Crafting the European Earth Observation Ecosystem 2040+

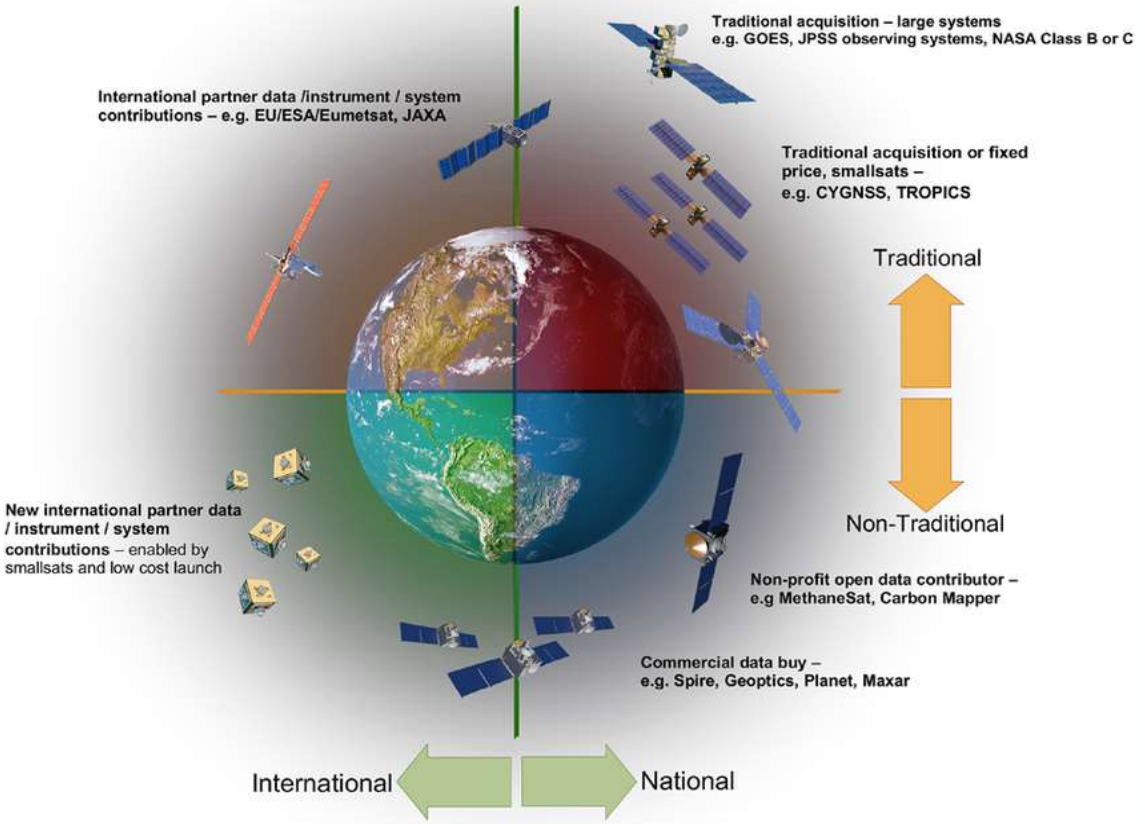
The European Earth Observation Ecosystem Workshop

12.02.2025

Craig Donlon, Hd. ESA Earth Observation System Architect Office.

Outline

- Emerging Challenges to Earth Observation
- European EO Ecosystem
- Blueprint (for a European EO Ecosystem)
- Reference Architecture
- Scenario based approach
- What we want from you



Waliser, Duane. (2024). Toward a US Framework for Continuity of Satellite Observations of Earth's Climate and for Supporting Societal Resilience. Earth's Future. 12. 10.1029/2023EF003757.

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

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.

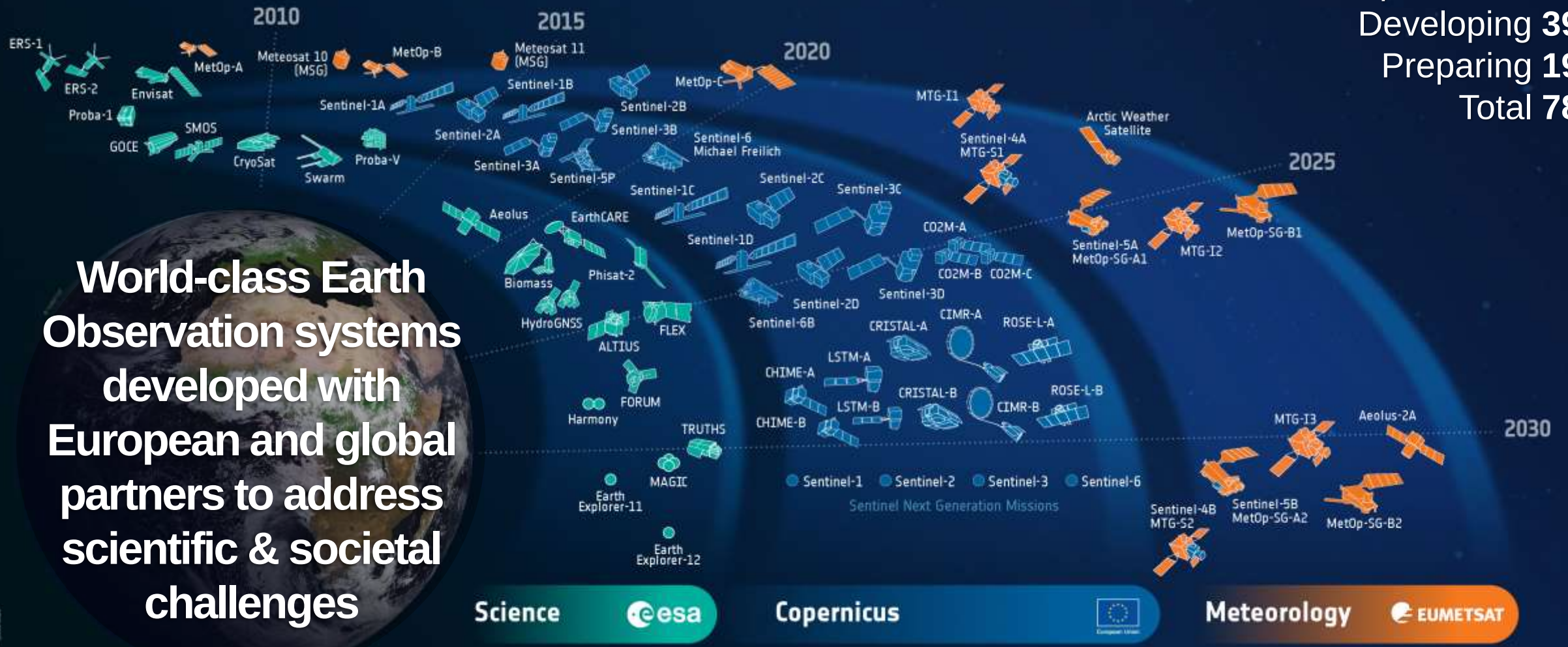
Earth Observation must continue to deliver, first and foremost, high-performance **scientific measurements from Space.**

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

European Earth Observation Today

Priority #1: Can we sustain and evolve it?

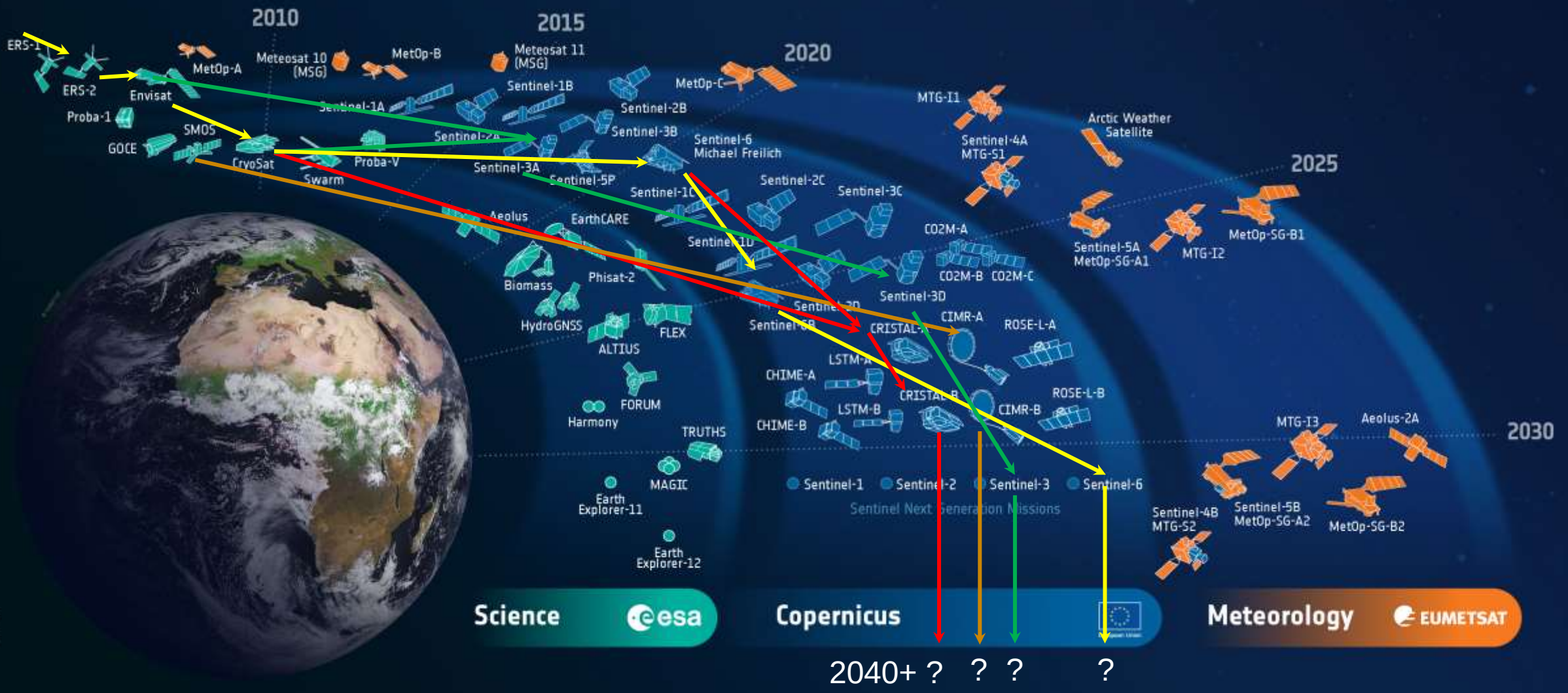
Satellites
Heritage **06**
Operational **14**
Developing **39**
Preparing **19**
Total **78**



