



● ● ● ● **A SYSTEMATIC REVIEW ON VEGETATION
MONITORING WITH SENTINEL-2:
ADVANCES IN WORKFLOWS, APPLICATION
AREAS, AND FUTURE DIRECTIONS**

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**7th Sentinel-2 Validation Team Meeting
13 – 15 October 2025 @ ESA-ESRIN**



INTRODUCTION

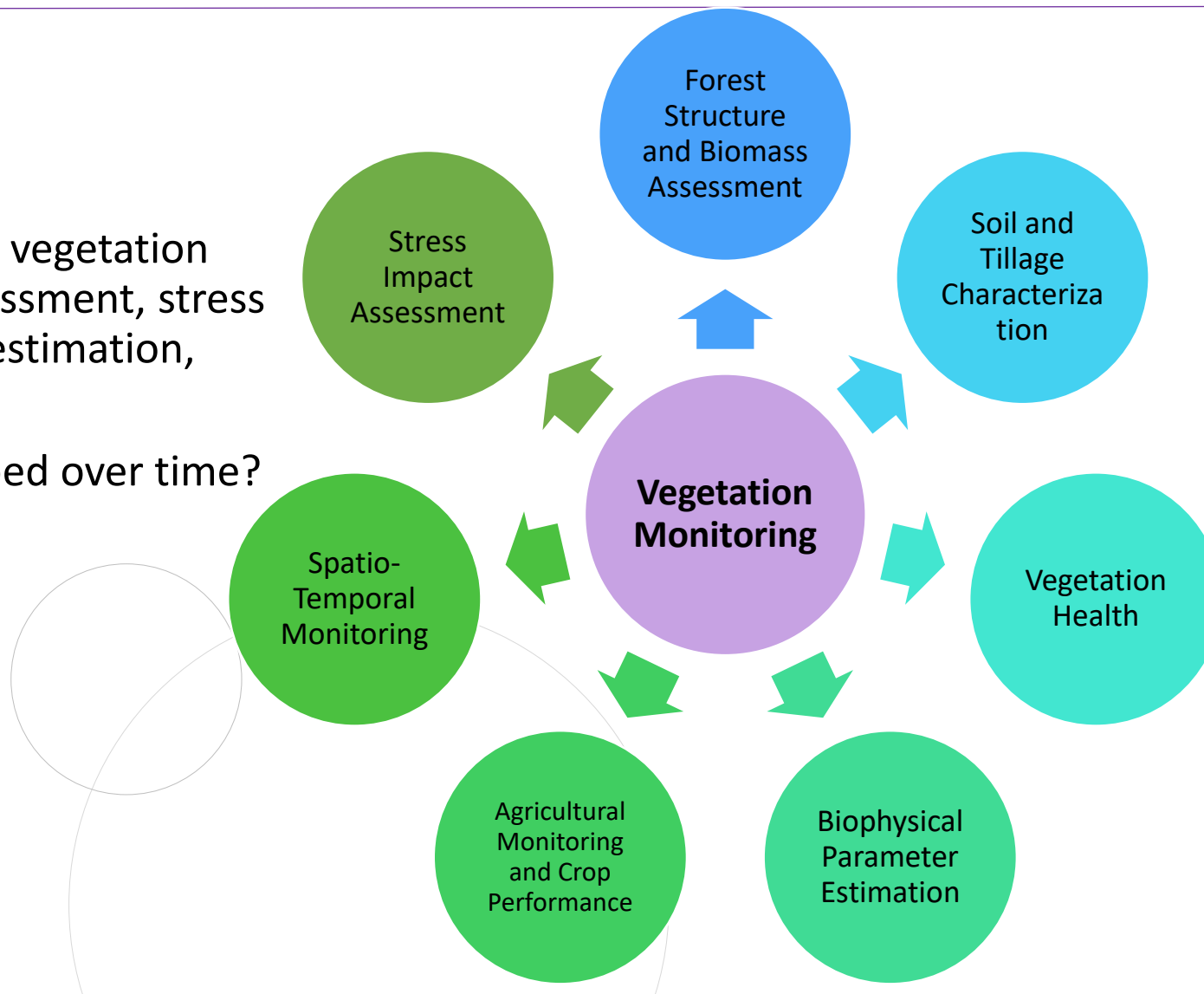
- S2 redefined the EO in terrestrial vegetation
- Applications: stress, PFT, phenology, crop yield, etc.
- Review aims from 2015-2025
- Identifies key applications, methods, and emerging trends
- Complementary dataset, along with other datasets, improves accuracy
- Lacking: rapid assessments (5-day revisit), lesser biochemical sensitivity, less soil moisture-related activities (absence of thermal bands)



