Future ESA Missions to Observe the Ocean and Ice Surface

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Introduction

Goal

- What do we have and what will we have? (i.e. in implementation or preparation) contributing to ocean/ice data products
- Overview of primary missions in Research and Operational domains
- Long term outlook for Evolution of Copernicus space capability

Contents in relation to ESA programmes:

- ESA's Living Planet Programme
- Operational Met Missions
- Copernicus Missions
- Copernicus Evolution

ESA's Living Planet Programme

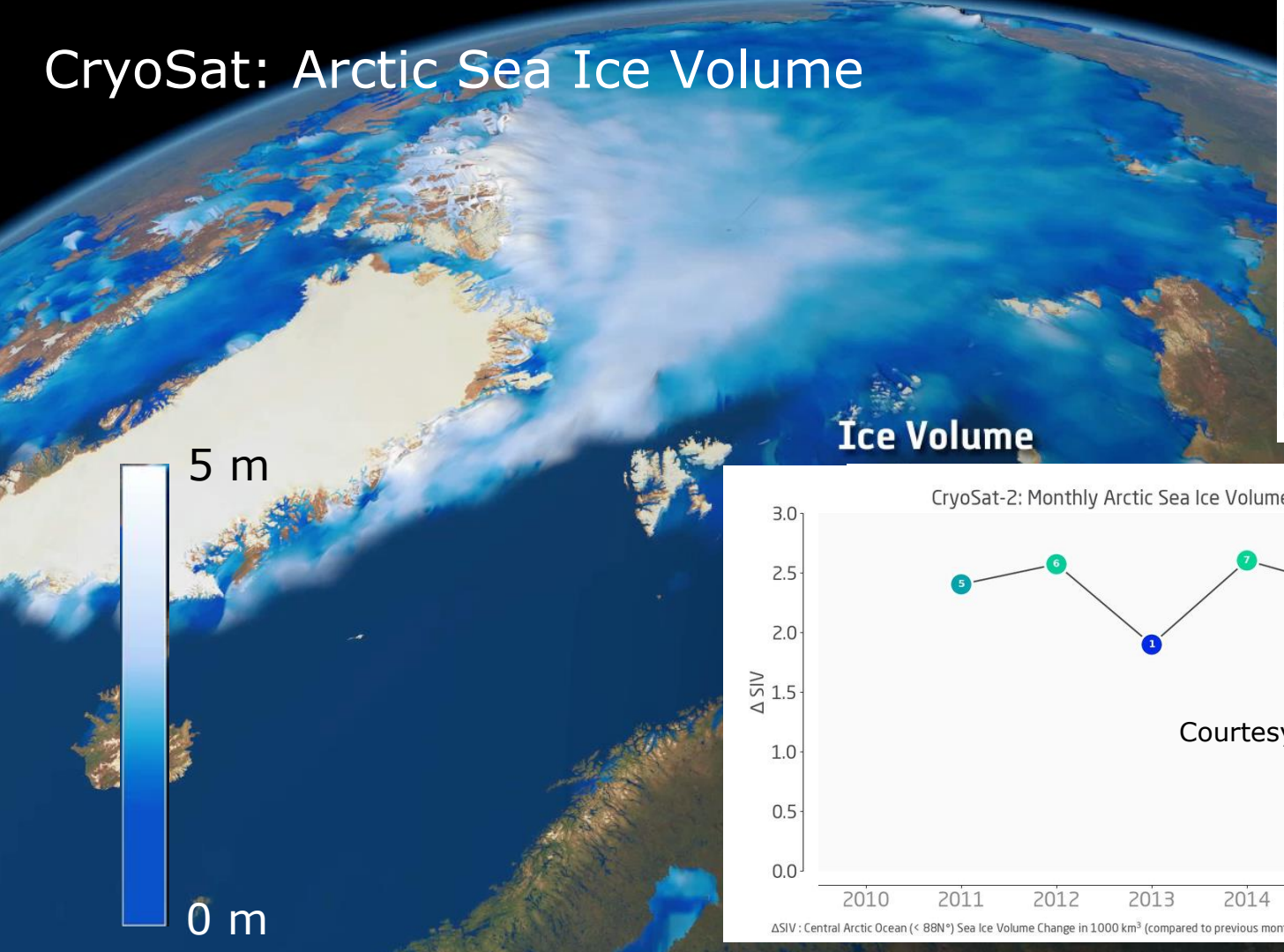
- **Research**
- **EarthWatch**
- **Meteorology**
- **Copernicus**

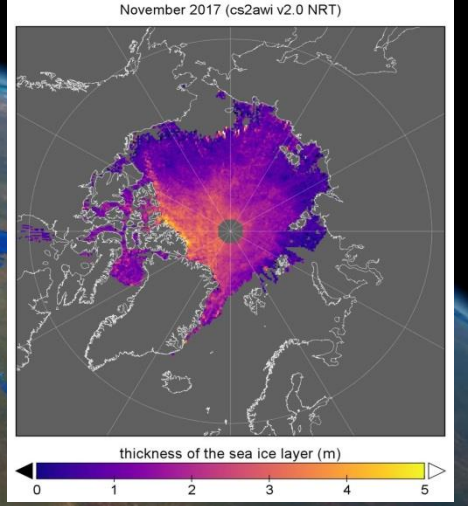
"Understanding the Earth system and its processes"

