Summer School
27 July-5 August 2010, Alpbach, Austria

Global Monitoring for Environment and Security (GMES) for Science

Josef Aschbacher
Head, ESA GMES Space Office

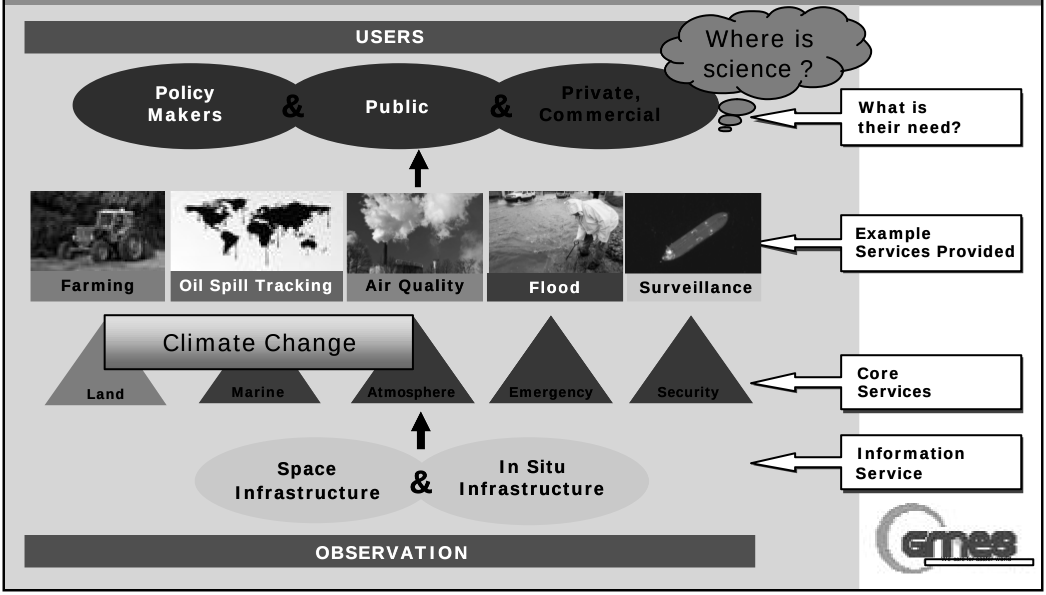
GMES Components

GMES is a user-driven EU led initiative

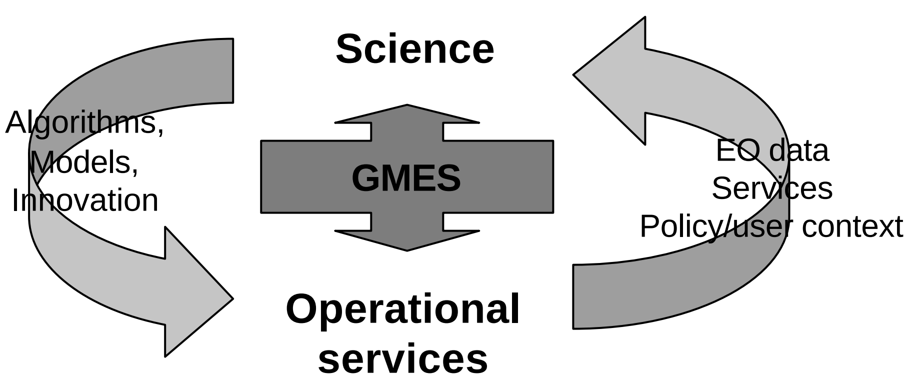
- **Services Component – coordinated by EC**
  - Information services in response to European policy priorities
- **In-situ component – coordinated by EEA**
  - Observations mostly within national responsibility, with coordination at European level
- **Space Component – coordinated by ESA**
  - Sentinels - EO missions developed specifically for GMES
  - Contributing Missions - offering part of their capacity to GMES (EU/ESA MSs, EUMETSAT, commercial, international)

GMES is a perfect example of a system of systems

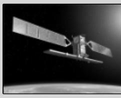
GMES Overall View



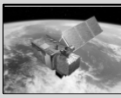
Science and Operations



GMES dedicated missions: Sentinels



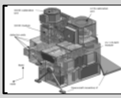
Sentinel 1 – SAR imaging
All weather, day/night applications, interferometry
2012 (A), 2014+ (B)



Sentinel 2 – Multispectral imaging
Land applications: urban, forest, agriculture,..
Continuity of Landsat, SPOT
2013 (A), 2015+ (B)

Sentinel 3 – Ocean and global land monitoring
Wide-swath ocean colour, vegetation, sea/land surface temperature, altimetry
2013 (A), 2015+ (B)

Sentinel 4 – Geostationary atmospheric
Atmospheric composition monitoring, trans-boundary pollution
2018



Sentinel 5 and Precursor – Low-orbit atmospheric
Atmospheric composition monitoring
2014 (5P), 2019

Sentinel–1: C-band SAR mission

✓ **Data continuity of ERS and EnviSat missions**

✓ **GMES C-band radar mission for land and ocean services**

✓ **Applications:**

- ice and marine/land monitoring
- mapping in support of humanitarian aid in crisis situations
- monitoring sea ice zones and the arctic environment
- surveillance of marine environment
- monitoring land surface motion risks
- mapping of land surfaces; forest, water and soil, agriculture

Sentinel–1 system

✓ **Space Segment:**

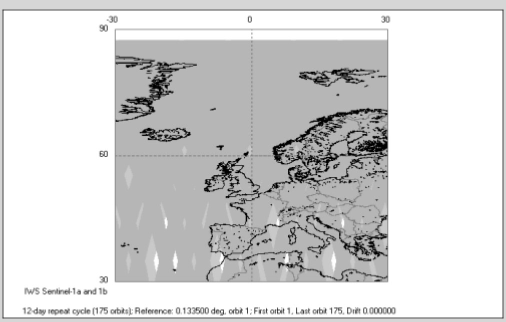
- ➢ A constellation of two satellites
- ➢ Nominal lifetime in orbit of 7 years (consumables for 12)
- ➢ Near-Polar Sun-Synchronous dusk-dawn orbit @ 693km.
- ➢ Repeat Cycle at equator 12 days (with 1 S/C) and 6 days (with 2 S/C)
- ➢ C-Band SAR Payload (centre frequency 5.045 GHz)
- ➢ Equipped with an Laser Communication Terminal for GEO laser link

✓ **Ground Segment:**

- ➢ Mission operations for a system of satellites over a period of 20 years
- ➢ S-Band station (Kiruna proposed), with a back-up for S/C contingencies
- ➢ Downlink currently assumes three X-Band receiving stations
- ➢ Alternative downlink via EDRS upon service availability

Sentinel–1: C-band SAR mission

- 25 min/orbit in any imaging mode + remainder in Wave mode
- Daily coverage of high priority areas, e.g. Europe, Canada, shipping routes.
- Global coverage in 6 days with S1A + S1B.

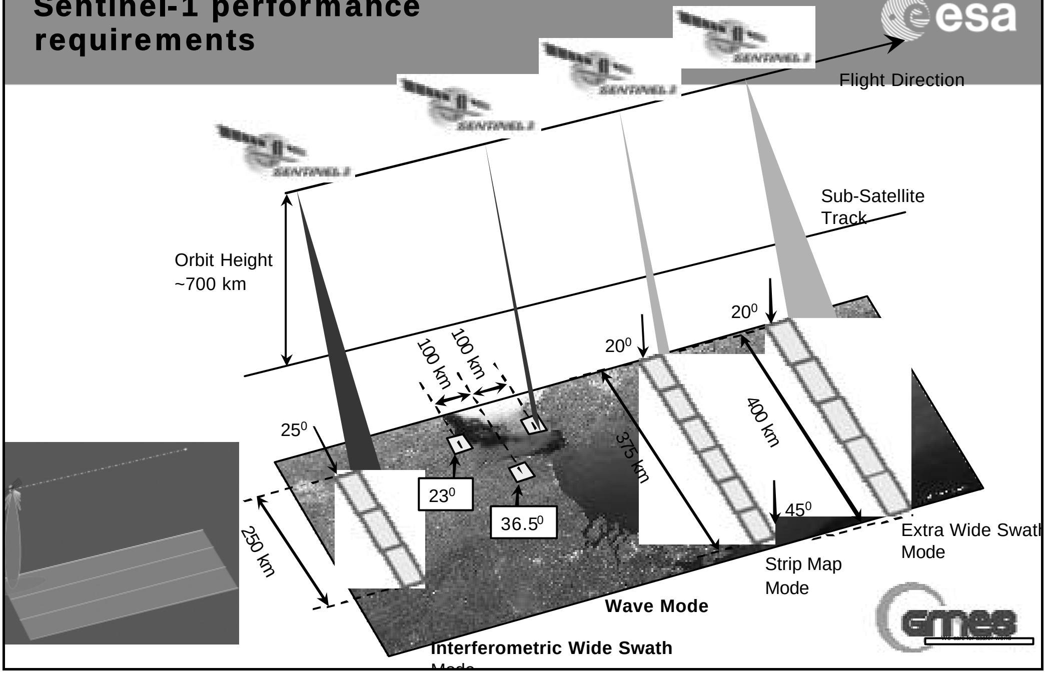


IWS Sentinel 1a and 1b, European region, 5 days, 1 day step

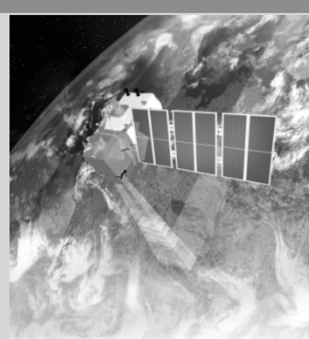
Operation modes:

Modes	Resolution	Swath Width	Polarisation
Stripmap (SM)	5 x 5 m²	> 80 km	HH+HV or VV+VH
Interf. Wideswath (IWS)	5 x 20 m²	> 250 km	HH+HV or VV+VH
Extra Wideswath (EW)	20 x 40 m²	> 400 km	HH+HV or VV+VH
Wave (W)	5 x 5 m²	20 x 20 km² at 100 km spacing	HH or VV

Sentinel-1 performance requirements



Sentinel–2: Superspectral imaging mission



✓ **Data continuity & enhancement of Landsat and SPOT-type missions**

✓ **GMES optical high resolution for operational land and security services**

✓ **Applications:**

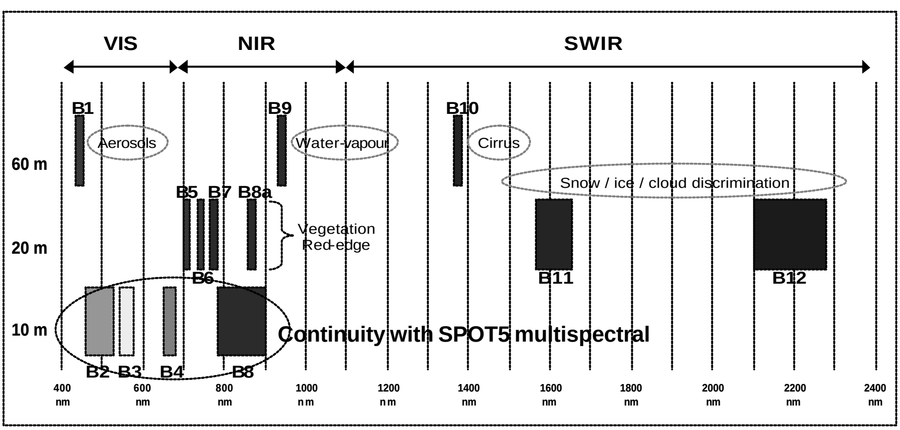
- land cover, usage and change detection maps
- geophysical variable maps (e.g. leaf chlorophyll content, leaf water content, leaf area index)
- risk mapping and fast images for disaster relief

Sentinel–2 precursor missions

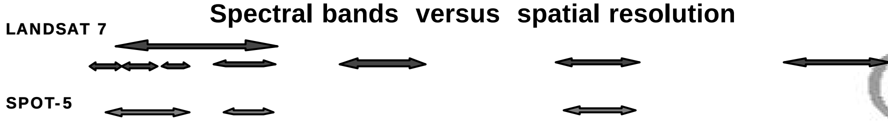
	Landsat	SPOT	Sentinel-2
Number in series	7 + 1*	5	starting with 2
Launch	1972 to 1999*	1986 to 2002	first launch 2013
Measurement principle	scanner	pushbroom	pushbroom
Earth coverage (days)	16	26	5
Swath (km)	185	2*60	290
Multispectral bands		4+1(panchromatic)	13
Spatial sampling distance (m)	30, 60	10, 20	10, 20, 60

* LCDM mission targeted 2012

Sentinel–2: 13 spectral bands !



Spectral bands versus spatial resolution

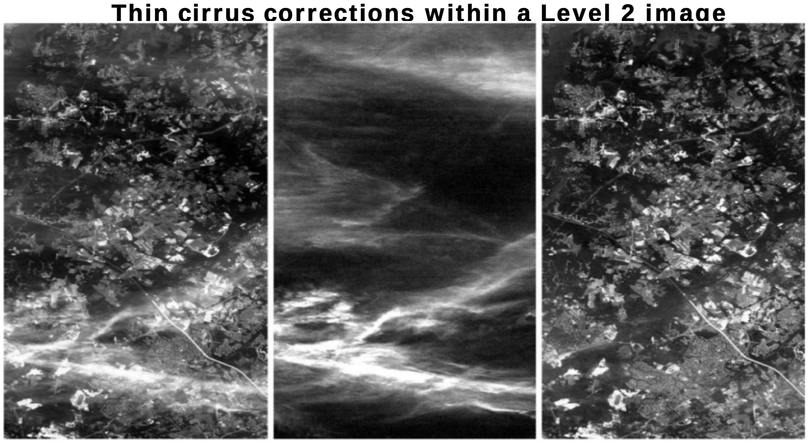


Sentinel–2 system

- **Space Segment:**
  - A constellation of two satellites in the same orbit (180º apart from each other) with 5 days revisit time at Equator
  - Spectral bands: 13 (VIS–NIR–SWIR domains)
  - Spatial resolution: 10m / 20m / 60m
  - Sun-synchronous orbit at 786 km and 290 km swath
  - Geographic coverage: Systematic, all land & coastal surfaces between -56° & +84° Latitude
  - Multispectral Instrument: operating in pushbroom principle, filter based optical system, low noise image compression
  - Lifetime: 7 years, extendable to 12 years
- **Ground Segment:**
  - Data delivered to 4 core GS within 1-3 hours after acquisition.
  - X band data downlink with instrument data rate of 490 Mbps (after onboard wavelet compression)
  - Laser Communication through geo terminal (can be operated simultaneously with the X band subsystem)
  - 900 GB per day: cloud-free images will be further processed

Sentinel–2 correction channels

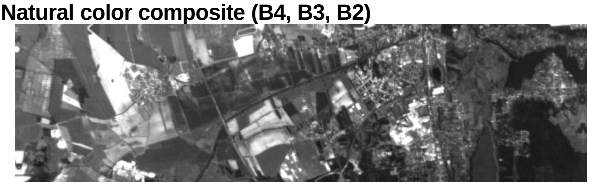
Thin cirrus corrections within a Level 2 image



Simulated Sentinel-2 scene containing cirrus clouds. True color coding: R/G/B = bands 4/3/1 (665, 560, 443 nm). Left: original scene, center: cirrus band (1.375 µm), right: after cirrus and atmospheric correction. Credits: DLR for data simulation and NASA/JPL for AVIRIS data supply

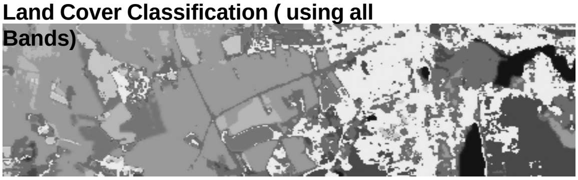
Sentinel–2 Level 2b simulated products

Natural color composite (B4, B3, B2)



Visible Near Infrared composite (B8, B4, B3)

Land Cover Classification (using all Bands)



Simulated Sentinel-2 images

	Urban
	Water
	Forest 1
	Forest 2
	Bare soil 1
	Bare soil 2
	Cultivated field 1
	Cultivated field 2

Sentinel–3: Ocean & global land mission

✓ **GMES medium resolution global land and ocean monitoring mission**

✓ **Applications:**

- Sea/land colour data in continuation of MERIS (EnviSat)
- Sea/land surface temperature in continuation of AATSR (EnviSat)
- Sea-surface and land-ice topography in continuation of Envisat altimetry

✓ **In addition, the payload design will allow:**

- data continuity of the Vegetation instrument (on SPOT-4/-5)
- enhanced fire monitoring capabilities
- Along-track SAR for coastal zones, in-land water and sea-ice topography

