The European Earth Observation Reference Architecture Blueprint

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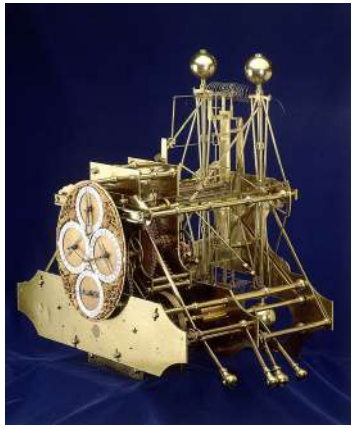
Scientific Measurements from Space – today and tomorrow

Antikythera Mechanism (89 BC)

Newton's Reflecting Telescope (1666)



H1 Marine Clock John Harrison (1735)

Sentinel-3 SLSTR (2014)

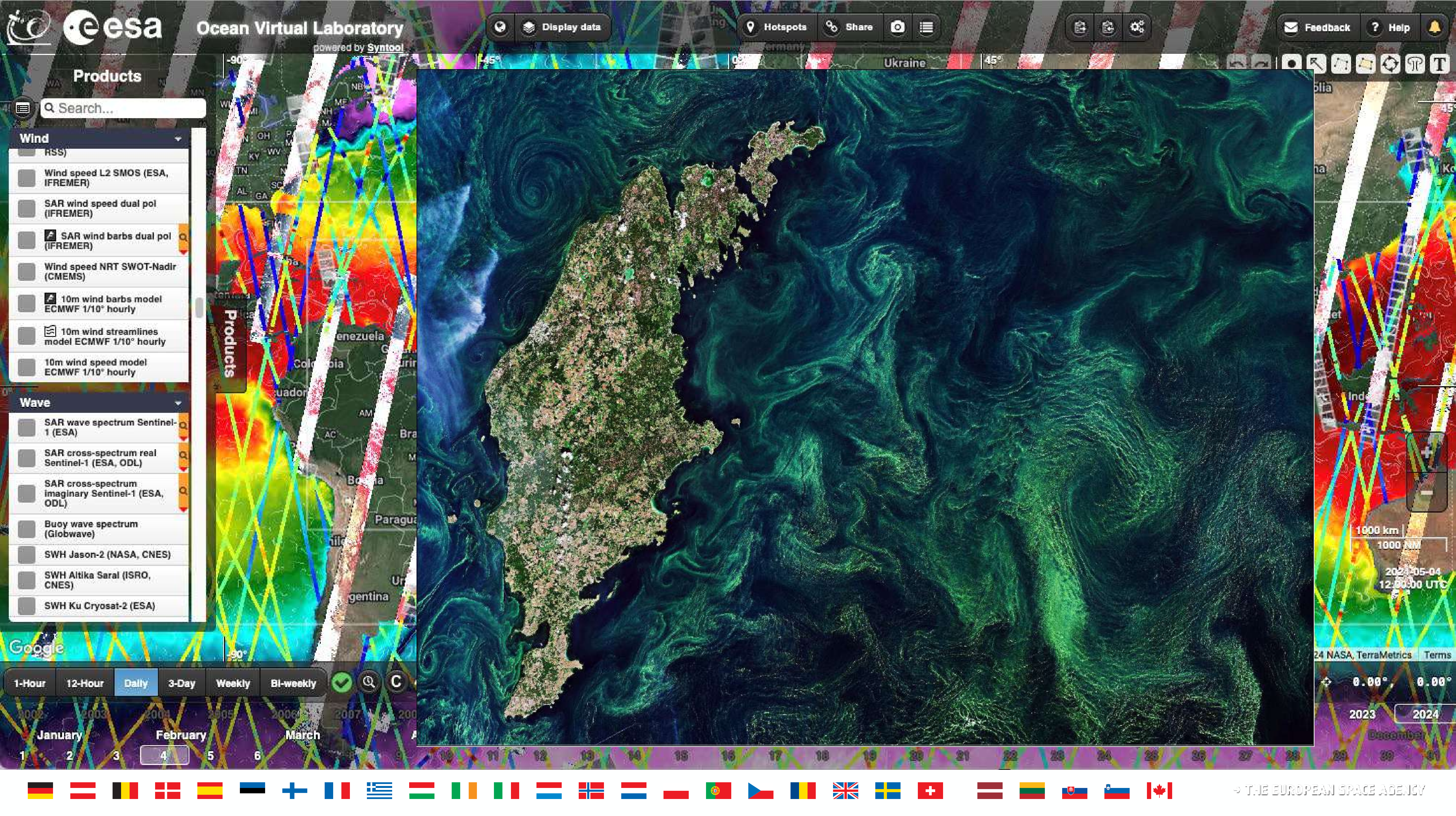
2050+?

Vision Statement

To craft world-class Earth Observation capabilities and information products for informed decisions and actions that best respond to today's challenges of understanding and sustainably managing our Earth environment.

Earth Observation must continue to deliver, first and foremost, **scientific measurements from Space.**

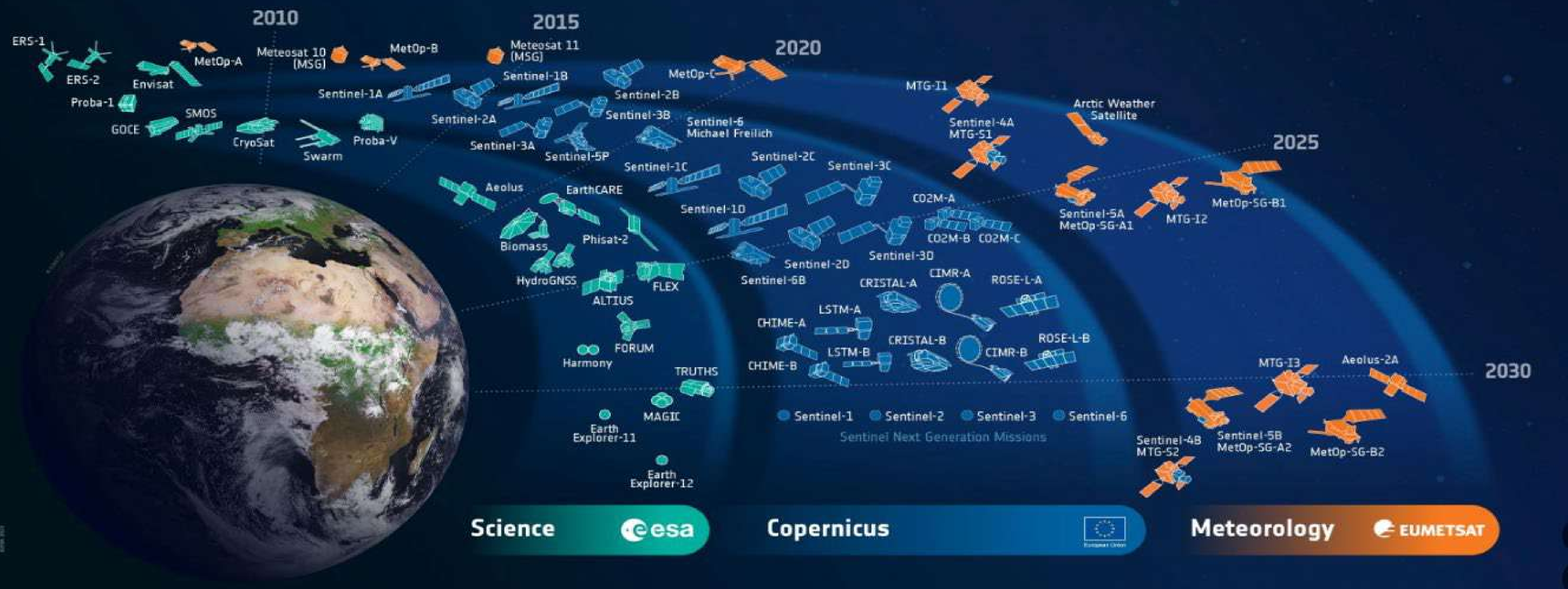
What are the priorities? Small Satellites? Reference quality Missions? A Hybrid Mix?


Ocean Virtual Laboratory
powered by Syntool
Display data
Hotspots
Share
Feedback
Help
Products
Search...
Wind
RSS)
Wind speed L2 SMOS (ESA, IFREMER)
SAR wind speed dual pol (IFREMER)
SAR wind barbs dual pol (IFREMER)
Wind speed NRT SWOT-Nadir (CMEMS)
10m wind barbs model ECMWF 1/10° hourly
10m wind streamlines model ECMWF 1/10° hourly
10m wind speed model ECMWF 1/10° hourly
Wave
SAR wave spectrum Sentinel-1 (ESA)
SAR cross-spectrum real Sentinel-1 (ESA, ODL)
SAR cross-spectrum imaginary Sentinel-1 (ESA, ODL)
Buoy wave spectrum (Globwave)
SWH Jason-2 (NASA, CNES)
SWH Altika Saral (ISRO, CNES)
SWH Ku Cryosat-2 (ESA)
Products
1-Hour
12-Hour
Daily
3-Day
Weekly
Bi-weekly
January
February
March
1000 km
1000 NM
2024-05-04
12:00:00 UTC
2023
2024
December
→ THE EUROPEAN SPACE AGENCY

