



→ SERVING EUROPEAN
COOPERATION
AND INNOVATION

Overview and Status of ESA Earth Observation Programmes

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Future Missions Division

Science, Applications and Future Technologies Department

Directorate of Earth Observation Programmes

European Space Agency

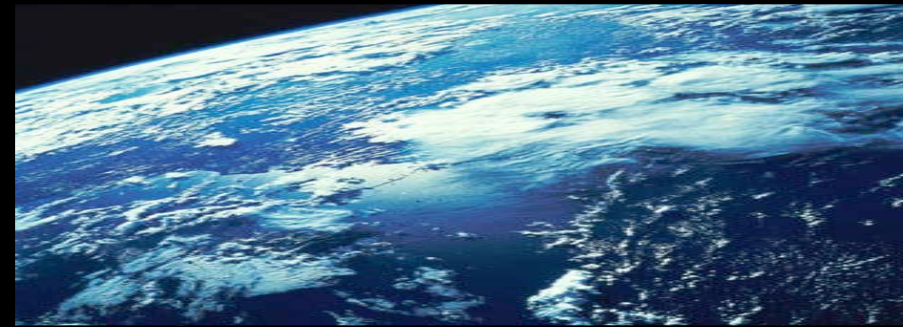
Noordwijk, The Netherlands

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CEOI-ST Technology Conference

21 and 22 April 2015

1. EO Living Planet Programme
2. ESA EO Science Strategy
3. Mission Status and Planning
4. ESA EO Technology
5. Convoys and Constellations



ESA's Living Planet Programme (LPP)

comprises two main components:

1. Science and Research element

including Earth Explorer missions

Aim: To better understand the Earth System

2. Earth Watch Element

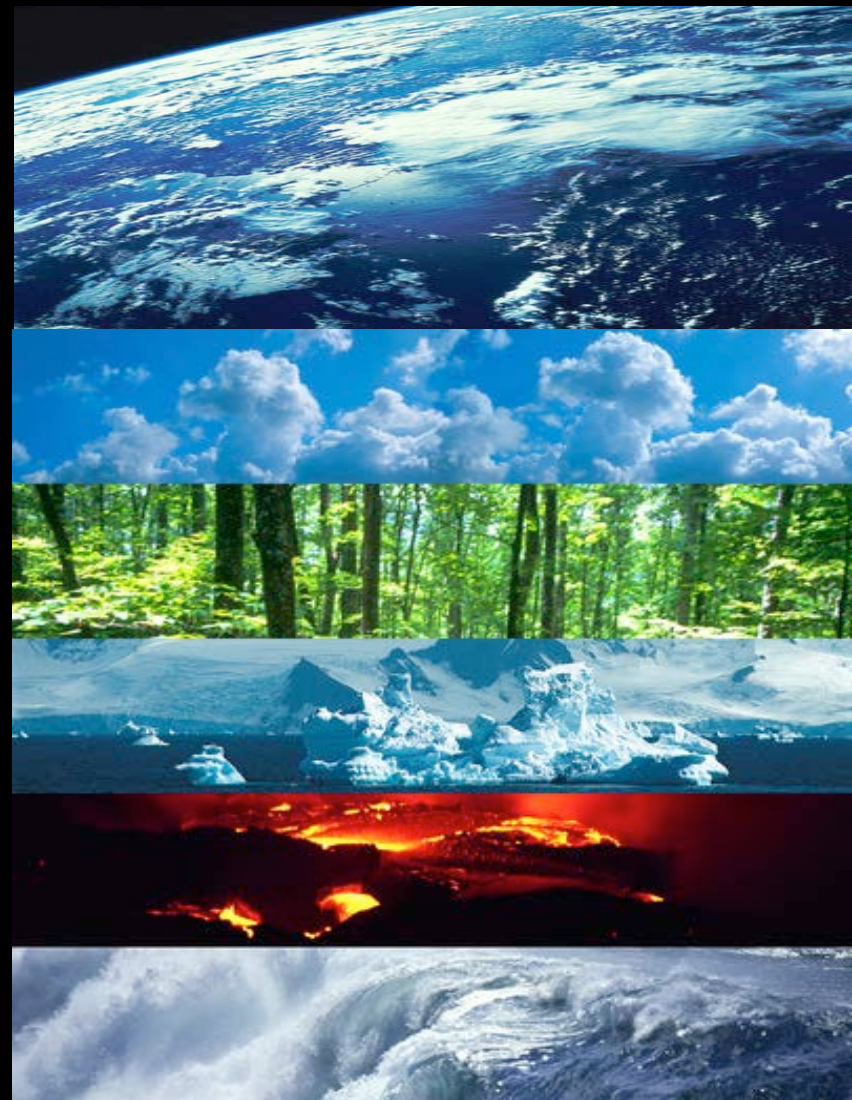
including EUMETSAT and Copernicus Space component

Aim: To facilitate long term monitoring and the delivery of EO data for operational services

Based on a EO science strategy derived from wide consultation with the science community



- The Earth Observation Envelope Programme (EOEP) is the key to implementing the Living Planet Strategy.
- It is a stable planning environment where all new missions and technologies are prepared.
- The EOEP is run as an optional ESA programme (optional = ESA member states decide whether to contribute or not)
 - Operates on a 4 - 5 year cycle
- The EOEP-4 runs from 2013 – 2016
- It provides a long-term, rolling environment for the planning of new EO activities, exploitation of results, contingency response and continuity of missions.



OVERVIEW OF ESA EO MISSIONS



Living Planet

Earth Explorer

Research driven

Core Missions



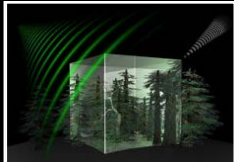
GOCE
2009 - 2013



ADM-Aeolus
2016



EarthCARE
2018



Biomass
2020

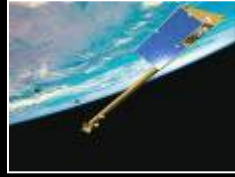
Opportunity Missions



CryoSat-2
08/04/10



SMOS
02/11/09



Swarm
22/11/13

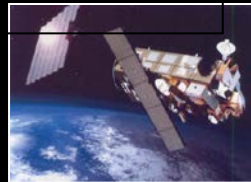


**CarbonSat
FLEX**

Continuity of Missions



ERS-2
1995 - 2011



Envisat
2002 - 2012

EE8
2022

Earth Watch

Operational Service driven

Operational Meteorology

- Meteosat
- MSG
- EPS (MetOp)
- MTG
- MetOp SG

Copernicus

- Sentinel 1
- Sentinel 2
- Sentinel 3
- Sentinel 4 (MTG)
- Sentinel 5 precursor
- Sentinel 5 (MetOp-SG)

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Living Planet

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Core Missions



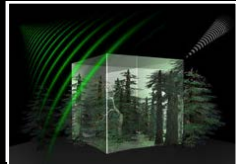
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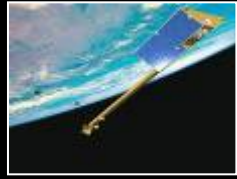
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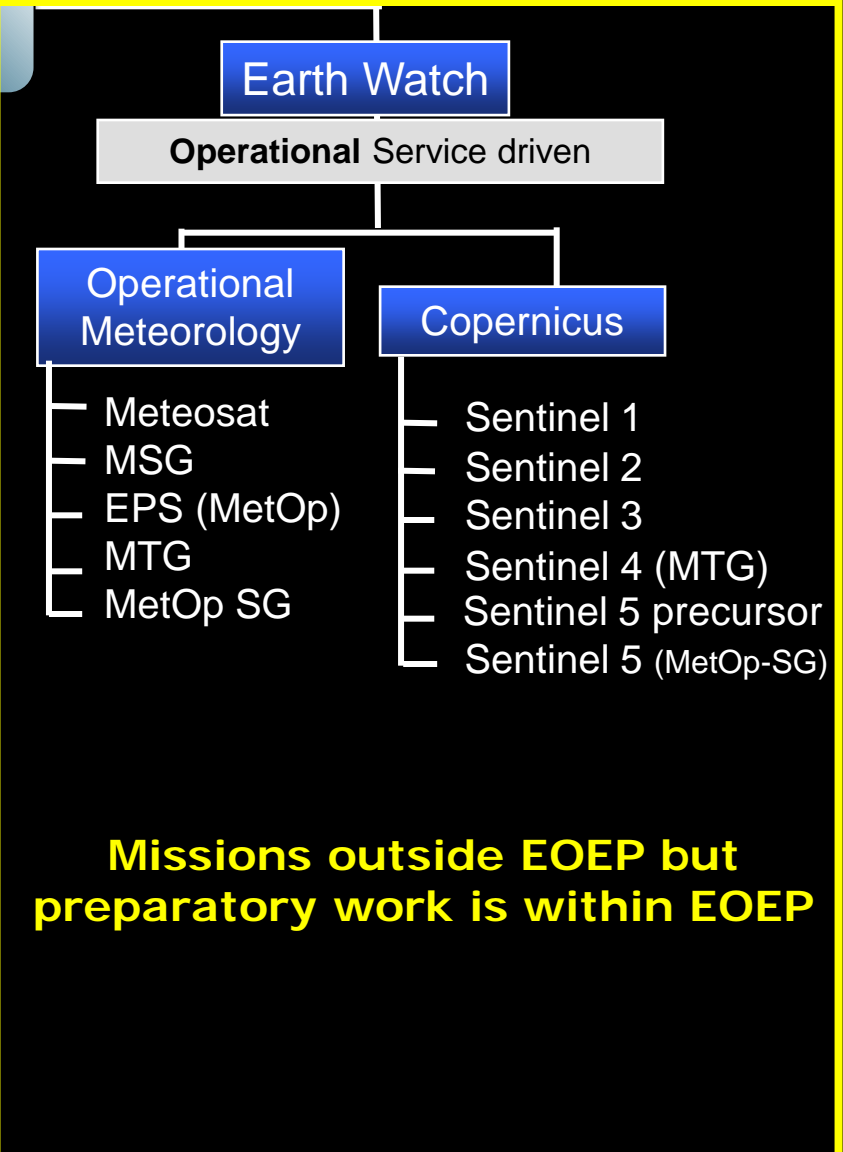
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Missions funded by EOEP

