

# Earth observations for aboveground carbon estimation

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*with contributions by many*



# Recent EU policies requiring EO data

- Stimulates varying sustainable/climate-smart forest/land management, land use and resource use practices
- Earth Observation becoming essential for policy making, compliance monitoring, transparency and enforcement
- Underpins data-driven environmental governance

## Agriculture:

- Common Agricultural Policy 2023-27: 02/12/2021 (CAP initiated 1962)
- Farm to Fork Strategy: 20/05/2020

## Forestry:

- Stepping Up EU Action to Protect and Restore Forests: 23/07/2019
- EU Forest Strategy for 2030: 16/07/2021
- Regulation on Deforestation-free Products: 31/05/2023
- Forest Monitoring Law: (proposed) 22/11/2023

## Climate:

- EU strategy on adaptation to climate change: 24/02/2021
- European Climate Law: 30/06/2021
- Communication on Sustainable Carbon Cycles: 15/12/2021
- General Union Environment Action Programme to 2030: 06/04/2022
- 2023 EU Regulation on Land, Land Use Change and Forestry: 19/04/2023
- Carbon Removals and Carbon Farming Regulation: 10/04/2024

## Soils:

- EU Soil Strategy for 2030: 17/11/2021
- Soil Monitoring Law (proposed): 05/07/2023

## Biodiversity:

- EU Biodiversity Strategy for 2030: 20/05/2020
- Nature Restoration Law: 22/06/2022

## Water:

- Proposal for a Directive amending the Water Framework Directive, the Groundwater Directive and the Environmental Quality Standards Directive: 26/10/2022

## Raw materials:

- Critical Raw Materials Resilience: 03/09/2020

# The right information for the right purpose

## Awareness



### Definition of the problems – policy anticipation:

- **CAP**: imbalance between agricultural production, rural development and environmental protection;
- **EU LULUCF**: decrease of the land carbon sink due to specific management actions;
- **EUDR**: agricultural production recognized as a major driver of global deforestation and forest degradation contributing more than 10% of global greenhouse gas emissions;
- **FML**: pressure on EU forests due to climate change and unsustainable human activity, gaps recognized in existing information.

## Evaluation - Compliance



### Solving of the problems with Copernicus?

- **CAP**: evaluation through independent monitoring of agricultural practices and land use changes;
- **EU LULUCF**: providing accurate, high-resolution data for tracking land use changes, forest management practices, and associated carbon fluxes;
- **EUDR**: potentially central role of EO data, may allow near-real time monitoring of forest cover and enabling independent verification of company claims;
- **FML**: potentially central role of EO data, allowing for independent verification of member state data collection and eventually early warning systems.

## Policy Design



### Policy formulation to solve these problems:

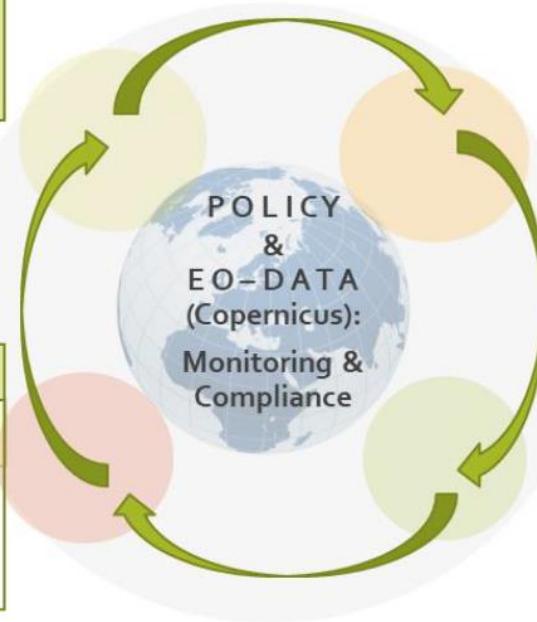
- **CAP**: financially supports EU farmers to ensure stable food supplies and rural development, while increasingly integrating environmental sustainability goals;
- **EU LULUCF**: tracks greenhouse gas emissions and removals associated with how we manage land, forests, and trees;
- **EUDR**: avoid deforestation and forest degradation from EU supply chains by ensuring only legal and deforestation-free products reach the EU markets;
- **FML**: a standardized system for collecting data on EU forests, improving our understanding of their health and enabling better-informed decisions about their protection and management.