European Earth Observation Today

It is amazing see the Hybrid Constellation we have in place

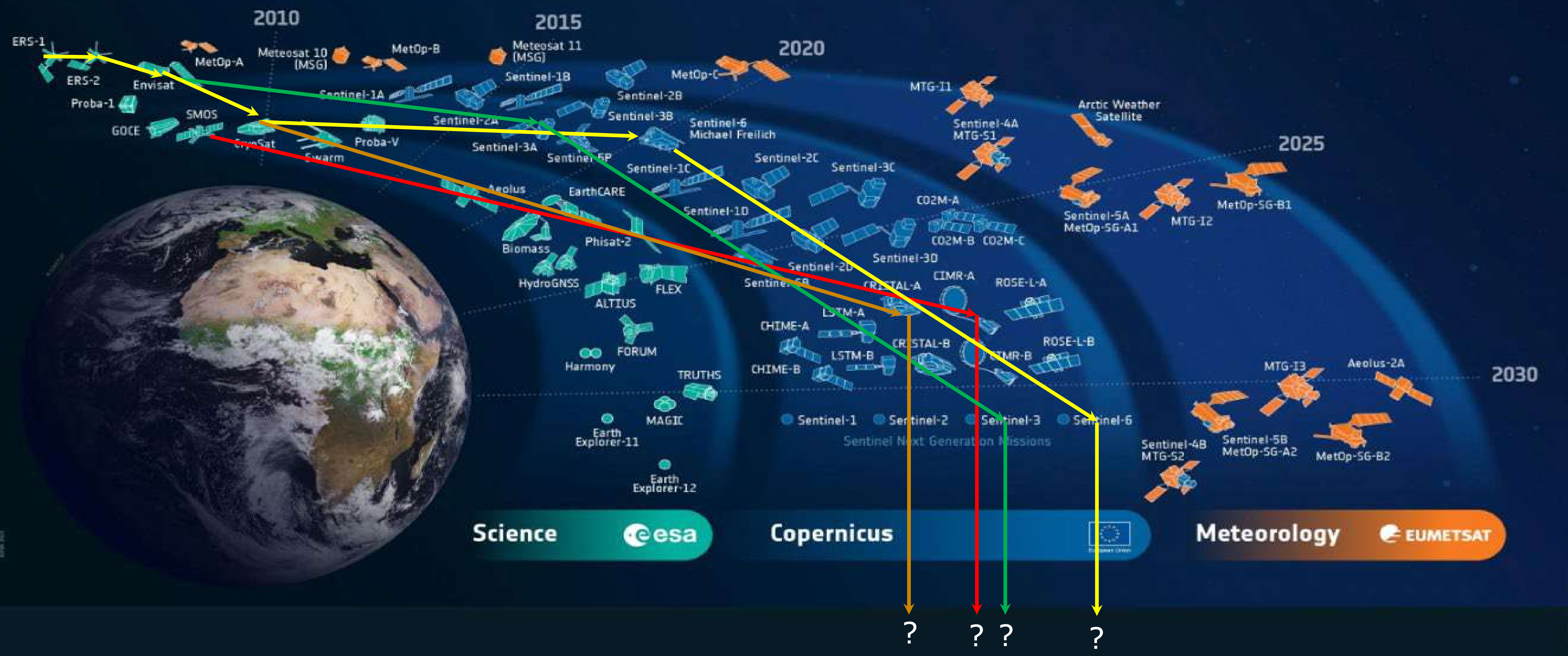
Priority #1: Can we sustain and evolve it?



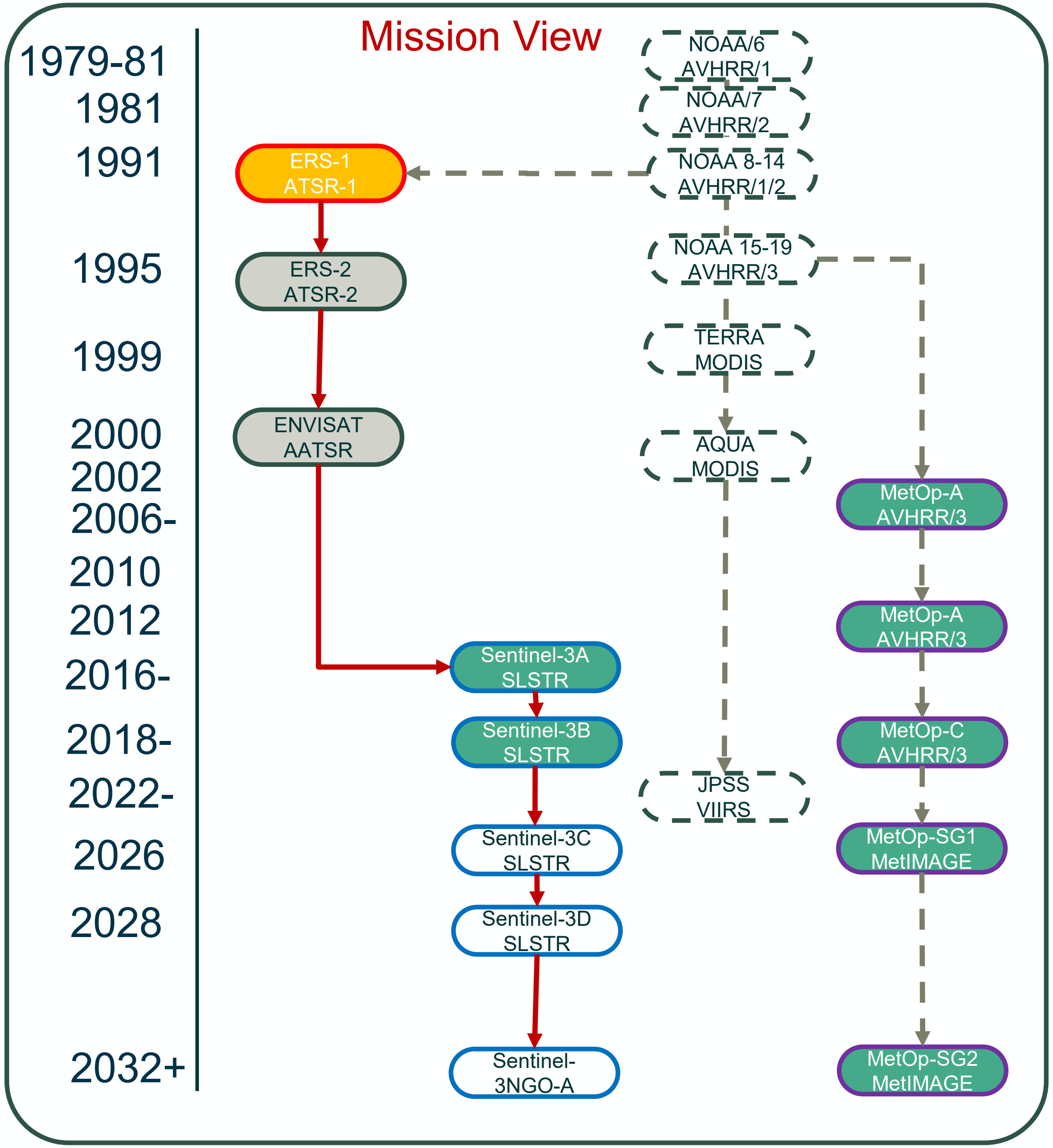
The amazing system we have today!

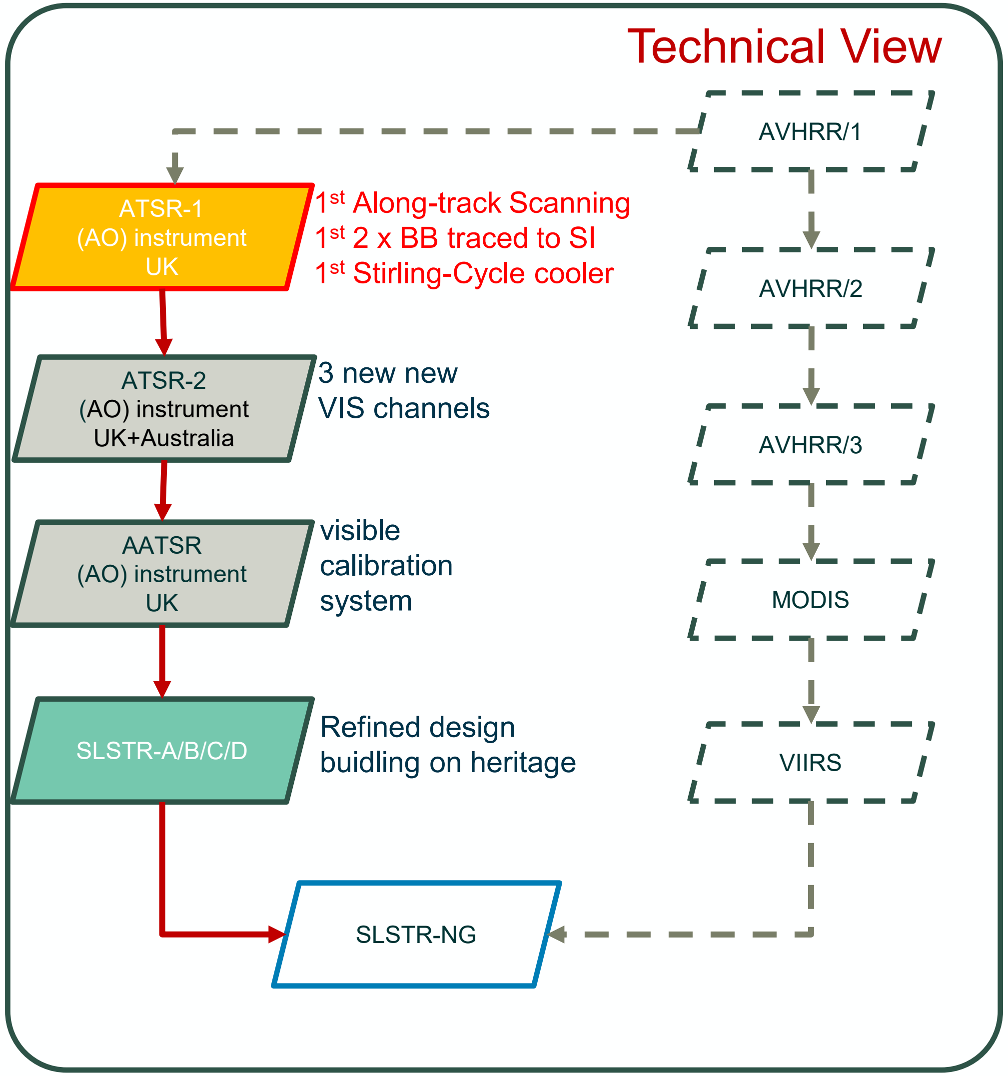
- **We have been part of a decade of profound change in Earth Observation**
- **Europe is providing an unprecedented and unique EO Evidence Base** that is supporting an enormous and growing number of applications across **all domains**
- The European Space Agency, together with the European Commission and EUMETSAT, is now preparing to sustain, **enhance and extend the EO System**
    - **The ESA Future-EO Program (Explorers)** continues to develop new scientific missions to view our planet Earth using **innovative techniques and technologies**.
    - **The ESA SCOUT missions** are exploring new ways to develop EO missions – as is the Arctic Weather Satellite
    - **The EUMETSAT Meteorology Satellite fleet** is formidable and provides a core element of the European EO Architecture.
    - **The Copernicus Satellite fleet** is formidable and provides a core element of the European EO Architecture.
    - **We have an extremely rich and growing data archive** for reanalyses and climate activities that provides an unparalleled scientific evidence base
- **All are critical for effective decision making and Policy implementation** – and of course our next generation of forecasting and prediction systems
- **Yet, Fundamental challenges remain to plan satellite systems in a manner allowing their exploitation in synergy** from the local process-driven perspective to the global climate challenges.

