

The Future of Earth Observation

The future of land monitoring – technologies, trends, transparency?

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05/06/2023



ESA's Earth Observation Vision

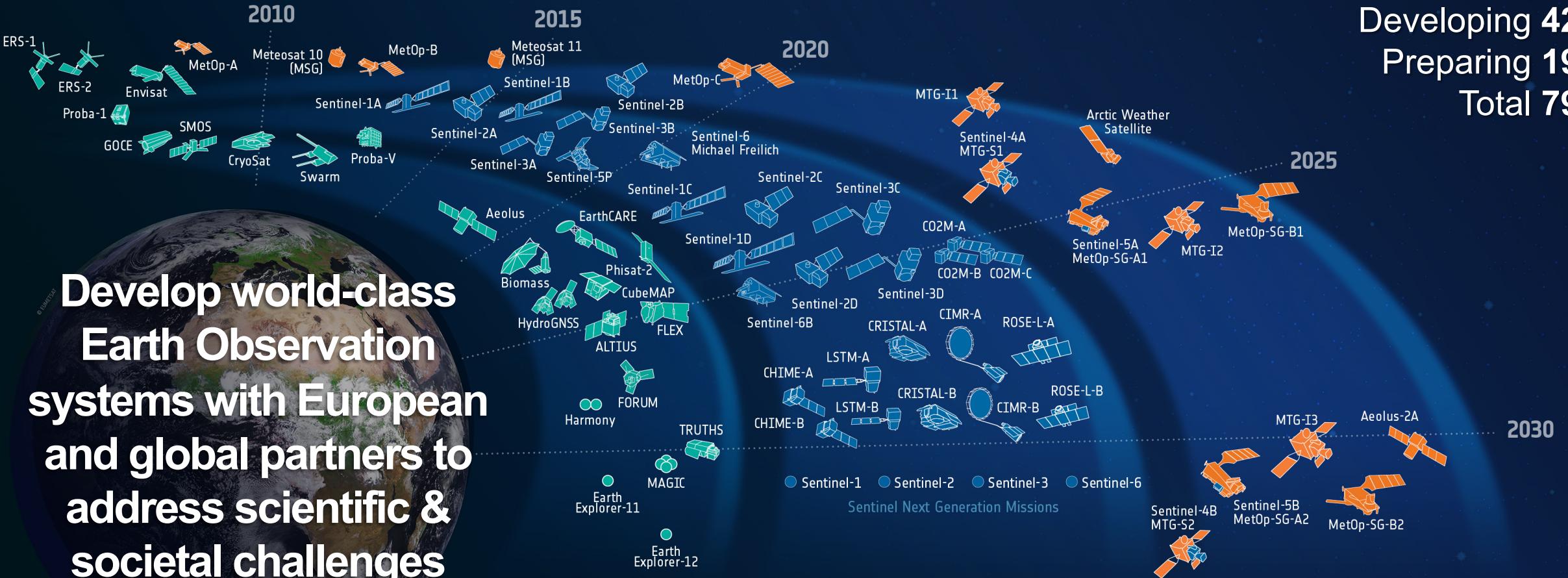
Taking the Pulse of our Planet

ESA's Earth Observation Mission



Satellites

Heritage 04
Operational 14
Developing 42
Preparing 19
Total 79



Develop world-class Earth Observation systems with European and global partners to address scientific & societal challenges

Science

Copernicus

Meteorology

The Copernicus Space Component – Sentinels



PROGRAMME OF THE
EUROPEAN UNION



Copernicus is the largest producer of EO data in the world

<p>1 ●● ○○</p> <p>2014 / 2016</p>	<p>3 ●● ○○</p> <p>2016 / 2018</p>	<p>5P ●</p> <p>2017</p>	<p>5 ○○ ○</p> <p>2025</p>
<p>2 ●● ○○</p> <p>2015 / 2017</p>	<p>4 ○○</p> <p>2024</p>	<p>6 ●○</p> <p>2020</p>	

<p>sentinel-1 → RADAR VISION</p>
<p>sentinel-2 → COLOUR VISION</p>
<p>sentinel-3 → A BIGGER PICTURE</p>
<p>sentinel-4 → EUROPEAN AIR MONITORING</p>
<p>sentinel-5p sentinel-5 → GLOBAL AIR MONITORING</p>
<p>sentinel-6 → SURFING THE SEAS</p>

* ESA Sentinel Data Policy (Sep 2013) and EU Delegated Act on Copernicus Data and Information Policy (Dec 2013)



