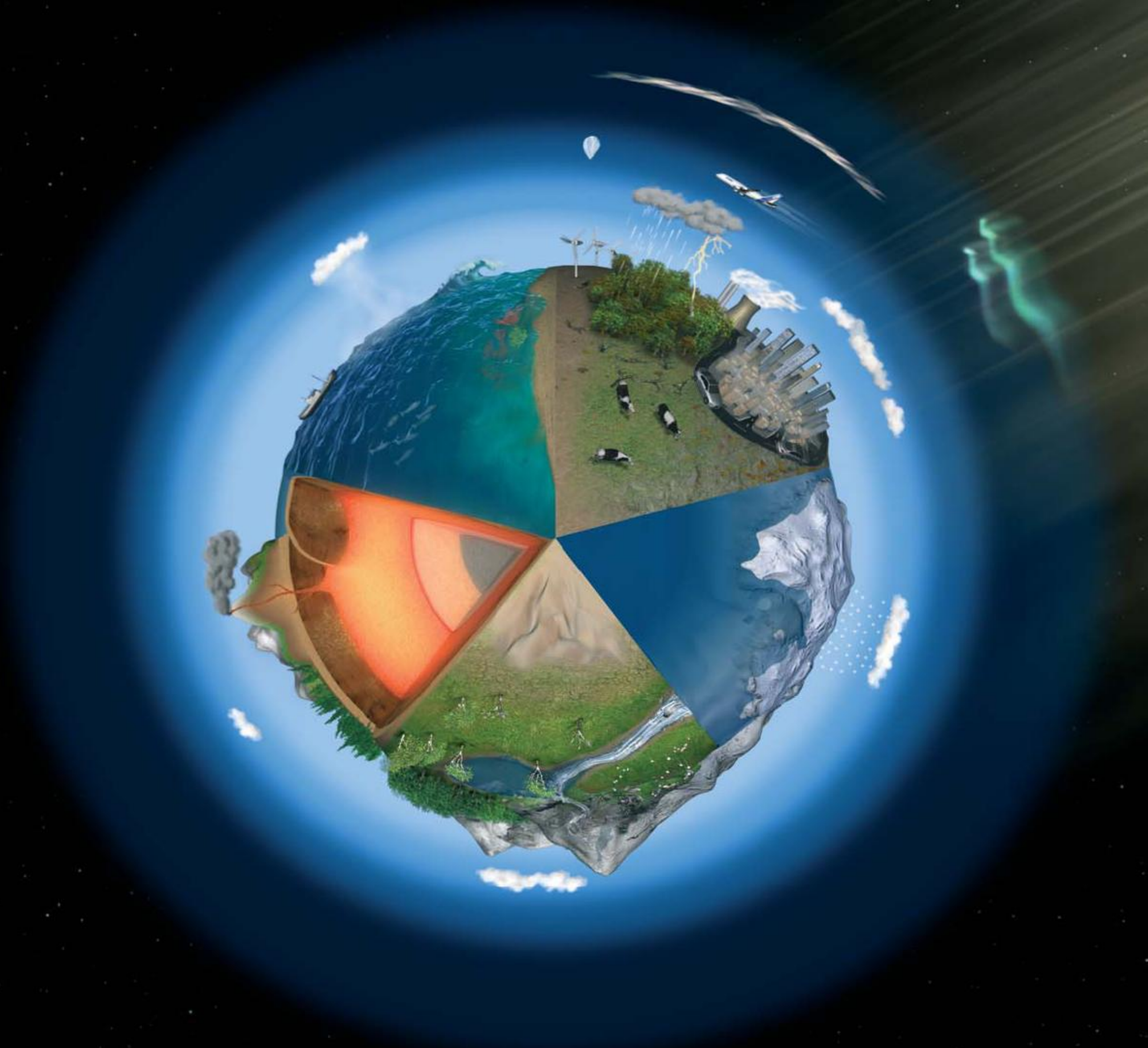
Future Missions for the Cryosphere



Michael Kern

European Space Agency

Earth Observation Programmes

Overview

- The ESA Living Planet Programme and Scientific Challenges for the Cryosphere
- IGOS-Cryosphere Theme
- Earth Explorer Missions
- Earthwatch/GMES Missions
- Summary

– SP-1304 Updated Science Strategy

The Challenges of the Cryosphere

Challenge 1: Quantify the distribution of sea-ice mass and freshwater equivalent, assess the sensitivity of sea ice to climate change, and understand thermodynamic and dynamic feedbacks to the ocean and atmosphere.

Challenge 2: Quantify the mass balance of grounded ice sheets, ice caps and glaciers, partition their relative contributions to global eustatic sea-level change, and understand their future sensitivity to climate change through dynamic processes.

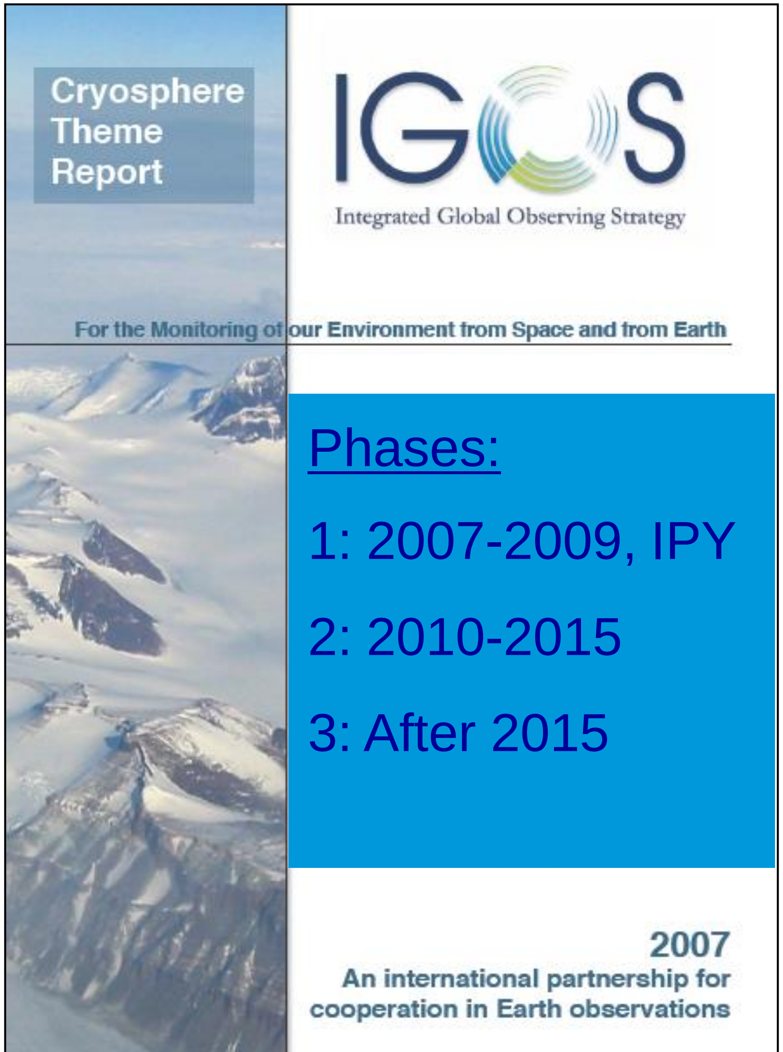
Challenge 3: Understand the role of snow and glaciers in influencing the global water cycle and regional water resources, identify links to the atmosphere, and assess likely future trends.

Challenge 4: Quantify the influence of ice shelves, high-latitude river run-off and land ice melt on global thermohaline circulation, and understand the sensitivity of each of these fresh-water sources to future climate change.

Challenge 5: Quantify current changes taking place in permafrost and frozen-ground regimes, understand their feedback to other components of the climate system, and evaluate their sensitivity to future climate forcing.