"Wise men say, and not without reason, that whoever wishes to foresee the future must consult the past" (Niccolò Machiavelli, 1532)

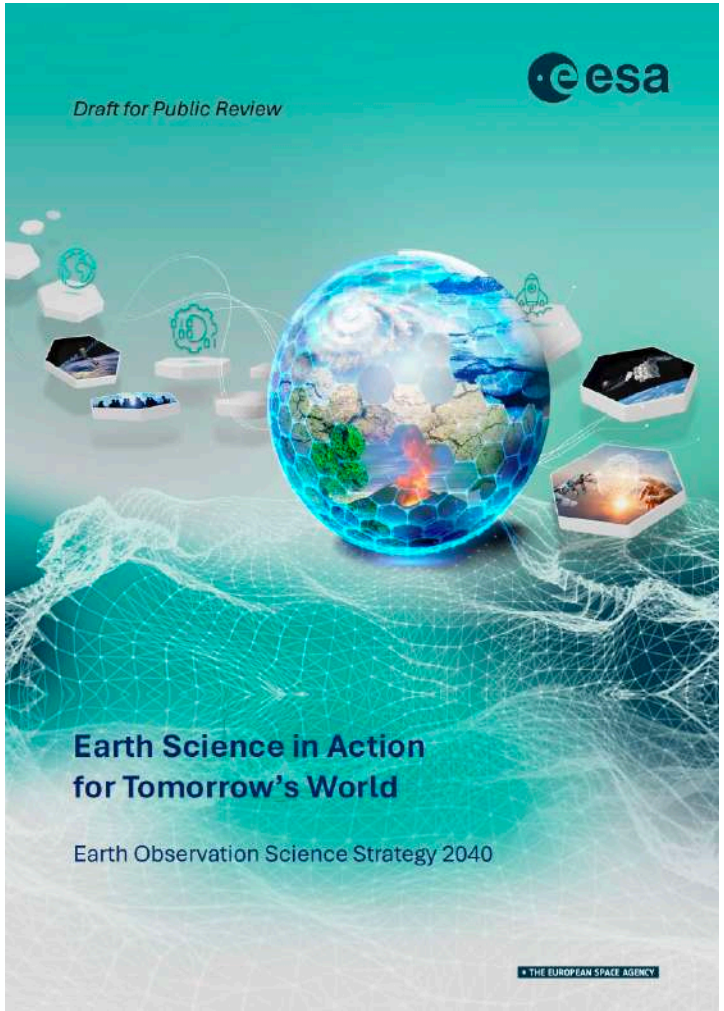


Reference sensors (ATSR→ AATSR →SLSTR)





EO Science Strategy



- A new (draft) Earth Observation (EO) Science Strategy has been developed.

- It is designed to elaborate the scientific foundation of ESA EO

- It has a 6-10 year outlook – providing a mechanism to keep abreast of the rapid and accelerating change within the EO sector - globally.

- The Strategy provides a basis for implementation choices built on a solid scientific foundation for the current EO ecosystem.

- The System Reference Architecture Blueprint is designed to address ***how*** the evolving European Earth observing infrastructure is configured and implemented.
    - ESA missions
    - EUMETSAT missions
    - SCOUT
    - Earthwatch
    - Copernicus
    - national and international partner missions,
    - and a rapidly growing commercial fleet of satellites
    - …

Earth Observation Reference Architecture

- **A Reference Architecture is a standardized set of guidelines, best practices, and design principles** that provides a framework that can be used to develop a European Earth Observation System of Systems.
- It provides **a common language and framework for communication, collaboration, and decision-making among stakeholders** involved in the development and operation the system.

- **What EO missions do we need to address EO Science Strategy?**
- **How should we implement the System?**

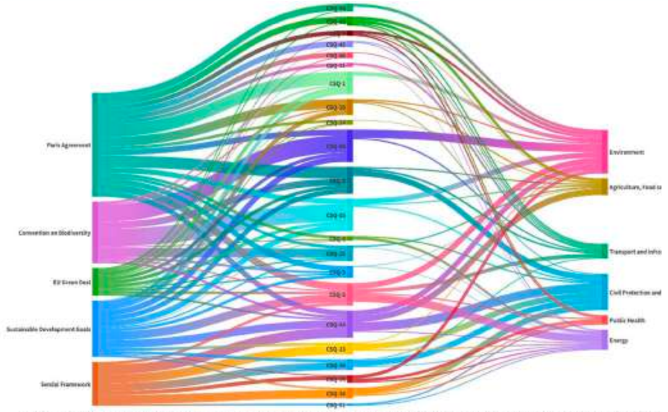
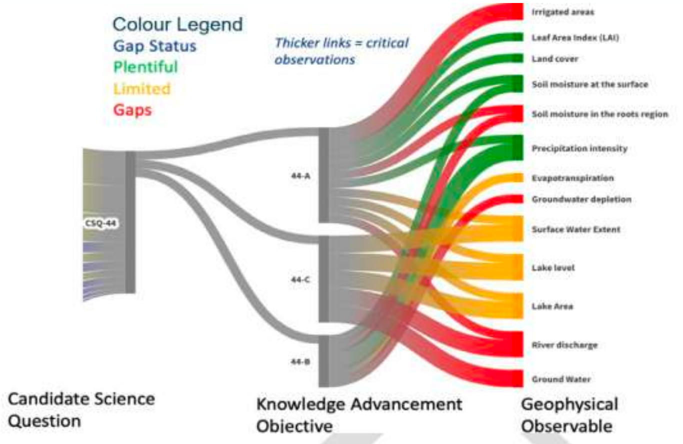
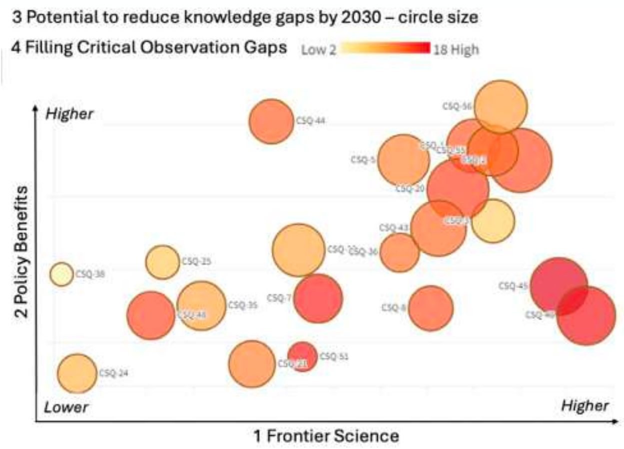
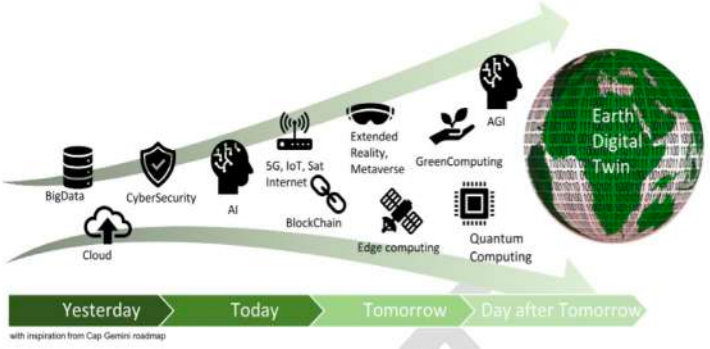


Figure 2. Traceability between each of the Candidate Science Questions (CSQs) in the centre and Intern. Agreements/ Treaties on the left, and socio-economically relevant application domains on the right.