OVERVIEW OF ESA EO MISSIONS



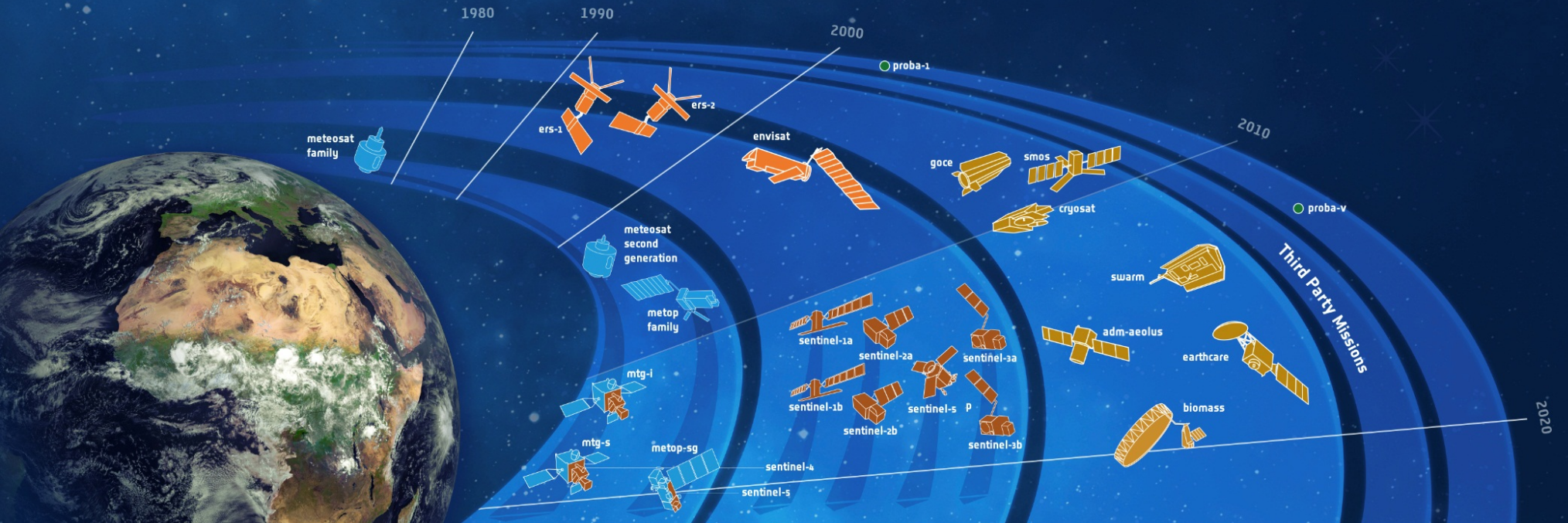
Living Planet



EO Mission Nomenclature



→ THE ESA EARTH OBSERVATION PROGRAMME



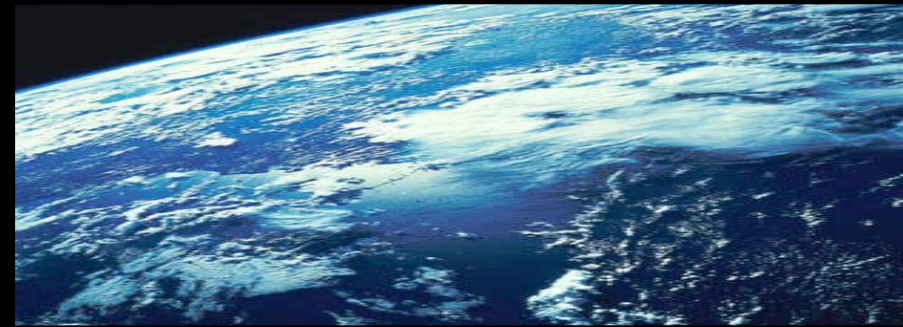
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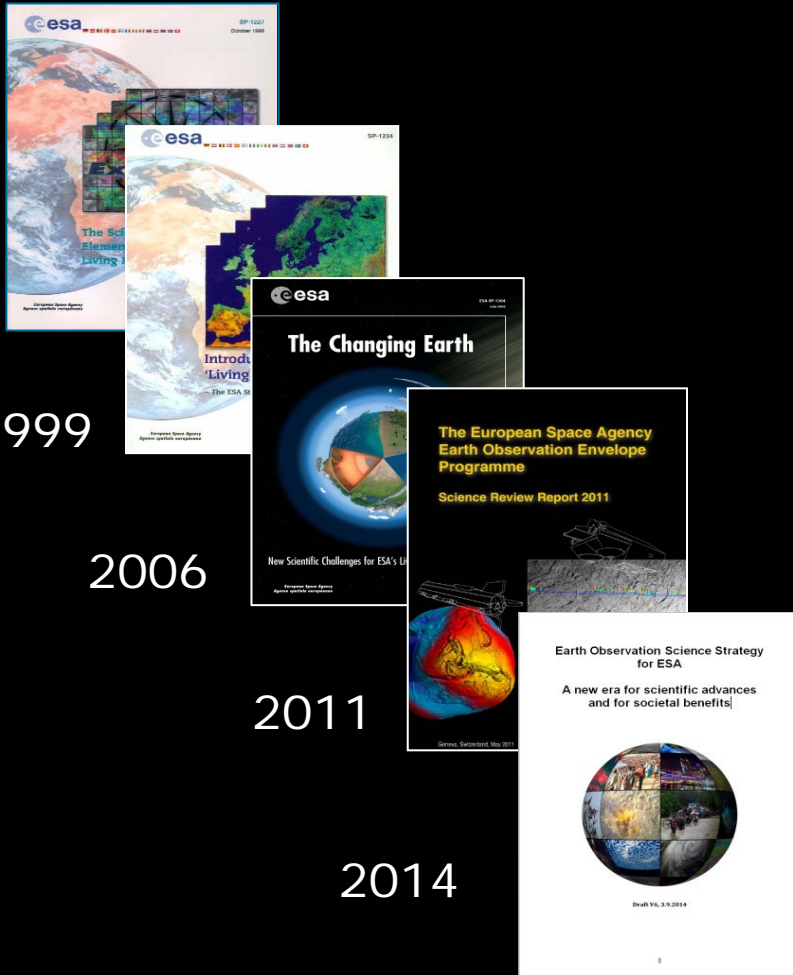
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Data from non-ESA Missions
ESA Operated Missions

1. EO Living Planet Programme
- 2. ESA EO Science Strategy**
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History of ESA EO Science Strategy



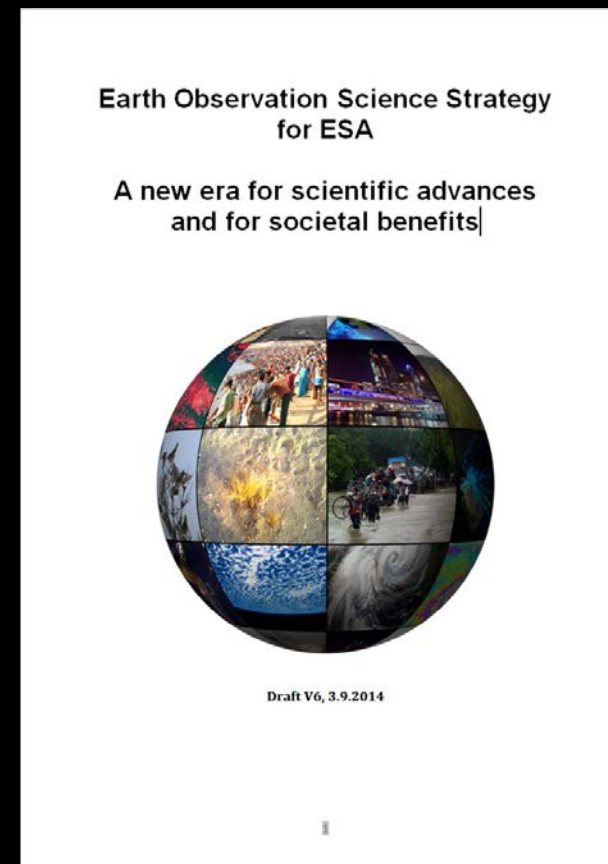
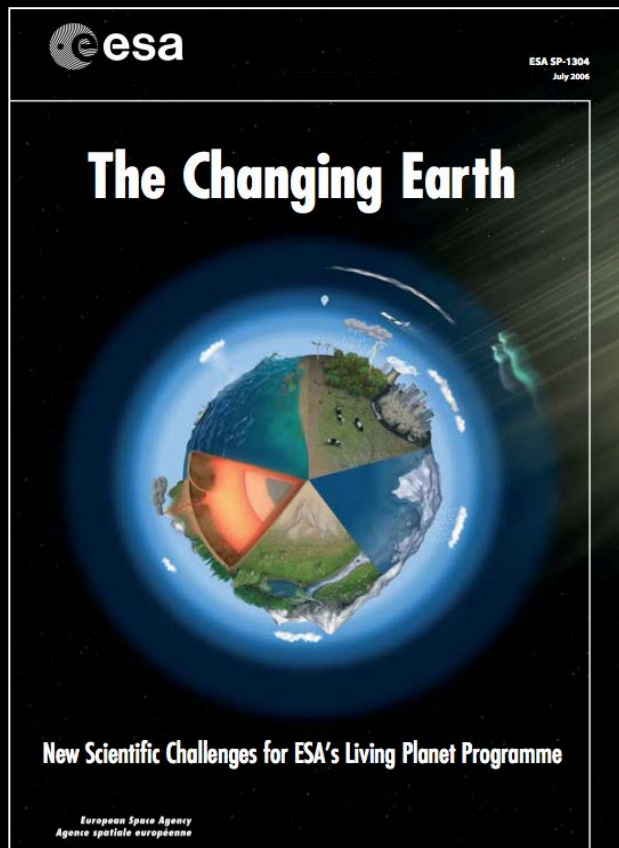
Mid 1990s – Establishment of LP Programme

1999 – EO strategy for implementation

2006 – New scientific challenges

2011 – EOEP Science review

2014 – EO Science Strategy for ESA



An update of this document was performed in 2013 at the Living Planet Symposium with the science community.

2006. The Changing Earth Scientific Challenges for ESA's Living Planet Programme

25 disciplinary scientific challenges in
5 Themes

ERS and Envisat satellites obs and
series of upcoming Earth Explorers
missions

Addressing these challenges required
space observations and infrastructure

2014. EO Science Strategy for ESA. A new era for scientific advances and for societal benefits

Exploratory missions and sustained
observing systems

Recognizing and building on changed EO
landscape e.g.

Copernicus, Meteorological
missions and smaller missions

Integration with international assets and
observing systems e.g.

- Convoys & constellations

Translational Science and Wider
Communication

ESA's EO Science Strategy at a glance



Ground-breaking exploratory missions integrated into flexible observing systems for Earth system science

Sustained observations to understand and attribute trends beyond the expected variability

International co-operation to provide an integrated, optimised Earth observing system, which can grow in capability in a cost-effective manner

Translational science to synthesize and adapt the data streams from individual instruments and satellites into knowledge

Wider Communication and dialogue with people beyond the scientific sector to help explain the value, opportunities and inspiration provided by EO from space