AIM OF RESEARCH

Research Question

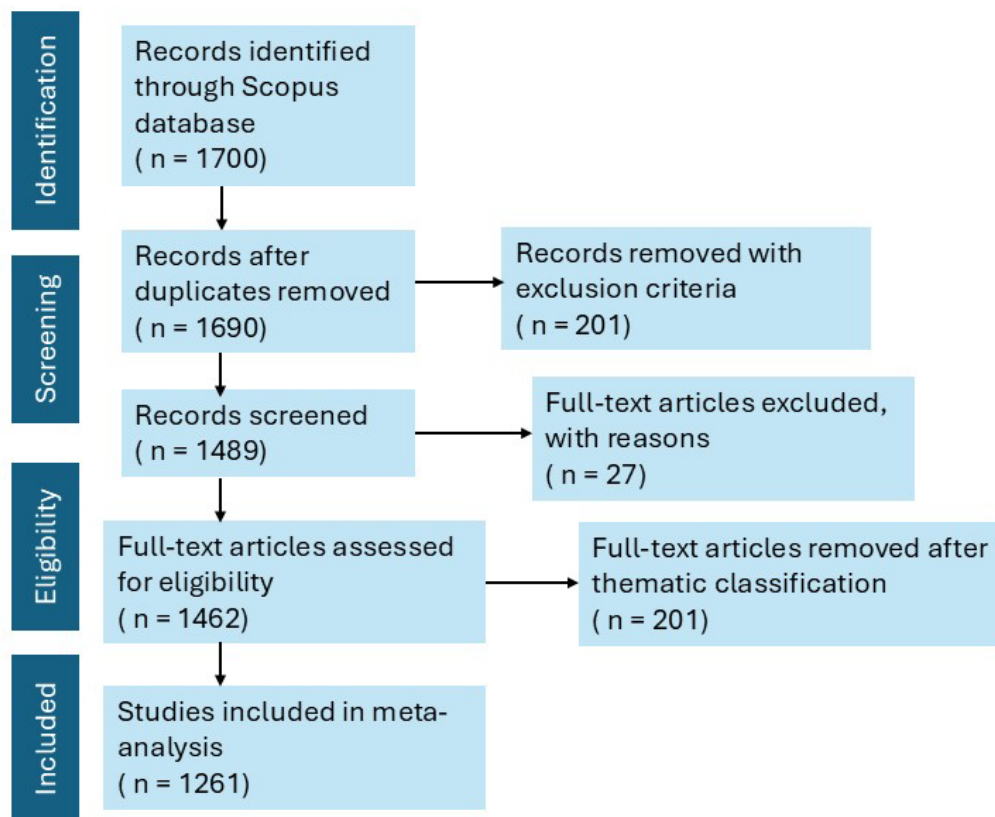
- How has Sentinel-2 data improved vegetation monitoring in terms of health assessment, stress detection, biophysical parameter estimation, and modelling?
- How have its applications developed over time?





META-ANALYSIS

PRISMA FLOWCHART



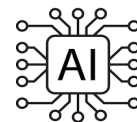
1. Search Key

TITLE-ABS-KEY ("Sentinel-2" OR "Sentinel 2") AND TITLE-ABS-KEY ("vegetation " OR "forest " OR "crop") AND NOT ("land use" OR "land cover" OR "LULC" OR "Snow" OR "Glaciers") AND PUBYEAR > 2014 AND PUBYEAR < 2026 AND (LIMIT-TO (SUBJAREA,"EART") OR LIMIT-TO (SUBJAREA,"COMP") OR LIMIT-TO (SUBJAREA,"AGRI") OR LIMIT-TO (SUBJAREA,"ENVI") OR LIMIT-TO (SUBJAREA,"ENGI") OR LIMIT-TO (SUBJAREA,"MULT")) AND (LIMIT-TO (DOCTYPE,"ar")) AND (LIMIT-TO (LANGUAGE,"English"))

