ESA’s Earth Observation Programmes

Meeting of the Space Studies Board’s Committee on Earth Science and Applications from Space (CESAS)

Washington, 30 April 2016

Maurice Borgeaud

Head of the Science, Applications, and Future Technologies Department

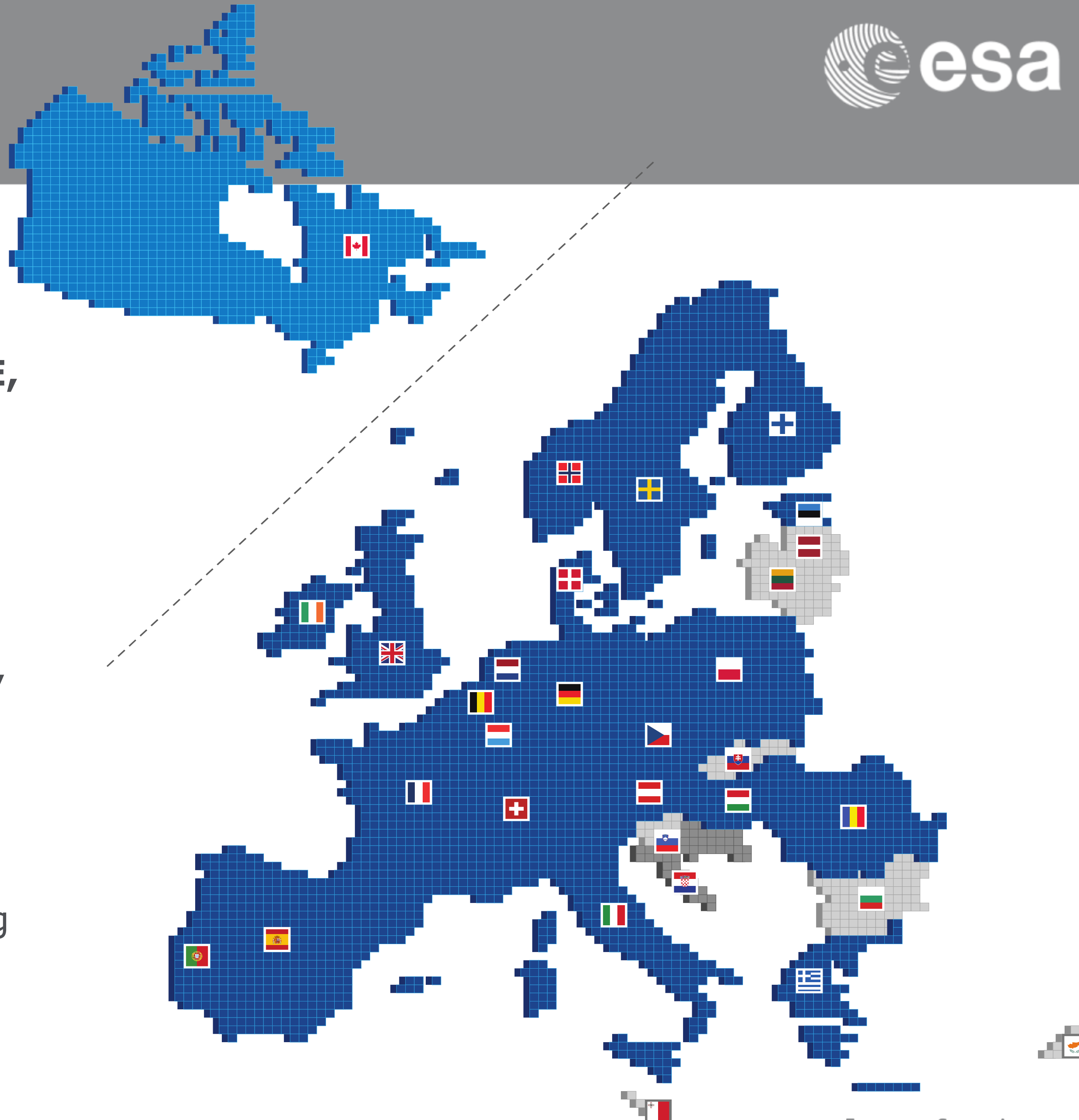
www.esa.int

Member States

ESA has 22 Member States: 20 states of the EU (AT, BE, CZ, DE, DK, EE, ES, FI, FR, IT, GR, HU, IE, LU, NL, PT, PL, RO, SE, UK) plus Norway and Switzerland.

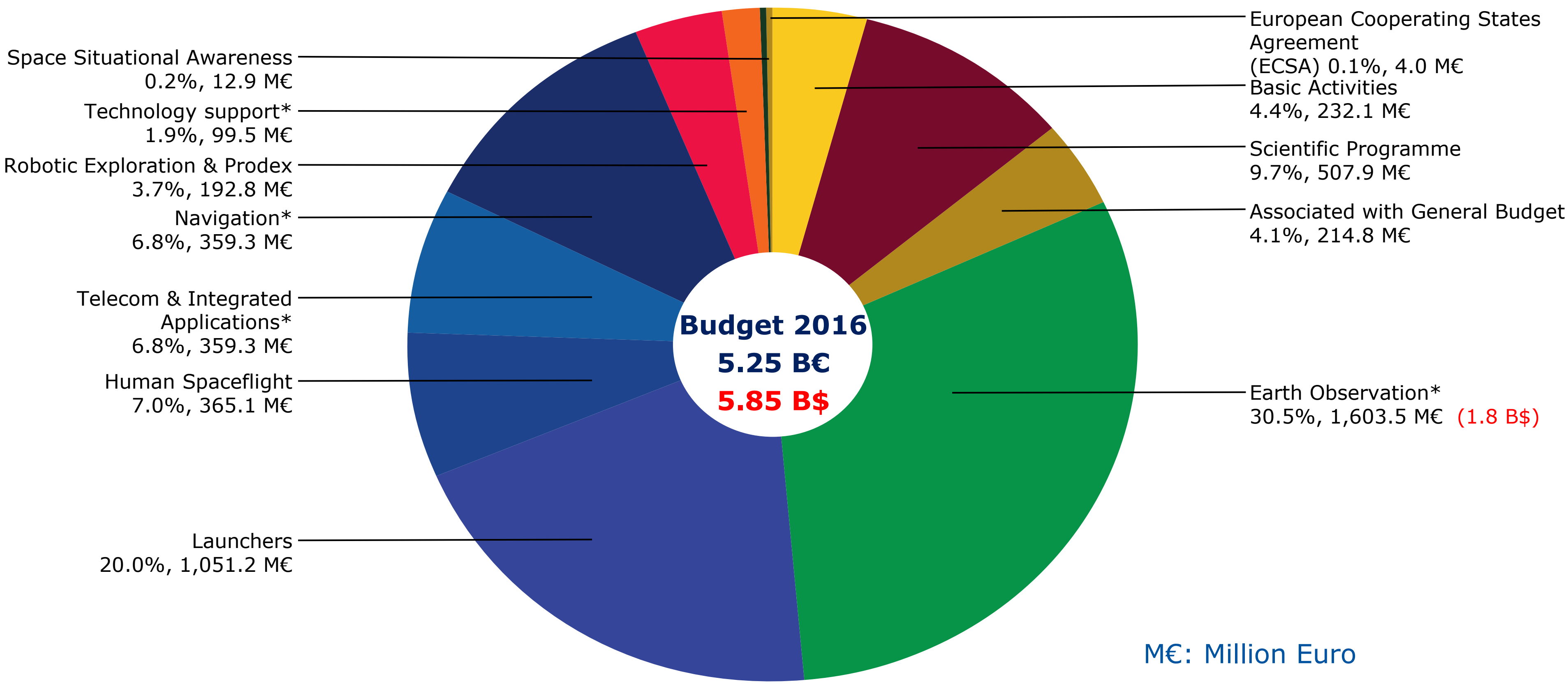
Seven other EU states have Cooperation Agreements with ESA: Bulgaria, Cyprus, Latvia, Lithuania, Malta, Slovakia and Slovenia. Discussions are ongoing with Croatia.

Canada takes part in some programmes under a long-standing Cooperation Agreement.



European Space Agency

ESA 2016 budget by domain



M€: Million Euro

*includes Programmes implemented for other Institutional Partners

European Space Agency

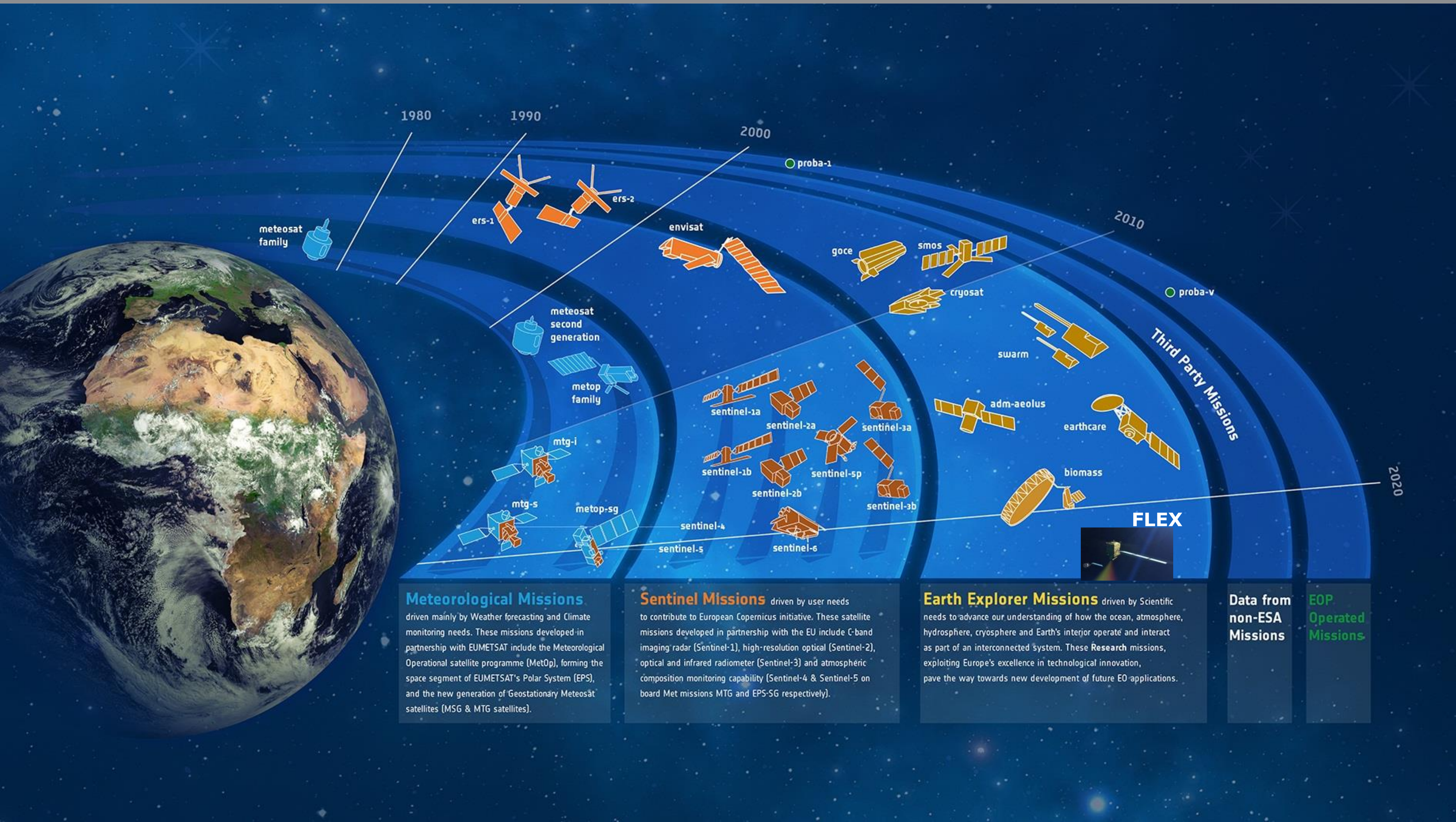
ESA Earth Observation Strategy

The prime objective of ESA Earth Observation Strategy is **to help society** to:

