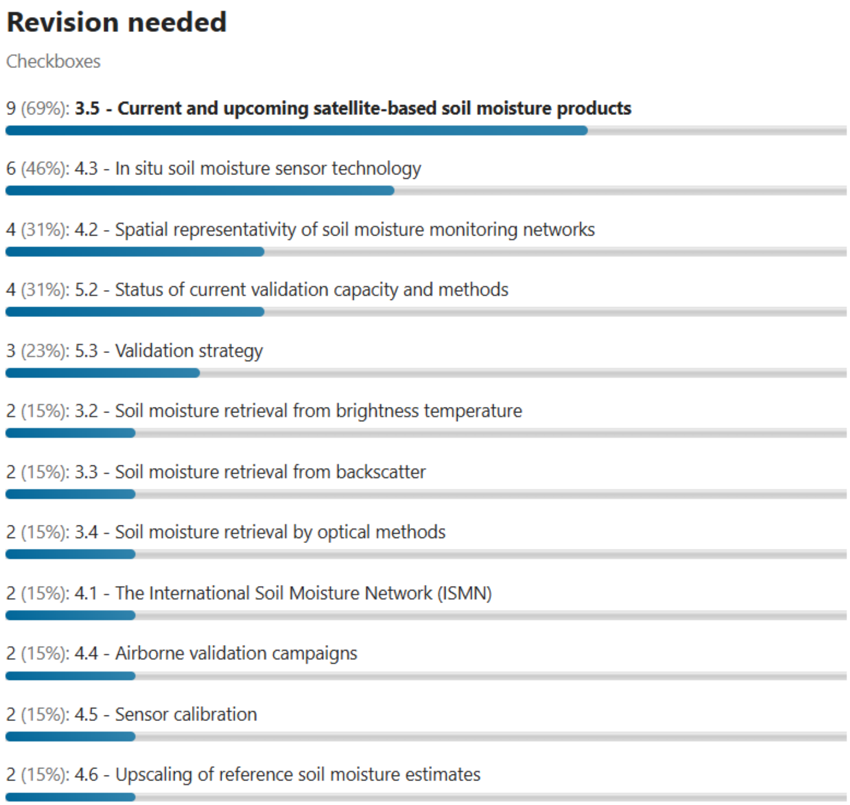
- Near-Nadir TOA (L1B) Trends Observed Over 13 Desert Calibration Sites (Averaged).
- Consistent agreement observed in all bands and across sensors.
- Similar stable trends observed in Golden-Tiles across major land cover types.



CEOS WORKING GROUP ON CALIBRATION & VALIDATION

Soil Moisture Validation Good Practice Protocol

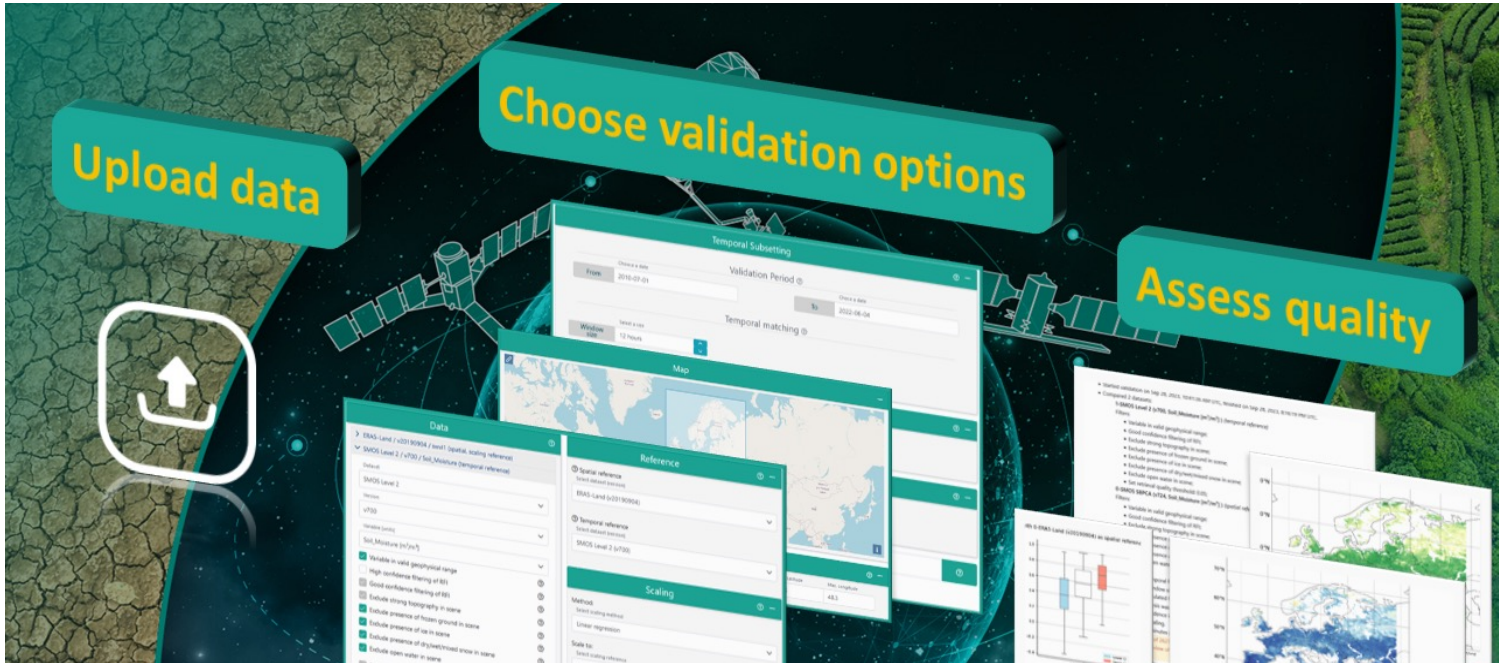
- Author consolidation for Protocol v2.0 ongoing
  - Revision draft planned for end 2026, publishing ~ March 2027?
  - 61 authors invited (Some updates to CEOS LPV SM mailing list done)
  - Survey ongoing about which sections require updates