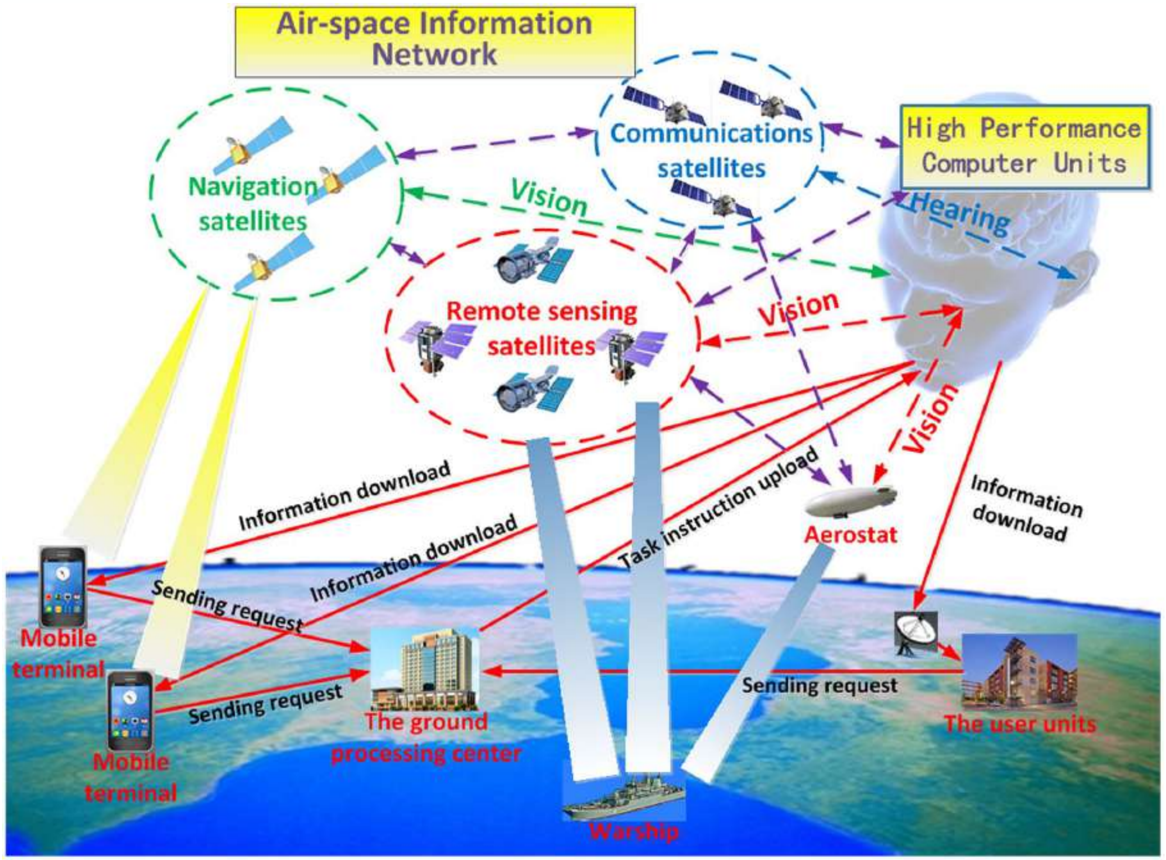
Systems of Systems Architecture: Strategic Compass for EOP

- Traceability -> Confidence & Trust
- science<>technical<>programmatic<>commercial

Aim: Enable ESA to plan strategic measurement evidence required to support a desirable future for Europe and our planet addressing current and future challenges for Society

Key characteristics of the living EO SoS ecosystem reference architecture include

1. **Relevant:**
2. **Standards:**
3. **Authenticity:**
4. **Long-term data preservation**
5. **Best Practices**
6. **Continuous improvement through evolution**
7. **Modularity and Scalability:**
8. **Complementarity:**
9. **Reusability:**
10. **Flexibility:**
11. **Interconnected:**
12. …



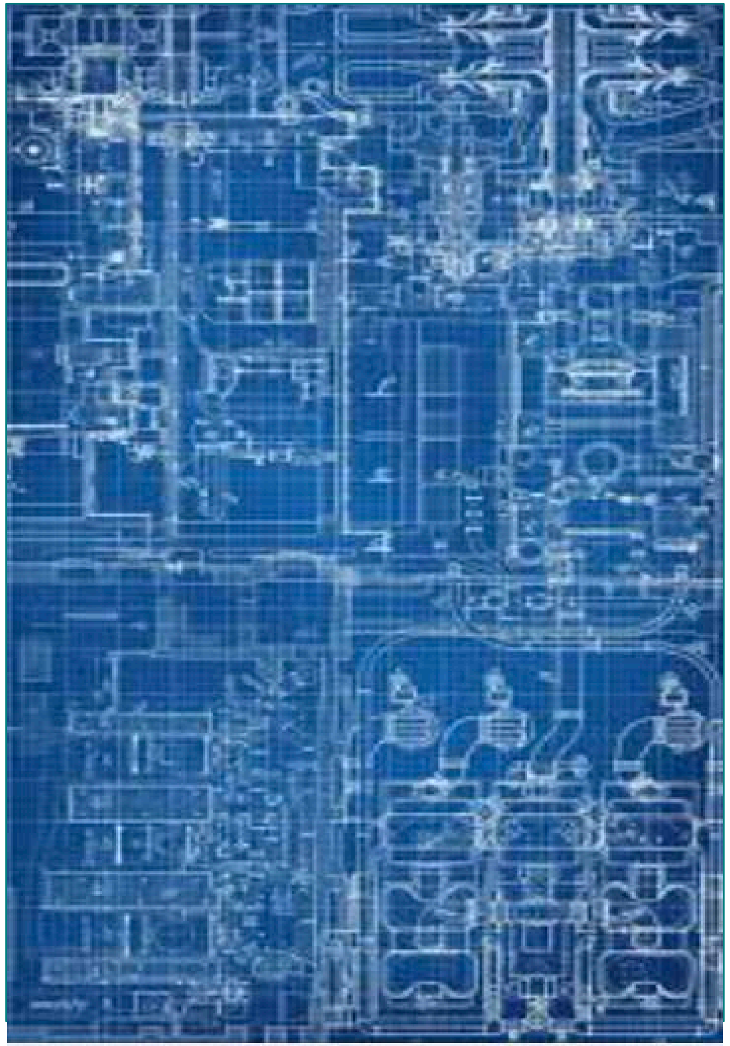
Earth observation brain (EOB): an intelligent earth observation system

Deren Li, Mi Wang, Zhipeng Dong, Xin Shen & Lite Shi

Pages 134-140 | Received 20 Feb 2017, Accepted 16 Apr 2017, Published online: 28 Jun 2017

Cite this article https://doi.org/10.1080/10095020.2017.1329314 Check for updates

EO Reference Architecture Blueprint



- New satellite missions to serve societal need remains a key focus of the science strategy
  - the Earth Observation envelope programme has delivered significant success, scientific progress and impact through this mechanism.

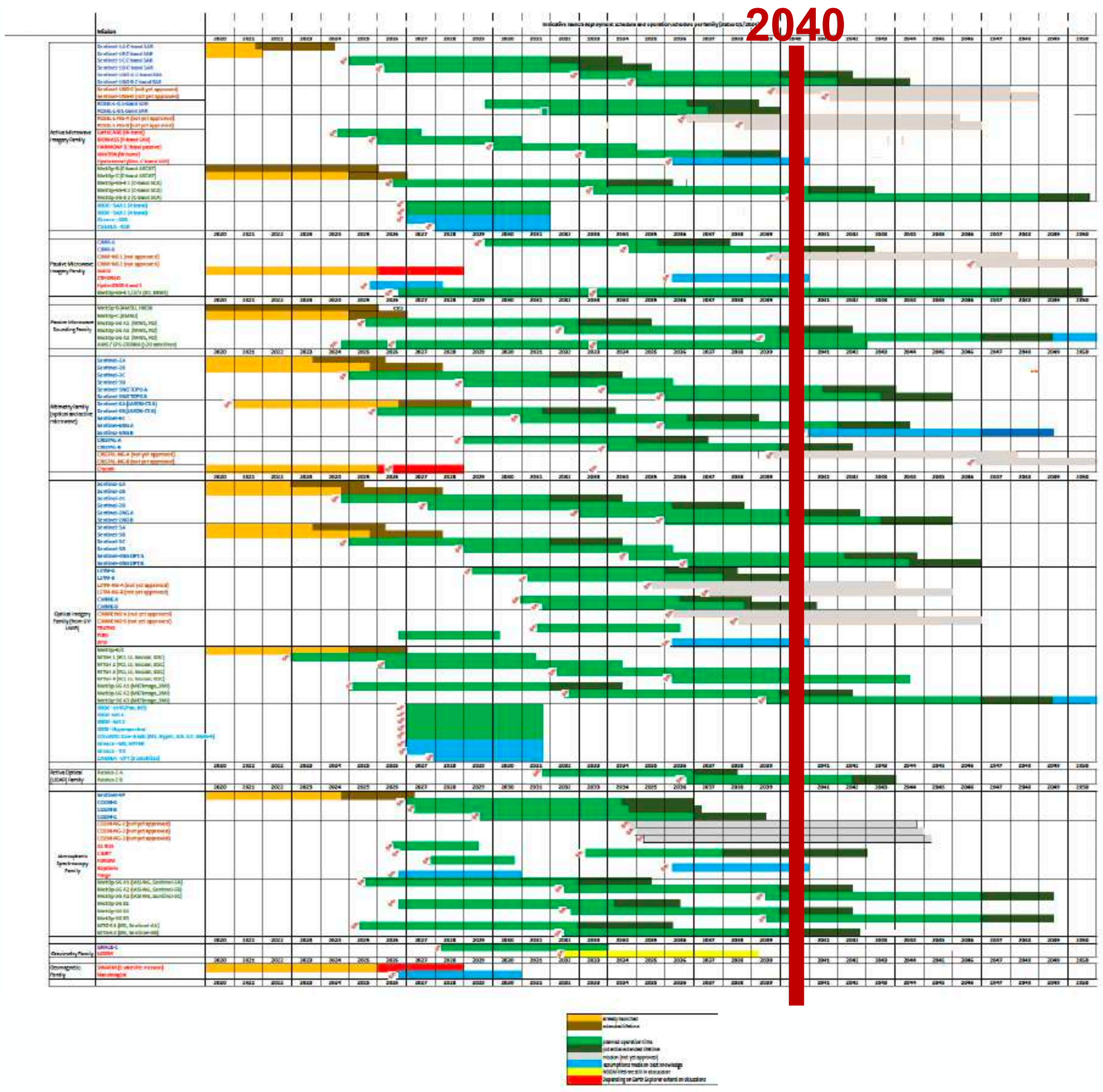
- **The EO Reference Architecture Blueprint is complementary to the Science Strategy**
- **It sets out the practical strategic basis for a living Earth Observation System of Systems that responds to the EO Science Strategy over a long timeline – out to 2050.**
- The Blueprint takes an Ecosystem system approach.
  - What EO do we need and what options are available?
  - What are the opportunities within the Earth Observation Paradigm we are living through now?