## Implementation



### Adoption phase with stakeholder information:

- **CAP**: implemented through diverse funds, instruments and measures, e.g. Agri-environment-climate measures (AECMs), organic farming;
- **EU LULUCF**: member states setting targets and reporting on land use changes, forestry practices, and associated greenhouse gas emissions and removals;
- **EUDR**: establish procedures for conducting checks on operator compliance (CNAs), develop a due diligence system to assess the deforestation risk of their products (operators)
- **FML**: if passed, implementation by member states following standardized data collection methods to create a central EU forest knowledge base.



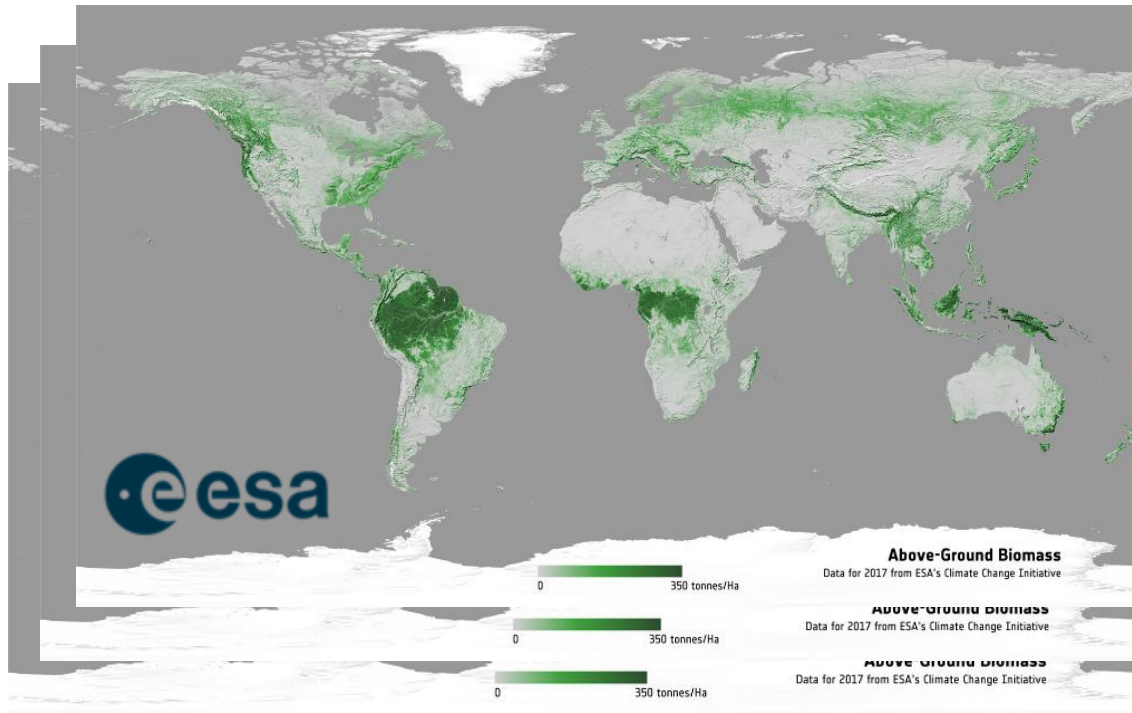
# EC LULUCF regulation and implications for EO monitoring

1. Geographically-explicit land use conversion data:
  - Higher IPCC approaches and more transparency
2. Geographically-explicit information to identify priority areas that have the potential to contribute to climate action:
  - Spatial information for climate policy purposes
3. Improved monitoring of natural disturbances and impacts:
  - Identification (location, type, period) and potential compensation for losses
4. Moving towards IPCC Tier 2 as minimum requirement from 2028 onwards:
  - Tier 3 in specific areas (i.e. high carbon stocks, high climate risk)
5. Increasing timeliness for providing data and estimates:
  - Annual inventories, compliance checks, closer ties to policies and actions