Quality Assurance for Soil Moisture

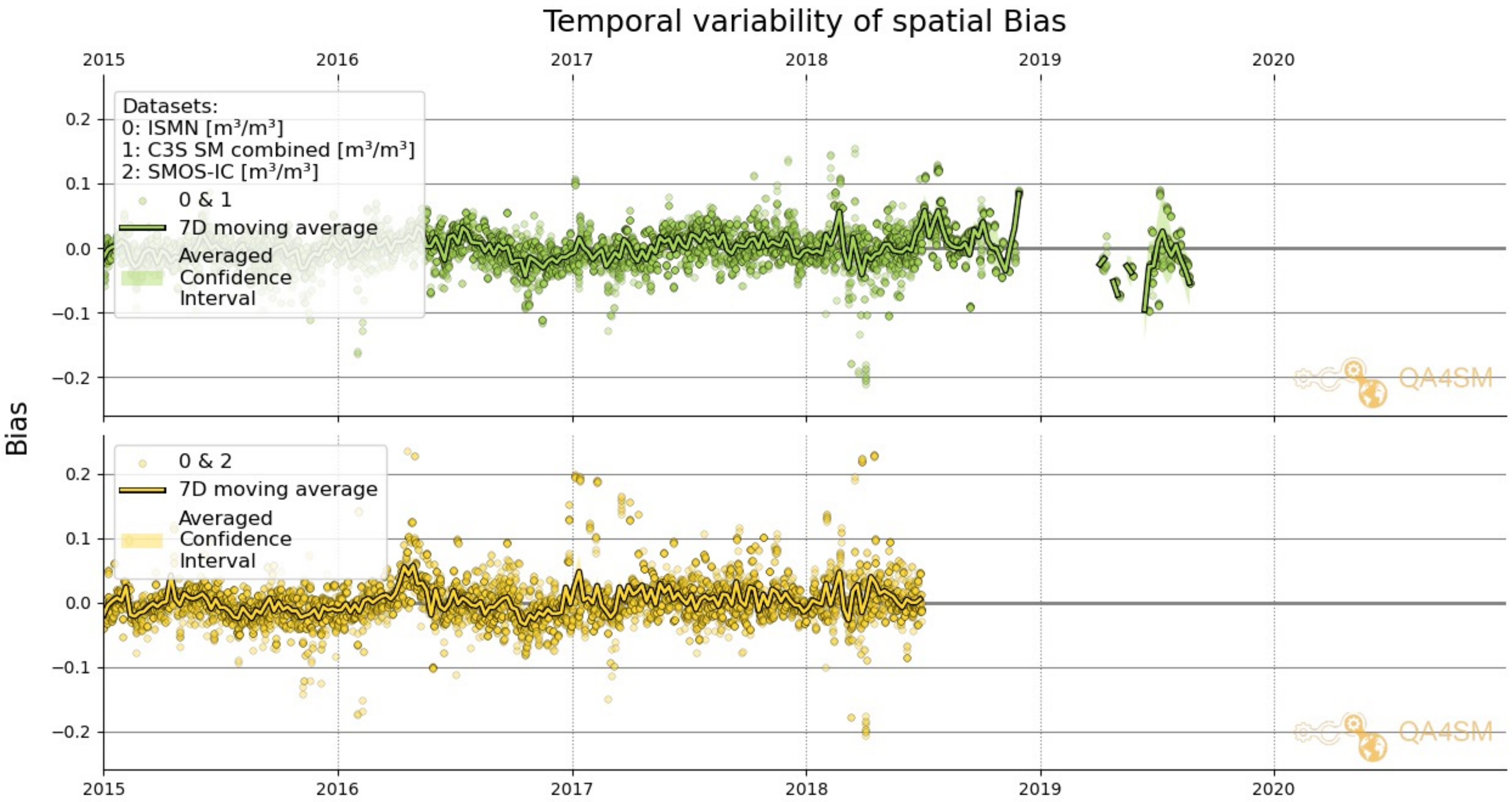
- Upcoming QA4SM Features
  - Temporal tracking of “spatial validation metrics”
  - Fully automated NRT validation reports
  - Interactive Validation Result Viewer

https://qa4sm.eu/



Quality Assurance for Soil Moisture

- Spatial validation metrics



CEOS WORKING GROUP ON CALIBRATION & VALIDATION

Quality Assurance for Soil Moisture

- Automated validation reports
  - Airflow-based NRT data updates
  - Custom API-based service automation
  - Customizable LaTeX Template to create validation reports (incl. epoch comparisons, etc.)

4 Validation run #1

Figure 4 shows the spatial extent of the validation run to compare SMOS L2 against ERA5-Land. All statistics and plots in this chapter refer to the area shown in 4.

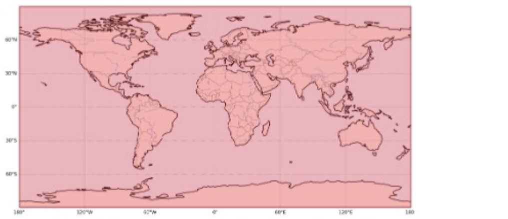


Figure 4: Spatial extent of the validation run to compare SMOS L2 against ERA5-Land. The area shown in red in included in the validation run.

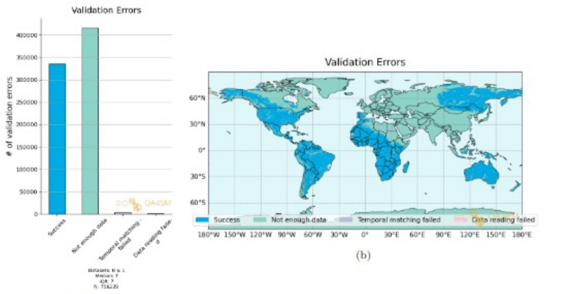
4.1 Validation settings

The following settings were chosen in the validation run of SMOS L2 against ERA5-Land:

- Spatial reference: **SMOS L2**
- Temporal reference: **SMOS L2**
- Scaling reference: **None**
- Temporal matching window was set to **6** hours.
- Validation metrics were calculated from **absolute value**.
- Triple collocation analysis was deactivated
- Bootstrapping of confidence intervals for Triple Collocation Analysis was deactivated.
- Stability metrics were deactivated.
- Intra annual metrics were deactivated.
- Scaling method: No scaling.
- Processing took 1050 minutes (wall time).

4.2 Results

For **55.627% (420664 of 756229)** of the processed locations (grid points) the validation metrics could not be calculated. The status code for all test cases is shown in Fig. ??. A map overview of locations where the validation run was successful and the potential reason for failed metrics computation is given in Fig. 5



(a) (b)

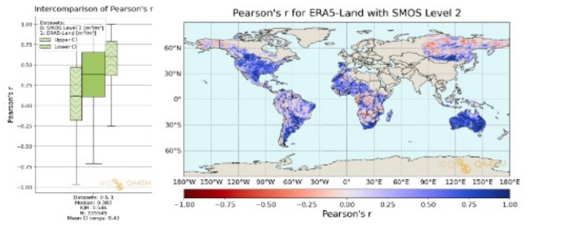
Figure 5: Number of successful test cases and errors raised (a), and their location (b) in the validation run of SMOS L2 against ERA5-Land.