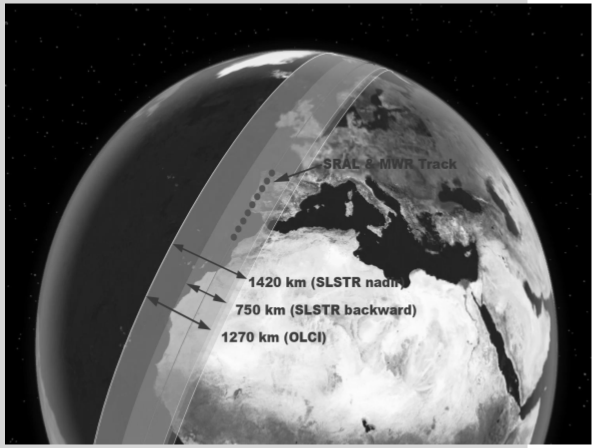
Sentinel–3 payload

Optical Mission Payload

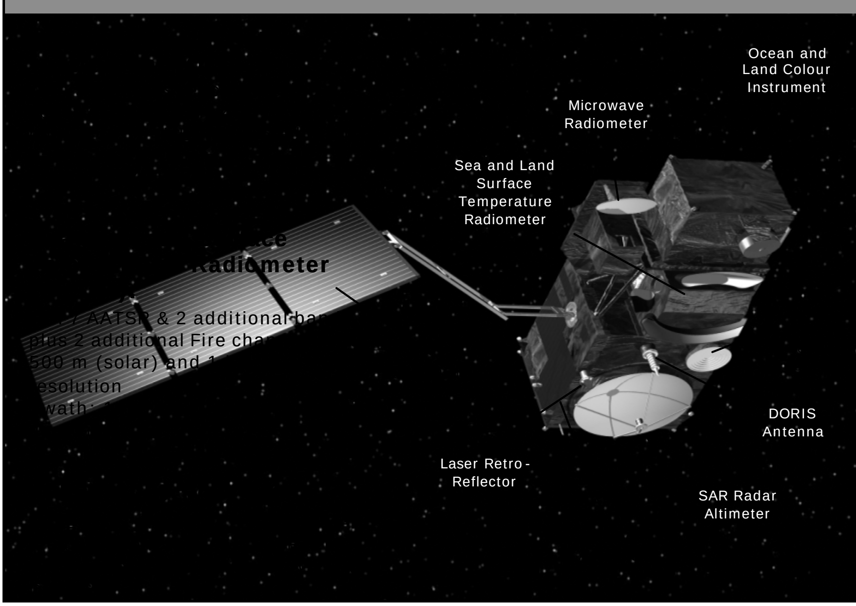
- Ocean and Land Color Instrument (OLCI)
- Sea and Land Surface Temperature Radiometer (SLSTR)

Topography Mission Payload

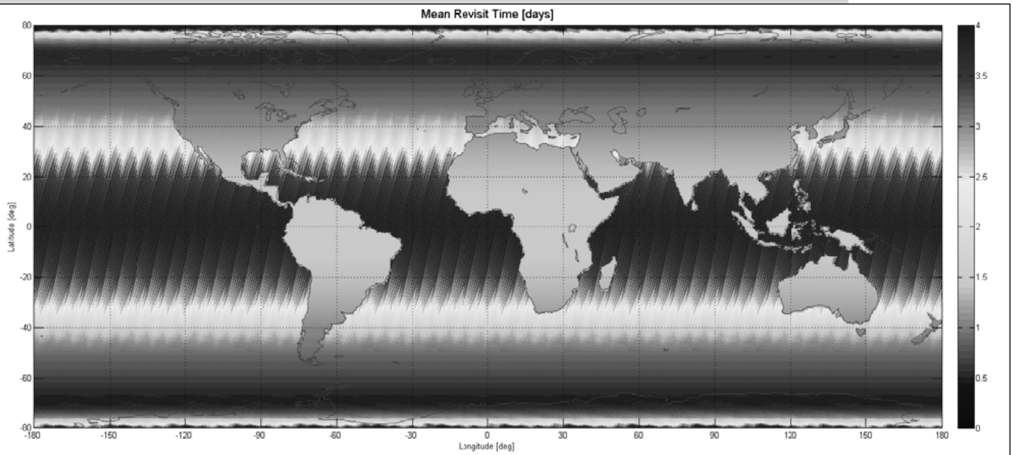
- Ku-/C-band Synthetic Aperture Radar Altimeter (SRAL)
- MicroWave Radiometer (Bi-frequency)
- Precise Orbit Determination (POD) including
  - GNSS Receiver
  - DORIS
  - Laser Retro-Reflector



Sentinel–3 mission instruments



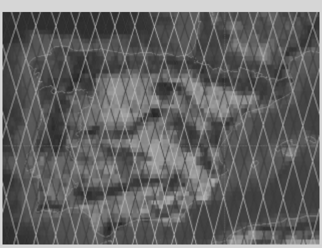
Sentinel–3: OLCI revisit time



OLCI mean revisit time map (14+7/27 orbit), with 1 S/C

Sentinel–3: revisit time and coverage

Topography Mission:
ground track repeatability, dense spatial sampling



Ground tracks after 1 complete cycle (27 days)

Optical missions:
Short Revisit times for optical payload, even with 1 single satellite

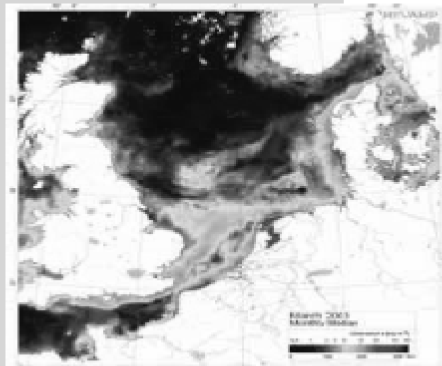
		Revisit at Equator	Revisit for latitude > 30°	Spec.
Ocean Colour (Sun-glint free, day only)	**1 Satellite**	< 3.8 days	< 2.8 days	< 2 days
	2 Satellites	< 1.9 days	< 1.4 days	
Land Colour (day only)	**1 Satellite**	< 2.2 days	< 1.8 days	< 2 days
	2 Satellites	< 1.1 day	< 0.9 day	
SLSTR dual view (day and night)	**1 Satellite**	< 1.9 days	< 1.5 days	< 4 days
	2 Satellites	< 0.9 day	< 0.8 day	

- **Near-Real Time (< 3 hr) availability of the L2 products**
- **Slow Time Critical (STC) (1 to 2 days) delivery of higher quality products for assimilation in models (e.g. SSH, SST)**

Sentinel–3: Comparison MERIS - OLCI

✓ **Close MERIS heritage (spectral bands and radiometric performances)**

✓ **Key Improvements:**
- number of spectral bands (from 15 to 21)
- reduced sun glint by camera tilt in west direction
- Full Resolution (FR, 300m) also over land/ocean
- Reduced Resolution (RR, 1200m) over Ocean
- improved coverage: Ocean < 4 days, Land < 3 days (MERIS eff. 15 days)
- Timeliness: 3 hours NRT Level 2 product
- 100% overlap with SLSTR

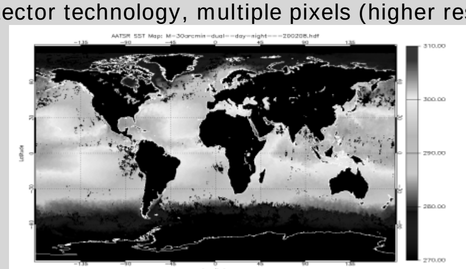


Chlorophyll Atlas of the North Sea (MERIS)

Sentinel-3: comparison SLSTR - AATSR

✓ **Conical scanning imaging radiometer with dual view capability**
- Heritage from (A)ATSR series on ERS-1/2, ENVISAT
- To allow sea/land temperature retrieval with typical absolute (relative) accuracy of 0.2 (0.08) K

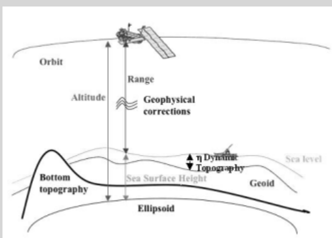
✓ **Key improvements:**
- 7 AATSR & 2 additional bands: 1.38, 2.2 µm
- One Vis channel used for co-registration with OLCI
- 3 instead of 1 mechanism, due to wider swath (2 scanners and one flip mechanism)
- More complex front-end & electronics (more channels)
- New detector technology, multiple pixels (higher res)