2. Exclusion

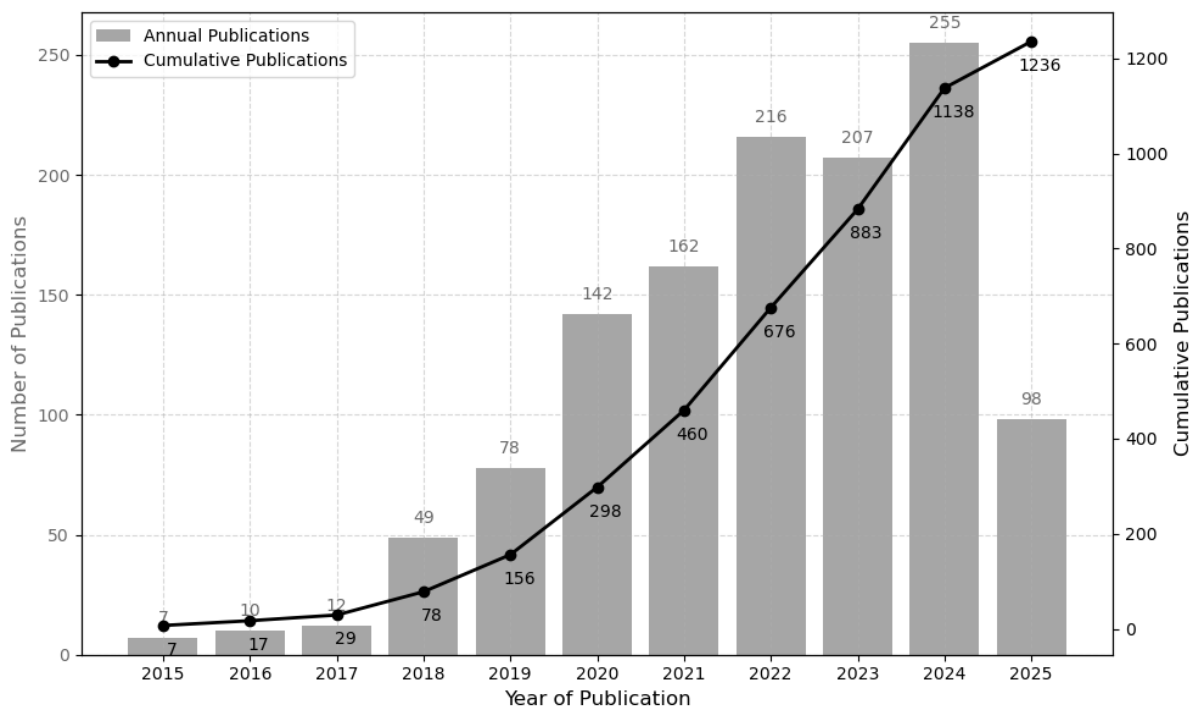
water quality, coastal areas, urban heat island, shoreline, bathymetric, mineral exploration, rivers, lakes, (**reasons:** full-text unavailable, foreign language, repetitive).