The summary statistics for all metrics computed by QA4SM are shown in Table 2.

Metric	Mean	Median	IQ range
N.obs.	28.26	0	66.
Pearson's r	0.45	0.38	0.55
Spearman's rho	0.41	0.34	0.49
Root-mean-square deviation in m^3/m^3	0.13	0.12	0.12
Bias in m^3/m^3	-0.10	-0.10	0.15
Unbiased root-mean-square deviation in m^3/m^3	5.6e-02	5.23e-02	4.45e-02
Mean square error in $(m^3/m^3)^2$	2.45e-02	1.55e-02	3.03e-02
Mean square error correlation in $(m^3/m^3)^2$	2.98e-03	2.02e-03	3.73e-03
Mean square error bias in $(m^3/m^3)^2$	2.05e-02	1.05e-02	2.81e-02
Mean square error variance in $(m^3/m^3)^2$	1.10e-03	3.26e-04	1.04e-03
Residual sum of squares in $(m^3/m^3)^2$	1.59	0.84	1.84
Validation errors	3.59	7.	7.

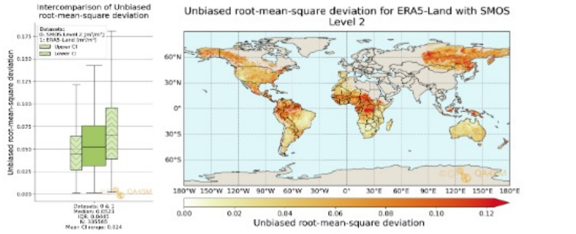
Table 2: Summary statistics

Figure 6 shows the distribution of Pearson's R values between SMOS L2 and ERA5-Land. Figure 7 shows the same in terms of ubRMSD, and 8 for the Bias. For visualizations of all other metrics, we refer to the validation results available on QA4SM (link in Table ??).



(a) (b)

Figure 6: Pearson's R between SMOS L2 and ERA5-Land as a box plot with the upper and lower confidence interval as narrow boxes (a), as a map plot (b).