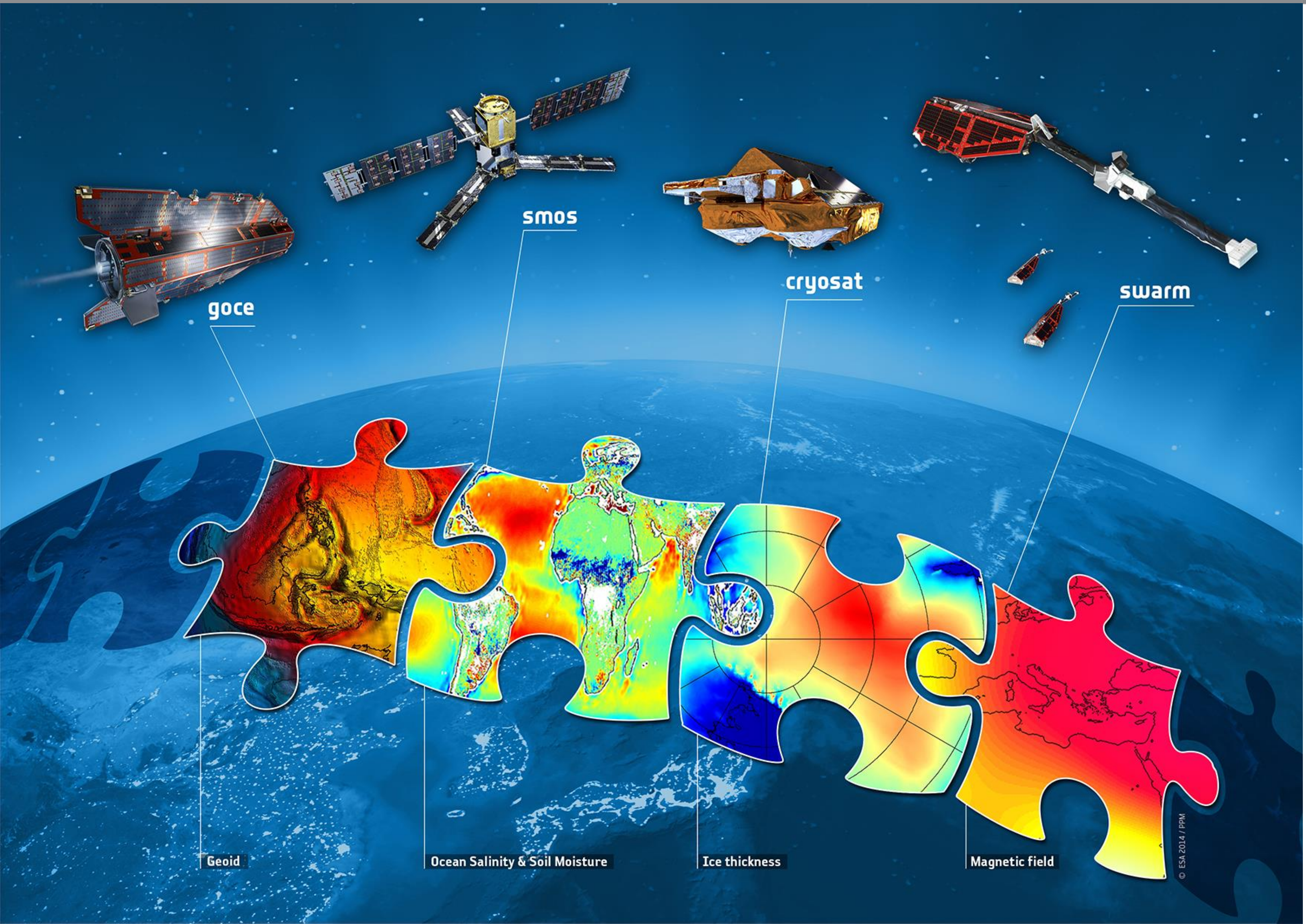
- **Observe**: develop and provide the observations to better understand the complexity of our planet and monitor its health;
- **Understand**: enable improved predictions of the physical interaction of society with the Earth system;
- **Decide**: inform decision makers and citizens on scenarios and consequences of political and economic decisions regarding our home planet.

The vision of ESA is to enable the maximum benefit of Earth observation for science, society and economic growth.

ESA Earth Observation Programmes



Science – the Earth Explorers



Earth Explorers Launched

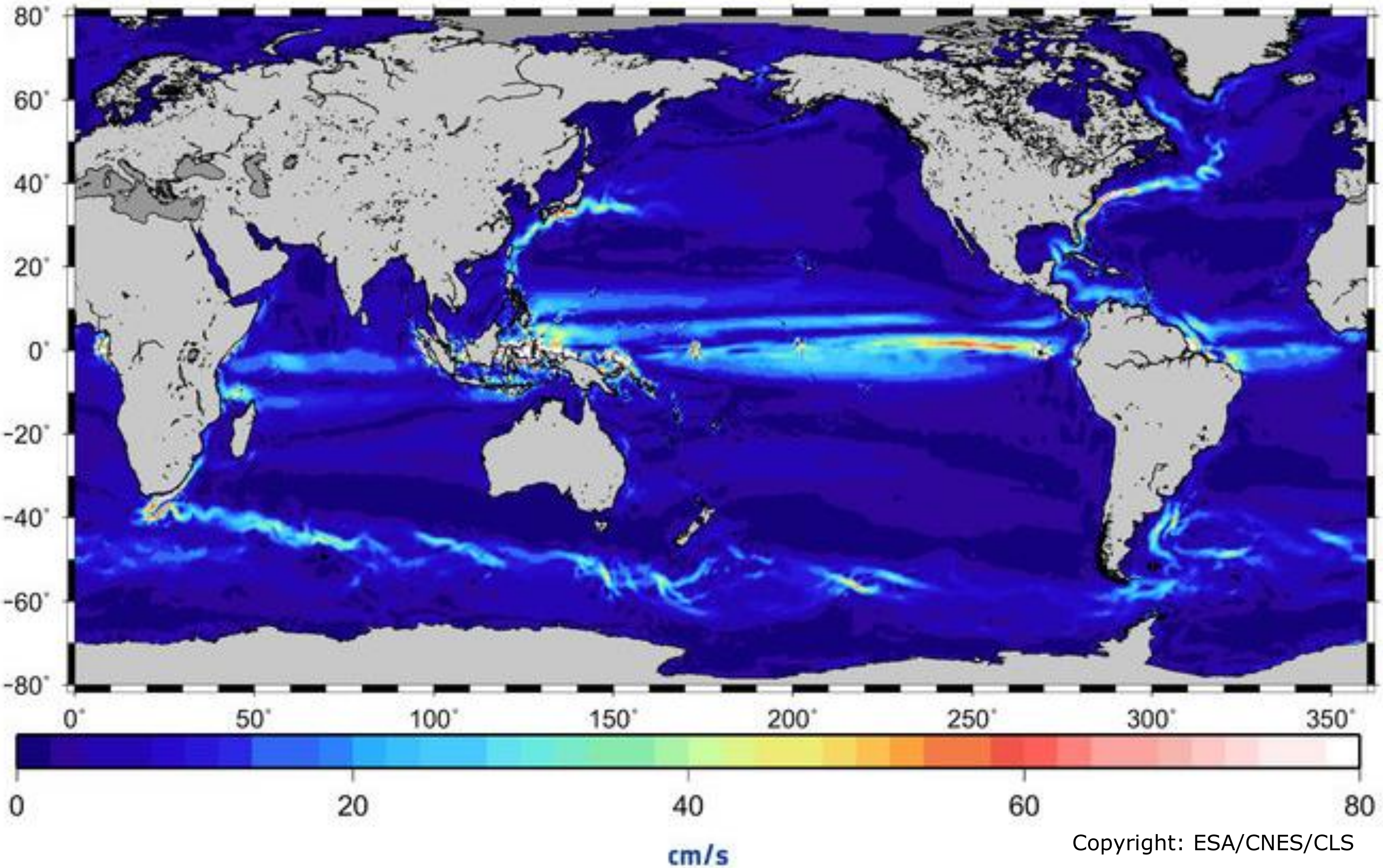
Dedicated to specific aspects of our Earth environment whilst demonstrating new technology

Synergy between the missions

GOCE: Gravity and Ocean Circulation

- First gradiometer in space
- Best geoid ever
- 5th version of geoid released in July 2014, including all GOCE measurements
- End of mission declared 21 October 2013 following depletion of Xenon fuel
- Re-entry 11 November 2013

GOCE: Ocean Currents



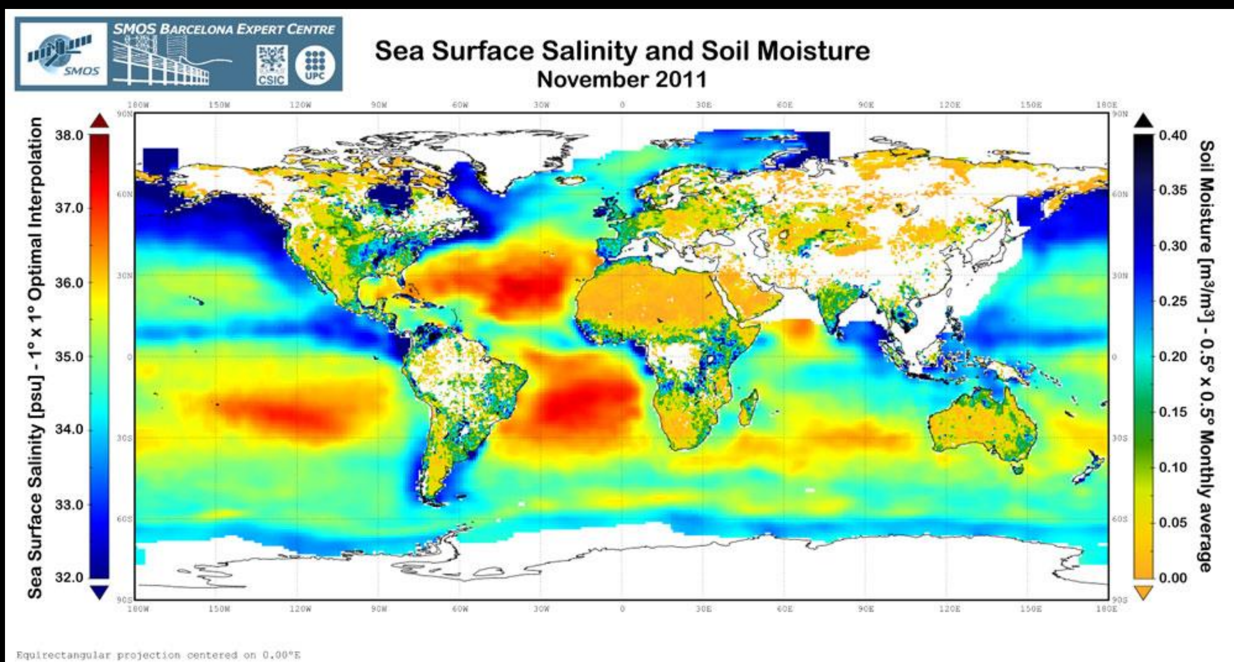
SMOS – Soil Moisture and Ocean Salinity

- Data delivery since February 2010
- Complete Earth coverage within three days
- Outstanding international cooperation
- Mission extension until 2017

SMOS – Soil Moisture and Ocean Salinity

smos

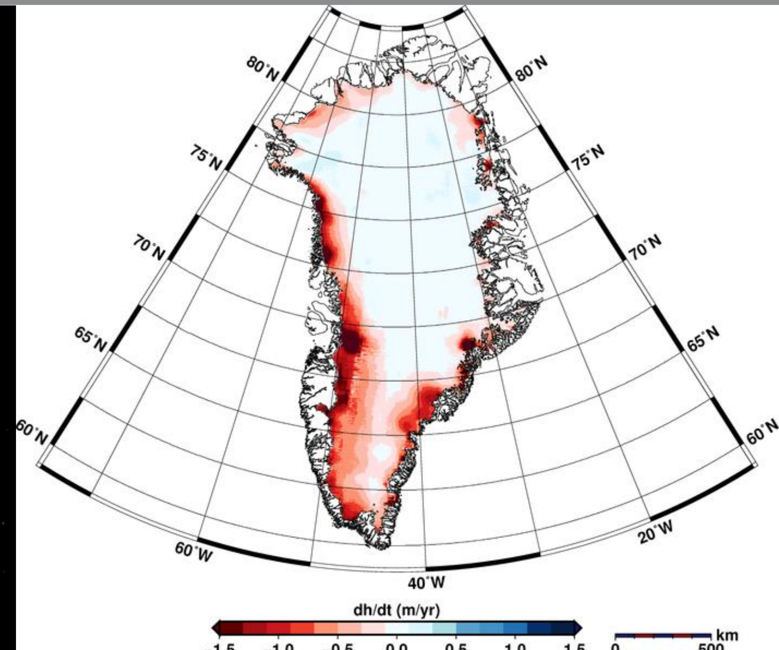
→ NOVEL CONCEPT

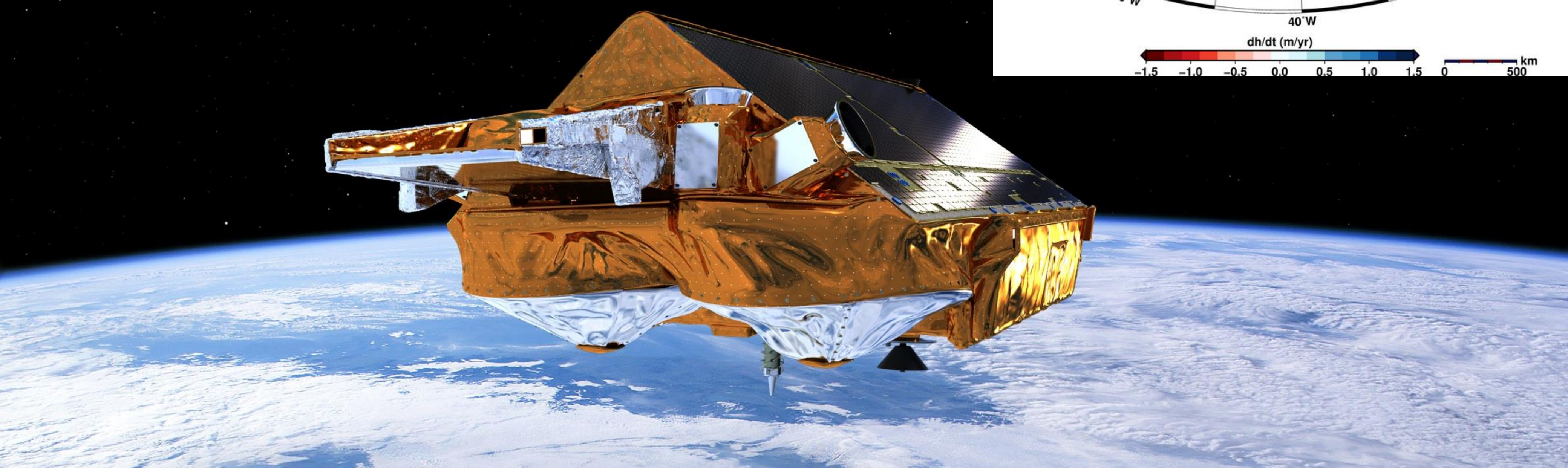


- L-band Microwave Imaging Radiometer with Aperture Synthesis
- Complete Earth coverage within three days
- ***Excellent status*** of space and ground segments
- No technical limitations to continue mission exploitation beyond 2017