The Earth Explorers

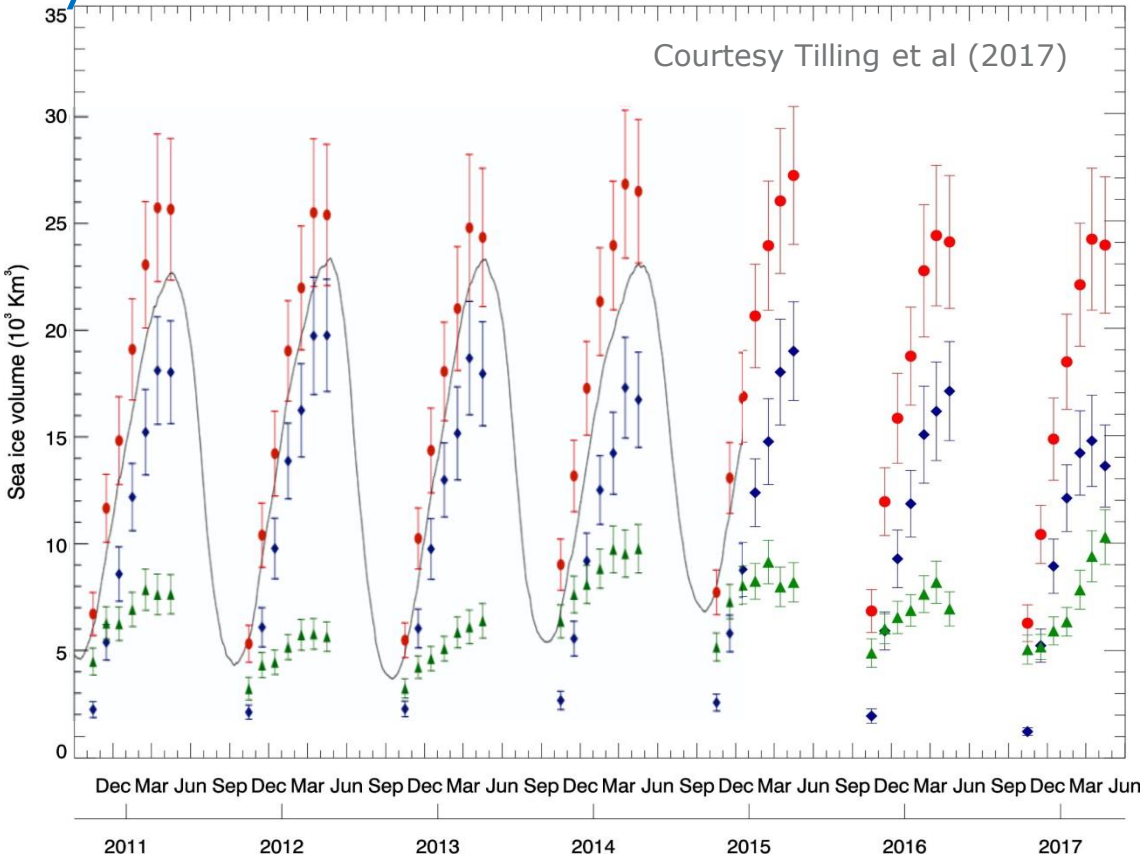
Research Missions

CryoSat: Arctic Sea Ice Volume





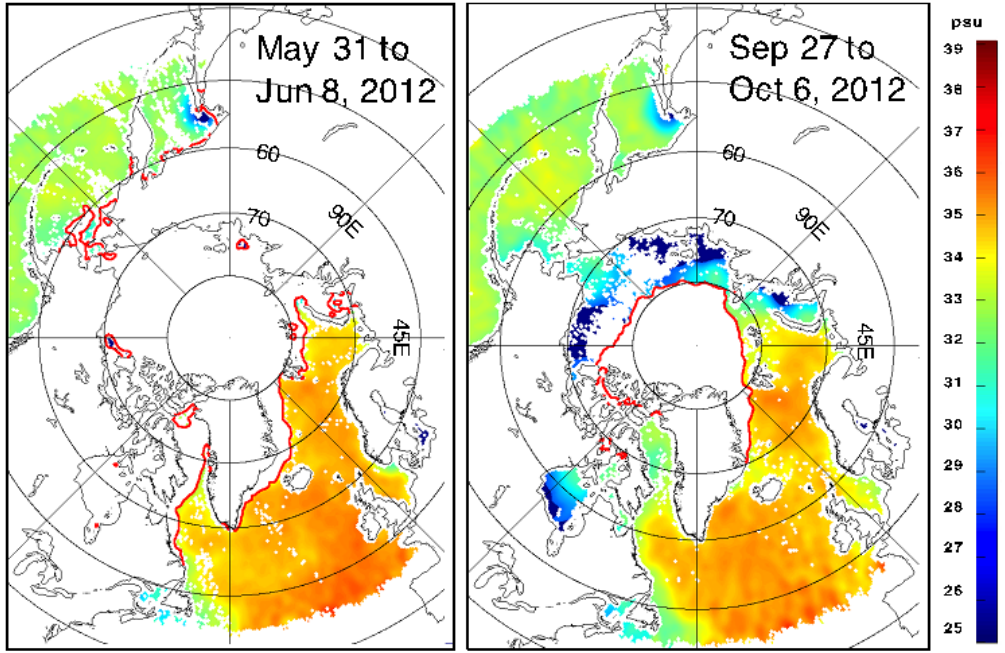
CryoSat and PIOMAS - Measured vs. Modelled



- Model underestimates ice volume by (~10-15%).
- Thermodynamic growth rates realistic
- Scope for improvement in dynamic thickening by ice deformation / ridging processes?

SMOS: Experimental Polar Ocean Salinity (SSS)

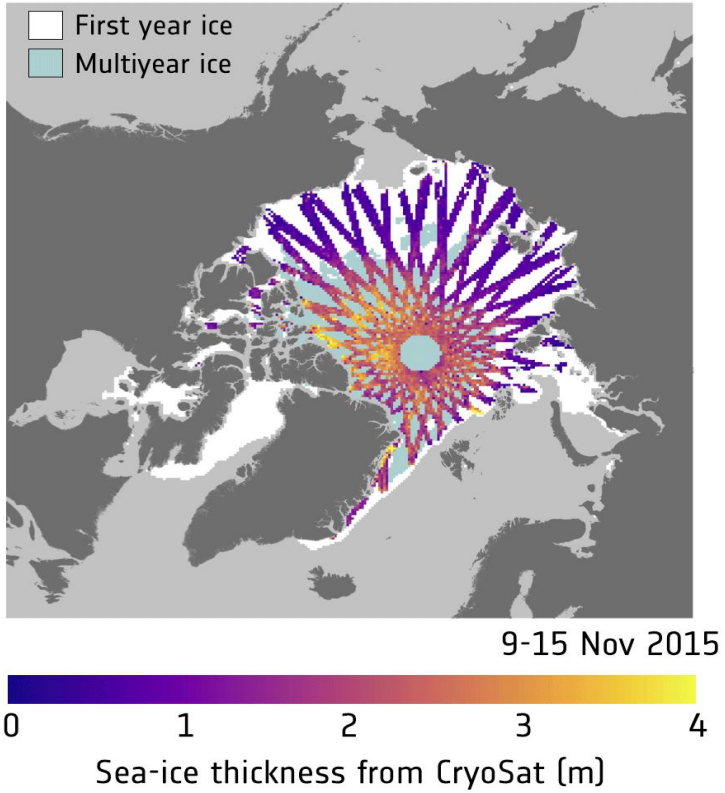
- Arctic objectively analysed L3 map: OA L3 maps are generated as 9-day avge.
- L2 data on a 25-km polar grid, served daily.
- Accuracy: average (about 0.3 psu).
- Experimental products at SMOS BEC



See also: Garcia-Eidell et al (2017): Satellite observed salinity distributions at high latitudes..

http://bec.icm.csic.es/ocean-experimental-dataset-high-latitude-and-arctic-sss/

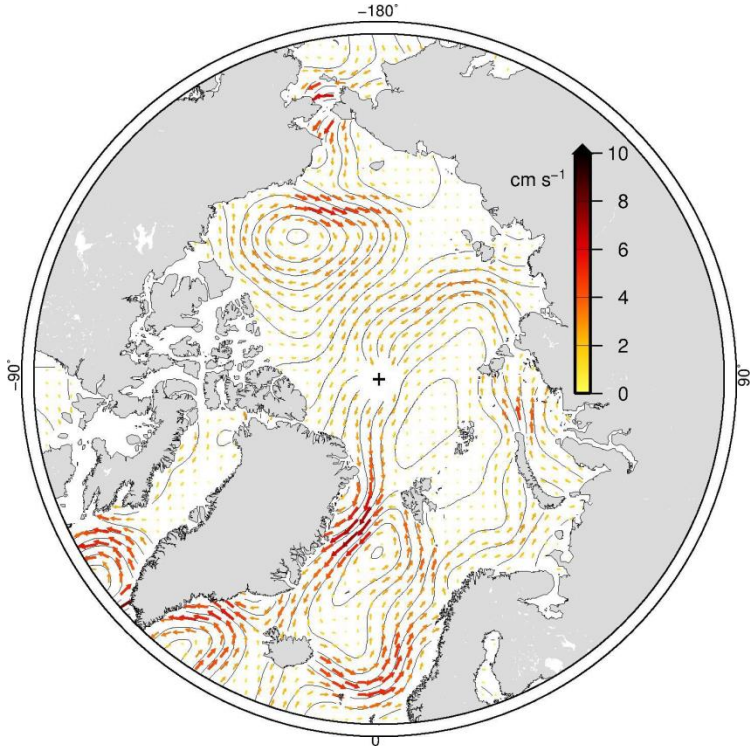
SMOS & CryoSat merging for optimal ice thickness



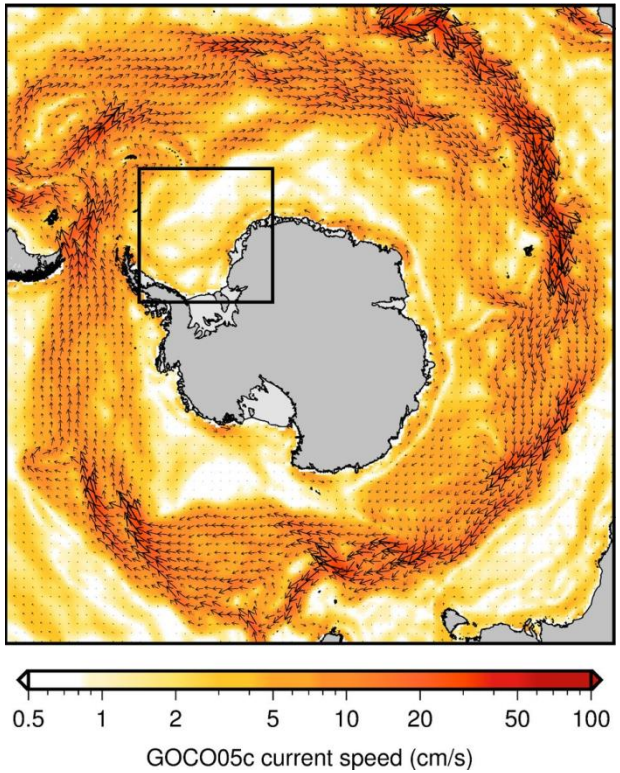
- Spatial distribution of thin first year (seasonal) ice thickness detected by SMOS
- Perennial (multiyear) and first-year ice thickness distribution measured by CryoSat
- Optimal combination of CryoSat and SMOS Arctic data with different sensitivities to sea-ice thickness

Courtesy L. Kaleschke – U. Hamburg

CryoSat-2: Polar Ocean Circulation



Armitage et al. (2017), TC



Courtesy Armitage et al (2018), from CryoSat SLA+GOCE geoid data

SKIM EE9 New Candidate: Mission Objectives
(Courtesy F. Ardhuin, PI)