- Copernicus Sentinels
- Optical CCM
- SAR CCM
- Upcoming CCM

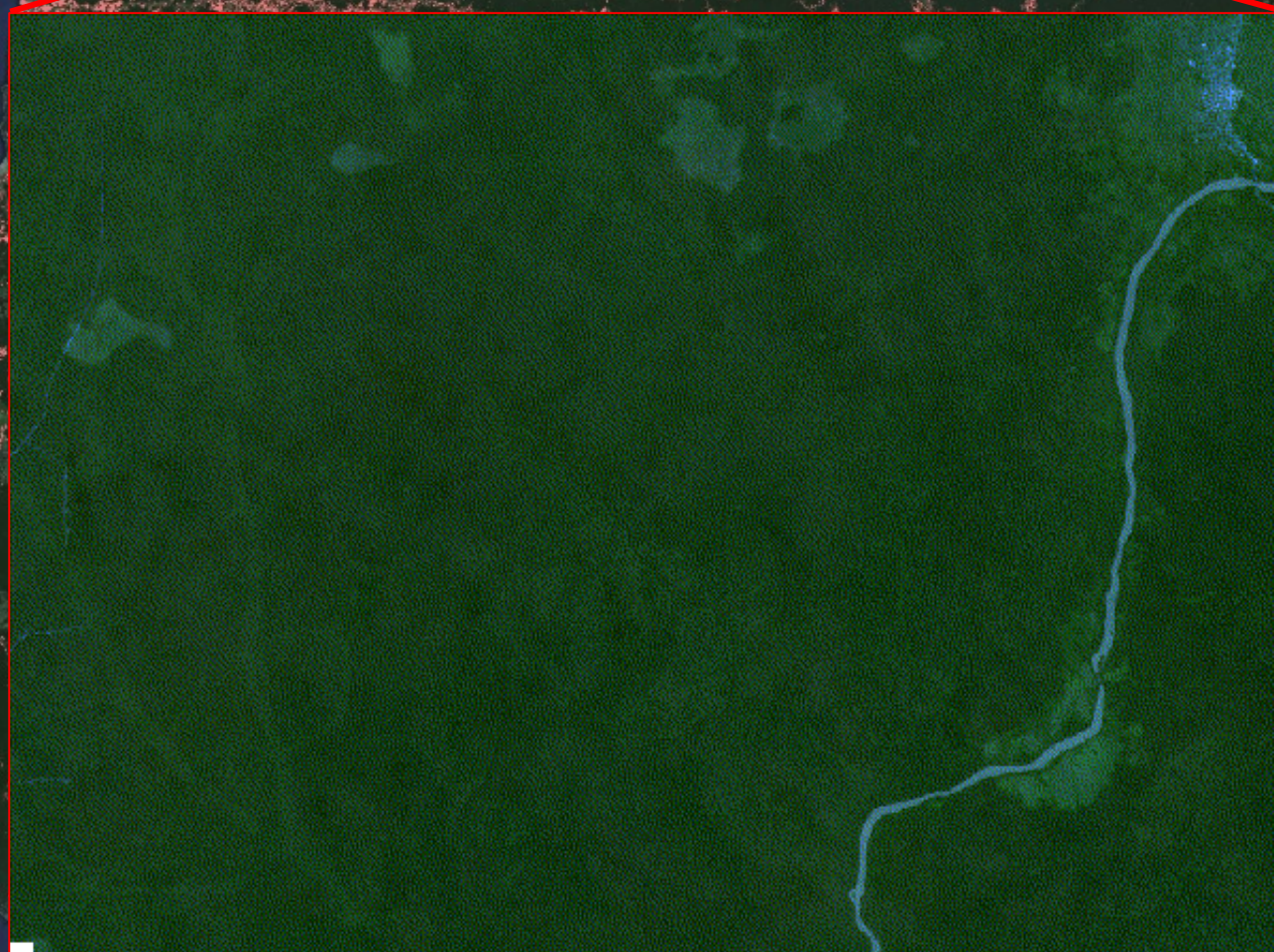


Radar for Detecting Deforestation

Congo Basin
RADD Alerts 2019 – 2022



Selective tree logging in the Central African Republic



Reiche et al.(2021), ERL



→ THE EUROPEAN SPACE AGENCY

Rainforest Clearing

Rondonia, Brazil

Landsat 5

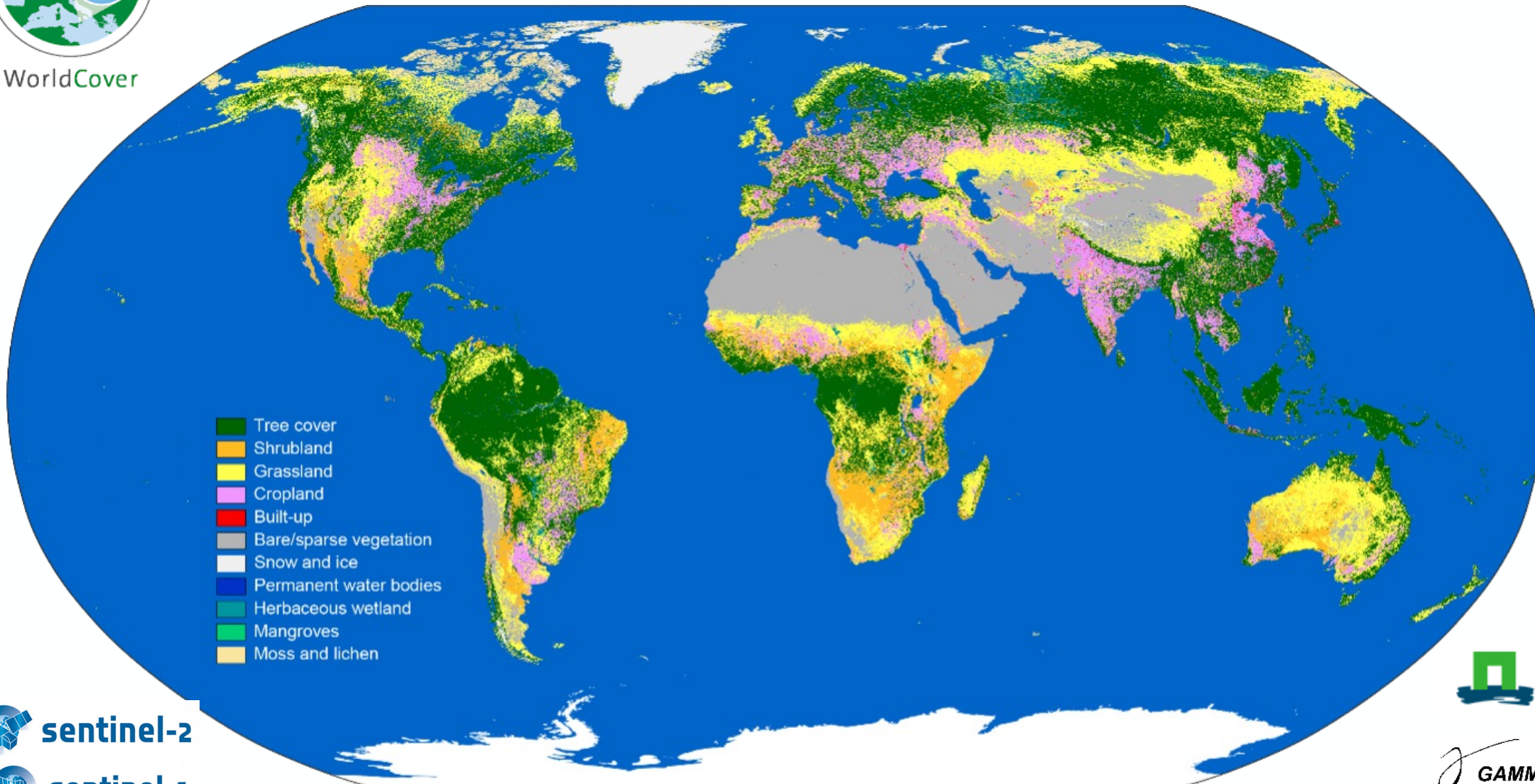
8 July 1989





WorldCover

WorldCover



Landsat – 50+ years of observations

Landsat 9 (2021 -)

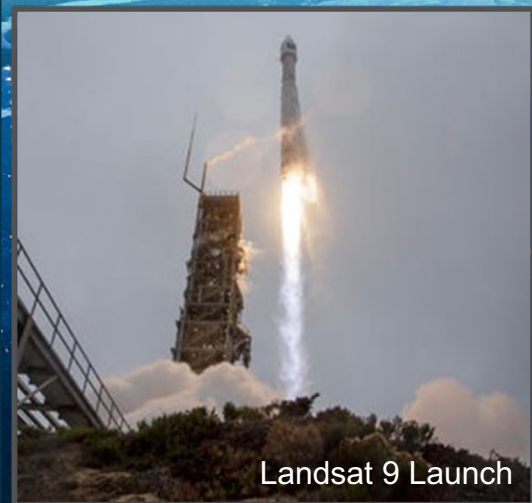
Collecting more than 700 new scenes per day; full mission transitioned to USGS in August 2022

Landsat 8 (2013 -)

Collecting more than 700 new scenes per day; night and off-nadir imaging of volcano and fire imaging

Landsat 7 (1999 -)

Recently lowered out of its operational orbit; awaiting NASA satellite rendezvous and refueling while continuing to provide imagery



Landsat 9 Launch

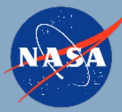


Earth Resources Observation and Science Center (EROS)
Sioux Falls, SD

Landsat Archive Operations

10 Million unique Landsat scenes available in the near 50-year archive, with well over 100 million downloads since Landsat data became freely available in 2008.

More than **4 billion** Landsat data accesses via the commercial cloud in the past year alone.



USGS
science for a changing world

Multi-Decadal Sustainable Land Imaging Program

First Phase of SLI

Landsat 9



Second Phase of SLI

Landsat Next



Commercial/Interagency/
International Partnerships

SLI Technology Development and Infusion (NASA)
(USGS)

User Needs Development (USGS)