CryoSat: The Ice Mission

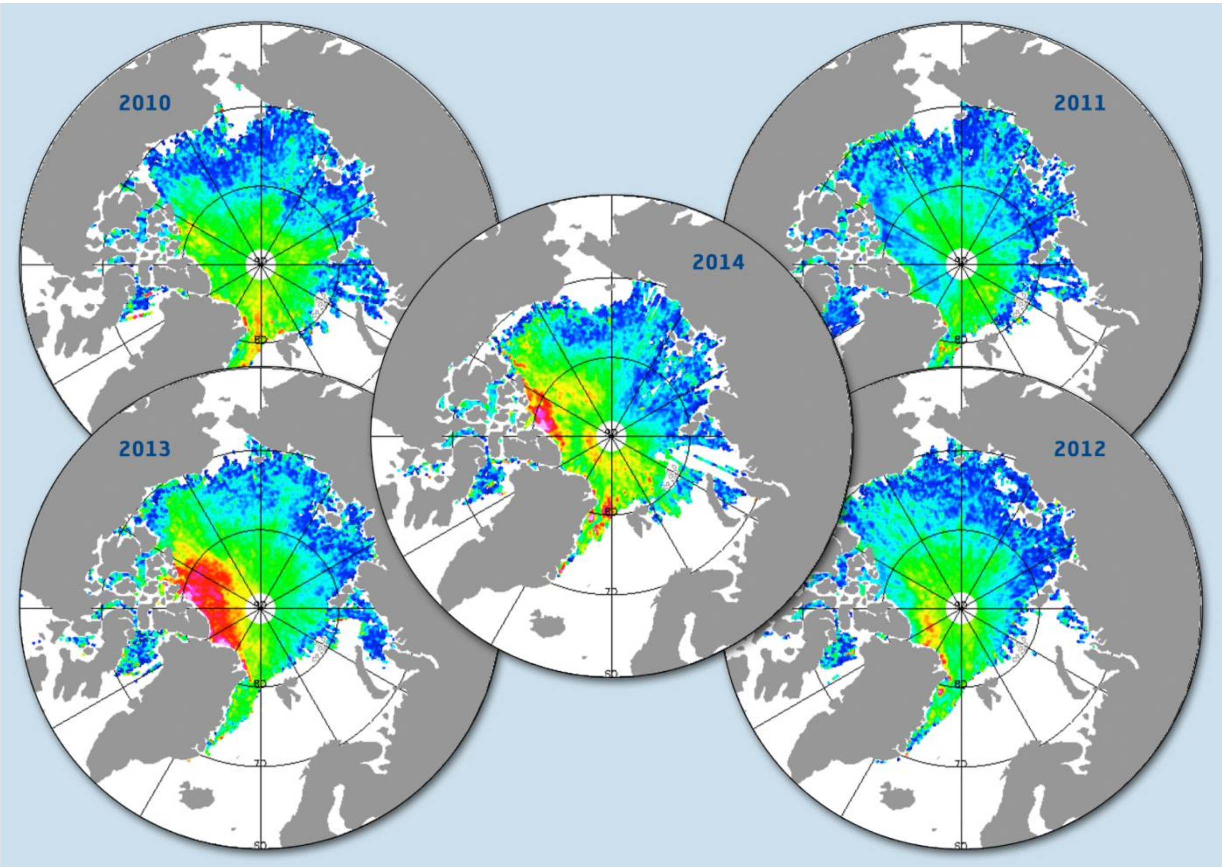
- First interferometric altimeter in space
- Global sea ice thickness measurements
- Data used for ice research, but increasingly also for oceanography
- Mission extension until 2017





CryoSat - the ice mission

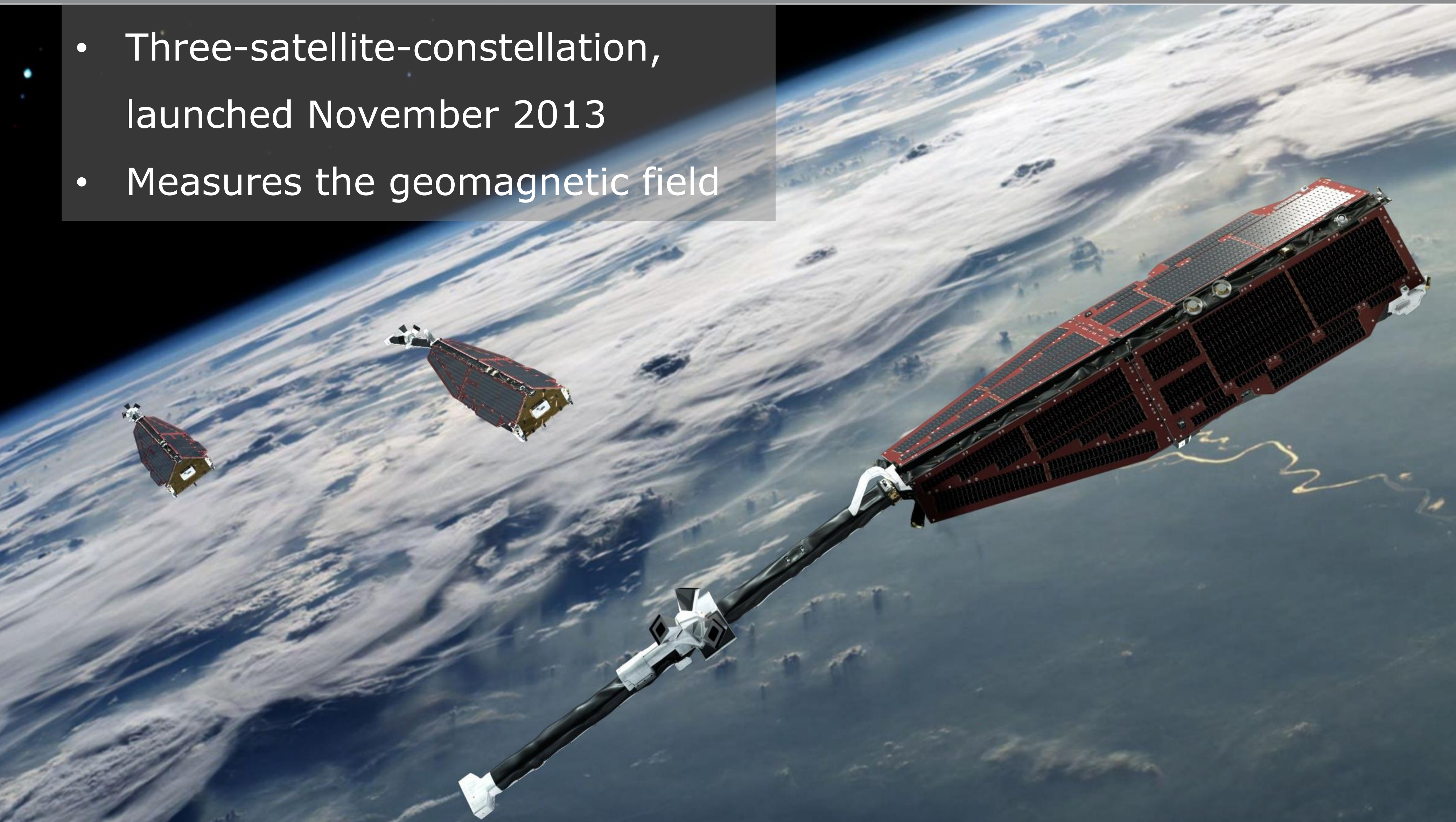
→ COOL TECHNOLOGY



- Sophisticated radar altimeter (3 modes of operations)
- Reaching higher latitudes than any other missions
- ***Excellent status*** of space and ground segments
- No technical limitations to continue mission exploitation beyond 2017

Swarm

- Three-satellite-constellation, launched November 2013
- Measures the geomagnetic field

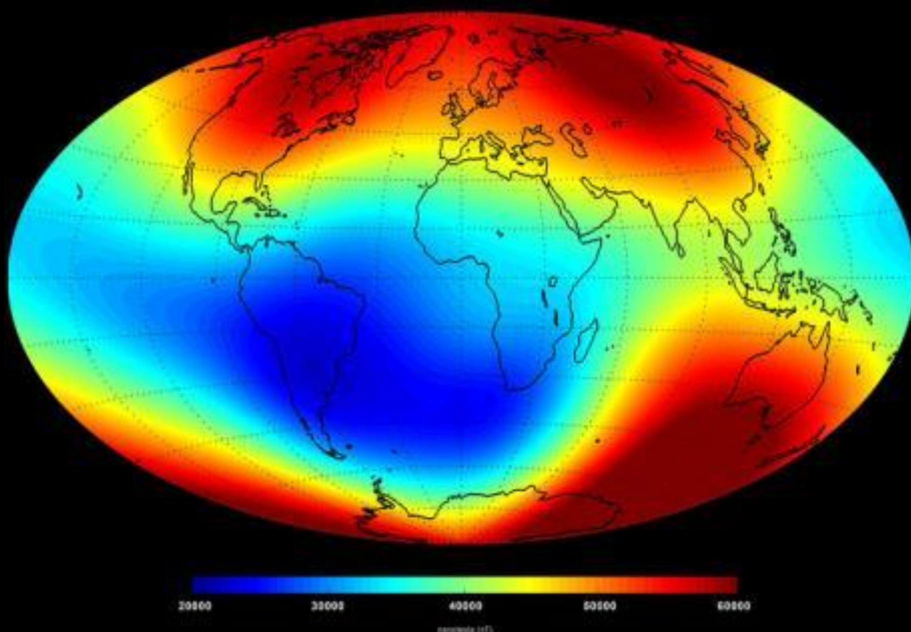


Swarm - the geomagnetism mission

esa

swarm

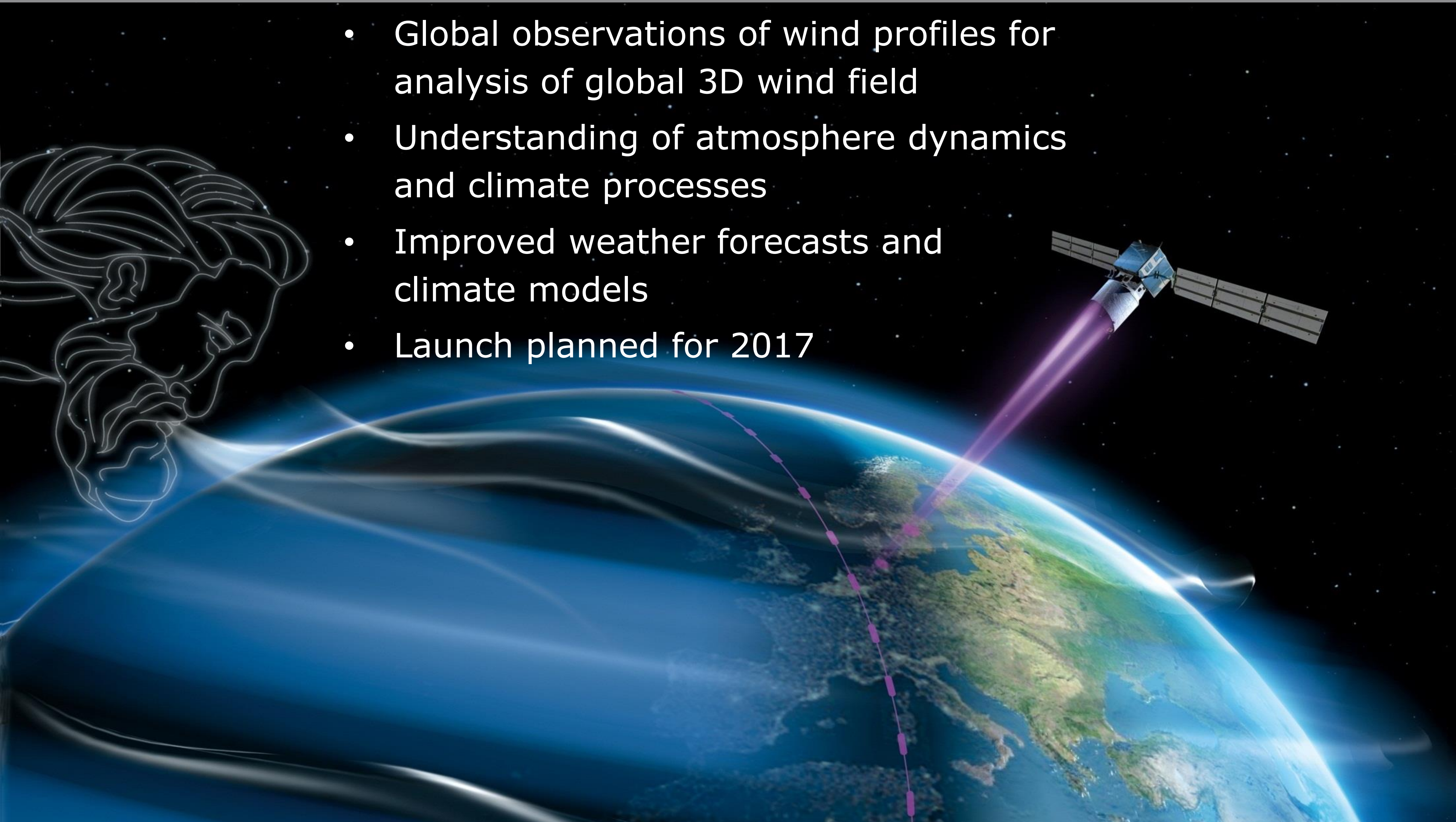
→ REVEALING THE EARTH COMPLEXITY



- Three identical satellites (Alpha, Bravo, Charlie) launched in 2013
- Constellation operating flawlessly, except for loss of Absolute Scalar Magnetometer on Charlie
- Magnetic measurement performance is brilliant; noise levels far below specification (1 nT)
- **First field models are all released and are of excellent quality**.