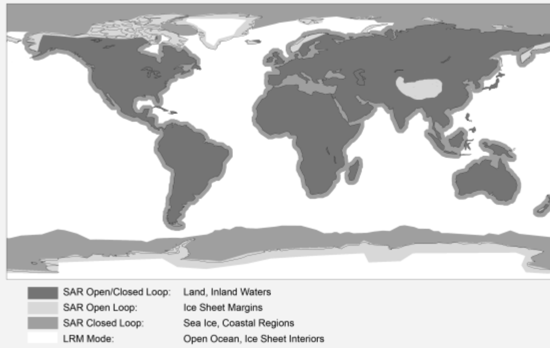


Sentinel–3: Comparison SRAL – RA-2

Observed surfaces
- Open ocean, coastal ocean
- Ice sheets (interiors and margins)
- Sea ice
- In-land water (rivers & lakes)

Topography package:
- **Open SRAL**
  Dual frequency Ku/Cband
  Radar Altimeter (CS/Jason heritage), with SAR mode and open loop tracking (used over rough surfaces)
- **MWR**
  Dual channel microwave radiometer





- **Precise Orbit determination:**
  GPS receiver
  Doris navigation receiver
  Laser retroreflector

Sentinel–4: GEO atmospheric mission

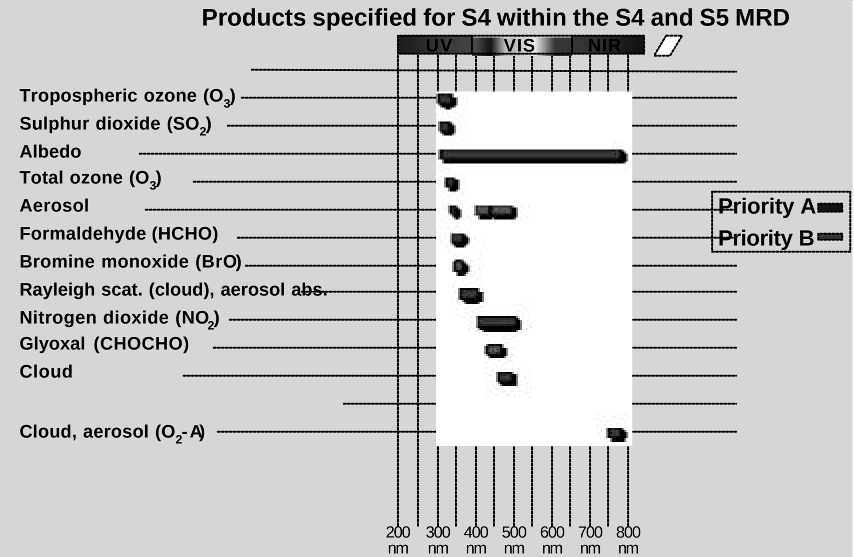
✓ **Mission for climate protocol monitoring (lower troposphere) and air quality applications**

✓ **Covering the need for continuous monitoring of atmospheric composition**

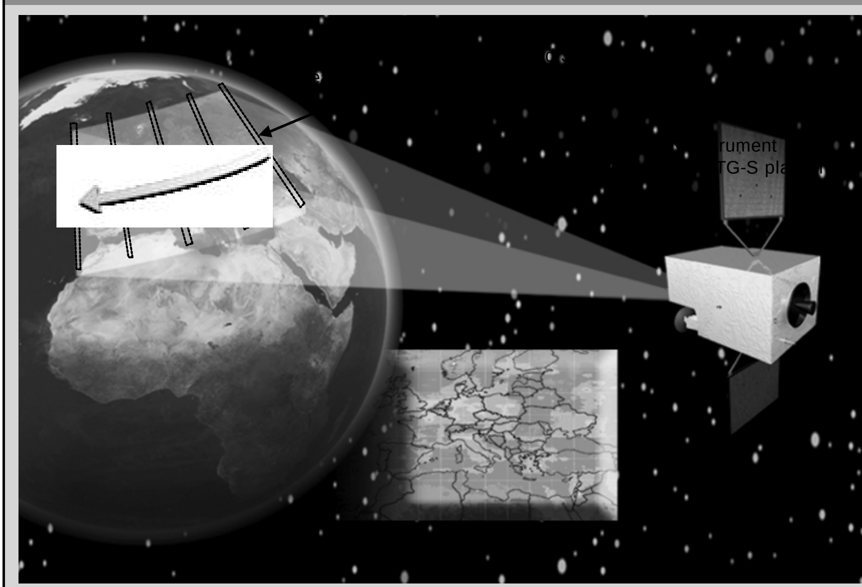
✓ **Focus on air quality with the main data products being O_3, NO_2, SO_2, HCHO and aerosol optical depth**

✓ **Supporting air quality monitoring and forecast over Europe with high revisit time (~1 hour) for the period of time between 2017 and 2032**

Sentinel–4 products



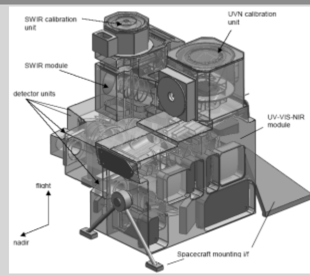
The Sentinel–4 / UVN instrument



Sentinel–5 and S-5 Precursor: LEO atmospheric missions

Applications:

- Air quality
- Climate forcing
- Stratospheric ozone
- Target parameters: O_3, NO_2, CO, SO_2, CH_4, H_2O, BrO and aerosols

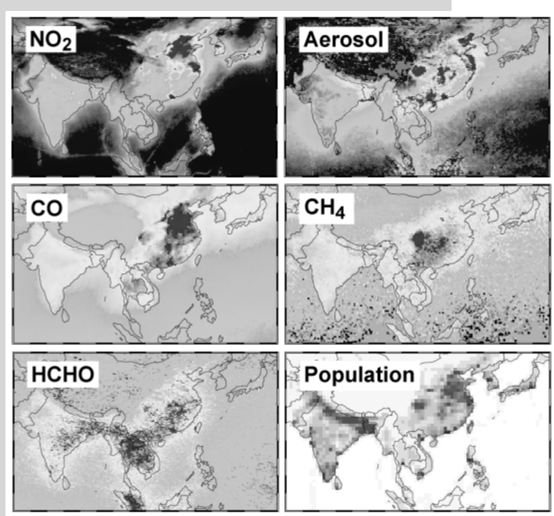


- ✓ **UV-Visible (270-500 nm), NIR (675-775 nm) and SWIR (2305-2385 nm) push-broom grating spectrometer**
- ✓ **Global daily coverage with 7x7 km^2 ground pixel**
- ✓ **Sun-synchronous LEO platform at 824 km mean altitude**
- ✓ **Sentinel-5 embarked on post-EPS and operated by EUMETSAT**
- ✓ **S-5 precursor guarantees data delivery for atmospheric GMES services between 2015-2020**

Sentinel-4 and 5: Air Quality & Tropospheric Composition

Global, regional and urban scale

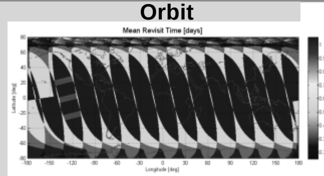
- On global & regional scales (processes of ozone, aerosols & their precursors):
  - export
  - transport
  - chemical transformation
- On urban scales:
  - distribution and variability of pollutants
  - attribution of major local sources
- Pollution levels in megacities and their contribution to background pollution levels on the regional and global scale



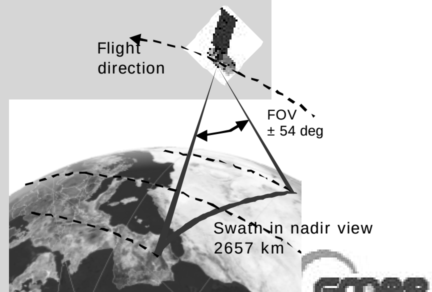
Sentinel–5 Precursor implementation concept

- ✓ Tandem flying with NOAA NPOESS satellite considered
- ✓ Temporal and spatial sampling:
  Daily global coverage
- ✓ Spatial sampling distance:
  5 km (goal),
  15 km (threshold)
  Note: band UV-1 has relaxed values
- ✓ Spectral bands: UV-Vis-NIR and SWIR
- ✓ Launch planned for early 2014
- ✓ Dedicated platform

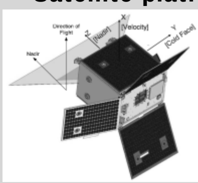
Orbit



Sun-synchronous orbit
828 km, LTAN 13:30



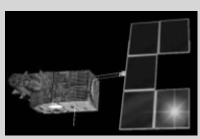
Satellite platform



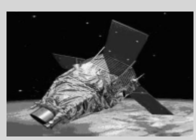
- ✓ Single instrument spacecraft
- ✓ Mass ~516 kg
- ✓ Power ~544 W
- ✓ 5 years nominal lifetime (plus 2 years extension)

Potential Contributing Missions to GMES

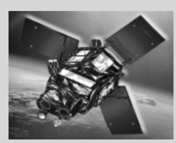
Cosmo-Skymed



SPOT

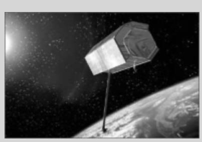


Pléiades

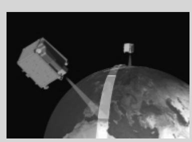


SeoSat

Radarsat

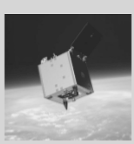


TerraSAR–X



RapidEye

METOP



DMCs

MSG

List not exhaustive

… will evolve based on service requirements and mission availabilities

+ PROBA-V, Seosar, TanDEM-X, EnMAP, Venμs, Altika, etc.