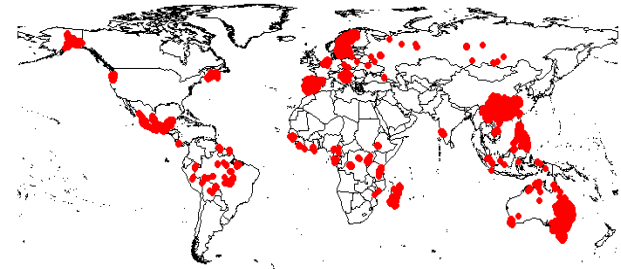
# CRCF requirements (related EO data)

- Focus is on carbon removals related to “activities”
- For aboveground biomass: agroforestry and planting of trees - mostly lower biomass ranges and (small) annual increments
- Different methodological approaches: models, on-site measurements, remote sensing etc. (incl. combination)
- Long-term monitoring:
  - Eligibility criteria, incl. prior land use
  - Activity period and monitoring period (up to 40 years)
- Remote sensing: high-resolution (i.e. 10 m resolution), different sources (satellite, airborne LIDAR etc.)
- Relevance for risk assessment (i.e. reversals, permanence, buffer)

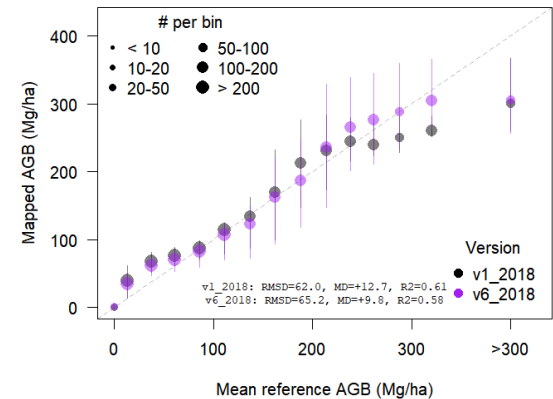
# Aboveground biomass mapping from space



Global reference database (~109.000 plots)