Available from http://esamultimedia.esa.int/docs/SP-1304.pdf

IGOS Cryosphere Theme (1)



Phases:

1: 2007-2009, IPY

2: 2010-2015

3: After 2015

Cryosphere is one of the most under-sampled elements within the climate system, and is undergoing dramatic changes, mostly as a consequence of climate change

Theme Objectives:

– **establish a framework** for improved coordination of cryospheric observations via research, long-term scientific monitoring, and operational programmes

– to **use requirements-based justification** of cryosphere observing system elements

– to achieve **robust, sustainable and long-term post-IPY capability**

IGOS Cryosphere Theme (2)

Cryospheric Elements

- Terrestrial Snow
- Sea Ice
- Lake and River Ice
- Ice Sheets
- Glaciers and Ice Caps
- Surface Temperature and Albedo of Snow and Ice
- Permafrost and Seasonally Frozen Ground
- Solid Precipitation

Remote Sensing Elements

SAR Imagery

InSAR

PMW

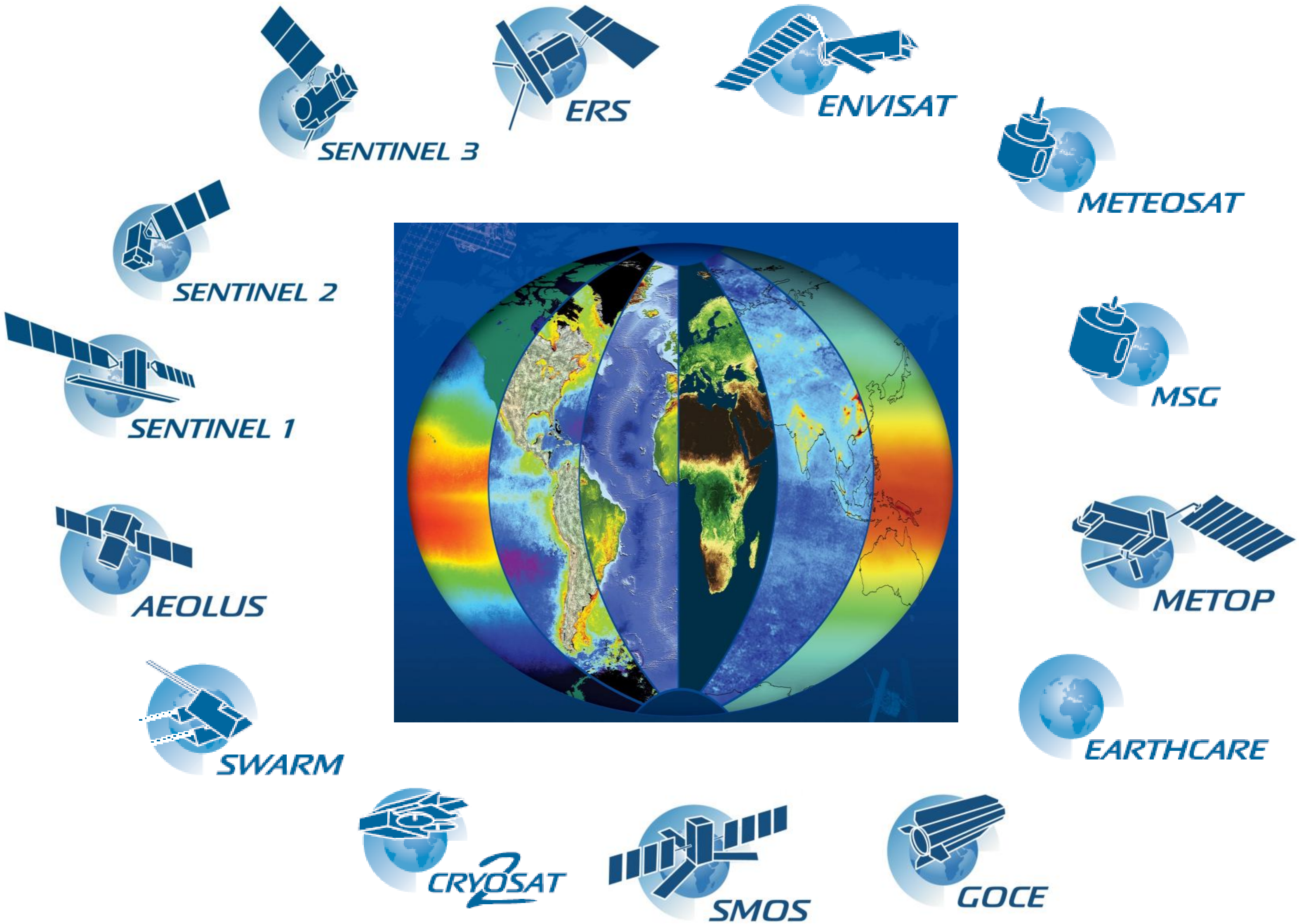
Altimetry

Radar Scatterometry

VIS to Thermal IR

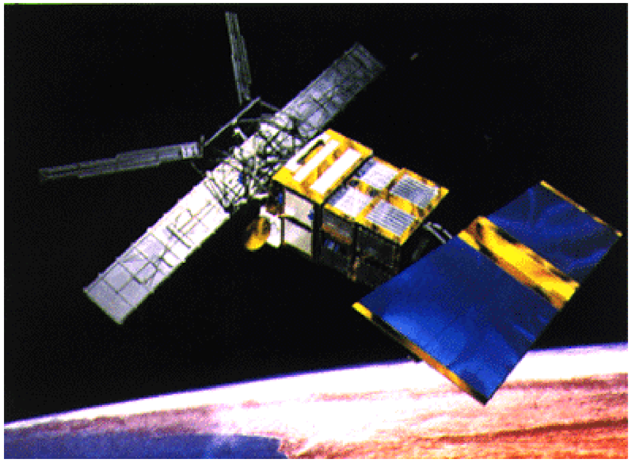
Gravity

ESA's Earth Observation Toolkit



Time line of ESA Earth Observation

Europe's expanding EO capability



2009 ➔

Earth Explorers

1991 **ERS 1** → 1995 **ERS 2** → 2002 **ENVISAT**

Earth Watch GMES

Oceans
Cryosphere
Land Surface
Climatology

+ Global Ozone
+ Land Surface

+ ***Ocean Colour***
+ Atmospheric Constituents

ESA's Living Planet Programme

www.esa.int/livingplanet

esa

Earth Explorer

Research driven

Core Missions

GOCE
March 17th 2009

ADM-Aeolus
2011

EarthCARE
2013

Opportunity Missions

CryoSat 2
February 25th 2010

SMOS
November 2nd 2009

Swarm
2011

? **Earth Explorer 7 2016** ← **+ 3 Candidate Core Explorers**

Earth Watch

Operational Service driven

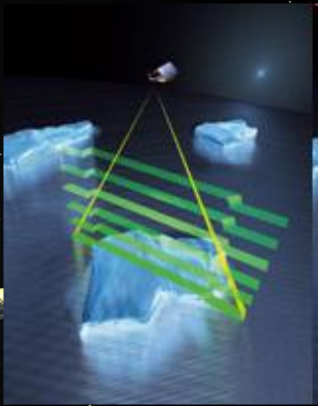
Operational Meteorology

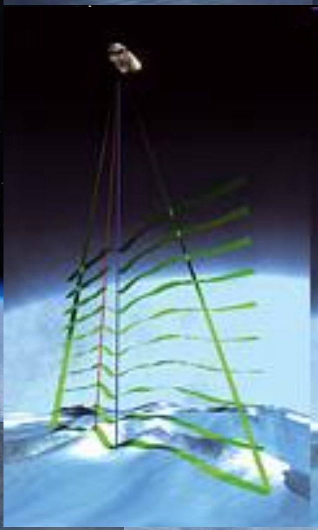
- **Meteosat**
- **MSG**
- **EPS (MetOp)**
- **MTG**
- **Post EPS**

GMES

- **Sentinel 1**
- **Sentinel 2**
- **Sentinel 3**
- **Sentinel 4**
- **Sentinel 5**

CryoSat2: ESA's Ice Mission





Its objectives are to improve our understanding of:

- thickness and mass fluctuations of polar land and marine ice
- to quantify rates of thinning/thickening due to climate variations
- Instrument: Ku band SIRAL (SAR Interferometric Radar Altimeter).

www.esa.int/livingplanet/cryosat

CryoSat: Ice mission

Approach

– *SAR interferometric* Radar Altimeter with *precise pointing* and *orbit determination*

– measurement of Arctic sea-ice thickness variations

– measurement of temporal variations in ice-sheet elevation, including dynamic margins