Example: SAR Contributing Missions

SAR missions	Principal Owner	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
ERS-2 (C-Band)	ESA	■	■	■													
Envisat ASAR (C-Band)	ESA	■	■	■	■	■	■										
Sentinel-1 A	ESA						▒	▒	▒	▒	▒	▒	▒				
Sentinel-1 B	ESA									▒	▒	▒	▒	▒	▒	▒	
Sentinel-1 C, ...	ESA											▒	▒	▒	▒	▒	▒
TerraSar-X (X-Band)	DLR	■	■	■	■	■	■										
TerraSar-X -2 (X-Band)	DLR						▒	▒	▒	▒	▒						
Tandem-X (X-Band)	DLR			▒	▒	▒	▒	▒									
Cosmo-Skymed (X-Band) -S/C 1,2,3	ASI	■	■	■	■	■											
Cosmo-Skymed (X-Band) -S/C 4	ASI			▒	▒	▒	▒	▒									
Cosmo-Skymed 2nd gen (X-Band)	ASI					▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒
Radarsat-2 (C-Band)	CSA	■	■	■	■	■	■	■									
RCM (C-Band)	CSA							▒	▒	▒	▒	▒	▒	▒			
SeoSAR/PAZ (X-Band)	CDTI					▒	▒	▒	▒	▒	▒						

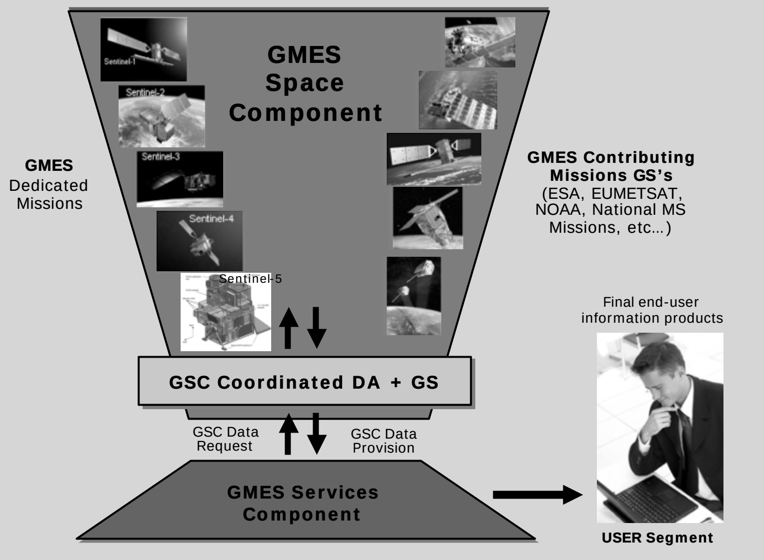
■ In orbit
▒ Approved
▒ Planned

Example: Optical HR and VHR Contributing Missions

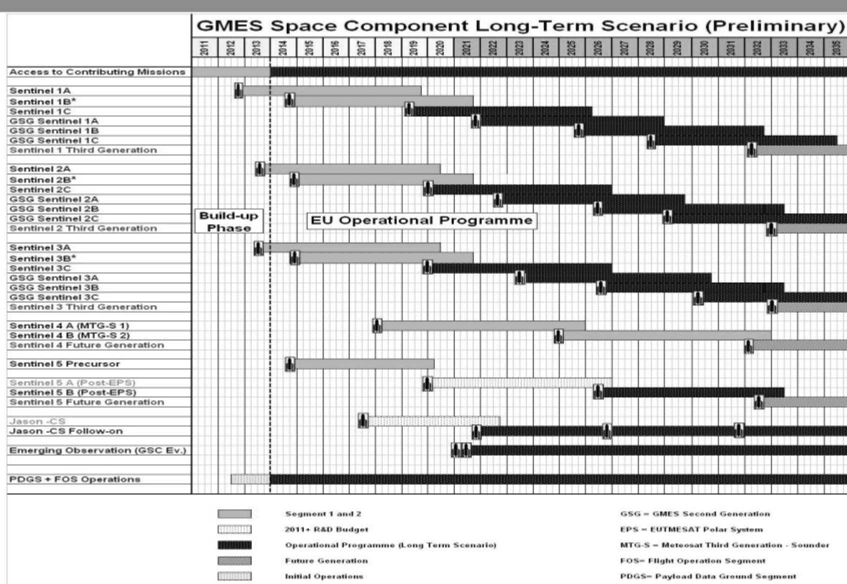
Optical High Resolution missions	Principal Owner	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Medium / High Resolution																	
Sentinel-2 A	ESA						▒	▒	▒	▒	▒	▒	▒				
Sentinel-2 B	ESA										▒	▒	▒	▒	▒	▒	▒
Sentinel-2 C, ...	ESA												▒	▒	▒	▒	▒
SPOT 4	CNES	■	■	■	■												
SPOT 5	CNES	■	■	■	■	■											
SPOT Follow-on	InfoTerra/Astrium						▒	▒	▒	▒	▒	▒	▒	▒	▒		
RapidEye - 5 S/C	RapidEye	■	■	■	■	■	■	■									
RapidEye Follow-on (TBC)	RapidEye							▒	▒	▒	▒	▒	▒				
UK-DMC & UK-DMCII	DMCII	■	■	■	■	■	■										
Deimos-1 DMC	Deimos		■	■	■	■	■										
Seosat / Ingenio	CDTI							▒	▒	▒	▒	▒	▒	▒			
EnMap (Hypersp.)	DLR						▒	▒	▒	▒	▒						
PRISMA	ASI				▒	▒	▒	▒	▒								
Venµs (Hypersp.)	CNES-ISA					▒	▒	▒	▒								
Very High Resolution																	
Pléiades 1 & 2 (VHR)	CNES			▒	▒	▒	▒	▒	▒	▒							
HiRos (TBC)	DLR							▒	▒	▒	▒	▒					