2010



LANDSAT 8

SLI

Architecture
Study
2013-2014

11/22/2017

JSG

SLI

Architecture
Study
2018-2019

04/01/2020

JSG

2020



LANDSAT 9

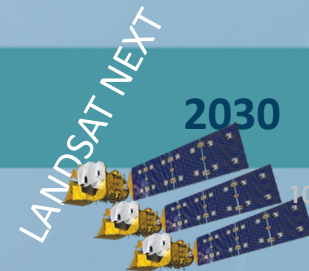
02/10/2022

JSG

SLI

Architecture
Study
2026-2027

2030



LANDSAT NEXT

LANDSAT BEYOND

JSG=Joint Steering Group Meeting

The Copernicus Space Component – Evolution



PROGRAMME OF THE
EUROPEAN UNION



Sentinel Expansion Missions: LSTM

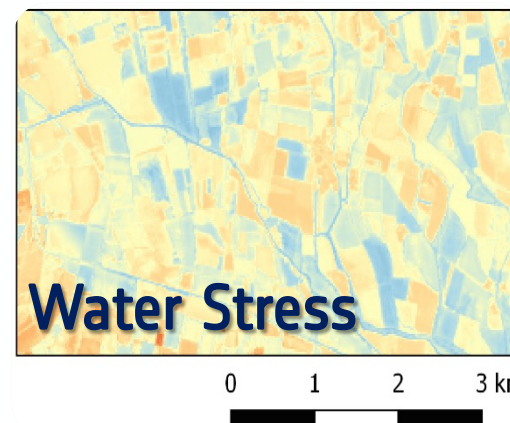
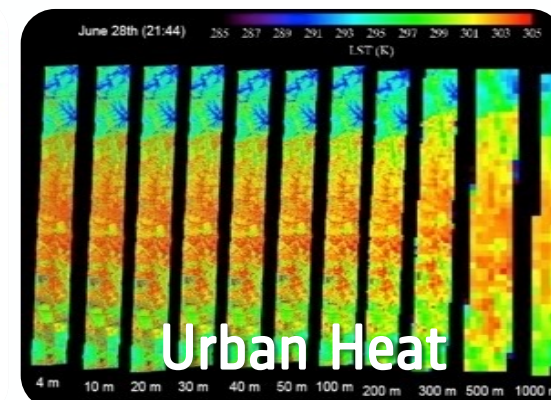
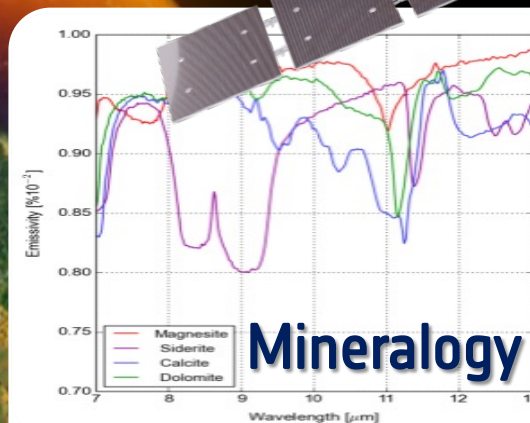
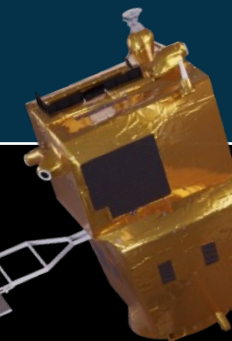
Land surface temperature observations supporting scientific research and applications for society

Land Surface Temperature Monitoring Mission

- TIR observations for monitoring evapotranspiration (ET) rate at European field scale
- Complement current S-2 and S-3 VIS and NIR data
- Further applications: soil composition, urban heat islands, coastal zone management, High-Temperature Events.

Optical imager with 3 bands in TIR

- Temperature observations over land & coastal regions, from approx. -20°C to +30°C, with high precision (0.3°C)
- Additional VNIR and SWIR narrow thermal bands for improved LST/emissivity separation
- 30-50m res., 600-700km swath, 4day revisit.



Supporting the European Green Deal and EU environmental policies

Hyper Spectral Imaging Mission

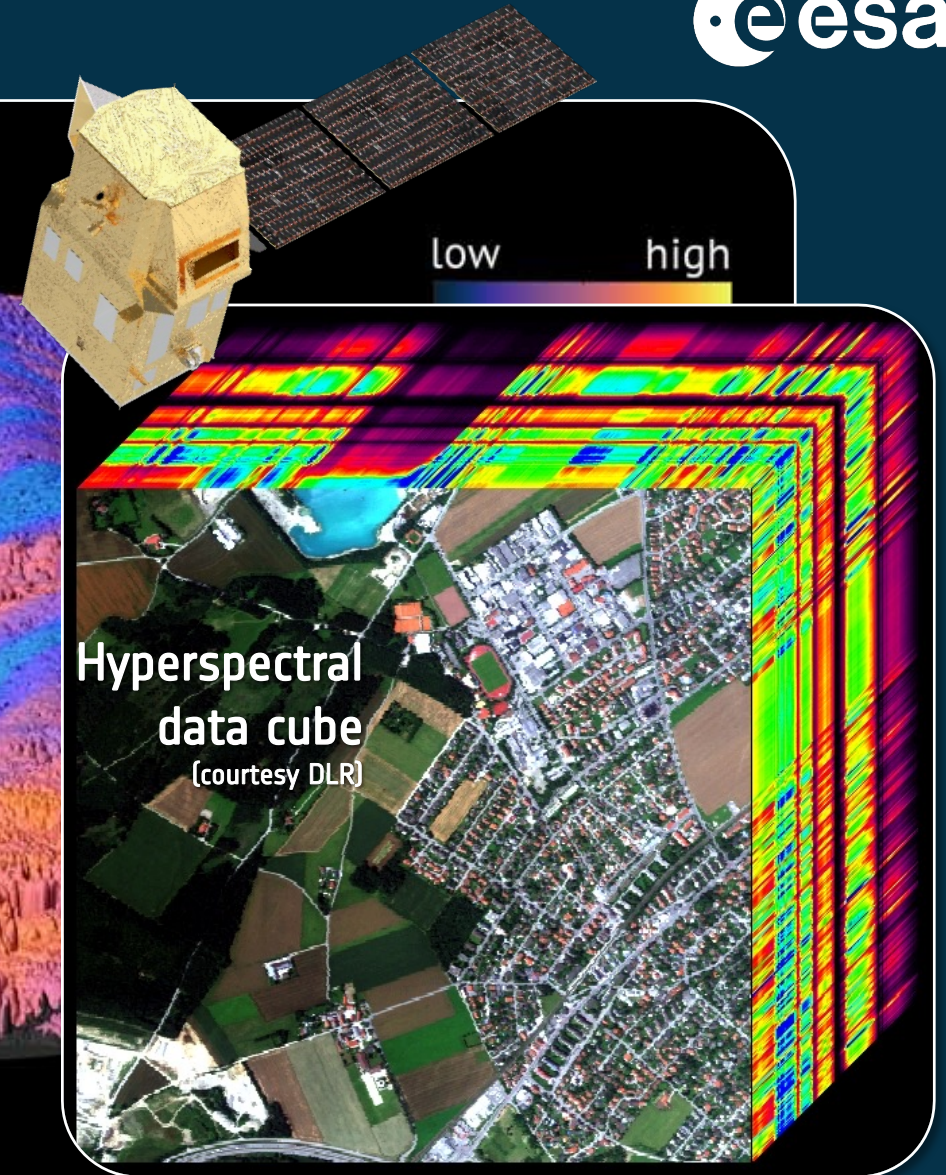
- Routine hyperspectral observations of terrestrial surface, inland water bodies and coastal regions to derive quantitative surface characteristics
- Supporting sustainable agricultural and sustainable mining, biodiversity management and environmental preservation

Visible-to-shortwave infrared spectrometer

- Push-broom acquisition configuration
- Spectral range from 400 to 2500 nm
- Spectral sampling of $\Delta\lambda \leq 10$ nm
- Spatial resolution of 20-30 m
- Revisit time of 10-12.5 days

(Physiological diversity of a temperate forest)

(Airborne imaging spectroscopy APEX data Schaeppman, Jehle et al. 2015)



Sentinel Expansion Missions: ROSE-L

Better services for disasters & geohazards, forests and agriculture management

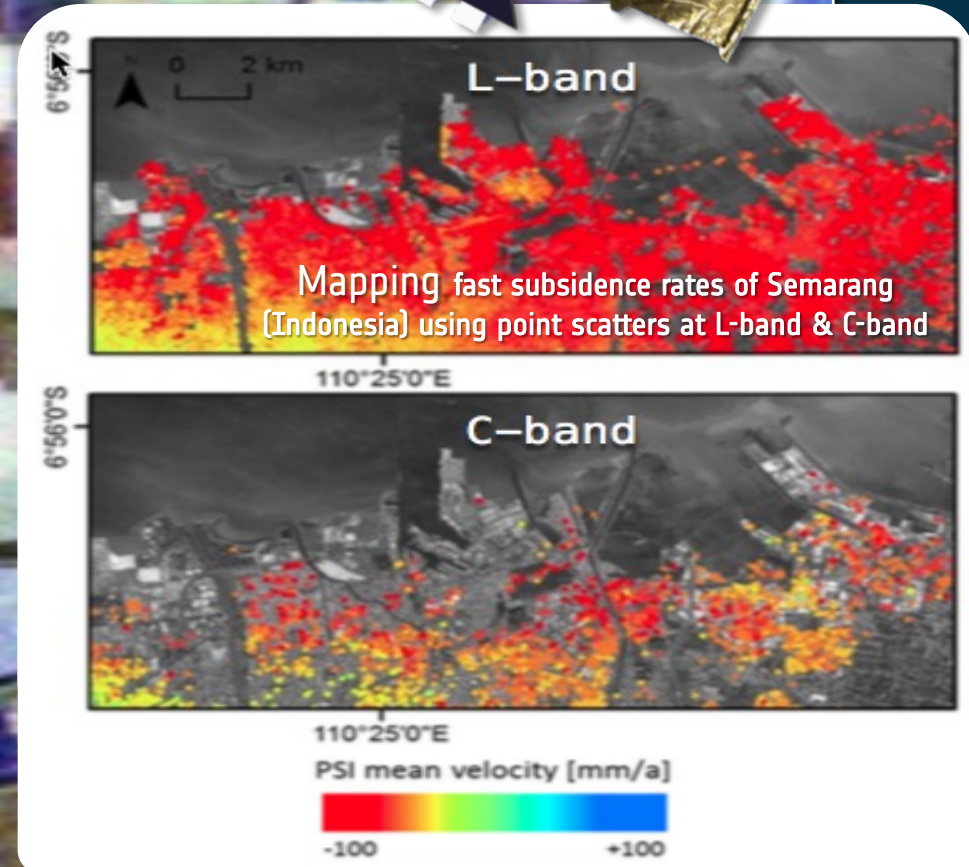
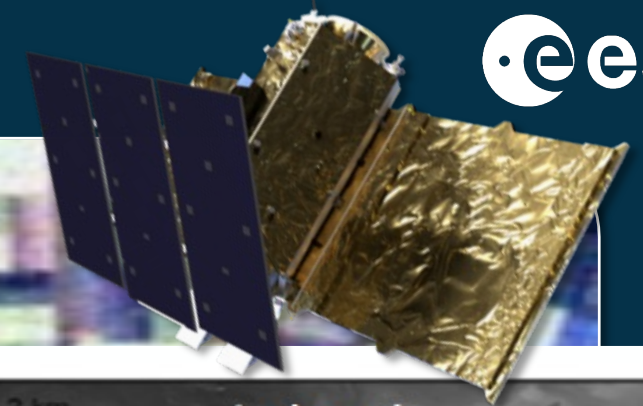
European spaceborne L-BAND SAR mission