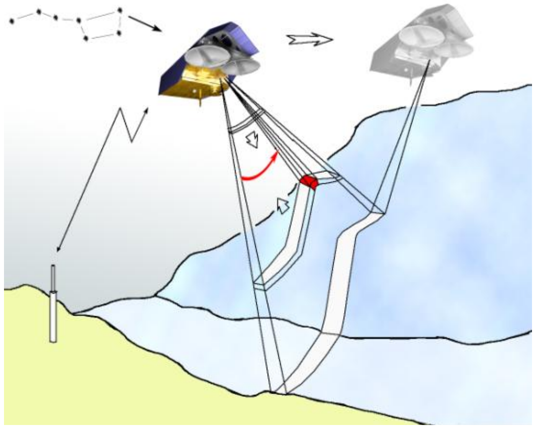
Benefits

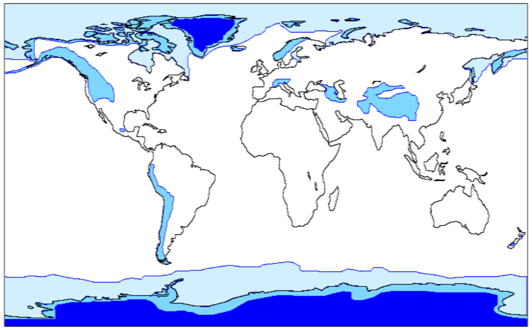
– improved parameterisation of sea-ice processes in coupled climate models

– reduced uncertainty in the ice-sheet contribution to global sea-level rise

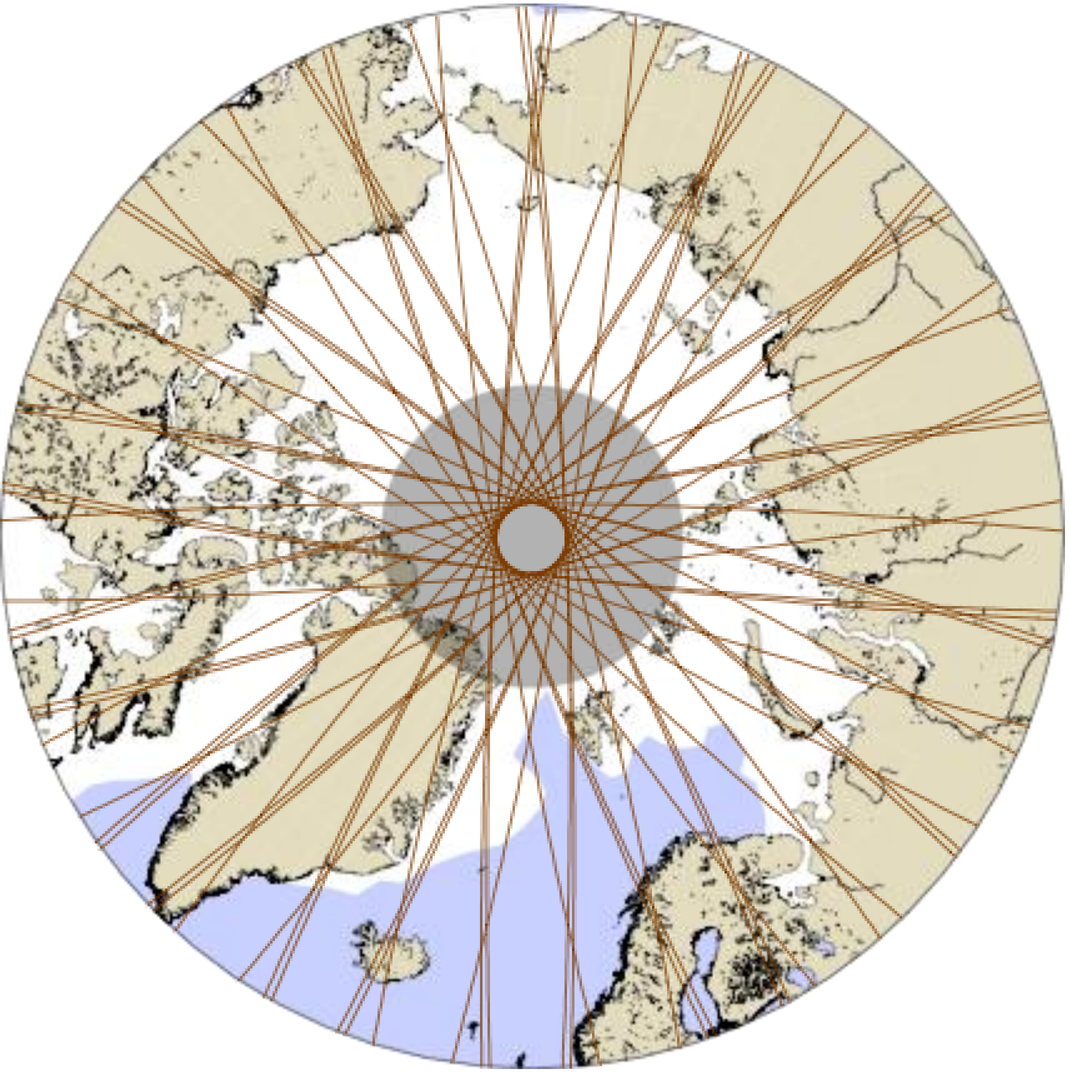
–advances in cryosphere and climate studies

www.esa.int/livingplanet/cryosat





CryoSat's Orbit Coverage

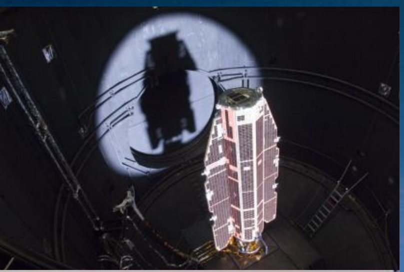


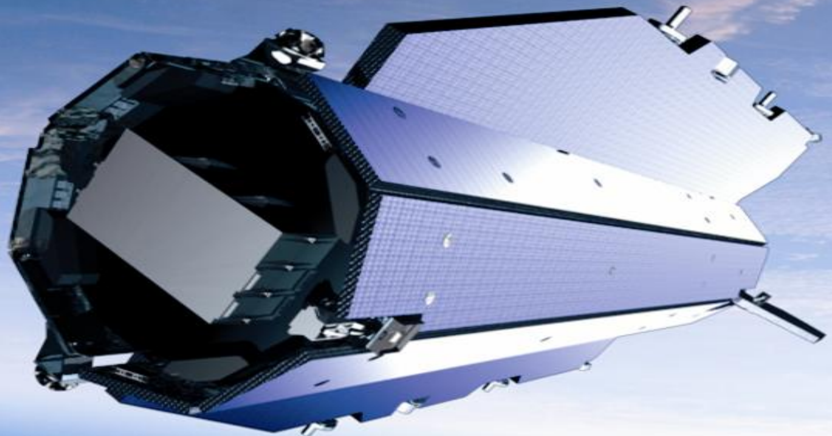
- inclination: 92˚
- repeat cycle: 369 days
- sub-cycle: 30 days
- inter-track spacing: 7.5 km
- orbit control: ±1 km
- altitude: 717 km
- *not* sun-synchronous

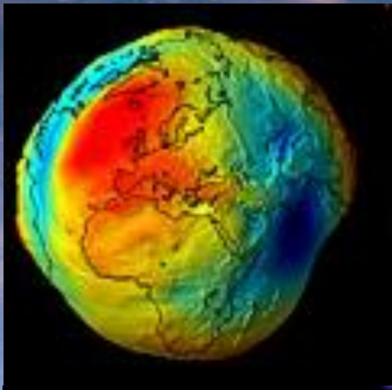
GOCE: ESA's Gravity Mission

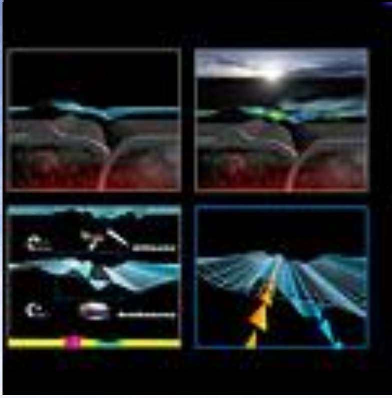
www.esa.int/livingplanet/goce

The Gravity field and steady-state Ocean Circulation Explorer (GOCE)