Integration of data across sensors and scientific disciplines

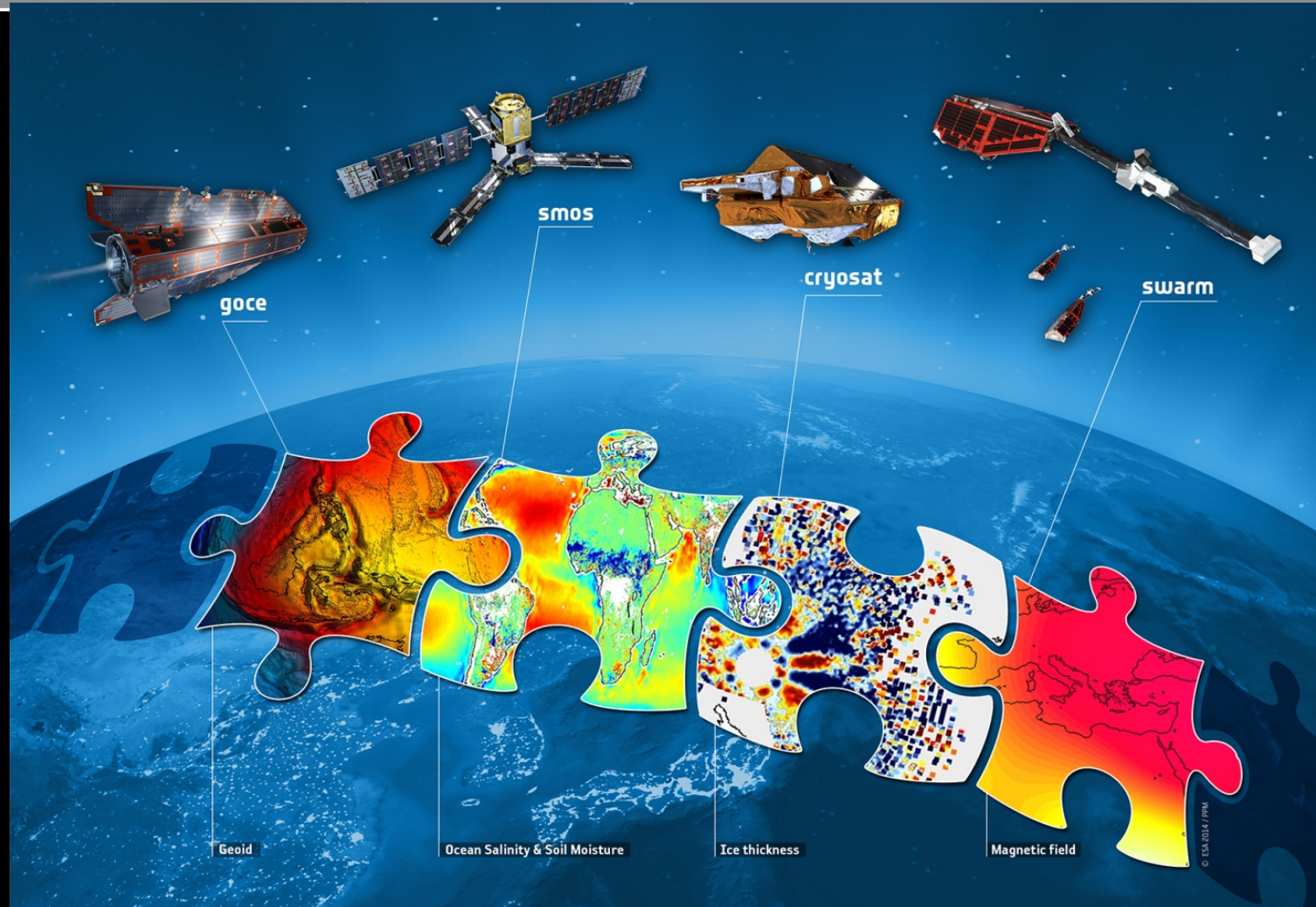


Integrated Earth system science approach

Optimal designed observing system

Science and technology innovation through exploratory missions

Flexibility in satellite mission concepts



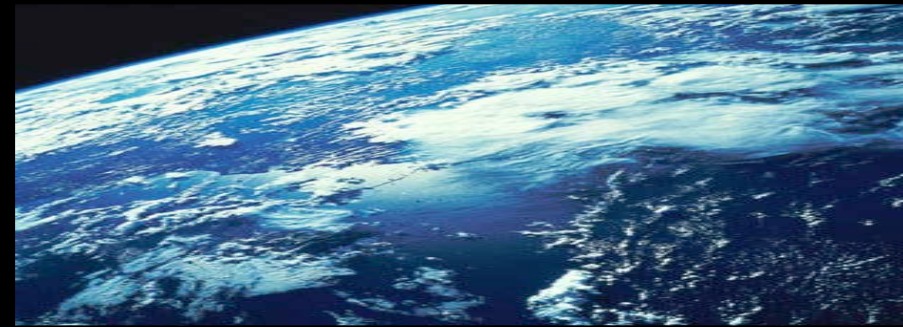
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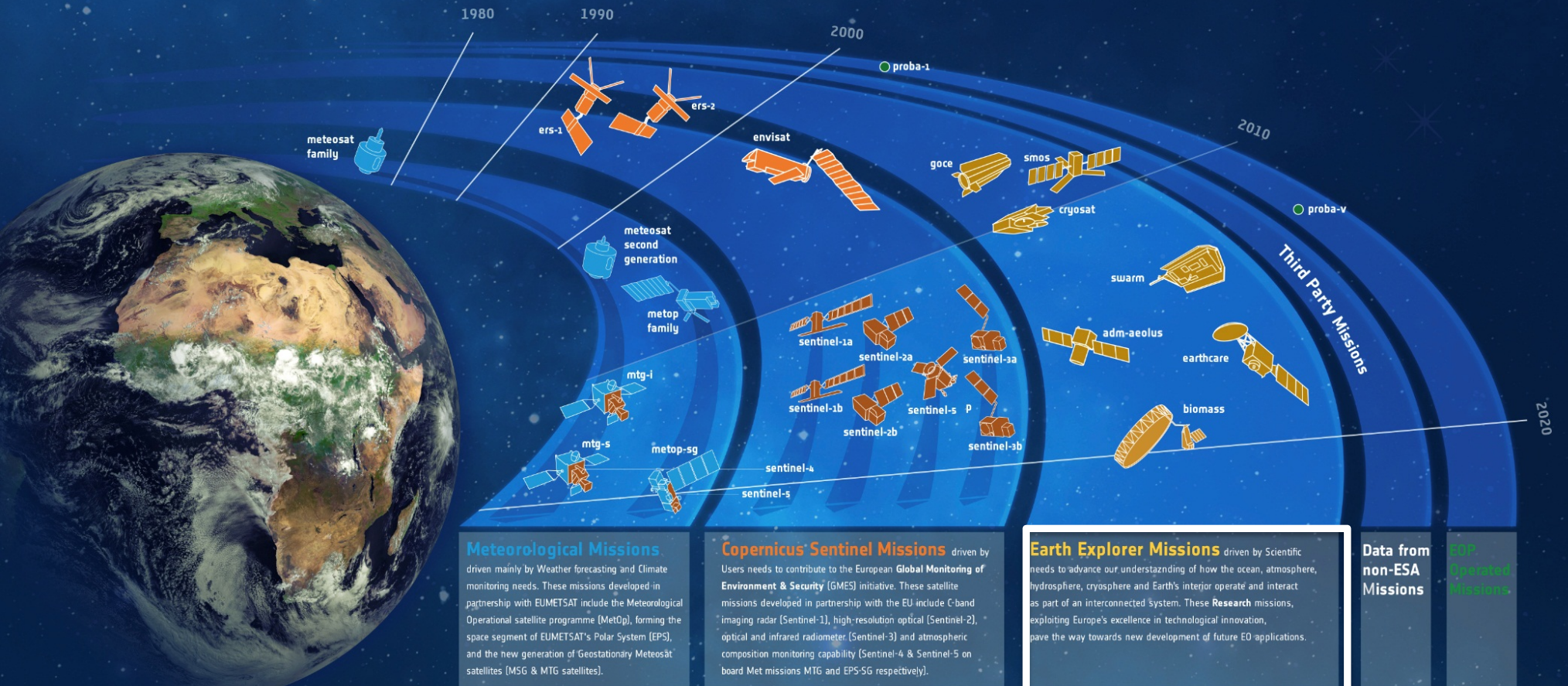
5. Convoys and Constellations



EO Mission Nomenclature



→ THE ESA EARTH OBSERVATION PROGRAMME



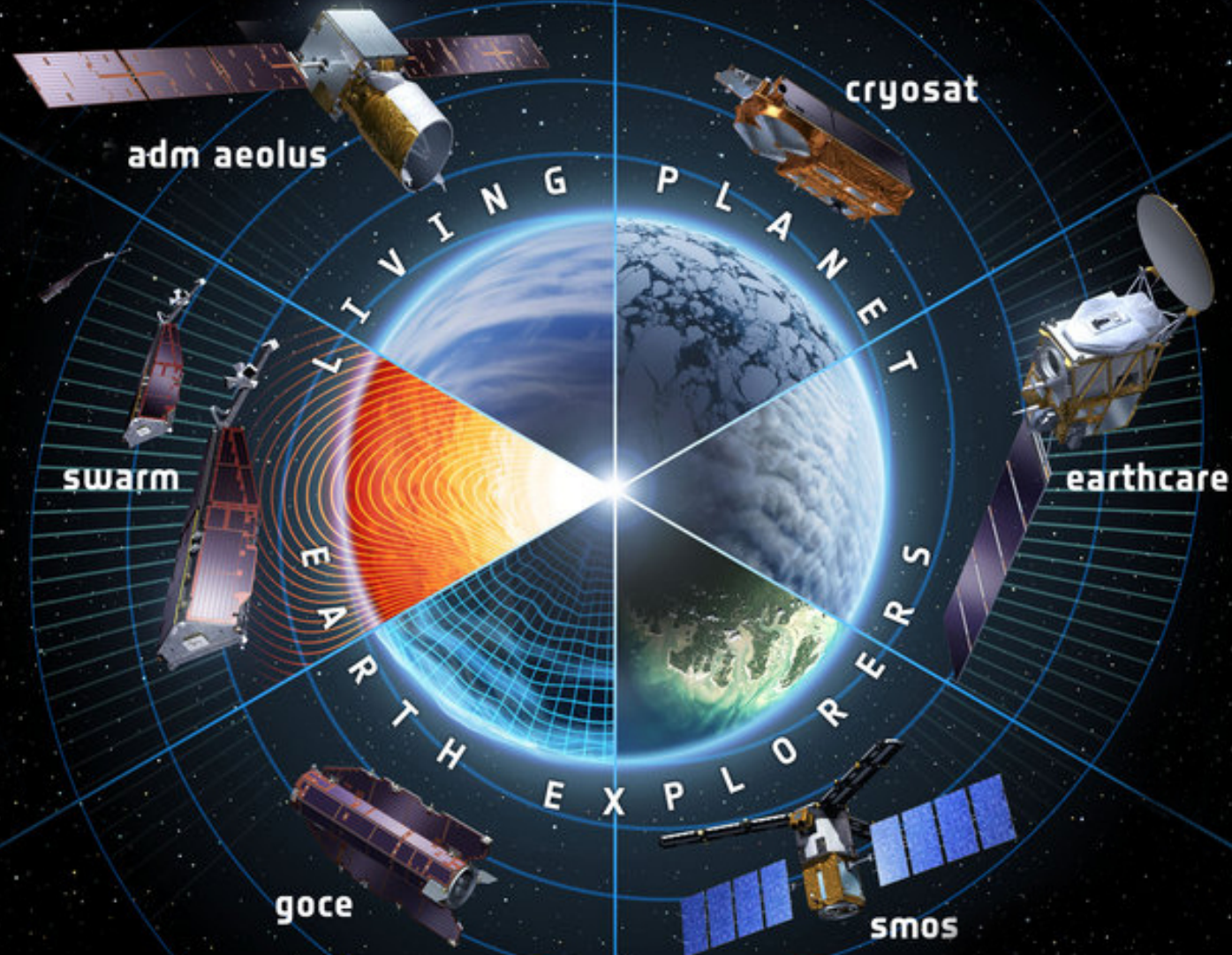
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Data from non-ESA Missions
EO Research Missions

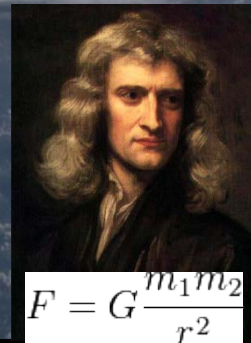
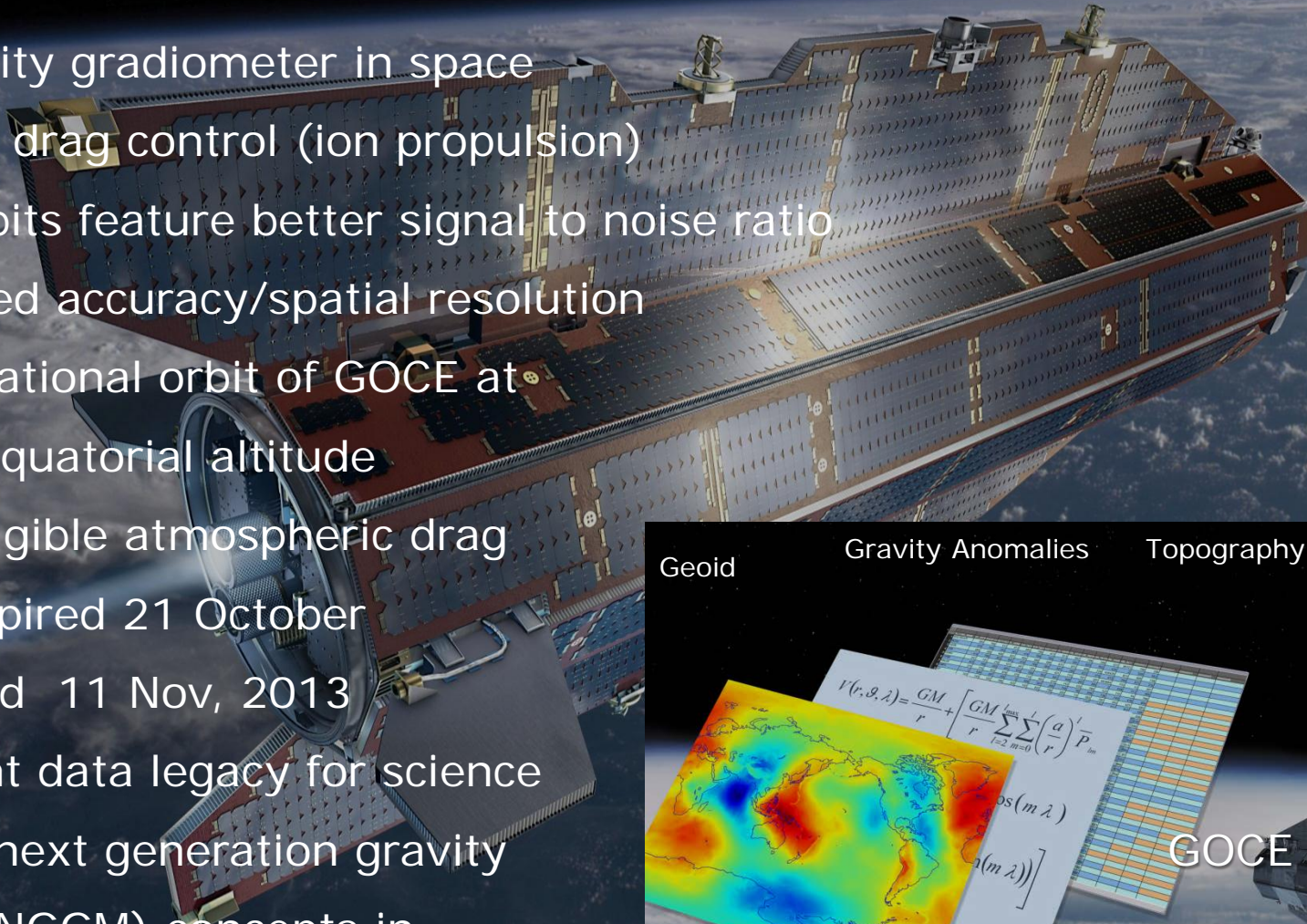
R&D Missions: Scientific Earth Explorers