Blueprint for the Reference Architecture

System-of-systems Families:

- Elements not fitting a system of systems family
- Active Microwave Imagery Family
- Passive Microwave Imagery Family
- Passive Microwave Sounding Family
- Altimetry Family (optical and active microwave)
- Optical Imagery Family (from UV – LWIR - FIR)
- Active Optical (LIDAR) Family
- Limb Sounder Family (passive and using active signal sources (RO))
- Atmospheric Spectroscopy Family
- Gravimetry Family
- Geomagnetic Family

- By 2040 the current portfolio of EO missions begins to thin out



Blueprint Systems of Systems Architecture:
A Strategic Compass for EOP

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The Netherlands

STRATEGIC EOP INTER-DEPARTMENTAL OBJECTIVE 1:
EO REFERENCE ARCHITECTURE (BLUEPRINT)

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	EOP-FA
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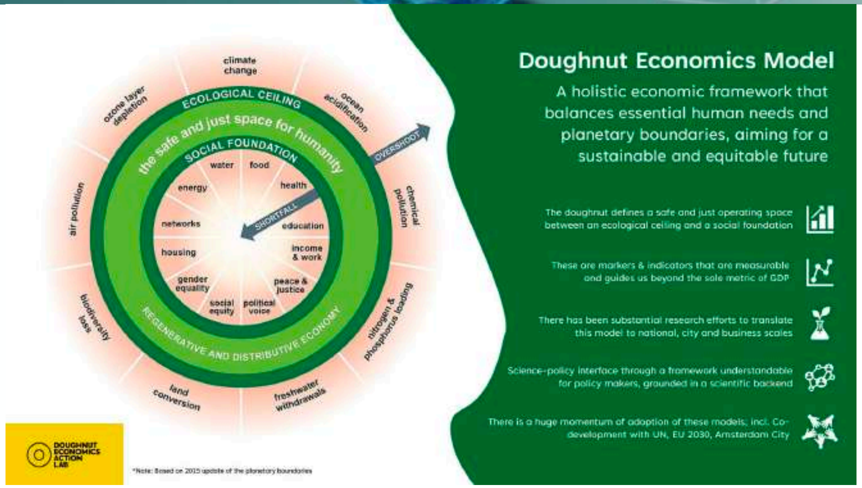
a living Earth Observation ecosystem for a living planet.

Socia-economic Scenario Based Approach

- The Earth System has ***already*** demonstrated regime change: we need to choose wisely our future direction for EO success and Climate Action.
- We have **a dense panorama of EO missions** (heritage)
- As such, <u>**we have already implemented the more achievable missions**</u>. This means that are:
  - high impact future missions de facto more complex and costly than previous missions.
  - low-cost missions are likely to have more limited impact compared to the existing system (sampling).
- DG says *"Dream for 10 years from now - if you do not your idea is obsolete today"*
- **We will adopt a scenario-based approach for T+20 years, T+40 years and T+60 years (IPCC and other organisations show the success of this approach).**



- *The basic principle of doughnut economics is to focus on meeting the needs of all people within the means of the planet. (Kate Raworth)*
- *Social and ecological boundaries*
- ***Can the same approach be used for EO system of systems planning?***

https://doughnuteconomics.org/about-doughnut-economics

Planetary Boundaries

POLICY AND PRACTICE REVIEWS article

Front. Environ. Sci., 22 March 2022
Sec. Environmental Informatics and Remote Sensing
Volume 10 - 2022 |
https://doi.org/10.3389/fenvs.2022.788843

This article is part of the Research Topic

Valuing Earth and Environmental Science

View all 8 Articles >

On-Going European Space Agency Activities on Measuring the Benefits of Earth Observations to Society: Challenges, Achievements and Next Steps

S1 S2 S3 CHIME CO2M BIOMASS FLEX HydroGNSS MTG

- Above Ground Biomass (AGB)
- Net Primary Production (NPP/HANPP)
- Vegetation characteristics (i.e., type, cover, he
- Plant species distribution, depletion and reco
- Soil health & type

S1 S2 S3 CHIME MT CRYOSAT

- Land Surface Analyses (i.e., Topo, Cover & Use)
- Biome & Ecosystem Mapping
- Freshwater Body Monitoring
- Urban Mapping & Development

S1 S2 S3 CHIME EarthCARE NGGM HydroGNSS Metop-SG MTG SMOS

- Freshwater Body Monitoring (i.e., Blue Water)
- Precipitation Profiling (e.g., intensity, patterns)
- Cloud Profiling (e.g., cover, type, liquid content)
- Soil Moisture at surface/roots (i.e., Green Water)
- Glacial & Ice Sheet Topography
- Surface Inundation

S3 S5 CHIME CO2M S2 S4

- NO2 Atmospheric concentrations
- Monitoring Fertiliser Use & Flows (e.g., HSI/MSI)
- Vegetation characteristics (i.e., type, cover, health)
- Water Quality Monitoring (e.g., algal blooms, eutrophication)
- Monitoring Sediment Transportation / level in rivers & lakes

S1 S3 S4 S5 S6 CRISTAL CIMR Metop-SG LSTM CO2M CRYOSAT AEOLUS EarthCARE NGGM HydroGNSS MTG

- Surface Albedo
- Surface Temperatures
- GHG Concentration
- Aerosol Optical Depth
- Carbon Sinks (i.e., Vegetation cover)
- Earth Energy Imbalance & Flux

S2 CHIME

- Pollution & Contaminant Detection
- Chemical Composition (i.e., Atmo-/ -land)
- Ecosystem impact of pollution

S3 S4 S5 Metop-SG MTG

- Ozone Concentration
- Mapping Ozone distribution, depletion and recovery
- ODS/Reactive Molecule monitoring

S3 S4 S5 S6 CO2M EarthCARE AEOLUS

- Aerosol Optical Depth (AOD)
- Aerosol Extinction / Backscatter
- Land Surface Analysis

CO2M S2 S3 CHIME

- CO2 Exchange
- Marine Ecosystem Health Monitoring

(Stephen George)

Hybrid Constellation

From a functional perspective, a hybrid satellite constellation **combines different satellite systems to strategically leverage the strengths of each through synergy** (e.g., orbits, latency, coverage, revisit and sampling (at relevant scales for a given application), ground processing, data delivery, operational capacity, resilience through redundancy, new multi-mission synergy products etc.) delivering enhanced performance to meet user/stakeholder requirements.

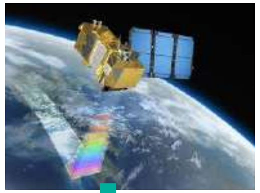
In the context of Copernicus and European Commission the hybrid constellation is **not** considered from a functional perspective but a responsibility balance between institutional and commercial providers:

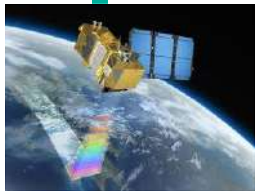
> ***“The hybrid-constellation is a mix of institutional and commercial missions to satisfy the user needs of the Copernicus services, with an increasing responsibility of the commercial actors”.***