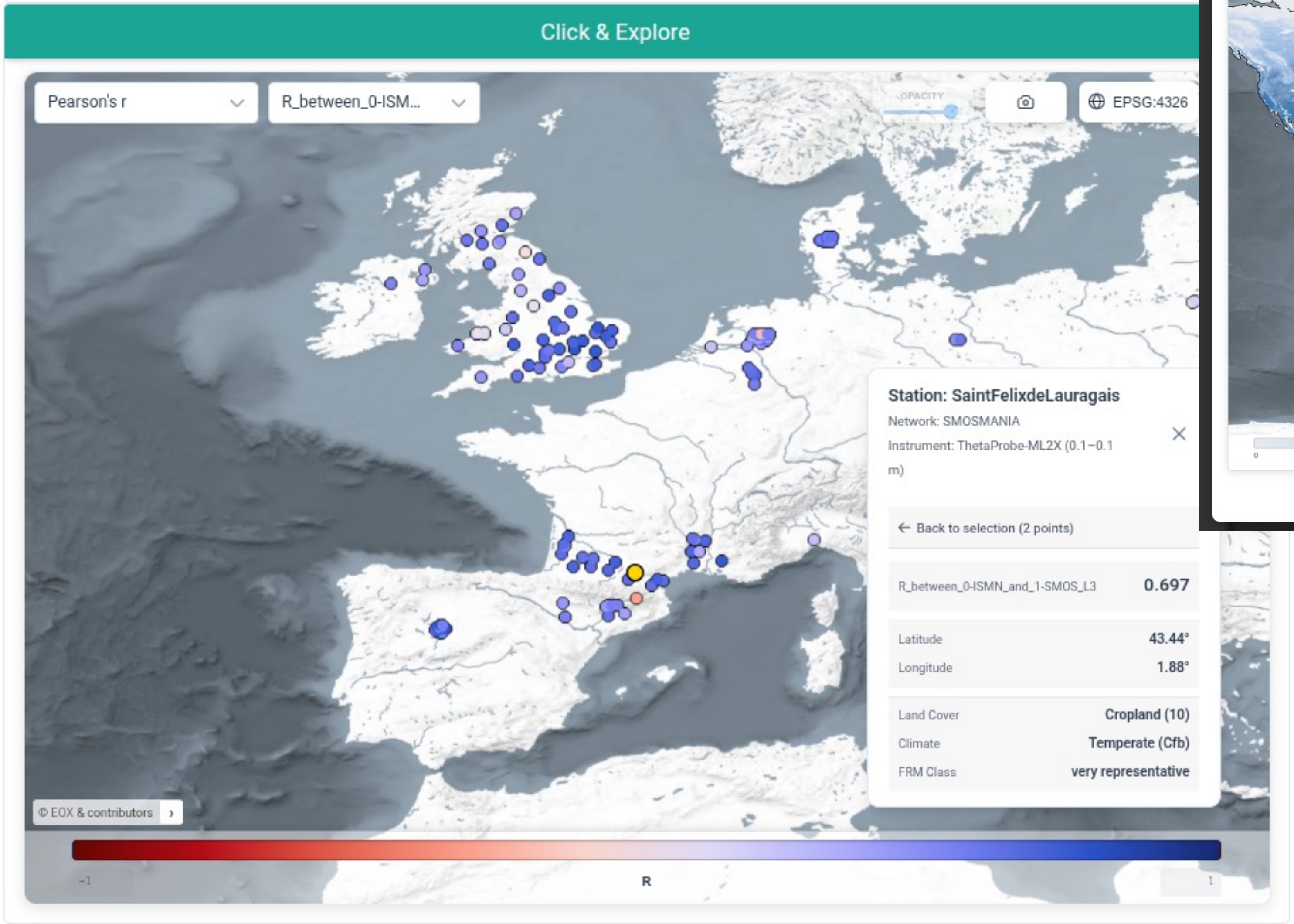


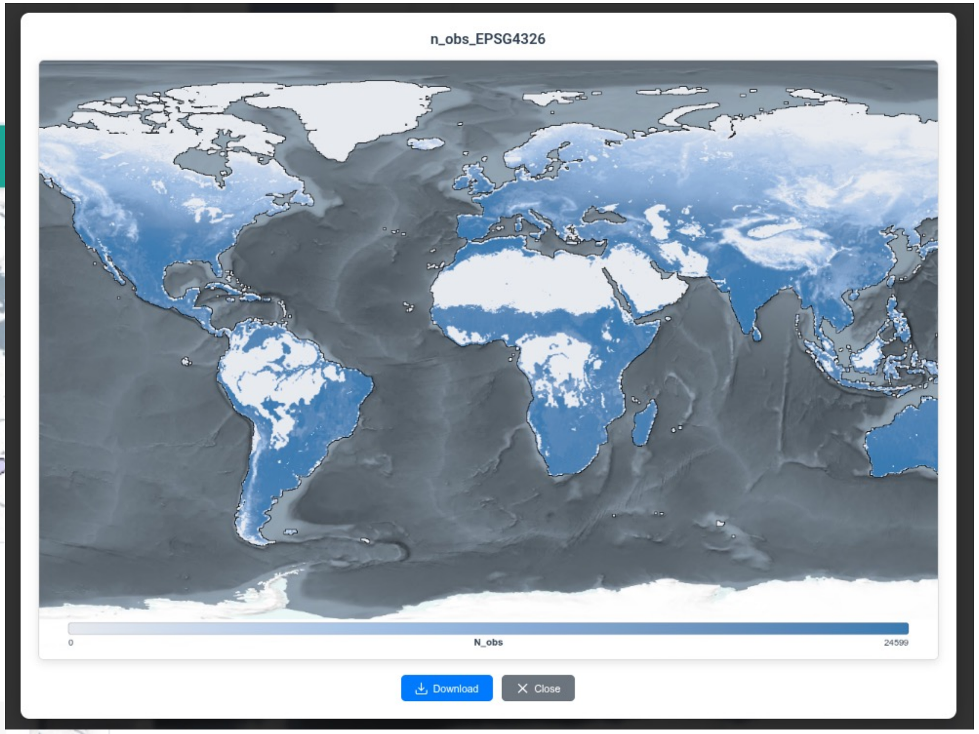
(a) (b)

Figure 7: ubRMSD between SMOS L2 and ERA5-Land as a box plot with the upper and lower confidence interval as narrow boxes (a), as a map plot (b).

Quality Assurance for Soil Moisture

- Interactive Validation Result Viewer





Conferences and workshops

- EGU 2026:
  - Remote Sensing of Soil Moisture
    - HS6.2 | PICO spot 4 | Mon, 4 May, 8:30 – 12:30
  - Advancing the monitoring, maintenance and utilization of in situ soil moisture
    - HS 8.3.1 | PICO spot A | Mon, 4 May, 16:15 – 18:00

- 8th Satellite Soil Moisture Validation and Application Workshop
  - To be held @ ESA ESRIN, 8 – 12 March, 2027

Land Surface Temperature and Emissivity

Upcoming Conferences

- EGU 2026, LST session: GI4.5 Thermal Infrared (TIR) Remote Sensing: Advances, Applications, and Data Integration, 3-8 May, 2026, Viena, Austria.
- LST_cci User Workshop, 12 – 14 May, 2026 at the Met Office, Exeter, United Kingdom.
- Landsat Cal/Val TIM will be hosted by USGS EROS between May 19-21, 2026.
- VIII RAQRS, 21 – 25 September, 2026, Valencia, Spain.
- EUMETSAT Meteorological Satellite Conference, 21 - 25 September 2026, Darmstadt, Germany.

Project news

- TIRCALNet preparation study: a field campaign at Gobabeb is planned for October 2026.
- USGS/NASA have selected the 2026/2030 Landsat Science Team, with a first meeting scheduled in May.
  - Landsat LST focused members are Forrest Melton (NASA), Kyle Knipper (USDA), Martha Anderson (USDA), and Yun Yang (Cornel U.).

CEOS WORKING GROUP ON CALIBRATION & VALIDATION

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Land Surface Temperature and Emissivity

TIRCALNet instruments comparison

Instruments deployed at Lacrau (France)

- JPL Radiometer *
  - Wavelength range: 8-14 µm
  - Field of view: 44°
  - Accuracy: 0.08 K
  - Self-calibrated with internal blackbody
- HEITRONICS KT15.85 *
  - Wavelength range: 9.6-11.5 µm
  - Field of view: 8.5°
  - Accuracy: 0.3 K
  - High long-term stability: <0.1 % per year
- CIMEL CE312-2
  - Wavelength range: 8-14 µm (6 bands)
  - Field of view: 10°
  - Accuracy: 0.1 K
  - Self-calibrated with external blackbody

*Since November 2024 a long-term intercomparison between JPL and KT15 radiometers is performed on Lake Constance.

Land Surface Temperature and Emissivity

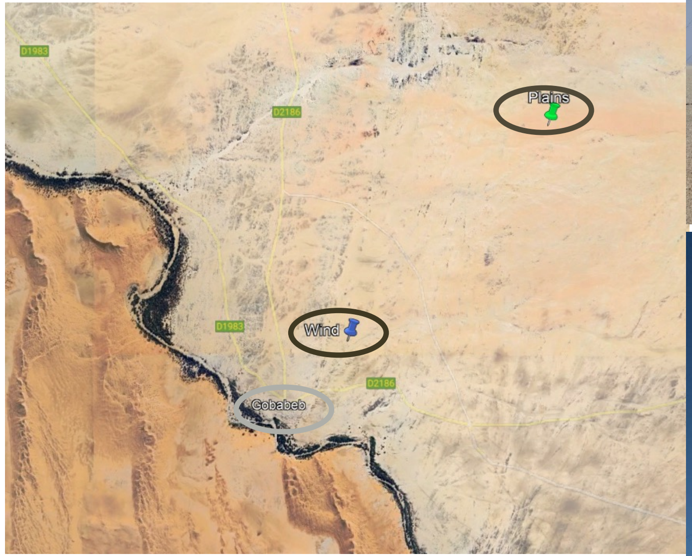
TIRCALNet instrument set-up at Gobabeb

Field campaign at Gobabeb (October 2026)

- Deploy two further radiometer types considered for TIRCALNet.
- Intercompare three radiometers & forward radiative transfer methodologies (TOA radiances).

