

“Earth Observation and Environmental Data for Society, Policy, and Sustainable Land Use”

Meeting of the Remote Sensing Working Group 2026

October 7–8 at Thünen Institute, Braunschweig, Germany

Keynote

Addressing the last mile gap: advanced optical Earth observation for evidence-based policymaking

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²European Space Agency (ESA), ESRI: International Policy Expert Scheme.



GFZ Helmholtz Centre
for Geosciences

HELMHOLTZ

THE STAKES

A rapidly changing world.

LAND

Nearly one-third of Earth's land area transformed since 1960.

Winkler et al., 2021

CLIMATE

Warming rate has more than doubled since the 1970s.

IPCC AR6

FOOD DEMAND

Global food demand projected to rise ~50% by 2050.

FAO



We are now entering a phase where the overall productivity growth declines to a point that might even see a complete end of productivity growth.

— Matthias Berninger, EVP Sustainability, Bayer, [source](#)

Earth observation is now indispensable!



EO is the only way to monitor these dynamics at scale, spot where action is needed, and respond.

THREE STREAMS

Everyone wants EO. All at once.



Stream	Who	What they need from EO
Science	Researcher, IPCC, GEO, ...	Long, consistent records; physics; uncertainty
Markets	Insurers, banks, traders, food industry; delivered by EO companies	Plot-level, fast, auditable, cheap at scale
<u>Policy</u>	EU and national authorities, via Copernicus	Legally defensible, reproducible, aligned to reporting cycles, uncertainty

→ The demand is diversifying, not just growing

Are we living through the golden age of Earth Observation?



12+ Copernicus satellites. Tens of terabytes per day. A new generation launching this decade.

Image credits: Martin Herold, GFZ

WHAT WE HAVE NOW - More technological opportunities to track critical dynamics from above:

Never before have we seen this diversity.



Remote sensing technology	In plain language: what it sees	Typical agricultural uses	What it misses or struggles with	Satellite data examples with Free/Public Access	Examples of Commercial/Paid
Optical	Reflected visible and infrared sun-light	Crop type, growing cycle, vegetation condition / management, yield proxies	Clouds, smoke, limited night use	Landsat, Sentinel-2 (10+ m)	PlanetScope (daily, 1-4 m), SkySat (tasked, sub-1m), others
SAR/RADAR	Surface structure and moisture response using microwave signals	Soil moisture proxies, flooding, crop type & structure, all-weather monitoring	Harder to interpret/more expertise needed; affected by geometry and surface conditions	Sentinel-1, NISAR, (ROSE-L 2029) – (10+ m)	ICEYE, Capella Space, RADARSAT-2
Thermal	Surface temperature / emitted radiation from land	Crop water stress, evapotranspiration / irrigation	Atmospheric effects; requires careful calibration	Landsat TIRS, ECOSTRESS, (LSTM 2029)	FLIR drone/airborne sensors, Hydrosat
Hyperspectral	Very detailed spectral signatures and land surface material properties	Crop traits, stress, biochemical properties (chlorophyll, nitrogen), soil characteristics (i.e. carbon)	Larger, complex data volumes, specialist analysis, ground calibration / validation	EnMAP, PRISMA, (CHIME 2029) – (30 m)	Tanager (Planet), Pixxel, Hyspex (i.e. drone)
LiDAR	Three-dimensional structure and height	Biomass, canopy structure, terrain	Coverage constrains repeated monitoring, current sensors with limited use for agriculture	GEDI, ICESAT-2 (spaceborne, gap-filled coverage only)	RIEGL (drone/airborne), Velodyne/Ouster (drone/airborne)

Credits: Martin Herold, GFZ Potsdam

WHAT'S COMING

*All data distributed
under a full, free
and open policy!*

Upcoming ESA missions: Enhanced sensing for land monitoring and EU policy



ESA Mission (launch year*)	Type	Key capability	Programme
CHIME (2028-2030)	Hyperspectral	Full-spectrum surface composition and vegetation traits	Copernicus expansion
S1NG (2033)	C-Band SAR	All-weather monitoring, high-resolution and maritime surveillance	Copernicus continuity
S2NG (2033)	Enhanced multispectral	Continuity + enhanced spectral and spatial detail	Copernicus continuity
LSTM (2028-2029)	Thermal infrared	Land-surface temperature and evapotranspiration	Copernicus expansion
ROSE-L (2028)	L-band SAR	Vegetation & soil moisture penetration	Copernicus expansion
 FLEX (launched 15 Sept 2026!)	Fluorescence	Direct photosynthesis proxy (SIF)	Earth Explorer
 BIOMASS (launched 29 April 2025!)	P-band SAR	Above-ground forest biomass	Earth Explorer

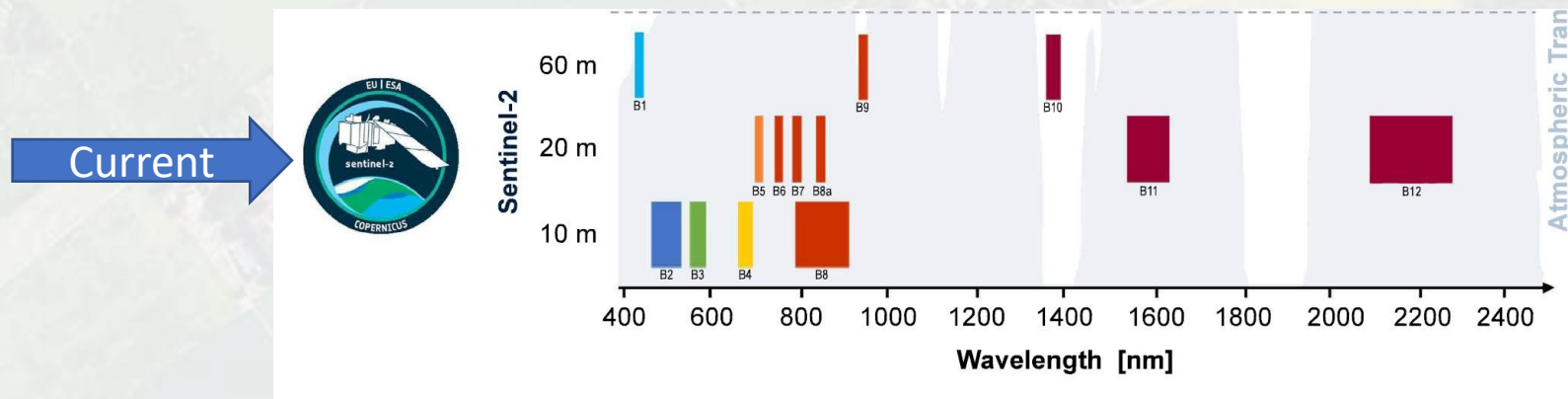
* Subject to change

Figures adapted from <https://sentiwiki.copernicus.eu/web>

THE SPECTRAL LEAP

From wide bands to a full spectrum.

S2NG and CHIME — the spectral, spatial (and temporal) resolution improves in the next generation.



