

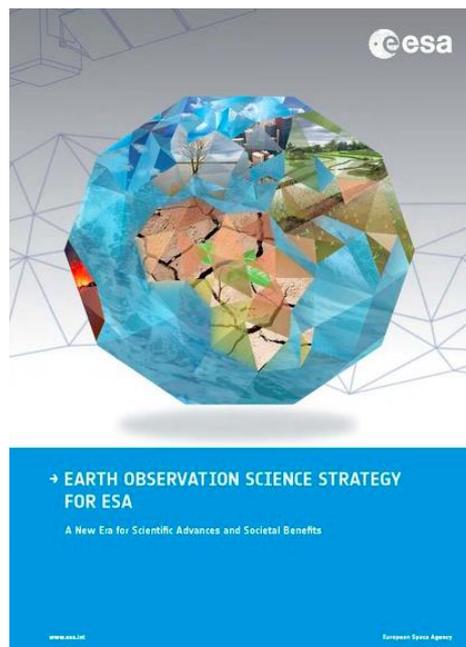
# Sentinels for Climate Services

*PP. Mathieu, J. Wagemann & many colleagues .. with many thanks to them!*

*ESA/ESRIN | pierre.philippe.mathieu@esa.int  
ECMWF, Obs Requirements for C3S, 1 Jul 2015 (v05)*

# 1. The Sentinel Era

A new era for Earth Observation  
Scientific Advances & Societal Benefits



# S-2A first images – Pavia / Po Valley, Italy



S2-A launched 23 June 2015,

- 13 Bands (VIR, NIR, SWIR, red edge),
- 290km swath,
- 10-20-60m resolution,
- 10d revisit.

Image of Pavia acquired on 27 June 2015 at 10:25 UTC,

**Sentinel-1** Radar Mission

**Sentinel-2** High Resolution Optical Mission

**Sentinel-3** Medium Res Imaging and Altimetry Mission

**Sentinel-4** GEO Atmospheric Chemistry Mission

**Sentinel-5P** LEO Atmospheric Chemistry Missions

**Sentinel-5** LEO Atmospheric Chemistry Missions

**Sentinel-6** Altimetry Mission



- 1. Multi-variate**      ECVs\* - Ocean/Atmo/Cryo/Land
- 2. Global**              Wide coverage
- 3. High-res**            5m - 300m, weekly revisit
- 4. Sustained**          Continuity + Routine + Operational
- 5. Quality**             Routine Cal/Val, Performance Cent
- 6. Open Data**          Cross-communities + Transparency

\* Partial Contribution to Sea-ice, Glaciers, Ice Sheet, Ocean Colour, Ozone, Aerosol, Clouds, Sea-Level, SST, Albedo, FAPAR, Land Cover, Fire Disturbance

ECV	S-1	S-2	S-3 (Opt/Topo)		S-4	S-5P	S-5
Cloud							
Ozone							
Aerosol							
GHG							
Sea Ice							
Sea Level							
SST							
Ocean Colour							
Glaciers							
Land Cover							
Fire							
Soil Moisture							
Ice Sheets							

**NOT Comprehensive**      Capability Gaps ECVs\*

**NOT Designed for single Purpose**      Sub-Optimal

**NOT Exploratory Measurement**      Earth Explorers

**NOT Designed for Climate Monitoring**

Accuracy / Stability ! / Consistency / [Ref Obs!]

**NOT Alone**      Part of Integrated Observing System

**Opportunity to influence requirements of the new**

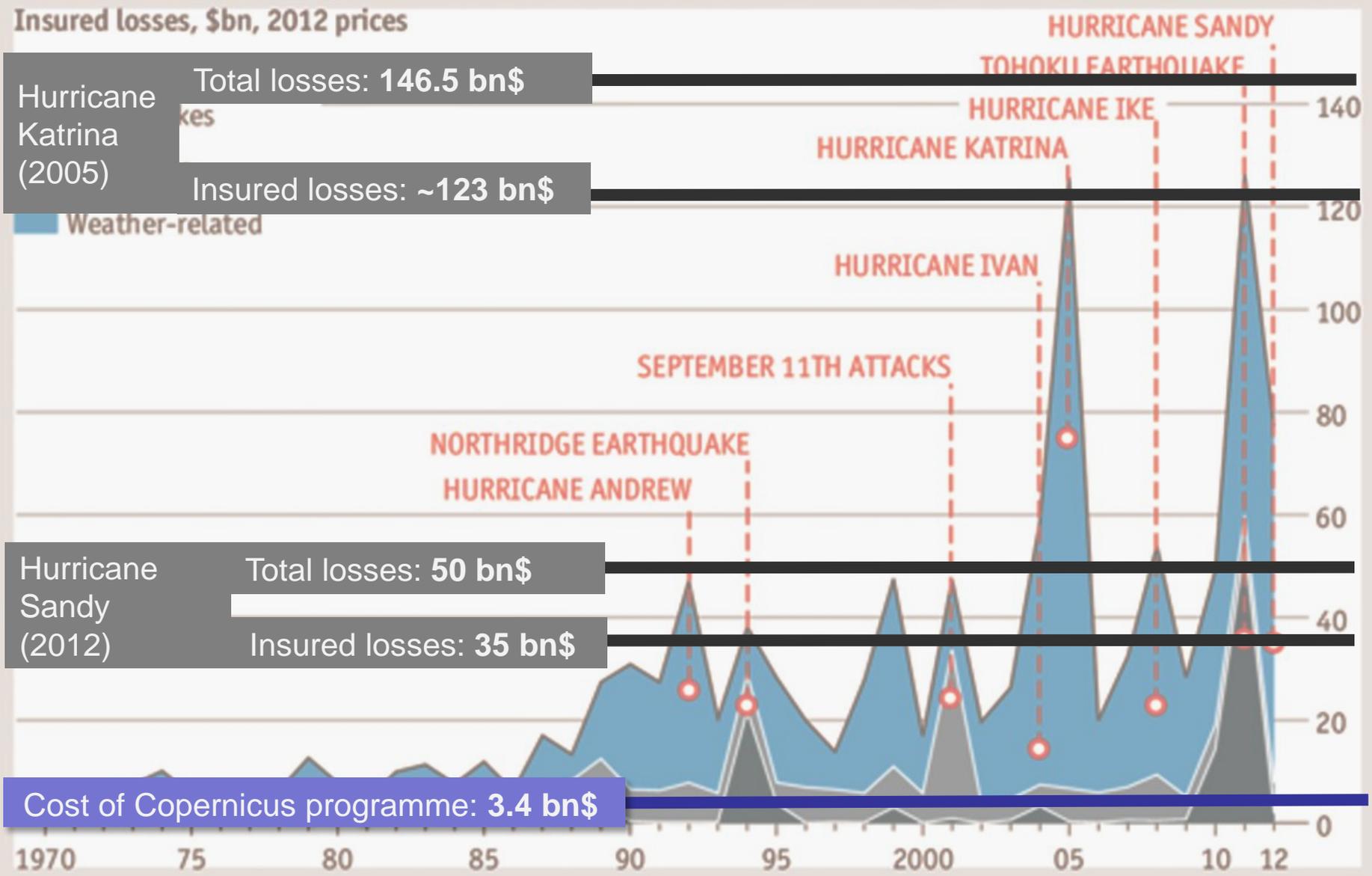
**generation of Sentinels to integrate R&D capability**