GOCE: Gravity and Ocean Circulation Explorer



- First gravity gradiometer in space
- Active air drag control (ion propulsion)
- Lower orbits feature better signal to noise ratio & improved accuracy/spatial resolution
- Last operational orbit of GOCE at 225 km equatorial altitude
- Non-negligible atmospheric drag
- Xenon expired 21 October
- De-orbited 11 Nov, 2013
- Significant data legacy for science
- Study of next generation gravity mission (NGGM) concepts in partnership with NASA



Geoid Gravity Anomalies Topography Altimetry

Positioning

Unified Height Systems

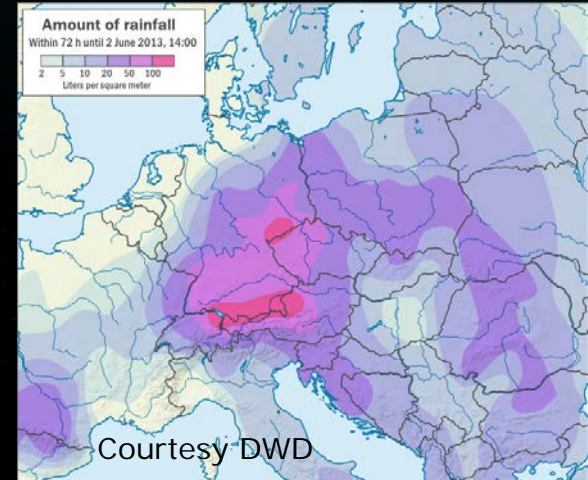
GOCE Applications

Ice Mass Balance Mean Ocean Circulation Oil and Gas Exploration Post Glacial Rebound

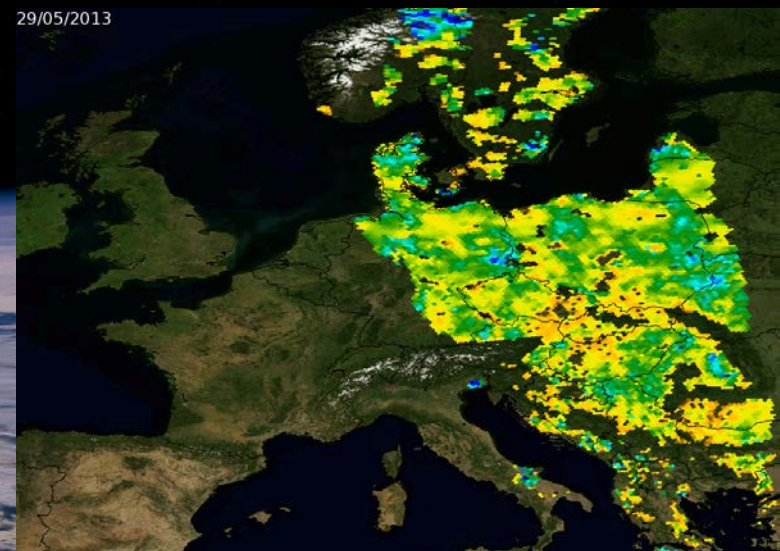
SMOS – Soil Moisture and Ocean Salinity



- Routine data delivery since February 2010
- Complete Earth coverage within three days
- Radio Frequency Interference (RFI) mitigation continues
- International cooperation and collaboration
 - France (CNES), Spain (CDTI)
 - Aquarius and SMAP missions
- Array of new scientific applications in development, beyond primary mission objectives
- Mission extension until 2017
- Aquarius, SMAP mission measurement synergies



29/05/2013

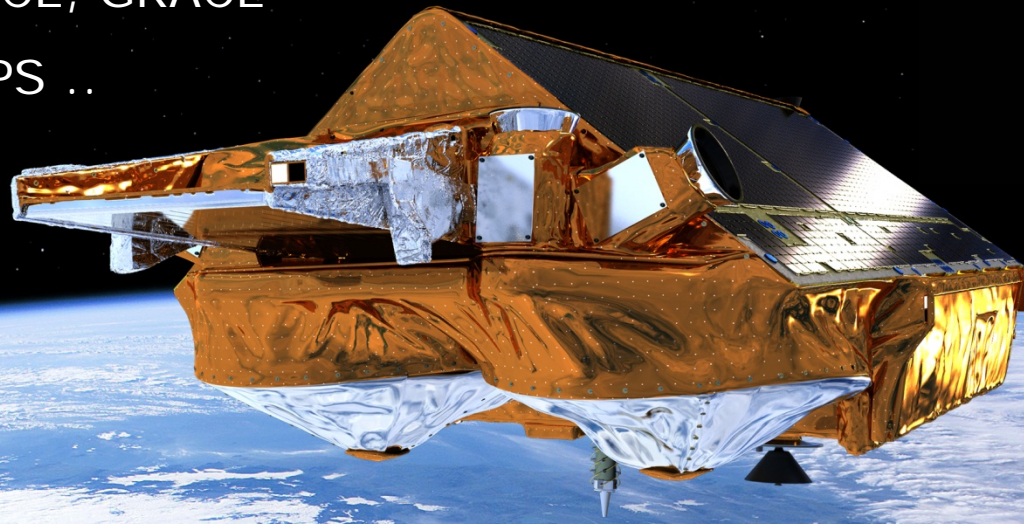
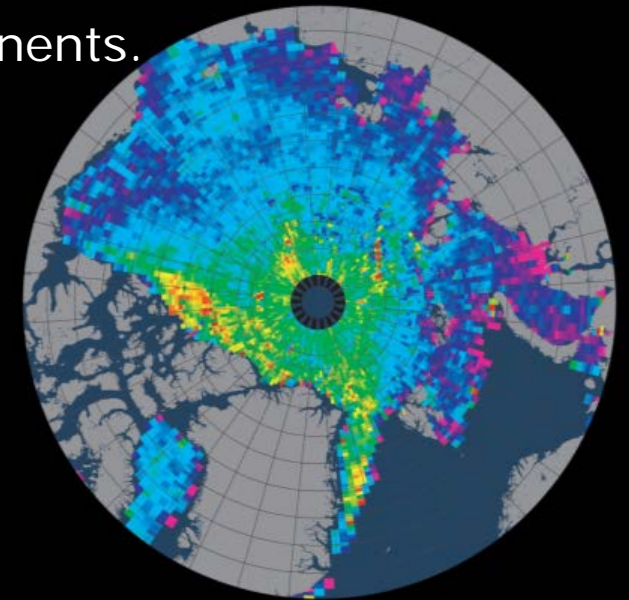


SMOS soil moisture for 29 May to 2 June 2013; The blue areas indicate wetter soils and the yellow and orange colours indicate drier soils: ©CESBIO

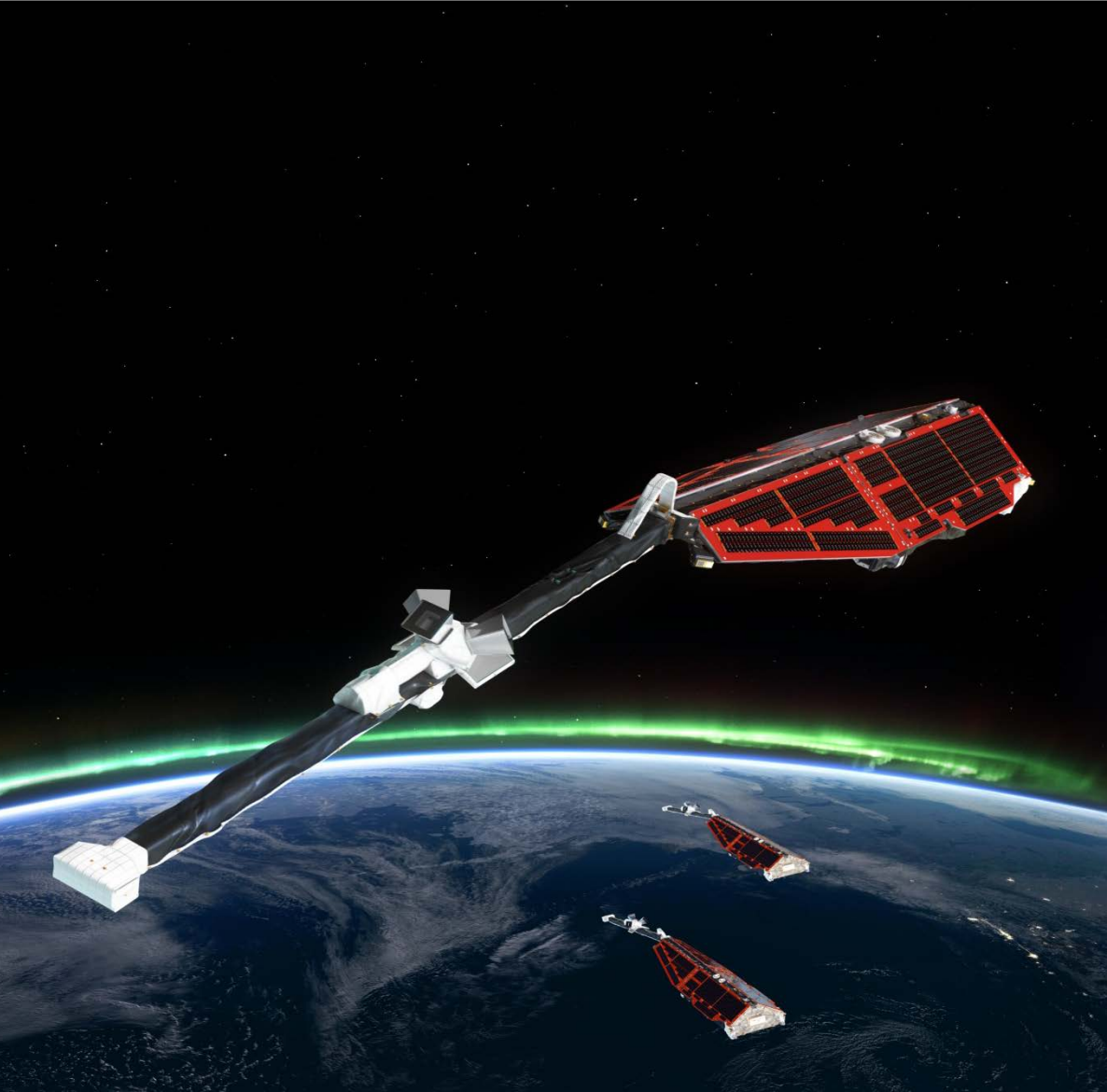
CryoSat: ESA's Ice Mission



- First interferometric altimeter in space
- Global sea ice thickness measurements over four continents.
- Data used for ice research, but increasingly also for oceanography. Important input to climate research
- Mission extension until 2017 (consumables -> 2020)
- Measurement synergies with a number of missions
e.g. Icesat, GOCE, GRACE
JASON, GPS ..