■ In orbit
▒ Approved
▒ Planned

GMES Ground Segment and Data Access



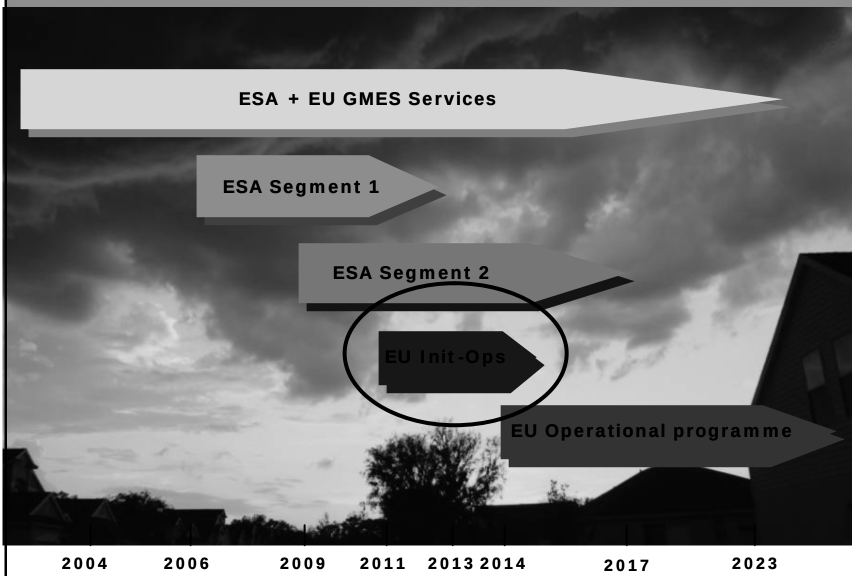
GMES Space Component Long Term Scenario



GSC build-up

2.3 bn Euro already provided by ESA MSs and EC

GMES Phasing



GSC Financing

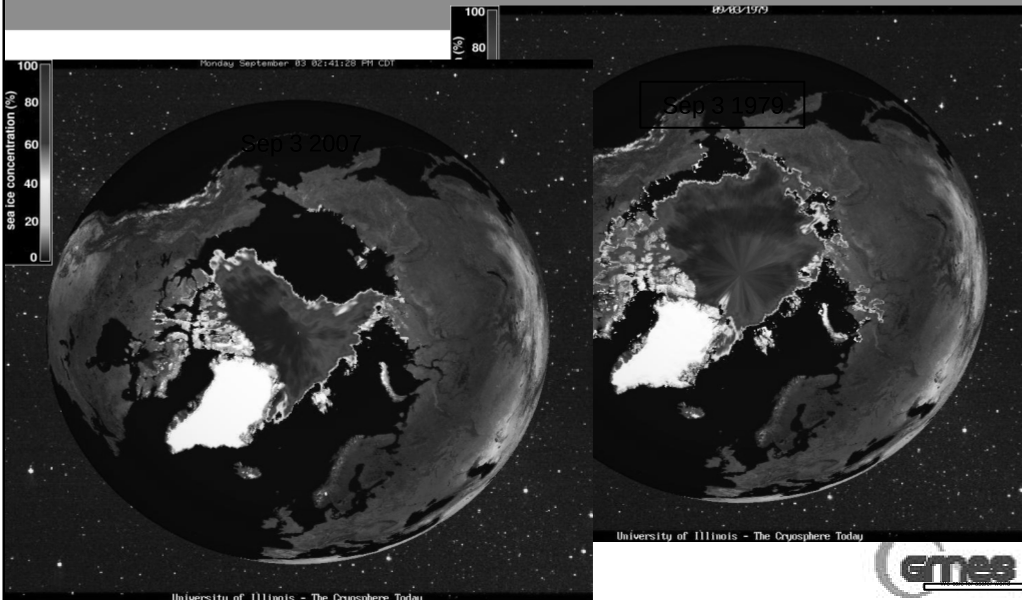
1. **GSC build-up (2006-2017)**
   - Almost completely funded, 2.3 bn Euro total
   - ESA and EC co-funding (72% + 28%)
   - smaller elements still to be funded (Sent-5, Jason-CS, S1/2/3 -B launchers, etc.)

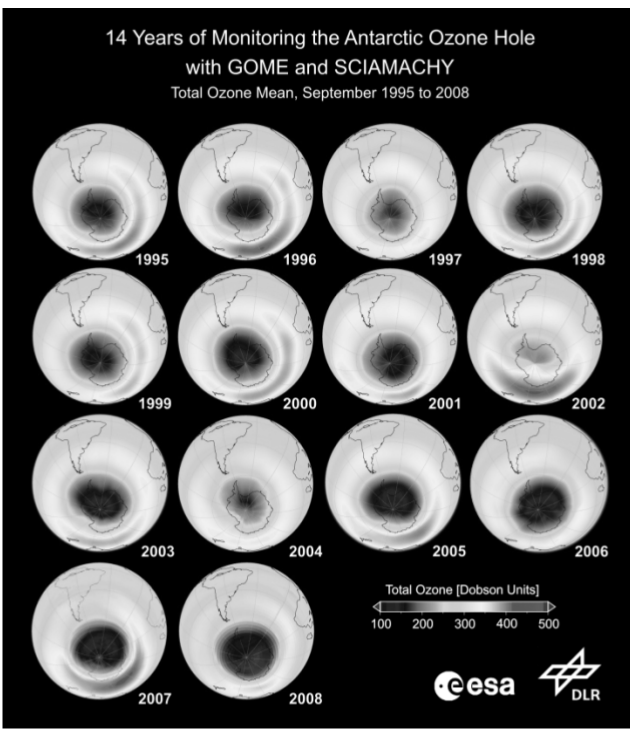
2. **Bridge Funding (2011-2013/14)**
   - EU GMES Regulation approved by EP in June 2010
   - 107 M for GSC: 64 M initial operations + 43 M data access
   - important elements still missing (Sent –A operations, -B launchers, -C critical components, Data access in 2014)

3. **Operations (2014 onwards)**
   - costs defined in GSC Long-Term Scenario
   - approx. 600 M per year (recurrent Sentinels, Data Access to GCMs, ground segment, next generation Sentinels)

GMES Sentinel Data Policy Principles

Marine applications: Arctic ice cap melting

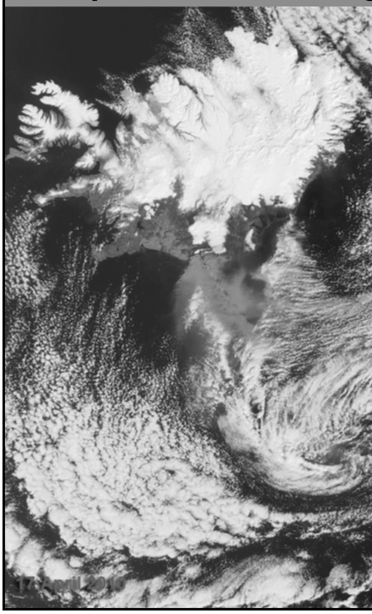


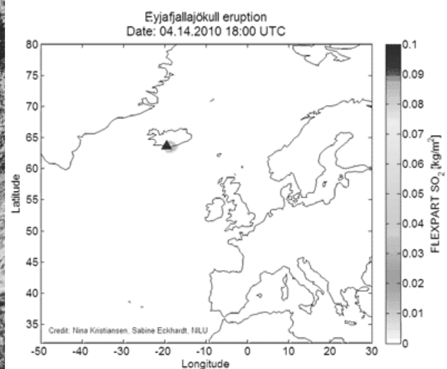


Example of Atmospheric service: Ozone monitoring

Antarctic ozone hole evolution between 1995 and 2008

Example of Atmospheric service: Volcanoes eruptions monitoring





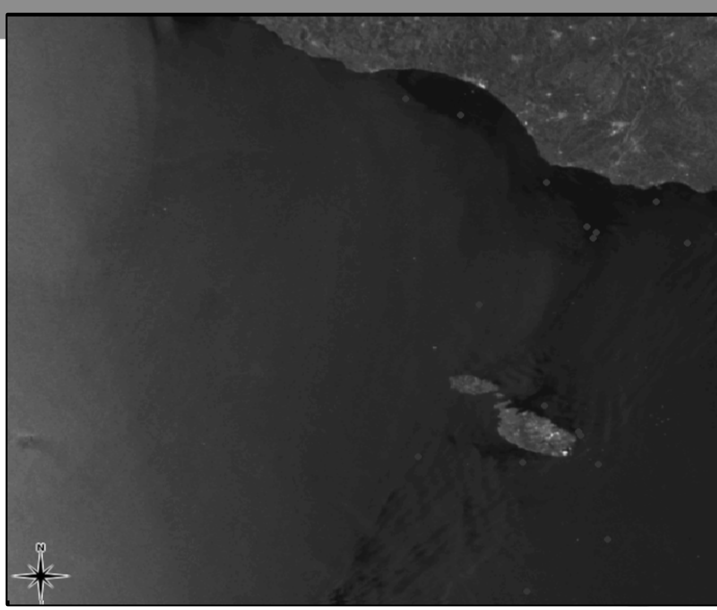
Iceland volcanoe's eruption 12-13 April 2010

Data: Envisat / MERIS acquired from 17 to 20 April and ash plume's animation produced by the Norwegian Institute for Air Research in the Department of Atmospheric and Climate Research

Example of maritime surveillance

- WEBGIS Coastline
- SAR Image L1B
- EO Plot
- EO Plot and AIS Tracks
- EO Plot Correlated with AIS Tracks
- EO not Associated Plot

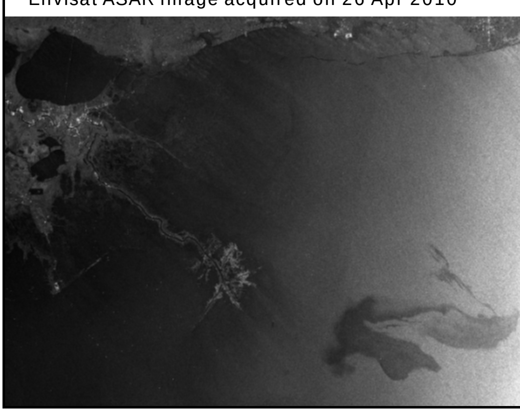
Service Timeline

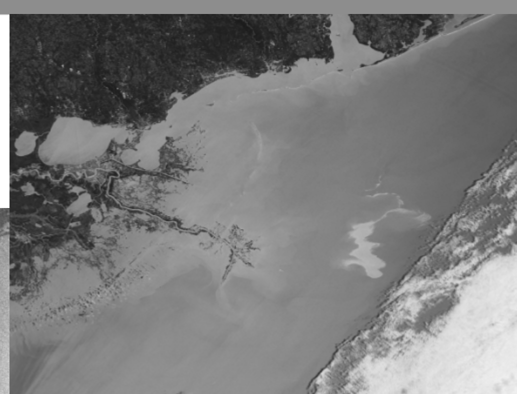


Land monitoring: Animation of Dubai's Palm Jumeirah island construction

Emergency response: Oil spill monitoring in Gulf of Mexico (22 April 2010)