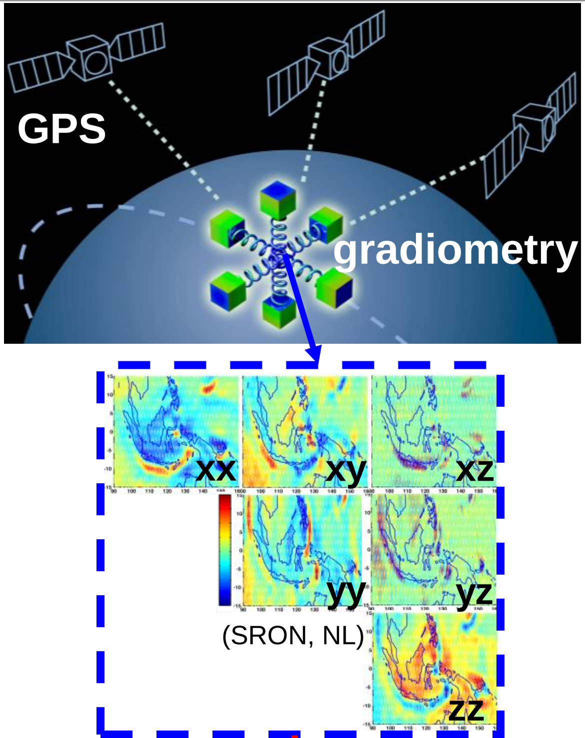
Its objectives are to improve understanding of:

- global ocean circulation and transfer of heat
- physics of the Earth's interior (lithosphere & mantle)
- sea level records, topographic processes, evolution of ice sheets and sea level change

GOCE: Gravity Mission

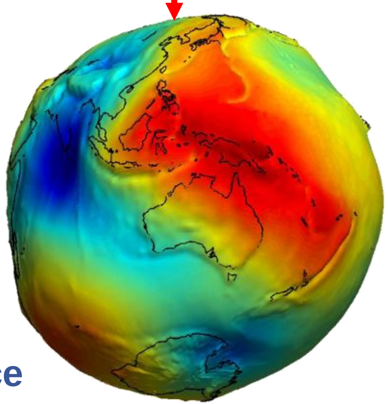
Approach

- Combination of *satellite gradiometry* and *high-low satellite-to-satellite tracking* at ± 260km altitude
- Develop improved model of the static gravity field and geoid to a resolution of 100 km with 1 mGal* 1-2cm accuracy, respectively
- (*1 mGal = 10^{-5} m/s^2 - or 1 millionth of *g*)



Benefits

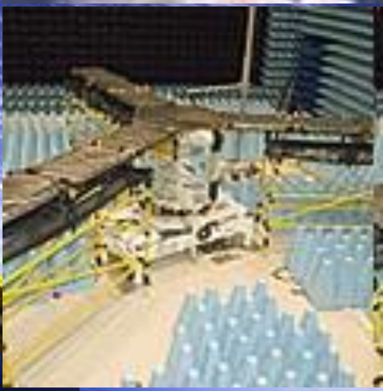
- An accurate marine geoid for absolute ocean currents and sea-ice thickness derivation
- Improved constraints for Earth-interior modelling calculation of rates of glacial isostatic adjustment
- Unified global height reference for land, sea, ice and surveying applications



www.esa.int/livingplanet/goce

SMOS: Soil Moisture and Ocean Salinity Mission

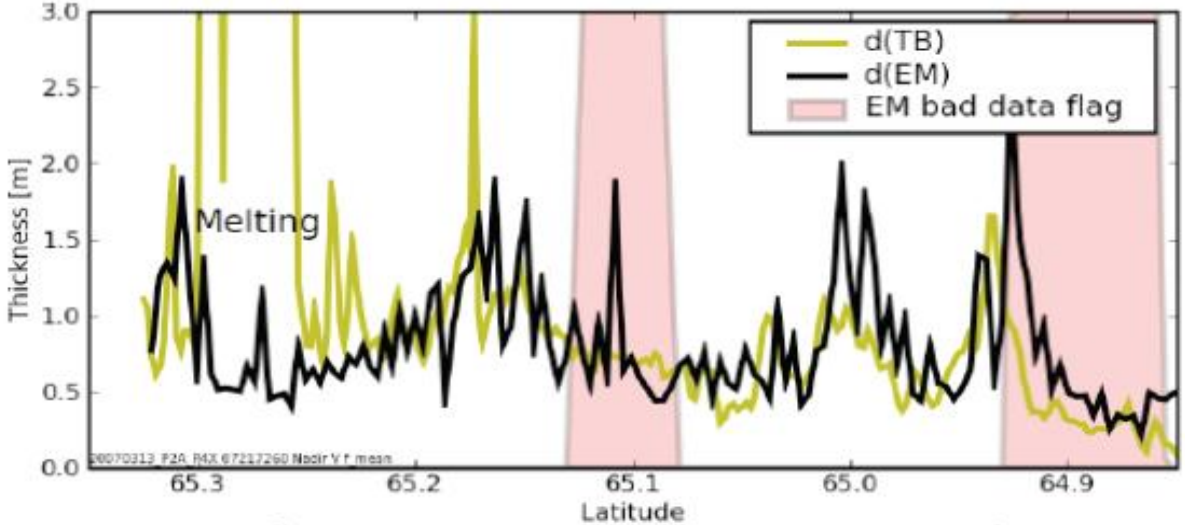
www.esa.int/livingplanet/smos

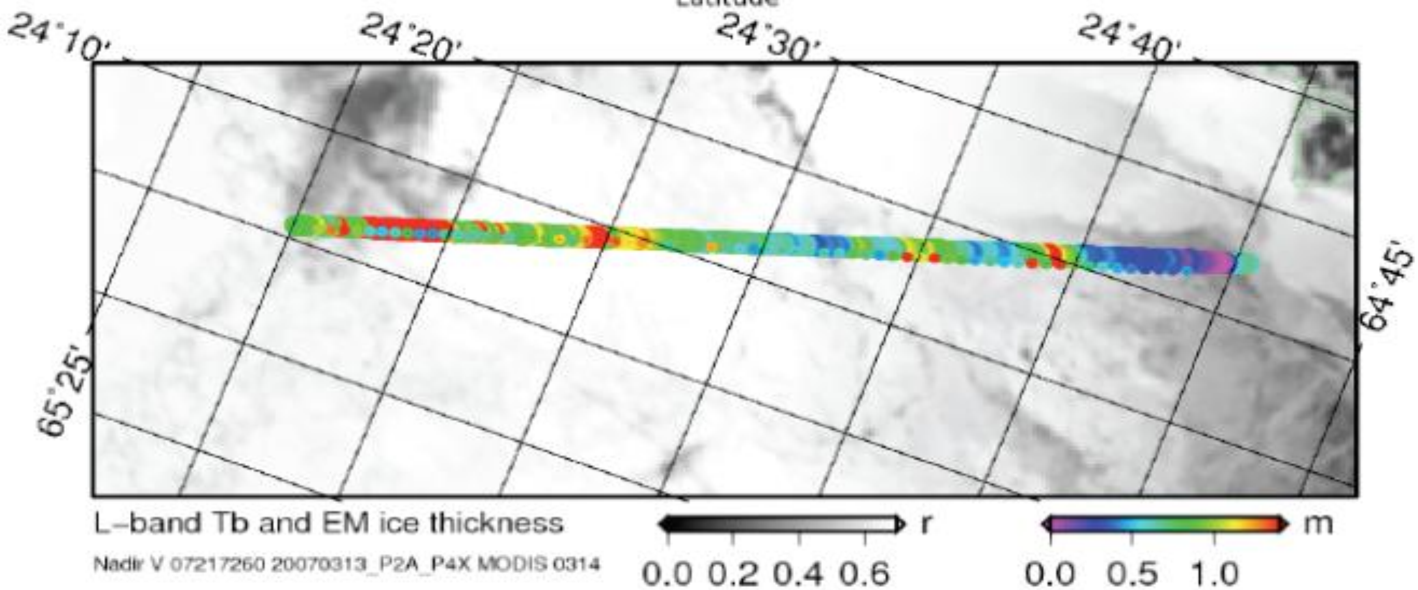


Its objectives are:

- to provide global maps of soil moisture and ocean salinity for hydrological studies
- to advance our understanding of the freshwater cycle
- to improve climate, weather and extreme-event forecasting
- Instrument: Microwave Imaging Radiometer with Aperture Synthesis (MIRAS)

SMOS Sea Ice Thickness Study: L-Band Radiometry for Sea Ice Applications





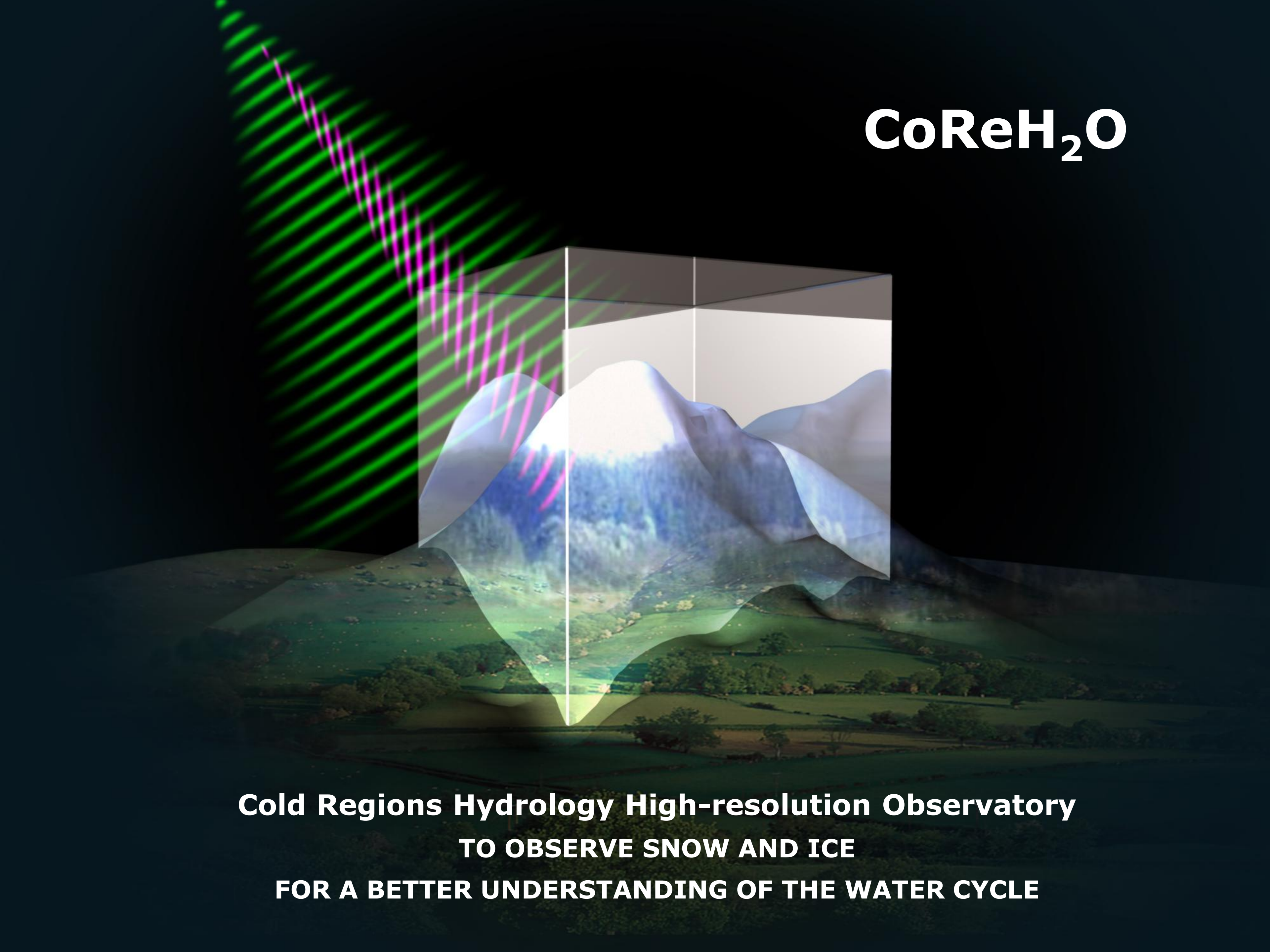
Pol-Ice Campaign 2007

The Three Candidate EE7 Missions

- **BIOMASS**
  To observe forest biomass for a better understanding of the carbon cycle
- **CoReH$_2$O (Cold Regions Hydrology High-resolution Observatory)**
  To observe snow and ice for a better understanding of the water cycle
- **PREMIER (PRocess Exploration through Measurements of Infrared and millimetre-wave Emitted Radiation)**
  To observe atmospheric composition for a better understanding of chemistry-climate interactions

Phase-A feasibility studies are now in progress and will be assessed at the next user consultation meeting currently planned for 2011/2012

One mission will be selected for implementation


CoReH$_2$O
Cold Regions Hydrology High-resolution Observatory
TO OBSERVE SNOW AND ICE
FOR A BETTER UNDERSTANDING OF THE WATER CYCLE

$CoReH_2O$ Mission objectives – water cycle and climate

Quantify the amount and variability of fresh water stored in terrestrial snow packs and snow accumulation on glaciers using X- and Ku-band SAR in order to:

- Reduce the **uncertainty of snow water storage** in regional and global water budgets
- Specify **snowmelt and glacier contributions to river discharge** modelling and forecasting
- Improve the **parameterisation and downscaling of snow and ice processes** in regional/global weather and climate models
- Validate the **magnitude and feedbacks of snow and ice processes** in climate models

$CoReH_2O$ Mission objectives – snow and ice processes

- Explore the distribution of snow properties in high-latitude regions to **support quantification of carbon cycling and trace gas exchanges**
- Evaluate **mass balance** of a broad sampling of glaciers and ice caps worldwide to understand atmospheric forcing and climate response
- Validate and improve **lake process models** to reduce model uncertainty and assess effects of lake ice on surface energy exchanges
- Explore the **snow accumulation on sea ice and the thickness of thin ice** to improve modelling of the sea ice mass balance and ocean-atmosphere heat fluxes



CoReH2O – OBSERVATION REQUIREMENTS

Primary parameters	**Spatial scale Regional/Global**	**Sampling (days)**	**Accuracy (rms)**
Snow water equivalent	200 m / 500 m	3-15	3 cm for SWE ≤ 30 cm, 10% for SWE > 30 cm
Snow extent	100 m / 500 m	3-15	5% area at hill slope scale
Snow accumulation on glaciers	200 m / 500 m	≤ 15	10% of maximum