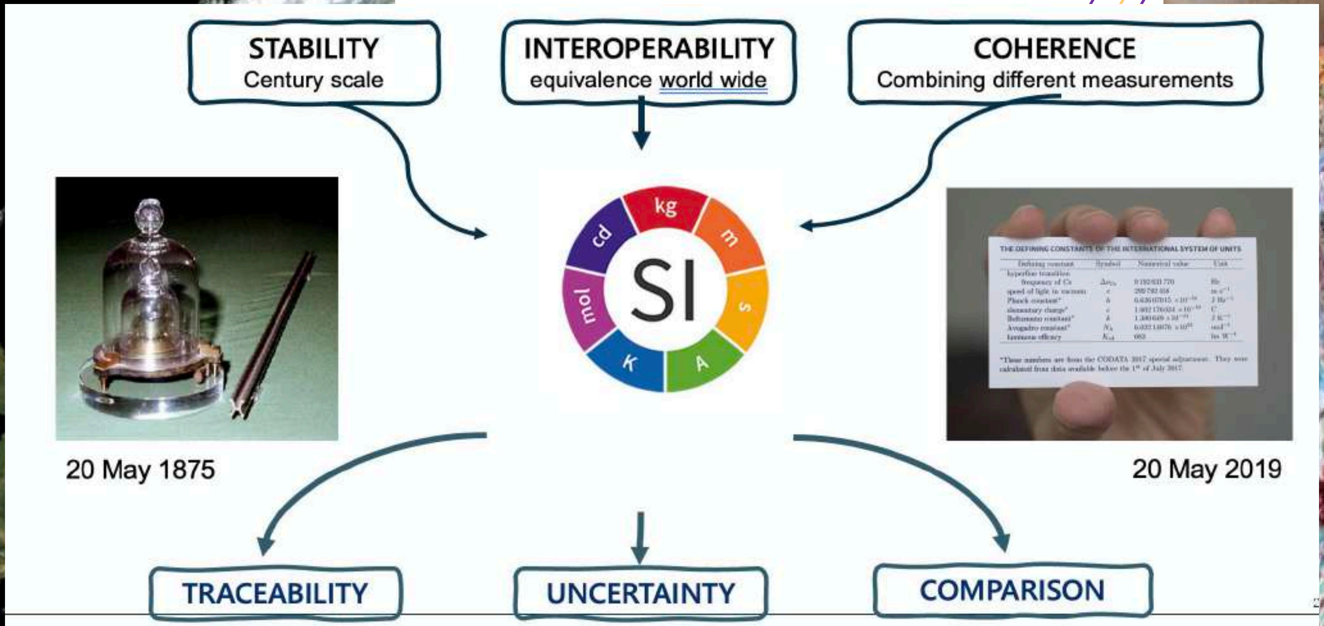
In this context, it is assumed that commercial data would be procured and delivered via public-private partnership mechanisms. **In the absence of strong user requirements and negotiation, these could ultimately evolve to a lowest common denominator in terms of performance driven by commercial return and minimisation of risk: the more challenging and superior performance satellite system “flagships”/reference mission capability may fall by the wayside.**

Calibration: Avoiding Grandmas' Patchwork Quilt

Sentinel-2







This image is a mosaic obtained by combining all the images acquired by the Copernicus Sentinel-2 satellites between 1 January 2022 and 30 November 2022, eliminating cloudy acquisitions and allowing us to observe the entirety of Europe clearly.

Grandmas' patchwork Quilt

Blueprint: Hybrid Constellation

From a functional perspective, a hybrid satellite constellation combines different satellite systems to strategically leverage the strengths of each through synergy (e.g., orbits, latency, coverage, revisit and sampling (at relevant scales for a given application), ground processing, data delivery, operational capacity, resilience through redundancy, new multi-mission synergy products etc.) delivering enhanced performance to meet user/stakeholder requirements.

"A hybrid satellite constellation combines different satellite systems in different ways to strategically leverage the strengths of each through synergy in a Systems of Systems architecture. It provides authenticated products and services with certified performance to meet user/stakeholder needs."

EO Reference Missions are the foundation for a hybrid-constellation in the ESA Reference Architecture Blueprint.

Reference Missions: How good is good enough?

esa

SLSTR A

Day						
Grade	MDif f	RSD	No	Overpass	Min Temp	Max Temp
1	-0.05	0.26	96	19	281.83	302.56
2a	0.17	0.42	538	44	279.12	304.09
2b	**0.03**	**0.30**	**403**	**31**	**281.83**	**302.56**
3	0.22	0.45	2005	57	279.12	304.14
4	0.20	0.48	5528	103	279.12	304.98

Night						
Grade	MDif f	RSD	No	Overpass	Min Temp	Max Temp
1	0.08	0.20	297	32	277.93	301.45
2a	0.01	0.32	686	49	276.62	301.45
2b	**0.03**	**0.23**	**1037**	**43**	**276.56**	**301.57**
3	-0.01	0.34	2656	62	276.55	301.75
4	-0.02	0.34	6908	106	275.67	303.42

SLSTR B

Day						
Grade	MDif f	RSD	No	Overpass	Min Temp	Max Temp
1	-0.12	0.22	167	19	283.30	299.22
2a	0.02	0.36	530	42	278.64	300.63
2b	**-0.09**	**0.28**	**646**	**31**	**283.30**	**299.48**
3	0.02	0.38	1978	54	278.64	303.02
4	0.03	0.40	6163	107	278.64	304.17

Night						
Grade	MDif f	RSD	No	Overpass	Min Temp	Max Temp
1	0.02	0.19	192	28	280.73	301.07
2a	-0.04	0.23	580	54	279.80	303.63
2b	**-0.02**	**0.22**	**732**	**43**	**276.69**	**303.05**
3	-0.07	0.25	2386	65	276.64	303.93
4	-0.08	0.30	6448	109	276.64	303.93

2020 – Sentinel-3A and Sentinel-3B SLSTR SSTskin FRM validation results

(W. Wimmer)

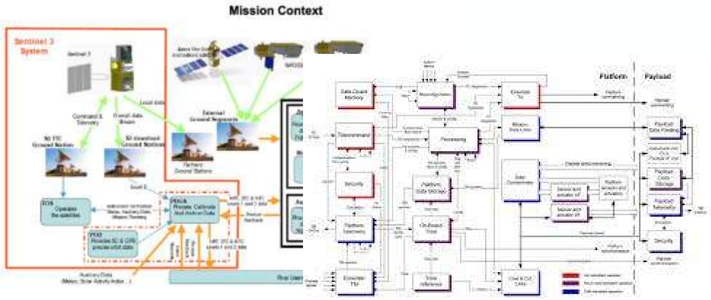
Blueprint: Authentication and Certification

- **Authenticity: For a successful application in a court of law, EO data must demonstrate authenticity in a world of increasing "deep fake" systems.**
- **Performance Certification:** EO data certification of the scientific content for EO data and the performance uncertainty of the measurements provided to the user community*.
- **By taking this approach the European SoS ecosystem and reference measurements embedded in such a hybrid hybrid constellation will be able to maintain coherent and traceable constellation inter-calibration and *allow* new national and commercial space providers, amongst others, participation and successful evolution. Pluse coherence of products**
- **As a strategic investment, develop sustained reference class satellite missions and supporting ground system services that form the backbone of the European EO Authentication and Measurement Performance Certification Service (AMPCS).**
- **It is typically assumed that the reference class mission has a calibration that is robust, stable and traceable to SI standards.*

Upcoming Opportunities

SPLINTER SESSION #1 – We want your feedback!

1-12197 EARTH OBSERVATION REFERENCE SYSTEM ARCHITECTURE DATA-BASE - EXPRO+ (500KEuro) – Closes 13/05/2024



1-12355 - FUTURE EARTH OBSERVATION SYSTEM ARCHITECTURE SYSTEM OF SYSTEMS ANALYSES FROM A SCIENCE NEED PERSPECTIVE - EXPRO PLUS (500KEuro) Closes 03/06/2024

INTENDED: FUTURE SCENARIOS FOR THE EARTH OBSERVAON BLUEPRINT

EO BLUEPRINT PRACTICAL REALITY WORKSHOP: Q3/4 @ ESTEC to explore options and discuss new approaches for the EO Blueprint

Thank you Any Questions?

Contact:
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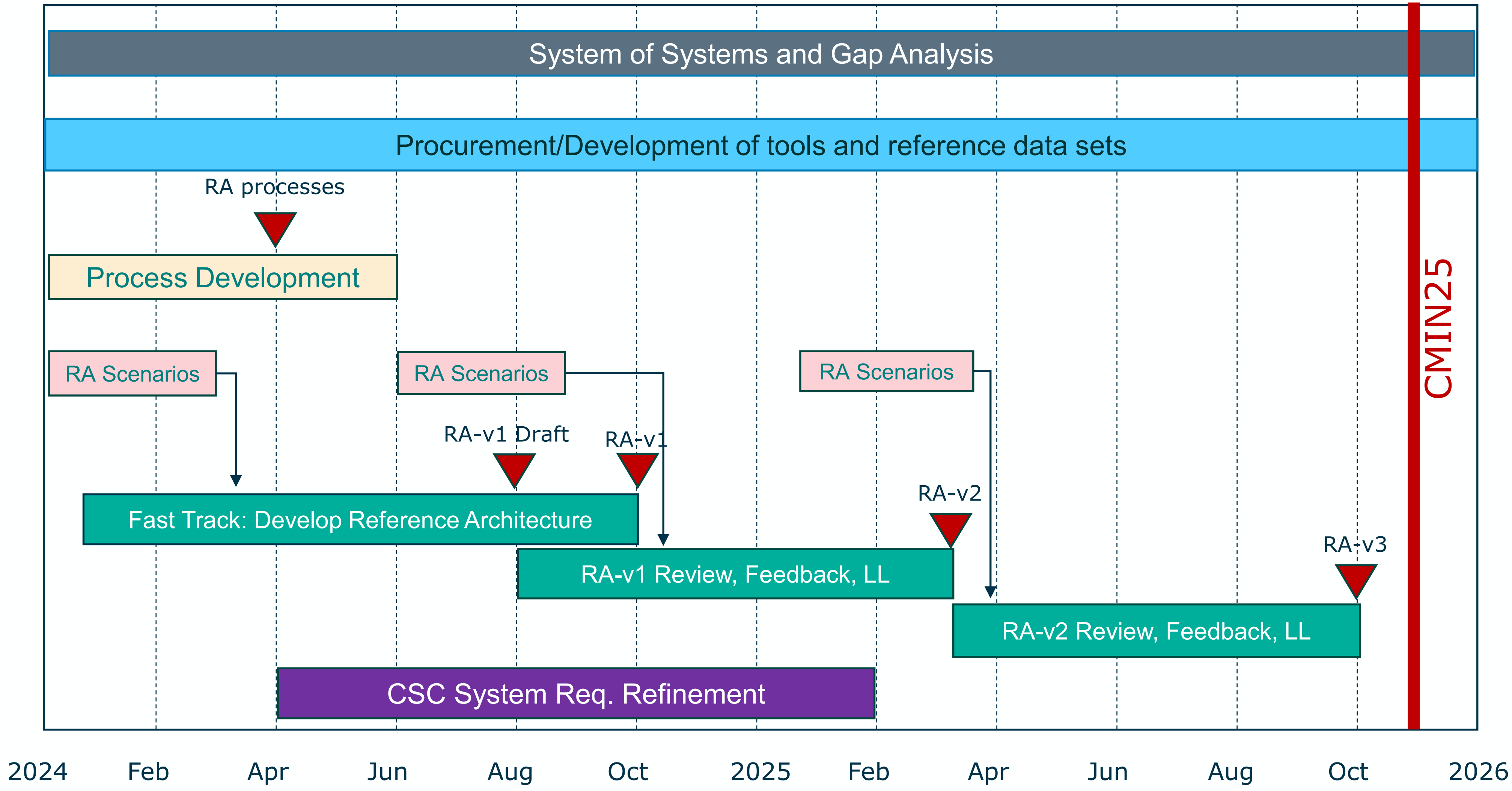
Schedule of Activities