3. Preliminary analysis:





PUBLICATION TRENDS



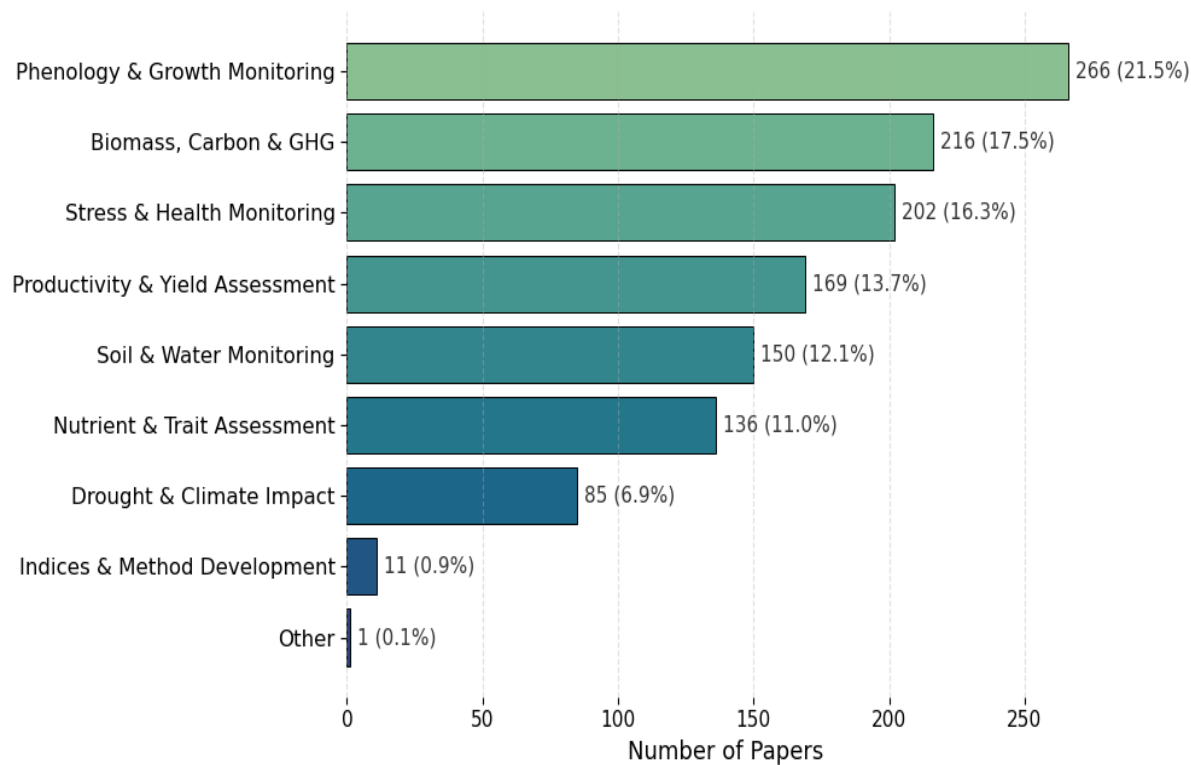
Papers Published in Top 10 Journals



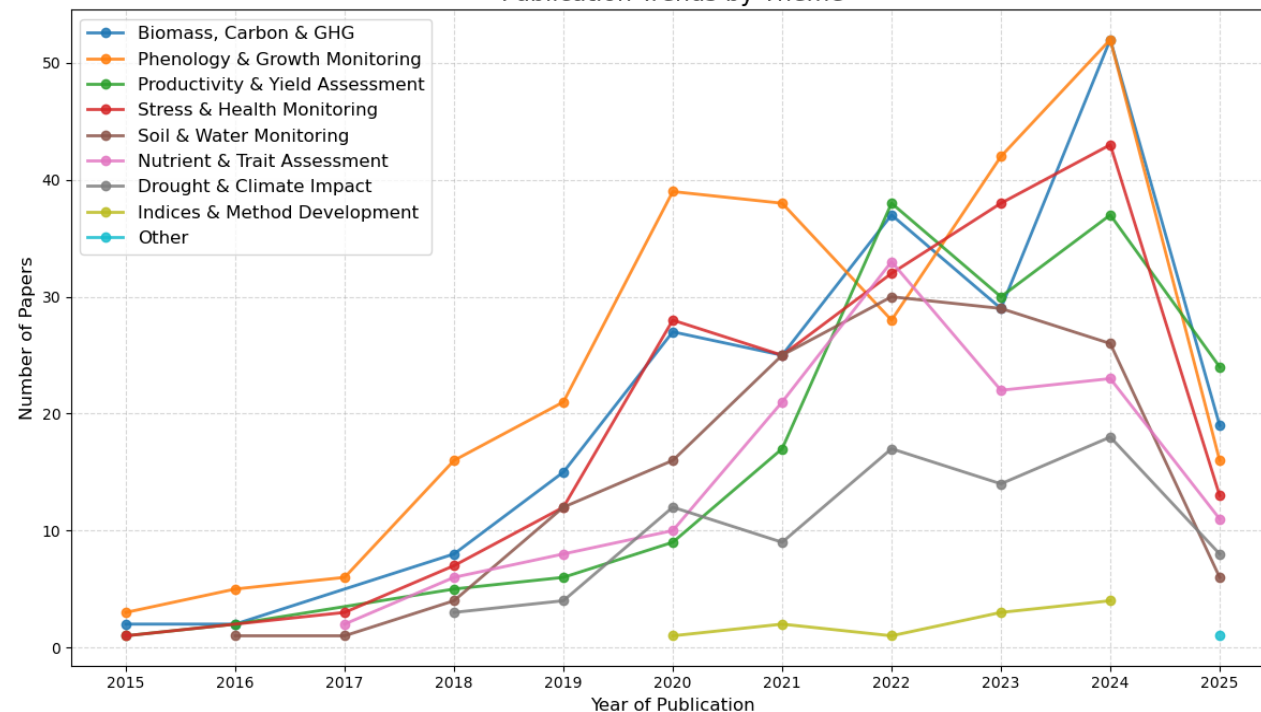


PUBLICATION DISTRIBUTION BY THEME

Distribution of Papers by Research Theme