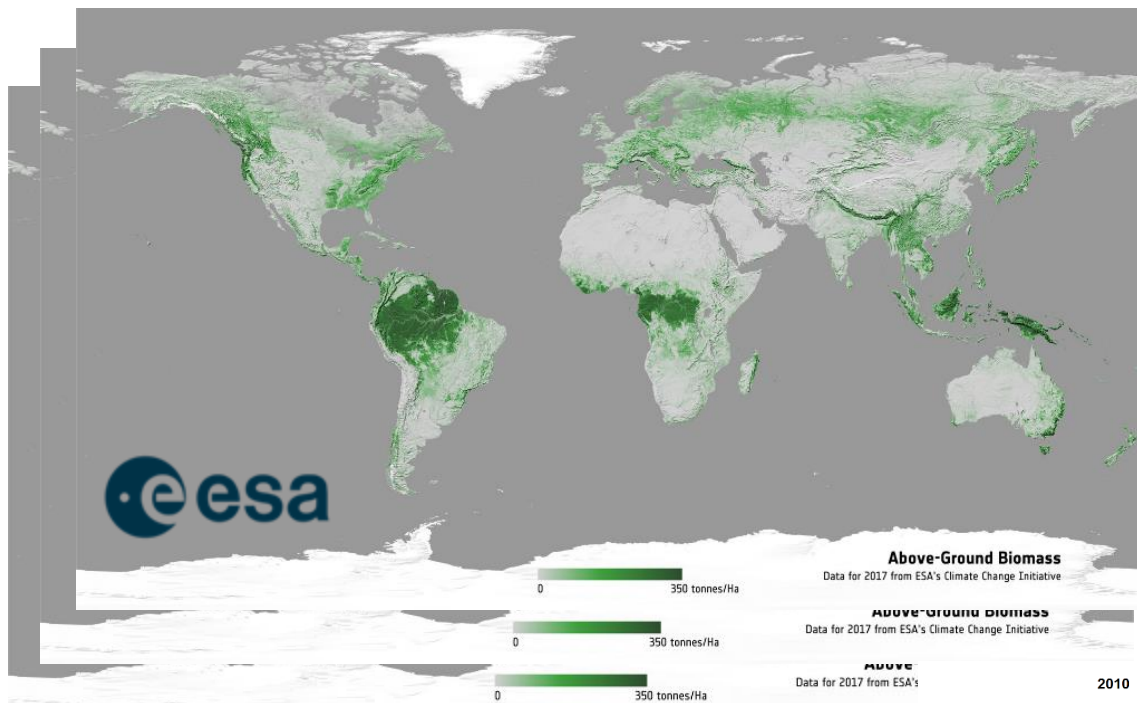


**Santoro et al. 2021, 2024** Global aboveground biomass for 2010, 2015-2022 at 100m spatial resolution. <http://cci.esa.int/biomass>, ESSD <https://doi.org/10.1016/j.srs.2024.100169> Science of RS

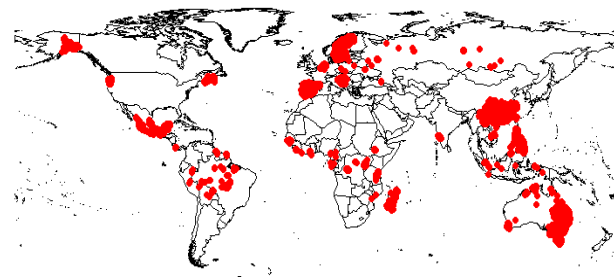


Products/satellite	Start time	Resolution	Open Access
ESA CCI biomass V6	2007, 2010, 2015 - 2022	100m	✓
ESA Forest Carbon v2	2015-2022	20m	✓

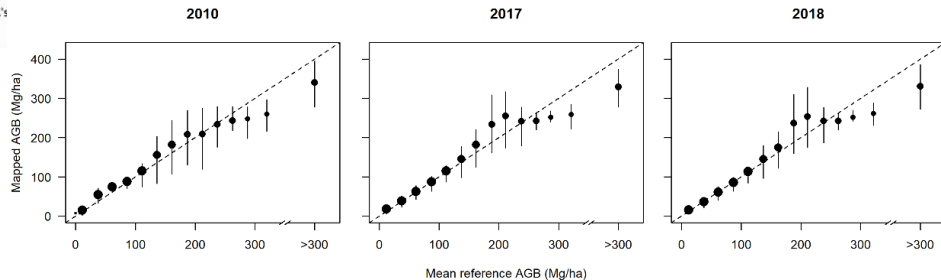
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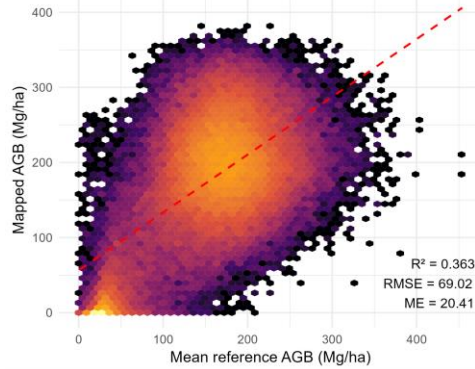
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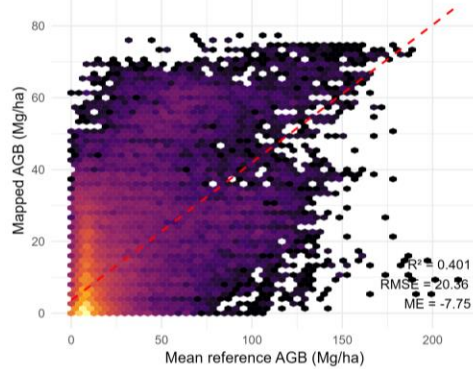
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# ESA forest carbon monitoring: European maps (20 m)