E.g. Missing ECVs, Carbon Dioxide, Precipitation, Air Temperature, Radiation Budget, Ocean Heat Content, Ocean Acidification



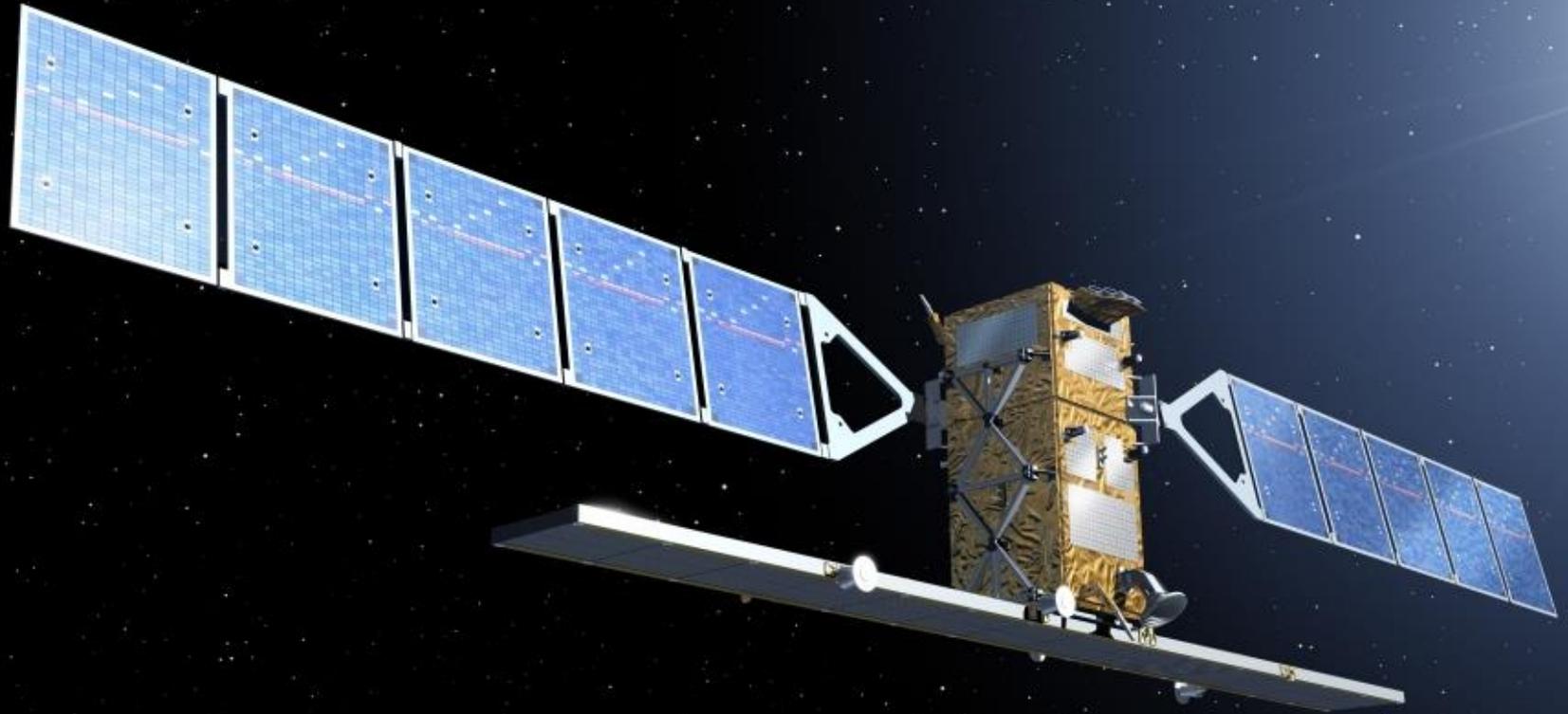
# Cost of weather-related catastrophes vs. Copernicus esa

Insured Loss (Swiss Re, 2012), Total Loss (WMO, 2014), Copernicus cost (EU, 2014)



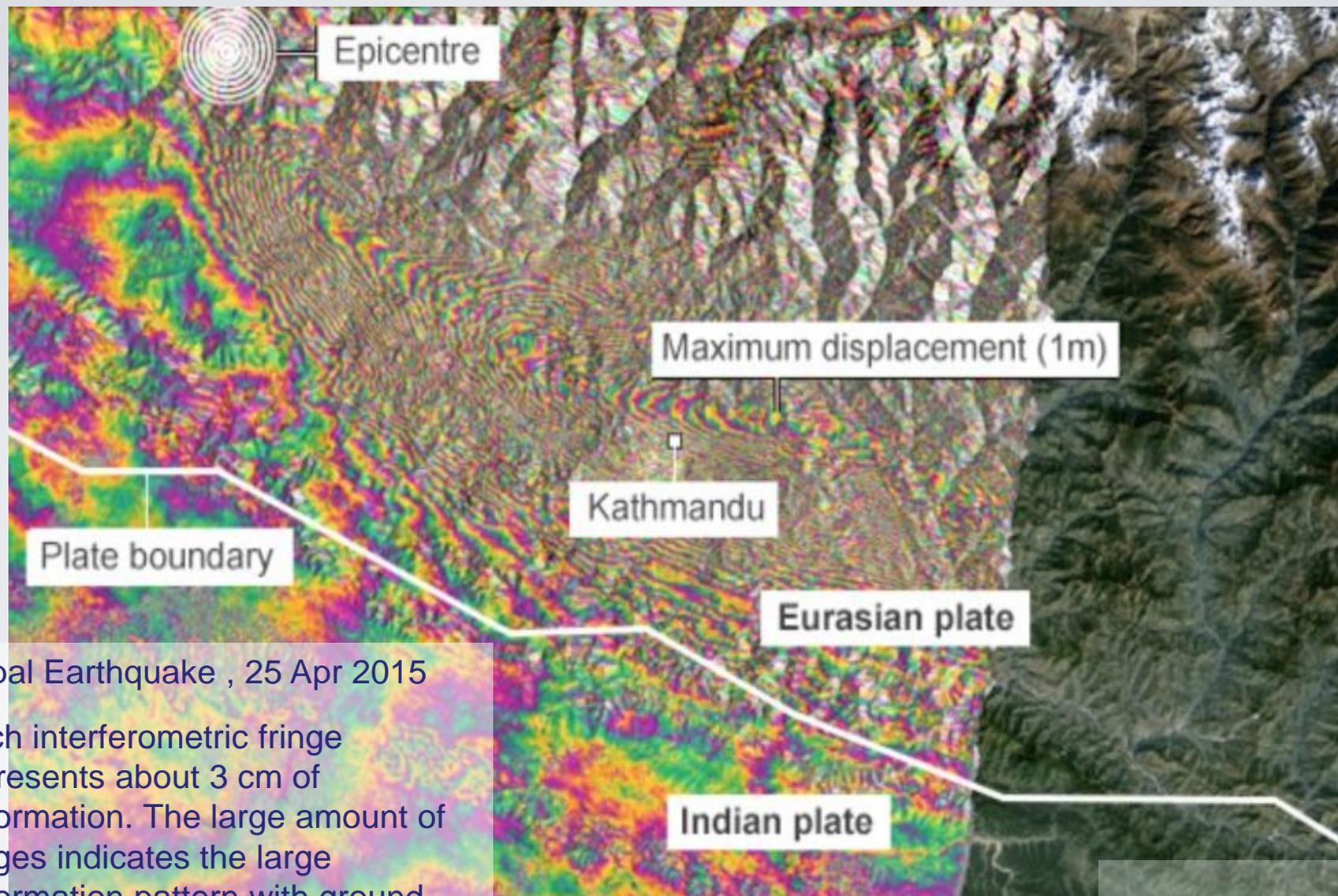
# **2. Sustained Observations from Space**