- High penetrative capability, providing additional and complementary data not observable at higher frequency
- Applications in land use, agriculture and snow and ice as well as improved disaster mitigation: earthquakes, volcanoes, landslides, flooding, etc.

L-band SAR paired with AIS

- Automatic Identification System (AIS) for vessel detection and classification
- Reflector antenna will be largest ever built at an impressive 11 metres by 3.6 metres
- 3 modes: Dual-polarization, Quad-polarization, Wave

(Temporal variations in Soil moisture & Crop type)

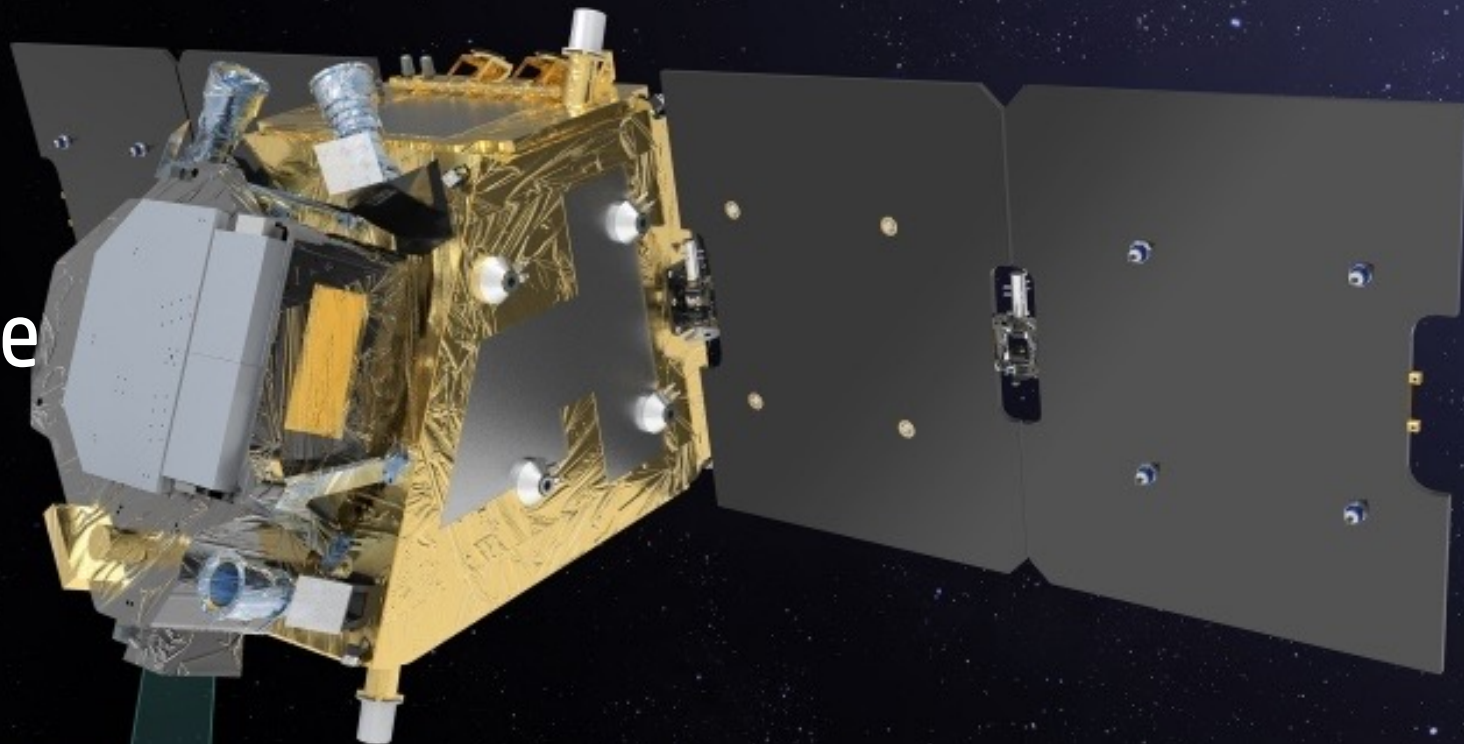


Earth Explorers Putting together the puzzle Earth Since 2009



FLEX

Imaging spectrometer mission for measuring vegetation fluorescence



Quantifying photosynthetic activity and plant stress on a global scale

Expected launch 2025



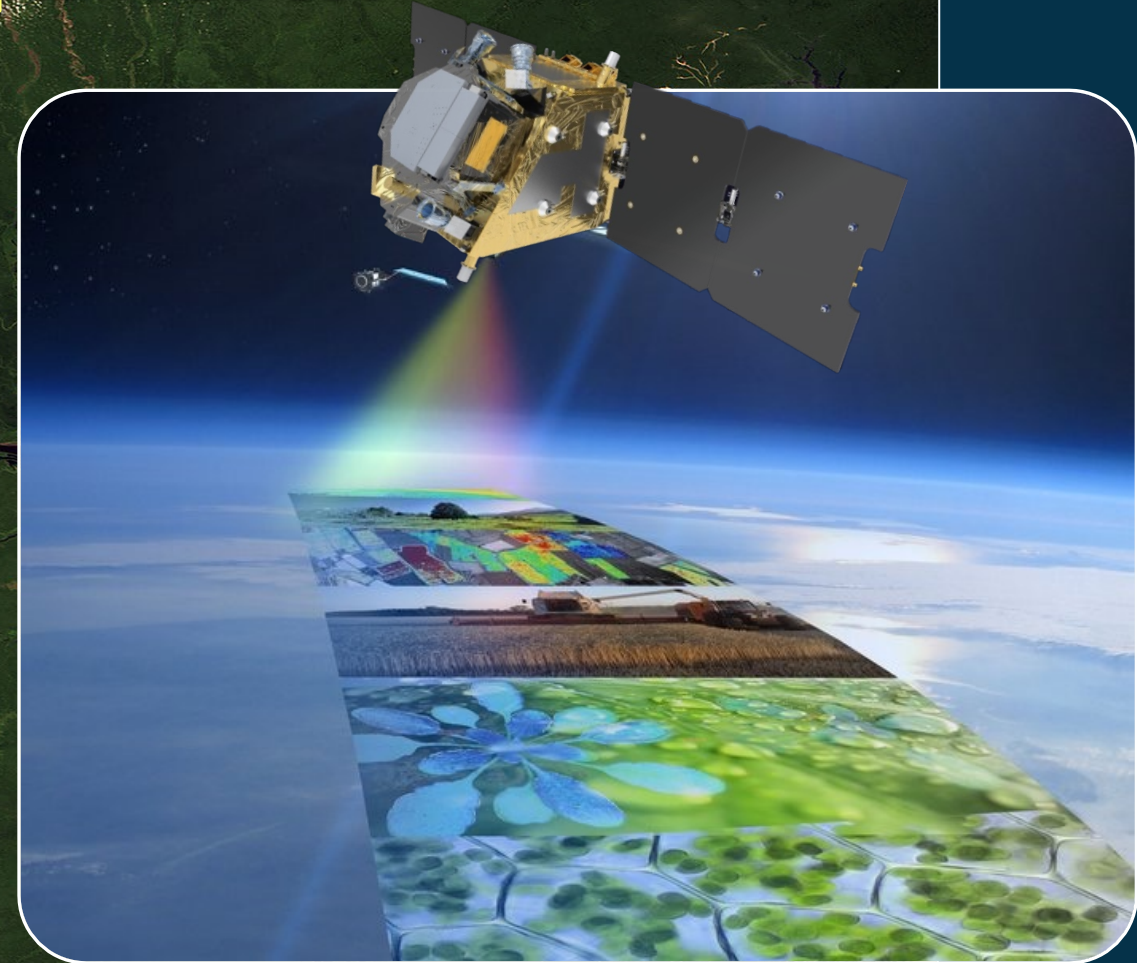
Study of photosynthetic activity and plant stress