Maintain CSC end to end system requirements

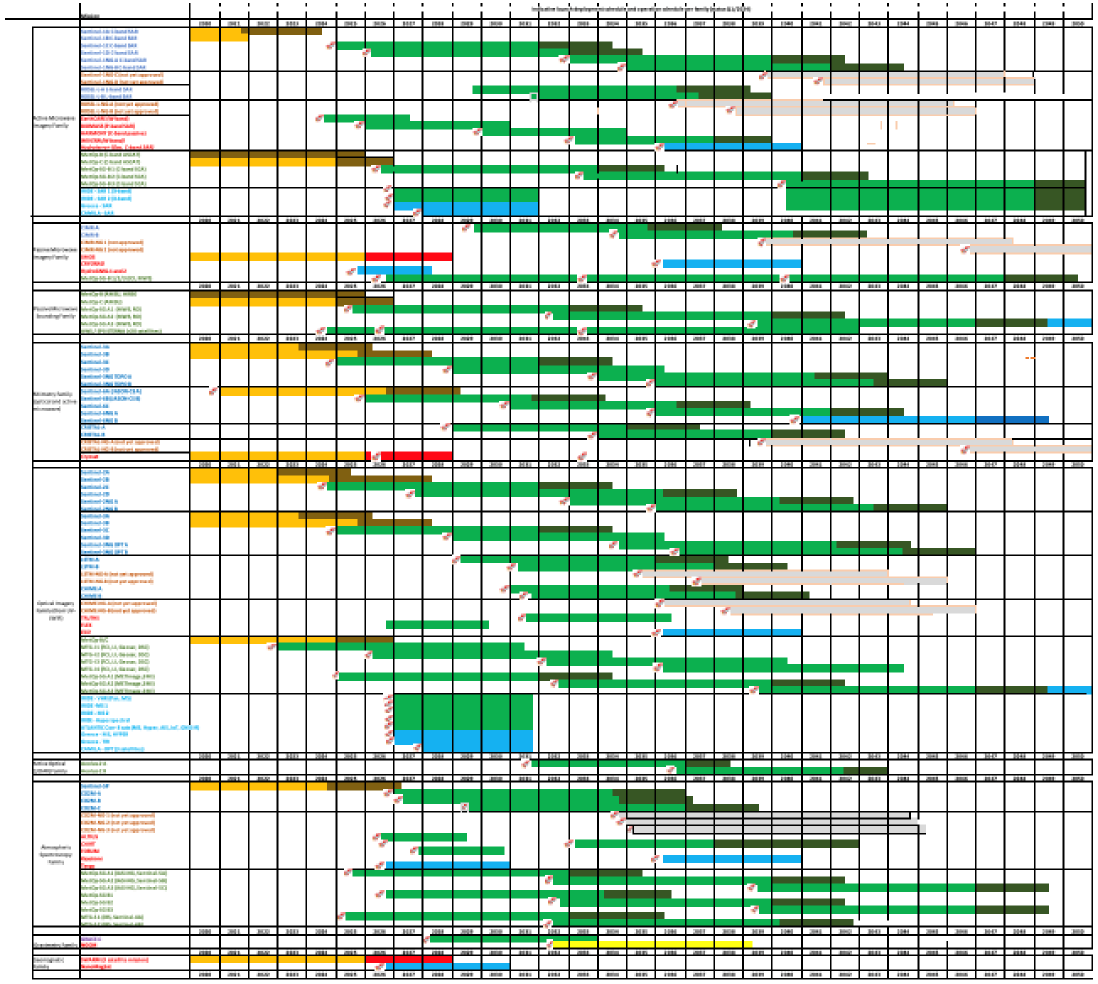
Maintain and update the end-to-end system requirements of the Copernicus Space Component (CSC) based on EU and Member States' user requirements.

Define CSC Evolution strategy and architecture

Define the strategy for preparing the evolution of the CSC and its system architecture, including 'make or buy' trade-offs and supports the definition and maintenance of the CSC Long Term Scenario document.

Observation Domain	Current Sentinel Missions	Sentinels Expansion and Next Generation	Contributing Missions (existing and/or potential)
Microwave Imaging Family	Sentinel-1 C-band SAR	Sentinel-1 NG C-band SAR ROSE-L L-band SAR CIMR	Various national, institutional and commercial missions
Optical Imaging Family	Sentinel-2 Sentinel-3	Sentinel-2 NG Sentinel-3 NG Optical LSTM CHIME	Various national, institutional and commercial missions
Topographic Ocean and Ice Measurement Family	Sentinel-3 Sentinel-6	Sentinel-3 NG Topography Sentinel-6C Sentinel-6 NG CRISTAL	Various national, institutional and commercial missions
Spectroscopic Atmosphere Measurement Family	Sentinel-5P Sentinel-4 Sentinel-5	CO2M	Various national, institutional and commercial missions

Table 1: CSC Measurement Families



Doughnut Economy and EO

POLICY AND PRACTICE REVIEWS article

Front. Environ. Sci., 22 March 2022
Sec. Environmental Informatics and Remote Sensing
Volume 10 - 2022 |
https://doi.org/10.3389/fenvs.2022.788843

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On-Going European Space Agency Activities on Measuring the Benefits of Earth Observations to Society: Challenges, Achievements and Next Steps

A good reflective starting point but:

- What about future missions?
- What are the correct DE model boundaries for EO?
- How to correlate Socio-political aspects to EO?
- New observatory functions are required

Ecological ceilings

Boundary	EO contributions (examples)
Climate change	EO monitors both the causes and effects of climate change and will soon support compliance of climate policies, in terms of: • Causes: e.g. GHG/deforestation monitoring and the monitoring of feed-back loops within the Earth system that could cause climate change to accelerate. • Effects on: e.g. sea ice, ice sheets, ocean salinity, ocean colour, sea surface temperature, aerosols, ozone, sea level, sea state, water vapour, clouds, soil moisture, land surface temperature, biomass, land cover, fire, lakes, glaciers, snow, permafrost (36 of the 54 Essential Climate Variables defined by the WMO benefit from space observations). •Compliance: first global stocktake of the Paris Agreement in 2023
Ocean acidification	• Sea salinity measurements, which play a key role in ocean acidification
Chemical pollution	• Oil spills, atmospheric chemical pollution (see air pollution), acid rain effects, impact assessment of industrial accidents
Nitrous and phosphorus loading	• Surface runoff and wind erosion monitoring (key drivers of eutrophication in surface waters), algae bloom monitoring
Freshwater withdrawals	• Sub-ground water table assessments using gravity measurements, above ground evolution of freshwater reserves within lakes, glaciers and snow
Land conversion	• optical, radar and hyperspectral measurements to monitor at local, regional and global scales
Biodiversity loss	• optical, radar and hyperspectral measurements to monitor at local, regional and global scales
Air pollution	• Nitrogen dioxide, sulphur dioxide, formaldehyde, carbon monoxide measurements
Ozone layer depletion	• The ozone layer and its evolution are monitored by EO satellites since several decades

Social Foundations

Boundary	EO contributions (examples)
Water	• Assess local and regional evolution of water reservoirs, monitoring soil moisture
Food	• Monitoring of crops, prediction of agricultural yields
Health	• EO data is used in epidemiological models, air pollution monitoring
Energy	• Assessing green energy potential and biomass reserves
Education	• EO images/results contribute to raise awareness amongst children and adults on global issues affecting humankind
Income and work	• Limited potential for EO contributions
Peace and justice	• Monitoring the impacts of war and large-scale conflict, potential for assessing aspects of environmental justice
Political voice	• Limited potential for EO contributions
Social equity	• Limited potential for EO contributions
Gender equality	• Limited potential for EO contributions
Housing	• Mapping of informal housing in developing regions and of parameters that determine housing quality (building age, thermal insulation etc.)
Networks	• Limited potential for EO contributions

ESA MISSIONS MAPPED TO EARTH SYSTEM GOVERNANCE ARCHITECTURES

Title	ESA Missions mapped to Doughnut Economics (first/best guess)
Version	0.1
Version Date	09/04/2024
Author/Owner	Steven George
Description	A mapping exercise aimed at aligning ESAs Earth Observation System-of-Systems with the planetary boundary framework and the social foundation of the doughnut economics model (which are derived from the SDGs). This high-level association underscores the relevance and contribution of Earth observation technologies within sustainability science frameworks. While a more detailed examination is necessary for a comprehensive gap analysis, this overview provides a foundational visual aid to support the rationale for integrating ESA's SoS into Earth system governance architectures and social development frameworks (i.e., Planetary Boundaries, Doughnut Economics & planetary boundaries). Additionally, this overview will guide the creation of any required graphics.