Swarm: ESA's Magnetic Field Mission



- Launched November 2013
- Swarm provides the best-ever survey of the Earth's geomagnetic field and its variation in time
- Swarm is also providing new insights into the Earth's interior and climate
- Constellation of three satellites.
- Data continuity: e.g. Magsat, Orsted, CHAMP

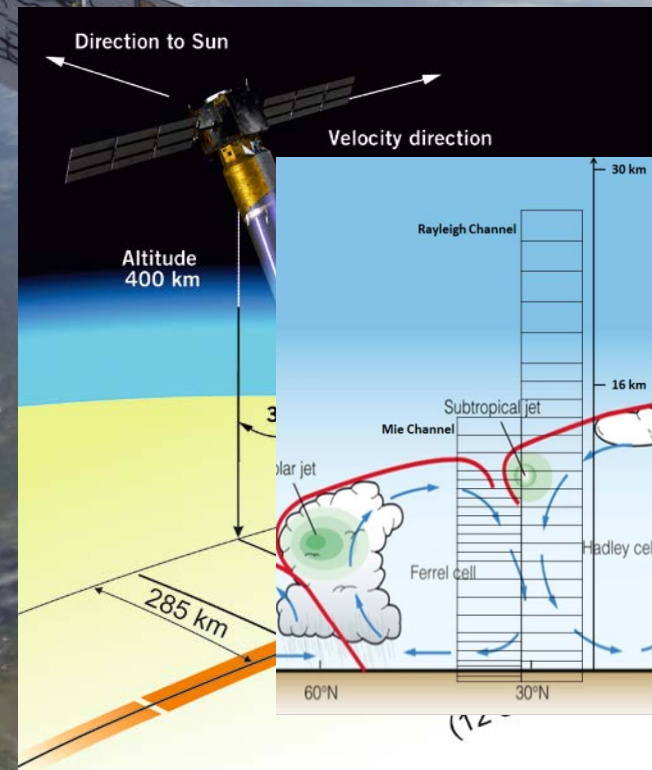
ADM-Aeolus – ESA's Wind Mission



- Global observations of wind profiles for analysis of global 3D wind field
- Understanding of atmosphere dynamics and climate processes
- Improved weather forecasts and climate models
- Qualification of flight models of laser transmitter currently undergoing operational qualification testing.
- Qualification and acceptance review planned for 2016



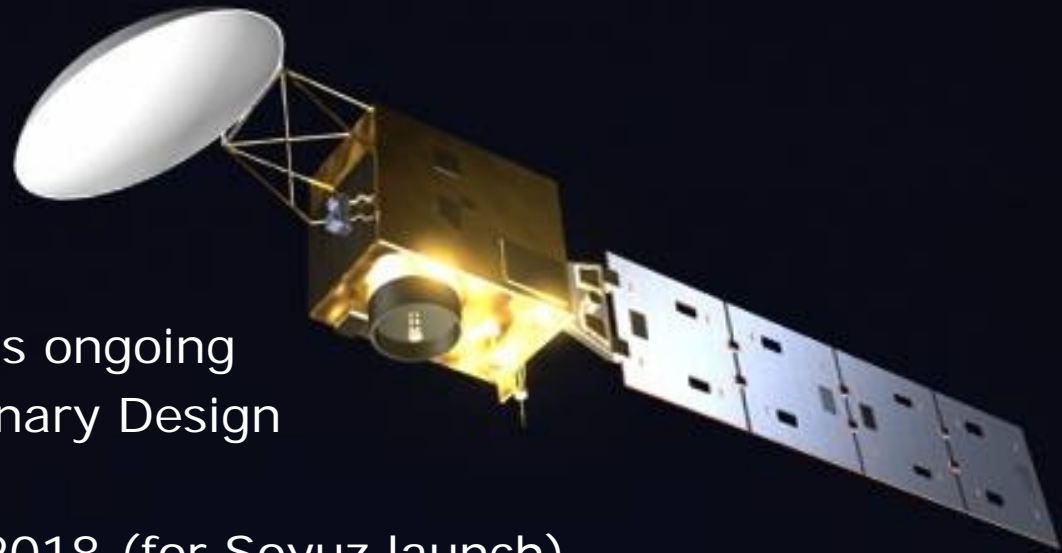
Measurement baseline



EarthCARE – ESA's Aerosol Mission



- Earth **C**loud **A**erosol **R**adiation **E**xplorer
- Global observations of clouds, aerosols and radiation
- ESA and JAXA cooperation
- Scientific instruments:
 - UV Lidar
 - Doppler Cloud Profiling Radar (JAXA)
 - Multispectral Imager
 - Broadband Radiometer
- Critical Design Reviews of instruments ongoing
- Close-out actions initiated for Preliminary Design Review of Ground Segment
- Flight acceptance review planned in 2018 (for Soyuz launch)

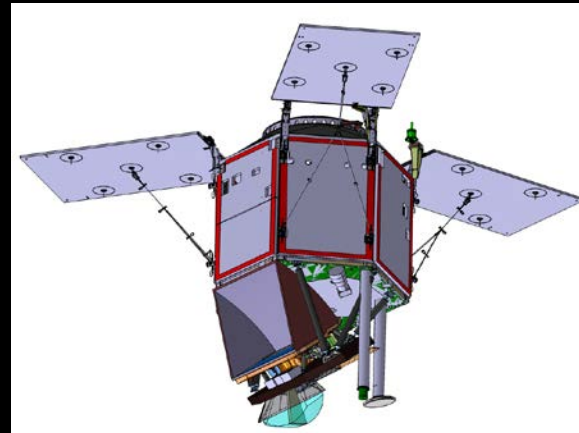
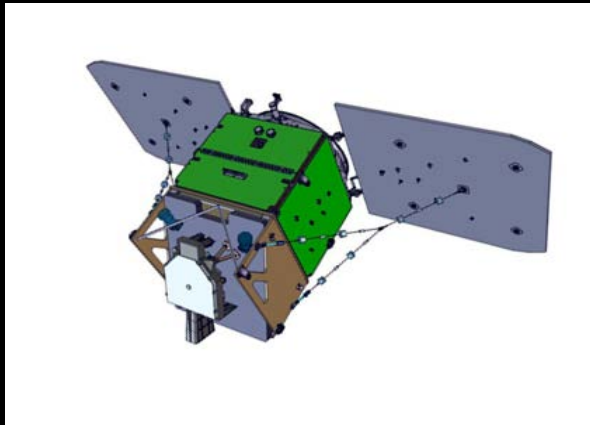
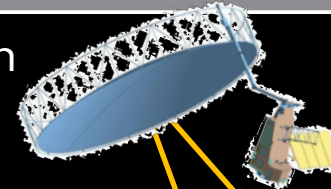


Earth Explorer 7 and Earth Explorer 8 Status

EE7 confirmed (after B1) in Feb PB/EO after selection in 2013: **BIOMASS**, a P-band SAR

EE8 parallel Phase AB1 activities on **CarbonSat** and **FLEX** now closing → User Consultation Meeting in Sept '15 -> recommendation by ESAC
Selection by PB/EO in Nov 2015

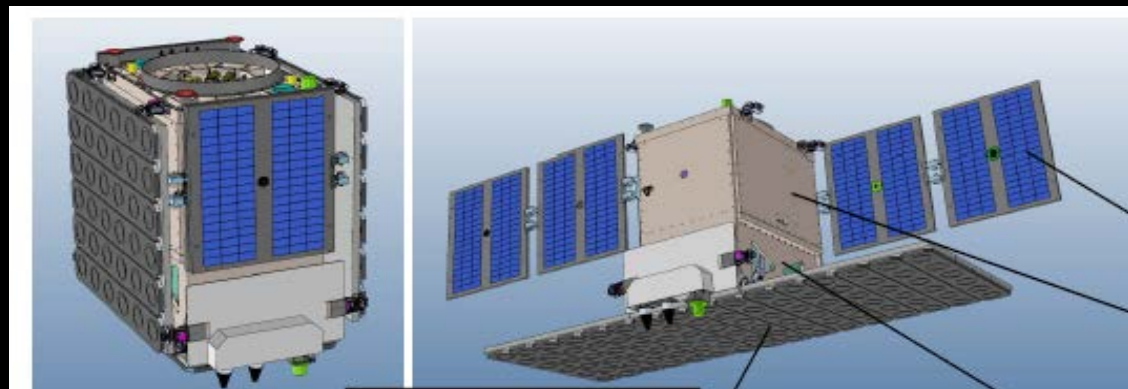
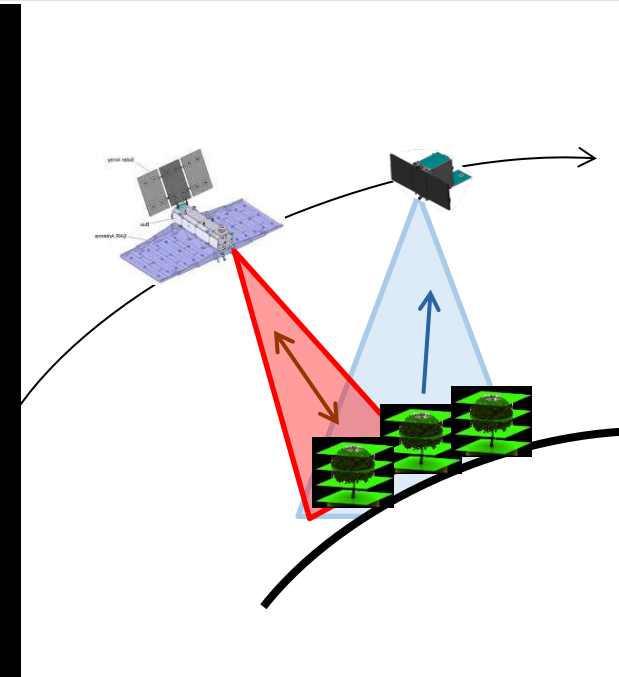
Both are very 'societally relevant' missions, measuring vegetation fluorescence and CO₂ (with imaging spectrometers in NIR and SWIR)



Outlook: A mission of opportunity with international cooperation



- Argentina, with support from IT, is developing an operational L-band SAR:
 - SAOCOM-1A/1B will fly in constellation with COSMO-SkyMed
- CONAE offered ESA a launch opportunity with SAOCOM-1b in 2018/19
- We proposed a passive bistatic SAR enhancing SAOCOM mission return, especially for boreal forest biomass
- Phase AB1 studies ongoing.
- New approach required to meet schedule and cost constraints
- Passive bistatic SAR mission under study -> C-band ("S-1 CS")



Outlook: Earth Explorers



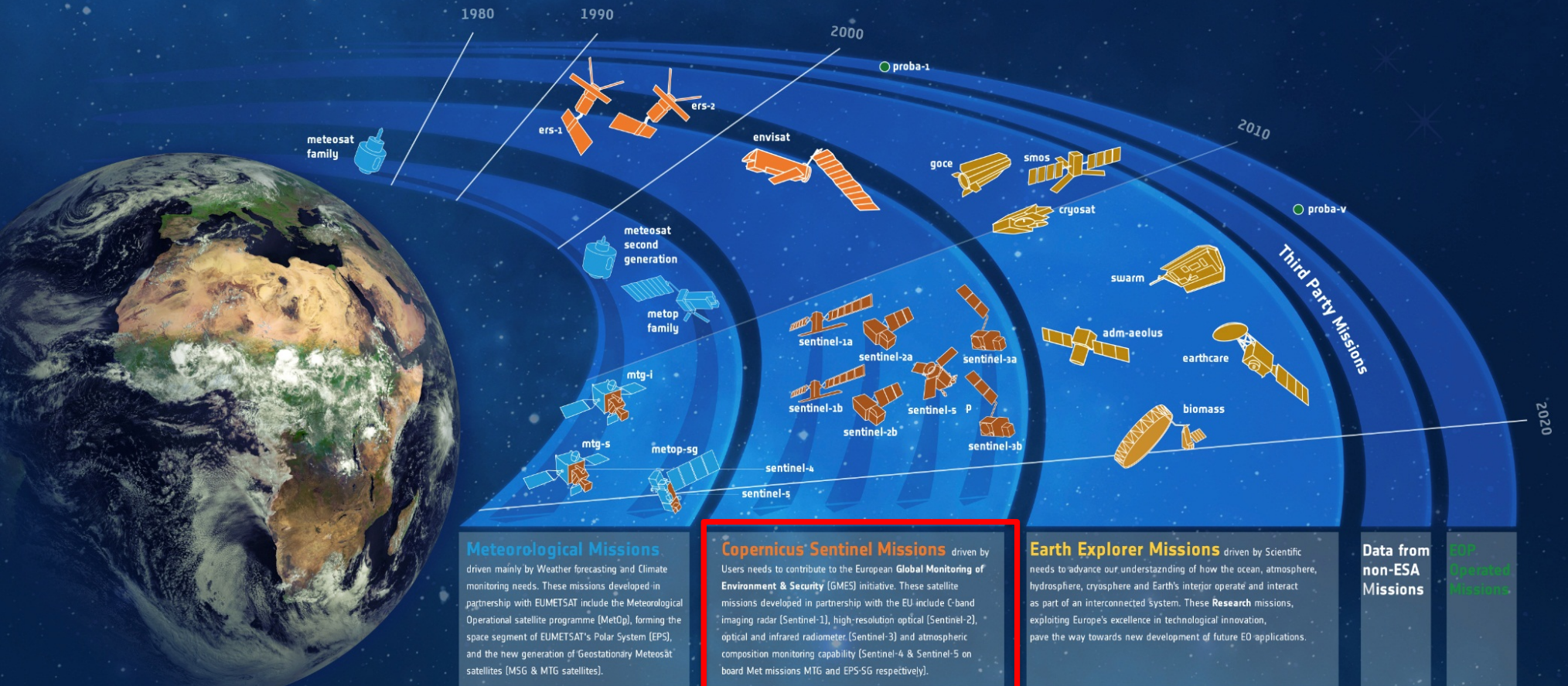
- Approval of EE9 Call (AO) planned for Nov '15
- Situation still open about type of EE (likely Opportunity type, entering directly Phase AB1) and budget.
- EE9 science will link to 'societal benefits', e.g. relevance to water-energy-food issues
- Crucial to foster initial ideas circulating in EO community, arising from:
 - Past EE Calls (and other AOs)
 - Many missions praised but not selected for implementation
 - ESA-internal R&D work e.g. via GSP, TRP, EOPA
 - Direct inputs from user communities