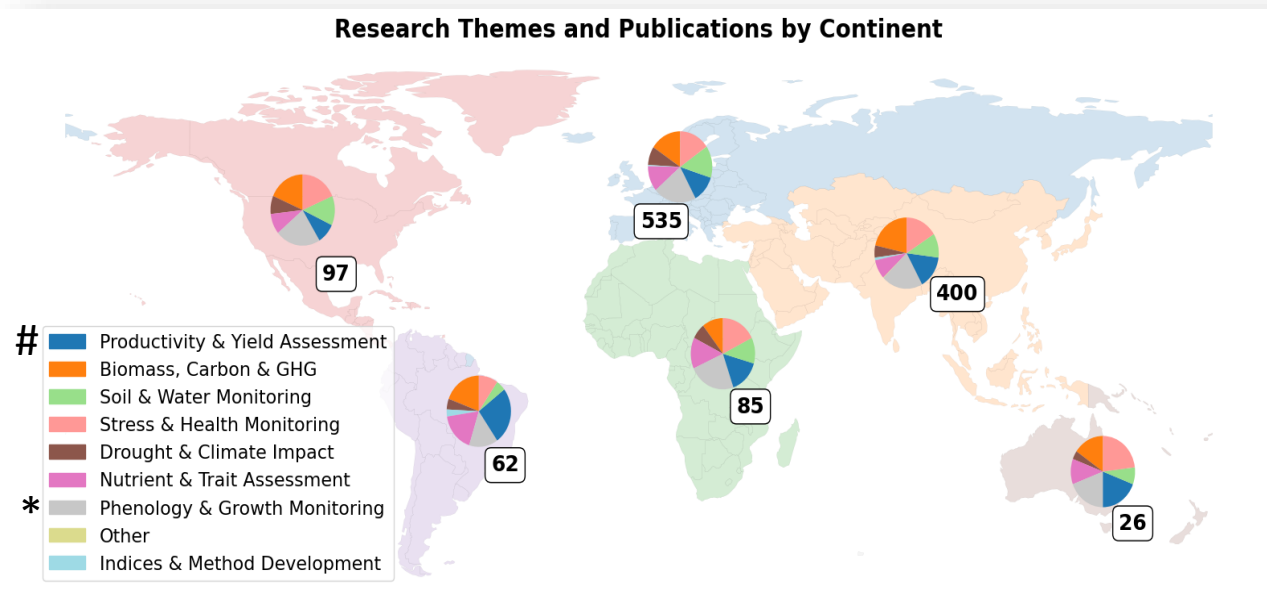
Publication Trends by Theme



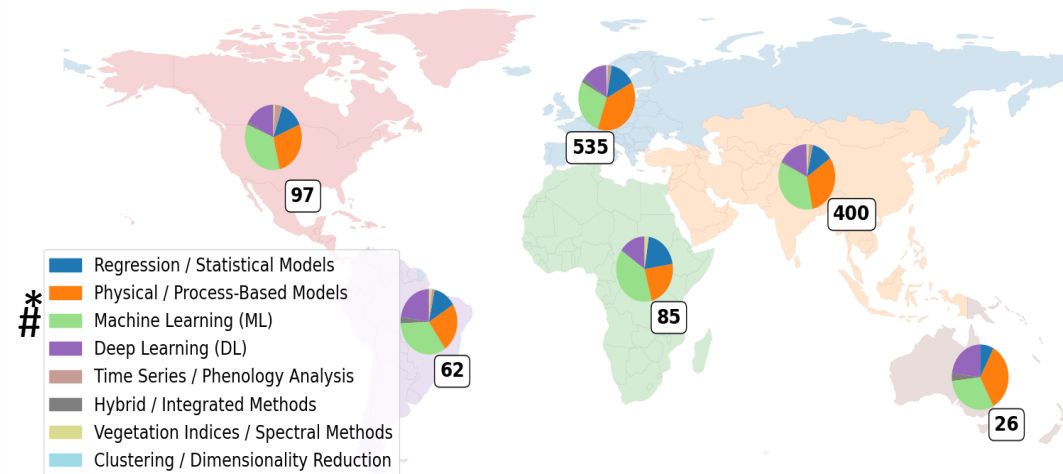


GEOGRAPHICAL DISTRIBUTION

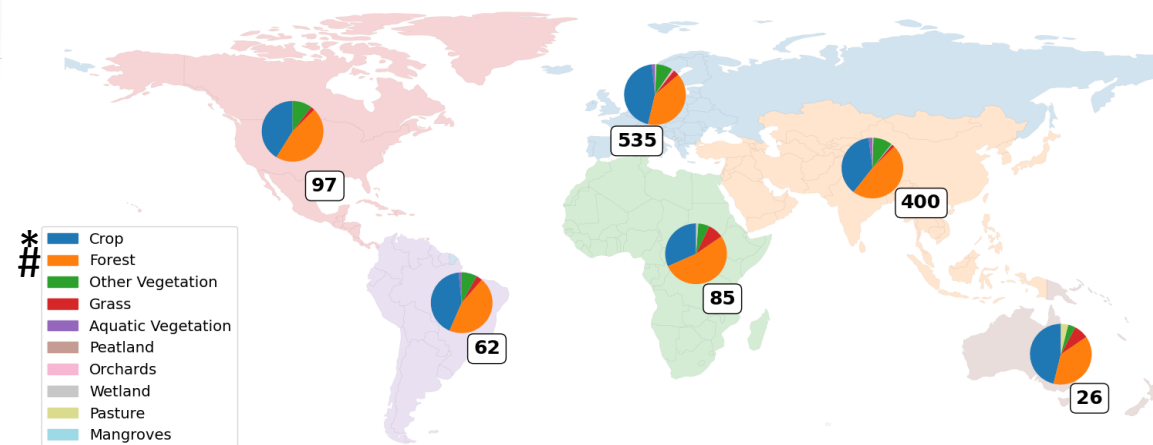
Research Themes and Publications by Continent