# Sentinel-1 European Radar Observatory Mission



<b>Sensor</b>	C-band Synthetic Aperture Radar (SAR) - continuity of ERS-1, -2, Envisat and Radarsat				
<b>Products</b>					
L0	<ul style="list-style-type: none"> <li>Compressed unfocused SAR raw data</li> </ul>				
L1 Single Look Complex (SLC)	<ul style="list-style-type: none"> <li>Focused SAR complex data, geo-referenced, provided in slant-range geometry</li> </ul>				
L1 Ground Range Detected (GRD)	<ul style="list-style-type: none"> <li>Focused SAR complex data detected, geo-referenced, multi-looked and projected to ground range geometry</li> </ul>				
L2	<ul style="list-style-type: none"> <li>Ocean Wind Field</li> </ul>	<ul style="list-style-type: none"> <li>Ocean Wave Spectra</li> </ul>	<ul style="list-style-type: none"> <li>Surface Radial Velocity</li> </ul>		
<b>Spatial and temporal sampling</b>					
Interferometric-Wide Swath (IWS)	250km swath – 5 x 20 m (HH+HV, VV+VH)				
Wave-mode (WV)	20x20km – 5 x 5 m (HH, VV)				
Extra-Wide Swath (EWS)	500km swath – 20 x 40 m ((HH+HV, VV+VH)				
Strip-Map mode (SM)	80km swath – 5 x 5 m (HH+HV, VV+VH)				
Repeat cycle	<b>12 days</b> repeat cycle (at equator) with S-1A (launched on 3 Apr 2014)				
<b>Application areas</b>					
<ul style="list-style-type: none"> <li>Land monitoring of forests, water, soil and agriculture</li> <li>Climate change detection</li> <li>Sea-ice observations and iceberg monitoring</li> </ul>		<ul style="list-style-type: none"> <li>High resolution ice charts</li> <li>Mapping oil spills</li> <li>Sea vessel detection</li> </ul>			
<b>Target potential ECVs</b>					
• Sea ice	• Glaciers	• Ice Sheets	• Land cover	• Soil moisture	





Nepal Earthquake , 25 Apr 2015

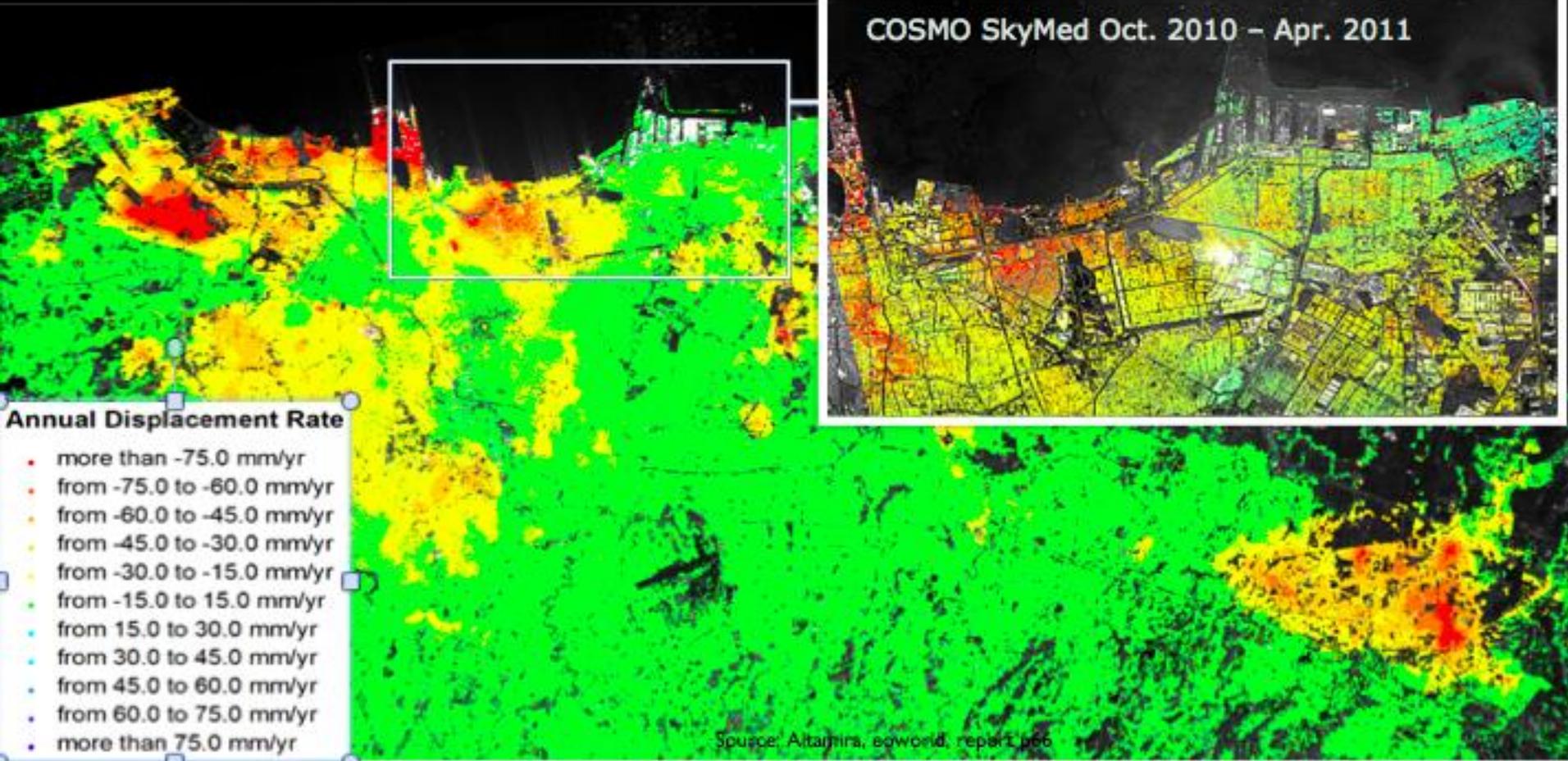
Each interferometric fringe represents about 3 cm of deformation. The large amount of fringes indicates the large deformation pattern with ground motions of more than 1m.