Mission for mapping vegetation fluorescence

- Measure fluorescence as proxy for photosynthesis
- Provide better understanding of the global carbon and water cycle
- Add insight into plant health and stress for agricultural management and food security

High-resolution imaging spectrometer FLORIS

- Fly in tandem with Sentinel-3 for contextual data
- FLEX and S-3 acquisitions within 6-15 seconds
- Specific retrieval algorithms needed to disentangle reflectance from fluorescence.
- 500–780 nm spectral range with 0.1 to 2.0 nm sampling



Biomass

P-band global
measurements of forest
biomass and carbon cycle

Providing global maps of
forest biomass stocks,
disturbance and growth

Expected launch 2024



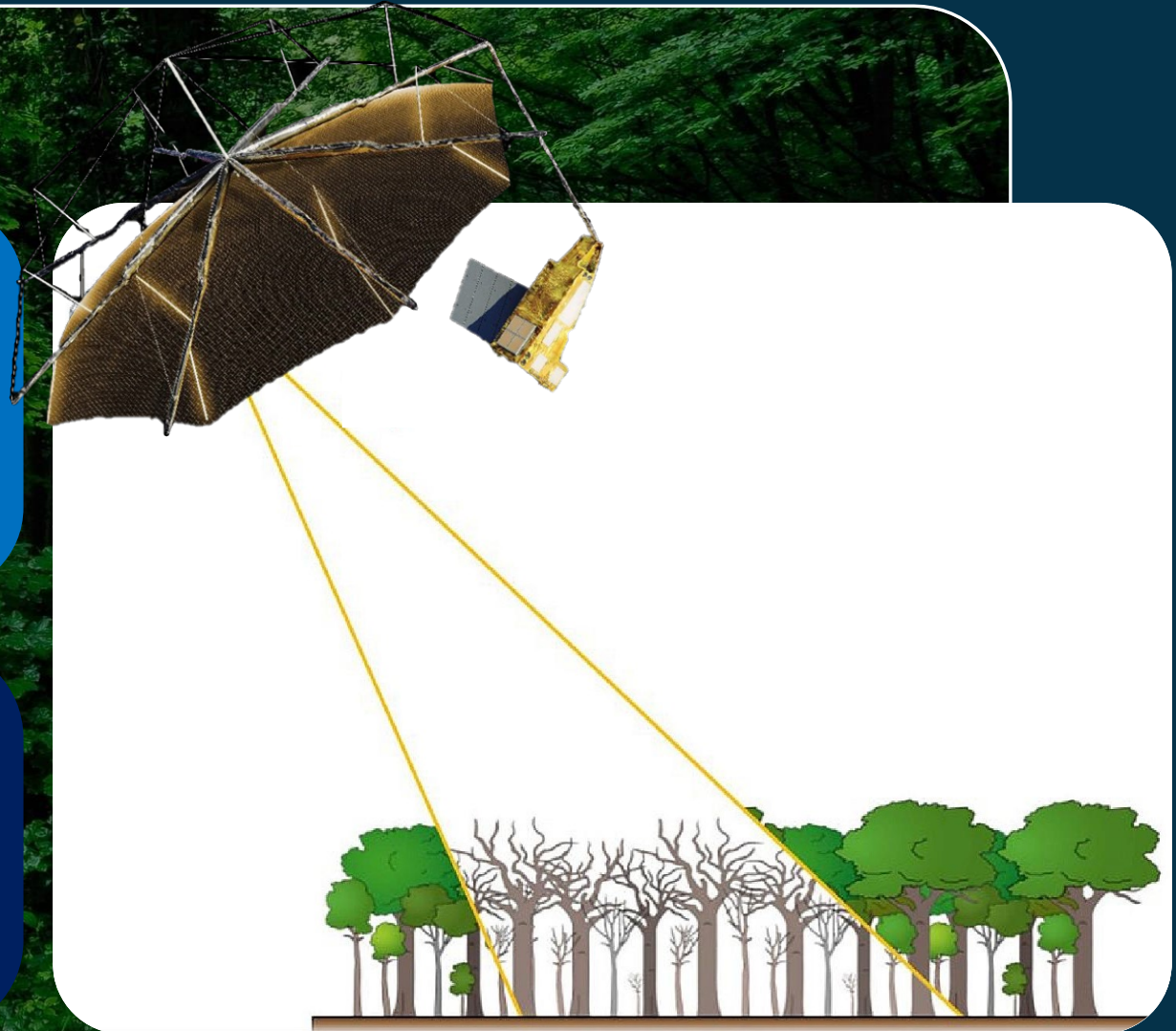
Study of terrestrial carbon cycle

Above-ground biomass mission

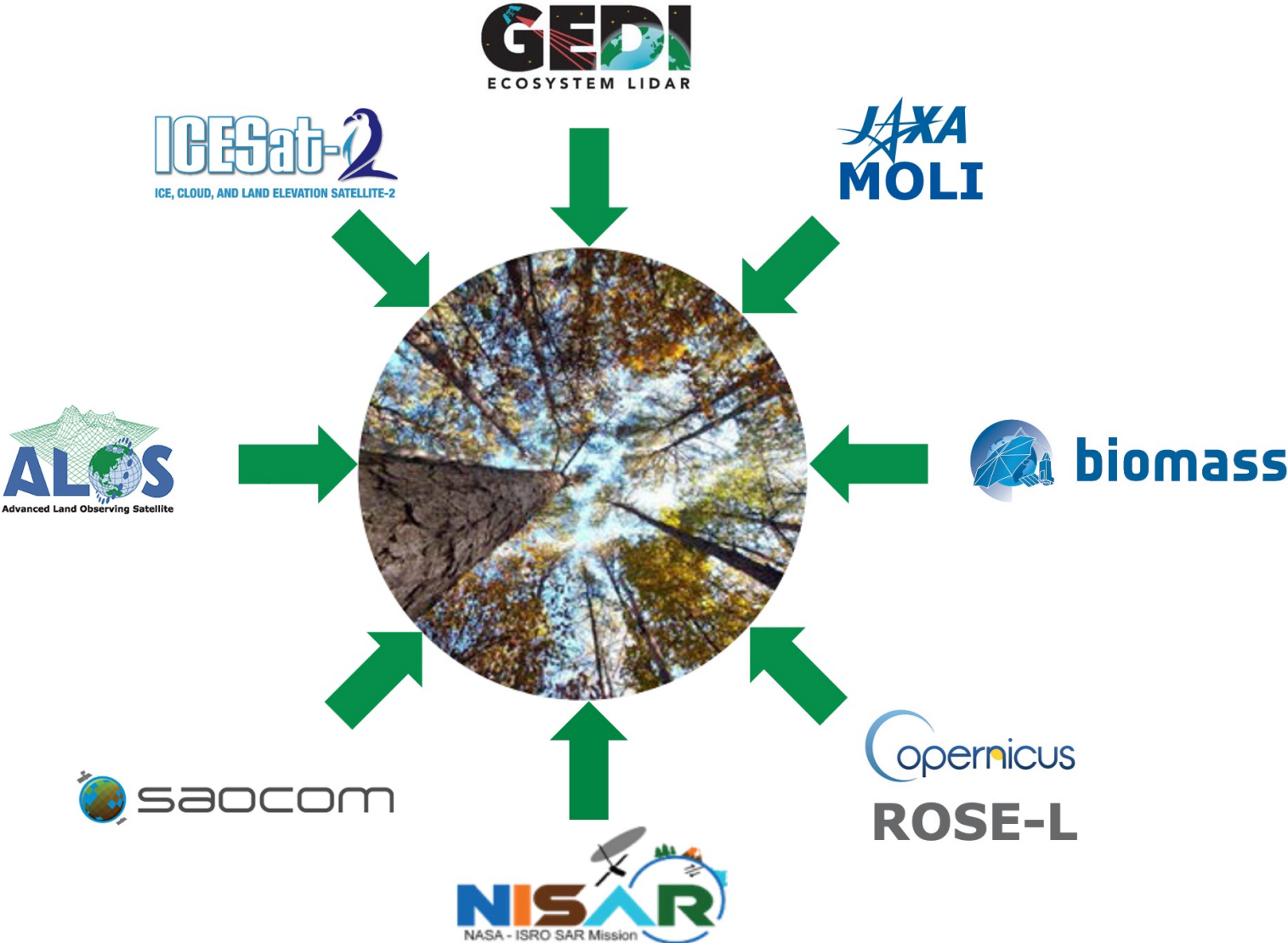
- Reduce the large uncertainties in the carbon flux
- Expand understanding of land carbon cycle & dynamics
- Surface topography under densely vegetated areas
- Additionally, mapping subsurface geological features in deserts and ice sheets