Gobabeb KIT Sites

- Near Gobabeb Namib Research Institute
- Highly homogeneous & stable sites
- In-situ emissivity spectra (FRM4STS campaign)
- Long-term datasets for comparisons & analyses
- KIT equipment
  - Regular maintenance
  - Annual recalibration of radiometers
- Dedicated to satellite LST validation
- BSRN site (broadband radiances available)



Sites location (courtesy of Google Earth)

Participants:

esa | KIT Karlsruher Institut für Technologie | cnes CENTRE NATIONAL D'ÉTUDES SPATIALES | JPL Jet Propulsion Laboratory California Institute of Technology | UNIVERSITY OF LEICESTER

Biomass (1/2)

Current Biomass Activities

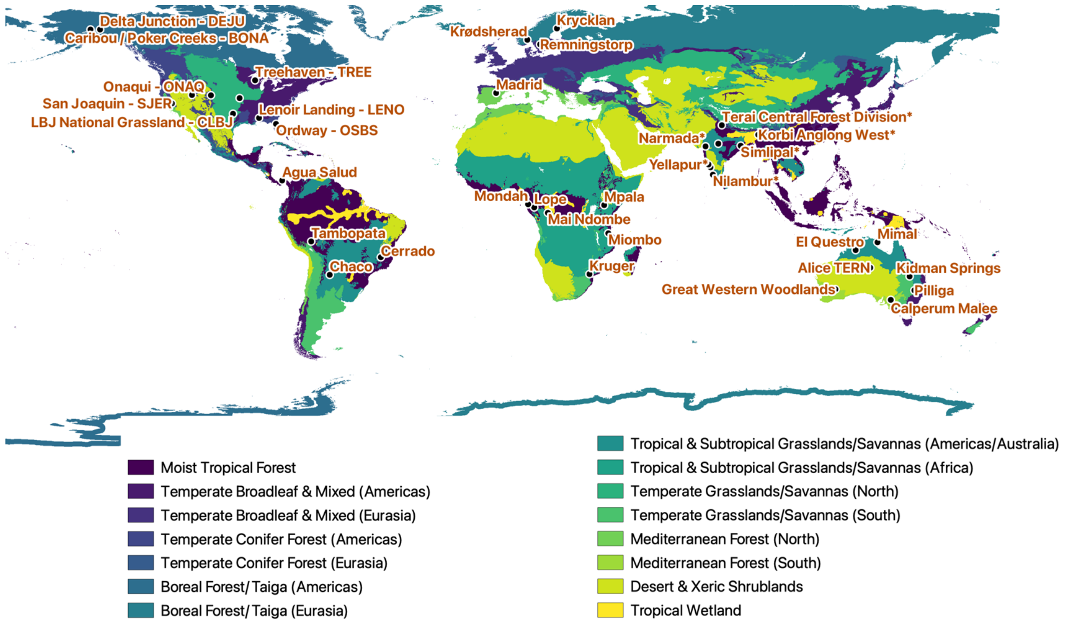
- TLS field campaign in Ghana (GFZ , Jan-Feb 2026, 7-ha) to support ESA-BIOMASS
  ALS planned, census completed

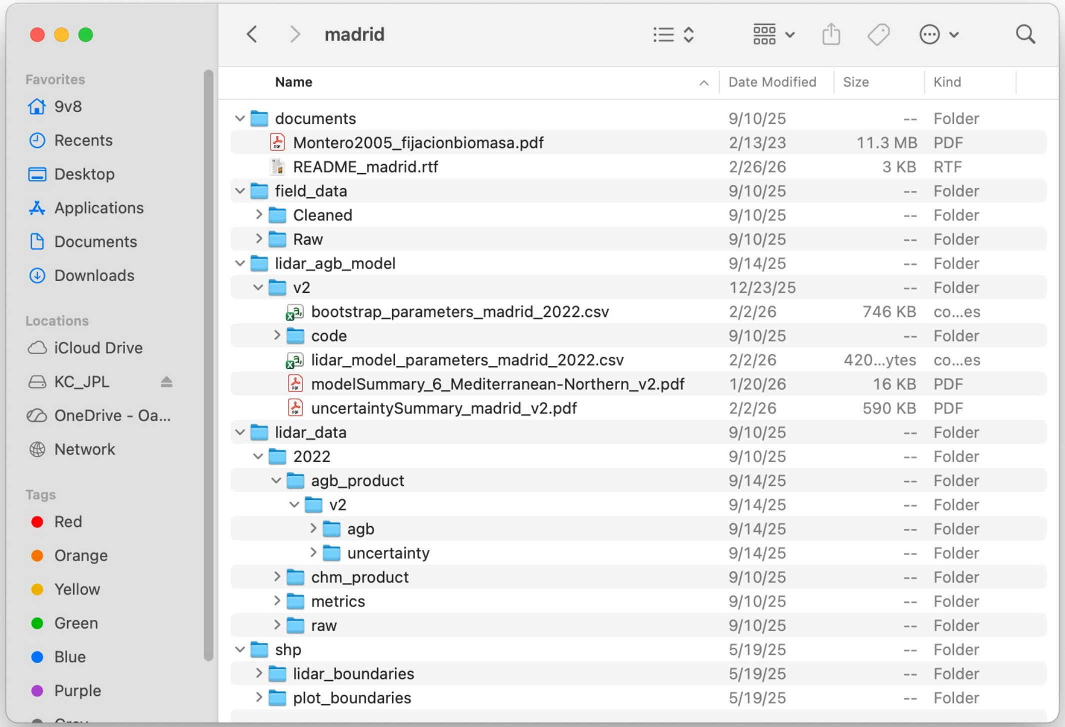
- GEO-TREES workshop in Panama (March 14–21, 2026) to integrate and harmonize the inventory, TLS, and ALS processing pipelines and automate their outputs within a modular GEO-TREES workflow.

Biomass (2/2)

Current Biomass Activities

- NISAR biomass reference data (from inventory and ALS) are organized for most sites on the NASA NISAR calibration/validation database.