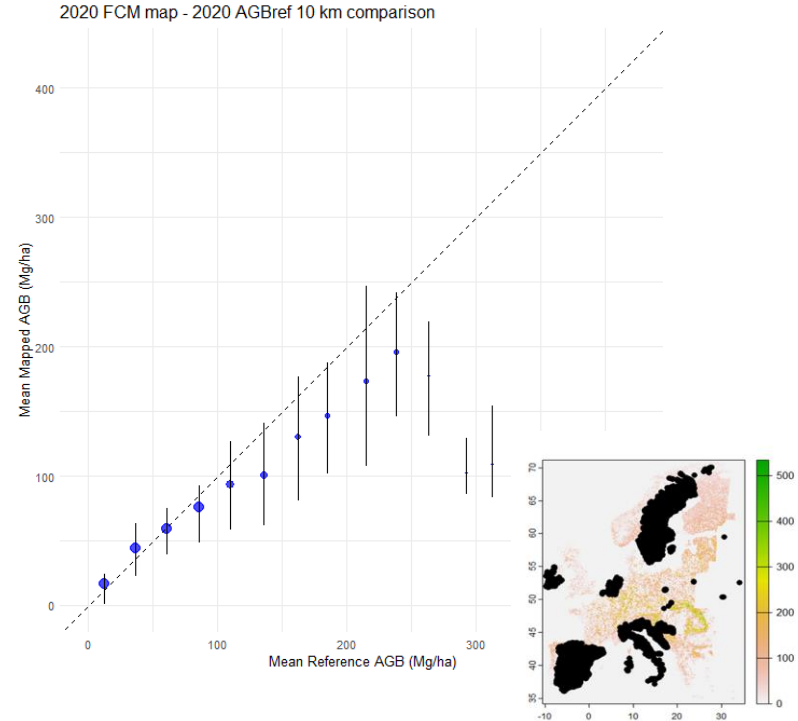
Validation for Poland, pixel-level



Validation for Spain, pixel-level



European-wide, aggregate level – 10km



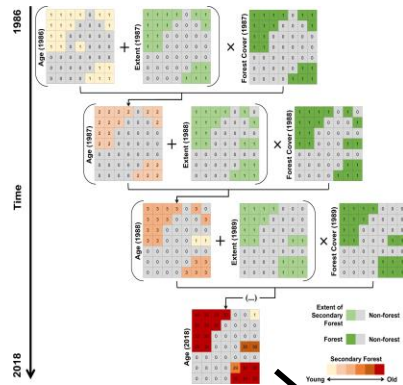
# On the use of available space-based biomass maps

- Important improvements over recent years: time, detail, quality
- Results from independent validation:
  - Reasonable uncertainties (only) for aggregate estimates
  - Pixel-level uncertainties remain high (link to activities!)
  - Having RS biomass time series does not mean we can estimate changes with confidence
- Opportunities for space for time approaches at aggregate levels (see also presentation of Viola Heinrich, breakout session)
- Enhancing detail and quality for C-stock estimation (see also presentation of M. Migliavacca and I. Wheeler, various posters)