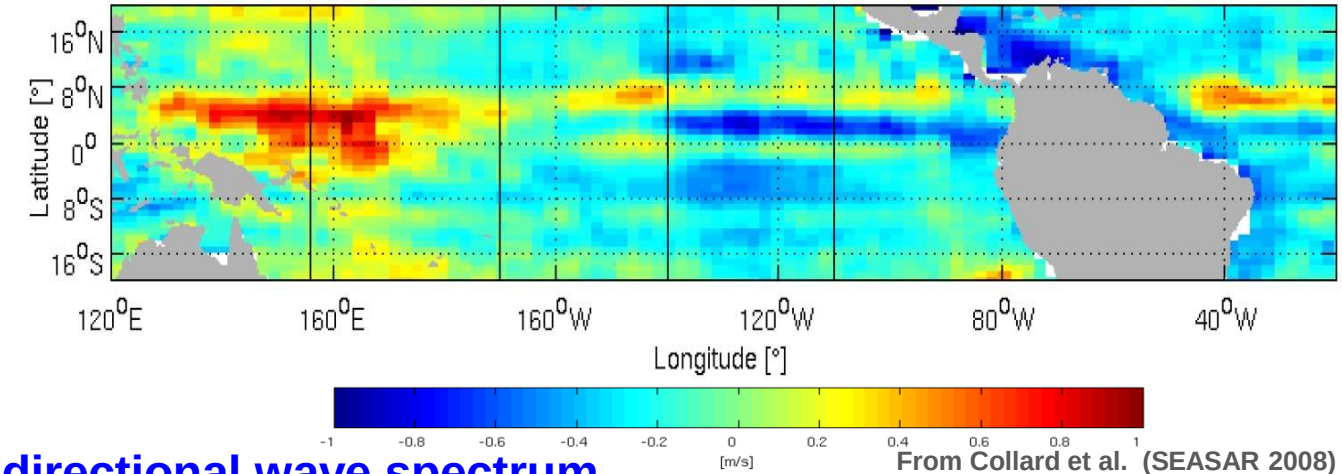
Primary objective : total surface current vector

→ transport of heat, salt, biota, microplastics …

→ follows 1-component current demo using Envisat (Chapron et al. JGR 2005)

Complementary to Altimetry, SST , SSS, in particular for:

- W. boundary currents
- marginal ice zones
- equatorial currents



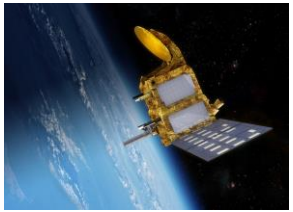
From Collard et al. (SEASAR 2008)
3-month averaged Envisat data

Secondary objective : directional wave spectrum

SKIM EE9 Candidate (Courtesy F. Ardhuin, PI)

The Sea-surface Kinematics Multiscale monitoring (SKIM) mission is built around a Ka-band instrument combining:

radar altimeter, **disco ball**, and **speed gun** …



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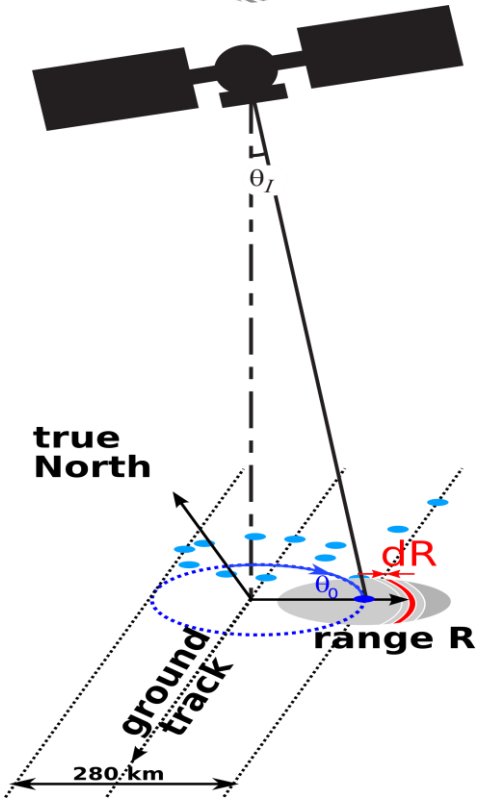
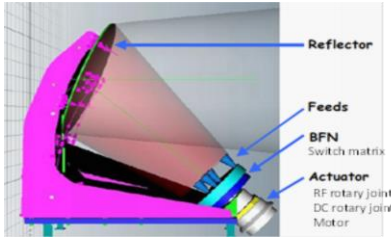


Altimeter: 32 Khz PRF, 200 MHz bandwidth, SAR unfocused

→ **very low noise for sea level, wave height, ice freeboard …**

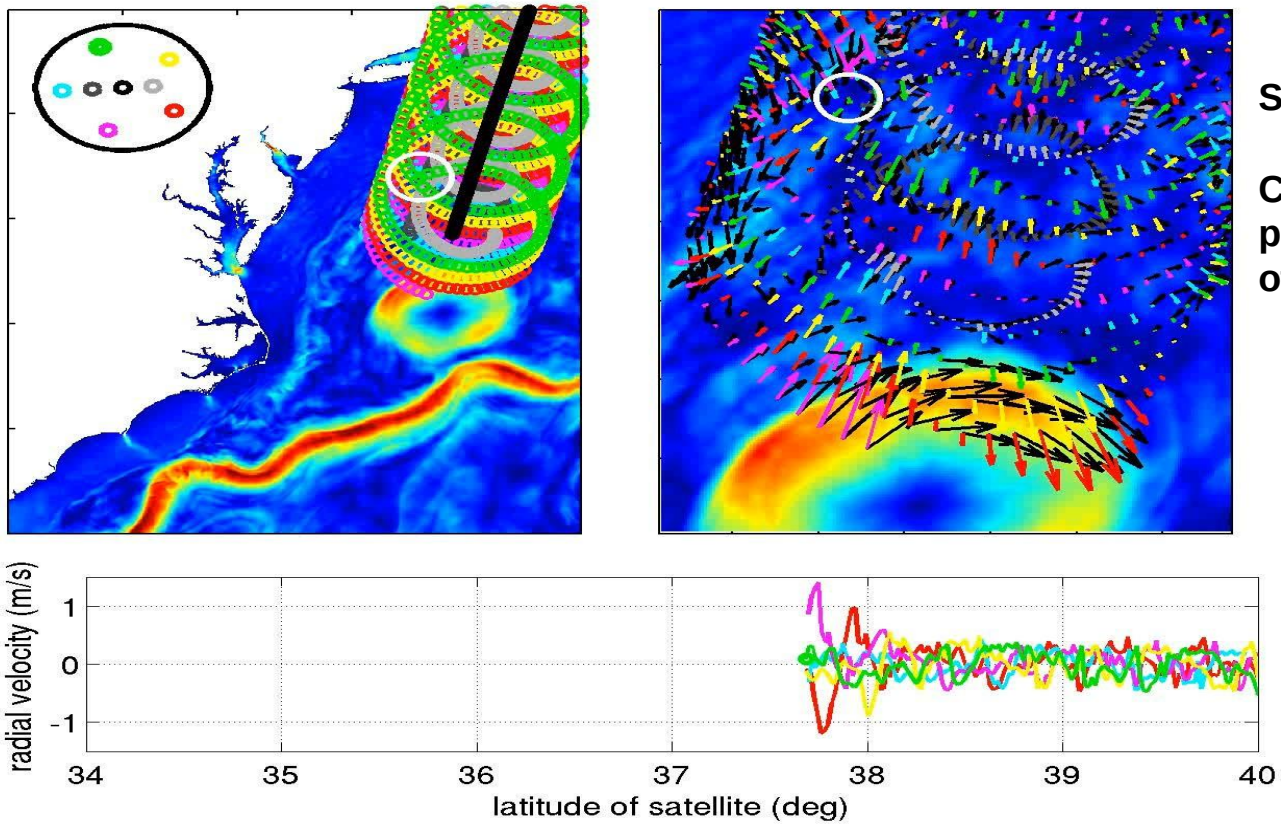
disco ball: a rotating plate with 8 horn feeds : one **nadir** beam (classical altimeter)



7 **other beams**
at 6 and 12° incidence
4 m range resolution

speed gun: Doppler analysis → **surface currents, ice drift** & **wave orbital velocities**.