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Data from non-ESA Missions
ESA Operated Missions

- Previously known as Global Monitoring Environment and Security (GMES)
- Joint initiative of EU and ESA
- The Sentinel satellite series represent the dedicated (long term) space segment of Copernicus, supported by:
 - contributing missions from ESA member states
 - ground (in-situ) observation capabilities
- to address a large number of information services and applications



Copernicus: A New Generation of Data Sources



Sent-1A/B



Sent-2A/B



Sent-3A/B



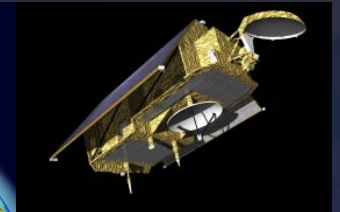
Sent-4A/B



Sent-5/5P



Sent-6/Jason-CS



- Copernicus: EU space flagship programme, in which ESA coordinates the space component
- Copernicus provides operational data needed for monitoring of the environment and for civil security
- EU Multiannual Financial Framework (2014-2020) foresees 3.783 Billion Euro for Copernicus operations and recurrent satellites (foreseen in Long-term Scenario)
- Delegated Act on (Free & Open) Data Policy approved and operating from October 3rd 2014.
- On 6 February 2015, the Sentinel-1C/D, -2C/D, -3C/D Invitation to Tenders (ITTs) were issued on EMITS). Offers have to be delivered by June 5, 30 and 5 respectively



Copernicus Dedicated Missions: Sentinels



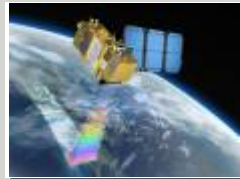
Unit A / Unit B



Sentinel-1 (A/B) – SAR imaging

All weather, day/night applications, interferometry **Unit A / Unit B**

03-04-14 / 2016



Sentinel-2 (A/B) – Multi-spectral imaging

Land applications: urban, forest, agriculture,...
Continuity of Landsat, SPOT

Q2 2015 / 2016



Sentinel-3 (A/B) – Ocean and global land monitoring

Wide-swath ocean color, vegetation, sea/land
surface temperature, altimetry

Q3 2015 / 2016

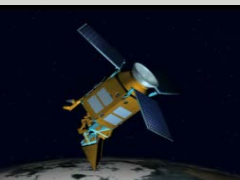


Sentinel-4 (A/B) – Geostationary atmospheric

Atmospheric composition monitoring, trans-
boundary pollution

2021

(Payload on MTG)

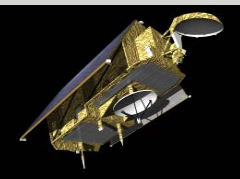


Sentinel-5 Precursor/ Sentinel-5 (A/B) – Low-orbit atmospheric

Atmospheric composition monitoring. S5p to follow ground track
of Suomi-NPP. Launch Q1 2016

2020

(Payload on Metop-SG)



Sentinel-6 Jason-CS (A/B) – Low inclination Altimetry

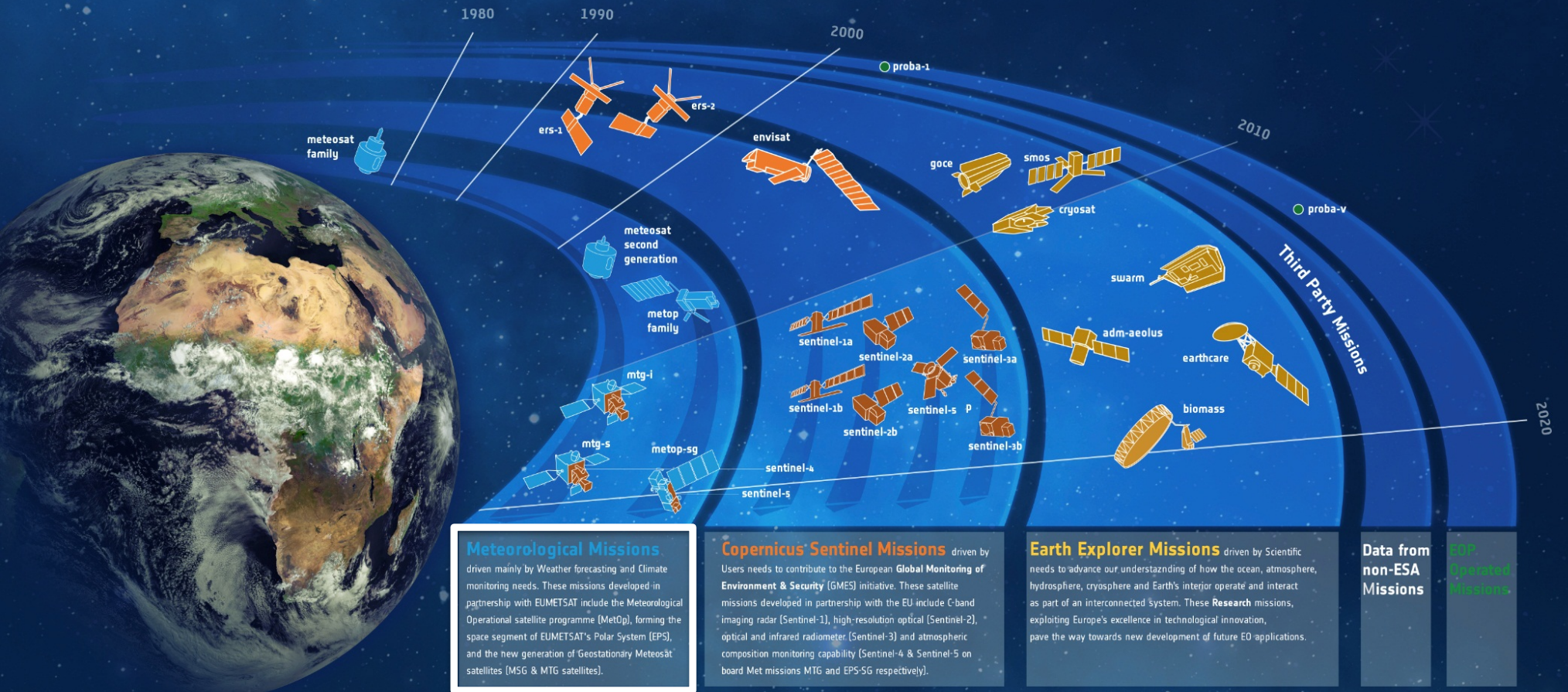
Sea-level, wave height and marine wind speed

2020 / 2025

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ESA Operated Missions

EUMETSAT operated missions



For MTG two types of missions are proposed comprising six satellites focusing on Nowcasting and Numerical Weather Prediction (NWP):

- 4 x MTG-I (Imaging) missions
- 2 x MTG-S (Sounding) missions



1977

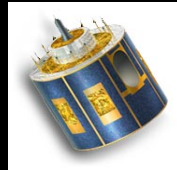
MOP

MVIRI, 3 channels
Spinning satellite

2002

MSG

SEVIRI, 12 channels,
GERB Spinning satellite



2019

MTG-I

Flexible Combined Imager,
Lightning Imager, IR sounder



2021

MTG-S

Includes Sentinel-4
payload

**GEO
Meteosat
series**

**LEO Metop
series**



2006

Metop-A

NOAA + EUMETSAT sensors
New sensors: ASCAT, GOME, GRAS

2012

-B

2016

-C

Metop SG-A

Several instruments on each
platform. Improved instrument
performance. Includes Sentinel-5
a payload)

2021

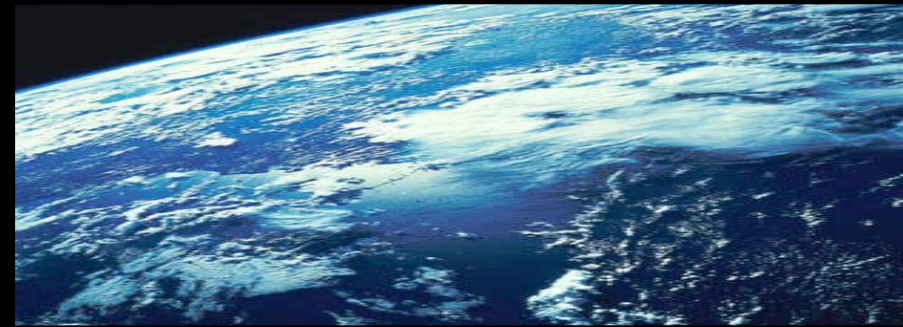
2022

-B

LTDN: 9.30 am, 817 km

European Organization for the Exploitation of Meteorological Satellites (EUMETSAT). ESA is the R & D agency for EUMETSAT missions

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4. **ESA EO Technology**
5. Convoys and Constellations