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

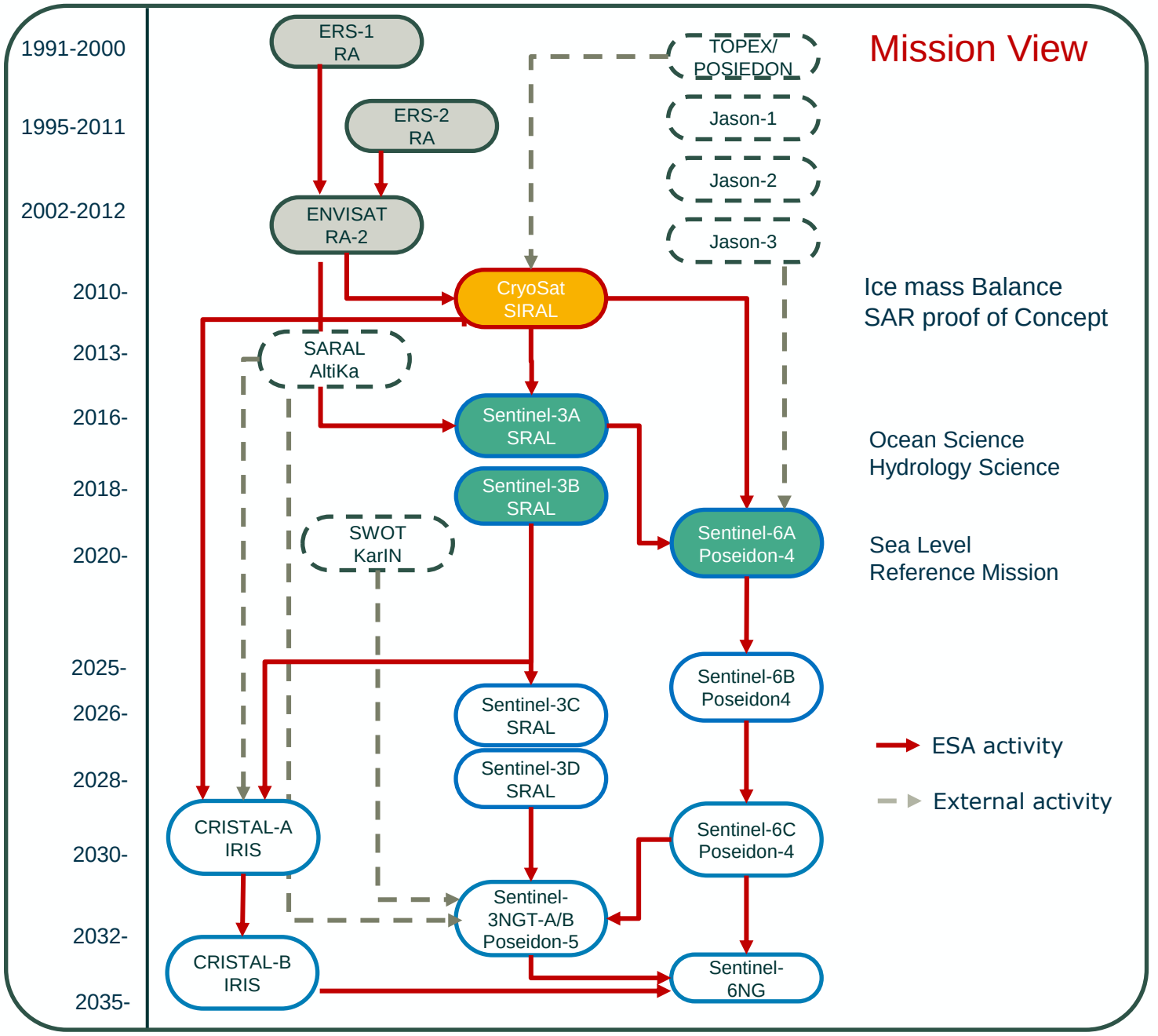
Science esa Copernicus Meteorology EUMETSAT