# Subsidence in Coastal Megacities (Jakarta)



THE WORLD BANK

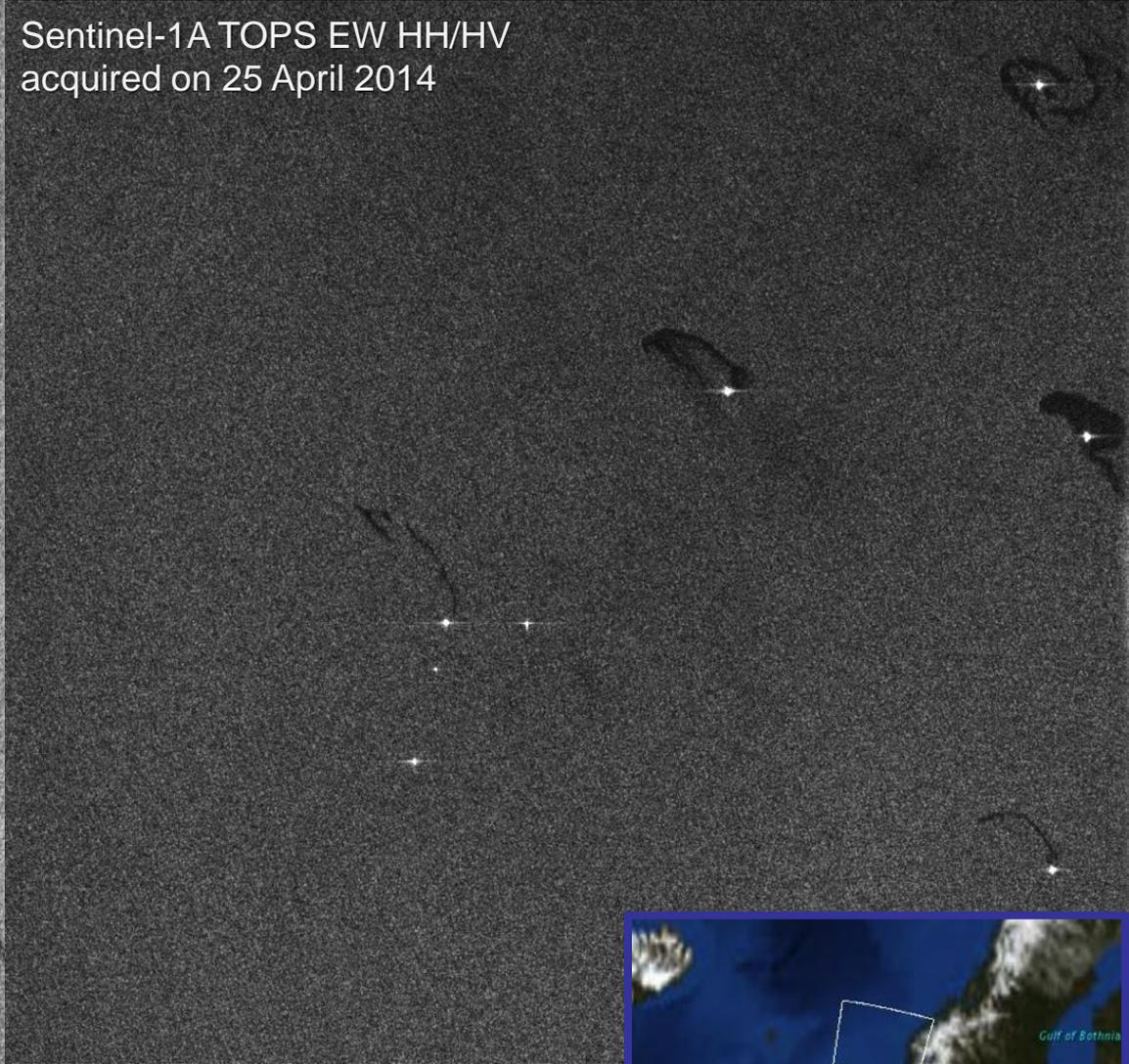
Source: eoworld, altamira



# S-1 Oil Spill and Ship detection



Sentinel-1A TOPS EW HH/HV  
acquired on 25 April 2014



CleanSeaNet: the European satellite oil pollution and vessel detection monitoring system, operated by the European Maritime and Safety Agency (EMSA) of the European Commission

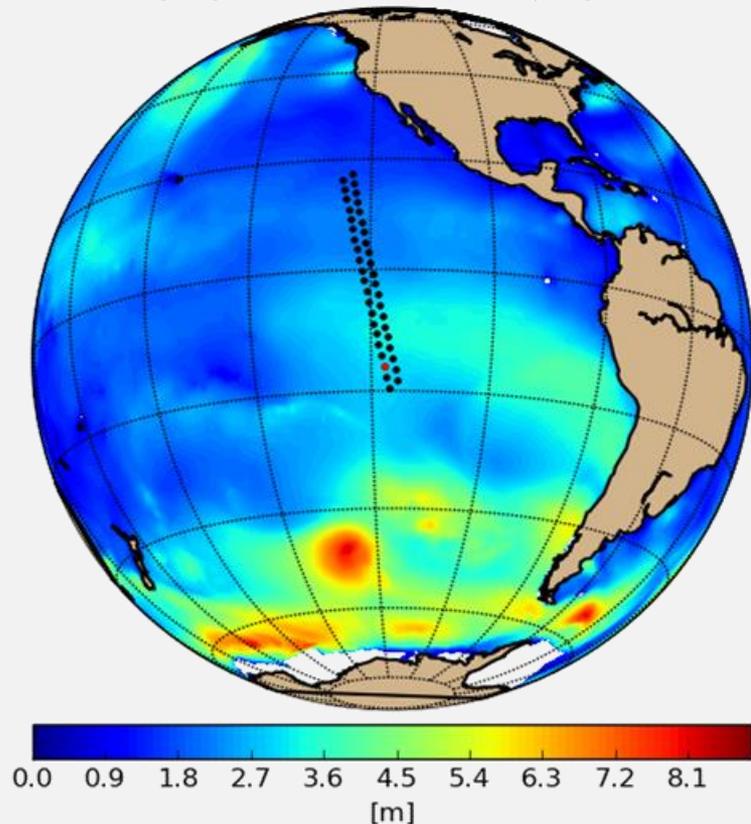
Sentinel-1A TOPS EW VV/VH  
acquired on 19 April 2014



## L2 Product - Significant Wave Height

- Wave Mode (WM) imagettes indicated as dots

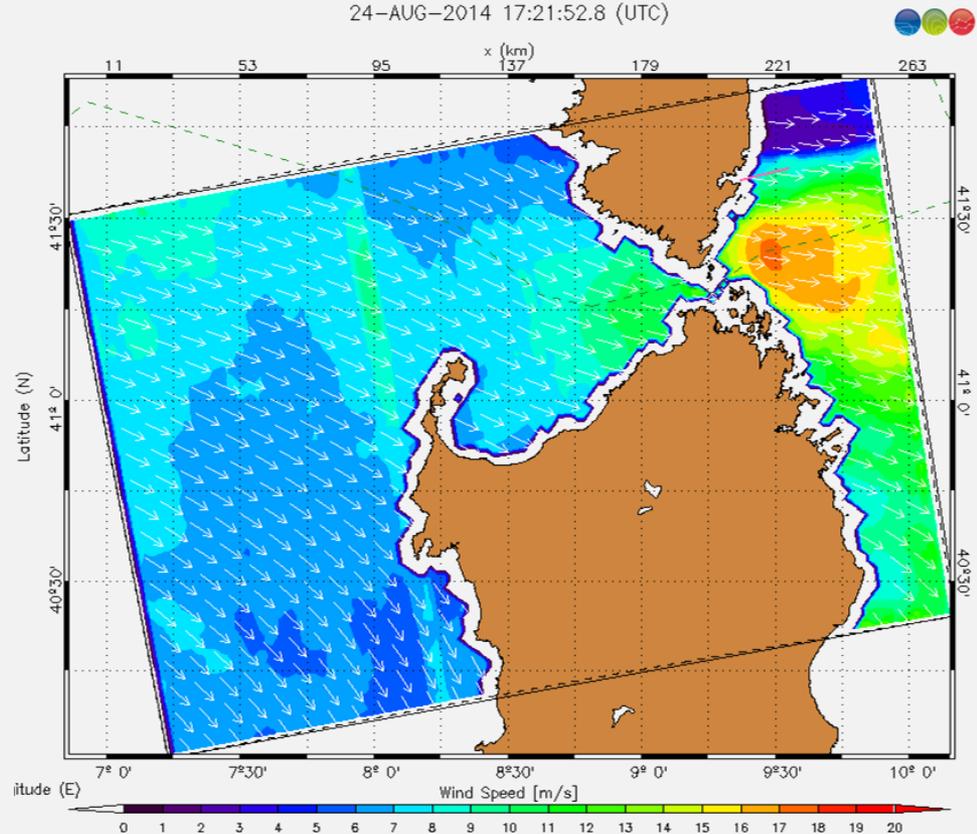
VV - 2014/04/12 02:11:23 - 2014/04/12 02:21:27