# Satellite data for carbon accumulation (at aggregate levels)

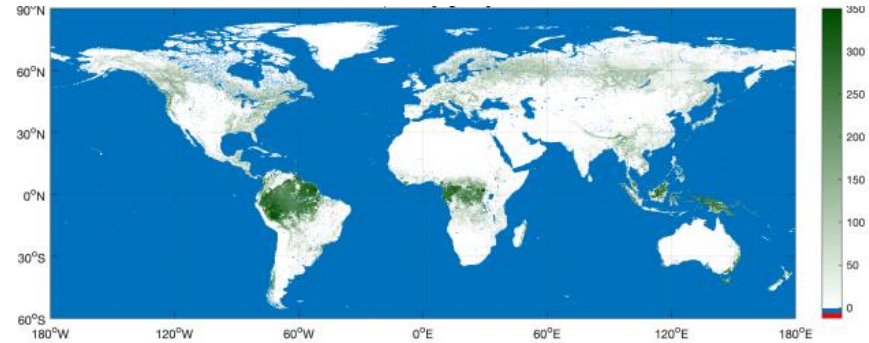
## Time

Map of activities and time

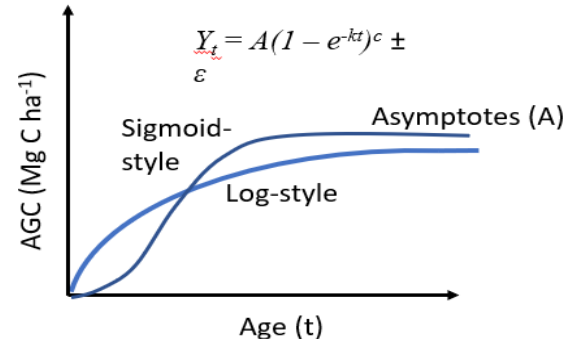


## Space

Map of Aboveground Carbon, ESA-CCI



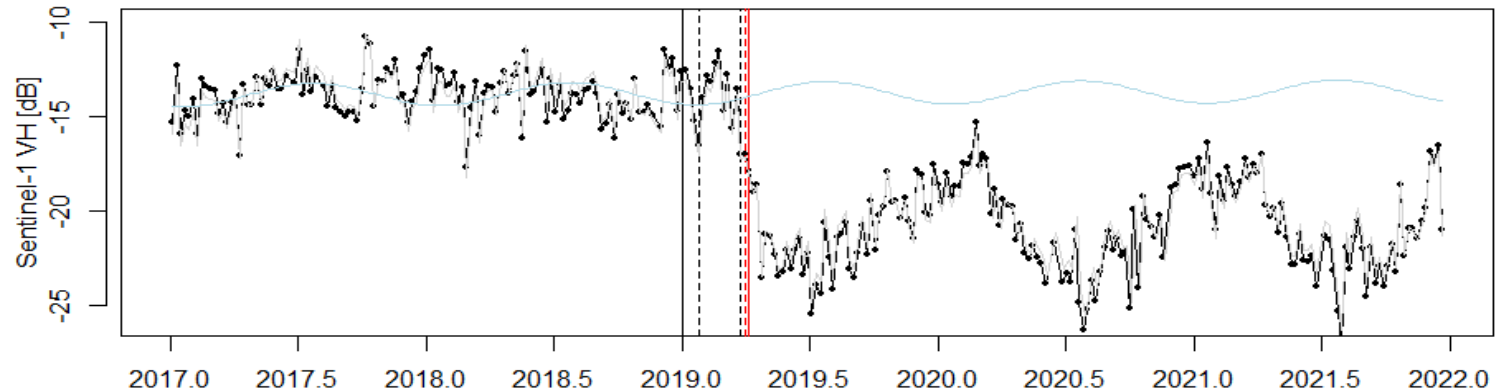
Space for time substitution



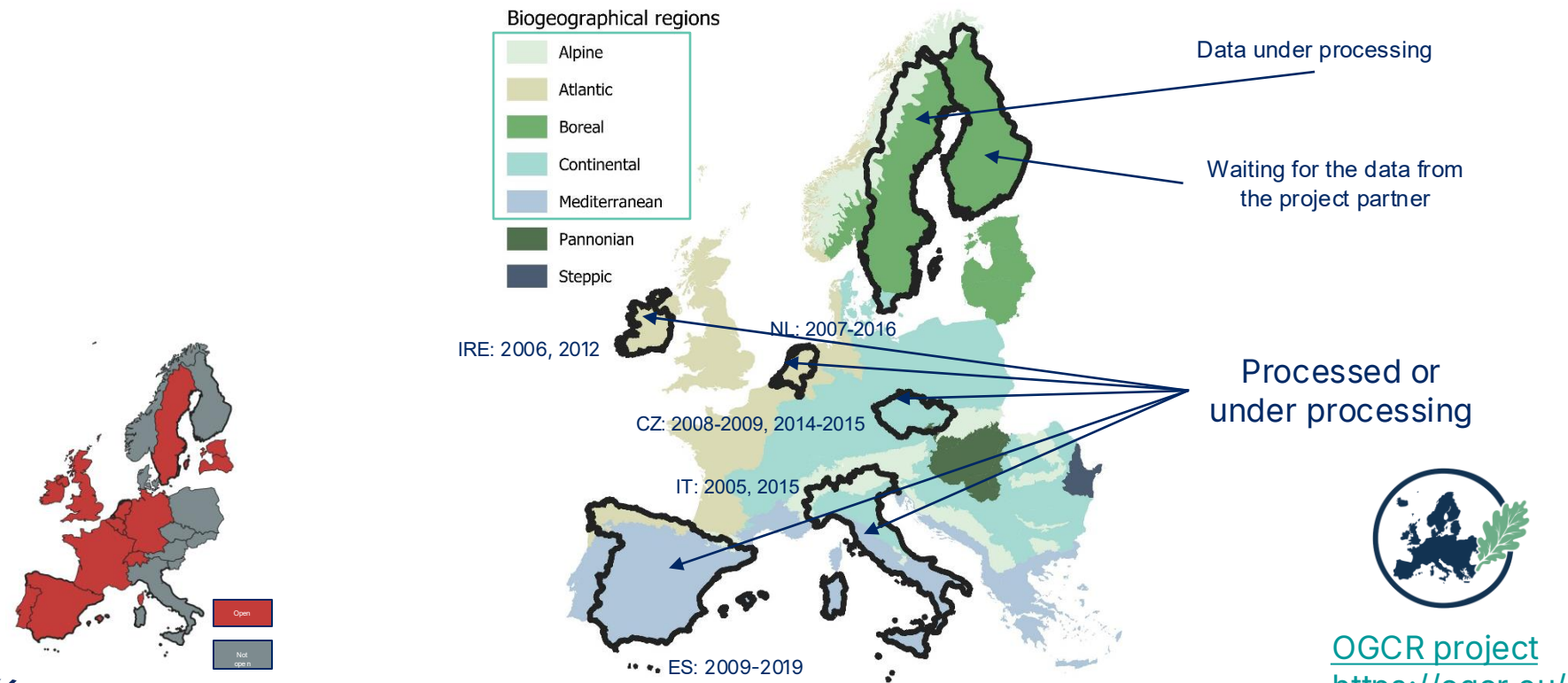
# Increasing temporal detail in disturbance monitoring and characterization