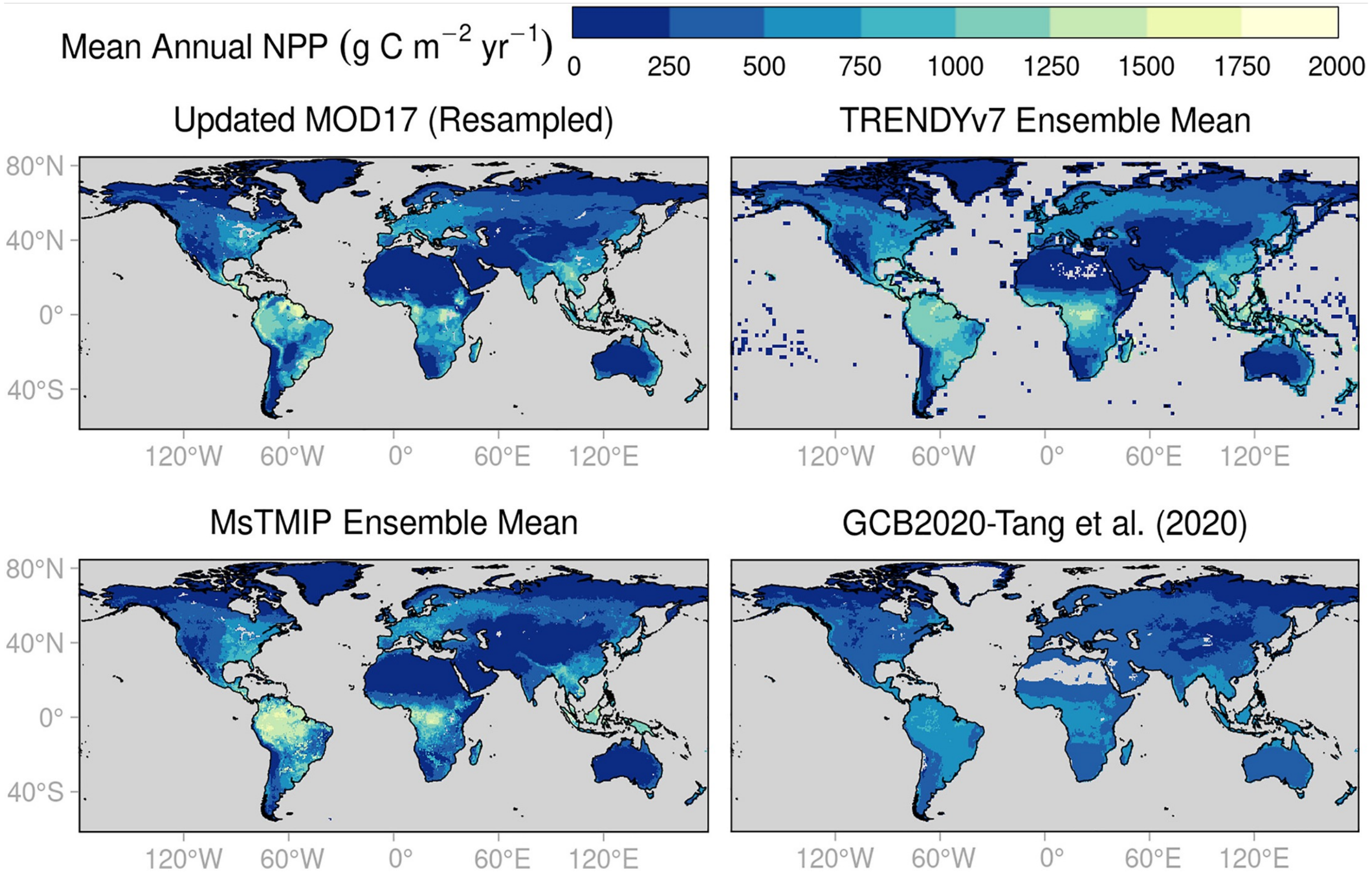
GPP/NPP updates (24-3-2026)

- List of state of the art GPP products and models checked and updated to be shared with the community.

- Questions related with the mailing list:
  - Has the LPV its own listserv web service that should be used to send the mailing?
  - Do we include them by default with an opt-out option?

- Relevant sessions in EGU 2026 related with GPP/NPP cal/val activities:
  - ITS1.10/BG10.6: Machine learning and hybrid modelling for carbon cycle science, monitoring and carbon market policy
  - BG2.4: Novel methods for bridging understanding of carbon, nitrogen, and water fluxes from leaf to continental scale

Global GPP and NPP from Updated MODIS and New VIIRS Algorithm



Endsley et al. (*JGR: Biogeosciences*)

- Comprehensive calibration, validation of MODIS Collection 7 MOD17/ MYD17
- New VIIRS VNP17 Collection 2 GPP+NPP product, designed for continuous, 30+ year record
- VIIRS Collection 2 now available on NASA Earthdata; MODIS Collection 7 almost ready

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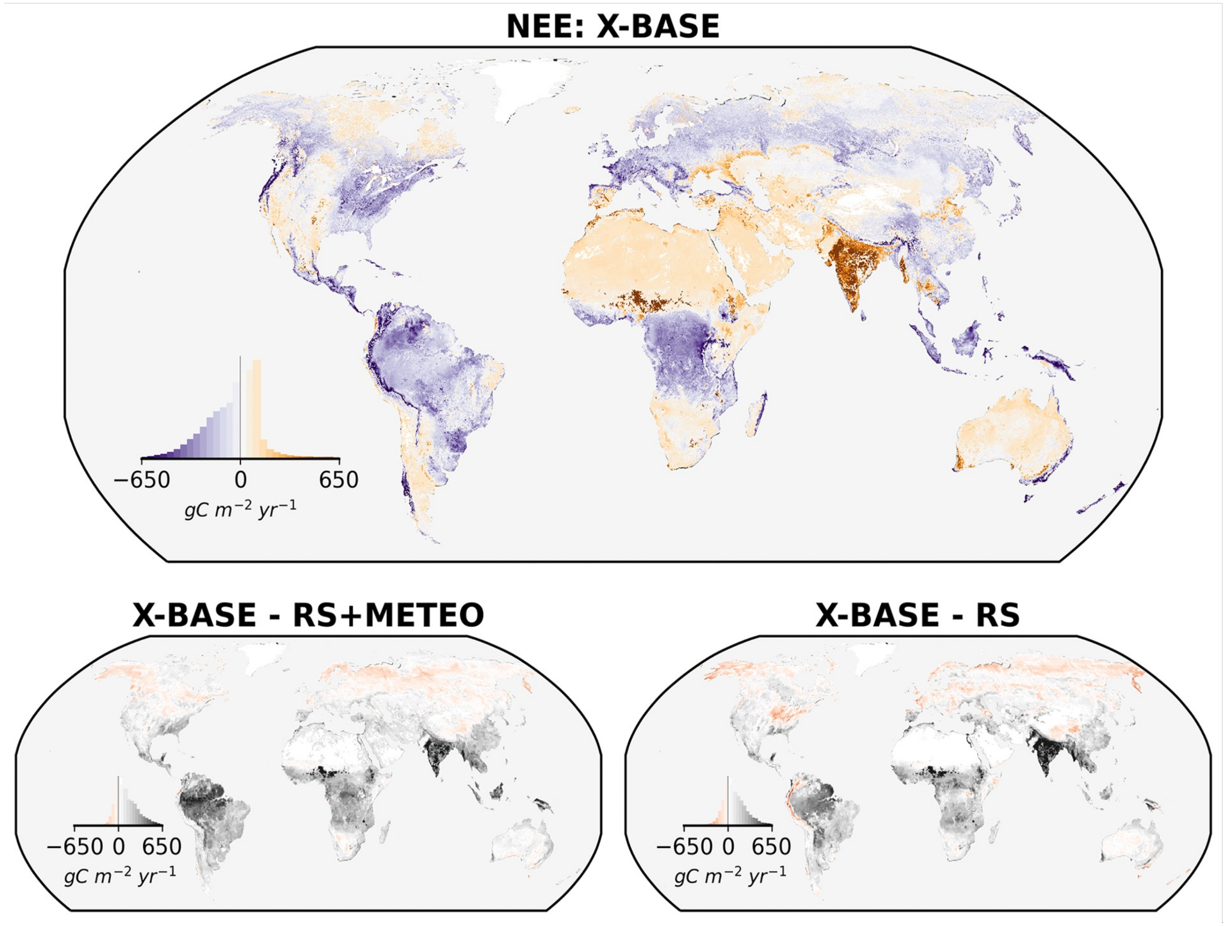
New Global Extrapolation from Eddy Covariance Towers: X-BASE and FLUXCOM-X