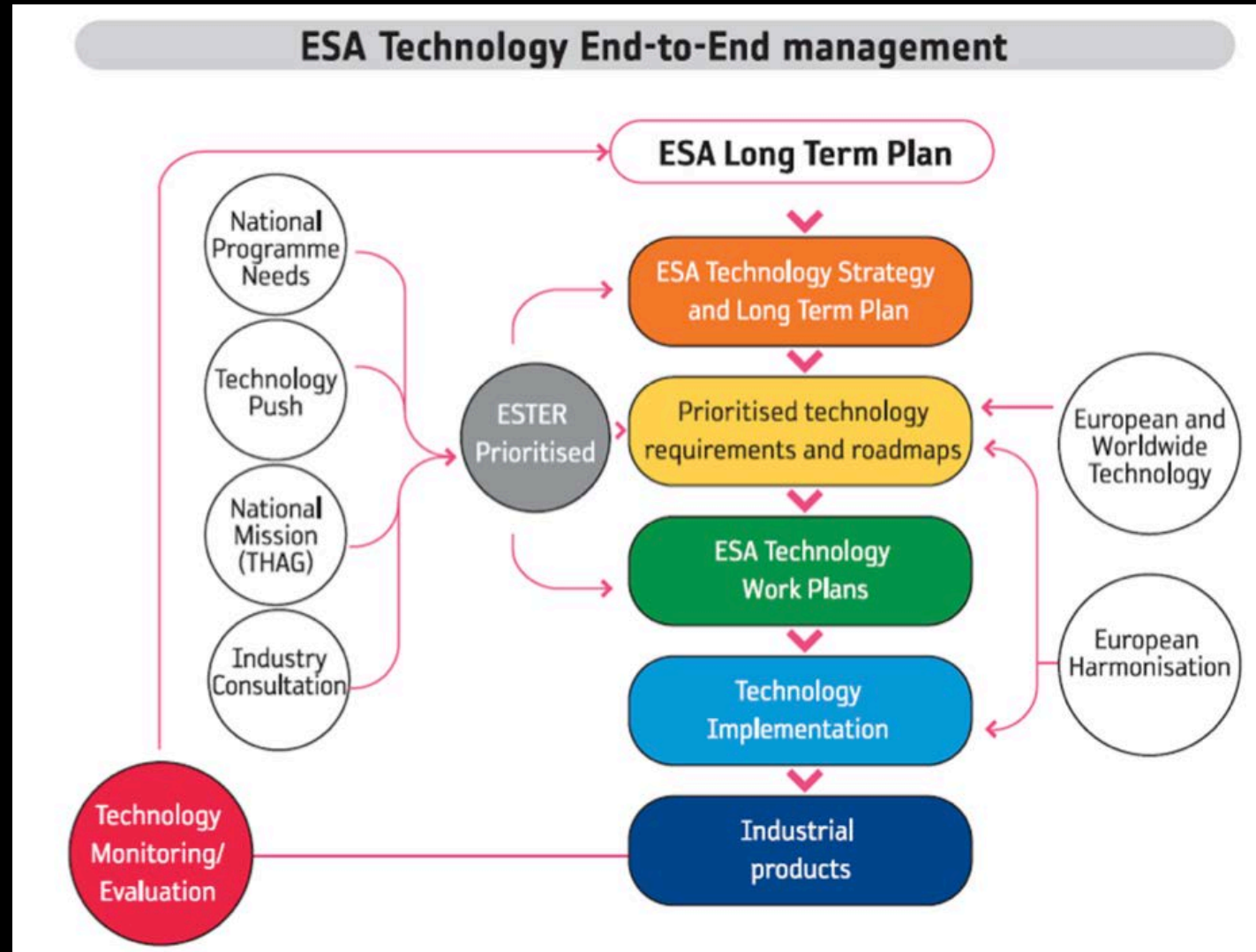
ESA End to End Technology Process



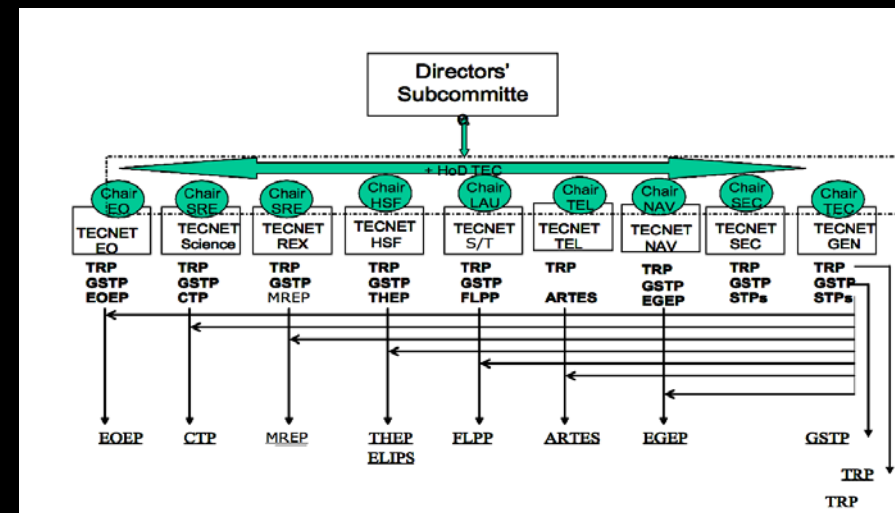
- Under the supervision of a Dedicated Director Sub-committee on Technology.

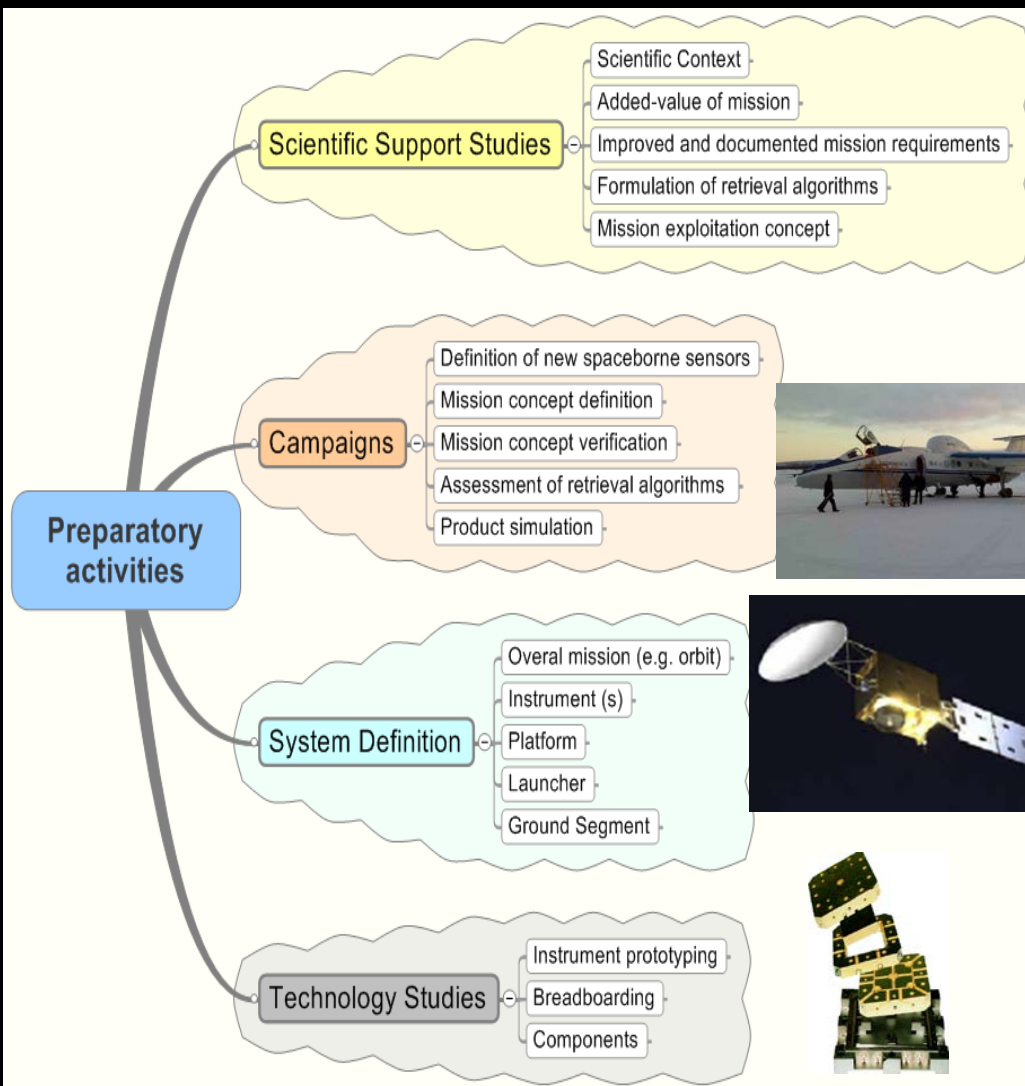
- ESTER: European Space Technology Req. Database

- THAG: Technology Harmonisation Advisory Group



- The process comprises in a top-down (users) approach complemented by a bottom-up development approach (technical experts).
- Organised by Service Domains across ESA.
- Working groups are set up for each service domain and all working groups together form the Technology Network (TECNET)
- SD1 (Earth Observation),
- SD2 (Space Science),
- SD3 (Human Spaceflight & Human Exploration)
- SD4 (Space Transportation)
- SD5 (Telecommunication)
- SD6 (Navigation)
- SD7 (Generic Technologies and Techniques)
- SD9 (Robotic Exploration)

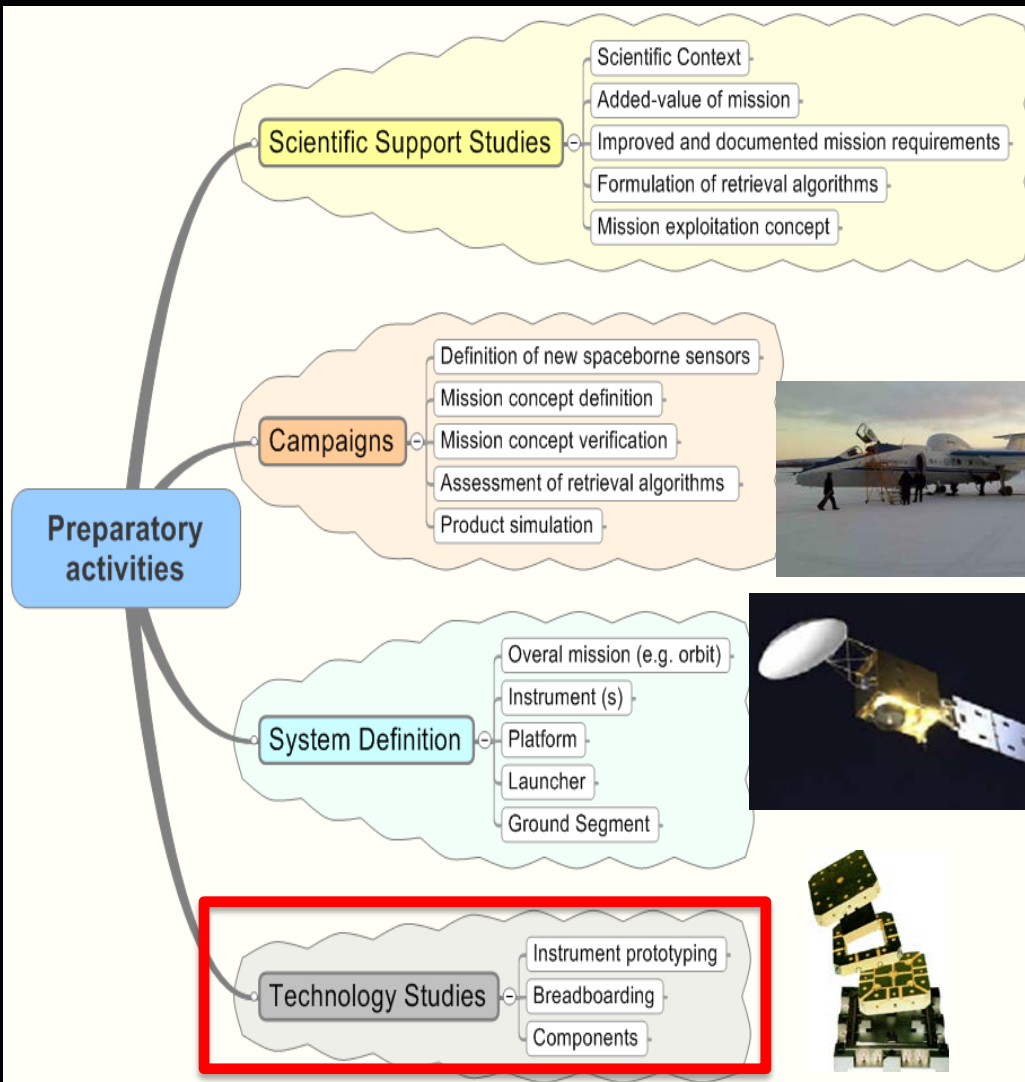




1. EOEP preparatory activities include all necessary activities to define and evaluate future EO space borne missions (Earth Explorer, Copernicus, meteorological,..)

2. Driving elements include:

- ESA EO Science Strategy
- Associated observation, mission and technology requirements
- Mission preparation through Phase-0 (Pre-feasibility) and Phase-A/B1 (Feasibility)
- Foster new ideas, cooperation opportunities and prepare technologies, also for European independent capabilities
- ESAC recommendations



Funding depends the nature of the activity as stated in the Living Planet strategy e.g. science / operational.

ESA Earth Observation available funding sources for preparatory activities

EOEP: e.g.