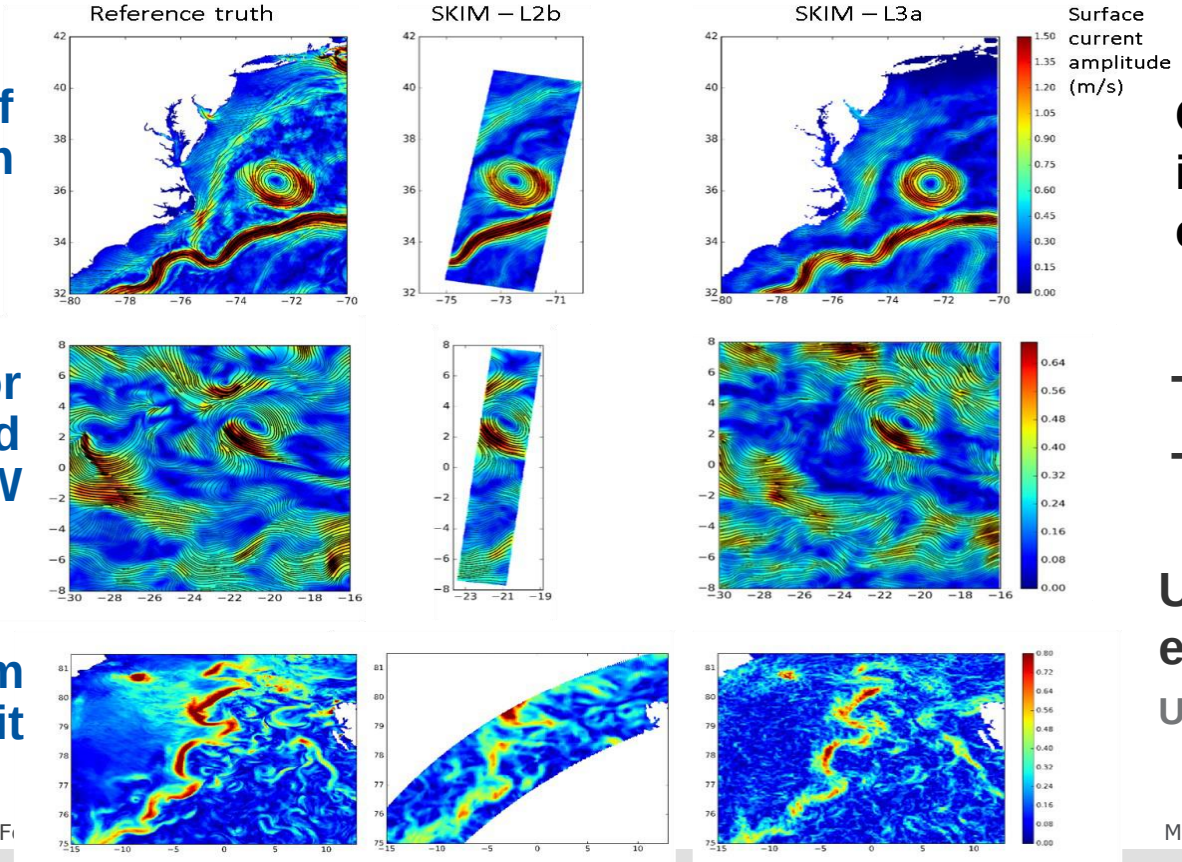
SKIM EE9 Candidate: illustration of sampling
(Courtesy F. Ardhuin, PI)



Swath: 280 km wide

Current vector (black) projects onto beam line of sight (color)

SKIM (EE9 Candidate): Expected resolution & accuracy (Courtesy F. Ardhuin, PI)



Optimal interpolated currents

- single swath : L2b

- multiple-swaths

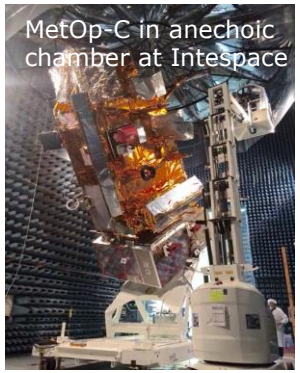
Using instrument error + Uwb error

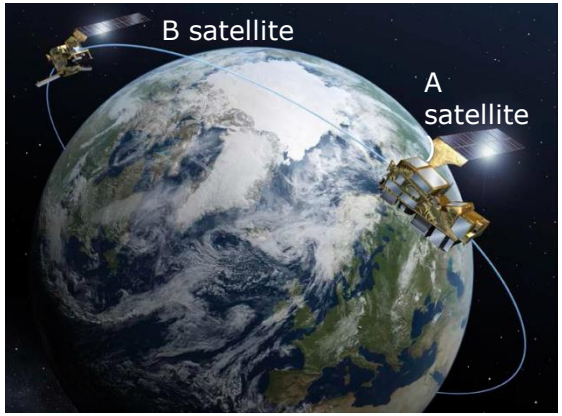
Ubelmann et al., in review)


Meteosat 9
Meteorological Missions
19 Sept. 2012

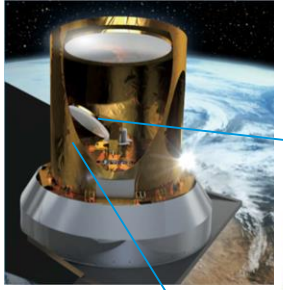
MetOp-SG: Key Features & Relevant Instruments

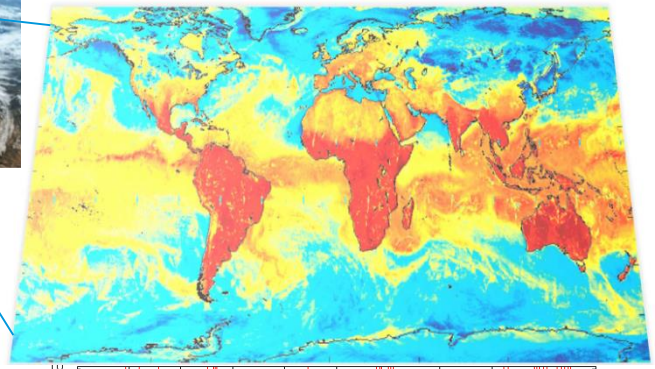
- ESA develops prototype satellites; and on behalf of EUMETSAT procures recurrent satellites
- EUMETSAT operates the satellites upon completion of commissioning
- MetOp-C (last in current series) to be launched in Sept.-Oct.'18 to join MetOp-B (primary) and MetOp-A
- MetOp-SG A/B pair with three satellite series will provide continuity to MetOp-A,-B,-C series of polar orbiters
- MetOp-SG B 3 satellite series carries microwave payloads, including MWI and SCA for ocean and ice products
- Equipment Critical Design Reviews almost completed
- MetOp-SG B1: Soyuz launch currently planned in late 2022 from Kourou

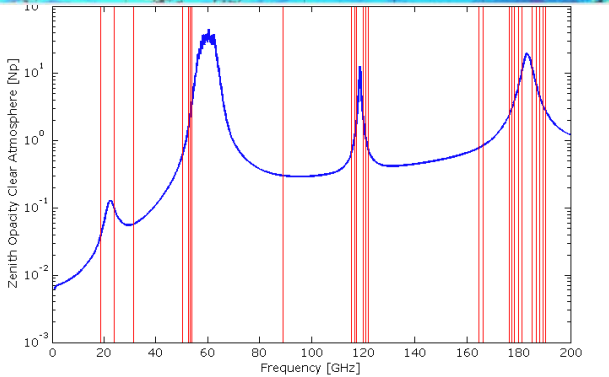




Microwave Imager (MWI)







High Level Products:

- Cloud and Precipitation Products
- Water Vapour and Temperature Profiles
- All weather surface imagery including:
  - Sea surface wind speed
  - Sea ice coverage (and type)
  - Snow coverage, depth and water equivalent

Level 1b Product:

Calibrated and Geolocated scene brightness temperature

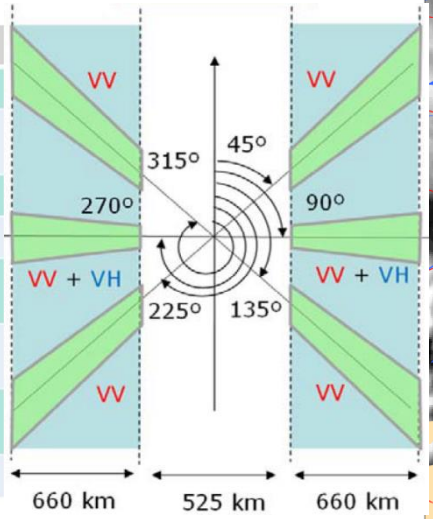
- Total of 26 Channels from 18.7 GHz to 183.31 GHz)
- Dual Polarisation Channels up to 89GHz
- Combination of Window and Sounding Channels