First P-band SAR for mapping of forests in four dimensions

- Horizontal mapping with PolSAR backscatter
- Height mapping with PolInSAR coherence
- 3D mapping with multi-baseline TomoSAR
- Global change mapping



Golden Age of Biomass missions





biomass
cci



- Version 4 with global maps from 2010, 2017, 2018, 2019 and 2020 in cooperation with

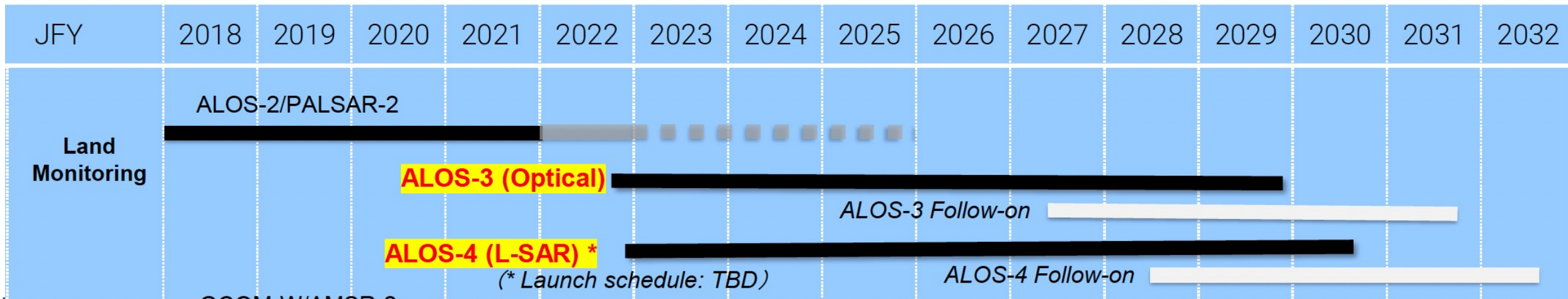
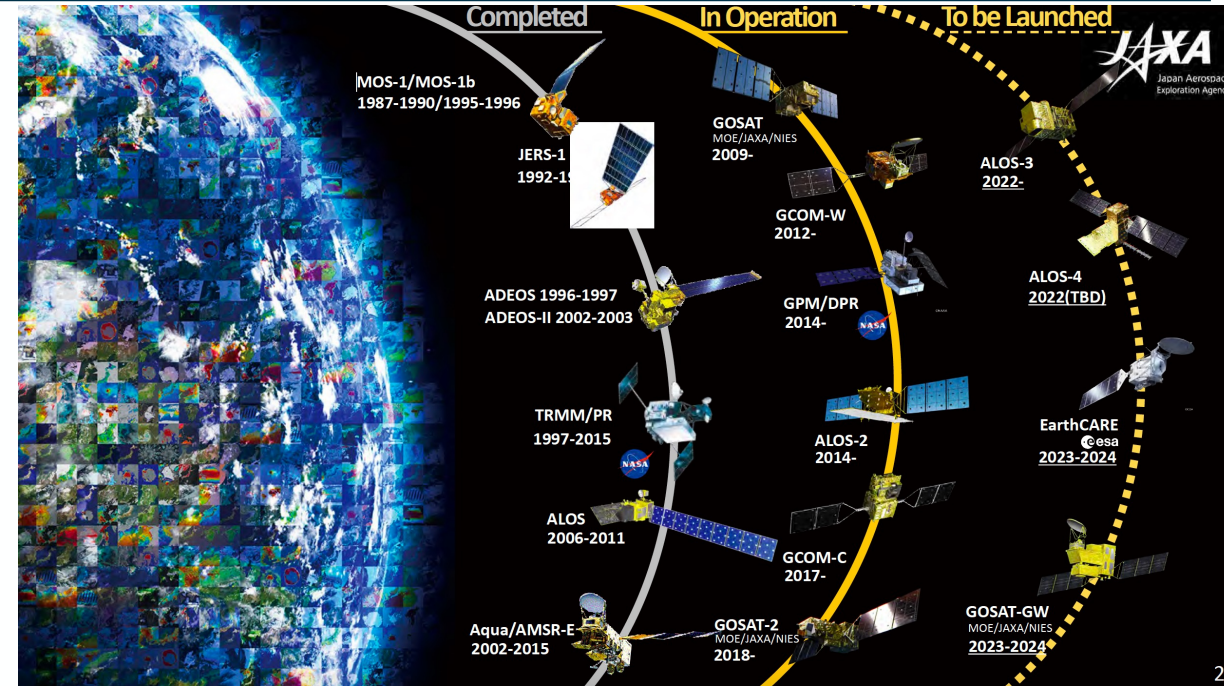


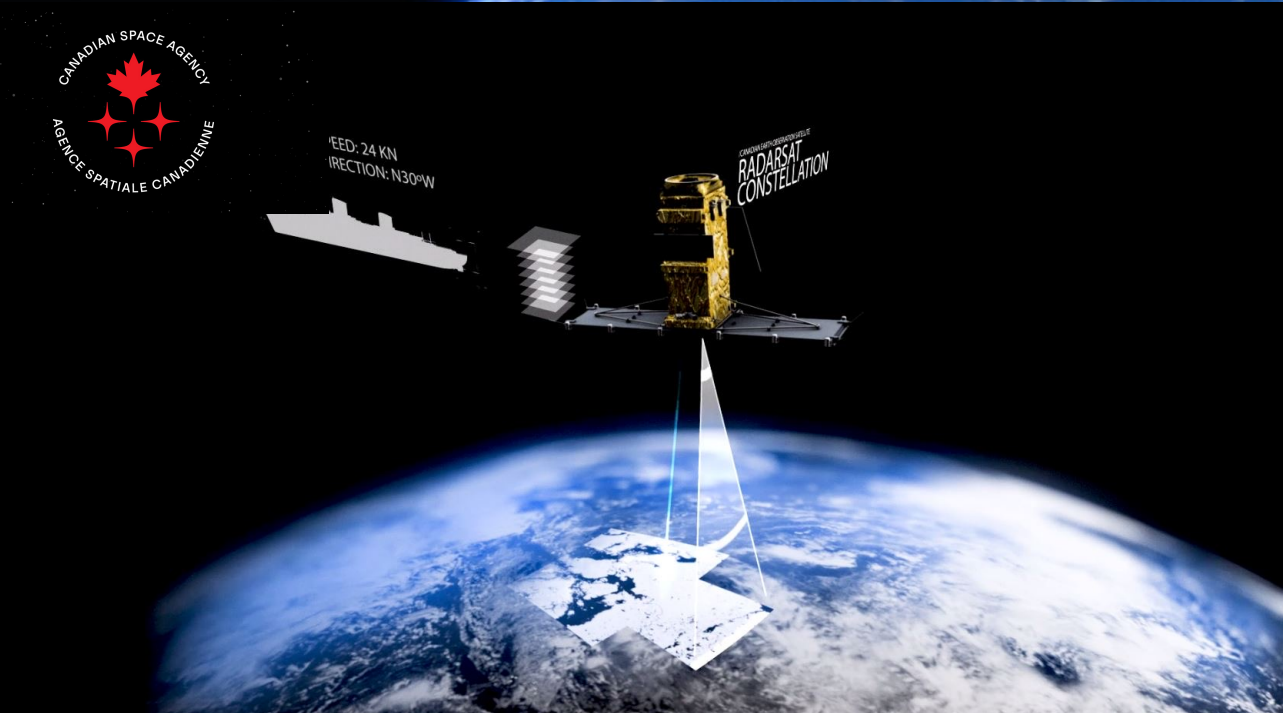
- Released at GFOI Plenary May 2023
- Consistency: a decade of change