KEY

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[insert text]

Planetary Boundaries: Climate Change, Biosphere Integrity, Land-System Change, Freshwater Change, Biogeochemical Flows, Ocean Acidification, Atmospheric Aerosol Loading, Stratospheric Ozone Depletion, Novel Entities

Social Foundation: Food, Health, Education, Income & Work, Peace & Justice, Political Voice, Social Equity, Gender Equality, Housing, Networks, Energy, Water & Sanitation

ESA Mission		Observation/Measurement	
Mission	**Instruments**	**Technology**	**Measurement Specification**
Sentinel-1	C-Band SAR	Imaging microwave radars	Wind speed over sea surface (horizontal), Wind vector over sea surface (horizontal), Significant wave height, Dominant wave period, Dominant wave direction, Ocean surface currents
Sentinel-2	MSI	High resolution optical imagers	Normalized Differential Vegetation Index (NDVI), Leaf Area Index (LAI), Photosynthetically Active Radiation (PAR), Fraction of Absorbed PAR (FAPAR), Vegetation type, Fire fractional
Sentinel-3	SLSTR, OLCI, SRAL	Imaging multi-spectral radiometers (vis/IR), Radar altimeters	Sea surface temperature, Sea-ice surface temperature, Land surface temperature, Fire fractional cover, Fire temperature, Precipitation Profile (liquid or solid), Aerosol Extinction /
Sentinel-4	UVN	High-resolution nadir-scanning SW spectrometer	Aerosol optical depth (column/profile), O_3 Mole Fraction, NO_2 Mole Fraction, BrO (column/profile), Cloud top height, SO_2 Mole Fraction, HCHO Mole Fraction, CHOCHO
Sentinel-5	UVNS	High-resolution nadir-scanning SW spectrometer	Atmospheric specific humidity (column/profile), Aerosol optical depth (column/profile), O_3 Mole Fraction, CH_4 Mole Fraction, CO Mole Fraction, NO_2 Mole Fraction, BrO (column/profile), Cloud
Sentinel-6	GNSS-RO Receiver, AMR-C, DORIS-NG, GNSS POD	GNSS radio-occultation receiver, Non-scanning MW radiometer, Laser retroreflector, Radar altimeter	Atmospheric temperature (column/profile), Atmospheric specific humidity (column/profile), Atmospheric specific humidity (column/profile), Sea level, Ocean dynamic topography, Aerosol
CRISTAL	AMR-C, IRIS	Imaging multi-spectral radiometers (passive microwave), Radar altimeters	Atmospheric specific humidity (column/profile), Sea level, Ocean dynamic topography, Atmospheric specific humidity (column/profile), Wind speed over sea surface (horizontal),
CIMR	CIMR	Imaging multi-spectral radiometers (passive microwave)	Sea surface temperature, Sea Surface salinity, Sea-ice cover, Sea-ice type, Sea-ice thickness, Sea-ice Concentration
ROSE-L	L-Band SAR	Imaging microwave radars	Crustal plates positioning
CHIME	HIS	Hyperspectral imagers	Ocean imagery and water leaving spectral radiance, Land surface imagery, Upwelling (Outgoing) spectral radiance at TOA
LSTM	LSTR	Imaging multi-spectral radiometers (vis/IR)	Land surface temperature
CO2M	CO2I, CLIM, MAP	High-resolution nadir-scanning SW spectrometer, Multi-purpose imaging Vis/IR radiometer, Multi-channel/direction/polarisation radiometer	CH_4 Mole Fraction, CO_2 Mole Fraction, NO_2 Mole Fraction, Cloud cover, Aerosol optical depth (column/profile)
CRYOSAT	SIRAL, ESA	Radar altimeters, Laser retroreflector	Sea-ice sheet topography, Land surface topography, Sea-ice thickness, Gravity field
SMOS	MIRAS	Multi-purpose imaging MW radiometer	Sea Surface salinity, Soil moisture at the surface
SWARM	ESA, ASM, VFM, STR, EFI, ACC, GPS	Laser retroreflector, Magnetometer, Electric field sensor, Gradiometer/accelerometer, GNSS receiver	Gravity field, Magnetic field (scalar), Magnetic field (vector), Electric Field (vector)
AEOLUS	ALADIN\-2	Doppler lidar	Wind profile (vertical), Aerosol Extinction / Backscatter (column/profile), Cloud top height, Cloud optical depth
EARTHCARE	MSI, CPR, ATLID, BBR	Multi-purpose imaging Vis/IR radiometer, Cloud and precipitation radar, Atmospheric lidar, Broad-band radiometer	Aerosol Extinction / Backscatter (column/profile), Cloud imagery, Cloud type, Cloud top height, Aerosol effective radius (column/profile), Cloud drop effective radius, Cloud optical depth, Cloud
BIOMASS	P-Band SAR	Imaging microwave radars	Vegetation Canopy (cover), Vegetation Canopy (height), Above Ground Biomass (AGB)
FLEX	FLORIS	Imaging multi-spectral radiometers (vis/IR)	Chlorophyll Fluorescence from Vegetation on Land
FORUM	FTS	Imaging multi-spectral radiometers (vis/IR)	Cloud type, Cloud drop effective radius, Long-wave Earth surface emissivity
HARMONY	Passive SAR, MTI	Imaging microwave radars, Imaging multi-spectral radiometers (vis/IR)	Glacier motion, Crustal Motion, Sea-ice motion
NGGM	LTI, MicroSTAR	Gravity instruments	Sea surface temperature, Sea level, Glacier motion, Soil moisture at the surface, Geoid, Crustal Motion, Soil moisture in the roots region, Ice sheet topography, Ocean temperature,
HydroGNSS	SGR-ReSI-Z	GNSS receiver	Wind speed over sea surface (horizontal), Significant wave height, Sea-ice cover Soil moisture at the surface, Sea-ice thickness, Sea-ice concentration, Above Ground Biomass
Metop-B/C	IASI, AVHRR/3, GRAS, HIRS/4, GOME-2, MHS,	Medium-resolution IR spectrometer, Multi-purpose imaging Vis/IR radiometer, GNSS radio-occultation receiver, Narrow-band channel IR	Atmospheric temperature (column/profile), Wind profile (vertical), Atmospheric specific humidity (column/profile), O_3 Mole Fraction, CH_4 Mole Fraction, N_2O (column/profile), HNO_3
MTG	SEVIRI, GERB	Multi-purpose imaging Vis/IR radiometer, Broad-band radiometer	Wind profile (horizontal), Atmospheric specific humidity (column/profile), O_3 Mole Fraction, Cloud imagery, Cloud type, Cloud cover, Cloud top height, Cloud top temperature,

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Sentinel-3	SLSTR, OLCI, SRAL	Imaging multi-spectral radiometers (vis/IR), Radar altimeters	Sea surface temperature, Sea-ice surface temperature, Land surface temperature, Fire fractional cover, Fire temperature, Precipitation Profile (liquid or solid), Aerosol Extinction
Sentinel-4	UVN	High-resolution nadir-scanning SW spectrometer	Aerosol optical depth (column/profile), O_3 Mole Fraction, NO_2 Mole Fraction, BrO (column/profile), Cloud top height, SO_2 Mole Fraction, HCHO Mole Fraction, CHOCHO
Sentinel-5	UNVS	High-resolution nadir-scanning SW spectrometer	Atmospheric specific humidity (column/profile), Aerosol optical depth (column/profile), O_3 Mole Fraction, CH_4 Mole Fraction, CO Mole Fraction, NO_2 Mole Fraction, BrO
Sentinel-6	GNSS-RO Receiver, AMR-C, DORIS-NG, GNSS POD	GNSS radio-occultation receiver, Non-scanning MW radiometer, Laser retroreflector, Radar altimeter	Atmospheric temperature (column/profile), Atmospheric specific humidity (column/profile), Atmospheric specific humidity (column/profile), Sea level, Ocean
CRISTAL	AMR-C, IRIS	Imaging multi-spectral radiometers (passive microwave), Radar altimeters	Atmospheric specific humidity (column/profile), Sea level, Ocean dynamic topography, Atmospheric specific humidity (column/profile), Wind speed over sea surface
CIMR	CIMR	Imaging multi-spectral radiometers (passive microwave)	Sea surface temperature, Sea Surface salinity, Sea-ice cover, Sea-ice type, Sea-ice thickness, Sea-ice Concentration
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Metop-B/C	IASI, AVHRR/3, GRAS, HIRS/4, GOME-2, MHS,	Medium-resolution IR spectrometer, Multi-purpose imaging Vis/IR radiometer, GNSS radio-occultation receiver, Narrow-band channel IR	Atmospheric temperature (column/profile), Wind profile (vertical), Atmospheric specific humidity (column/profile), O_3 Mole Fraction, CH_4 Mole Fraction, N_2O (column/profile),
Meteosat-9/10	SEVIRI, GERB	Multi-purpose imaging Vis/IR radiometer, Broad-band radiometer	Wind profile (horizontal), Atmospheric specific humidity (column/profile), O_3 Mole Fraction, Cloud imagery, Cloud type, Cloud cover, Cloud top height, Cloud top