Nelson et al. (*Biogeosciences*)

- Global GPP, NEE, and (new) *hourly* ET for 2001-2020 based on upscaling eddy covariance tower measurements
- Now at 0.05 deg spacing (compared to 0.083 deg in FLUXCOM)
- Change since previous FLUXCOM product: Increased CO2 sink strength in Tropics, Northern Temperate/ Boreal regions (*left figure)*

CarbonBench: A Global Benchmark for Upscaling of Carbon Fluxes Using Zero-Shot Learning

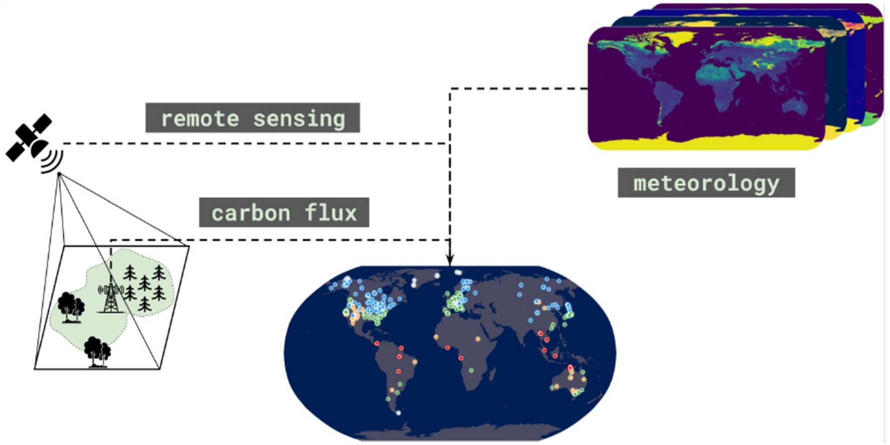


Table 2: Baseline zero-shot performance on *CarbonBench*. Results are averaged over an ensemble of 10 models trained with different random seeds. Arrows indicate the direction of improvement.