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
- Launch planned for 2017

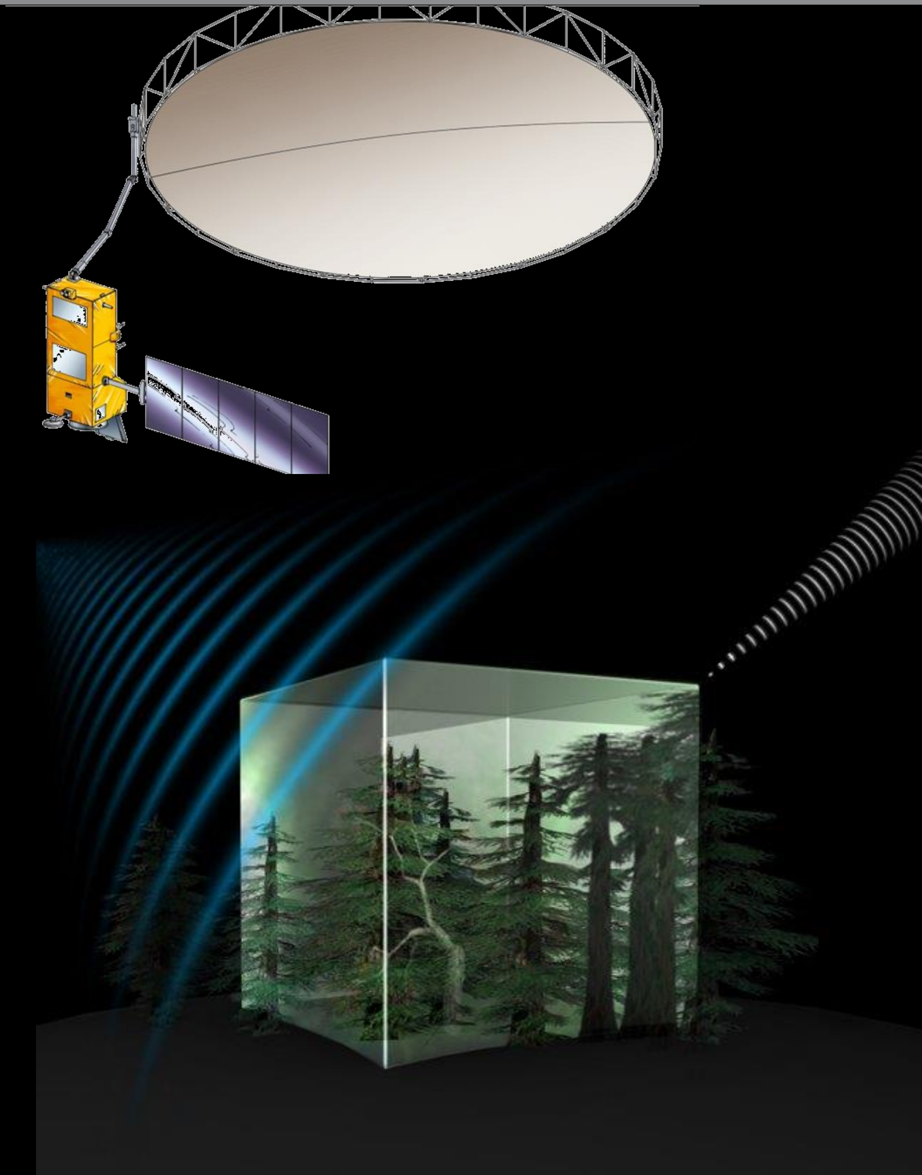


EarthCARE – ESA‘s Aerosol Mission

- Global observations of clouds, aerosols and radiation
- Collaboration with JAXA
- Scientific instruments:
  - First UV Lidar
  - First Doppler Cloud Profiling Radar (JAXA contribution)
  - Multispectral Imager
  - Broadband Radiometer
- Launch planned for 2018

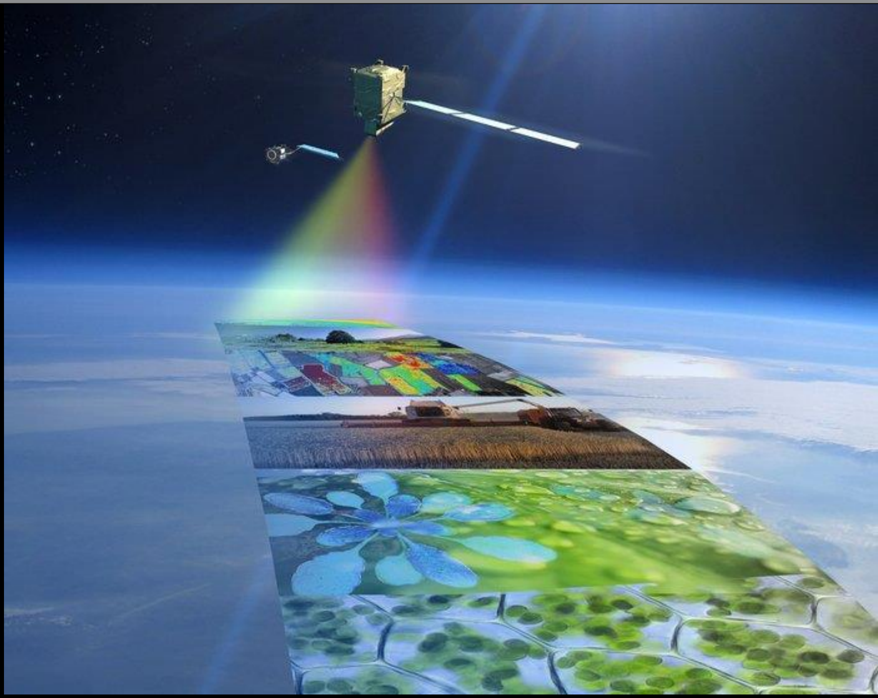
BIOMASS

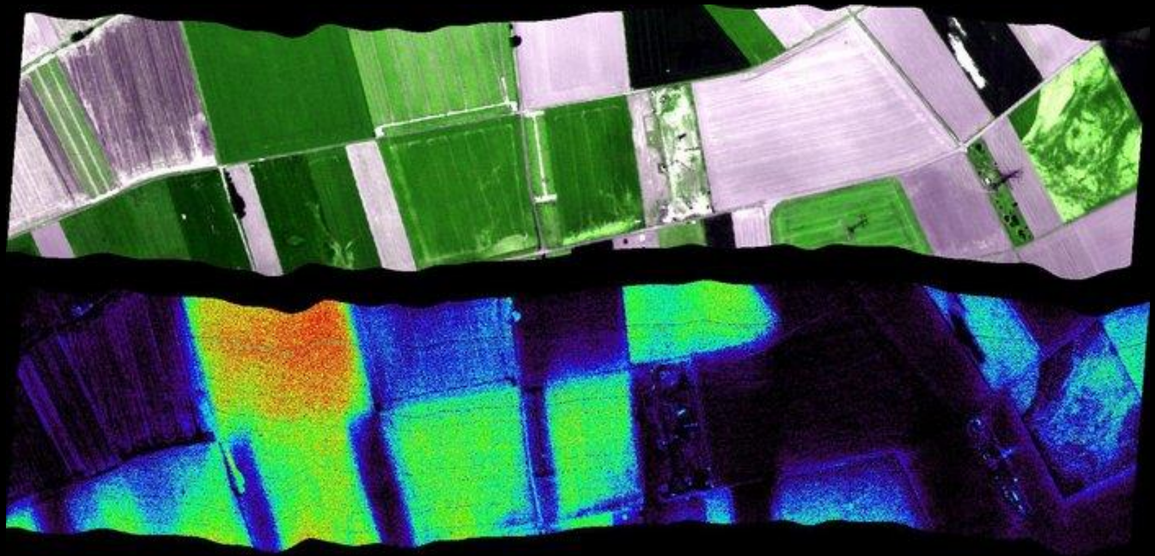
- 7th Earth Explorer
  - Selected by ESA's Earth Observation Programme Board
  - Biomass estimates based on global interferometric and polarimetric P-Band Radar observations
  - Essential to understand the Earth's carbon cycle
  - To be launched in 2021



FLEX, the 8th Earth Explorer

- decision by PB-EO in November 2015
- global maps of vegetation fluorescence, which can be converted into an indicator of photosynthetic activity





Copernicus: A New Generation of Data Sources

Sent-1A/B

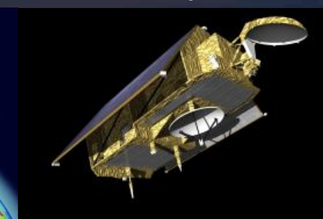
Sent-2A/B

Sent-3A/B

Sent-4A/B

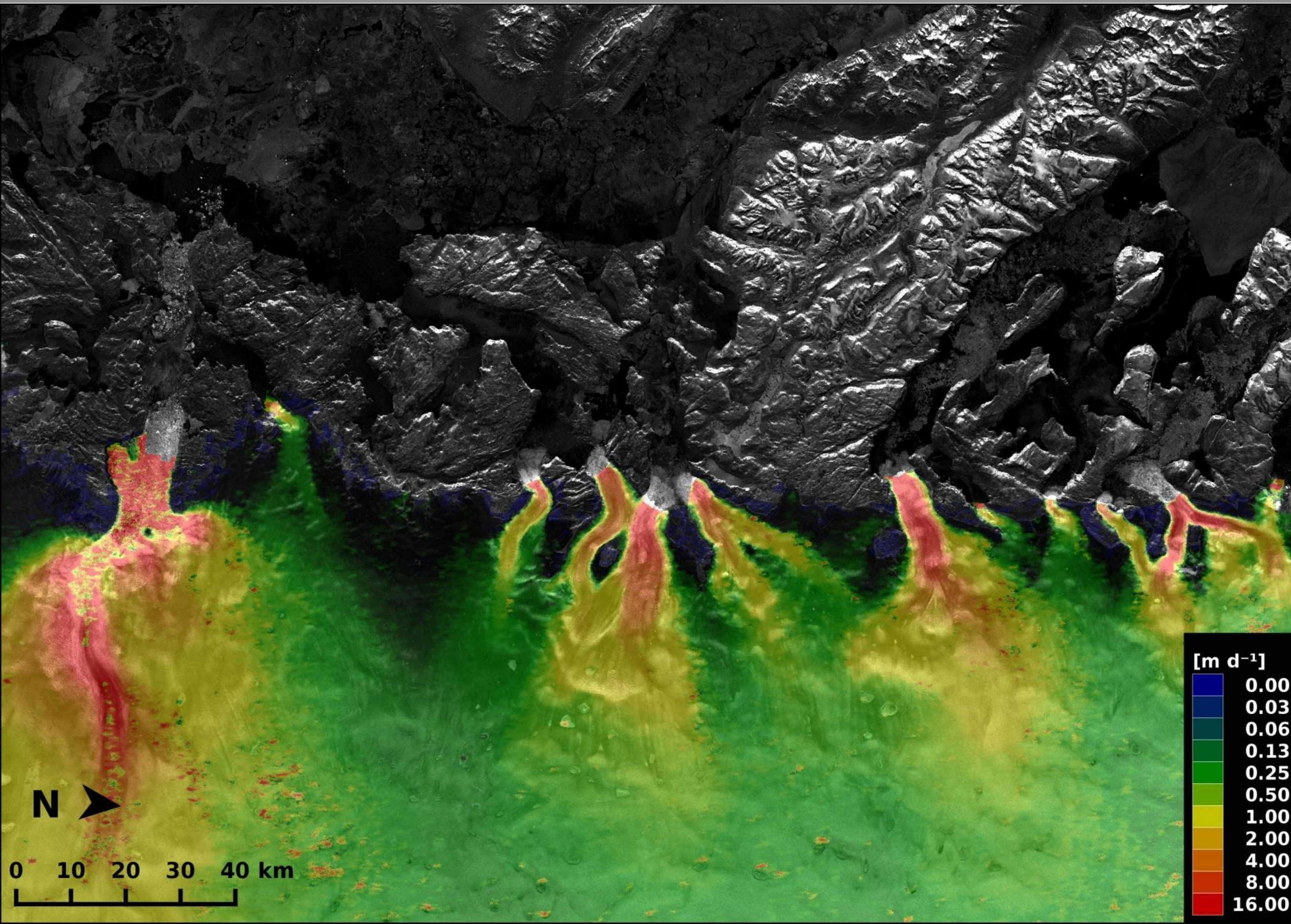
Sent-5/5P

Sent-6A/B



- Copernicus is a European space flagship programme led by the European Union
- ESA coordinates the space component
- Copernicus provides the necessary data for operational monitoring of the environment and for civil security
- Free and open data policy