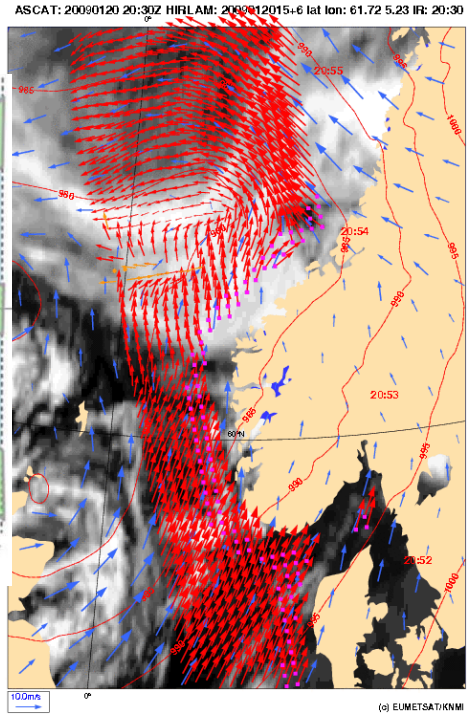
Scatterometer (SCA)

Enhanced continuity in C-band Scatterometer of MetOp series

- Scatterometer specifications: ASCAT versus SCA

Parameter	ASCAT	SCA
Frequency	5.3 GHz	
Polarisation	VV for all beams	VV for all beams + VH for Mid-beams
Azimuth views	45°, 90° and 135° w.r.t. satellite track	
Min. incidence	25°	20° [G]
Horizontal resolution	Nom: (50 km)² High res.: (25 - 35 km)²	Nom: (25 km)² [G] High res.: (17 - 22 km)²
Horizontal sampling	Nom: (25 km)² High res.: (12.5 km)²	Nom: (12.5 km)² [G] High res.: (6.25 km)²
Radiometric resolution	≤ 3 % for $\theta_i \leq 25°$ at 4 m/s cross-wind (VV) ≤ (0.175×θ_i – 1.375) % for $\theta_i > 25°$ at 4 m/s cross-wind (VV)	
Coverage	97 % in 48 hrs.	99 % in 48 hrs. [G]



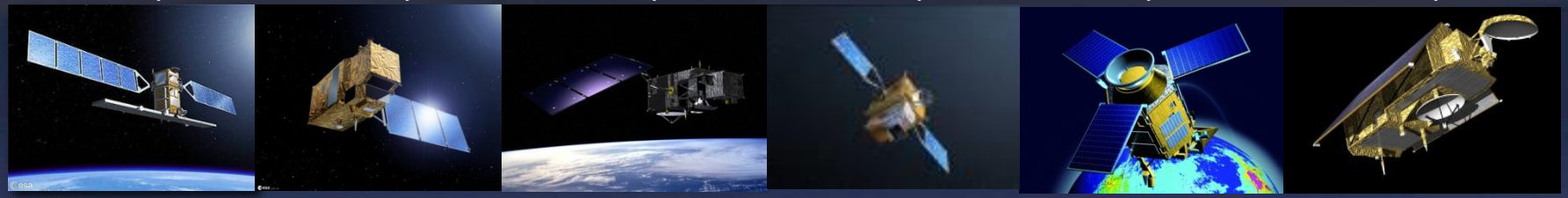


- Compared to ASCAT, SCA shall have a smaller nadir gap by reducing the minimum incidence angle from 25° (ASCAT) to 20°.


Copernicus

Sentinels: A Sustained Data Source

Sent-1A/B | Sent-2A/B | Sent-3A/B | Sent-4A/B | Sent-5/5P | Sent-6A/B

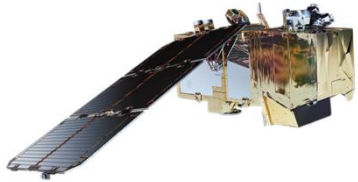


- Copernicus - European space flagship programme, led by the EU
- ESA is responsible for space component, Sentinel development, operation of some Sentinels, data buy from other partners, system evolution
- Sentinels – designed to monitor various elements of the Earth System in a fully operational manner
- Free, full and open data policy

Sentinels with Marine/Ice Contributions

Sentinel-1

- All-weather, day-and-night radar imaging satellite for ocean, ice and land surfaces
- C-band Synthetic Aperture Radar Instrument
- Able to “see” through clouds and rain
- Data delivery within 1hr of acquisition
- S-1A/B launched



Sentinel-2

- Medium Res. Multispectral optical satellite for observation of land, vegetation and water
- 13-band Multispectral Instrument with 10, 20, or 60m res. and 290km swath
- Global coverage of the Earth’s land surface every 5 days
- S-2A/B launched

Sentinel-3

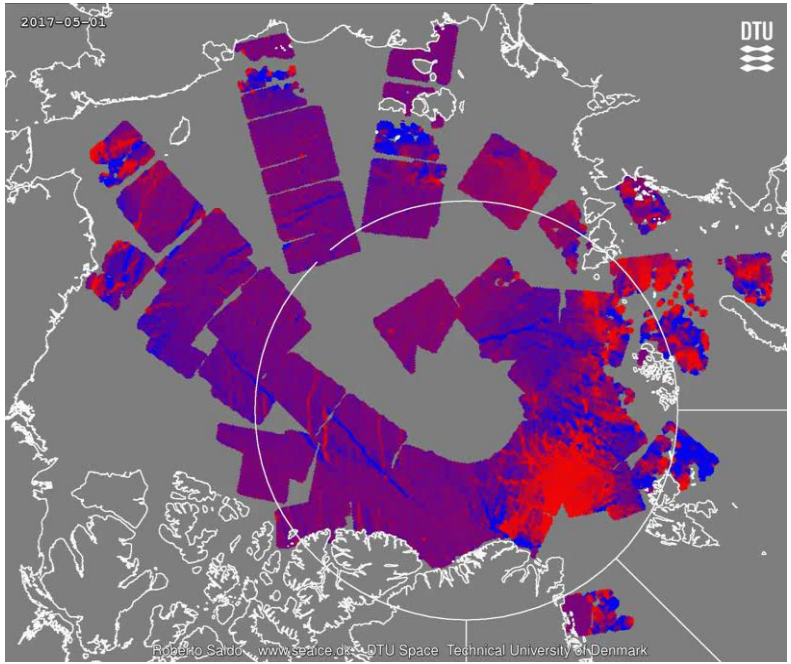
- Measures sea-surface topography with 300m res., ocean colour and sea and land surface temp., with 300m and 1km resolution
- Ku-band SAR Altimeter, Ocean and Land Colour Imager, and Sea and Land Surface Temp. Radiometer (SLSTR)
- Measures sea surface height cloud properties, ocean colour and thermal radiation emitted by the ocean and land surfaces
- S-3A launched
- S-3B launch scheduled in Spring 2018 on Rockot

Sentinel-6

- Precision measurement of changes in sea surface topography with ranging accuracy of a few cm
- Ku-band SAR Altimeter, microwave radiometer and GNSS-RO package
- Precise reference altimeter for sea-surface height, sea-level anomalies and sea-level change
- Launch S-6A scheduled 2021/2022 on Falcon-9

Sentinel-1: Routine observations of sea ice

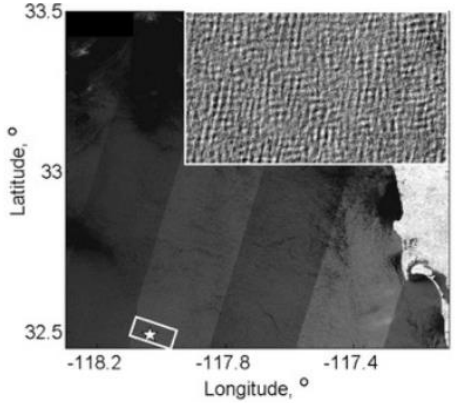
Sentinel-1: Sea Ice Kinematics



- Differential kinematic motion products generated on 3-6d timescales from Sentinel-1
- Divergence, Shear, Vorticity, Opening/Closing
- Sentinel-1 shows linear features with persistence of a few days
- Indication of importance of boundary conditions, stress transfer from coastline over large distances
- Strong constraint on location of opening, and high ice formation rates, or thickness redistribution

Sentinel-2: MSI directional wave spectra

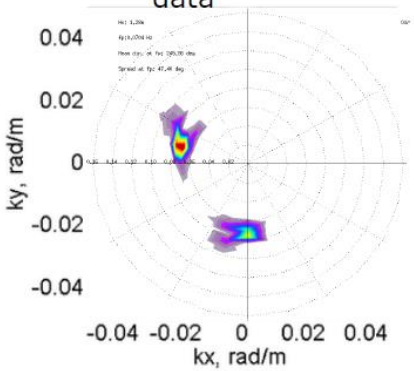
- S-2 Multi-Spectral Imager (MSI) data reveals wave patterns from reflection of solar radiation by the sea surface (Sun Glitter)
- **MSI**: 290 km swath with 13 spectral channels (4 Vis and NIR bands at 10 m resolution; 6 red-edge/SWIR bands at 20 m and three atmospheric correction bands at 60 m.