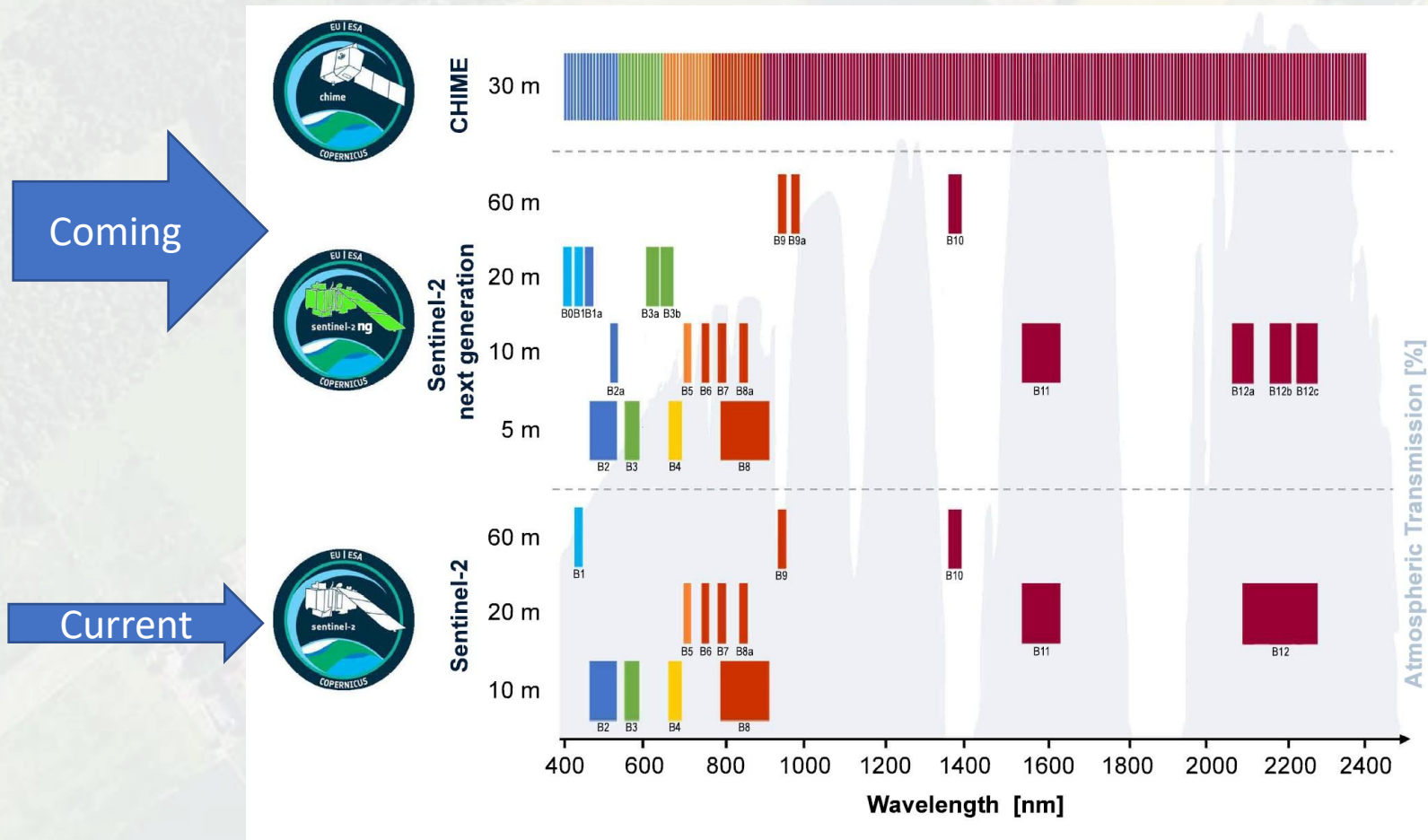
Source: Berger et al. 2026 (Environ. Sci. Eur., 10.1186/s12302-026-01346-3)

Credits: Markus Immitzer, BOKU, Vienna

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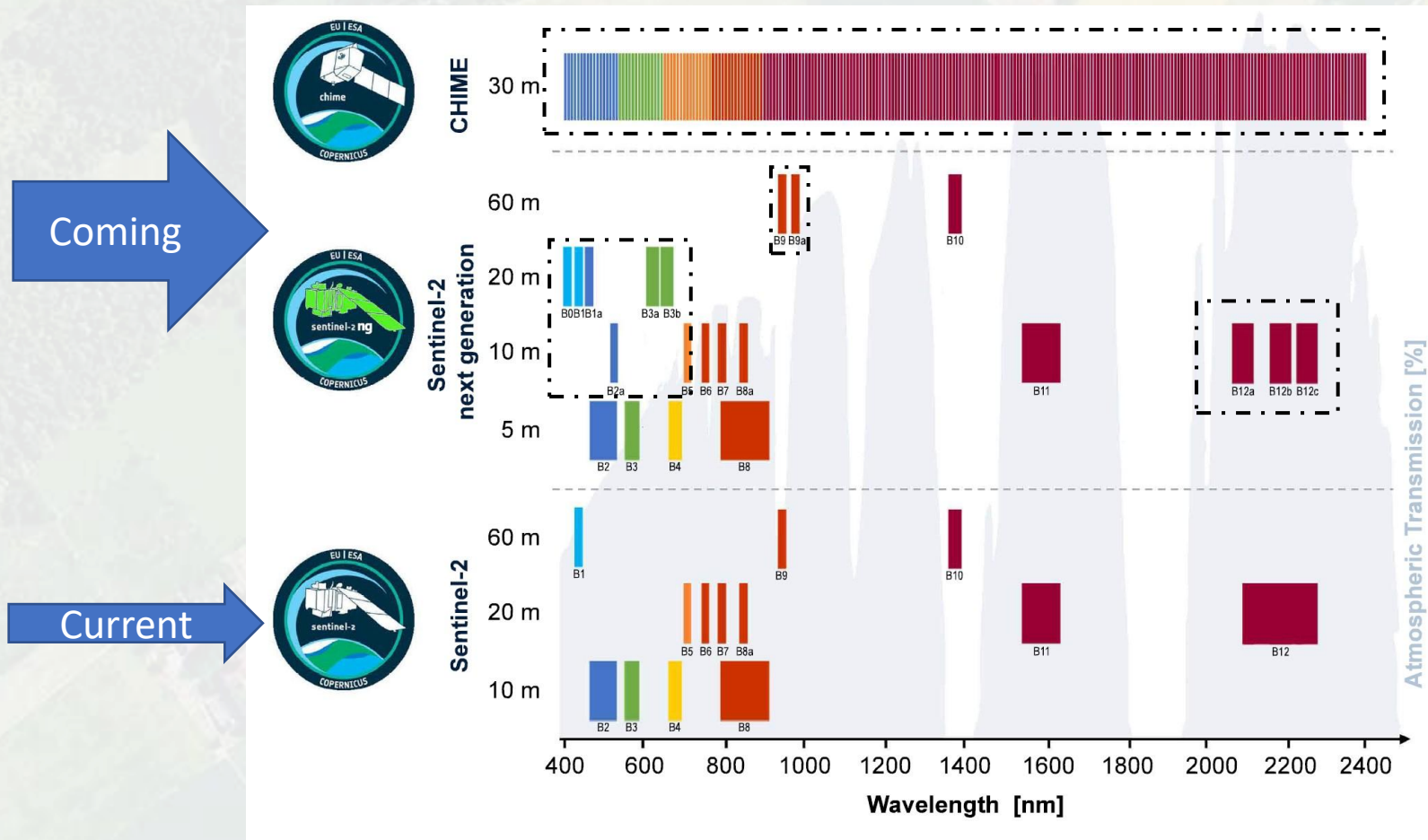
Source: Berger et al. 2026 (Environ. Sci. Eur., 10.1186/s12302-026-01346-3)