Secondary parameters

Snow

Melting snow area, snow depth

Glaciers

extent, glacial lakes

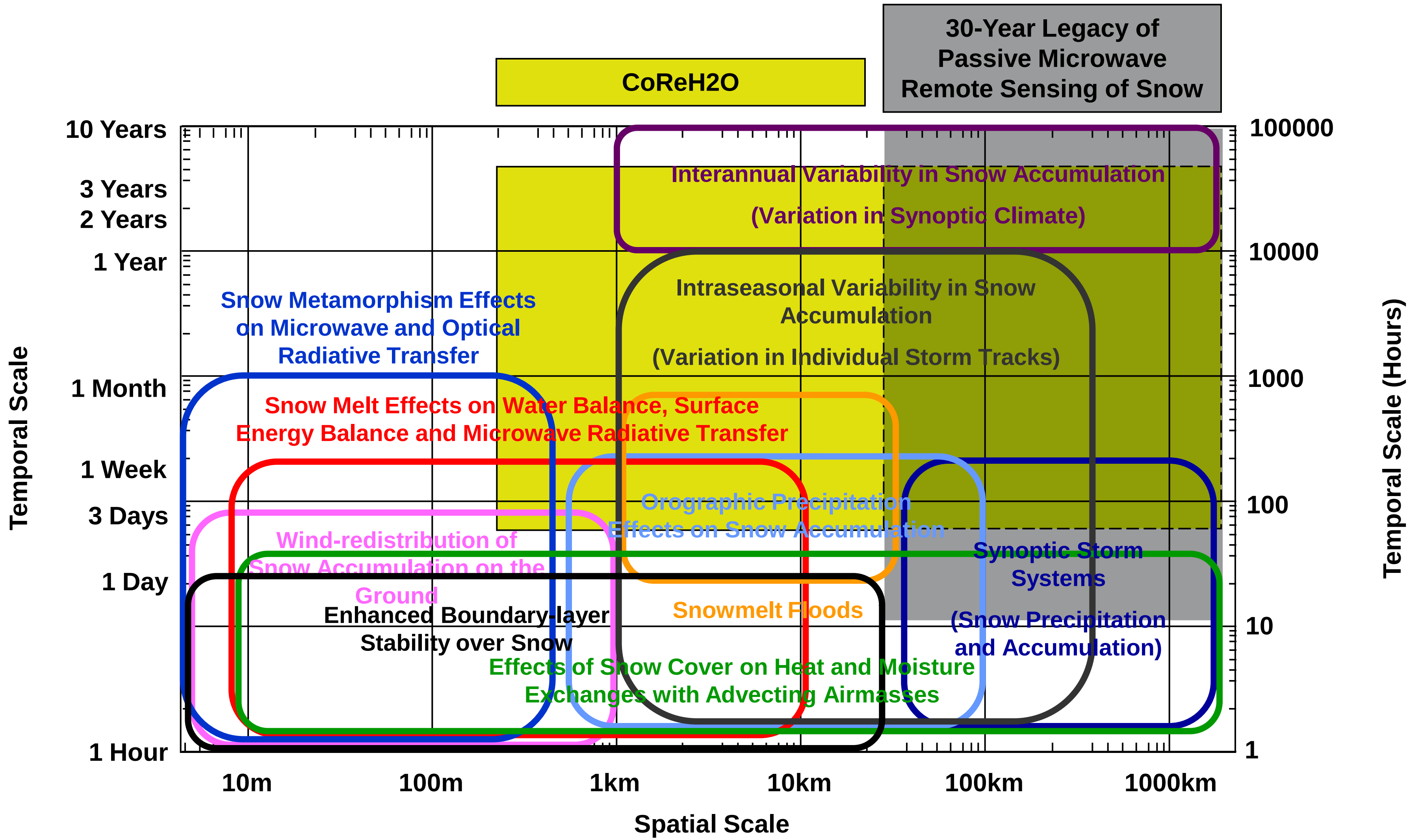
Lake and river ice

Ice area; freeze up and melt onset

Sea ice

Snow on ice (SWE, melt onset and area); type and thickness of thin ice

CoReH2O fills important gaps

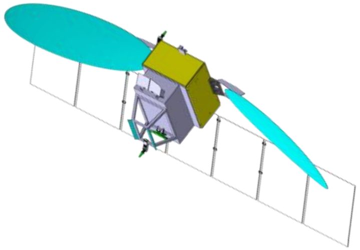


Modified from Cline (2005)

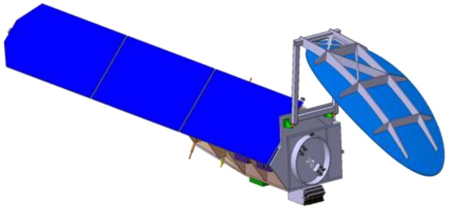
CoReH2O – ACTIVITY OVERVIEW

Industrial preparations

- parallel industrial phase A activities
- payload related bread boarding activities



technical concepts further analysed in Phase A



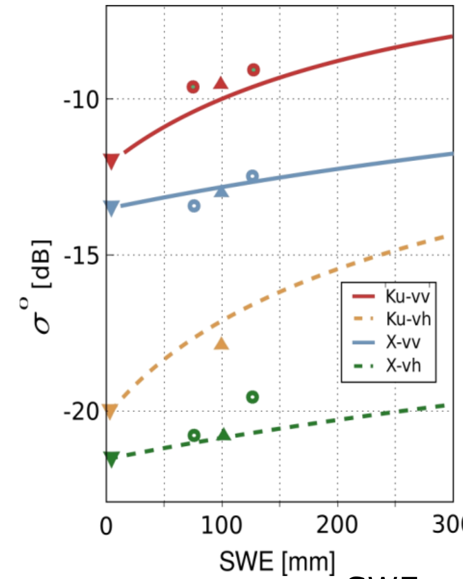
Scientific preparations

- scientific studies (Retrieval study, synergy study active/passive microwave, COSDAS, Synergy of different SARs for snow and ice parameter retrieval)
- campaigns (NoSREX, CAN-CSI, POLSCAT/CLPX)

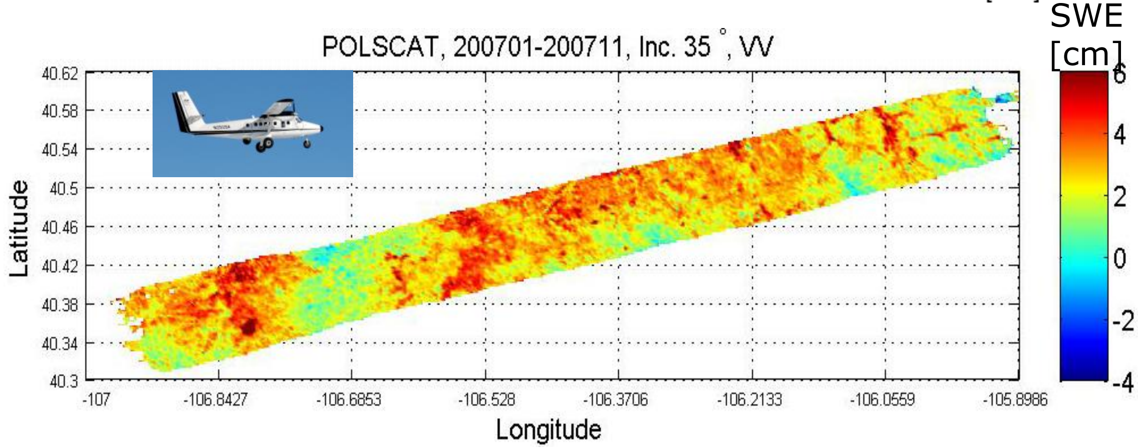
CoReH2O – RECENT CAMPAIGN RESULTS

Backscatter sensitivity to SWE for different snow conditions demonstrated

O **HeliSnow** ▲ **SARAlps**



Campaign data are the basis for validation of theoretical backscatter models and development of retrieval algorithms



POLSCAT/CLPX-II Colorado and Alaska

CoReH2O – ONGOING NoSREX CAMPAIGN

Aims

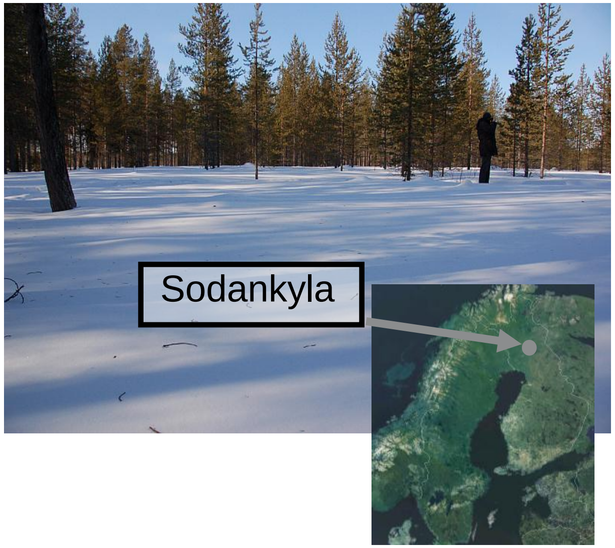
- Study the effects of snow accumulation (SWE) and temporal evolution of snow morphology on backscatter signatures, starting from the first snowfall until melting.
- Validation of theoretical backscattering models of snow at Ku- and X-band frequencies.
- Sensitivity studies for Ku- and X-band backscattering in regard to physical parameters of the snow pack.
- Validation of SWE retrieval algorithms.
- Acquisition of L-band radiometer data for synergy studies.