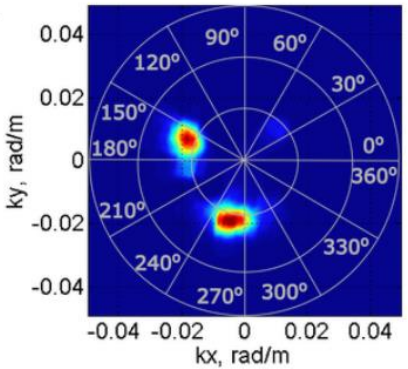
California coast, 2016-04-19 18:44.
Buoy 46086 - San Clemente Basin, National Data Buoy Center (NDBC).

Courtesy ESA GLITTER project

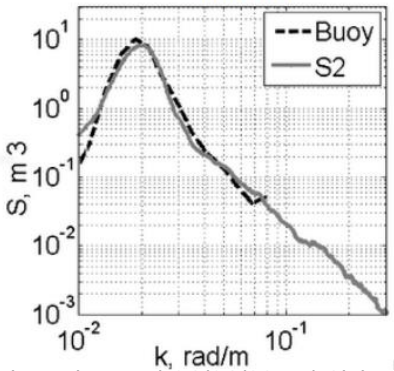
Spectrum from buoy data



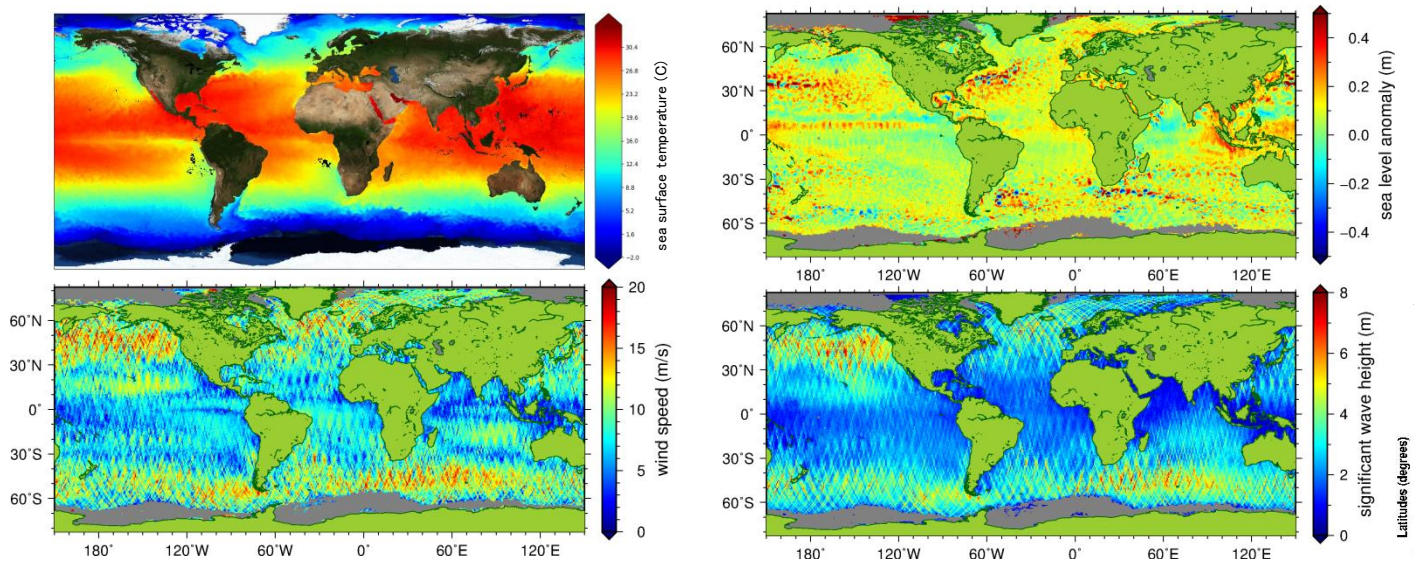
Spectrum from S2 data

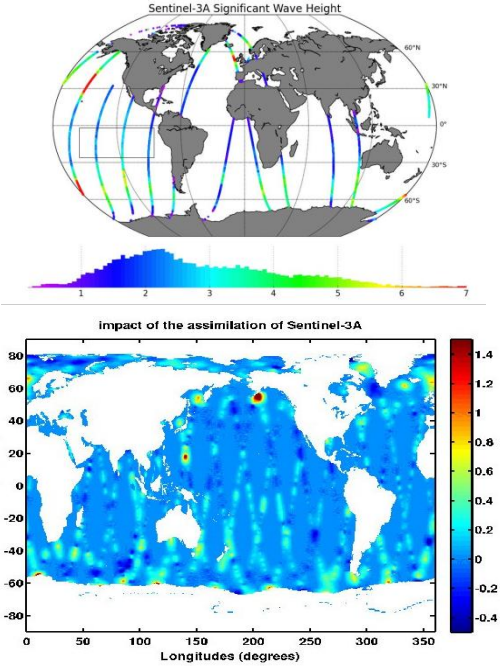


Omnidirectional spectra



Sentinel-3: Met-Ocean Products





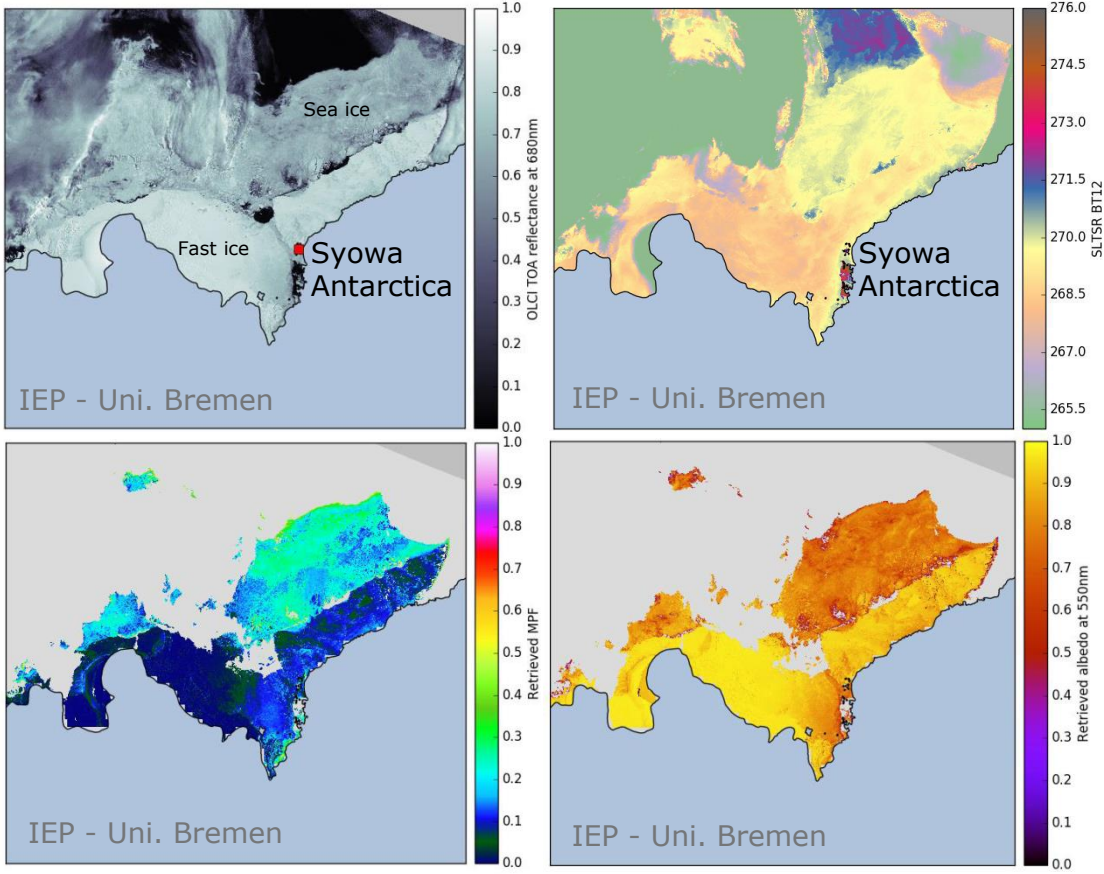
Courtesy EUMETSAT

Courtesy Météo France/CMEMS

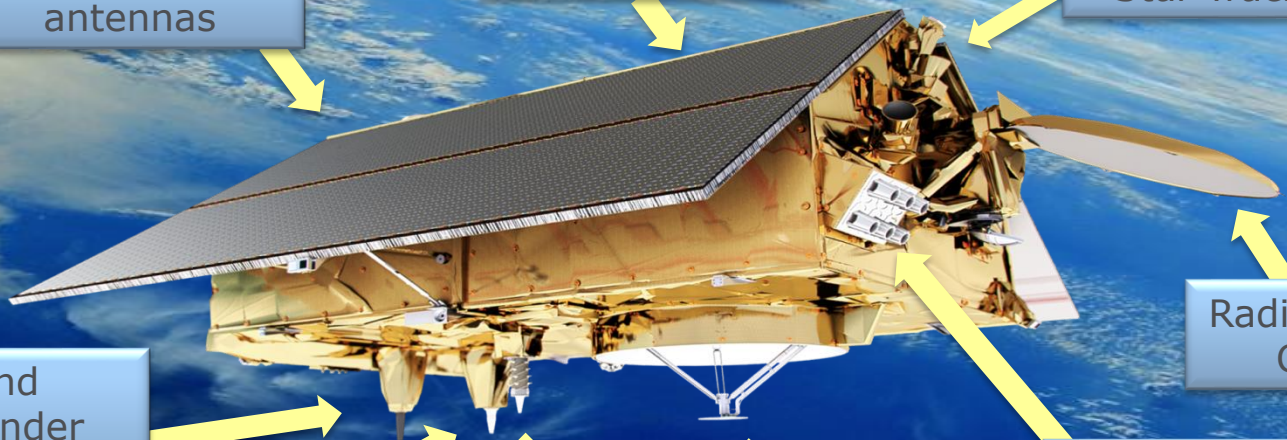
- (Above) Sentinel-3A providing routine operational products relevant for met-ocean forecasting and climate use
- (Right) CMEMS model analysis increment (in metres) from 1d assimilation into MFWAM global wave model
- Sentinel-3B scheduled for launch in spring 2018 from Plesetsk, Russia on Rockot

Sentinel-3: New Prototype Sea-Ice Products

- Summer OLCI+SLSTR derived albedo and melt pond fraction (MPF) being prototyped in H2020 SPICES project
- Preprocessing: cloud screening, equalisation, radiance to reflectance correction, subsetting
- MPF retrieval relies on > 8 suitable spectral channels in the VIS and NIR
- Simplified MPF parameterised via NDMI of two spectral bands (550nm and 860nm)
- Beneficial input to global climate models and for analysing extended MPF trends.



Sentinel-6/Jason-CS Spacecraft



GNSS-POD antenna

GNSS-RO/POD antennas

Star Trackers

Radiometer AMR-C antenna

S-Band transponder antenna

GNSS-RO/POD antenna

X-Band transmitter antenna

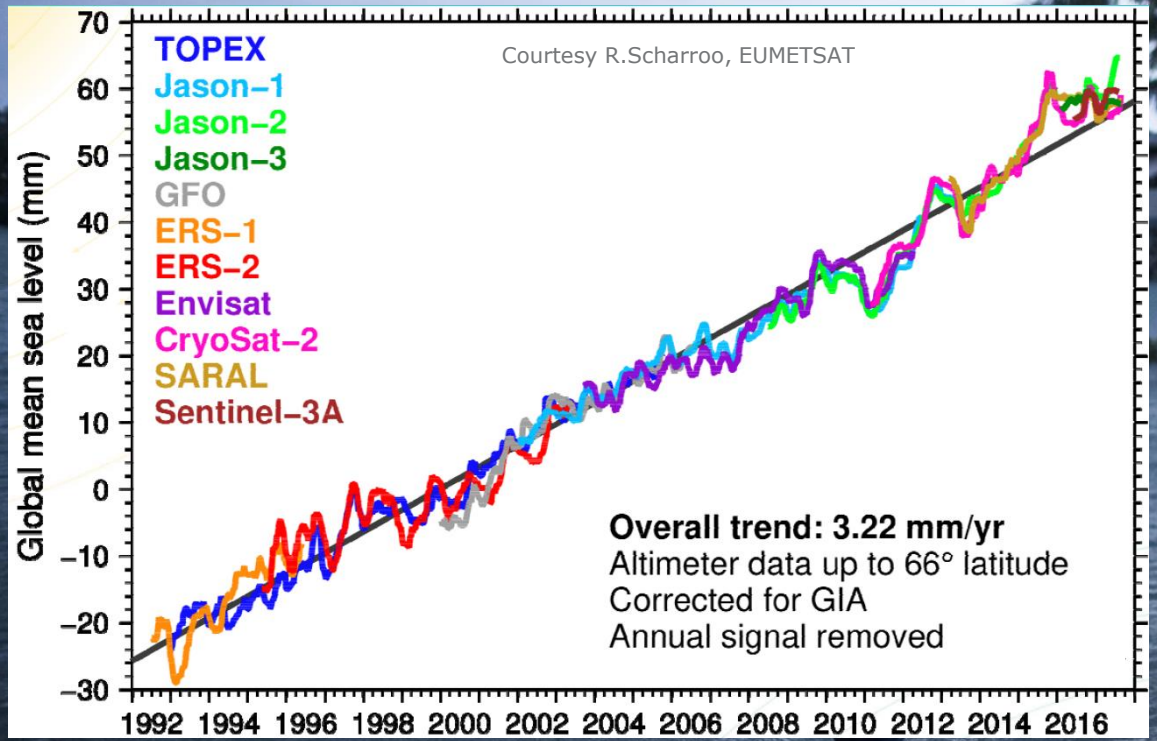
DORIS antenna

Radar Altimeter Poseidon-4 antenna

Sentinel-6/Jason-CS Partnership Mission

Orbit	LEO non sun-synchronous • Repeat cycle: 10 days • Mean altitude: 1336 km; Inclination: 66°
Lifetime	6 months commissioning **5 year operational mission**