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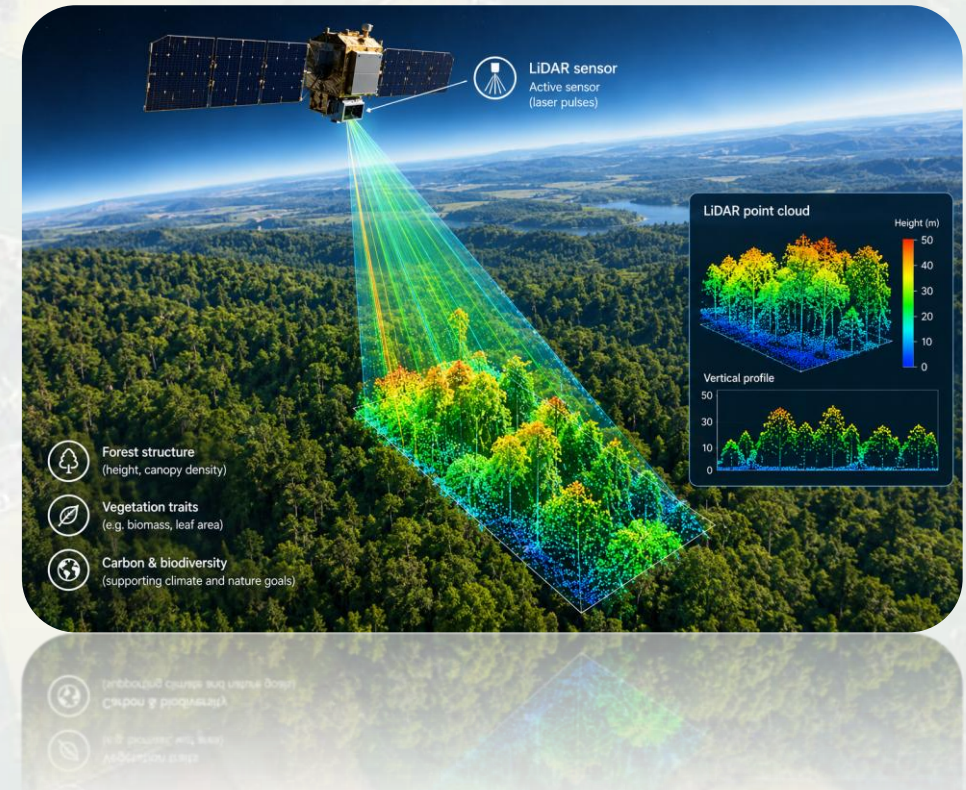
Source: Berger et al. 2026 (Environ. Sci. Eur., 10.1186/s12302-026-01346-3)

Credits: Markus Immitzer, BOKU, Vienna

And a third dimension: structure from space.

- **BIOMASS** (P-band SAR, launched April 2025) → tropical AGB
- **ROSE-L** (2028) → L-band penetration into canopy and soil
- **GEDI / ICESat-2** → canopy height baseline
- **Veggie-H** (German High Priority Candidate Mission, if selected) → the future of dedicated vegetation vertical structure. Also, ESA has interest in future European spaceborne LiDAR...

Vertical structure closes the loop with the biomass and carbon products we'll see later.



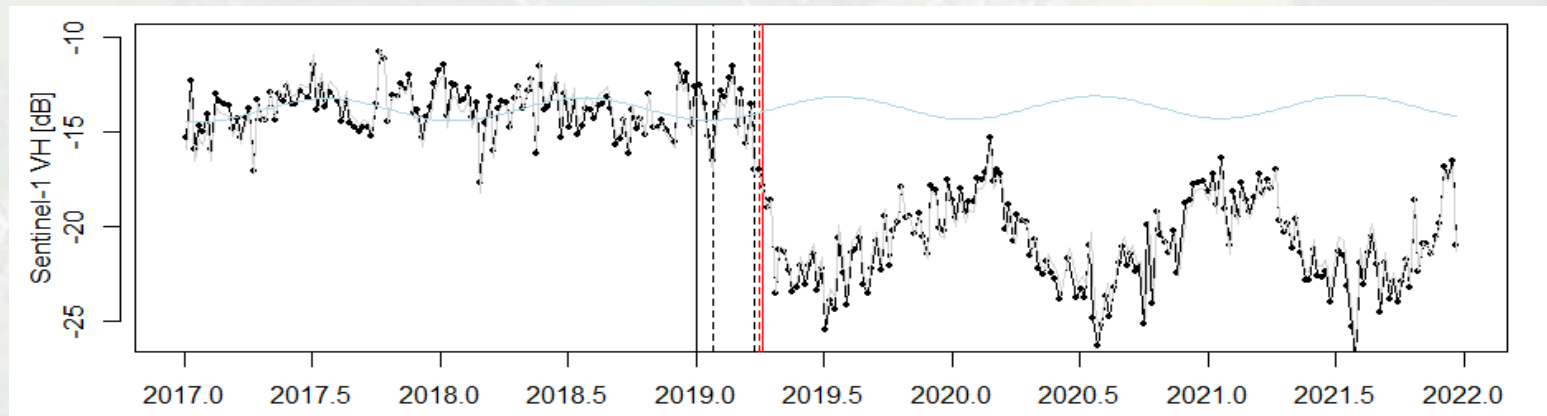
Credits: Benjamin Brede, GFZ Potsdam

WHAT WE HAVE NOW– What will come

More frequent and **near-real time** monitoring.



- Importance of dense global time series data (i.e. Sentinel 1: ~10x10 m, 2-5 days repeat)
- Rapid detection of changes and tracking of land use, agricultural developments and management



Van der Woude et al., 2024: [Sensitivity of Sentinel-1 Backscatter to Management-Related Disturbances in Temperate Forests](#)

Credits: Martin Herold, GFZ Potsdam

**but data is
not yet the
product...**



*Data from (existing/ new) sensors allows to derive variables/
products*

THE PULL



Growing EO demand from recent land-related EU policies.

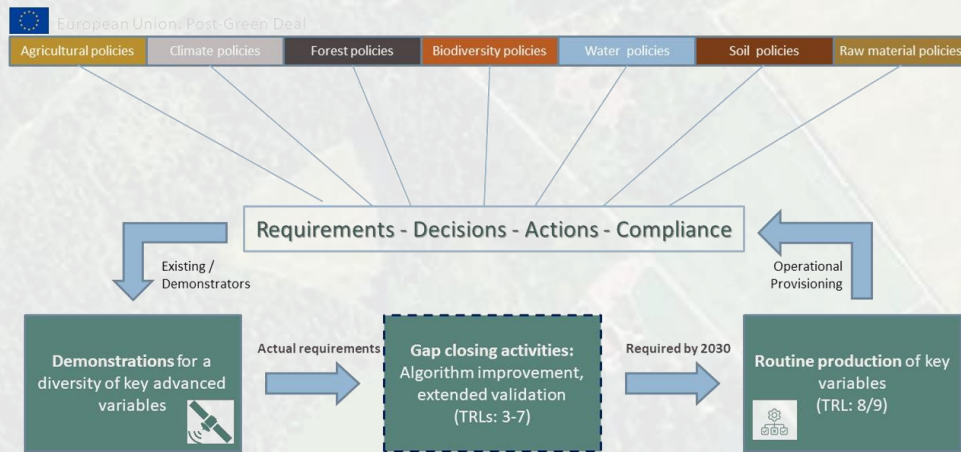
A wave of land-related regulations since the European Green Deal (2019): from problem identification to compliance monitoring, each defining the use of EO data/satellites/Copernicus in their legislative text.