Split	Model	Targets								
		GPP			RECO			NEE		
		$R^2\uparrow$	RMSE↓	nMAE↓	$R^2\uparrow$	RMSE↓	nMAE↓	$R^2\uparrow$	RMSE↓	nMAE↓
IGBP	XGBoost	$0.495^{0.701}_{0.121}$	$1.833^{2.600}_{1.319}$	$0.522^{0.687}_{0.395}$	$0.330^{0.617}_{-0.093}$	$1.316^{1.933}_{0.967}$	$0.406^{0.654}_{0.310}$	$0.287^{0.496}_{-0.086}$	$1.340^{1.937}_{1.017}$	$2.105^{4.493}_{1.195}$
	LightGBM	$0.537^{0.779}_{0.201}$	$1.611^{2.585}_{1.226}$	$0.440^{0.675}_{0.308}$	$\mathbf{0.464}^{0.710}_{-0.215}$	$1.209^{1.802}_{0.817}$	$0.376^{0.542}_{0.268}$	$\mathbf{0.335}^{0.542}_{0.123}$	$1.340^{1.882}_{0.847}$	$2.058^{4.106}_{1.098}$
	LSTM	$0.582^{0.780}_{0.219}$	$\mathbf{1.571}^{2.454}_{1.091}$	$0.417^{0.630}_{0.312}$	$0.414^{0.728}_{-0.293}$	$1.229^{1.784}_{0.776}$	$\mathbf{0.345}^{0.604}_{0.272}$	$0.315^{0.512}_{-0.060}$	$\mathbf{1.303}^{1.995}_{0.910}$	$\mathbf{1.846}^{4.093}_{1.108}$
	CT-LSTM	$0.614^{0.795}_{0.235}$	$1.578^{2.538}_{1.120}$	$0.400^{0.633}_{0.301}$	$0.406^{0.750}_{-0.317}$	$1.202^{1.754}_{0.821}$	$0.367^{0.584}_{0.256}$	$0.285^{0.481}_{0.004}$	$1.337^{2.048}_{0.944}$	$2.056^{4.593}_{1.162}$
	GRU	$0.520^{0.733}_{0.138}$	$1.658^{2.659}_{1.190}$	$0.464^{0.609}_{0.353}$	$0.389^{0.708}_{-0.273}$	$1.273^{1.747}_{0.823}$	$0.369^{0.558}_{0.288}$	$0.281^{0.441}_{0.025}$	$1.344^{2.087}_{0.942}$	$1.985^{4.004}_{1.182}$
	CT-GRU	$0.559^{0.790}_{0.243}$	$1.668^{2.534}_{1.157}$	$0.416^{0.649}_{0.323}$	$0.321^{0.732}_{-0.448}$	$1.245^{1.857}_{0.843}$	$0.375^{0.598}_{0.273}$	$0.284^{0.467}_{0.013}$	$1.440^{2.021}_{1.028}$	$2.095^{4.876}_{1.271}$
	Transformer	$0.600^{0.801}_{0.198}$	$1.679^{2.684}_{1.138}$	$0.413^{0.623}_{0.310}$	$0.376^{0.737}_{-0.498}$	$1.269^{1.887}_{0.823}$	$0.386^{0.603}_{0.265}$	$0.288^{0.489}_{-0.103}$	$1.433^{2.015}_{1.018}$	$2.134^{4.442}_{1.231}$
	Patch-Transformer	$0.487^{0.743}_{0.042}$	$1.806^{2.714}_{1.397}$	$0.442^{0.630}_{0.344}$	$0.309^{0.696}_{-0.758}$	$1.322^{1.880}_{0.901}$	$0.400^{0.606}_{0.292}$	$0.116^{0.367}_{-0.214}$	$1.486^{1.982}_{1.100}$	$2.064^{4.647}_{1.242}$
	TAM-RL	$\mathbf{0.631}^{0.810}_{0.251}$	$1.594^{2.671}_{1.090}$	$\mathbf{0.385}^{0.595}_{0.297}$	$0.459^{0.761}_{-0.411}$	$\mathbf{1.173}^{1.703}_{0.798}$	$0.362^{0.558}_{0.258}$	$0.324^{0.504}_{0.053}$	$1.334^{1.926}_{0.906}$	$1.916^{4.545}_{1.143}$
Köppen	XGBoost	$0.419^{0.645}_{-0.119}$	$2.098^{2.837}_{1.475}$	$0.541^{0.813}_{0.409}$	$0.216^{0.577}_{-0.601}$	$1.475^{2.077}_{1.146}$	$0.411^{0.635}_{0.320}$	$0.096^{0.374}_{-0.336}$	$1.526^{2.239}_{1.094}$	$2.688^{6.467}_{1.369}$
	LightGBM	$0.605^{0.786}_{0.265}$	$1.618^{2.224}_{1.034}$	$0.419^{0.613}_{0.291}$	$0.500^{0.737}_{0.010}$	$1.116^{1.688}_{0.760}$	$0.348^{0.463}_{0.262}$	$0.351^{0.528}_{-0.147}$	$1.275^{2.006}_{0.810}$	$2.330^{4.823}_{1.215}$
	LSTM	$0.635^{0.807}_{0.329}$	$1.591^{2.251}_{1.032}$	$0.410^{0.547}_{0.298}$	$0.450^{0.744}_{0.079}$	$1.124^{1.827}_{0.780}$	$0.349^{0.498}_{0.273}$	$0.284^{0.559}_{-0.228}$	$1.281^{2.068}_{0.910}$	$2.449^{4.861}_{1.306}$
	CT-LSTM	$0.687^{0.818}_{0.327}$	$\mathbf{1.478}^{2.150}_{0.925}$	$0.402^{0.528}_{0.288}$	$0.467^{0.768}_{0.062}$	$1.083^{1.742}_{0.729}$	$\mathbf{0.334}^{0.461}_{0.255}$	$\mathbf{0.384}^{0.564}_{-0.145}$	$\mathbf{1.182}^{1.864}_{0.796}$	$\mathbf{2.126}^{4.830}_{1.217}$
	GRU	$0.666^{0.786}_{0.342}$	$1.676^{2.275}_{1.032}$	$0.409^{0.582}_{0.311}$	$0.458^{0.703}_{-0.194}$	$1.169^{1.840}_{0.811}$	$0.368^{0.513}_{0.284}$	$0.266^{0.555}_{-0.330}$	$1.374^{2.082}_{0.925}$	$2.630^{4.992}_{1.282}$
	CT-GRU	$0.665^{0.813}_{0.226}$	$1.599^{2.134}_{0.981}$	$0.410^{0.571}_{0.308}$	$0.460^{0.735}_{0.093}$	$\mathbf{1.080}^{1.547}_{0.707}$	$0.353^{0.481}_{0.262}$	$0.320^{0.510}_{-0.189}$	$1.337^{2.067}_{0.845}$	$2.476^{5.141}_{1.185}$
	Transformer	$\mathbf{0.709}^{0.804}_{0.311}$	$1.554^{2.181}_{0.921}$	$\mathbf{0.396}^{0.535}_{0.296}$	$0.464^{0.730}_{-0.089}$	$1.163^{1.679}_{0.780}$	$0.356^{0.458}_{0.260}$	$0.331^{0.565}_{-0.212}$	$1.265^{1.898}_{0.849}$	$2.190^{4.940}_{1.183}$
	Patch-Transformer	$0.589^{0.760}_{0.218}$	$1.724^{2.464}_{1.034}$	$0.458^{0.594}_{0.333}$	$0.439^{0.704}_{-0.088}$	$1.137^{1.726}_{0.799}$	$0.364^{0.490}_{0.286}$	$0.200^{0.375}_{-0.230}$	$1.455^{2.359}_{0.945}$	$2.702^{5.100}_{1.324}$
	TAM-RL	$0.692^{0.816}_{0.376}$	$1.505^{2.202}_{0.947}$	$0.404^{0.547}_{0.284}$	$\mathbf{0.480}^{0.756}_{0.085}$	$1.081^{1.602}_{0.725}$	$0.340^{0.474}_{0.261}$	$0.340^{0.556}_{-0.166}$	$1.266^{1.912}_{0.866}$	$2.315^{4.676}_{1.247}$

Rozanov et al. (arXiv/*Under_review*)

- Establishes the first standardized framework for zero-shot spatial transfer in carbon flux modeling.
- Compiles 1.3M+ daily observations from 567 global sites (2000–2024) with harmonized features.
- Tests how models perform across unseen vegetation and climates to improve global carbon accounting.

CARBONSENSE: A MULTIMODAL DATASET AND BASELINE FOR CARBON FLUX MODELLING

Matthew Fortier
Mila Quebec AI Institute
matthew.fortier@mila.quebec

Mats L. Richter
ServiceNow Research

Oliver Sonnentag
Département de géographie
Université de Montréal

Chris Pal
Mila Quebec AI Institute
Polytechnique Montréal
Canada CIFAR AI Chair

.LG] 24 Mar 2025

ABSTRACT

Terrestrial carbon fluxes provide vital information about our biosphere's health and its capacity to absorb anthropogenic CO_2 emissions. The importance of predicting carbon fluxes has led to the emerging field of data-driven carbon flux modelling (DDCFM), which uses statistical techniques to predict carbon fluxes from biophysical data. However, the field lacks a standardized dataset to promote comparisons between models. To address this gap, we present CarbonSense, the first machine learning-ready dataset for DDCFM. CarbonSense integrates measured

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