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

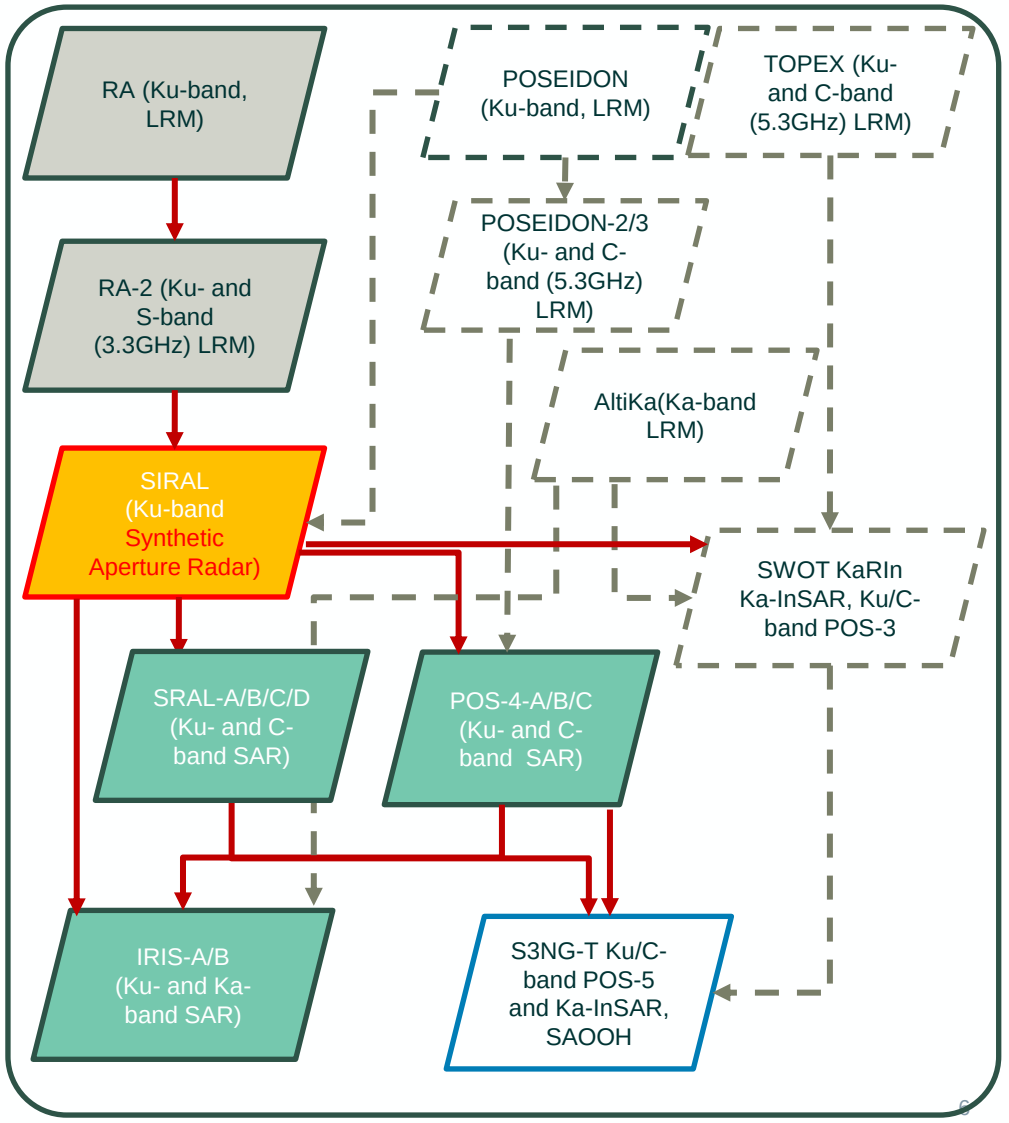


ESA altimetry

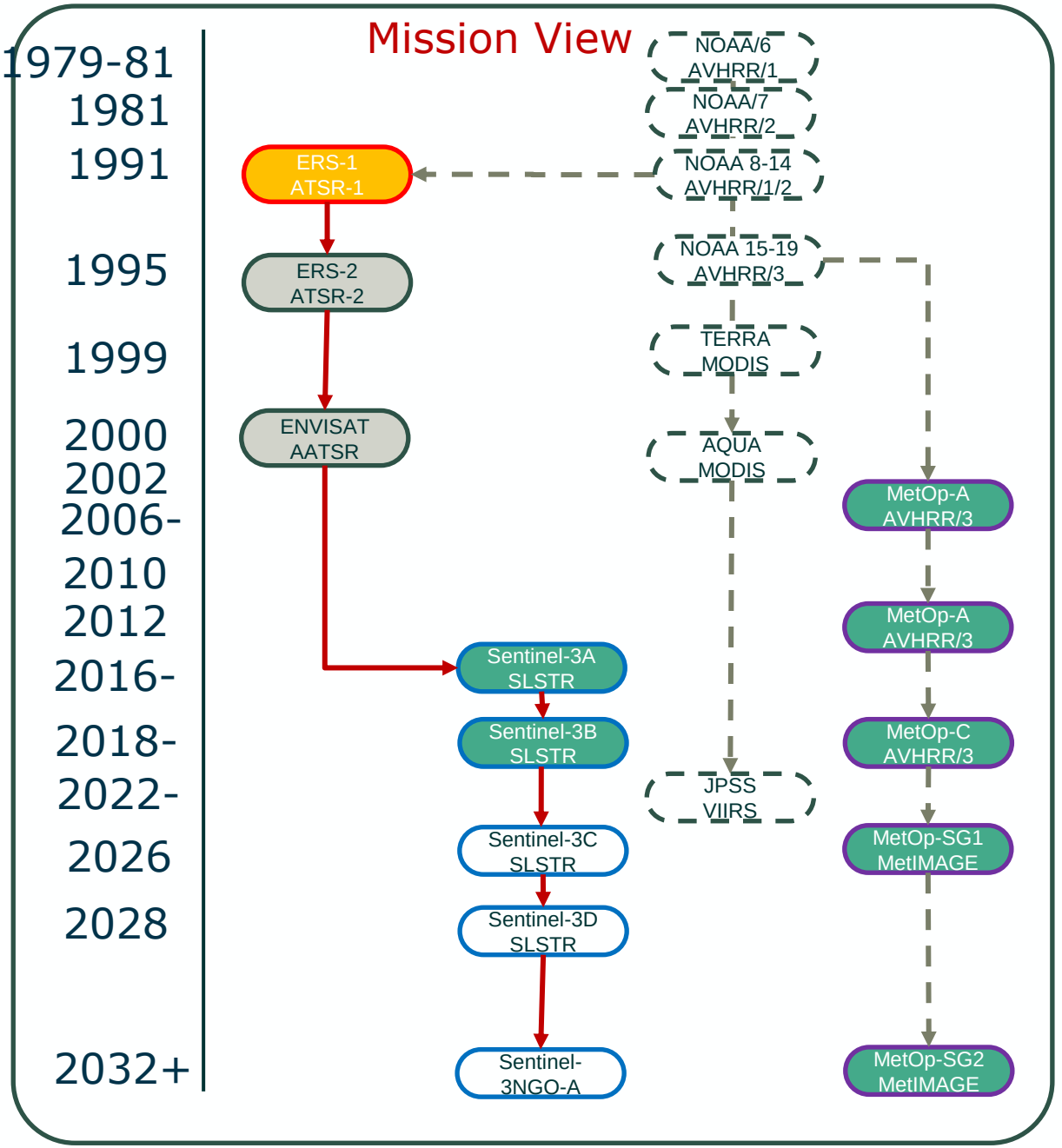
Mission View

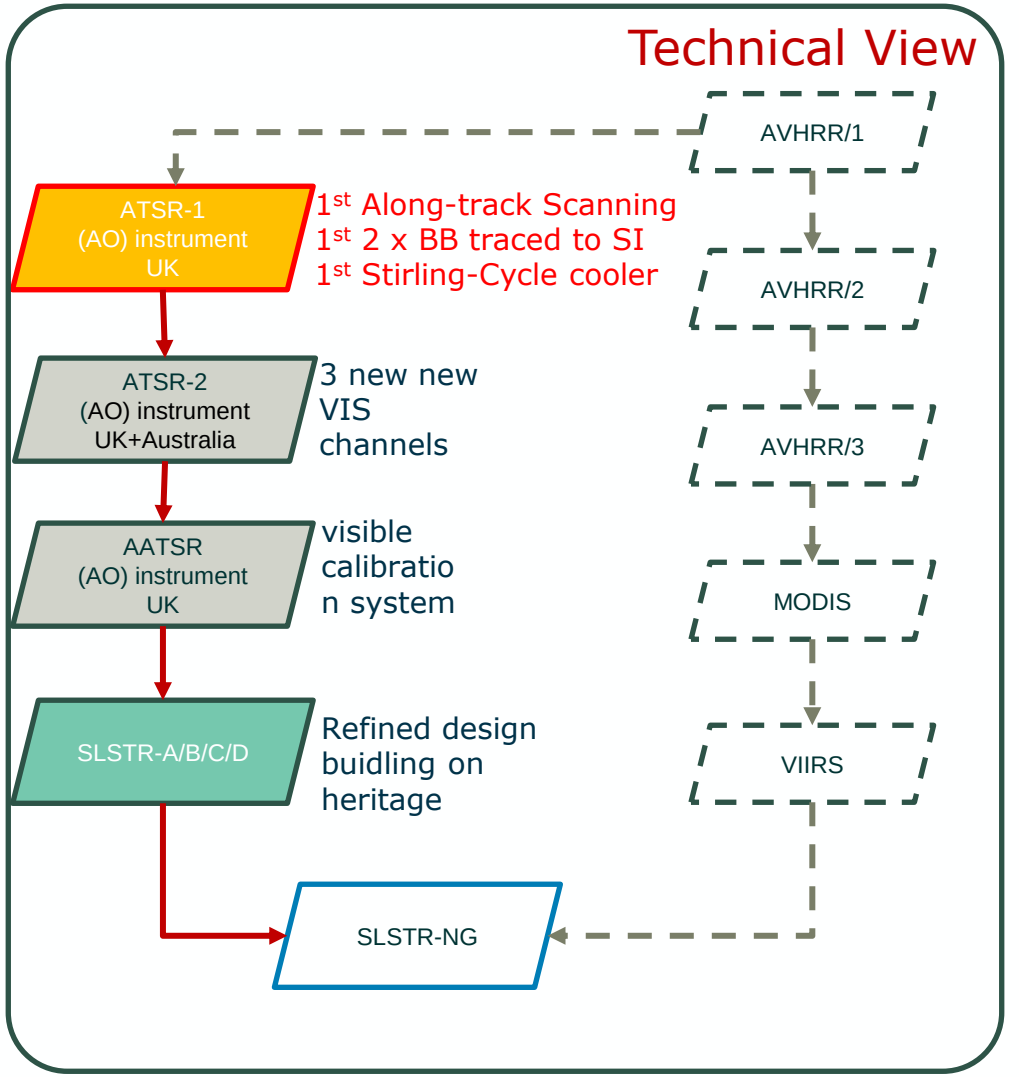


Technical View



TIR reference sensors (ATSR→ AATSR →SLSTR)





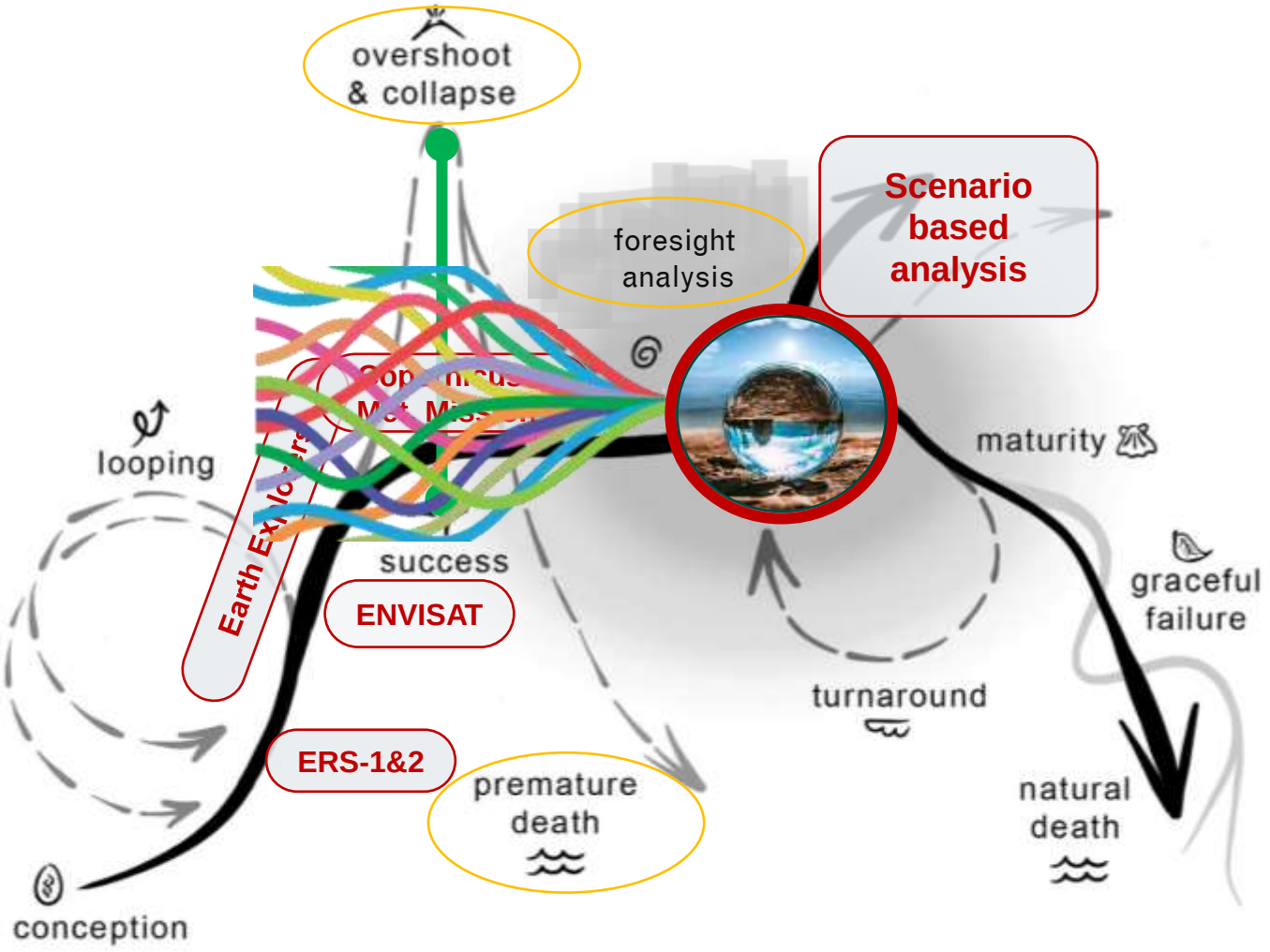
EO Boom and Bust or Optimised Sustainable and affordable Growth?

- **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**

- **Fundamental challenges remain to plan satellite systems in a manner allowing their exploitation in synergy.**
- **The "plan" must avoid Boom and Bust" through optimised sustainable and affordable growth.**

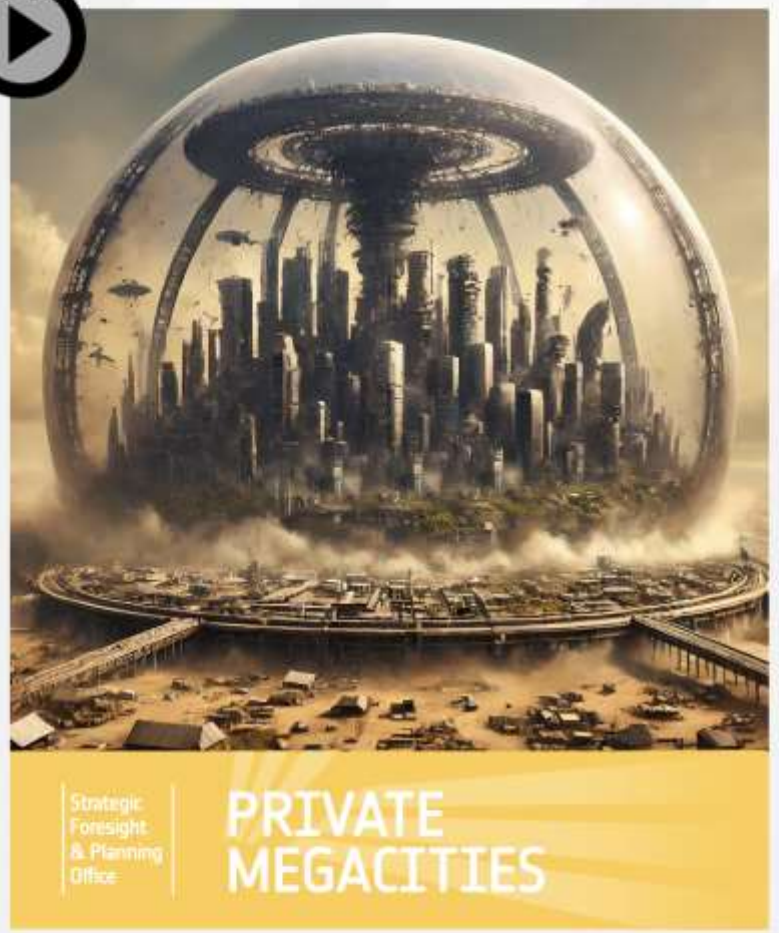
Where are we? Where are we going?

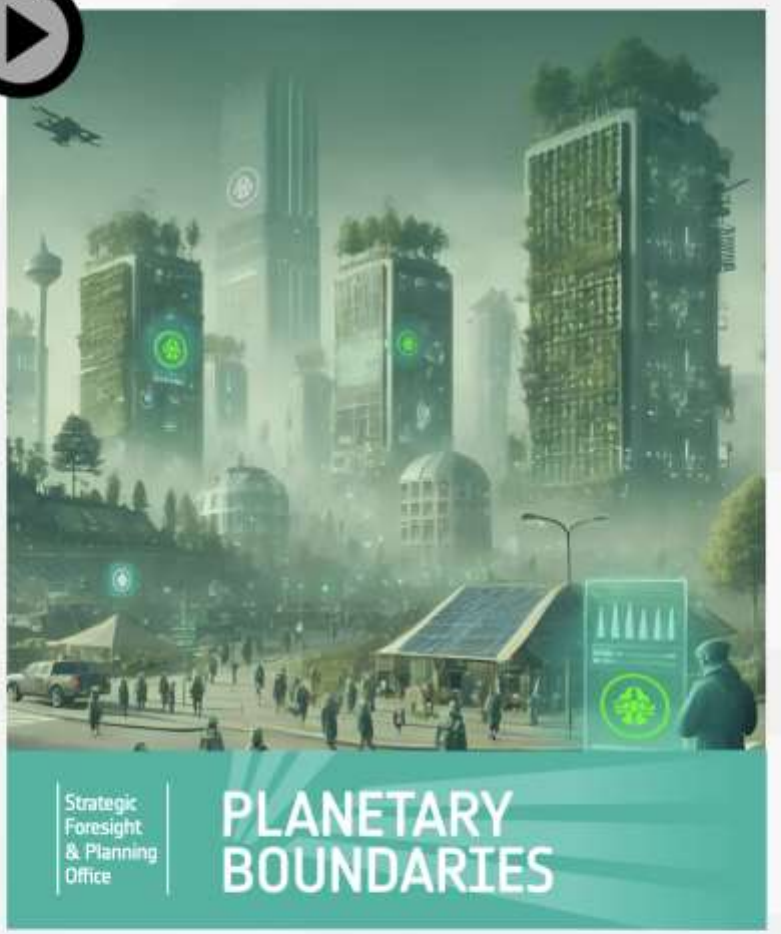
- The **Stages of an MGT Enterprise** model schematically represents an enterprise **life cyle.**
- **Where is ESA on that model?**
  - ERS-1/2, ENVISAT and Earth Explorers “Looped” us up through innovations
  - New Met Missions and Copernicus led us to “success” and ideally, a plateau of stability
- Where are we in that plateau and what comes next? **Are we stable or are we in overshoot?**
- What is our **Foresight Scenario based analysis for a future EO Ecosystem?**