Experiment details

- Leverage FMI infrastructure at Sodankylä Observatory test site, northern Finland, 67° 22' N, 26° 38' E, 180 m
- Deployment of ESA SnowScat, SnowRad (FMI) and ELBARA-II (ESA) instruments from October 2009 to May 2010 to cover full range of snow conditions

SnowScat

SnowRad and Elbara-II

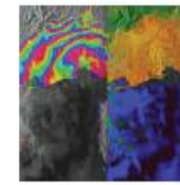


Earthwatch - GMES dedicated missions: Sentinels

Sentinel 1 – SAR imaging

All weather, day/night applications, Continuity of established C-band SAR applications, interferometry

2011



Sentinel 2 – Multispectral imaging

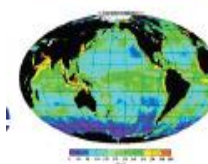
Land applications: urban, forest, agriculture, etc. Continuity of Landsat, SPOT data

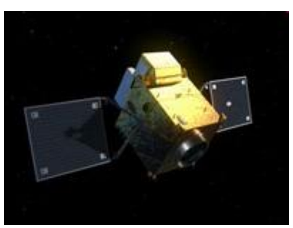
2012

Sentinel 3 – Ocean and global land monitoring

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

2012

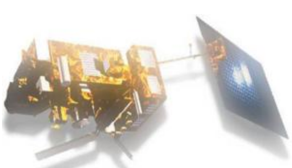




Sentinel 4 (MTG-S) – Geostationary atmospheric

Atmospheric composition monitoring, trans-boundary pollution

2017+



Sentinel 5 – Low-orbit atmospheric

Atmospheric composition monitoring & trans-boundary pollution

2019+

GMES Sentinel-1

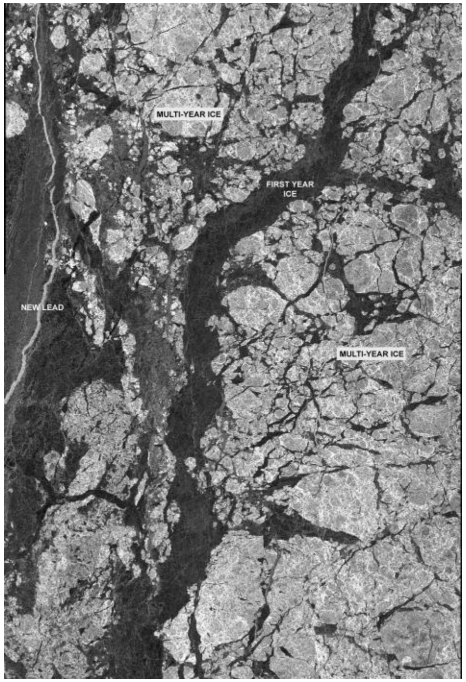
www.esa.int/gmes

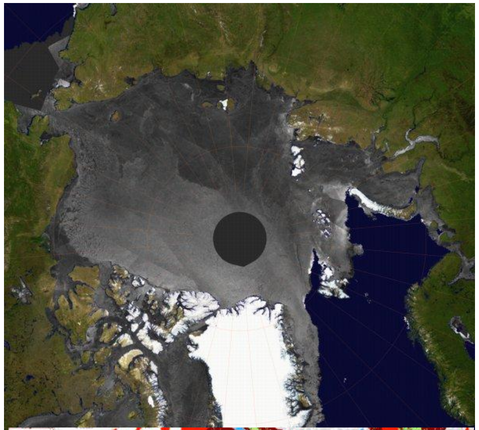
C-band SAR-based monitoring

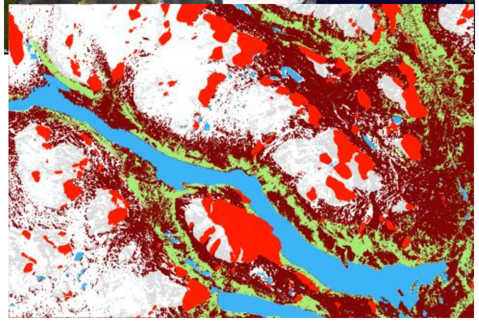
Monitoring sea ice zones and the arctic Surveillance of marine environment Monitoring land surface motion risks Mapping of land surfaces: forest, water and soil, agriculture Mapping for humanitarian aid in crisis situations
C-Band SAR Payload: Centre frequency: 5.405 GHz Polarisation: HH, HV, VH, VV Incidence angle: 20º – 45º
Modes: Strip map, wave, interferometric wide swath, Extra-wide Swath Mode
2300 kg spacecraft mass
12 days repeat cycle
Sun-Synchronous orbit @ 693km (98.18 deg)
7 years design life, consumables for 12 years

S-1: Cryosphere Applications

- **Global sea-ice monitoring**
  - Extent/type/drift
- **Iceberg monitoring**
  - Detection/drift
- **Ice sheet/glacier monitoring**
  - InSAR- topography
  - InSAR- ice movement
- **Land snow cover monitoring**
  - Area/Depth/SWE
- **River and Lake ice monitoring**
- **Ocean monitoring**
  - Waves
  - Surface winds
  - Ocean currents
  - Frontal structures



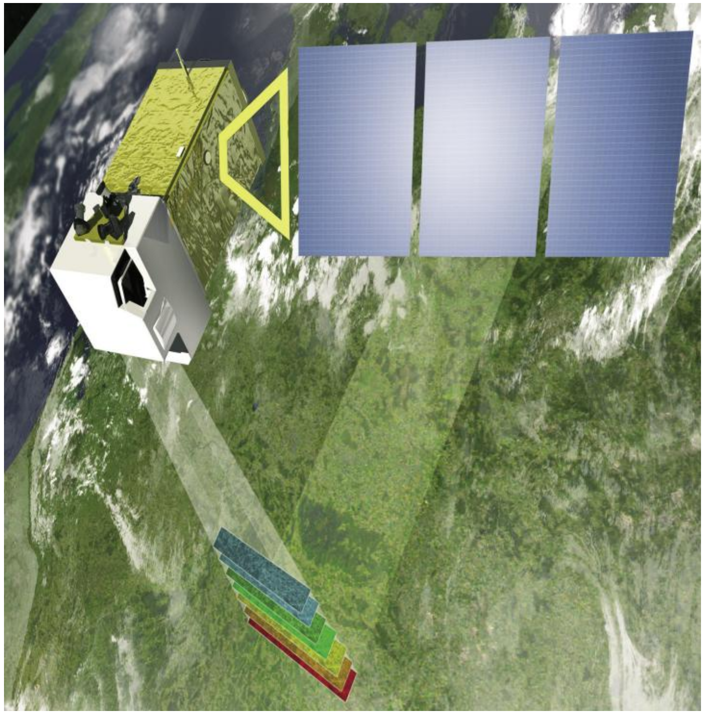




GMES Sentinel - 2

www.esa.int/gmes

Multi-spectral imaging mission



Applications: **Generic land cover maps, risk mapping and fast images for disaster relief, leaf coverage, leaf chlorophyll content and leaf water content** – **Surface albedo** – **Snow cover**
Pushbroom filter based multi spectral imager (MSI) with 13 spectral bands (VNIR & SWIR)
Spatial resolution: 10, 20 and 60 m
Field of view: 290 km
1098 kg spacecraft mass
10 days repeat cycle
Sun synchronous orbit at 786 km mean altitude
7 years design life time, consumables for 12 years