Mass	1440 Kg (including fuel)
Satellite Dimensions	Flight configuration 5.13 m x 4.17 m x 2.35 m Stowed configuration 5.13 m x 2.47 m x 2.35 m
Power	891W average consumption
RF Links	- X-band data downlink: 150 Mbps at 8.090 GHz - S-band TTC link: 32 kbps uplink,1 Mbps downlink
Data	Volume: order of magnitude 1200 Gbit/day; On-board storage: 496Gbits (BoL)
Instruments	• **SAR Radar Altimeter**: Poseidon-4 • AMR-C **Climate-quality microwave radiometer** (NASA/JPL contribution) • Precise Orbit Determination: **GNSS POD** Receiver; **DORIS** • Laser Retroreflector Array (NASA/JPL contribution) • TriG Receiver for **Radio Occultation** (NASA/JPL contribution)
Flight Operations	Mission control for LEOP from ESOC. IOV, Commissioning and routine operations from EUMETSAT. Two operational ground stations, at Fairbanks and Kiruna (TBC)
Launch Vehicle	US launcher baseline (Falcon-9, Atlas-4 or Antares) procured by NASA-JPL/KSC.

Sentinel-3/-6/CryoSat: Sea-Level Monitoring



Mean Sea Level Rise (cm)

Satellite Altimetry Sea Level Data:

- Sentinel-3 and
- Sentinel-6 (>2020)
- (CryoSat-2)

Copernicus Evolution

A Long-Term Scenario (LTS) for the CSC

- A Long Term Scenario (LTS) needed to establish a vision/perspective for Copernicus observation capability beyond the current generation of Sentinels
- Fundamental aspects of a LTS assure:
  - **user-driven continuity** and increase the **robustness** of the existing CSC in the future **increase the quality and quantity** of the existing measurements (Priority)
  - **expansion of observation** types according to policy and user needs
  - employment of **latest technologies** for maximum efficiency in observations
  - consideration of **partnerships and cooperation** essential to success