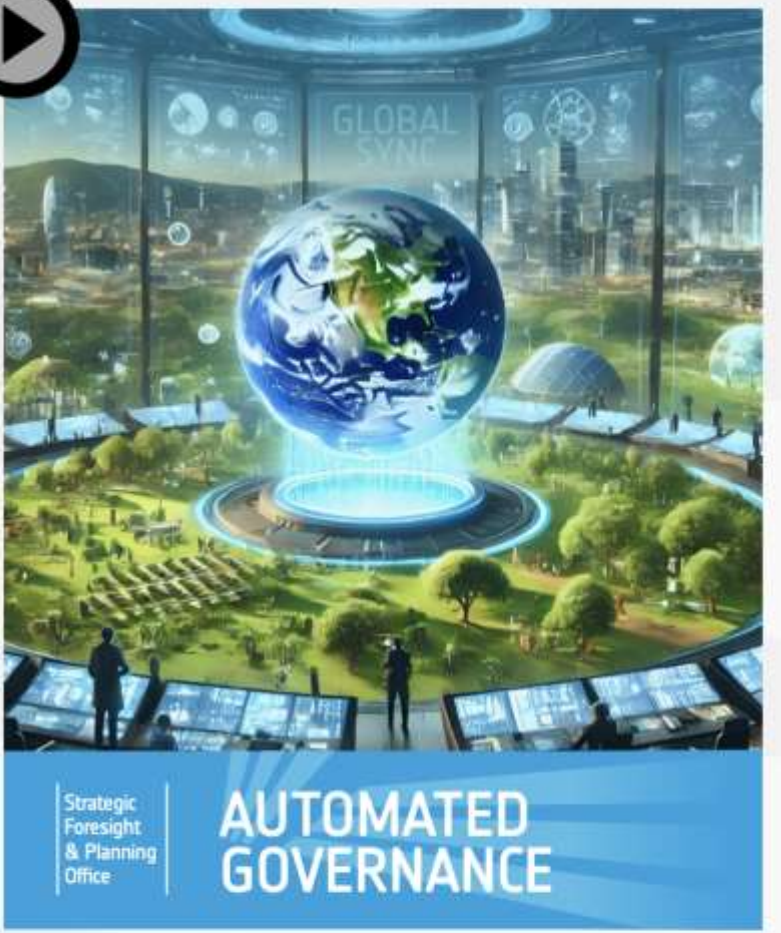


Stages of an Enterprise model — MG Taylor — Visual from The Collaboration Code: Models, published By Rob Evans and Matt Taylor.

EXPLORING SCENARIOS FOR THE WORLDS THAT THE EUROPEAN SPACE SECTOR WILL INHABIT IN 2060 - CHOOSE A SCENARIO







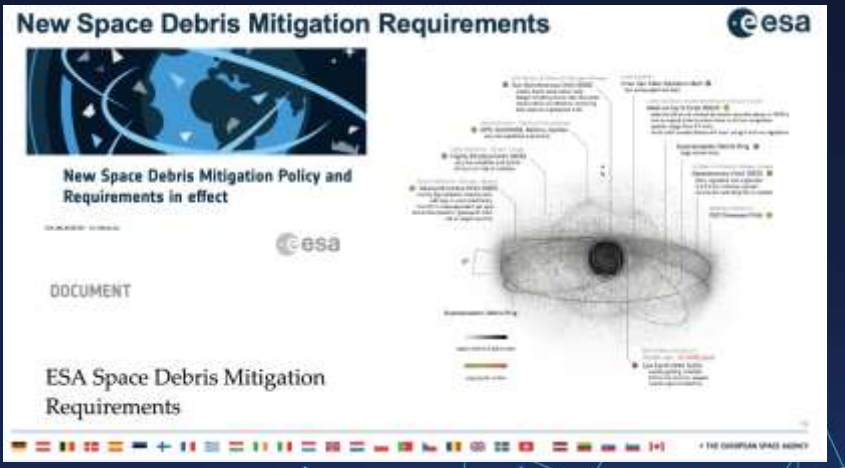
https://researchprofiles.ku.dk/files/414118188/20241011_Interactive_report_A_journey_into_the_future_of_ESA.ppsm

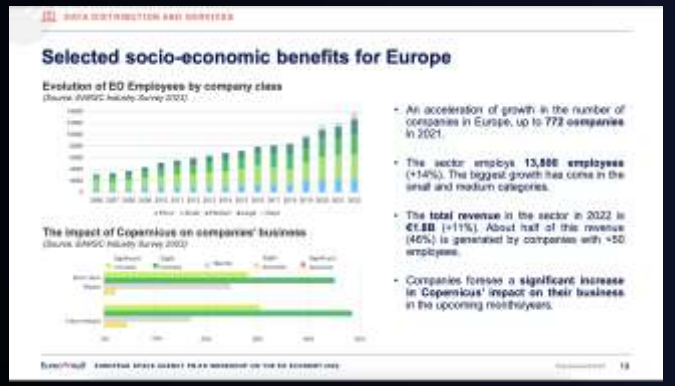
SPACE IN 2060 - COMPARISON TABLE ACROSS SCENARIOS

The Future Earth Observation Ecosystem…?

chatgpt.com
https://chatgpt.com

Scenarios assess the potential future impact of plausible decisions..





The rise of Starlink…

SPACENEWS
BUSINESS | POLITICS | PERSPECTIVE

COLORADO SPRINGS — Commercial space station developer Vast will use SpaceX's Starlink

Vast announced April 9 that it will install laser intersatellite link terminals on its Haven-1 station to enable communications with Starlink satellites. The agreement between Vast and SpaceX extends to future space stations Vast plans to develop.

Max Haot, chief executive of Vast, said in an interview during the 39th Space Symposium that his company will use terminals supplied by SpaceX. Gwynne Shotwell, president of SpaceX, announced at the Satellite 2024 conference March 19 that SpaceX would sell laser terminals it developed for Starlink to other customers, a product offering she dubbed "Plug 'n' Plaser."

The Starlink terminals will provide Haven-1 with up to one gigabit per second connectivity to and from the station. "There's nothing that we can think of that's going to use more than that," he said, including requirements for crews and payloads as well as 20 cameras mounted inside and outside the station.

STARLINK

Future missions could allow direct SSH to your satellite and payload, 1Gbit/s connectivity, anywhere, always…

Another Game changer coming for EO architecture…

DestinE and ESA's Digital Twin Earths (DTEs)

DestinE Platform

Your gateway to a sustainable future

A unique ecosystem of services harnessing the power of Destination Earth.

DestinE Components

DestinE Platform

Digital Twins and Digital Twin Engine

Destination Earth Data Lake

"From Sensing to Sense Making"

ESA DTE aims at bringing the latest EO-based products, science results and capabilities to a pre-operational level and develop a comprehensive set of novel EO-based Digital Twins Components, designed to demonstrate the potential value of EO for the future evolution of DestinE alongside national digital twin initiatives.

ESA DIGITAL TWIN EARTH

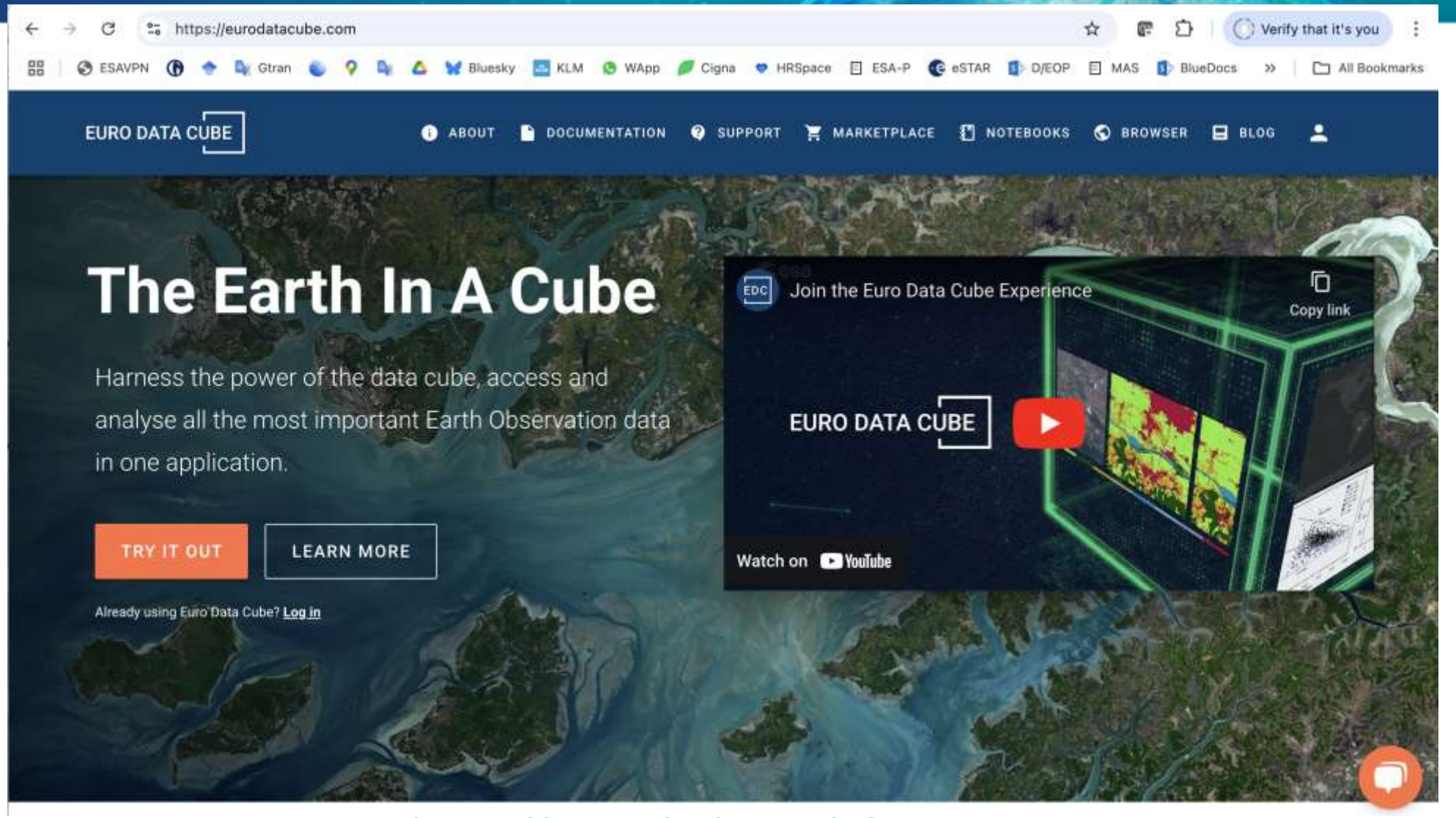
2040+: What EO data do we need for AI applications?