GMES Sentinel-3

www.esa.int/gmes

SENTINEL 3

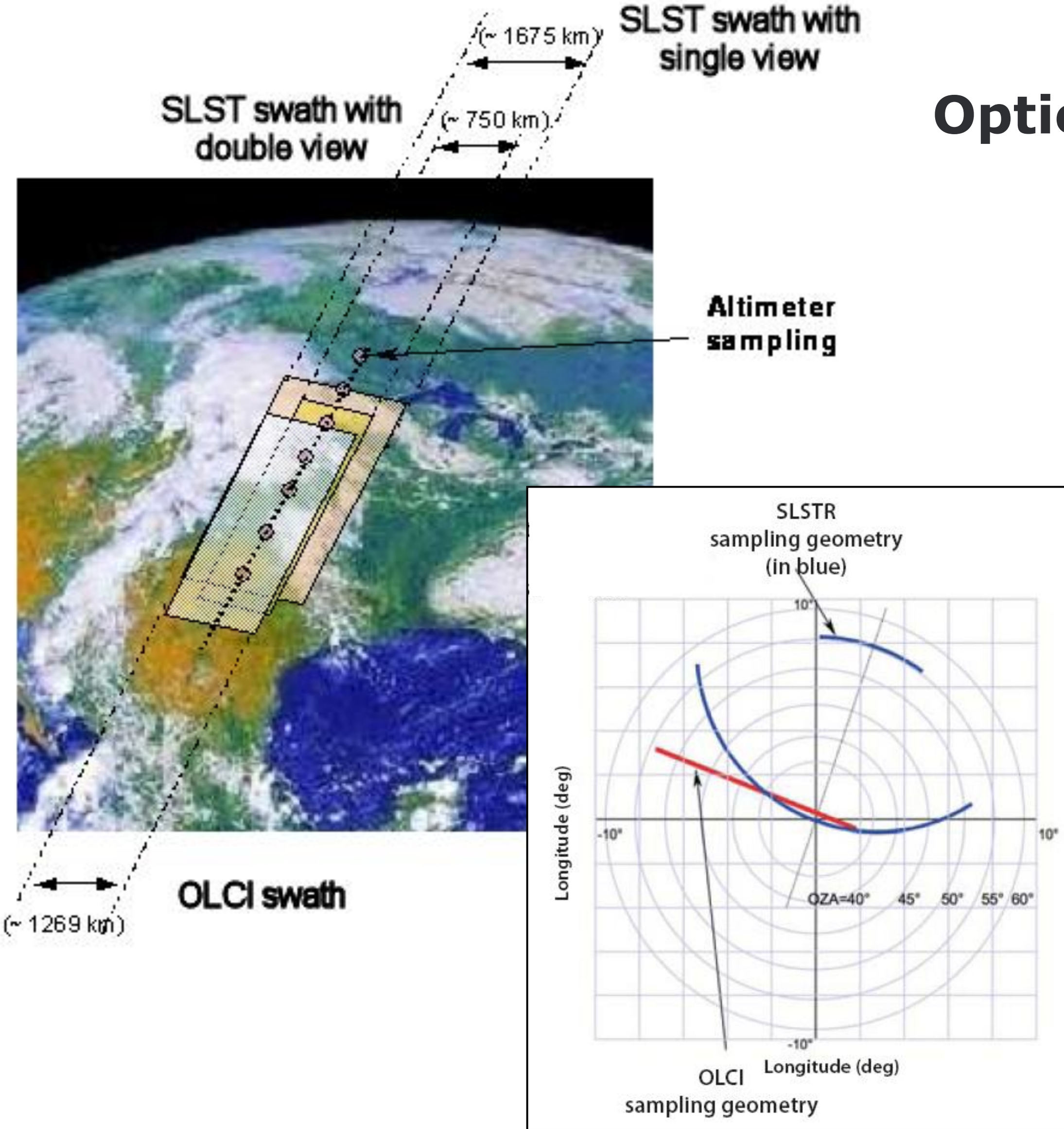
esa

Global Ocean & Land mission

http://www.esa.int/gmes

Applications: – Sea/land colour data and surface temperature – sea surface and land ice topography – coastal zones, inland water and sea ice topography – vegetation products – Aerosol products
1198 kg spacecraft mass
Sun synchronous orbit at 814.5 km mean altitude
27 days repeat cycle
7 years design life time, consumables for 12 years

S-3 Payload Complement



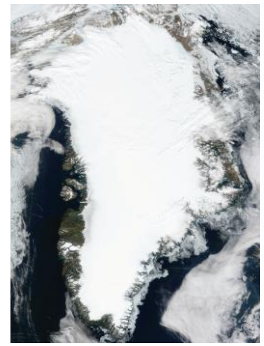
Optical Mission Payload

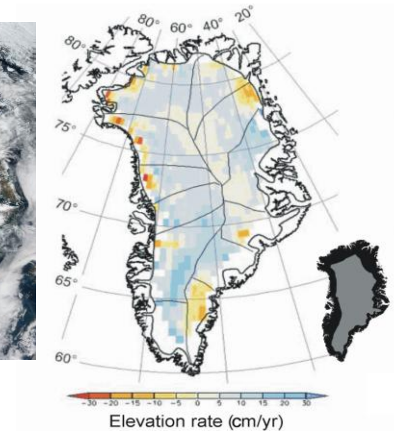
- Ocean and Land Color Instrument (OLCI – 21 bands, 1.2km & 300m resolution)
- ENVISAT- MERIS heritage

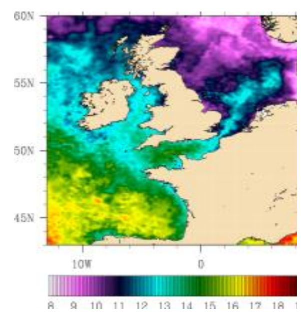
- Sea and Land Surface Temperature Radiometer (SLSTR 9 bands VIS/IR + dedicated fire channels)
- ENVISAT- AATSR heritage

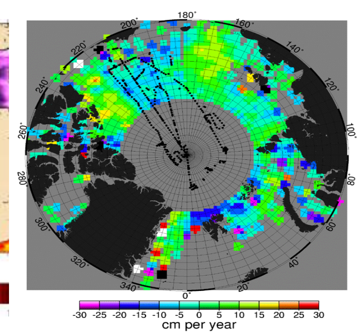
S-3: Cryosphere Applications

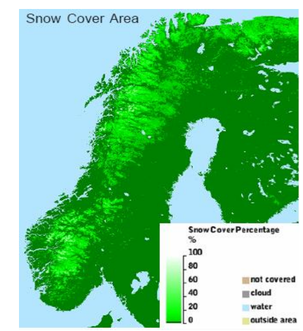
- **Surface Topography**
  - Sea-ice elevation/thickness
  - Land Ice elevation
- **Surface Temperature**
  - Snow/ice
  - Land surface
- **Ocean & Land Colour**
  - Snow/Sea ice extent
- **By-products**
  - Clouds
  - Albedo

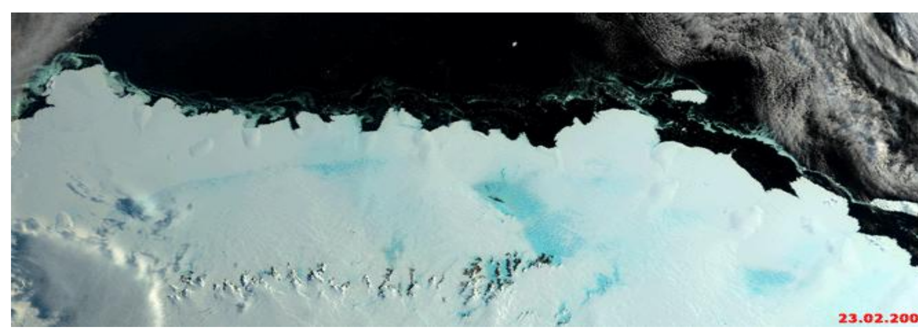












Launches…

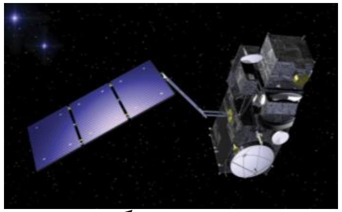
GOCE

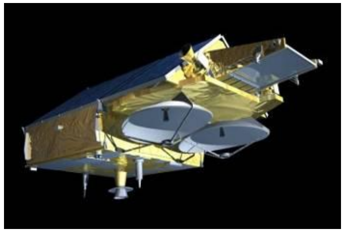
Gravity Field and Steady State Ocean Circulation Explorer

SMOS

Soil Moisture and Ocean Salinity

Sentinel-3a,b





Cryosat 2

Sea Ice thickness and Ice sheet topography

Sentinel-1a,b

Sentinel-2a,b

Summary

- ESA's Living Planet Programme features user-driven missions with specific scientific (Explorer) and operational (EarthWatch) goals.
- ESA will launch 15 new EO satellite missions in next 10 years at regular intervals.
- New ESA missions directly contribute to IGOS- Cryosphere needs and help establish elements of space infrastructure of *CryOS* (cryosphere observing system).
- This is the golden age of Cryosphere remote sensing. We will likely never ever have better European EO capability (research + ops).

  = now is best opportunity to understand the cryosphere using EO tools.

For more Information

http://www.esa.int

Thank You

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