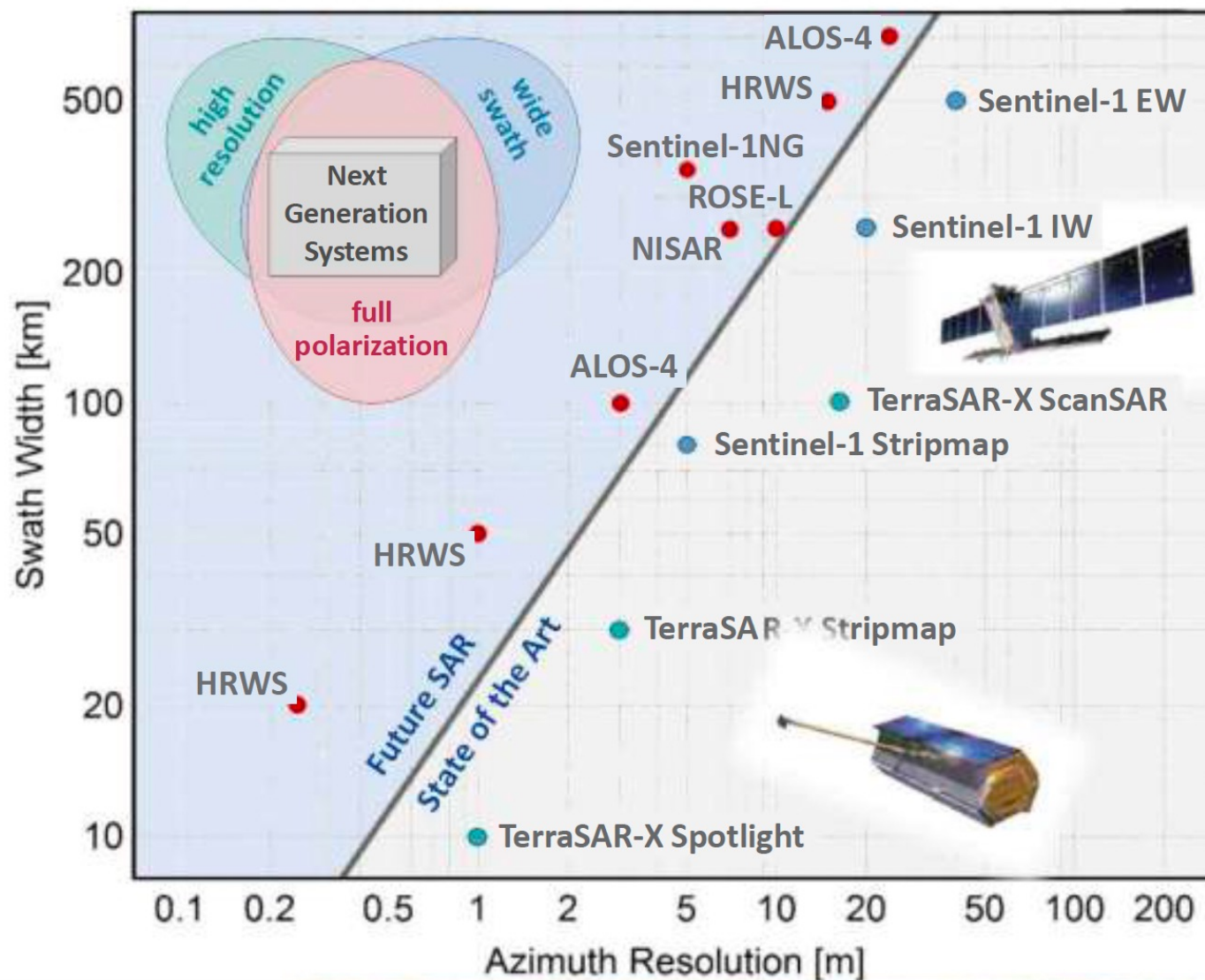
JAXA ALOS Heritage and Future

- JAXA has almost 3 decades legacy in L-band SAR missions initiated with J-ERS1 and followed by the ALOS satellite series.
- JAXA and JICA established a satellite based deforestation monitoring system for tropical forests, “JICA JAXA Forest Early Warning System in the Tropics (JJ FAST)”
- JAXA is supporting the Global Forest Mangrove Watch





Future Spaceborne SAR systems



© A. Moreira (DLR)

Present and future SAR missions

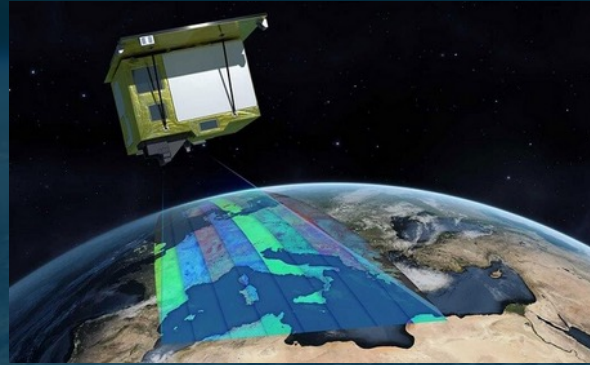
Agency	Mission	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
ESA	ENVISAT	█	█	█																							
EC/ESA	Sentinel-1 A-D					█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█
ESA	BIOMASS (Earth Explorer)														█	█	█	█	█	█	█	█	█	█	█	█	█
EC/ESA	ROSE-L																				█	█	█	█	█	█	█
ESA	Harmony (Earth Explorer)																				█	█	█	█	█	█	█
EC/ESA	Sentinel-1 NG																								█	█	█
NASA/ISRO	NISAR															█	█	█	█	█	█	█	█	█	█	█	█
NASA	Decadal Survey mission																					█	█	█	█	█	█
DLR	TerraSAR-X/TanDEM-X	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█
DLR	HRWS (High Resolution Wide Swath SAR)																					█	█	█	█	█	█
DLR	Tandem-L																					█	█	█	█	█	█
ASI	COSMO-SkyMed (CSK)	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█
ASI	COSMO-SkyMed 2G (CSG)																					█	█	█	█	█	█
CONAE	SOACOM 1a+b																					█	█	█	█	█	█
CONAE	SAOCOM 2																								█	█	█
CSA	Radarsat-2	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█
CSA	RCM																										
CSA	SARNext																					█	█	█	█	█	█
CSA	TSMM (Terrestrial Snow Mass Mission)																										
CSA	EOSC																										
JAXA	ALOS	█	█																								
JAXA	ALOS-2					█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█
JAXA	ALOS-4																										
JAXA	ALOS-6																										
CDTI	PAZ																										
ISRO	RISAT-1/1A																										
ISRO	RISAT-2/2A	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█
CNSA	GAOFEN-3																										
KARI	KOMPSAT 5/6																										
Commercial SAR missions																											
NovaSAR																											
ICEYE																											
Capella																											
SAR X/L (UrthCast)	OptiSAR																										
SpaceNorway	MicroSAR																										
XpressSAR																											
iQPS	QPS-SAR																										
Synspective	StriX																										