 Agriculture	• Common Agricultural Policy 2023-27 (Reg. (EU) 2021/2115-2117): 02/12/2021 (CAP initiated 1962) • Farm-to-Fork Strategy (COM(2020) 381): 20/05/2020 — superseded 2025 • Vision for Agriculture and Food (COM(2025) 75): 19/02/2025
 Forestry	• Stepping Up EU Action to Protect and Restore Forests (COM(2019) 352): 23/07/2019 • EU Forest Strategy for 2030 (COM(2021) 572): 16/07/2021 • Regulation on Deforestation-free Products (EUDR) (Reg. (EU) 2023/1115): 31/05/2023
 Climate change mitigation/adaptation	• EU strategy on adaptation to climate change (COM(2021) 82): 24/02/2021 • European Climate Law (Reg. (EU) 2021/1119): 30/06/2021 • Communication on Sustainable Carbon Cycles (COM(2021) 800): 15/12/2021 • General Union Environment Action Programme to 2030 (8th EAP) (Dec. (EU) 2022/591): 06/04/2022 • 2023 EU Regulation on Land, Land Use Change and Forestry (LULUCF) (Reg. (EU) 2023/839): 19/04/2023 • Carbon Removals and Carbon Farming Regulation (CRCF) (Reg. (EU) 2024/3012): 27/11/2024
 Soils	• EU Soil Strategy for 2030 (COM(2021) 699): 17/11/2021 • Soil Monitoring Law (COM(2023) 416) (proposed): 05/07/2023
 Biodiversity	• EU Biodiversity Strategy for 2030 (COM(2020) 380): 20/05/2020 • Nature Restoration Regulation (Reg. (EU) 2024/1991): 24/06/2024
 Inland Water/Marine waters and pollution	• Water Framework Directive (Dir. 2000/60/EC): initially adopted in 2000 • Proposal for a Directive amending the Water Framework Directive, the Groundwater Directive and the Environmental Quality Standards Directive (COM(2022) 540): 26/10/2022
 Air quality	• Zero Pollution Action Plan (COM(2021) 400): 12/05/2021
 Raw materials	• Critical Raw Materials Resilience (COM(2020) 474): 03/09/2020

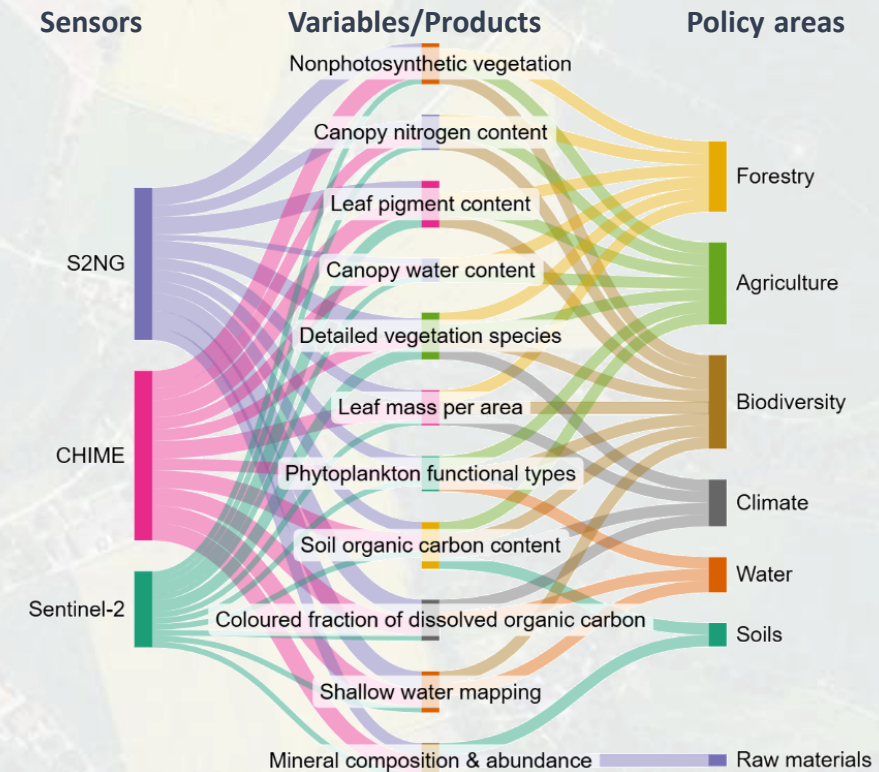
„In order to increase the timeliness and effectiveness of soil health monitoring, Member States should, where relevant, **use remote-sensing data**, including outputs from the **Copernicus** services, for the monitoring of relevant soil descriptors and soil sealing and soil removal indicators...”
Directive (EU) 2025/2360, art. (46)

Source: adapted from Berger et al., (2025): Evolving Earth observations for recent EU environmental policies, Land Use Policy, <https://doi.org/10.1016/j.landusepol.2025.107749>

Traceability: linking regulations to EO variables.



CHIME and S2NG will provide newly accessible or substantially improved **variables (=products)** serving diverse policy areas...



Hyperspectral (and superspectral) capability unlocks variables Sentinel-2 alone cannot, and each flows into multiple EU policy domains

Source: Berger et al. 2026 (Environ. Sci. Eur., 10.1186/s12302-026-01346-3), right figure not published

Land productivity and soil health.

AGRICULTURE — CAP

CAP shifted from compliance-based controls to outcome-based incentives (GAECs, eco-schemes).

Sentinel-2 underpins area monitoring / crop-type mapping → • the heaviest user of EO

S2NG + CHIME may unlock sustainability indicators:

- Canopy nitrogen → fertilisation efficiency
- NPV → residue cover, tillage verification
- Crop water content → drought and irrigation

SOILS — Soil Monitoring Law

Soil Monitoring Law entered into force in December 2025 — spatially explicit indicators are needed.

~60–70% of EU soils are in unhealthy condition (*EUSO, 2024*).

CHIME + LSTM together may deliver:

- Soil organic carbon (SOC)
- Salinisation, mineralogy, texture
- Soil moisture and evapotranspiration
- Degradation trend detection over time

Same missions. Two policies. Both need spectral depth beyond Sentinel-2.



Images generated with ChatGPT, Sept. 2026

Ecosystems and materials.

WATER

Water Framework Directive

"good ecological status" for all water bodies

CHIME + S2NG may deliver:

- Chl-a, cyanobacterial blooms
→ *Bathing Water Directive*
- Turbidity, CDOM, TSM
→ *Drinking Water Directive*

BIODIVERSITY

Nature Restoration Regulation

30% degraded areas restored by 2030 · national plans due Sept 2026

CHIME + S2NG may deliver:

- Leaf mass per area (LMA), pigments
 - Tree species discrimination
- = Functional traits for biodiversity indices

RAW MATERIALS

Critical Raw Materials Act

encourages EO for exploration and monitoring

CHIME (now EnMAP) may deliver:

- Surface mineral mapping
- Rare-earth element detection
- Tailings & mine-site monitoring

→ *A classic hyperspectral application.*

Asadzadeh et al., 2024 · EnMAP global archive since 2022:

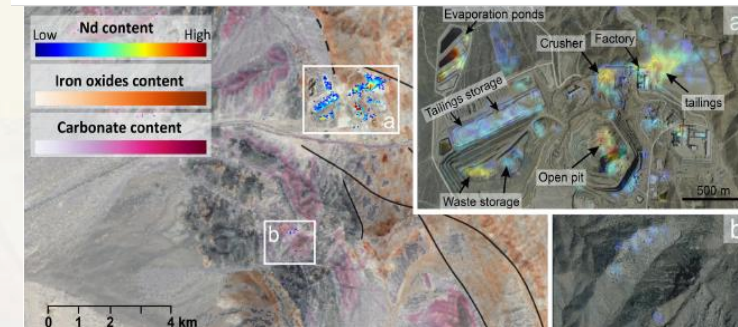


Image generated with ChatGPT, Sept. 2026

Asadzadeh et al., 2024

Article | [Open access](#) | Published: 05 September 2024

Detecting rare earth elements using EnMAP hyperspectral satellite data: a case study from Mountain Pass, California