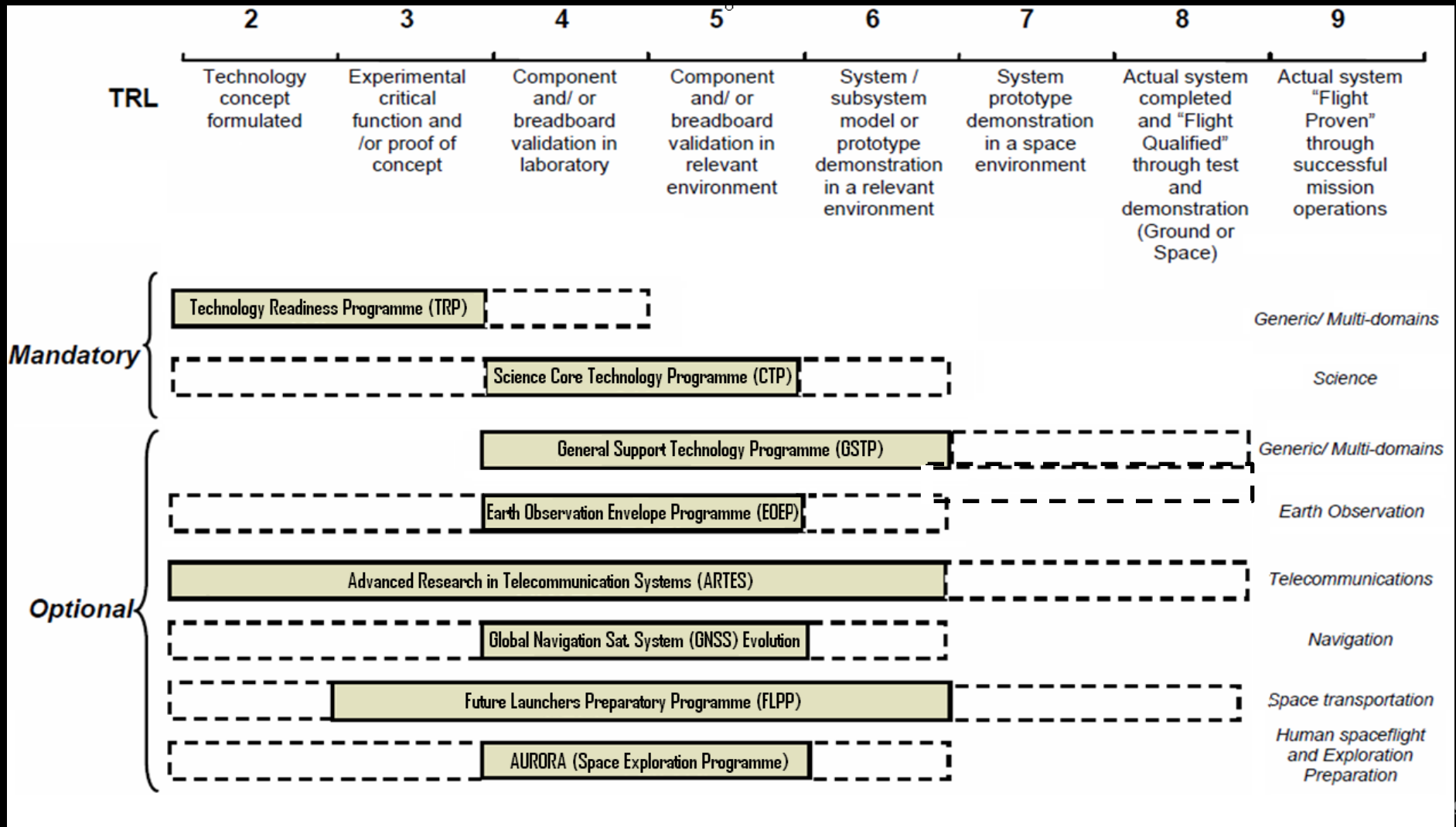
- Earth Observation Preparation Activities (EOPA)
- Instrument Pre-Development (IPD)
- Earth Watch Definition (EWD)
- Support to Science Element (STSE)

ESA Technology Programmes e.g.

- Technology Research Programme (TRP)
- General Support to Tech. Prog (GSTP)

ESA General Studies Programme (GSP)

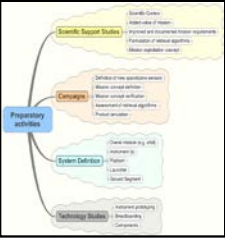
ESA Technology Programmes vs. TRL



EECM Phase A: what does it mean ?



Example: BIOMASS Core Mission Phase A Activities (mission now in Phase B)



System ● ●

- BIOMASS Phase A System Study (x2), addressing:
 - Space segment : payload, platform
 - Mission analysis and operations
 - Launcher
 - Ground segment
 - Critical technologies
 - Programmatics

Technology ● ● ●

- Large P-Band SAR antennas critical breadboard (x2)
- Very Large P-Band Antennas performance verification methodology & Facilities
- P-Band HPA technology assessment
- Very large space antenna aperture – demo model
- P-Band Reflector antenna Feed elements
- P-band ice sounding radar demo development
- P-band passive sub-array development
- Very large space antenna aperture architecture trade-off (x2)
- SSPA breadboard (incl. circulator/switch, power divider and calibration coupler) (x2)
- Study of P-Band transponder with ionospheric correction capabilities (x2)

Science and Campaigns ●

- Development of algorithms for forest biomass retrieval
- Study of ionospheric disturbance mitigation schemes
- Assessment of the BIOMASS retrieval error on flux
- P-Band SAR wave interaction and information retrieval
- Analysis of BIOMASS secondary objectives

e.g.

- TropiSAR campaign (completed)
- TropiScat campaign (on-going)
- BioSAR 2 campaign (completed)
- BioSAR 3 campaign (completed)

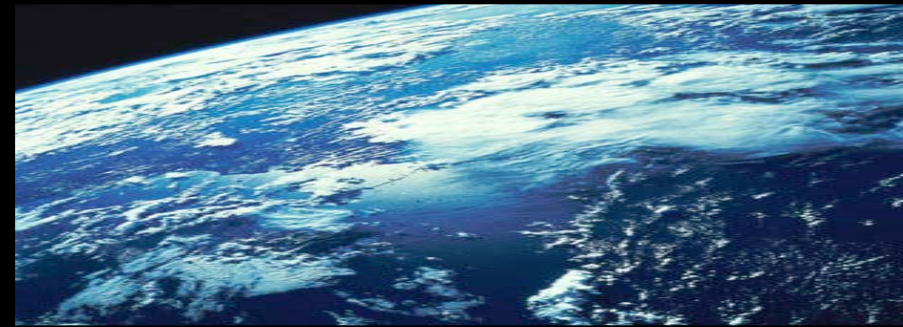
End-to-end Performance Evaluation and System Support ●

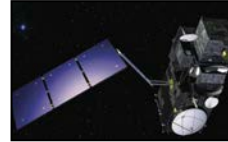
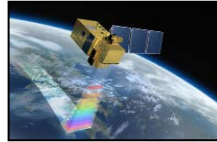
- BIOMASS End-to-End Mission Performance Simulator
- OpenSF end-to-end (E2E) simulator framework infrastructure
- Modern attitude control of EO satellites with large flexible elements (x2)

● = EOPA ● = IPD
● = TRP / GSTP ● = GSP

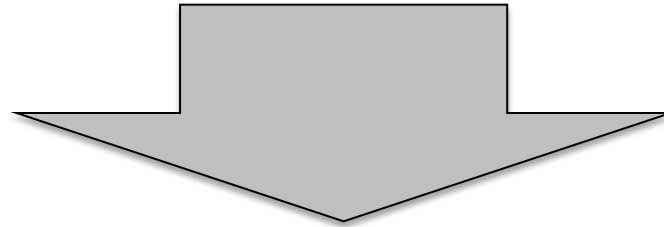
European Space Agency

1. EO Living Planet Programme
2. ESA EO Science Strategy
3. Mission Status and Planning
4. ESA EO Technology
5. **Convoys and Constellations**

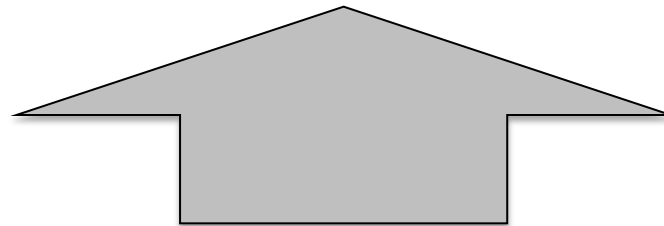




Operational missions



Opportunities for synergetic EO



Additional missions

The Convoy Studies



- Three Convoy studies have been defined and have been initiated following a “user driven” approach:
- Theme 1: Use of novel and additional observations for Ocean & Ice research & applications
- Theme 2: Use of novel and additional observations for Land research & applications
- Theme 3: Use of novel and additional observations for Atmosphere research & applications



Ocean and Ice Study: Preliminary Convoy Mission Concepts



Passive C-band SAR	+	Sentinel-1
C-band SAR	+	Sentinel-1
VNIR + SWIR	+	Sentinel-1
TIR	+	Sentinel-1
L-band SAR	+	Sentinel-1
PMR (L-band)	+	Sentinel-1
Laser altimeter	+	Sentinel-3
PMR (L-band)	+	Sentinel-3
Microwave Imager	+	Sentinel-3
Ku-band scatterometer	+	Metop SG
PMR (L-band)	+	Metop SG

Ocean and Ice Study:

Convoy Mission Concepts selected for further study



Passive C-band SAR	+	Sentinel-1
C-band SAR	+	Sentinel-1
VNIR + SWIR	+	Sentinel-1
TIR	+	Sentinel-1
L-band SAR	+	Sentinel-1
PMR (L-band)	+	Sentinel-1
Laser altimeter	+	Sentinel-3
PMR (L-band)	+	Sentinel-3
Microwave Imager	+	Sentinel-3
Ku-band scatterometer	+	Metop SG
PMR (L-band)	+	Metop SG

Land Study: Examples of Preliminary Convoy Mission Concepts

Passive C-band SAR	+	Sentinel-1
L-band SAR	+	Sentinel-1
Multi-angle optical imager	+	Sentinel-2 Sentinel-3
Multi-channel thermal imager @ 100 m (Microbolometers)	+	Sentinel-2 Sentinel-3
MIR / TIR @ ~ 200 m (Microbolometers / Cooled Detectors)	+	Sentinel-2 Sentinel-3
Laser altimeter	+	Sentinel-1

Land Study: Convoy Mission Concepts selected for further study



Passive C-band SAR	+	Sentinel-1
L-band SAR	+	Sentinel-1
Multi-angle optical imager	+	Sentinel-2 Sentinel-3
Multi-channel thermal imager @ 100 m (Microbolometers)	+	Sentinel-2 Sentinel-3
MIR / TIR @ ~ 200 m (Microbolometers / Cooled Detectors)	+	Sentinel-2 Sentinel-3
Laser altimeter	+	Sentinel-1

Atm. Study: Examples of Preliminary Convoy Mission Concepts for Atm Composition and Chemistry



UV/Vis multi-angle mapper / profiler	+	Metop SG (3MI)
UV / Visible mapper	+	Sentinel-3 (SLSTR)
NO2 Lidar	+	Metop SG (S5) S5P (UVNS)
3 micron spectrometer	+	Metop SG (IASI) / S5
Aerosol Lidar	+	Metop SG (3MI /S5)
FLEX + CarbonSat	+	Sentinel-3 (SLSTR)

Atm. Study: Convoy Mission Concept selected for further study



UV/Vis multi-angle mapper / profiler	+	Metop SG (3MI)		
UV / Visible mapper	+	Sentinel-3 (SLSTR)		
NO2 Lidar	+	Metop SG (S5)	S5P (UVNS)	
3 micron spectrometer	+	Metop SG (IASI) / S5		
Aerosol Lidar	+	Metop SG (3MI /S5)		
FLEX	+	CarbonSat	+	Sentinel-3 (SLSTR)

Atm. Study: Preliminary Convoy Mission Concepts for Meteorology



Doppler wind lidar	+	Metop SG (3MI/S5)
Multi-angle TIR	+	Metop SG
Radio-occultation	+	Metop SG (S5) S5P
Cloud profiling radar	+	Metop SG (IASI)
Multi-wavelength cloud aerosol lidar	+	Metop SG (3MI/S5)
Differential absorption Lidar (DIAL)	+	Metop SG

Atm. Study: Convoy Mission Concepts selected for further study



Doppler wind lidar	+	Metop SG (3MI/S5)
Multi-angle TIR	+	Metop SG
Radio-occultation	+	Metop SG (S5) S5P
Cloud profiling radar	+	Metop SG (IASI)
Multi-wavelength cloud aerosol lidar	+	Metop SG (3MI/S5)
Differential absorption Lidar (DIAL)	+	Metop SG

Conclusions and Outlook



ESA has a **set of Earth Observation Programmes** which deliver R&D Earth Explorer missions and missions which delivered operational services.

The Copernicus Programme is underway. The first Sentinel-1A was launched April 2014. Sentinel-2A and -3A are planned for launch in June and October 2015.

ESA has updated the **25 Living Planet Challenges** and will publicly publish the **new ESA Science Strategy** shortly, which will form the basis for the new calls

The concept of **convoys and constellations** has been built into the updated science strategy.

No mission can be built in isolation any longer, measurement synergies are needed and **international cooperation is essential** to address global issues.



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