- **We expect AI techniques become more established in hierarchical models and a rise in multi-modal regenerative AI**
- Fundamental **L1a/b observation data sets become the "input"**
- But, EO AI 'chips' must be prepared and tagged with socio-economic and Earth System properties for the AI to be effective…

- Are we sure we **are measuring the "right" things from space to enable AI systems** in the future?
- **How do we include the societal elements** (in the original GMES system view) into the mix?
- What **service evolution** do we need to **empower EO driven AI solutions**?

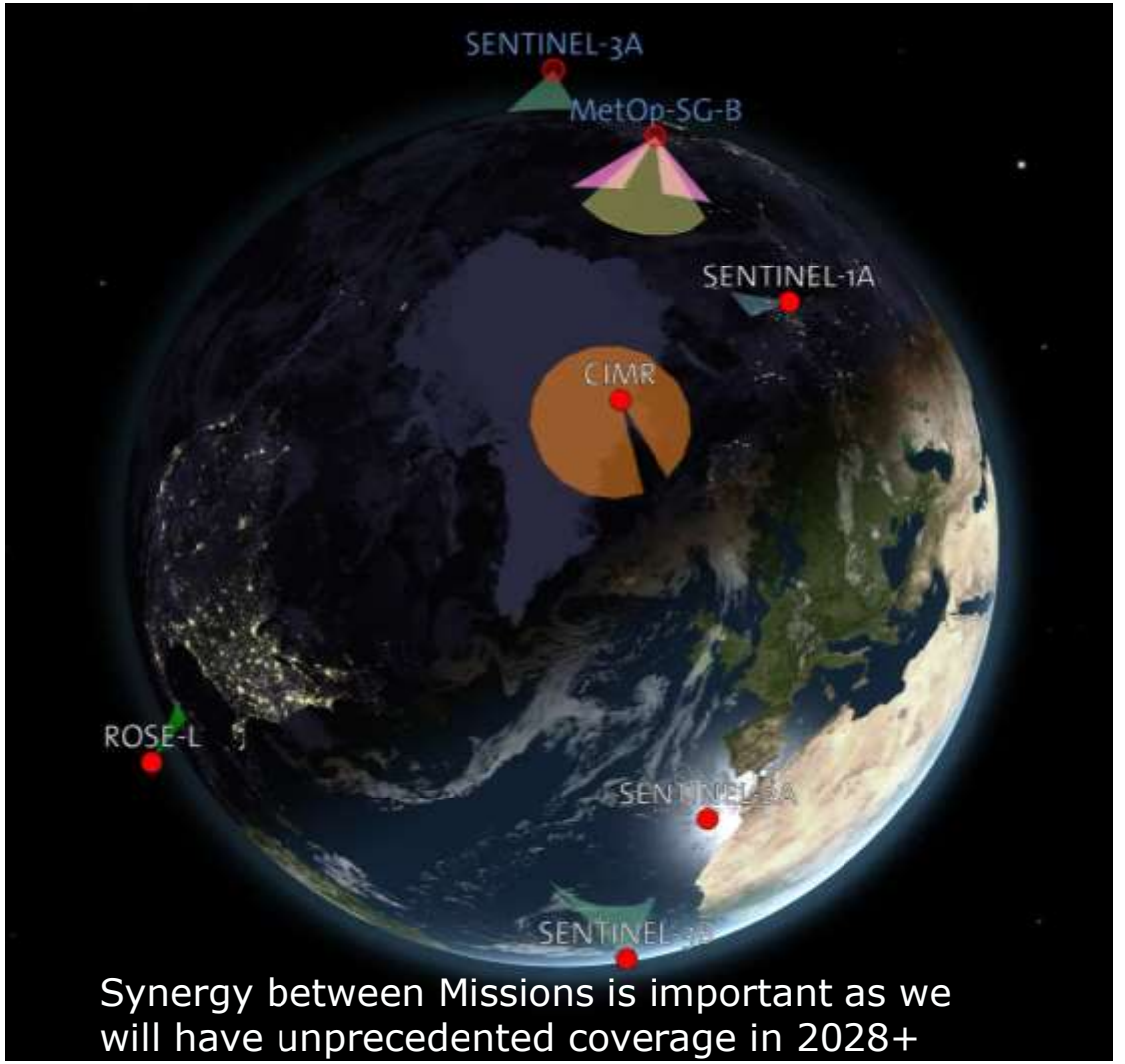
https://www.ngpcap.com/insights/the-next-generation-of-earth-observation-and-the-great-convergence-with-ai

Multi-dimensional hypercube + HPC + AI

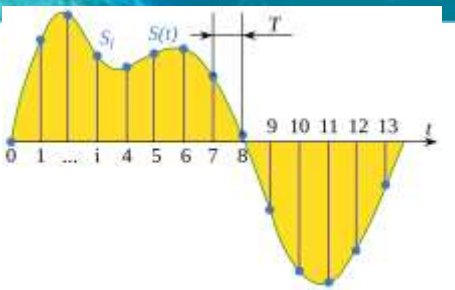


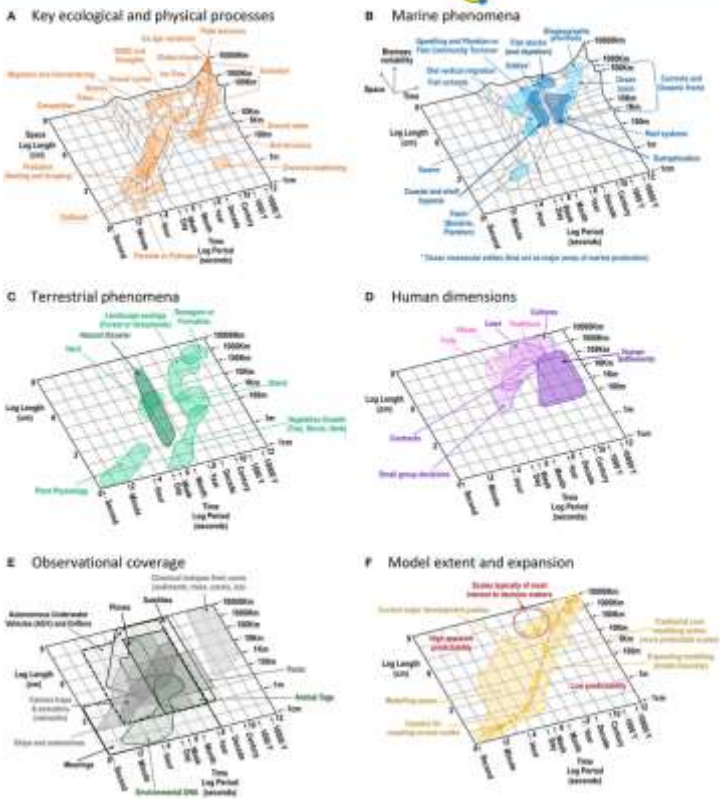
https://youtu.be/tv9RNl2fLpU

2040+ time-space sampling limits Copernicus knowledge
Constellations: swarms, trains, tip & cue, reference…



Synergy between Missions is important as we will have unprecedented coverage in 2028+





(Fulton et al, 2019)

2040+: Preparing EO Resilience & inter-connectivity

https://kuvaspace.com/

Development of a networking infrastructure for satellite constellations

Virginia Tech and George Mason University have teamed to develop distributed, mobile space and terrestrial networking infrastructure for multi-constellation coexistence.
Image courtesy of Mohamed Kassem, University of Surrey

The race is on to provide high speed satellite internet to the Earth's most remote areas.

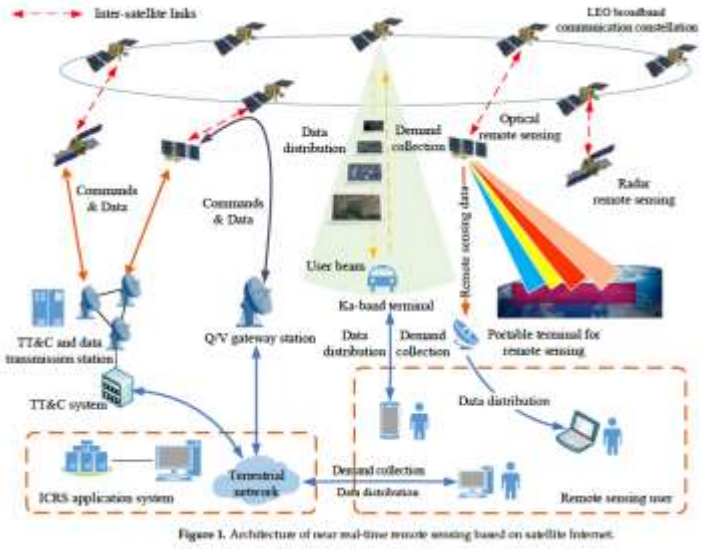
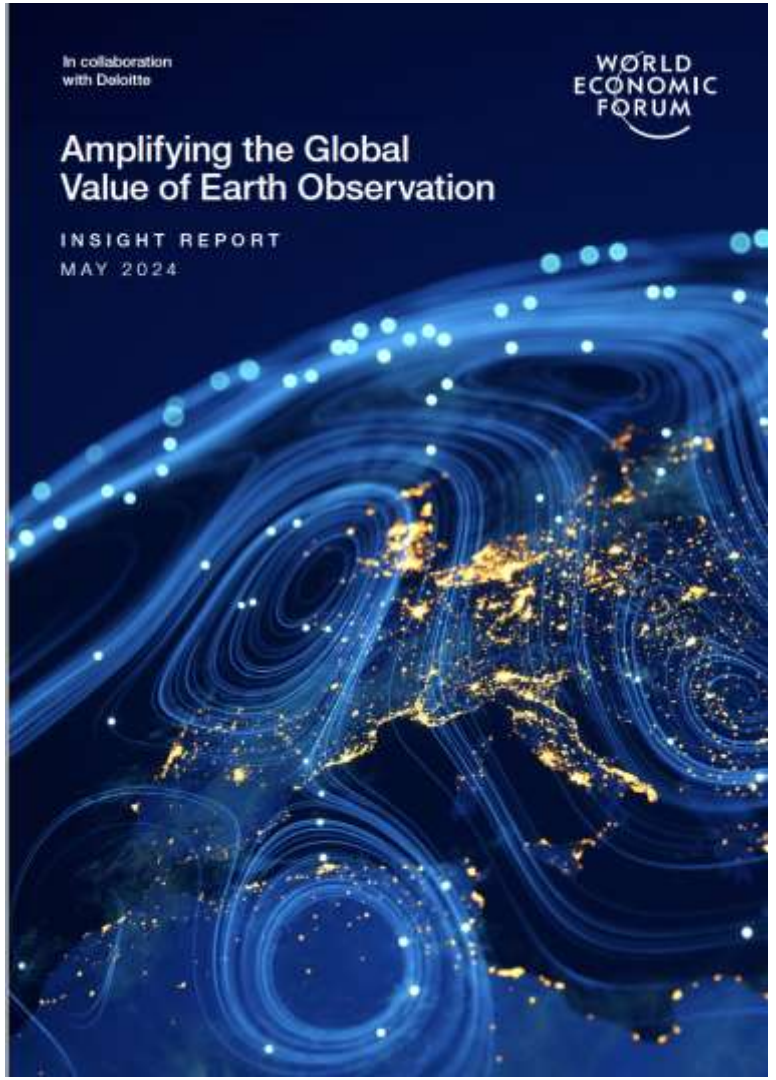


Figure 1. Architecture of near real-time remote sensing based on satellite Internet.

Peng et al (2023) https://www.mdpi.com/2226-4310/11/2/167

Streamlining and optimising the EO Ecosystem…



Earth observation has the potential to drive $3.8 trillion in economic benefit from 2023-2030 while positively impacting climate and nature.