Ice Streams seen by Sentinel-1A



Greenland,
West Coast

January 2015

Sentinel-1A Data Statistics

- free and open access

sentinels.copernicus.eu

Users and Products Statistics:
(status 21 March 2016)

- 27,407 registered users
- more than 457,000 products available for download
- 3.780,269 image downloads, representing 4.56 PB of data

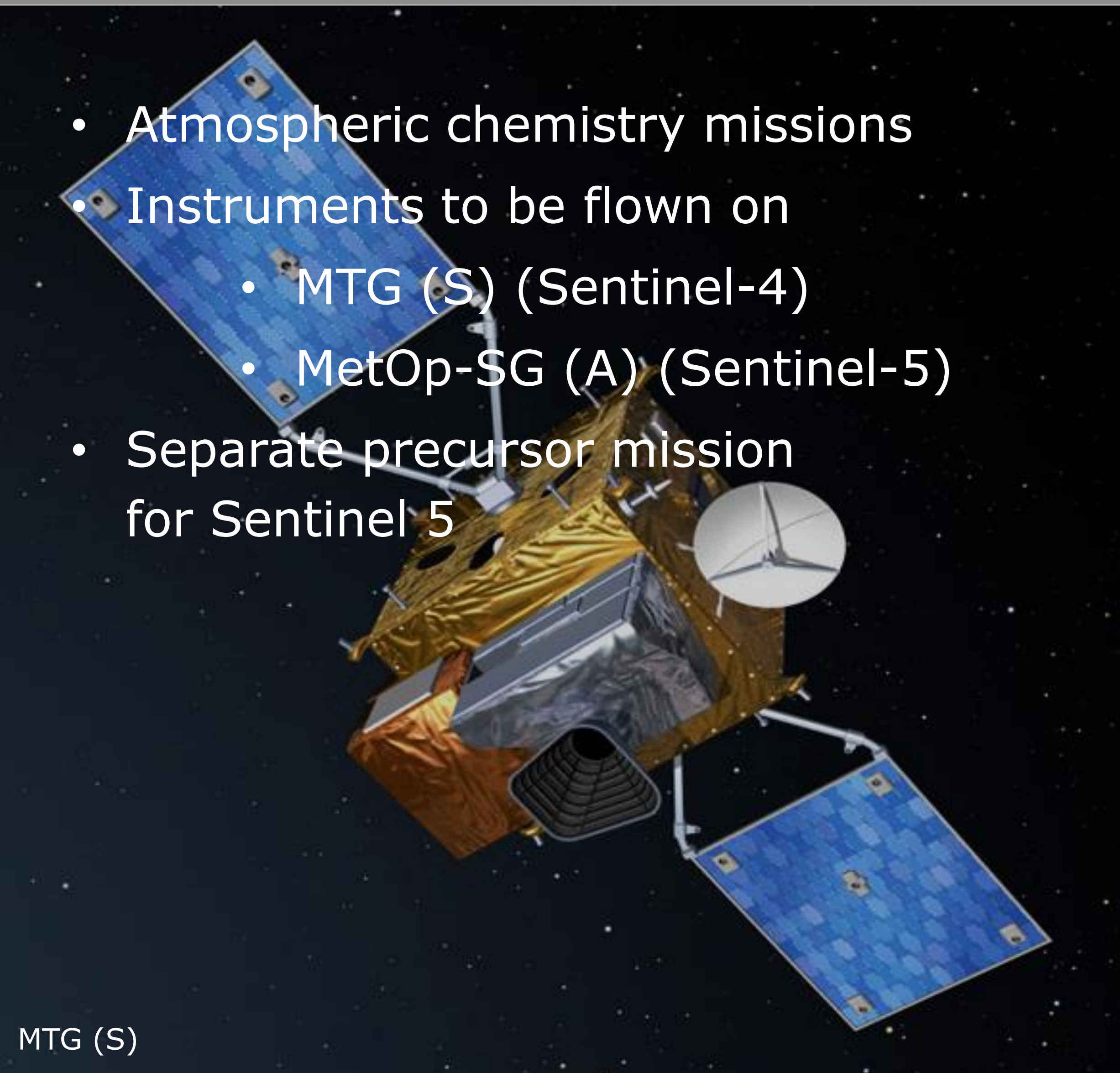
Sentinel-2A: First images

Sentinel-3A

- Image acquired on 1 March 2016
- OLCI (Ocean and Land Colour Instrument
- Continuity with ENVISAT MERIS FR data at 300 m

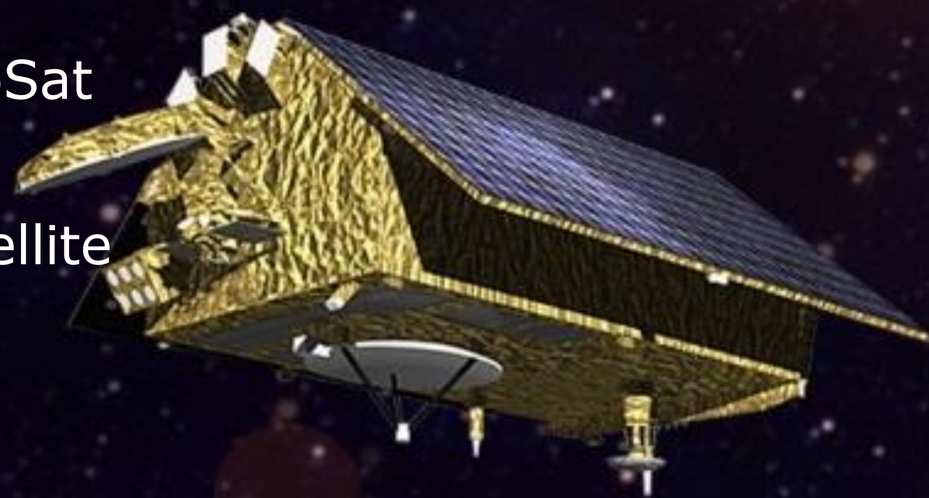
Sentinel-4/5/5p

- Atmospheric chemistry missions
- Instruments to be flown on
    - MTG (S) (Sentinel-4)
    - MetOp-SG (A) (Sentinel-5)
- Separate precursor mission for Sentinel 5

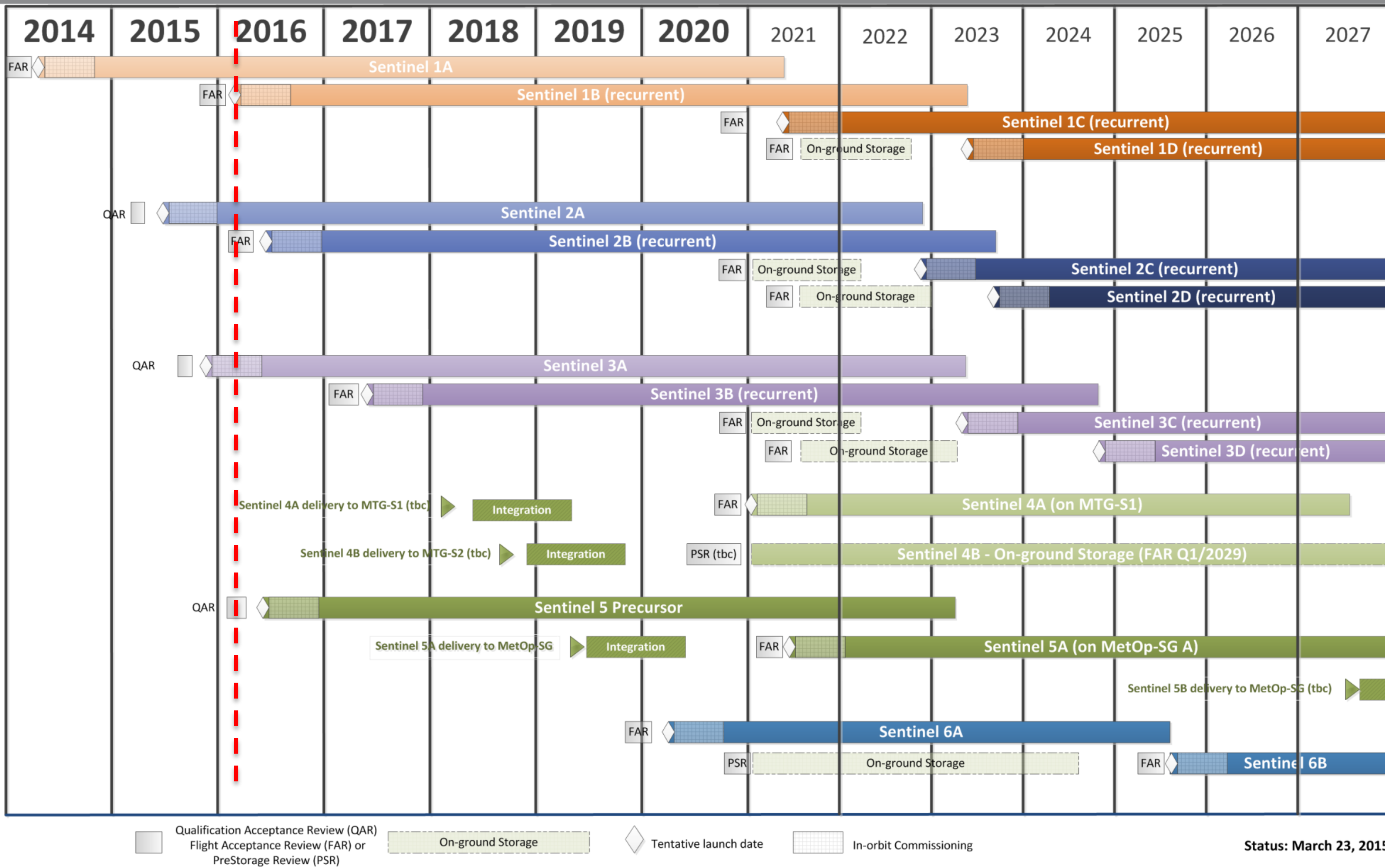


Sentinel-6 / Jason CS

- To provide continuity of the reference, high-precision ocean topography service after Jason-3
- Configuration based on CryoSat
- ESA is responsible for the development of the first satellite
- EUMETSAT in charge of the system definition and is responsible for the ground segment
- Cooperation with NASA & NOAA