Methods and Publications by Continent



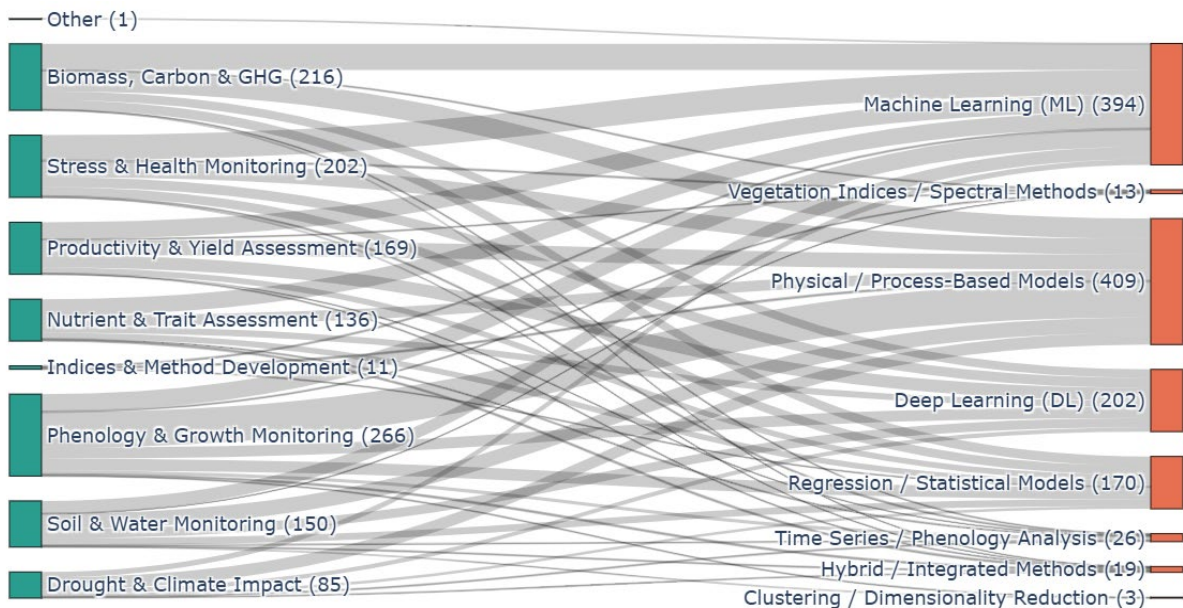
Vegetation Type Distribution and Publications by Continent



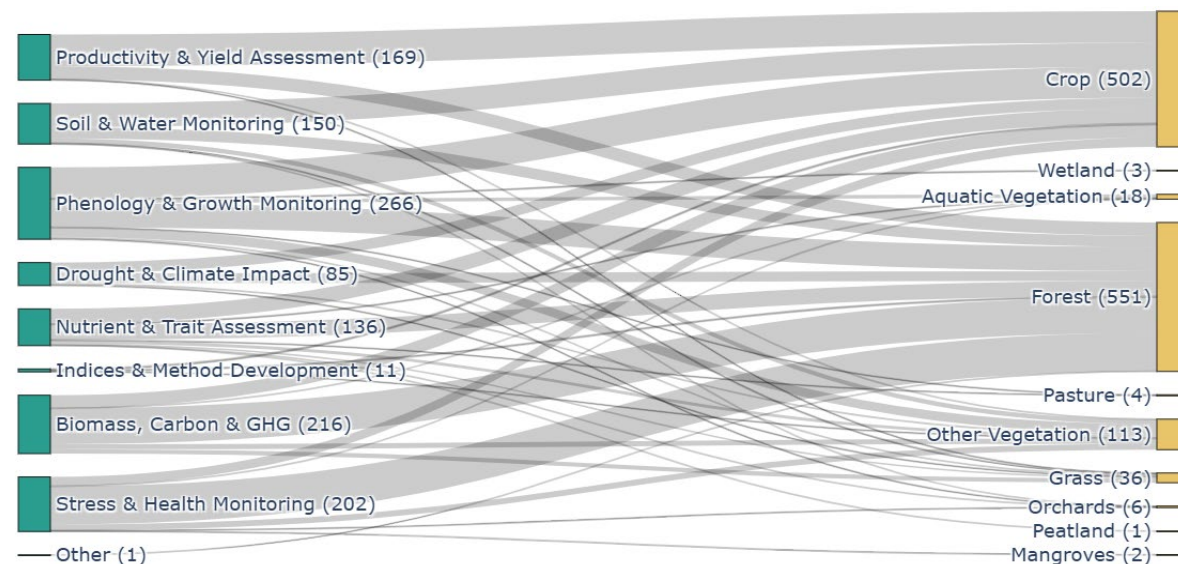


CONNECTING THE DOTS: THEMES, APPROACHES, AND VEGETATION

Themes vs. Methods



Themes vs. Vegetation Type





THEME 1: DETECTION AND IMPACT ASSESSMENT OF DROUGHT AND MULTIPLE STRESSORS

Trait-based drought assessment in forests and crops:

- Sentinel-2-derived GLAI integration into Crop models (LINTUL-CC2, WOFOST, and DO3SE) and GLAI time series revealed reduced winter wheat growth during droughts. **(Sjulgård et al., 2025)**.
- Chlorophyll content (CCC) is the most sensitive drought indicator in forests (CCC > LAI > CWC) **(Savinelli et al., 2024)**.
- Bands: B4 (red), B8 (NIR), B11 & B12 (SWIR) can distinguish: leaf discoloration vs. Defoliation **(Bucha et al., 2024)**
- SWIR bands (e.g., B12) of Sentinel 2 excel at detecting early-stage drought stress in crops **(Xiao et al., 2023)**.
- Sentinel-2 NDVI/EVI indices significantly correlated with diversity effects. Higher plant diversity is linked to lower drought sensitivity in arid forests **(Ma et al., 2025)**.
- Sentinel 2-based Z-NDVI & NDWI captured short-term forest stress and regeneration over 6 years and enabled stand-level tracking of compound drought-heat events **(Bolla et al., 2024)**

- **Applications have evolved from NDVI-only to:** Full trait retrieval, Phenology modelling, Integrated drought-risk assessment
- **Limitations:** No direct measurement of subsurface water stress, Limited in spectral range



THEME 2: NOVEL INDICES DEVELOPMENT

- **Trait estimation:** Three red-edge VIs (VI3RE) overcame saturation issues at high LAI and reduced effects of chlorophyll and leaf angles (Qiao et al., 2024).
 - **Vegetation Destruction Detection:** **BVDI (Baseline-based Vegetation Destruction Index)** outperformed NDVI, EVI, NBR, etc., in identifying damage from **wildfire, insect outbreaks, landslides, and logging** with finer spatial precision (Zhao et al., 2024).
 - **Post-Harvest Residue Monitoring:** New indices **AIRSI (B4:B5:B12)**, **PNISI(B4:B8)**, **NDSSI (B12:B9)** achieved **>90% accuracy** in mapping upright maize straw, aiding **straw burning reduction** (Zhou et al., 2024).
 - **Pest and Disease Detection:** Coffee Leaf Miner Index (**Blu:red:nir**) & CRDI (Coffee Rust Detection Index (**B4:B8A:B7**)) detected pests/diseases with **>89% accuracy** using red-edge and NIR bands + ML (Emerson & Castro et al., 2023). Rice Blast Index captured ground-to-satellite infection dynamics (Tian et al., 2023).
 - **Cotton Boll Opening Estimation:** New indices **BARI ($R^2 = 0.75$)** & **BORI ($R^2 = 0.67$)** (**Blu:redEdg3:red**) enabled regional-scale cotton harvest readiness monitoring, outperforming published VIs (**Ren et al., 2020**).
 - **Tree Health & Forest Risk:** **nVVI** (Normalized Vegetation Vigour Index) negatively correlated with tree age ($r = -0.815$), used for tree failure risk management (**De Petris et al., 2020**).
- **S 2 enabled next-gen indices** (e.g., VI3RE, BVDI, CRDI, OSI, ABDI) that outperform traditional indices (NDVI, EVI, etc.).
- **S-2 can detect** drought, pest infestation, crop failures, and forest decline before visible symptoms escalate.
- **Limitation:** Indices may not capture 3D structural variations in complex vegetation (e.g., cotton vertical layers or mature forests).



THEME 3: ADVANCING PHENOLOGY & VEGETATION GROWTH DYNAMICS

- **Fine-Scale Phenology Detection:** 10–20 m resolution and 5-day revisit enable precise SOS, EOS estimation at field/sub-field scales, capturing variability in **heterogeneous** landscapes (**Wang et al., 2023; Liet et al., 2023**).
- **Climate & Land-Use Sensitivity:** Dense time series capture intra- and inter-annual dynamics and reveal **phenological shifts** driven by **warming trends, drought, land-use change, and urban heat effects** (**Kumar et al., 2020; Garcia et al., 2023**).
- **Multi-Trait Retrieval:** Red-edge bands allow simultaneous estimation of LAI, chlorophyll, biomass, and canopy structure, improving detection of subtle growth changes and early stress signals (**Wan et al., 2024**).
- **Improved Applications:** Sentinel-2-derived Phenology metrics (SOS, EOS) better **constrain** crop and ecosystem model parameters, enhancing model calibration, yield forecasting, and biomass estimation (**Sun et al., 2022; Möckel et al., 2020**).
- **High-Resolution Operational Value:** Products like **HR-VPP** showcase Sentinel-2's spatial detail for field-level phenology and productivity mapping, detecting subtle growth patterns, and landscape heterogeneity (**Martinez et al., 2023**).