"While EO is an extraordinary tool for creating both economic value and positive environmental impact, **maximizing its value depends on a dramatic increase in end-user adoption**.

Achieving that calls for **resolute strategies and investments to increase awareness of what is possible with EO**, encourage innovation, advance core and enabling technologies, ensure equity in **access to EO insights** and bridge the gap between EO data and end-user solutions worldwide."

User/Policy driven system design remains fundamental to our future

Consumer experience: Providing individual users value through information such as air quality or weather forecasts.

Early warning: Detecting disasters – like floods and wildfires – with more speed and accuracy to bolster planning, response and recovery.

Environmental impact monitoring: Providing a trusted, third-party source to measure environmental impacts and help verify certain environmental commitments and mandates.

Post-event analysis: Analysing environmental changes to better direct emergency response and measure the extent of damages.

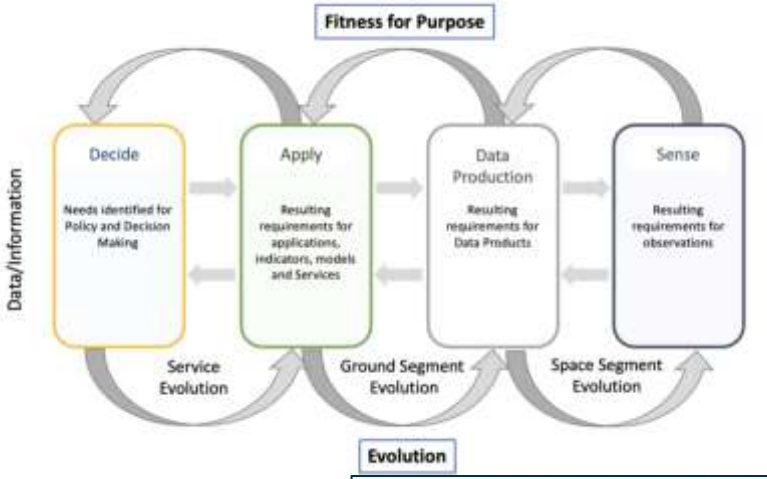
Precision agri/aquaculture: Enhancing regenerative practices, reducing input costs and monitoring in-season performance and yield.

Route optimization: Optimizing transport routes in concert with GNSS data by detecting potential environmental disruptions and offering alternatives based on environmental impact.

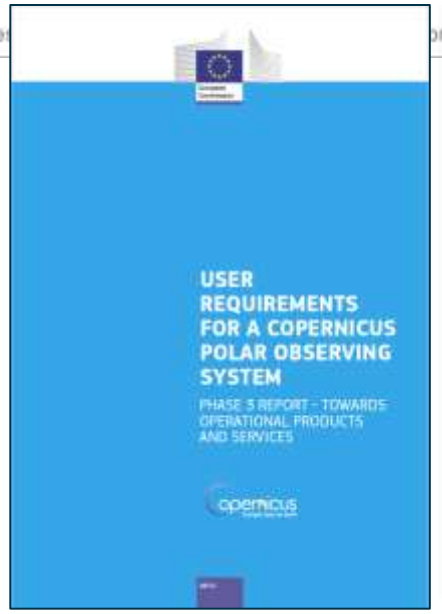
Site selection: Identifying operational sites for large-scale infrastructure with the best yield, efficiency and/or relative environmental impact.

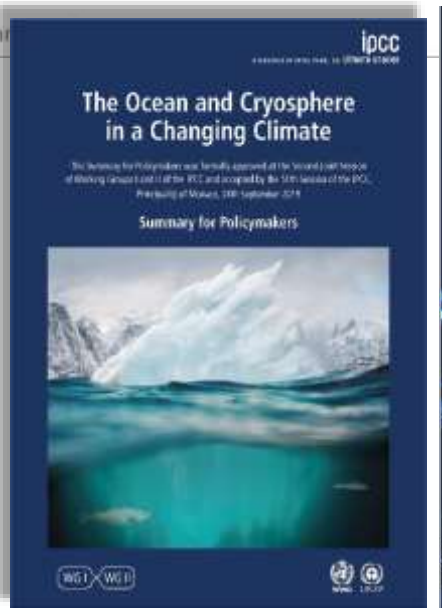
Supply chain monitoring: Detecting changes to physical goods supply chains and their impacts on international commerce and ecological indicators.

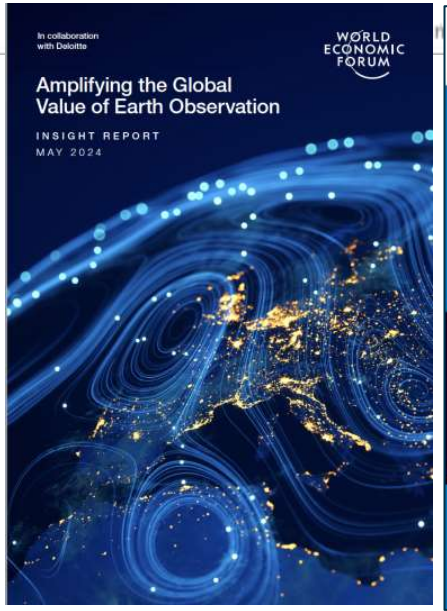
Vulnerability analysis: Characterizing and assessing the risks posed by climate and nature changes and other hazards that may materially impact people, infrastructure and operations.



EO data serves





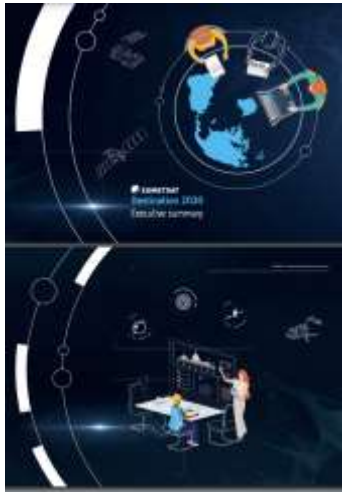


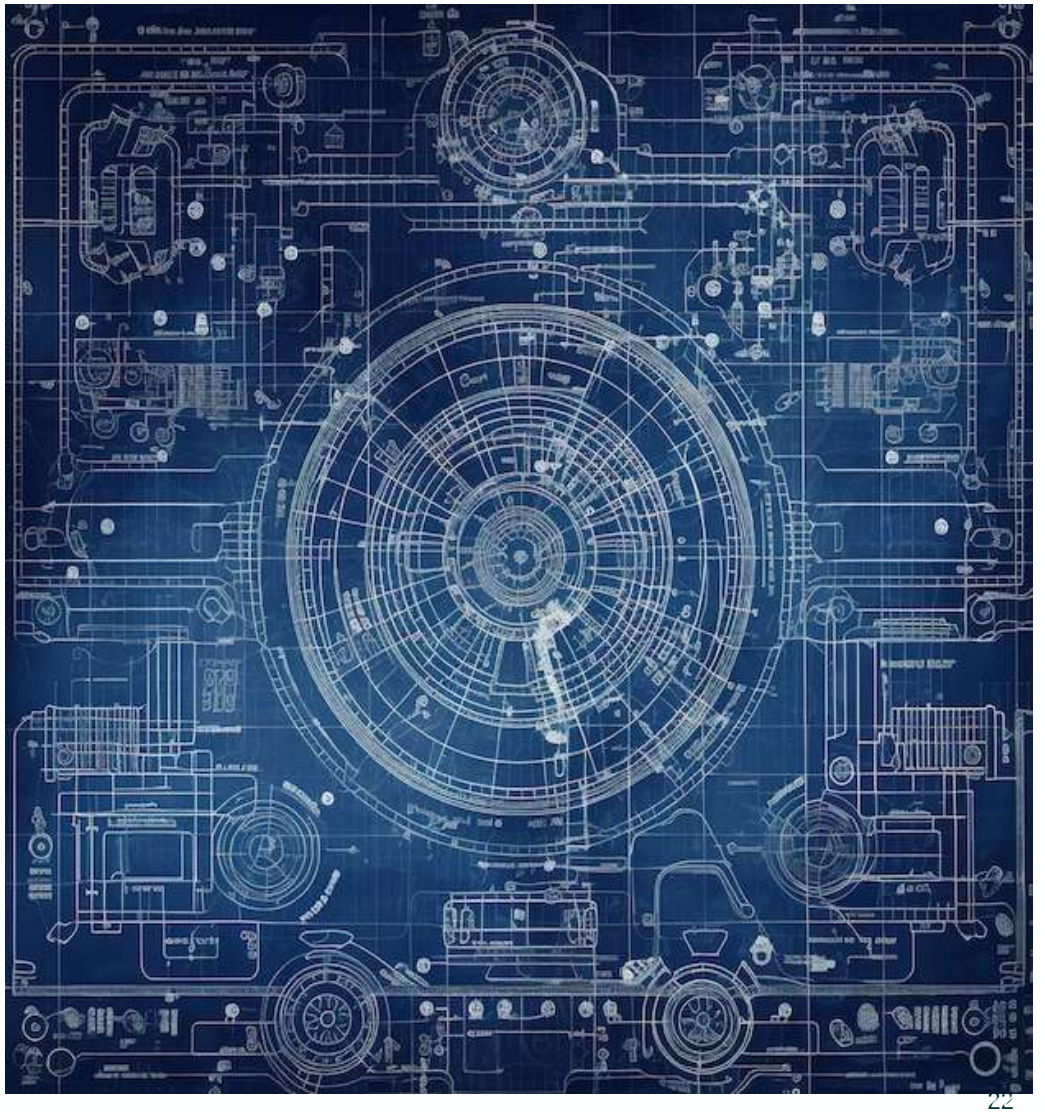
2040+ … is not so far away in terms of typical EO development…can we streamline for efficiency?

What is “the Blueprint”?

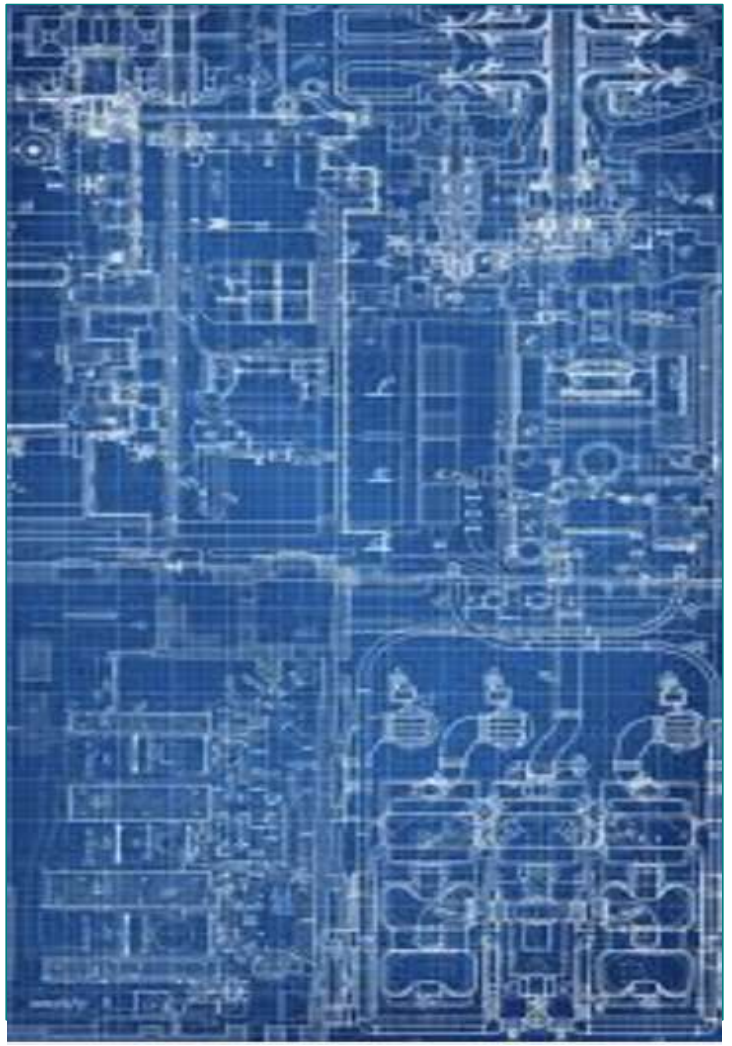
The Earth Observation Ecosystem Blueprint is essentially a roadmap providing a clear understanding of ***what*** needs to be accomplished and ***how*** to accomplish it

The Blueprint defines actions that can be measured to assess progress and success.