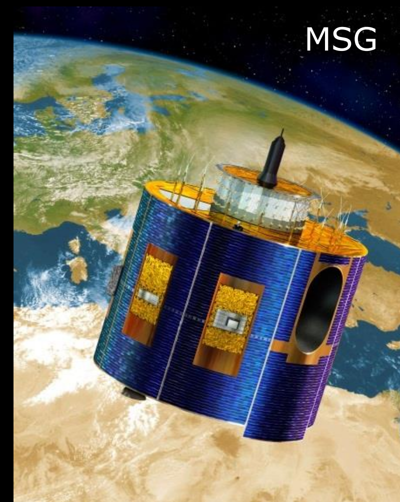
Tentative Sentinel Schedule

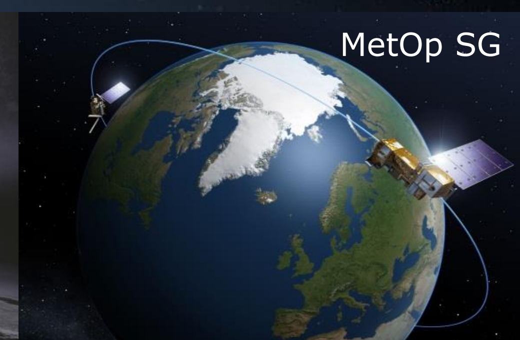


Status: March 23, 2015

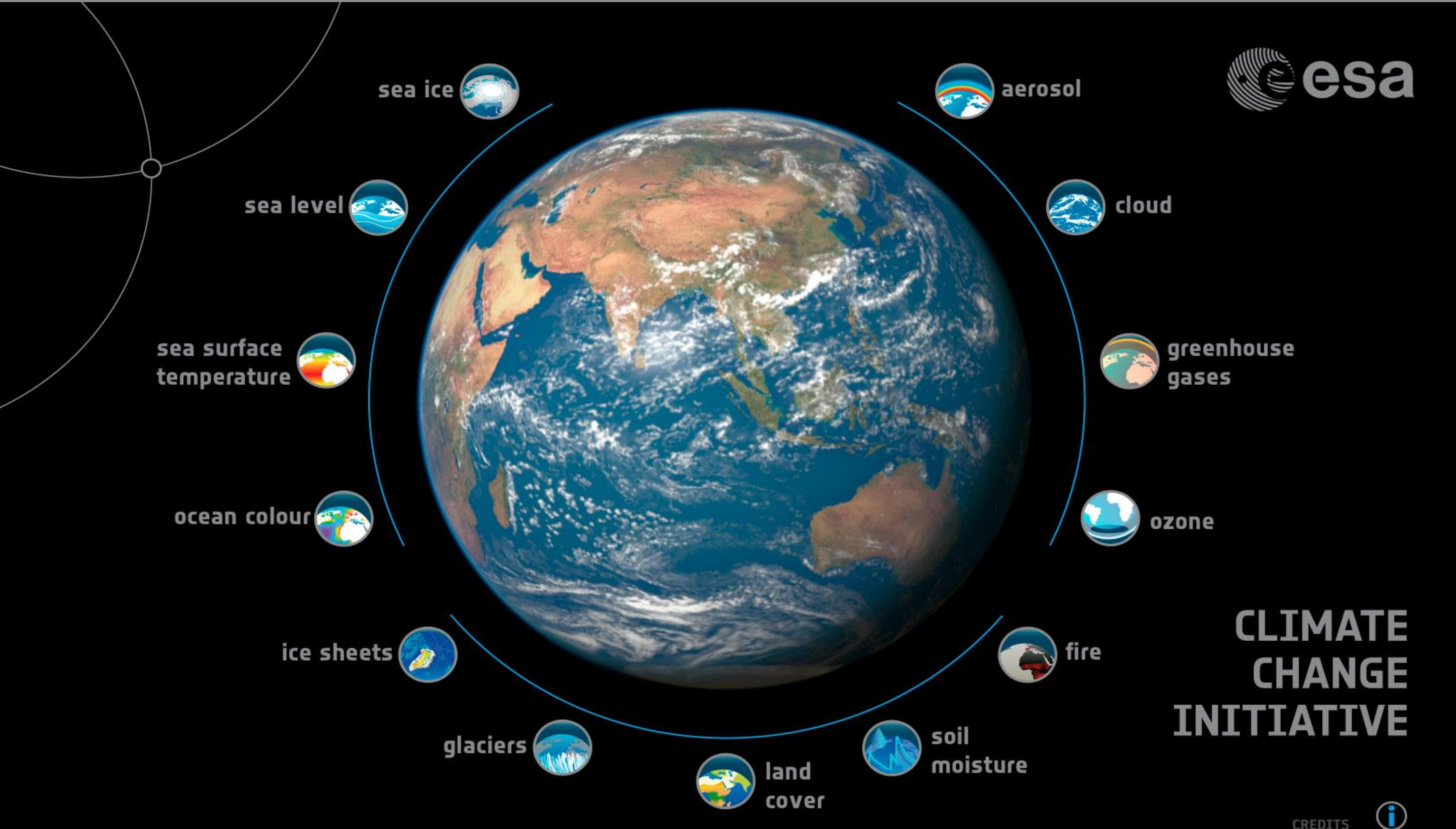
Meteorological Missions

- ESA develops prototype satellites and, on behalf of EUMETSAT, procures recurrent satellites
- EUMETSAT operates the satellites
- Currently Meteosat Second Generation (MSG) missions in GEO and MetOp missions in LEO
- MeteoSat Third Generation (MTG) and MetOp Second Generation under development
- MSG-4 launched 15 July 2015





CCI: Essential Climate Variables



ESAS2017 on international Collaboration

From Project Summary (20 March 2015) on Decadal Survey for Earth Science and Applications from Space (ESAS2017):

"… The Committee may also identify:

- potential interagency and international synergies
- proposed augmentations to planned international missions
- and adjustments to U.S. missions planned, but not yet implemented…."

ESA's EO Science Strategy at a glance (2014)

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

International cooperation ESA-NASA in Earth Observation (1)

- Formal ESA/NASA Earth Science and Observation Framework for Cooperation signed on 7 September 2010
- Setup of a joint NASA-ESA Earth Science **Joint Program Planning Group (JPPG)** to enhance cooperation in the area of Earth sciences, observation techniques, and applications including global climate change
- Annual joint meetings held dealing with three main collaboration domains:
  - WG-1: Mission and Technology
  - WG-2: Cal/Val and Field Campaigns
  - WG-3: Ground segment and data

International cooperation ESA-NASA in Earth Observation (2)

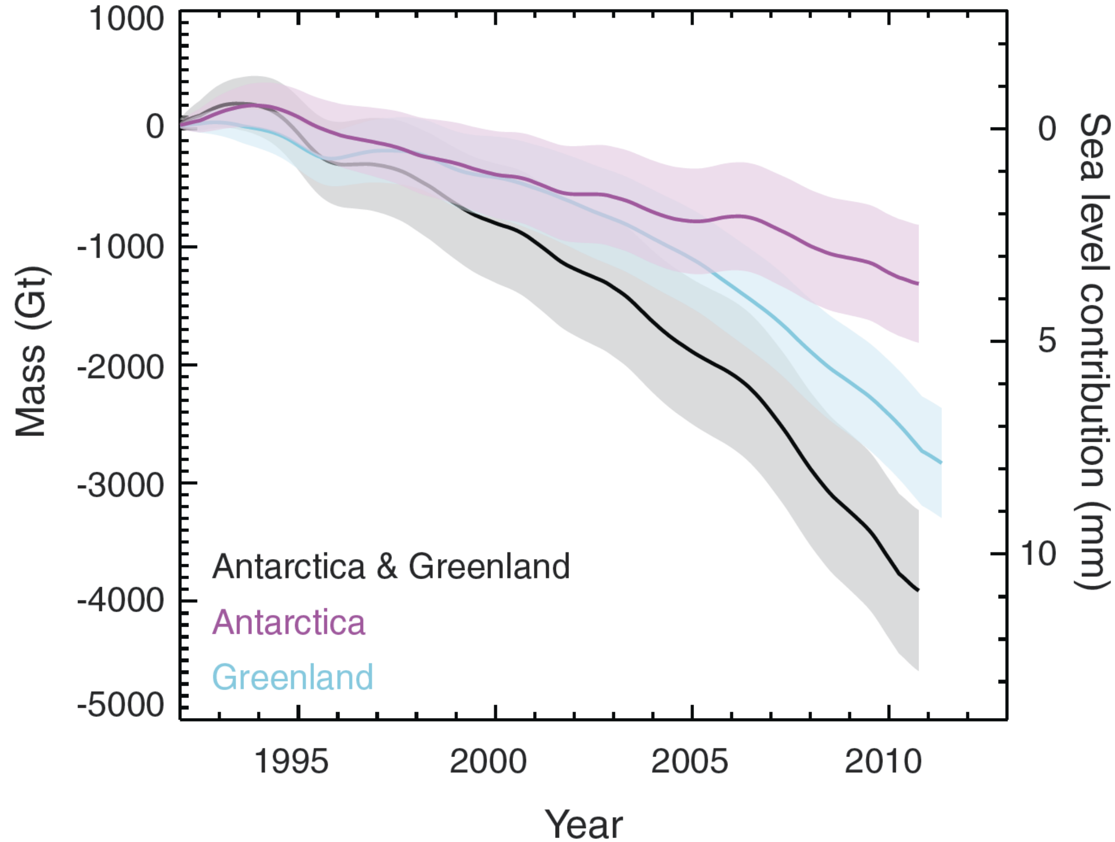
- Some major achievements of NASA-ESA JPPG:
  - Joint Arctic campaign for ICEBridge and CryoVex
  - Approved the exchange of the LDCM and S2 pre-launch calibration hardware
  - Bulk exchanges of MERIS/MODIS/SEAWIFS data sets
  - Set up International Science Working Group for joint gravity monitoring initiative (GRACE-2 from Decadal Survey plus ESA’s post-GOCE gravity mission)
  - Coordination and cross-participation in the on-going international constellation developments constellation/convoy effort
  - Support scientists participation in each other science teams (SDT/MAG)

International cooperation ESA-NASA in Earth Observation (3)

- Potential for future cooperation
  - Use of Sentinel-2 in the NASA Sustained Land Imaging (LI) within joint effort on future global land monitoring (extendable to multi-spectral imaging in VNIR/SWIR/TIR, hyper-spectral imaging, persistent imaging,..)
  - Cal/Val & cross-calibration activities (e.g. SMOS/Aquarius/SMAP, CryoSat/IceSat-2, S-2/LDCM, EarthCare/Capliso/Cloudsat)
  - Biomass (collaboration with NASA/JPL on large deployable reflector LDR)
  - Define scenarios with satellites in constellation/formation (each Agency contributing with its own missions) towards common objectives
  - Flight opportunities to embark one each other's instrument
  - Joint (or at least coordinate) Calls for missions
- Cooperation to be based on
  - Complementarity, unless strategic for a partner
  - Build "real constellations" besides "virtual constellations"
  - If hardware exchange, favor senior/junior partnership

International Cooperation (IMBIE)
Ice mass balance intercomparison exercice

- ESA and NASA supported
- Contribution to AR5
- Reconciled satellite estimates of ice sheet mass balance
  - Radar altimetry
  - Laser altimetry
  - Gravitmetry
  - Radar (INSAR)



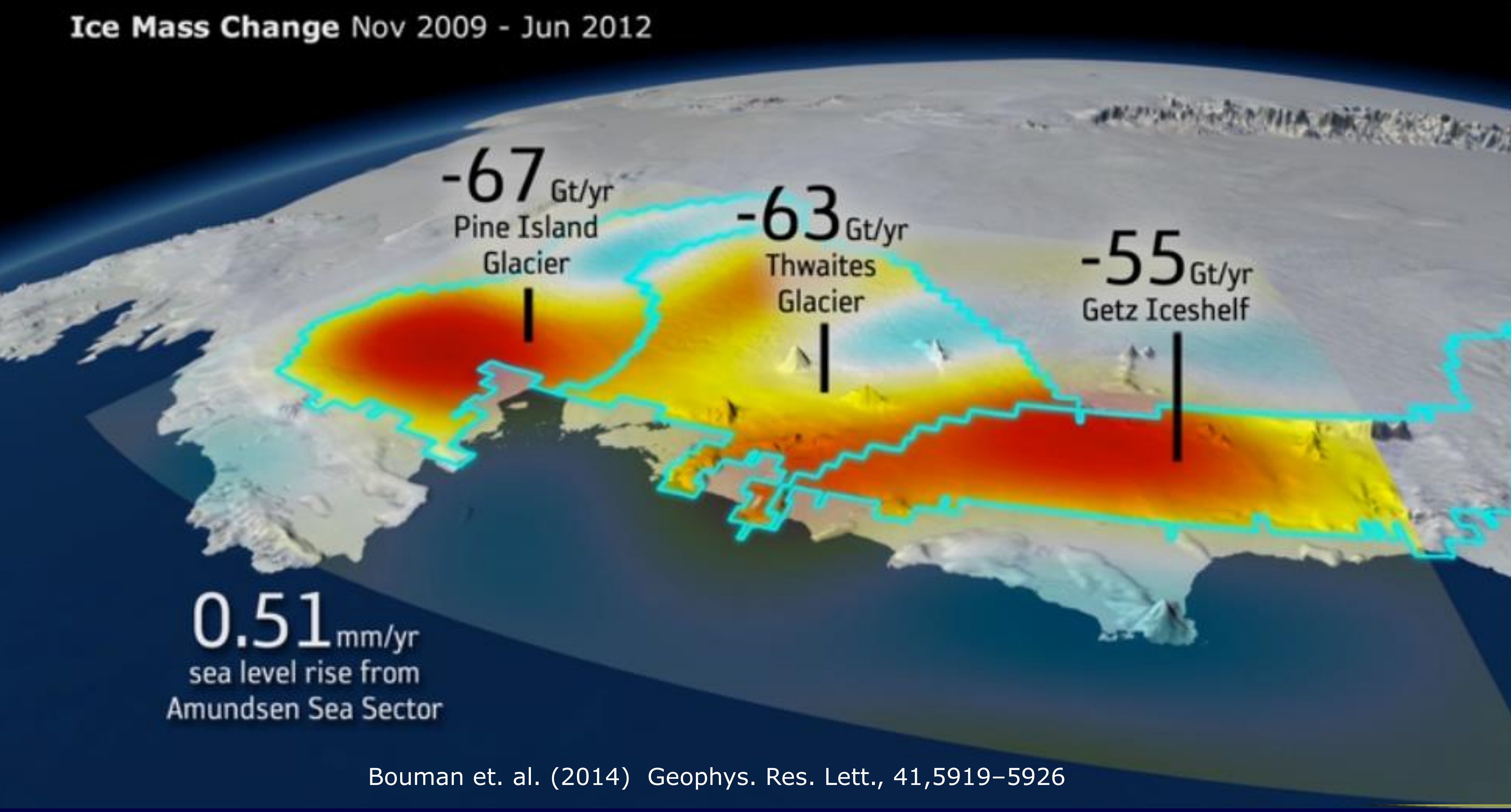
A Reconciled Estimate of Ice-Sheet Mass Balance

Andrew Shepherd,[1*] Erik R. Ivins,[2*] Geruo A,[3] Valentina R. Barletta,[4] Mike J. Bentley,[5] Srinivas Bettadpur,[6] Kate H. Briggs,[1] David H. Bromwich,[7] René Forsberg,[4] Natalia Galin,[8] Martin Horwath,[9] Stan Jacobs,[10] Ian Joughin,[11] Matt A. King,[12,27] Jan T. M. Lenaerts,[13] Jilu Li,[14] Stefan R. M. Ligtenberg,[13] Adrian Luckman,[15] Scott B. Luthcke,[16] Malcolm McMillan,[1] Rakia Meister,[8] Glenn Milne,[17] Jeremie Mouginot,[18] Alan Muir,[8] Julien P. Nicolas,[7] John Paden,[14] Antony J. Payne,[19] Hamish Pritchard,[20] Eric Rignot,[18,2] Helmut Rott,[21] Louise Sandberg Sørensen,[4] Ted A. Scambos,[22] Bernd Scheuchl,[18] Ernst J. O. Schrama,[23] Ben Smith,[11] Aud V. Sundal,[1] Jan H. van Angelen,[13] Willem J. van de Berg,[13] Michiel R. van den Broeke,[13] David G. Vaughan,[20] Isabella Velicogna,[18,2] John Wahr,[3] Pippa L. Whitehouse,[5] Duncan J. Wingham,[8] Donghui Yi,[24] Duncan Young,[25] H. Jay Zwally[26]

SCIENCE VOL 338 30 NOVEMBER 2012

International Cooperation

First combination of GOCE & GRACE gravity gradients for improved resolution



Bouman et. al. (2014) Geophys. Res. Lett., 41,5919–5926

ESA-NASA Sentinel-2 & Landsat
Research Cooperation

Common S2 & L8 Research community

- Recurrent (annual) scientific workshops alternating between US and Europe
- Focus on S2 & L8 synergy & products
- Supported by NASA and ESA research activities (e.g. tools, portable archives)