## L2 Product - Wind Measurement

- S-1 acquired on 2014-08-24 T 17-21-27
- Strait between Sardinia and Corsica
- IWS Double Polarisation, only VV processed

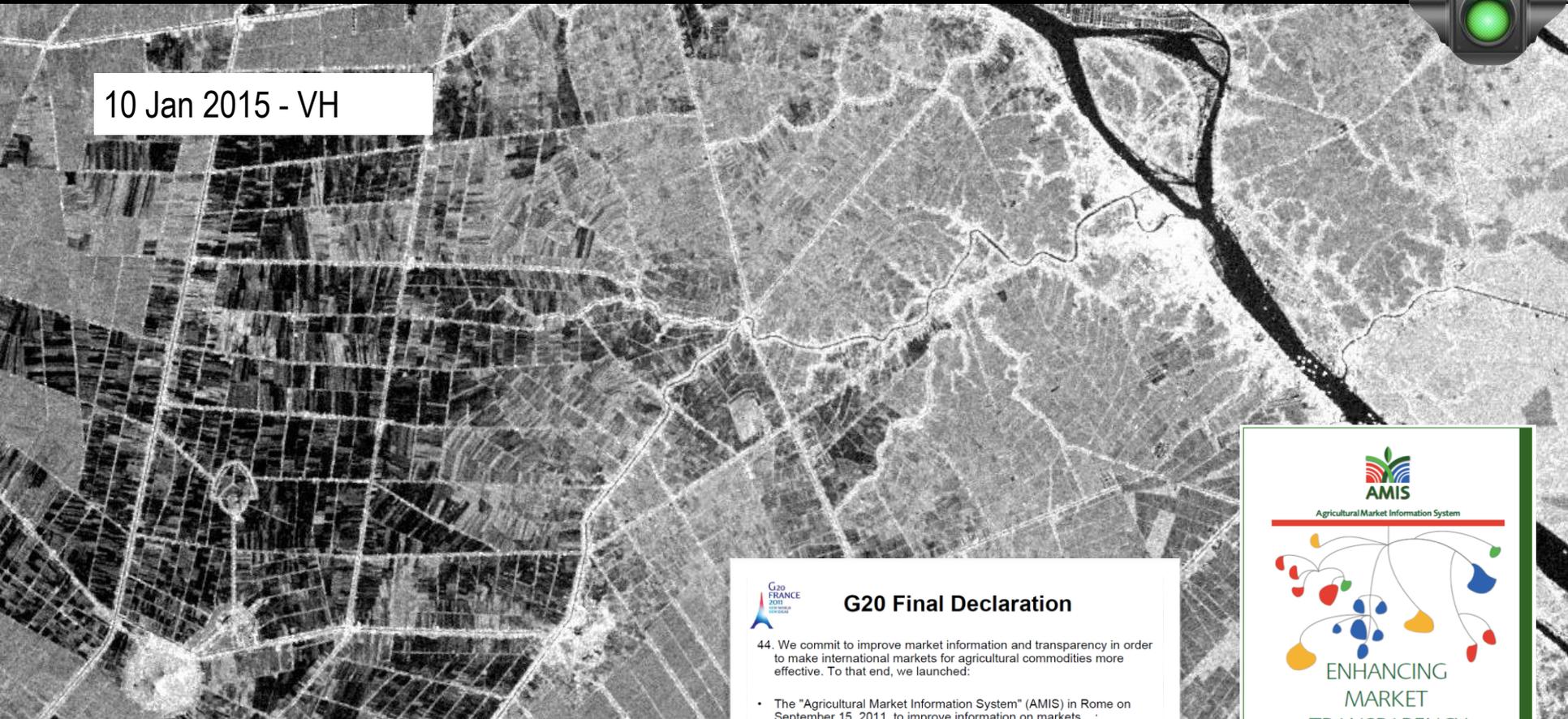
24-AUG-2014 17:21:52.8 (UTC)



## Sentinel-1 time series (Oct.2014-Jan.2015) GEOGLAM Asia-RICE Site: An Giang (Mekong River Delta, Vietnam)



10 Jan 2015 - VH



### G20 Final Declaration

44. We commit to improve market information and transparency in order to make international markets for agricultural commodities more effective. To that end, we launched:
- The "Agricultural Market Information System" (AMIS) in Rome on September 15, 2011, to improve information on markets ...;
  - The "Global Agricultural Geo-monitoring Initiative" (GEO-GLAM) in Geneva on September 22-23, 2011. This initiative will coordinate satellite monitoring observation systems in different regions of the world in order to enhance crop production projections and weather forecasting data.



Agricultural Market Information System



ENHANCING  
MARKET  
TRANSPARENCY



# Ice movements in Lincoln Sea



20141102

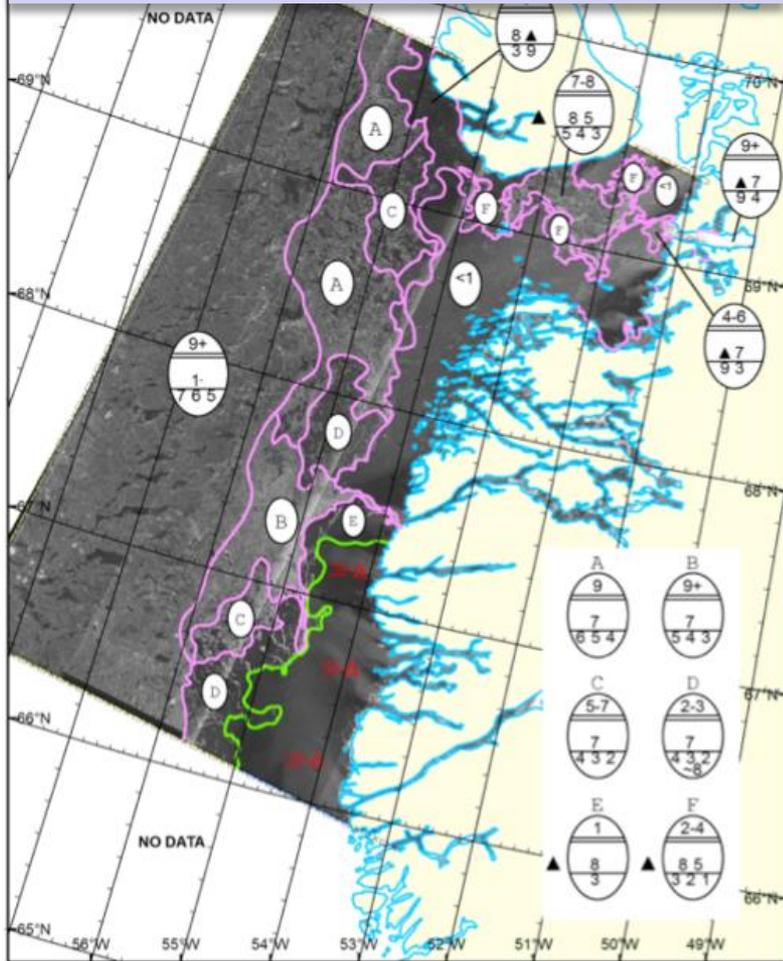
Roberto Saldo DTU Space/Technical University of Denmark rs@space.dtu.dk