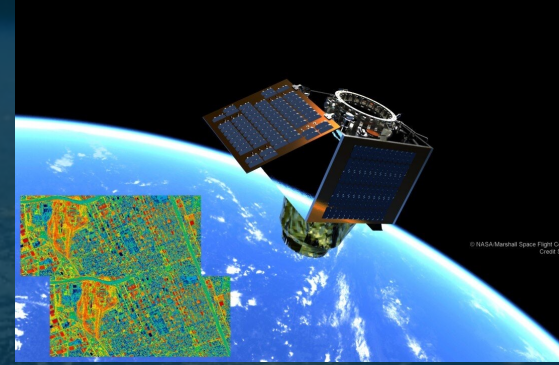
NewSpace capabilities – interoperable constellations



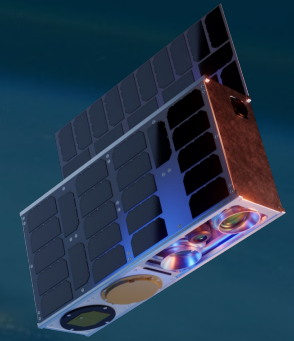
Iceye: >30 X-band SAR platforms



Satlantis (4 satellites by 2024)



SatelliteVu MIR/TIR imagery + video
1 satellite in 2023
(Full constellation = 7 satellites)



OroraTech: 8 satellites for 2024
>100 satellites for 2026



Capella : 9 X-band SAR platforms
going to 30 by mid 2020s



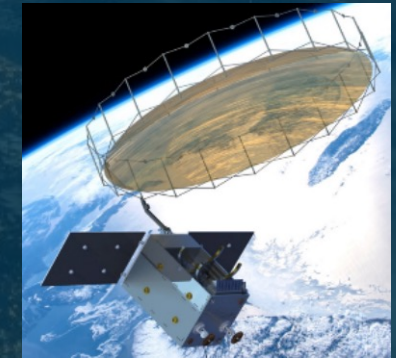
BlackSky:
14 satellites in 2023



PlanetLabs: 32 new VHR
satellites to replenish current
constellation of 21 sats

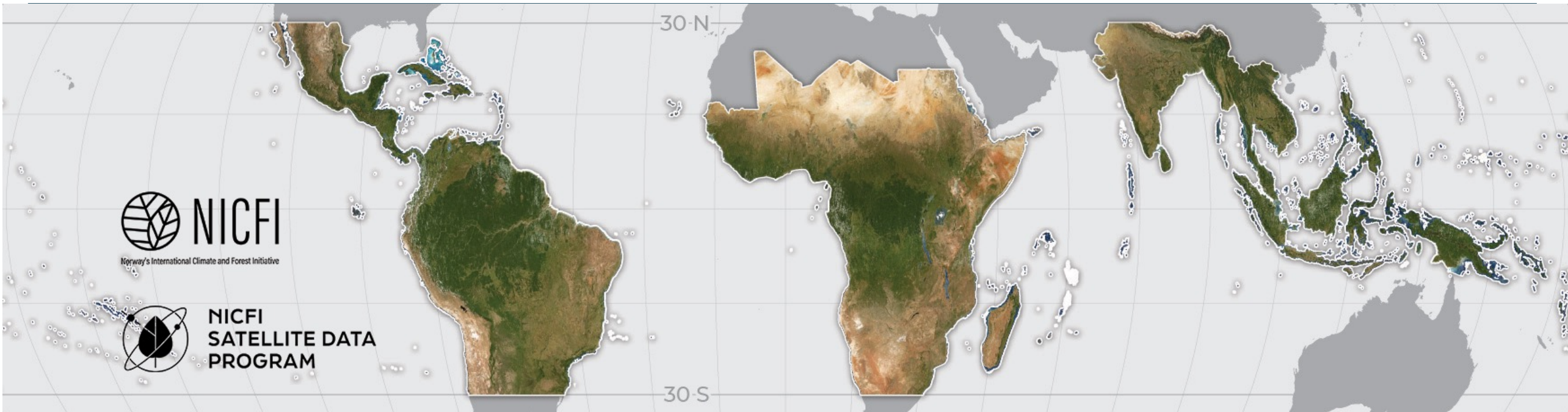


ConstellIR – TIR data at 30m
first satellite 2022
Full constellation > 60
satellites



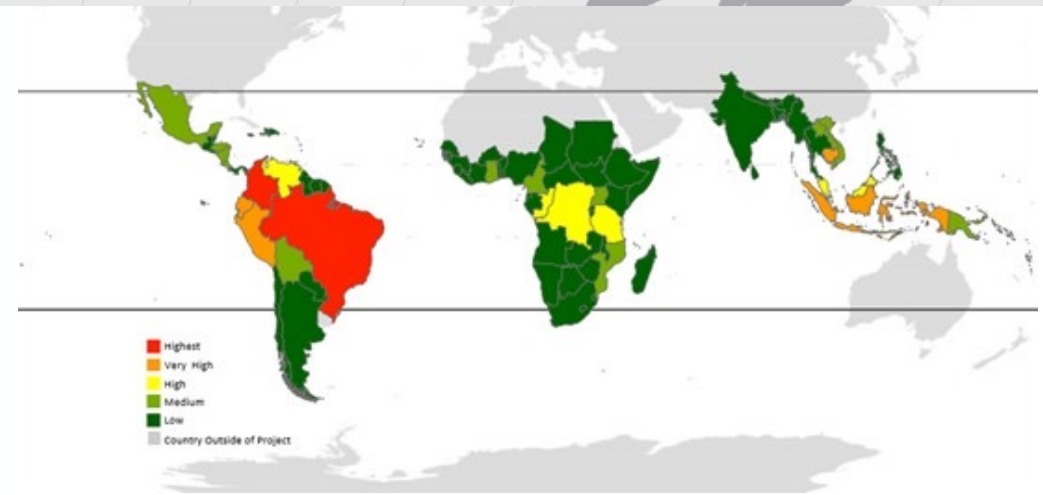
MicroSAR (Norway)
1 satellite in 2025
Full constellation ???
SAR + AIS payload

NICFI – VHR in the Tropics



Norway's International Climate and Forest Initiative (NICFI) extended its partnership with Kongsberg Satellite Services, Planet and Airbus to provide access to high resolution satellite imagery complementing other earth observations to inform action on climate change, forest management and sustainable development until

September 2024



High-accuracy ground data for satellite-derived biomass mapping

Building a **Forest Biomass Reference System** as an equitable and sustainably-funded system of recurrent site-based measurements that will serve as a lasting interface between the Earth Observation and Ground-Based tree-by-tree measurement communities.

- Land vegetation is a **large carbon store** and represents opportunities to **sequester additional carbon**
 - Many Earth Observation missions aim to estimate forest carbon from space, their **calibration and Validation** is critical
 - GEO-TREES implements the recommendations of the **CEOS Aboveground Biomass Land Product Validation** protocol
- ➔ GEO-TREES aims to become a network of over 100 Biomass Reference Measurement sites and 210 distributed BRM sites

<https://geo-trees.org/>

NASA, CNRS, CNES, DLR, UAS, Canada, ESA, JRC, IASA, etc.

Committee on Earth Observation Satellites

CEOS Working Group on Calibration and Validation
Land Product Validation Subgroup

Aboveground Woody Biomass Product Validation
Good Practices Protocol

Version 1.0 – 2021

Editors: Laura Duncanson, Mat Disney, John Armston, David Minor, Fernando Camacho, Jaime Nickeson

LIÈGE, BRISTOL, UNSW, BRISTOL, UNIVERSITY OF LEEDS, UNIVERSITY OF ZÜRICH, UNIVERSITY OF CAMBRIDGE, GHEENT, THE UNIVERSITY OF STIRLING, UNIVERSITY OF MINNESOTA, BROWN, ETH zürich, ABERYSTWYTH UNIVERSITY, NIBIO, NAU, NMBU

Take Home Message

- **Long term data availability is secured** by national programmes like the US Landsat and the European Copernicus Sentinels for the next decades.
- Data policies with **full, free and open-access** satellite data are spreading and enable **transparency** of information;
- **On ground reference data** are essential to unplug the wealth from synergy with satellite data and models;
- **New Space** and private companies are **complementing** the public sector satellites;
- We are in a **data rich period**, a good basis for high quality products and services, with clear **uncertainty** levels and **consistency** over time;
- IT capabilities like cloud computing and AI enable **dense time series analysis** and **analytics** at large scale;

Thanks for your attention!

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