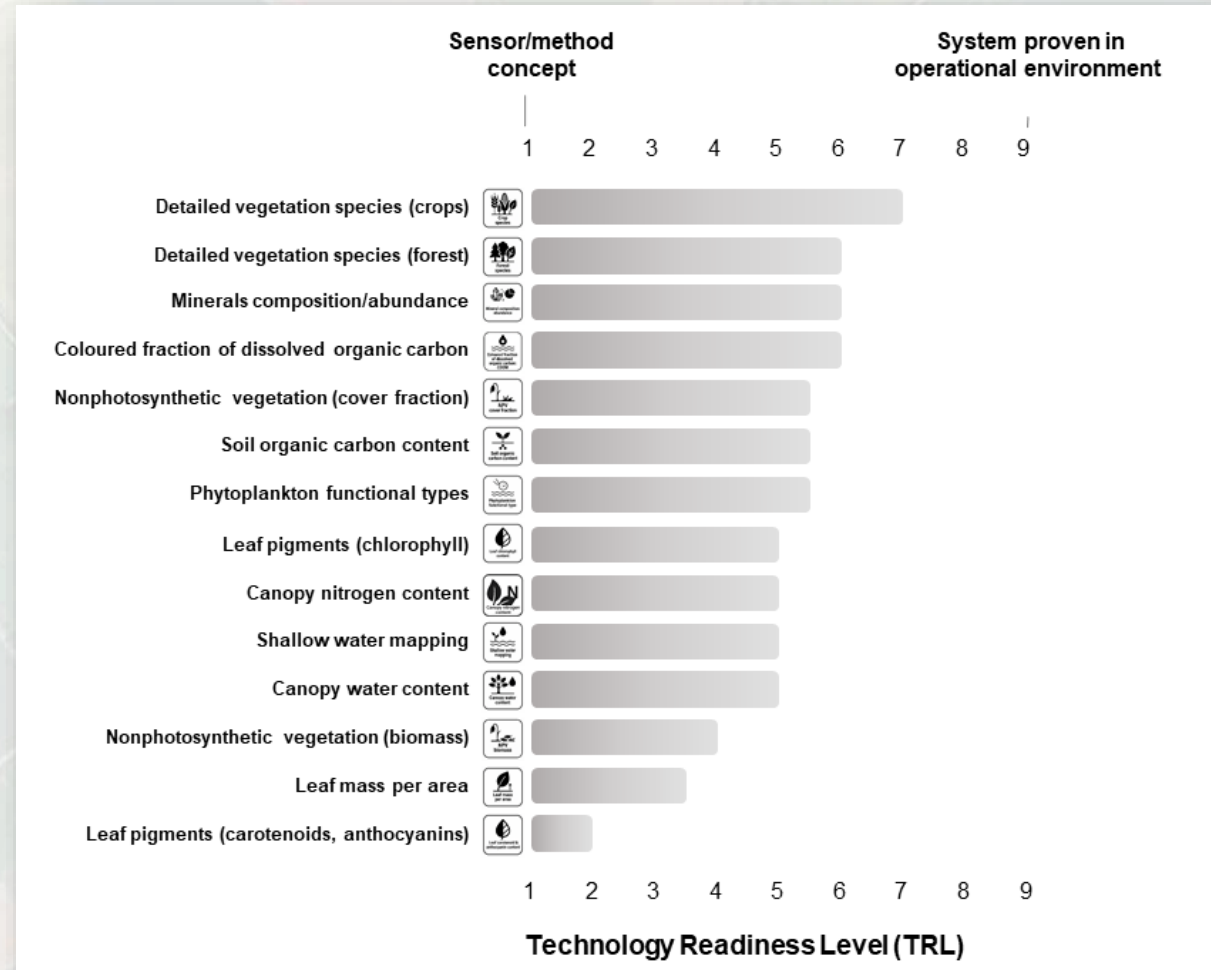
Credits: Saeid Asadzadeh, GFZ Potsdam

One set of missions. Three regulations. Hyperspectral is the common enabler.

Most products are stuck at medium Technology Readiness Level - TRL

- **Mature (TRL 6–7):** tree and crop species, CDOM
- **Progressing (TRL 4–5):** CWC, CNC, (SOC), NPV fraction, Cab,...
- **Emerging (TRL 2–4):** LMA, carotenoids, anthocyanins, NPV biomass

The gap between "demonstrable" and "operational" is real and must be closed before CHIME and S2NG are in space!

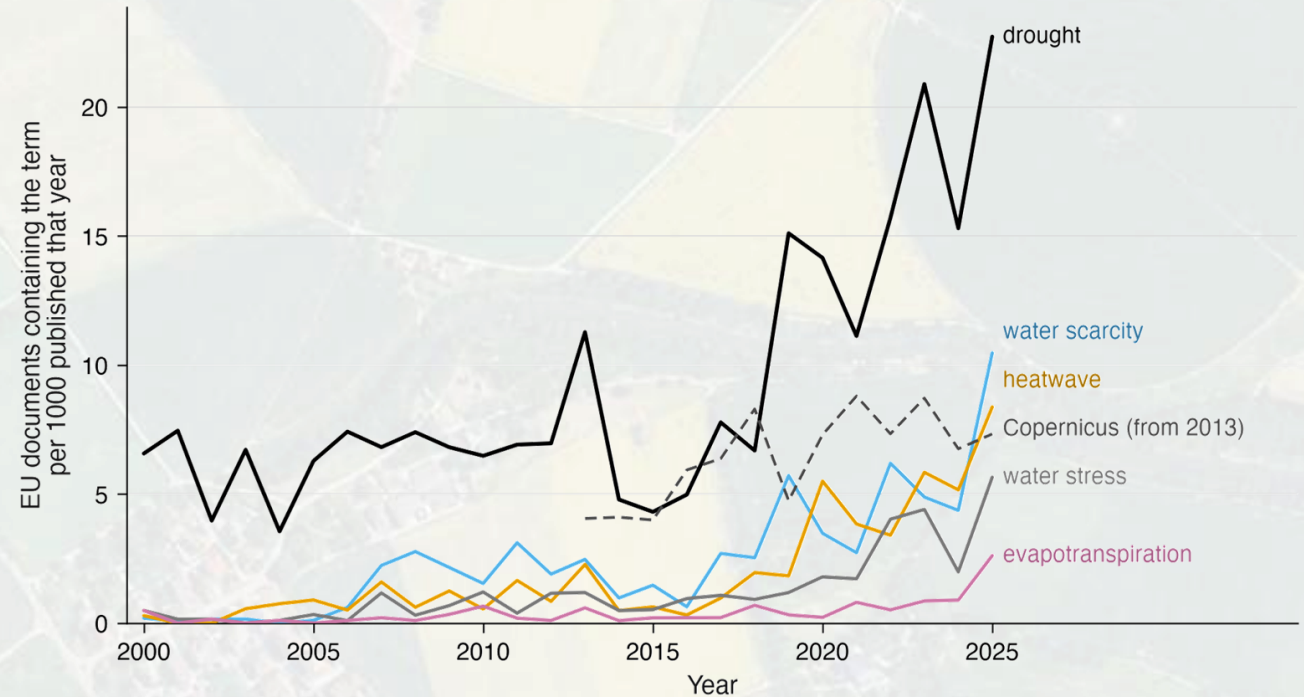


Source: Berger et al. 2026 (Environ. Sci. Eur., 10.1186/s12302-026-01346-3)

Thermal EO: the policy pull is already there.