Blueprint Systems of Systems Architecture: A Strategic Compass for European EO Ecosystem



- Today, Europe, led by ESA, has designed, implemented, and operates the most proficient and extensive Earth Observation system in the world. It includes Earth Explorer, Copernicus, Meteorology, Scout, Earth Watch, and PhiSat satellite missions
- **This has enabled the complementary growth of Commercial Space**
- **The EO Reference Architecture Blueprint sets out the practical basis for a living Earth Observation System of Systems that responds to the European EO User/Producer Strategies over a long timeline – out to 2050+**
- The Blueprint takes an “EO Ecosystem system” approach building on currently defined capability:
  - What EO do we need to sustain?
  - What are the gaps and options to address them?
  - **What are the opportunities within the European Observation Paradigm we are living through now?**

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.

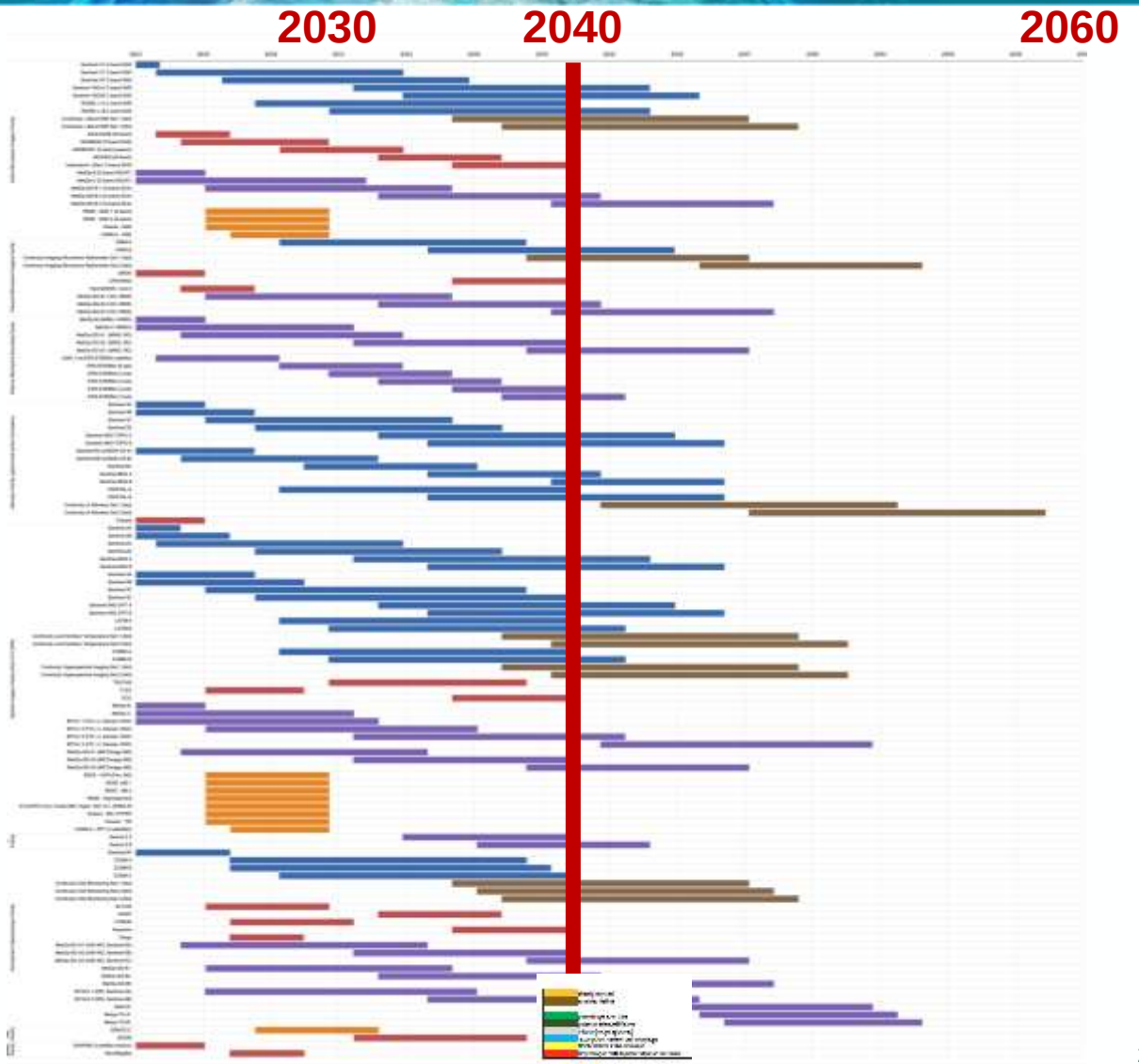
- **What EO missions do we need to address user/policy needs?**
- **How can we streamline and optimise?**
- **What are credible implementation scenarios?**
- **How do we maintain a flow of new "Blue Sky" research missions within a *defined* future Ecosystem?**

Blueprint for the Reference Architecture

System-of-systems Families:

- 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
- Elements not fitting a system of systems ‘family’

- **By 2040 the current portfolio of EO missions begins to thin out**
- **Brown bars indicate potential timelines of measurement continuity function**

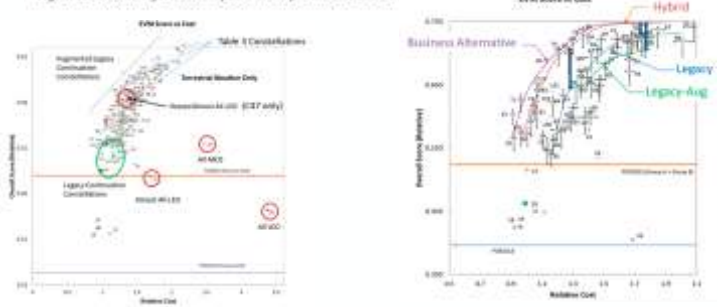


2040+ Scenario based EO Architecture analysis

Architecting the Future of Weather Satellites

Mark W. Maier, Frank W. Gallagher III, Karen St. Germain, Richard Anthes, Cinzia Zuffada, Robert Menzies, Jeffrey Piepmeier, David Di Pietro, Monica M. Coakley, and Elena Adams

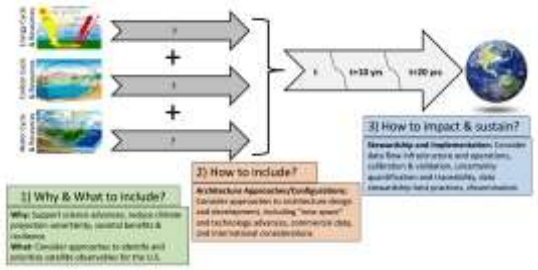
Fig. 1. NSOSA analysis: seven process steps used in each design cycle.

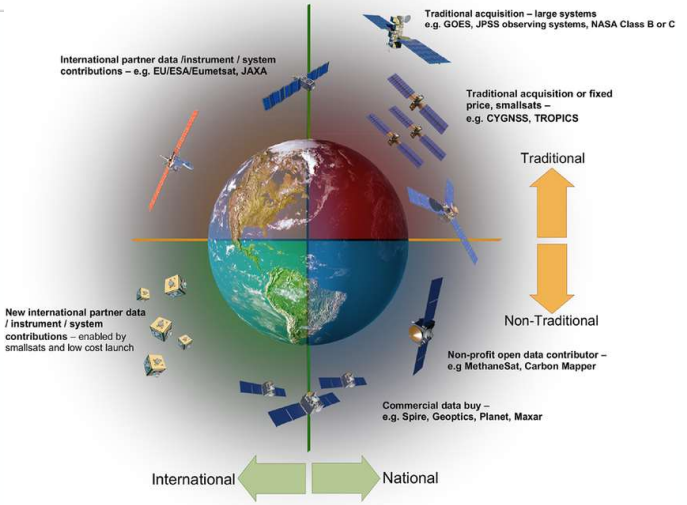


Toward a US Framework for Continuity of Satellite Observations of Earth's Climate and for Supporting Societal Resilience

Duane Waliser[1] and KISS Continuity Study Team[2]

[1]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, USA, [2]See Appendix A





Waliser, Duane. (2024). Toward a US Framework for Continuity of Satellite Observations of Earth's Climate and for Supporting Societal Resilience. Earth's Future. 12. 10.1029/2023EF003757.

A Scenario-Based Approach to Assess Continuity Gaps in Earth Observations

1. Identification of adverse events
2. Modeling of possible causes of adverse events
3. Quantification of the likelihood of adverse events to occur
4. Stochastic analysis
5. Definition of scenarios
6. Analysis of impact of decisions on SoS for a given scenario
7. Comparative analysis of scenarios

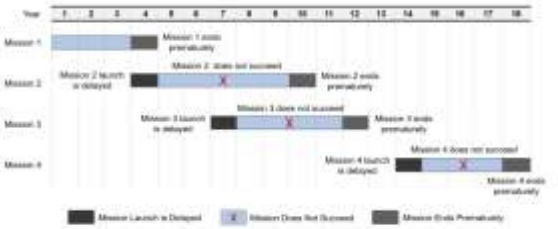
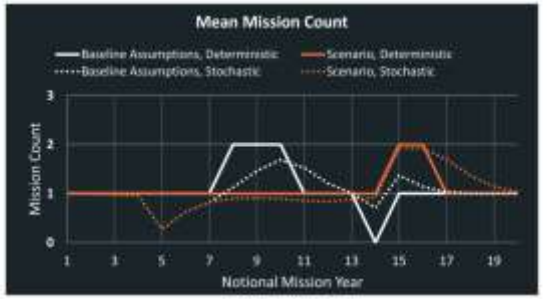


Figure 3. Notional timeline for a multi-mission architecture and associated potential adverse events



Tradespace Analysis Capabilities for the Next Generation of the Joint Polar Satellite System (JPSS)