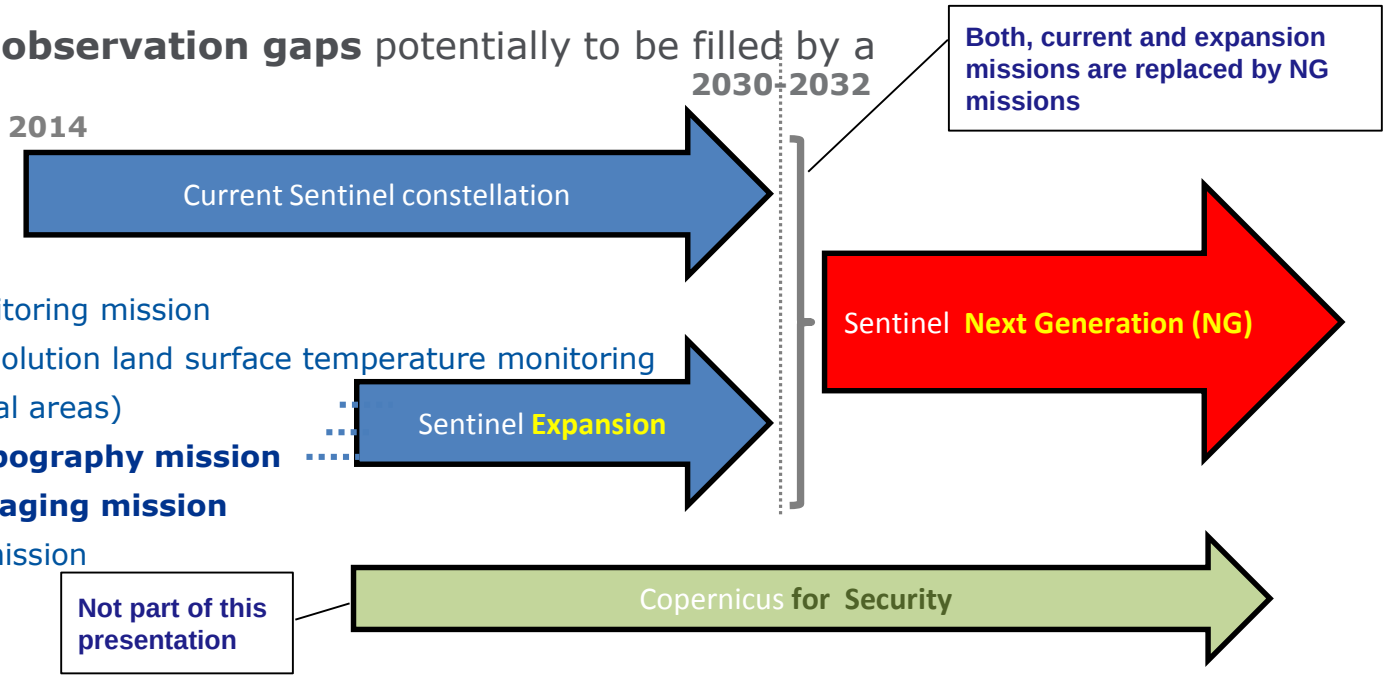
- **Key driver is the evolving needs of the services prioritised by EC** through various consultative processes over the last year

Evolution of the Copernicus Space Component (CSC)

At its **14 Sept User Requirements Workshop** the European Commission:

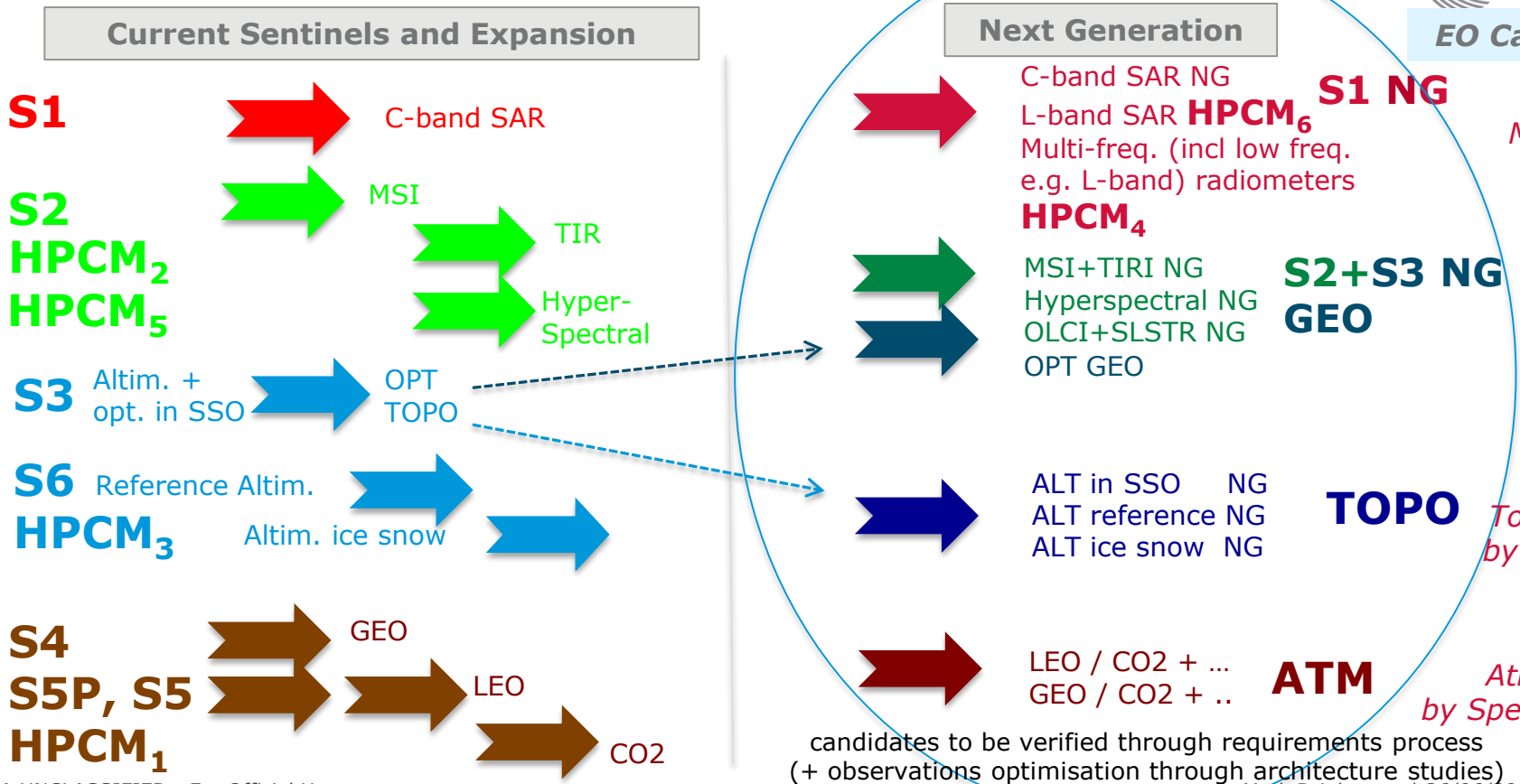
- Underlined that the **priority** is **enhanced continuity** in the existing CSC observing capacity
- Identified a number of **observation gaps** potentially to be filled by a CSC **Expansion**.

- **High Priority Candidate Missions (HPCMs):**
  1. Anthropogenic CO2 monitoring mission
  2. High spatio-temporal resolution land surface temperature monitoring mission (including coastal areas)
  3. **Polar ice and snow topography mission**
  4. **Passive microwave imaging mission**
  5. Hyperspectral imaging mission
  6. **L-band SAR mission**



Preliminary assumptions for Sentinels Next Generation

EO Capability



candidates to be verified through requirements process
(+ observations optimisation through architecture studies)

LTS "Families" (potential extension + expansion) with marine aspects highlighted (1 of 2)

- **Microwave Imaging Family (polar, maritime and emergency services)**
  - Enhanced continuity of C-band SAR (wider swath, better revisit)
  - Expansion to include L-band SAR
  - VHR X-band SAR with high revisit
  - Expansion candidates to include passive microwave imaging

- **Optical Imaging Family (benefit to all services)**
  - Enhanced continuity of multi-spectral hi-res from S2
  - Enhanced continuity of medium-res VIS → TIR from S3
  - VHR imagery with rapid access and timeliness
  - Hi-res spatial/temporal TIR for LST monitoring including coastal regions
  - Hyperspectral (VIS->SWIR) for land and coastal regions

LTS "Families" (potential extension + expansion) with marine aspects highlighted (2 of 2)

- **Topographic Measurement Family (operational Oceanography)**
  - Enhanced continuity of sun-synchronous (S3) topography
  - Enhanced continuity of reference mission (S6/JCS) topography
  - Complementary polar-orbiting altimeter for enhanced ice monitoring
  - Optimisation of orbits for optimal sampling
- **Spectroscopic Atmospheric Measurement Family**
  - Monitoring of the anthropogenic emissions contribution to the CO2 cycle
  - Long-term enhanced continuity of the measurements provided by Sentinel-4/5 (beyond 2030+)
- **Other Missions (cross cutting all services highlighted in EC user needs)**
  - Gravimetry and geodetic observations, sea surface salinity

Summary

- ESA preparing new Earth Explorer missions with new capabilities to build on the successes of SMOS, CryoSat and to address new scientific frontiers: SKIM Phase A/B1 preparatory studies now starting in 2018
- MetOp-SG will secure enhanced continuity in critical met-ocean measurements
- Europe's Copernicus system, including ESA-developed Copernicus Space Component (CSC), now developed into the largest and most proficient user-driven observation system in the world
- Vision of the future embodied by the Copernicus long-term scenario (jointly developed by ESA-EC-EUMETSAT) addresses gaps and emerging priority needs for new types of measurements in an expansion of the CSC
- Six HPCM Phase A/B1 studies being prepared to start in early 2018 to prepare for potential expansion of Copernicus, en-route to Copernicus Next Generation
- LTS will continue to evolve, with regular updates as the definition continues in close and continuous collaboration with all stakeholders (leading to 4th slice of CSC financing at 2019 Ministerial Council)