DTU

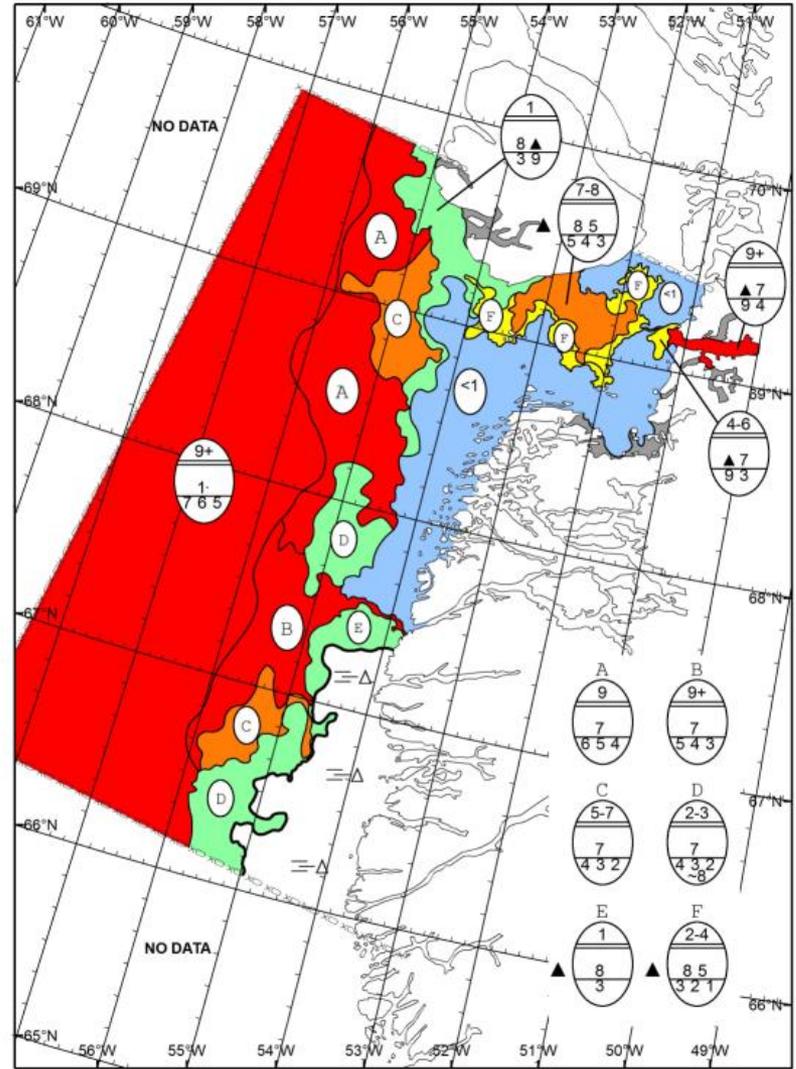


# S-1 Sea Ice Charts

S1A Image from 20140426 10:10 UTC  
EWS mode, HH



West Greenland Ice Chart Data: Sentinel-1A  
Danish Meteorological Institute Valid: 26 April 2014



West Greenland Ice Chart Data: Sentinel-1A  
Danish Meteorological Institute Valid: 26 April 2014