➤ Phenology monitoring remains challenged by cloud cover, complex multi-layered canopies, fine-scale variability, and the need for ground validation.



CONCLUSIONS AND WAY FORWARD

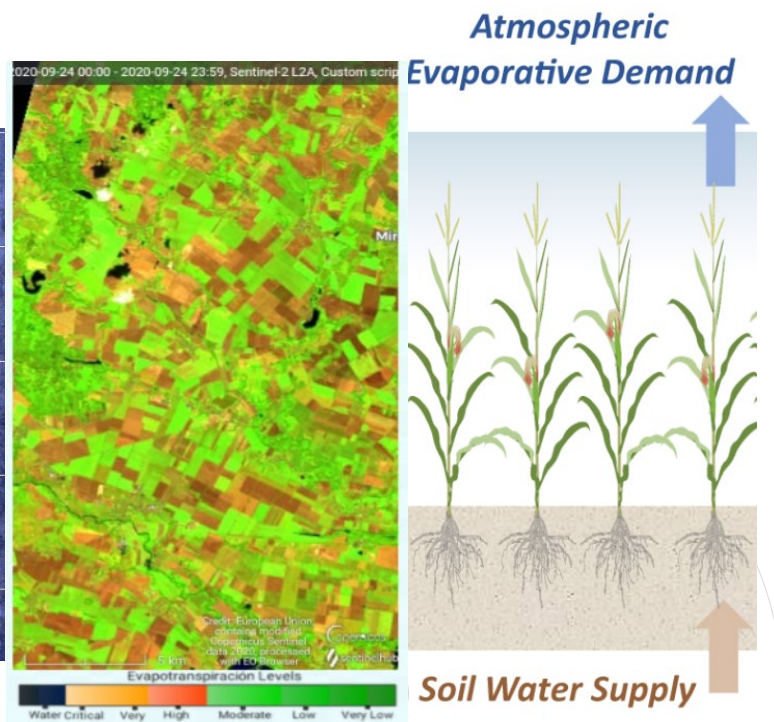
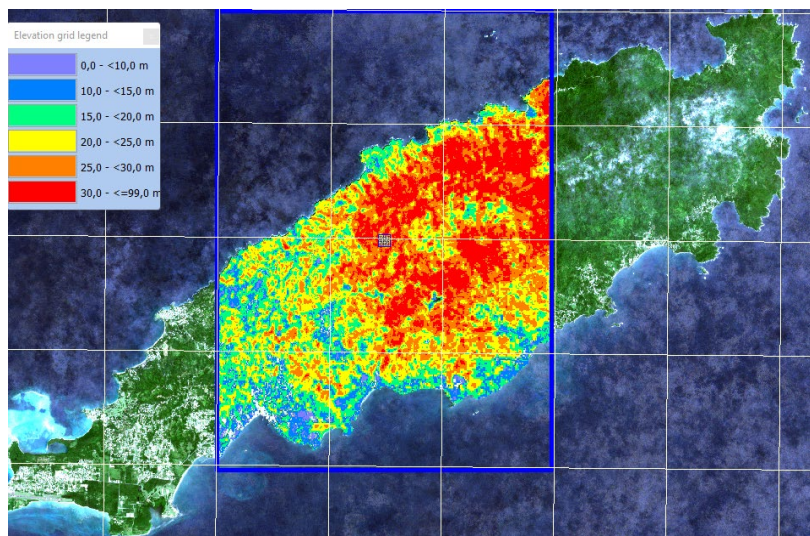
- **Widespread Adoption:** Steady growth in publications ; used in agriculture, forestry, rangelands, and other ecosystems.
- **Drought & Stress Assessment:** GLAI, CCC, SWIR bands, and NDVI/EVI derivatives detect drought, heat, and early stress in crops and forests.
- **New Indices:** VI3RE, BVDI, CRDI, OSI, ABDI outperform traditional NDVI/EVI for pest, disease, post-harvest, and forest risk detection. A wider scope for other areas of application.....
- **Phenology & Growth Tracking:** 10–20 m resolution and 5-day revisit enable SOS/POS/EOS monitoring, multi-trait retrieval, and improved crop/ecosystem model calibration.
- **Operational Impact:** High-resolution products (e.g., HR-VPP) enable field-to-landscape applications for precision agriculture and ecosystem management.
- **Multi-Sensor Integration:** Combine Sentinel-2 with Landsat, Sentinel-1, and hyperspectral data to fill temporal gaps and enhance spectral coverage.
- **Limitations:** Cloud gaps, canopy complexity, sub-field variability, 3D structure, and reliance on ground validation.



NEXT STEPS

Sentinel 2 application in the

- Biomass, Carbon stock and GHG monitoring
- Soil and canopy water monitoring
- Productivity & Yield Assessment
- Nutrient and trait assessment



Systematic Review is still in process

THANK YOU FOR YOUR ATTENTION