- Legislative attention to thermal-observable stressors has risen sharply since 2015
- LSTM (2028–29) and TRISHNA arrive as this demand peaks, mission timing matching regulatory need.

Thermal is no longer a niche capability—it's a policy-mandated one.



Credits: Adrian Kreiner, ESA, ESRIN, paper in progress

AI and foundation models: enablers but not the complete answer.

- *Traditional workflows* are per-task, per-region, per-mission → costly to scale.
- **Geospatial foundation models** pre-train once on massive EO archives, adapt with fewer labels.
- **Real promise:** better generalisation, faster iteration, lower labelling burden.
- **Open points:** uncertainty, physical consistency, benchmarking on policy-regulated variables...
- **To not forget:** the environmental costs



AI accelerates the technical side. It does not replace the science–policy interface.

No operational EO without ground networks.

Needed for calibration and validation:

- Every operational variable (SOC, biomass, canopy nitrogen, ET, LAI) needs traceable reference data across biomes, seasons, and management systems.
- **In situ data also have their own purpose** – we can not see all from space!

What's still missing (selection):

- **Coverage of underrepresented biomes** (drylands, tropics, boreal peatlands)
- Interoperability in situ/EO — data are still hard to combine
- **Long-term funding** — most networks live project-to-project



Image generated with ChatGPT, Sept. 2026

Examples of networks doing this work today:

- ICOS (EU) + NEON (US) + TERN (AUS), FluxNet (global) — ecosystem carbon and water fluxes
- eLTER / TERENO — long-term ecological/ecosystem observatories
- JECAM / GEOGLAM — cropland calibration sites worldwide
- GBOV, FRM4Veg, FRM4SM, FRM4STS — cal/val for vegetation

Credits: Benjamin Brede, Viola Heinrich, GFZ Potsdam

**but the
product is not
yet the
information...**

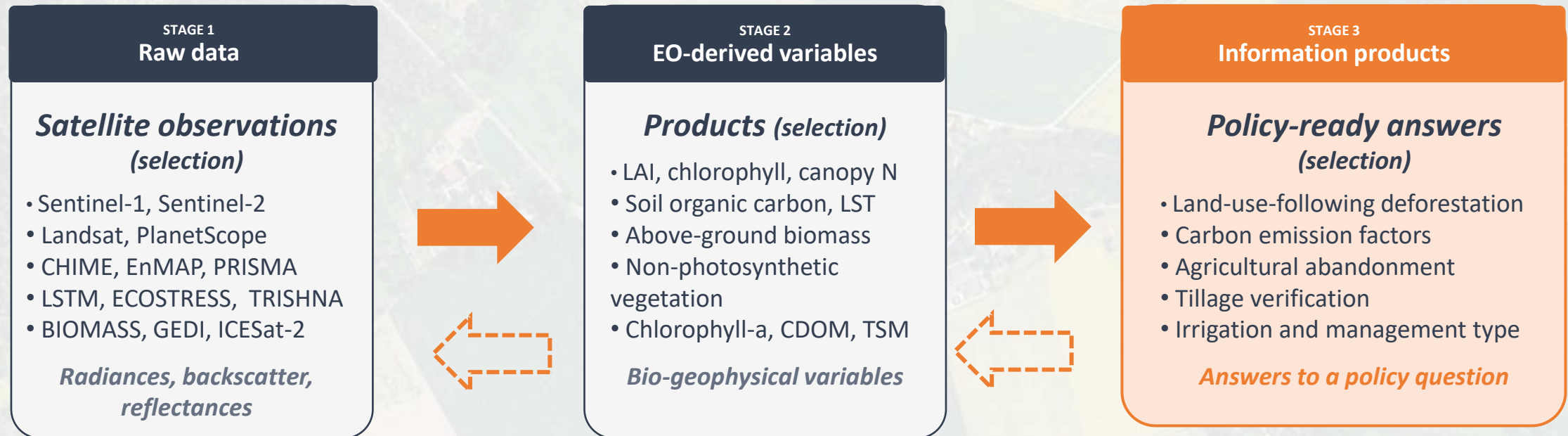


Multiple products allow to derive information products.



From raw data to actionable information.

Three stages, each adding interpretation and context — only the last one answers a policy question.



Data feeds variables. Variables feed information. Only information reaches policy.

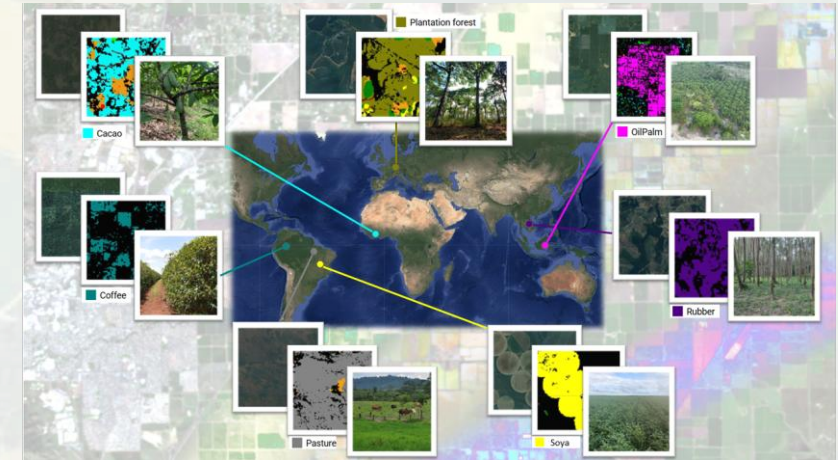
The EU deforestation regulation: EUDR.

EUDR (EU) 2023/1115: core is a deforestation-free supply chain, i.e., specific commodities (cattle, cocoa, coffee, palm oil, rubber, soy, and wood) placed on the EU market must not be linked to deforestation after the cut-off date Dec 2020.

- **Implementation:** December 2026-July 2027.
- **Operational products to support it:** GFC, RADD, GLAD-S2, DIST-ALERT, TMF, WHISP.
- **Gaps:** sub-0.5 ha clearings, (agro)forestry misclassification, limited spatial resolution (VHR)

What CHIME and S2NG (and BIOMASS/ROSE-L) would add:

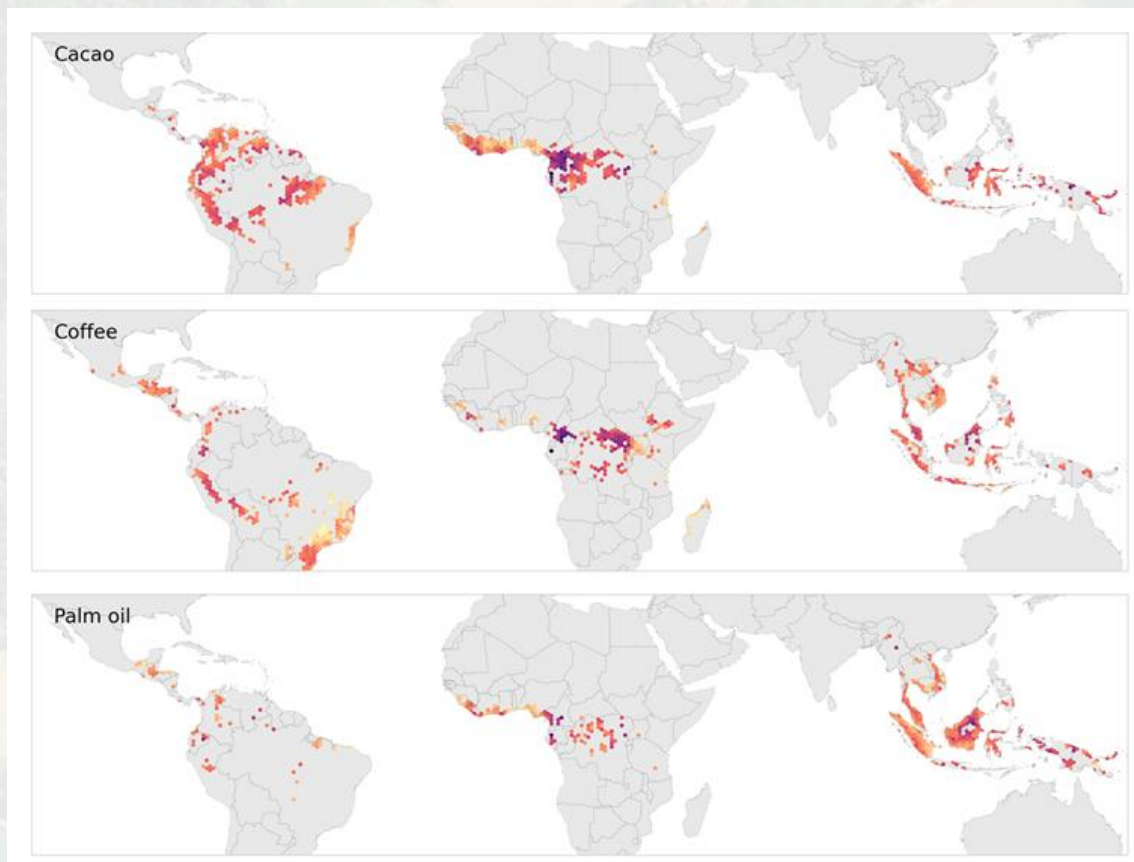
- Primary vs. planted vs. agroforestry distinction; degradation signals; NPV and post-clearing residues
- Finer commodity attribution, sub-hectare change detection (S2NG)
- Improved tropical AGB reference to anchor historical baselines (BIOMASS)



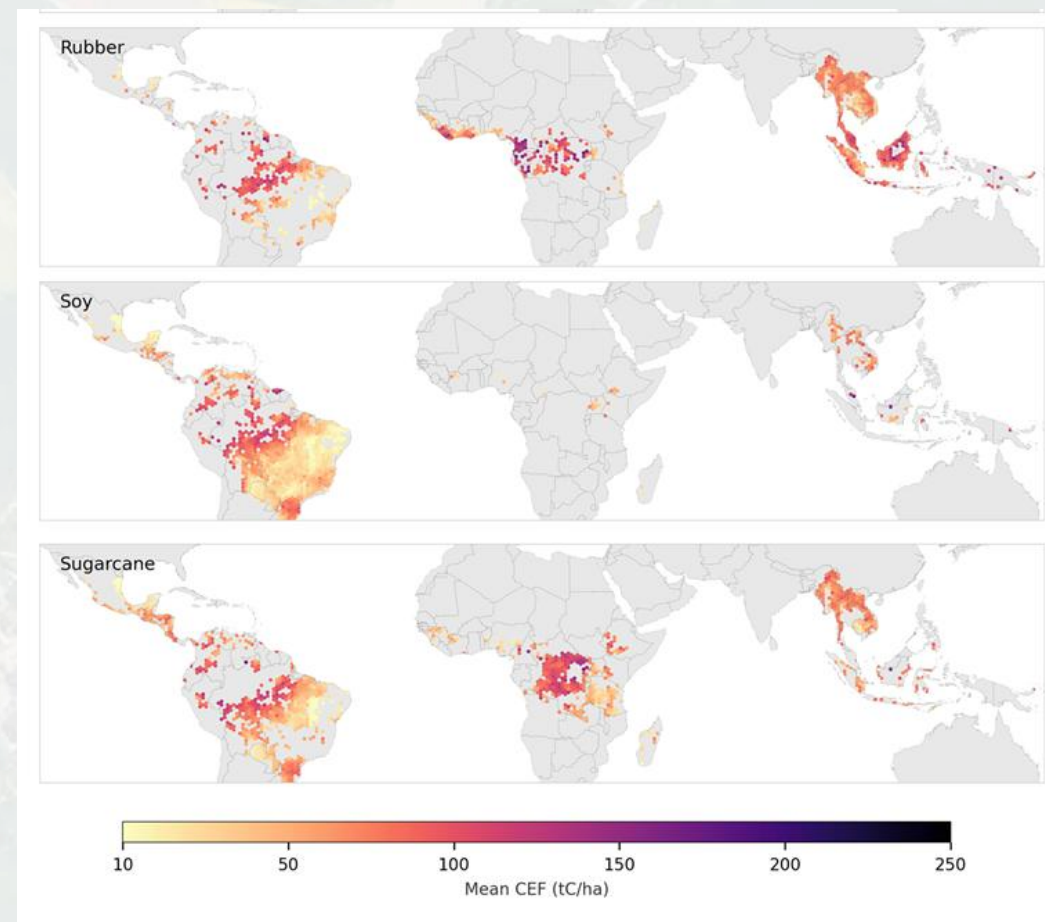
Source: Berger, Herold, Szantoi 2025 (*npj Climate Action*, 10.1038/s44168-025-00276-9), using information from Masolele et al., 2024

Mandating EO data would be critical for systematic monitoring, providing timely, and standardized evidence!

From pixels to policy: carbon emission factors.

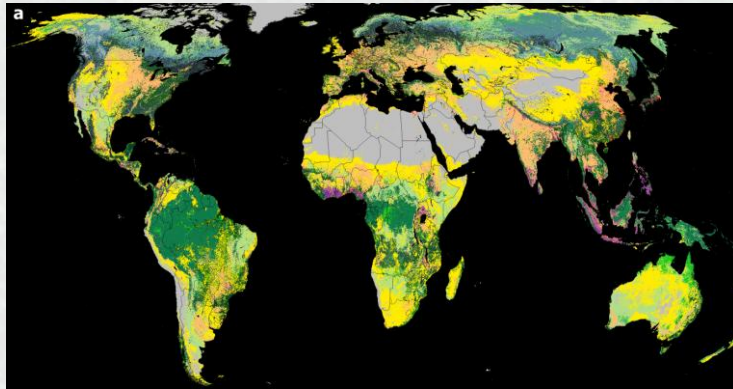


CEFs represent the intensity of carbon loss as aboveground biomass carbon loss per hectare of forest converted to agricultural use

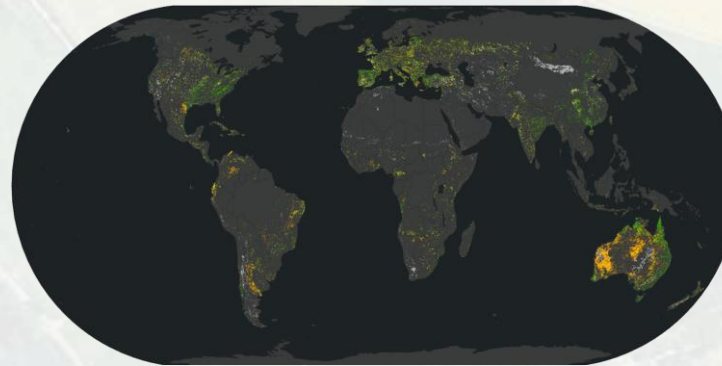


Credits: Camilo Zamora, GFZ Potsdam, paper in preparation

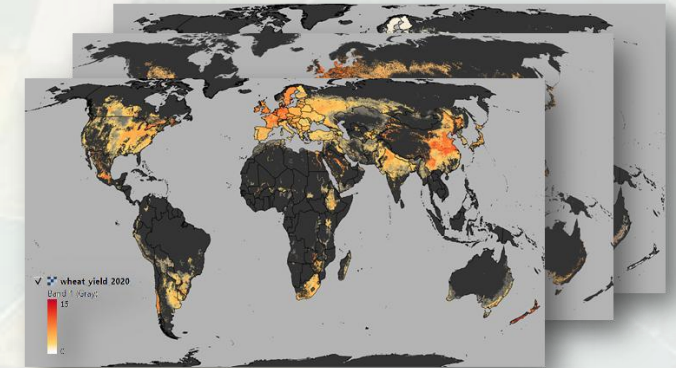
HILDA+ Agricultural information products: Abandonment - Yield - Management.