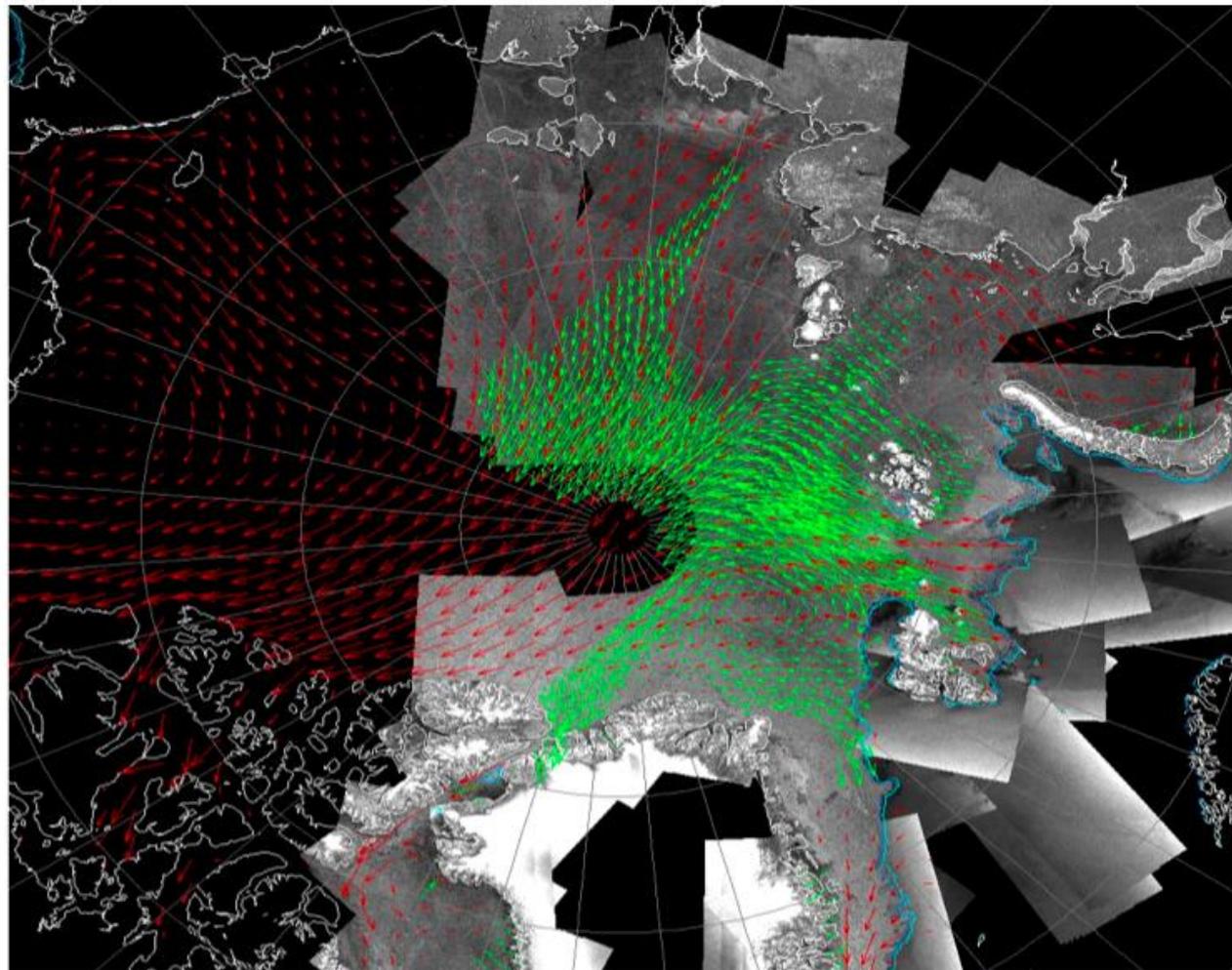
Courtesy of DMI, MyOcean

3-day mosaic of S-1a data  
(January 6-8),

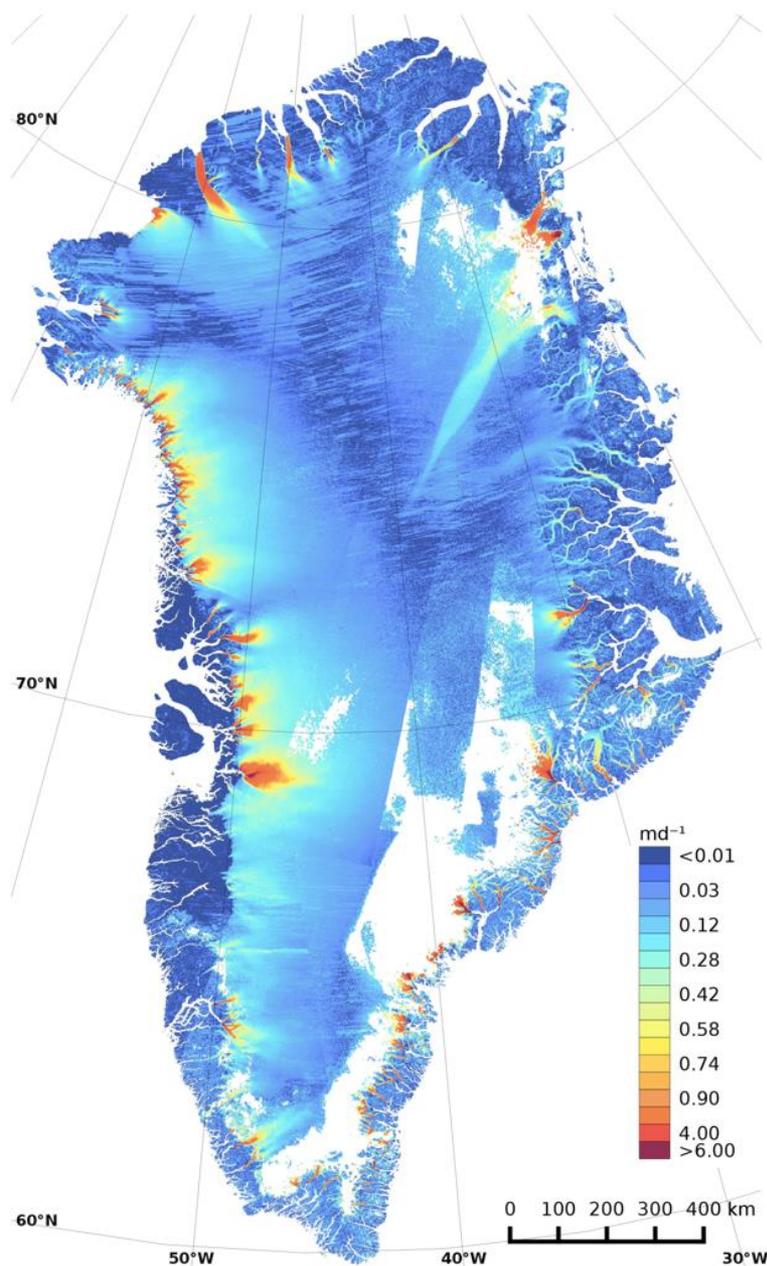
Ice drift on January 7 from  
S1 (green vectors) and from  
Arctic MFC (red vectors).

Good correspondence in  
some areas not so good in  
others, illustrating how the  
S-1 data can be used to  
validate and improve the  
forecasts.

From DMI/DTU



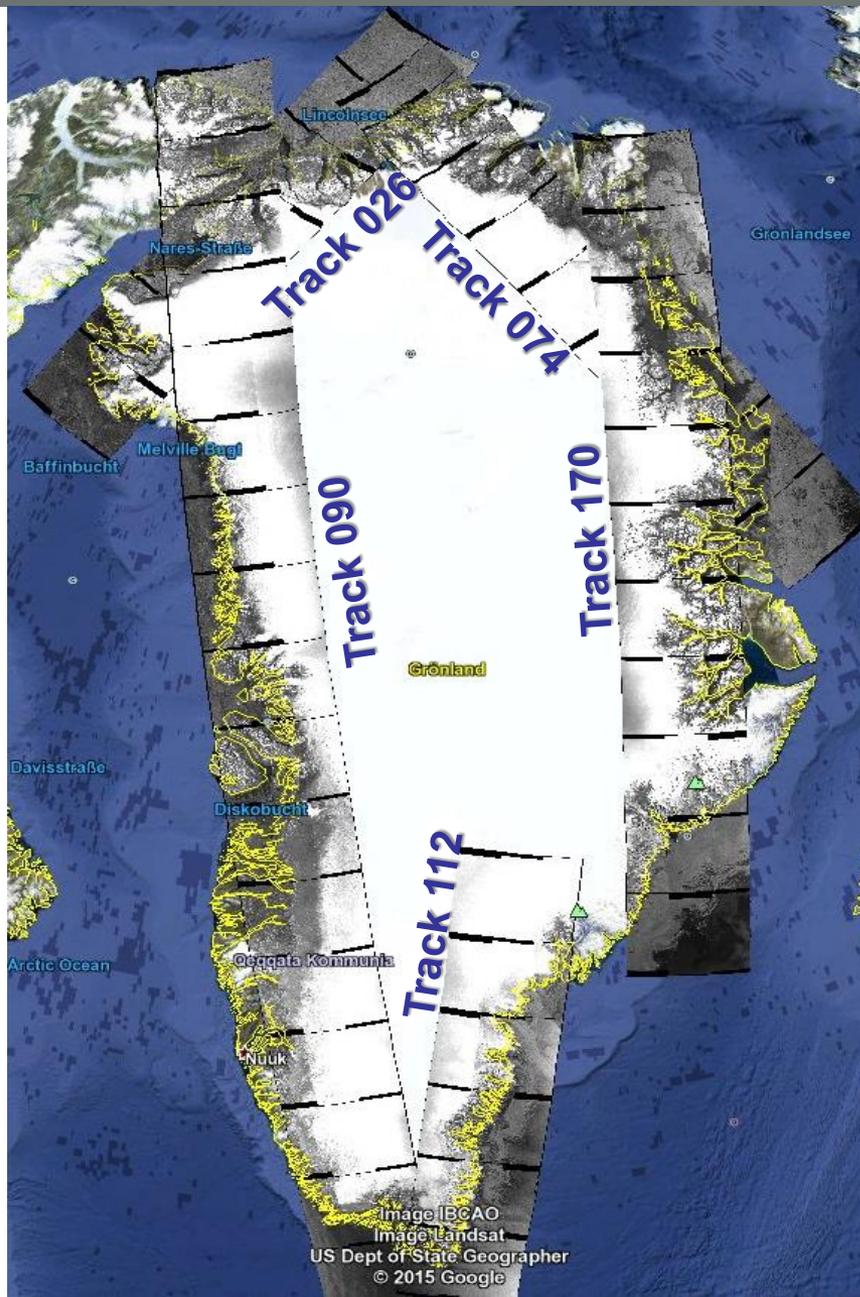
# S-1 Greenland Ice Sheet Velocity



Based on SLC products from  
S-1 IWS mode

Period: Jan-Mar 2015  
(some scenes from Oct-Dec  
2014)