Envisat ASAR image acquired on 26 Apr 2010





Envisat MERIS image acquired on 25 Apr 2010

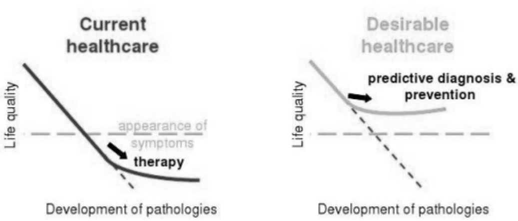
Emergency management: Earthquake

Earthquake management at Port-au-Prince, Haiti – 13 January 2010

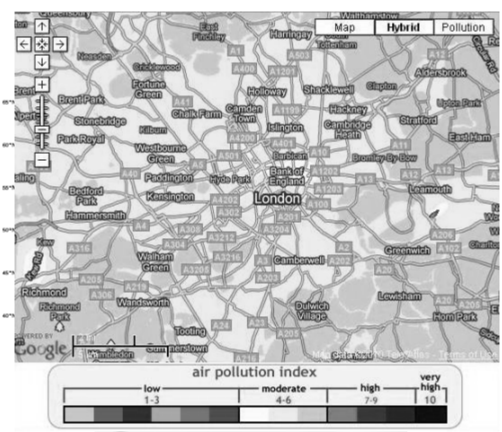
Dati: ALOS, SPOT-5, GeoEye

Credits: SERTIT/SAFER

Air Quality Impacts
Working towards predictive medicine



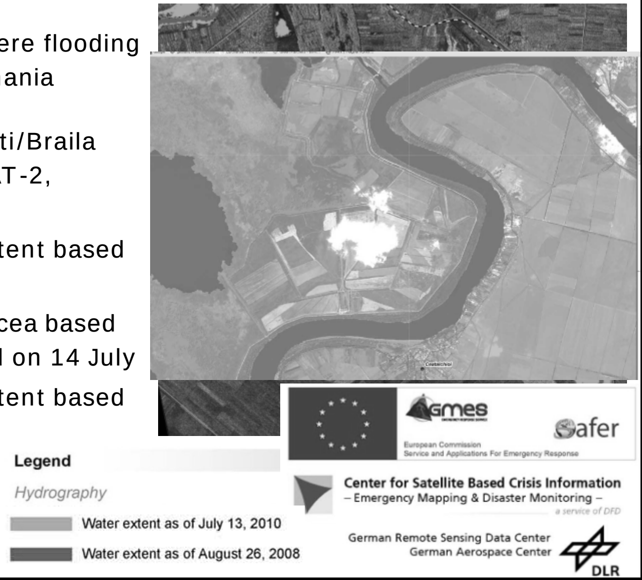
- European Air Quality forecasts produced daily using models with EO and *in situ* data as input
- Local Air Quality forecasts use European-scale forecasts plus additional *in situ* input data
- City and street-level forecasts communicated to individuals
  - ✓ physicians now exploring its use in predictive medicine



yourair for London — airTEXT
Air pollution alerts by text, email, and voicemail

Rapid Mapping during Flood Crisis Romania, July 2010

- Heavy rainfall causing severe flooding in central and eastern Romania
- 3 July flood extent of Galati/Braila district based on RADARSAT-2, produced on 4 July
  - ✓ Pre-flood water extent based on Landsat-7
- 13 July flood extent of Tulcea based on RADARSAT-2, produced on 14 July
  - ✓ Pre-flood water extent based on SPOT



Main Upcoming Challenges (for the GMES Space Component)

✓**Ensure timely implementation of GSC**
- launch of Sentinels
- data access to National/EUM missions
- ground segment readiness

✓**Ensure short- and long-term funding needs**
- GSC build-up
- GSC Initial Operations
- GSC Operations

✓**Prepare GMES governance**
- define GSC governance as part of GMES overall governance
- consolidate roles of key players, EU, EC, ESA, EUM, MS

✓**Define "S" of GMES**
- prepare input for discussion with EU/EC, ESA, MSs, etc.

Further information

For further information please visit:

ESA GMES website
www.esa.int/gmes

EC GMES website
www.ec.europa.eu/gmes

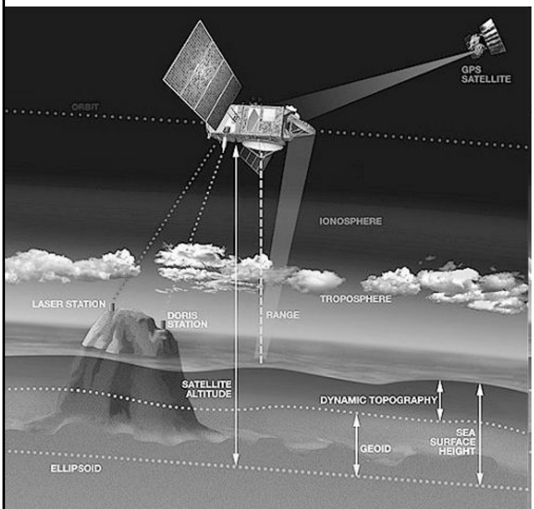
I also hope to see you at the

Sentinel scientific products for Land, Ocean, and Cryosphere - Assessment & Consolidation Workshop

22-25 March 2011, ESRIN Frascati

Radar Altimetry – some details

Radar Altimetry Principle



A radar altimeter measures the transit time and radar backscatter power of individual transmitted pulses

➔ The transit time is proportional to the satellite's altitude above the surface

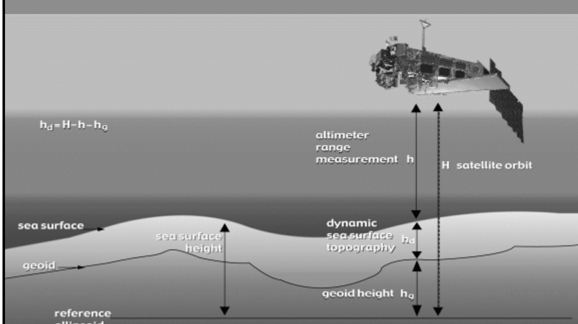
The magnitude and shape of the returned echoes also contain information about the characteristics of the reflecting surface

➔To derive (over ocean) significant wave height and wind speed

A microwave radiometer is normally associated to the radar instrument to receive and measure microwave radiation generated and reflected by the Earth

➔ To provide an estimate of the total water content in the atmosphere, needed to correct for the altimeter measurements path delay

Altimeter measurement principle



Sea surface height (SSH) = Satellite altitude (H) – measured altimetric range (h) – geophysical corrections (h_g)

Sea Level Anomalies = Sea Surface Height – Mean Sea Surface

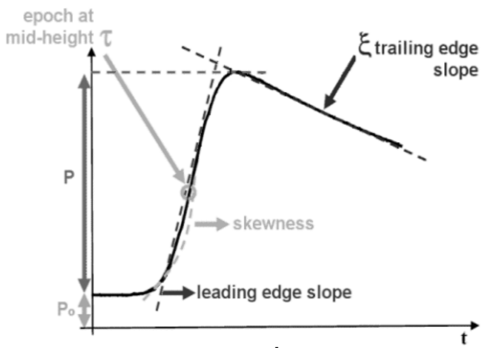
Where **SSH** comprises:

1) The geoid (or sea surface height which would exist without any perturbing factors like wind, currents, tides), is determined by gravity variations around the world, which are in turn due to major mass and density differences on the seafloor (~100 m)

2) The ocean circulation, or dynamic topography, i.e. permanent circulation linked to Earth's rotation, permanent winds, etc and a highly variable component due to eddies, seasonal variations, etc. (~1 m)

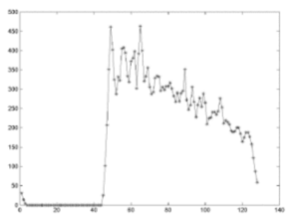
and **MSS** is the displacement of the sea surface relative to a mathematical model of the earth

Return echo over the ocean (1)