Coordination of ESA & NASA research

- Set up of an international Land Imaging Science Team with focus on L8 & S2 synergy
- Coordination of parallel research calls from ESA and NASA on land imaging (e.g. Multi-Source Land Imaging and DUE Innovator calls)

Building a European & US research community

Common scientific workshops

- MuSLI (Multi-Source Land Imaging) Science Team meeting, 20-21th April – Washington DC, US
- 2nd EARSeL LULC/NASA LCLUC Workshop, 6–7th May Prague, Czech Republic
- Special Sessions – S2 & L8 exploitation synergy – Living Planet Symposium, 9th May, Prague
- CEOS-WGCV Atmospheric Correction Inter-comparison Exercise (1st ACIX), 21-22nd June, Washington
- ESA participation to the Landsat Science Team

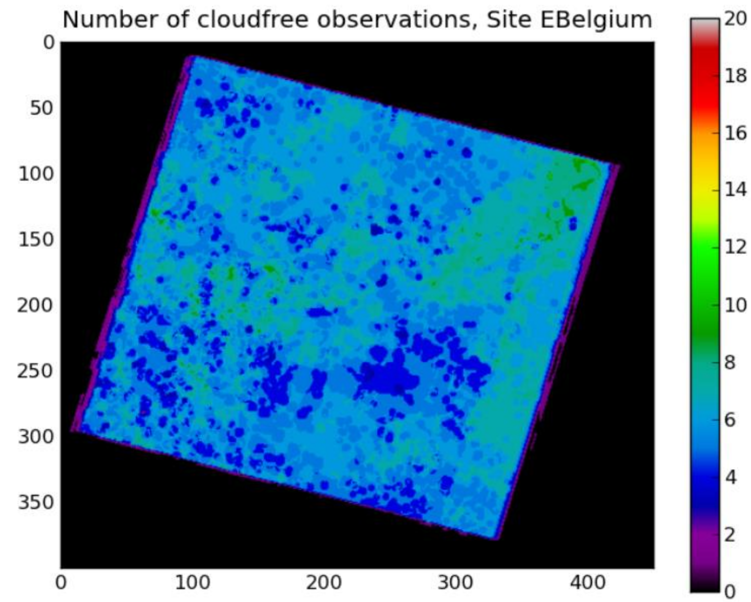
Land-Cover / Land-Use Change

S-2 & Landsat long-term continuity

- Historic Landsat archives necessary for long-term monitoring
- Continuity improved with Sentinel-2
- Exchange of archives and cross-calibration required

S-2 & Landsat coverage

- S-2 5 days revisit does not guarantee sufficient temporal coverage for services
- S-2a/b + L7/8 missions increase revisit to 3.1 days



Spot4-Take5 Belgium: Cloud free pixels, with 5 days revisit in 4 months

Post GOCE & GRACE-FO mission:
→ *community urging to implement long-term gravity/mass transport measurement system (2015)*

UGGI
IUGG

International Union of Geodesy and Geophysics

Resolutions

ADOPTED BY THE COUNCIL
AT THE XXVI GENERAL ASSEMBLY
PRAGUE, CZECH REPUBLIC
(22 JUNE – 2 JULY 2015)

- ✓ IUGG (Int. Union of Geodesy and Geophysics) embodies all geophysical and geodetic disciplines
- ✓ Represents about 100,000 users worldwide,
- ✓ Resolution 2 is the only resolution which makes explicit mention of satellite missions → GRACE (FO), GOCE & Swarm

Resolution 2:

Future Satellite Gravity and Magnetic Mission Constellations

The International Union of Geodesy and Geophysics

Considering

- The interest and need of the IUGG scientific community to understand processes of global mass transport in the Earth system, and the interaction among its subsystems including continental hydrology, cryosphere, atmosphere, ocean and solid Earth, in order to close the global water budget and to quantify the climate evolution of the Earth,
- The long lead time required to bring an earth observation system into operation,

Acknowledging

- The experience acquired in the last decade within the IUGG in analyzing data from dedicated satellite missions such as CHAMP, GRACE, GOCE and Swarm for the purpose of estimating the gravity and magnetic fields and their time variations,
- The clear expression of need from the user communities so far, and the definition of joint science and user requirements for a future satellite gravity field mission constellation by an international working team under the umbrella of IUGG,

Noting

- The need for a long-term sustained observation of the gravity and magnetic fields and related mass transport processes of the Earth beyond the lifetime of GRACE and the GRACE Follow-On planned for the 2017 - 2022 period, and beyond the lifetime of Swarm, currently 2013 to 2018,
- The demonstrated need for satellite constellations to improve temporal and spatial resolution and to reduce aliasing effects,

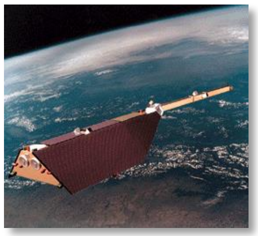
Urges

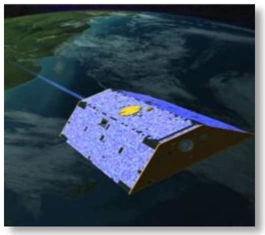
International and national institutions, agencies and governmental bodies in charge of supporting Earth science research to make all efforts to implement long-term satellite gravity and magnetic observation constellations with high accuracy that respond to the aforementioned need for sustained observation.

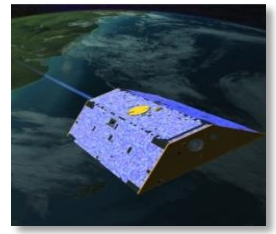
Past, present and "near" future mission ideas to meet community science and application needs?

esa

Past, present and planned







CHAMP

GRACE

GRACE FO

GOCE

2000 2010 2020 2030

Future constellation

Continuation of observations at lower resolution

more accurate & better space/time resolution

GRACE II (NASA)

NGGM (ESA)

Start of sustained observations at high resolution

Simulation studies show that an ESA/NASA collaborative future constellation will provide more return than the sum of two missions

Example collaboration: Atmospheric CO_2/CH_4 (EE8 CarbonSat, HyspIRI, OCO)

esa

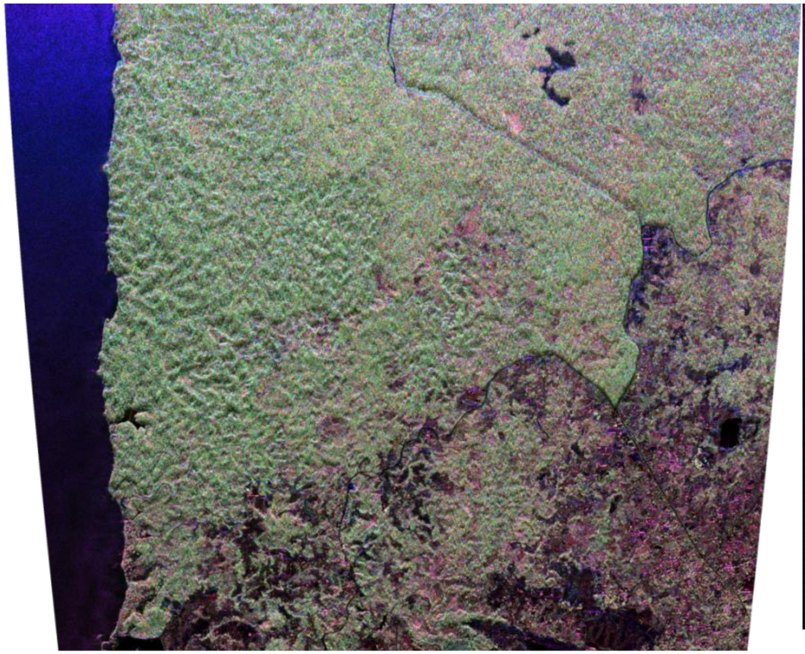
- Demonstrate synergies between higher spectral resolution non-imaging and lower spectral resolution imaging spectroscopy
- Truly "joint" airborne campaign from very start
  - ESA and NASA airborne payloads and science expertise
  - Campaign objectives elaborated jointly by European and US PIs
  - Science review by science reviewers (NASA) and Mission Advisory Group (ESA)
- Campaign details (Spring 2014, USA)
  - NASA HyspIRI campaign (AVIRIS instrument) + ESA-funded MAMAP
  - MAKO (Aerospace, Corp.) is a TIR HSI spectrometer
  - Picarro GHG sensor
- Precursor surface-based dat place already!

Example Collaboration in Airborne campaigns: AfriSAR

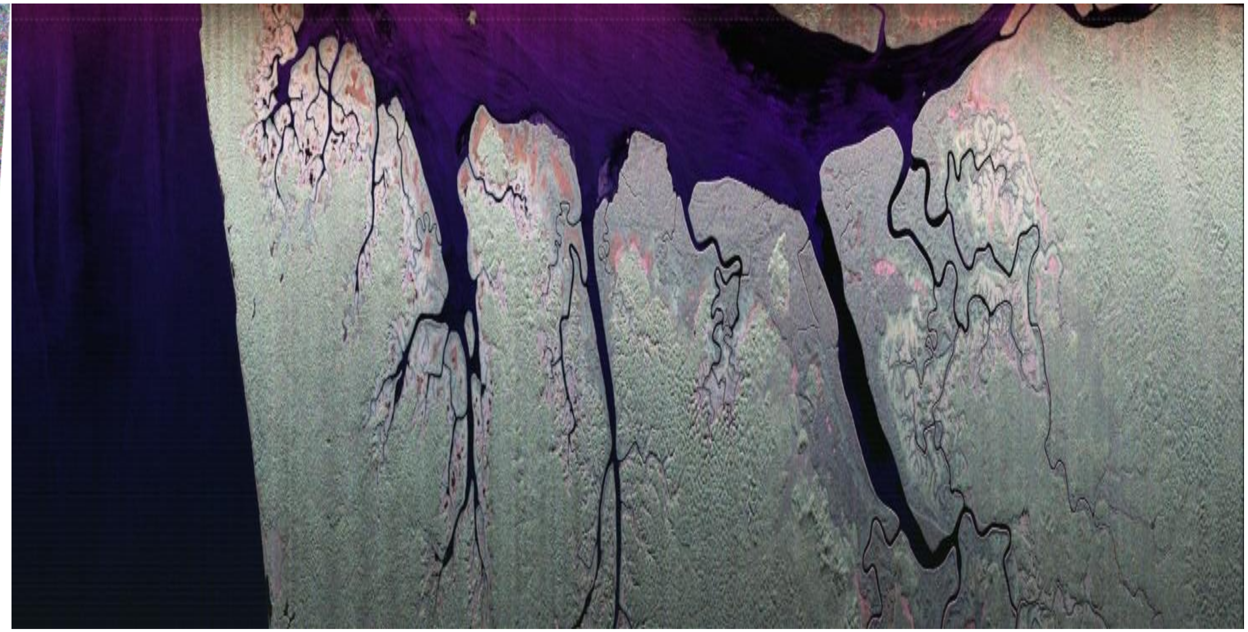
1. Three Missions one Goal – measure forest biomass and ecosystem dynamics.
   - NISAR (NASA-ISRO Synthetic Aperture Radar) is an L-band S-band spaceborne SAR (launch 2020)
   - GEDI (NASA Global Ecosystem Dynamics Initiative) is a spaceborne Lidar on the International Space Station (launch 2019)
   - BIOMASS (ESA) is a P-band spaceborne SAR (launch 2021)
2. AfriSAR – One campaign serving three missions and the forest ecosystem science community
   - Pooling of resources (airborne and in-situ ground work) and leveraging of existing international agreements (e.g. ESA with Gabon)
   - 4 Airborne Instruments: DLR F-SAR (P- and L-band SAR), ONERA Sethi (P-band SAR), JPL UAVSAR (L-band SAR), GSFC LVIS (canopy lidar)
   - Joint operations collocated in time (February/March 2016) and in space (Gabon, Africa)
   - Enhanced ecosystem coverage throughc cooperation
   - Support research into the synergistic use of lidar/SAR for ecosystem mapping and enable development of science products and validation
   - Unique opportunity to compare and cross-calibrate US and European airborne instruments

AfriSAR first images – Airborne SAR at L- and P-band and lidar

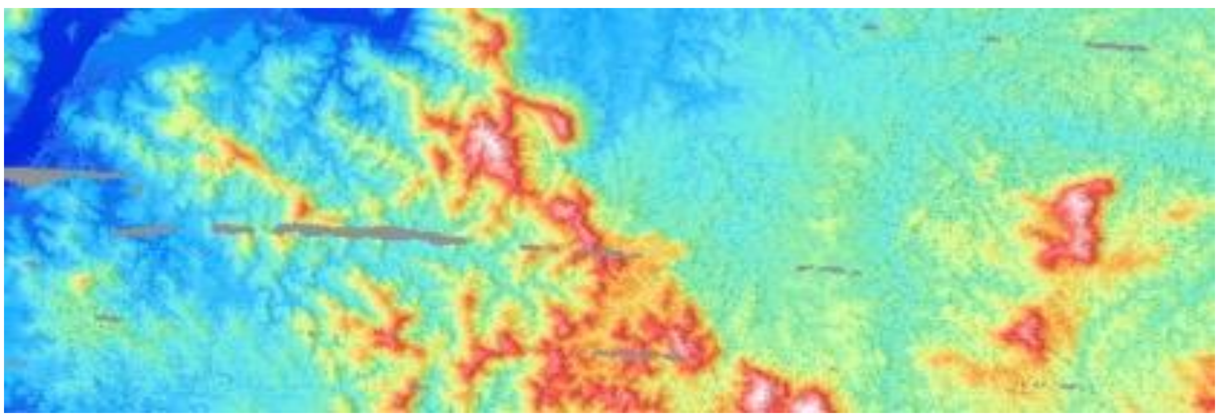
P-band SAR image (ESA/DLR)