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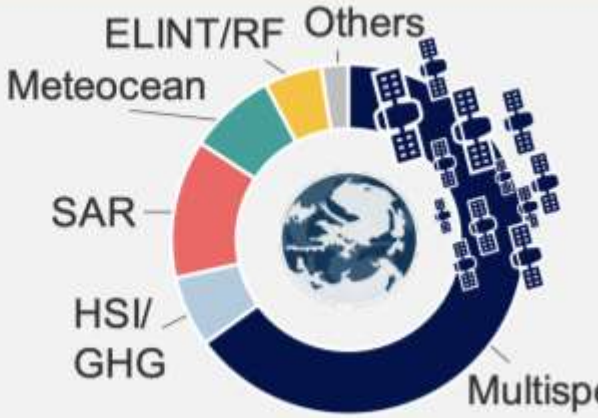
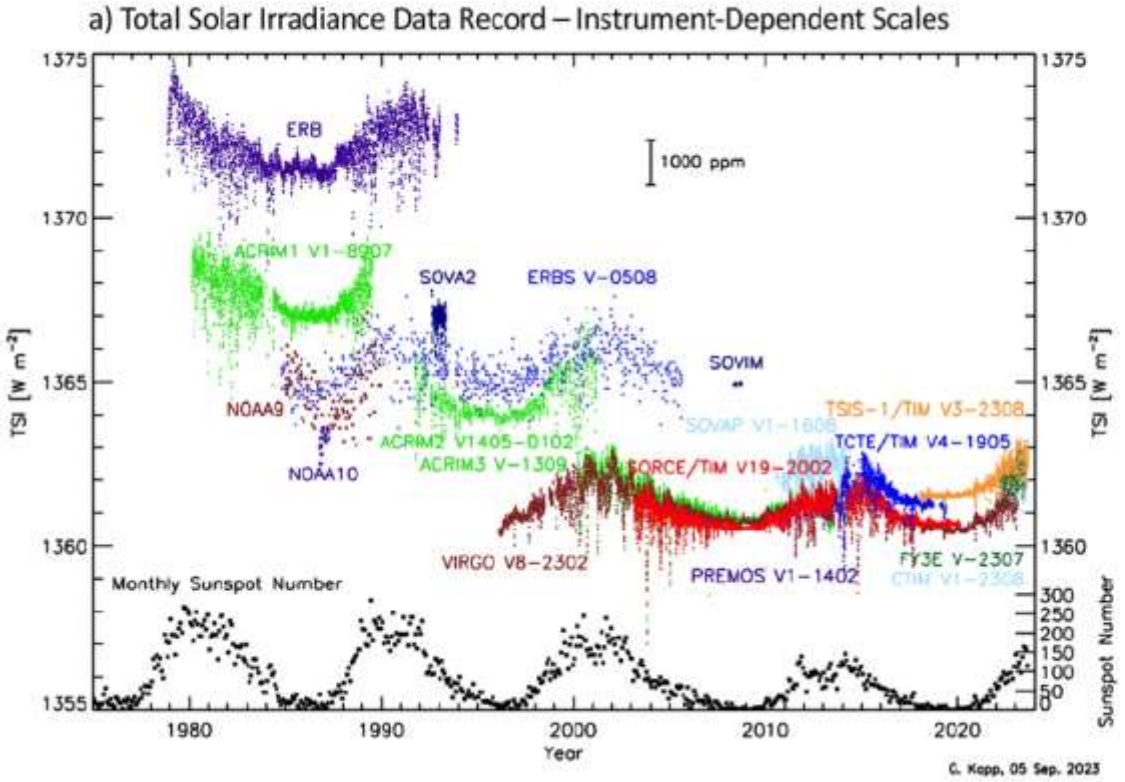
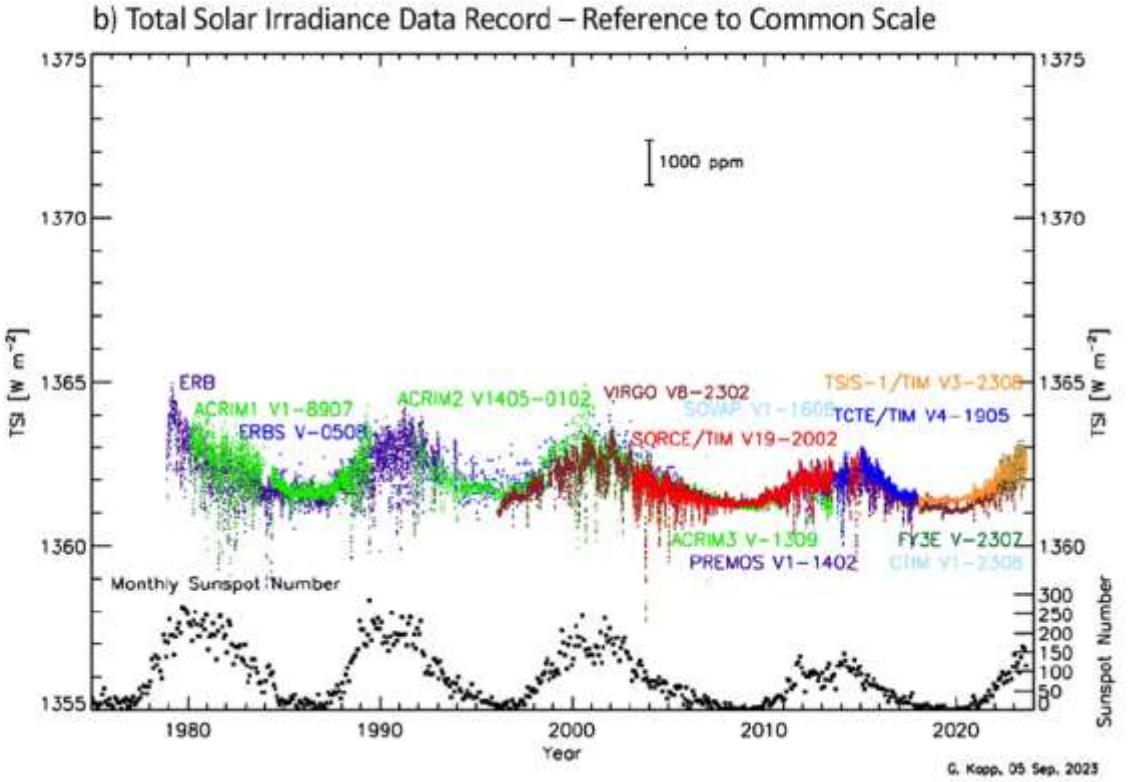
Payload Diversification brings Costly Challenges…

2012	2022	2032
		
~50 sats **Incumbent operators** **(with 1–2 units)**	**~600** sats **Constellations era** **(with 50–100 units)**	**~1,600** sats **Payload diversification** **(with 10–20 units)**
MAXAR, AIRBUS, MDA, ISI, e-geos	Spire, ICEYE, SATELLOGIC, CG SATELLITE, planet., BLACK SKY, Capella Space	OGK, GHGSAT, unseenlabs, Synspective, tomorrow.io, SatVu, HawkEye 360, umbra, EOI, PIESAT, ORORA TECHNOLOGIES, HYPERSAT, constellr, SATLANTIS

Costly Challenges: European EO Ecosystem Inter-Calibration



Observations shown at each instrument's native calibration scale: mission calibration anomalies clearly evident.

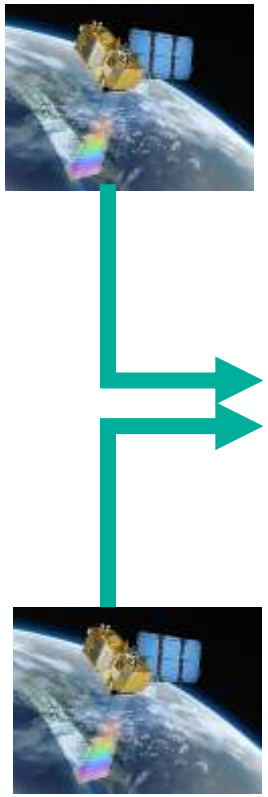


Observations adjusted for bias and calibration differences presenting a coherent time-series.

Figure from Kopp (2023)

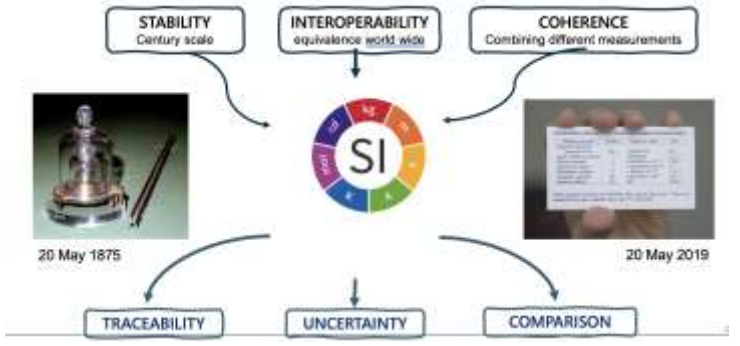
Costly Challenges: Avoiding the paradigm of Grandmas' Patchwork Quilt (GPQ)

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.

Diverse EO solutions



A standards-based approach to calibration mitigates GPQ

Grandmas' patchwork Quilt

If inadequate inter- and cross-sensor calibration of fundamental parameters derived from satellite payloads is apparent in the system of systems, it becomes a challenge to produce a unified output when combining data.

Authentication and Certification

ESA EO Performance Certification is predominantly at Level-1b and is founded on **Uncertainty knowledge**

Design satellite payload with **excellent** on-board calibration for **ALL** missions

Actively monitor and certify data on a regular basis across the mission lifetime

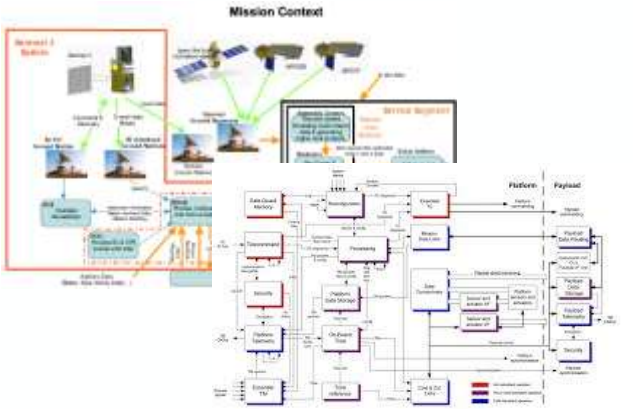
Level-2 is **application specific and requires an authority** to manage certification (e.g. bathymetry, navigation, weather, climate, …) → **under the guidance of an appropriate certification organisation**

Scenario based Approach

- Scenarios asses **the impact of possible decisions** on the ecosystem **characterising future states** of the EO ecosystem (*Ivanco et al* 2024).
- There are several “Foresight” activities that set out alternative future “societal” worlds
- **Most futures are predicated on managing the impact of climate change (or not)**
    - Coupled with assumptions of geo-politics, the rise of AI, technology development and societal response…
- ESA foresight considers 3 worlds:
    1. **MegaCity** top-down governance
    2. **Just and fair society**
    3. **AI** decision making **dominance**

What do we want from you today and tomorrow?

- **Your vision for the European EO Ecosystem in 2040+:**
  - What constitutes the EO Ecosystem?
  - What are your “red-line” requirements for the EO Ecosystem?
  - What are the essential EO Ecosystem elements?
  - What are the challenges to overcome – technical, scientific, system…
  - Which systems must be linked across the EO landscape to create an Ecosystem?
  - How can institutional missions best enable commercial space?
- **Your feedback captured as Future Vision Scenarios that can be evaluated**
- **What do you need to make the Blueprint a useful compass for you? How will you leverage its content?**
- We have setup an EO system architect mail address: EO-System-Architect@esa.int
  - **For this meeting we will capture inputs until 28th February**
  - **But YOUR VISION AND INPUT IS WELCOME ANYTIME!**



Where are we? Where are we going? What do you need?

Stages of an Er odels, published By Rob Evans and Matt Taylor.

Our Future European Earth Observation Ecosystem **is in your hands** for the next two days!

Send your requirements, user needs, policy drivers, vision, comments, feedback, and any other contributions to:

EO-System-Architect@esa.int

Thank you Any Questions?

Contact:
Craig.Donlon@esa.int

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