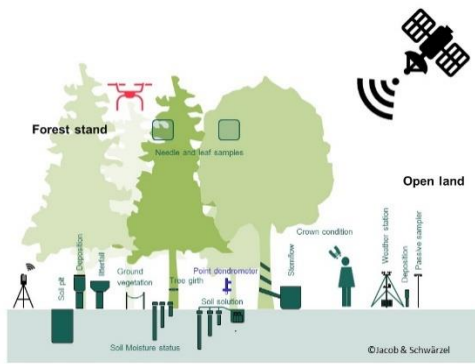
- Importance of dense time series data for tracking changes and dynamics (S1 2-3 days repeat for most of Europe)
- Potential for rapid detection of changes and tracking of forest and land use/management



# Making use Airborne Laser Scanning data overlapping with National Forest Inventories



# Linking ground- & space-based monitoring



Supersite monitoring concept  
EC projects: FORWARDS / REMOTREE

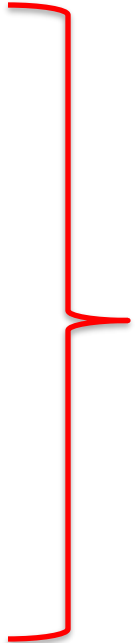


Restoration  
supersites  
(FORWARDS)

- Many EU countries run national forest inventories
- Expanding measurements and need for supersites to measure impact of different CRCF activities
- Developing and integrating complementary data streams:
  - New technologies
  - Systematic measurements at scale

# Integrating different observations for CRCF

Type of observation/ dataset	Advantages	Disadvantages
<b>Satellite Earth Observations</b>	EU-wide, long-term, high-resolution time series (activities, biomass ...)	Current uncertainties in carbon estimation at level of pixel (10 m!) and activities
<b>Airborne Laser scanning</b>	Good availability for EU, proven quality for biomass estimation (if properly calibrated)	Varying availability and quality across Europe Limited, systematic use for woody biomass (processing, calibration ...)
<b>Ground-based inventories / NFIs</b>	High-quality measurements of biomass stocks and changes in member states	Availability and quality varies across Europe Limited coverage for CRCF activities (i.e. forest areas)



Combine the advantages for estimation

# Earth observations for aboveground carbon estimation

- Methodological framework for CRCF: focus is on carbon removals related to “activities”
- Need to invest in measurements
- Opportunities in combining satellite time series, airborne LIDAR and ground-based inventories
- Delineation of activity areas and characteristics very important

# GFZ Helmholtz Centre for Geosciences

Thanks you