L-band SAR image (UAVSAR NASA/JPL)

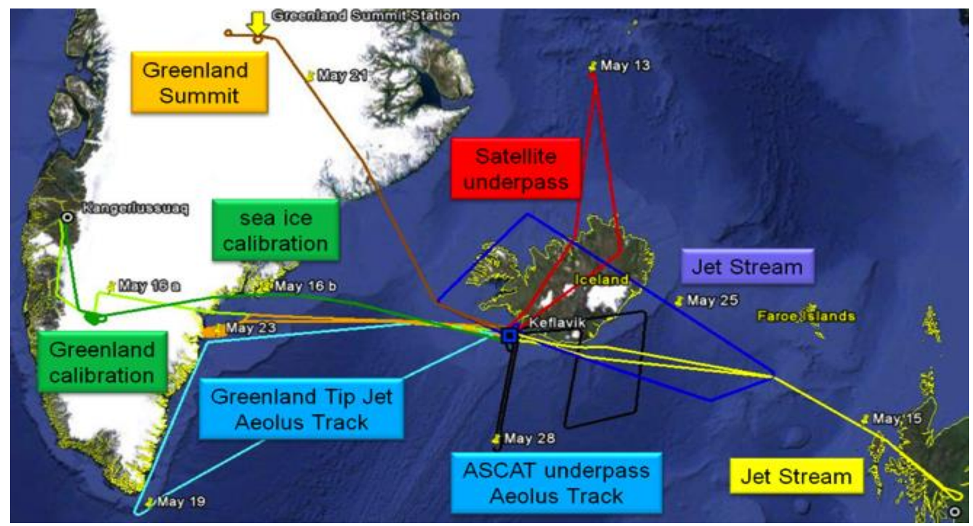


Lidar image (LVIS/NASA)



ADM-Aeolus: WindVal Campaign

- **Objectives**
  - Fill data gaps on Rayleigh and Mie wind observations including highly variable wind conditions and heterogeneous conditions
  - Extend dataset on response calibrations over ice or land in nadir-pointing mode
  - Preparation for post-launch validation campaigns (i.e. rehearsal)
- **Campaign details**
  - Campaign executed in collaboration with DLR, NASA and NSF in May 2015
  - First time with collocated 4 Wind Lidars on 2 aircraft
  - DLR Payload: The ALADIN airborne demonstrator + 2-µm reference wind lidar
  - Data processing and analyses underway



ESA/NASA JPPG Sub-Group

Ground Segment and Data Systems

- ✓ Key Objectives: Exchange basic information on ESA and NASA Earth Observation missions data, suborbital campaigns
- ✓ Collaboration Topics: EO Data Exchange, Technical Interfaces: Information Sharing & Improved Interoperabilit

Activities status:

- 2013: ***Exchange of data*** (Envisat MERIS / Aqua MODIS)
- 2016: ***Sentinel*** data access for US through NASA Sentinel gateway:
  → *signed Sentinel Technical Operation Arrangement between ESA and NASA*
- On-going:
  - initiative in the area of user identification management / joint avocation of agreed ***standards*** in international forum (e.g. CEOS),
  - develop prioritized list of ***historical datasets*** to recover (preserve) for extending critical long-term science observations

ESA and NASA Earth Observation Programmes (Space missions)

ESA

- 1.8 B$ (2016), with Copernicus
- Mission en collaboration with international partners (JAXA) and Member States

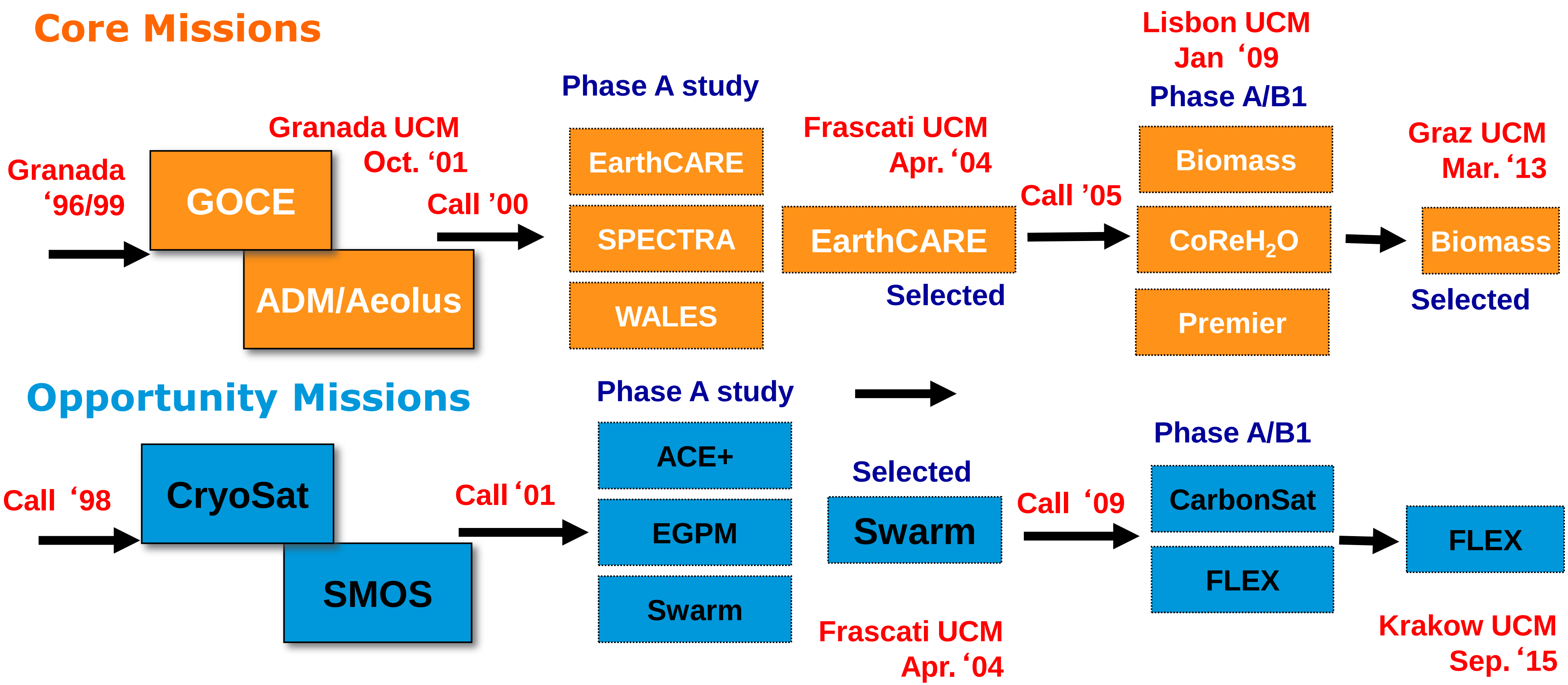
Collaboration ESA+NASA

- Some on Biomass
- S6

NASA

- 1.92 B$ (2016)
- Mission en collaboration with international partners (CNES, ISRO, DE)

Earth Explorer Missions History



Selection Criteria for Earth Explorer Candidate Missions

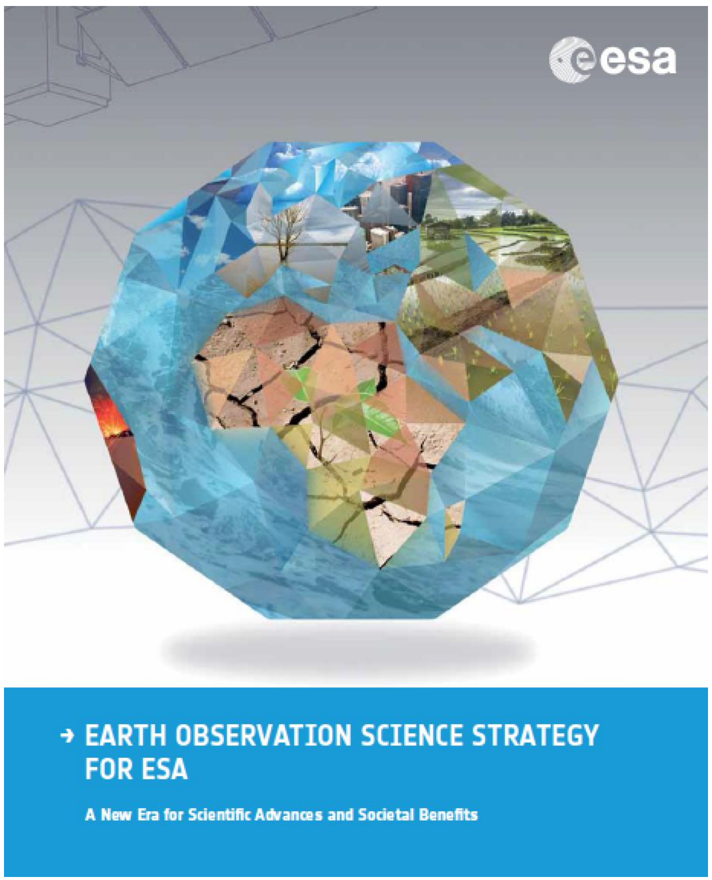
- **Relevance to the ESA research objectives for Earth Observation** - for this criterion reference must be made to the general and specific objectives and scientific challenges set forth in the documents 'Earth Observation Science Strategy for ESA' -A New Era for Scientific Advances and Societal Benefits and 'ESA's Living Planet Programme: Scientific Achievements and Future Challenges' – Scientific Context of the Earth Observation Science Strategy for ESA(ESA SP-1329/1+2, 2015). Here account shall be taken of how scientific advances anticipated from the mission contribute to addressing major societal issues.
- **Need, usefulness and excellence** - this must take account not only of scientific requirements and/or the importance of a mission viewed as a precursor but also the extent to which the requirements, including those of space/time sampling, can be met by the proposed mission.
- **Uniqueness and complementarity** - this must take account of other (i.e. not space) means of addressing the mission requirements as well as the activities and plans of other national and international bodies for space missions.
- **Degree of innovation and contribution to the advancement of European Earth Observation capabilities** - this relates to technical/industrial aspects as well as to user interests.
- **Feasibility and level of maturity** - this encompasses the technical constraints with a particular emphasis on the technology readiness, and the scientific readiness, as well as the status of the associated user community within ESA member states and the maturity of its requirements.
- **Timeliness** - this must take account not only of the timeliness of a mission from the point of view of user needs but also with regard to implementation constraints.
- **Programmatics** - in addition to the considerations of development schedule, cost, risk, etc. (set within the overall Earth Explorer Programme), this addresses the implications of possible cooperation with other bodies, including synergies with other national and international developments, and taking account of the planned availability of relevant data from other observing systems

Decadal Survey and impact on ESA planning (1)

- ESA has its own Earth science strategy setup in the mid-1990's and keeps it regularly updated (new issue in 2014)
- Next programmatic decision for ESA EOEP programme will be end 2016 for which international collaboration is emphasized
- ESA would welcome a closer interaction with NASA on next EO science missions
    - Overall science objectives
    - Programmatics
    - Options for synergistic Earth observation efforts

New ESA EO Science Strategy

- Developed by ESA Earth Science Advisory Committee (ESAC) 2012-2014
- Endorsed by PB-EO in 2014



Decadal Survey and impact on ESA planning (2)

- Based on the 2012 Mid-term Assessment of NASA's Implementation of the Decadal Survey, a closer NASA-ESA collaboration could yield:
  - Mission harmonization and synergy
  - Improve the balance between prioritizing science objectives and constraining how those objectives are accomplished
  - Contribute to a better use of funding to develop an all-encompassing program to enhance every aspect of Earth system science
  - Foster the EO science collaboration between the US and Europe

International Collaboration

- International cooperation is not only an opportunity but a “must”
    - Number of excellent and urgent proposals from science increases while the budgets stay constant
    - Cannot afford to double efforts anymore and need to work more than in the past together
    - Flying constellations (convoys) with international partners to reach a larger objective compared to a single mission

- Promising cooperation between ESA and NASA but could be firmed up in the future

Conclusions

- ESA keen in a balanced and reliable cooperation with NASA in the frame of Earth observation

- Strong synergy between the priorities of the NASA Decadal Survey and ESA’s future EO plans => Obvious cooperation

- Concerns not only NASA and ESA but other Space Agencies

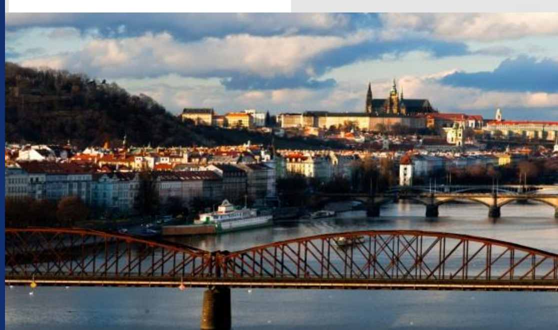
Upcoming LPS

PRAGUE 09-13 MAY 2016

Main Objective: Presentation of Exploitation Results based on ESA Earth Observation Measurements

http://lps16.esa.int

European Space Agency



Thank you for your attention

European Space Agency