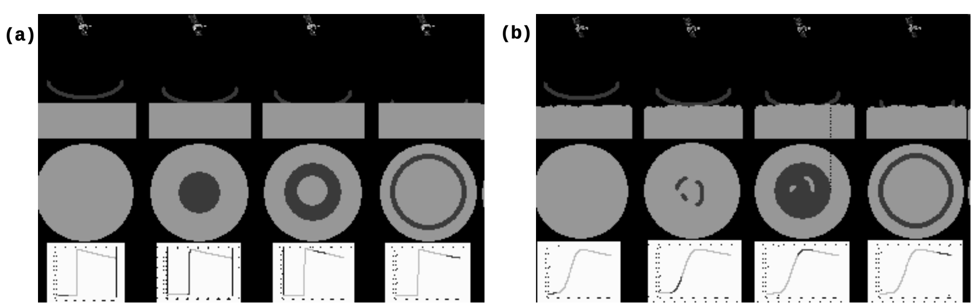
Over an ocean surface the echo waveform has a characteristic shape that can be described analytically (the Brown model). From this shape it can be deduced:

- ✓ **Epoch at mid-height**: this gives the time delay of the expected return of the radar pulse, and thus the time the radar pulse took to travel the satellite-surface distance (or ‘ range’) and back again
- ✓ **P**: the amplitude of the useful signal. This amplitude with respect to the emission amplitude gives the backscatter coefficient (sigma0)
- ✓ **Po**: thermal noise
- ✓ **Leading edge slope**: this can be related to the significant wave height
- ✓ **Skewness**: the leading edge curvature
- ✓ **Trailing edge slope**: this is linked to any mispointing of the radar antenna (i.e. Any deviation from nadir of the radar pointing)



Real Envisat waveform over ocean

Return echo over the ocean (2)

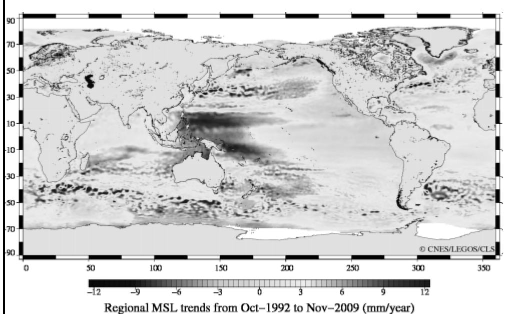


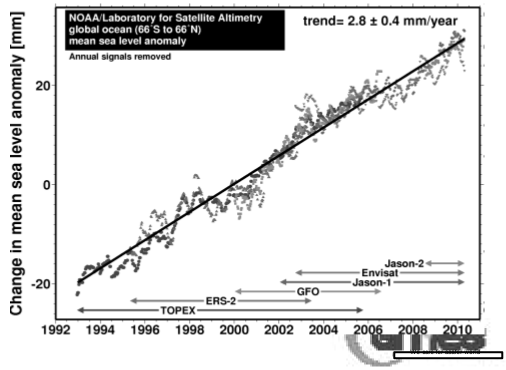
The radar altimeter receives the reflected wave (echo) which varies in intensity over time. Where the surface is flat (a) the reflected wave’s amplitude increases sharply from the moment the leading edge of the radar signal strikes the surface. However, in rough seas (b) the echo strikes the crest of one wave and then a series of other crests which cause the reflected wave’s amplitude to increase more gradually. Ocean wave height can be derived from the information in this reflected wave, since the slope of the curve representing its amplitude over time is proportional to wave height.

Retrieval of corrected range

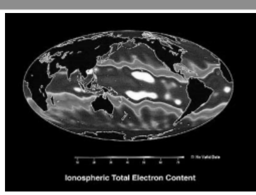
The time taken to make the round trip between the satellite and the surface, translated into distance (i.e. *c/2) gives the altimetric range. This must be corrected for path delay in the atmosphere through which the radar pulse passes and for the nature of the reflecting sea surface:

Corrected Range = Range - Wet Troposphere Correction - Dry Tropo Correction - Iono Correction - Sea State Bias Correction - Inverse barometer effect - Tides





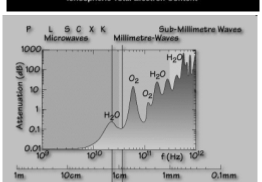
Geophysical corrections to the range (1)



Free electrons are present in the earth's ionosphere. As with water vapour, these electrons delay the return of the radar pulse from the altimeter and thus interfere with the accuracy of sea-level measurements.

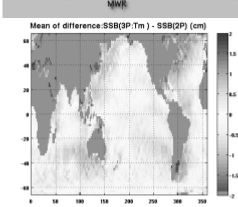
To correct for this delay the altimeter takes measurements at tw o radio frequencies. The difference between the two measurements provides both a measure of the electron content and a **ionospheric correction** for the range delay.

Order of magnitude: up to 0.5 m



The contribution of the **water vapour** to the delay of the radio pulse can be estimated by measuring the atmospheric MWR brightness near the water vapour line at 22.2356 GHz, while the secondary channel removes the sea surf ace emission and other atmospheric contributions.

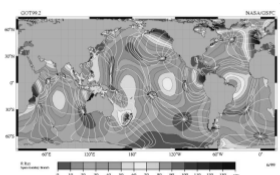
Order of magnitude: up to 0.5 m (with annual cycle amplitude of up to 0.2 m)



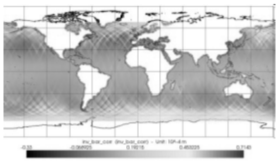
The sea-state effects are an intrinsic property of the large footprint radar measurements. The surface scattering elements do not contribute equally to the radar return; troughs of waves tend to reflect altimeter pulses better than do crests. Thus the centroid of the mean reflecting surface is shifted away from mean sea level towards the troughs of the waves. The shift, referred to as the electromagnetic (EM) bias, causes the altimeter to overestimate the range. In addition, a skewness bias also exists from the assumption in the onboard algorithms that the probability density function of heights is symmetric, while in reality it is skewed. Finally, there is a tracker bias, which is a purely instrumental effect. The sum of EM bias, skewness bias, and tracker bias is called **'sea state bias**'

Order of magnitude: ~3% of SWH

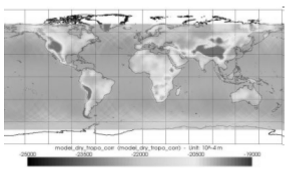
Geophysical corrections to the range (2)



Tides are highly predictable and are removed from the data in order to study ocean circulation. There are several contributions to the tidal effect, related to luni-solar forcing of the earth or to variations in the earth's rotation.
Order of magnitude: up to 15 m



As atmospheric pressure increases and decreases, the sea surface tends to respond hydrostatically, falling or rising respectively. This effect is referred to as the **inverse barometer** (IB) effect.
Order of magnitude: ±15 cm

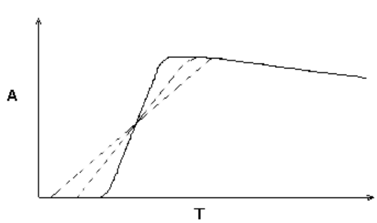


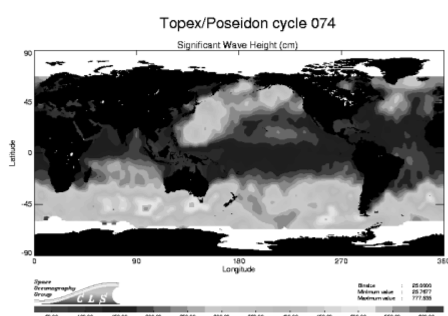
The radar pulse is slowed down by air molecules in the troposphere, this is called the **dry tropospheric** delay. This range delay is proportional to sea level pressure and also depends on the latitude, and is obtained from meteorological models.
Order of magnitude: ~2.3 m (low temporal variations of only a few cm)

Retrieval of SWH

SWH is obtained by analyzing the leading edge slope of the altimeter radar beam reflected from the sea surface

The solid line in the figure represents a "flat sea" situation with a return strong condensed pulse. In a rough sea with high waves, the signal wavefront will initially interest only the wave tips, then gradually extend to all the surface, within a time proportional to the wave height.
This results in a reduced slope of the echo leading edge, corresponding to the dashed lines in the figure, for increased wave height.





Retrieval of wind speed

Wind velocity is obtained by analyzing the intensity of the altimeter radar beam reflected from the sea surface

The effect of the wind over a sea surface is to increase its roughness, in a way proportional to the speed of the wind itself.

A perfectly planar surface behaves, with regard to electromagnetic waves, like a mirror: the greatest part of the energy in then scattered back toward the transmitter.

If the surface is rough, the "radiation backscattering lobe" of the backscattered signal is widened, and the energy is then distributed over a larger angle. The surface reflectivity (s0) decreases.

The observable effect is then a change of amplitude: with increasing wind speed, the amplitude of the echo signal decreases.