HILDA+ land use/cover (states) 2023
(Winkler et al., in prep)

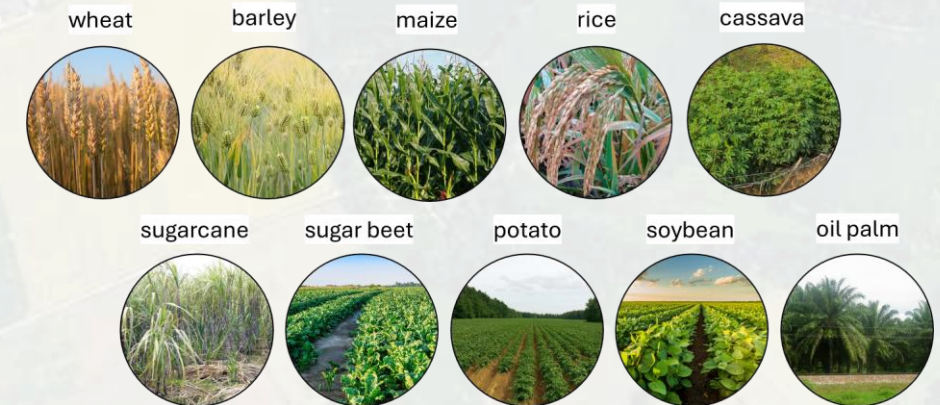


**HILDA+ 3.0 Agricultural
Abandonment**



Layers of management factors such as crop type-specific yield (here for wheat)

This is what "actionable" looks like — a policy-ready number, not a data cube.



Credits: Richard Fuchs and colleagues, KIT / HU Berlin

So back to the question:

Are we living through the golden age of Earth Observation?



Not yet but approaching: we need to first shift from monitoring for compliance to monitoring for learning

Fit-for-purpose, or not useful at all.

For designing the EO-derived information product for policymakers, we need to work together and ask them, among others:

- *Which policy question shall it answer?*
- *At what scale and with what uncertainty is it required?*
- *What are the technical requirements (spatial-temporal-time range-coverage...)*
- *Is the user community sufficiently trained and equipped?*



The science is ready. The interfaces must catch up.

Mind the gap. Then close it.

The constraint on EO's policy impact is institutional, not sensor-side. To close the gap, we need to:

- **Invest:** advance EO variables from prototype to operational maturity
- **Interface:** establish structured Science–Policy Interfaces (SPIs)
- **Co-produce:** scientists, policymakers and service providers, from the start
- **Dialogue:** sustain cross-community collaboration

Bridge the TRL gap through co-production!

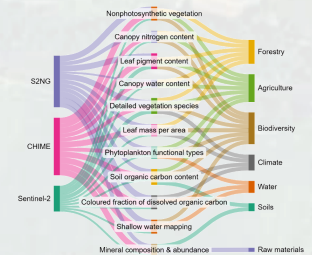


Relevant reference: Zhou et al., 2026, Nature Food

Conclusion.



- **Demand for EO is diversifying, not just growing:** policy, services and science are pulling;
- **We are approaching the golden age of Earth observation** through unprecedented data, sensors, and openness, but:
- **Turning raw EO data into information** is what is really needed for policymakers and other stakeholders; there is now AI, foundation models, embeddings, etc., and it is all possible, but:
- **Mind the gap between technology and user capacity/uptake**, including fit for purpose, and questions of access, fairness, uncertainties, privacy and ownership.



THE END

Thank you.

Questions welcome.

Dr. Katja Berger

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Evolving Earth observation capabilities for recent land-related EU policies

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[Evidence/Examples Used](#)

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Earth observation as enabler for implementing the EU regulation on deforestation-free products

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- **Berger K., Herold M., Szantoi Z.** (2025). Earth observation as enabler for implementing the EU regulation on deforestation-free products. *npj Climate Action*. doi:10.1038/s44168-025-00276-9
- **Masolele R. et al.** (2024). Mapping the diversity of land uses following deforestation across Africa. *Scientific Reports*. doi:10.1038/s41598-024-52138-9
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- **Asadzadeh S. et al.** (2024). Detecting rare earth elements using EnMAP hyperspectral satellite data: a case study from Mountain Pass, California. *Scientific Reports* volume 14, 20766 (2024) <https://doi.org/10.1038/s41598-024-71395-2>.
- **Singh, C., Persson, U.M.** Global patterns of commodity-driven deforestation and associated carbon emissions. *Nat Food* 7, 138–151 (2026). <https://doi.org/10.1038/s43016-026-01305-4>
- **Zhou, Y., Fiorini, A., Croci, M. et al.** Remote sensing, fairness and institutional capacity in European agricultural governance. *Nat Food* 7, 820–822 (2026). <https://doi.org/10.1038/s43016-026-01427-9>

Reports & data

- IPCC AR6 — climate warming rate
- FAO — global food demand projections
- EU legislation as cited on individual slides; compilation in Berger et al. (2025), *Land Use Policy*

In preparation / unpublished

- Kreiner et al: Advancing Thermal Infrared Earth Observation for EU policies: needs, opportunities, recommendations. in preparation
- Zamora C. et al.: Pixel to policy: assessing commodity-driven deforestation and emissions footprints across pantropical ecoregions. in preparation
- Fuchs R. and colleagues (KIT / HU Berlin) — HILDA+ 3.0 Agricultural Abandonment
- Winkler K. et al. — HILDA+ land use/cover (states) 2023, in preparation

Image credits, quotes & online sources

- Berninger M. (Bayer, EVP Sustainability) — [youtube.com/watch?v=AhpQFBEDvzY](https://www.youtube.com/watch?v=AhpQFBEDvzY)
- Asadzadeh S. (GFZ) — image credit, Raw materials slide
- Christoph Sannier (GFZ) — image courtesy, agrocommodities.info
- Benjamin Brede (GFZ) — text input, LiDAR and in situ
- EnMAP global archive since 2022 — www.enmap.org
- Martin Herold (GFZ) — text input, what we have today
- Markus Immitzer (BOKU), figure 2 in Berger et al., 2026

Abstract opening soon. Stay tuned.

The poster features a green and blue color scheme. At the top left is the ESA logo. A horizontal line with a green glow passes through three circular icons: a green plant, a satellite map, and a globe. To the right of the globe are four stacked teal tabs labeled 'UPTAKE', 'POLICY', 'APPLICATIONS', and 'SCIENCE'. The background is a composite of a sky, a field, and a satellite map.

esa

EO4AGRI 2027
Scaling EO for Agricultural Resilience Conference
26–29 April 2027 | ESA-ESRIN | Frascati (Rome), Italy

UPTAKE
POLICY
APPLICATIONS
SCIENCE

Organised by Zoltan Szantoi, ESA, and team