- ~ 800 scenes
- ~ 25 000 bursts
- ~ 2.7 TB of SLC data



Continuous Monitoring  
of Greenland margins

every Cycle → Overall  
ca 50 slices

+ Campaigns

→ Allows to monitor  
outlet glaciers  
with high  
observation  
frequency  
of 12 days



## Sensors

- **OLCI:** Ocean and Land Colour Instrument (21 bands / 400 nm to 1040 nm)
- **SLSTR:** Sea and Land Surface Temperature Instrument
- **SRAL:** SAR Radar Altimeter

## Application areas

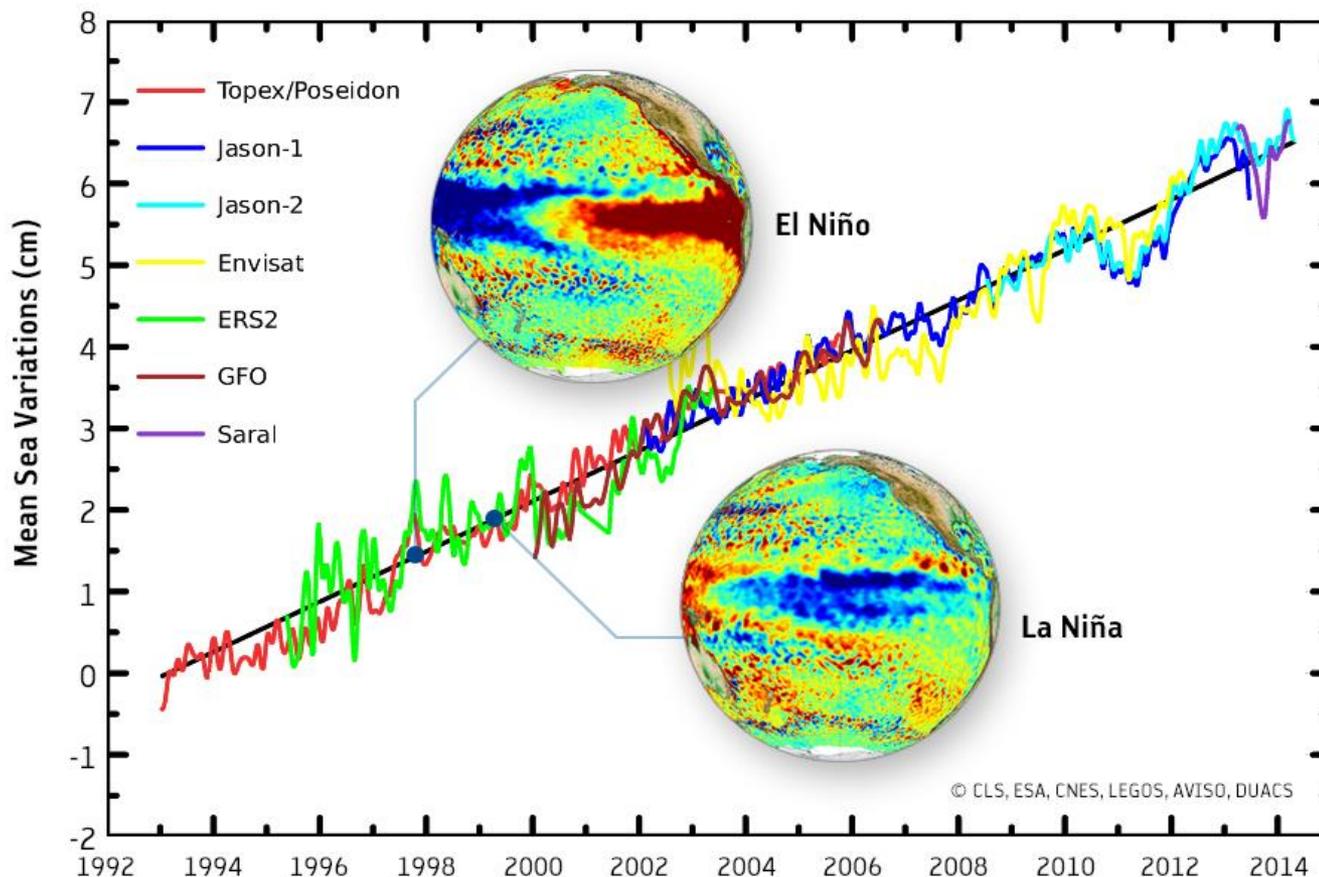
- Operational Oceanography (Forecasting atmospheric and oceanic conditions)
- Maritime Safety and Security (e.g. monitoring of pollution, passenger vessel safety, potential terrorist actions)
- Coastal Zone Monitoring (water quality, harmful algal blooms)
- Open Ocean and Ice Monitoring
- Atmospheric Services
- Global Land Monitoring Applications (vegetation, land cover, river and lake, DEM)

## Target potential ECVs

- **Cloud**
- **Aerosol**
- **SST**
- **Ocean Colour**
- **Land cover**
- **Fire**
- **Sea Ice**
- **Ice Sheets**
- **Sea Level**

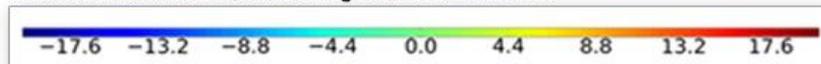
## Expected launch date

- 2015 (S-3A) and 2017 (S-3B)



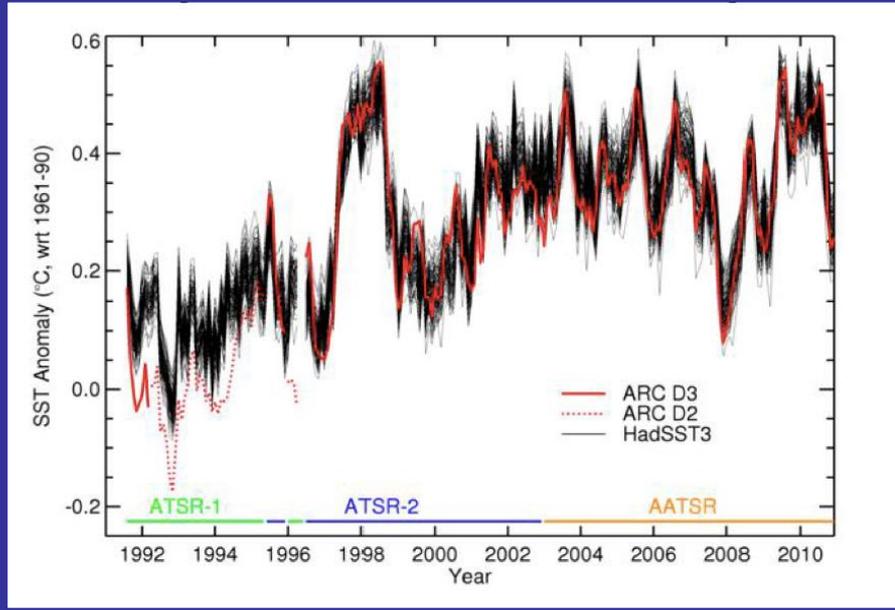
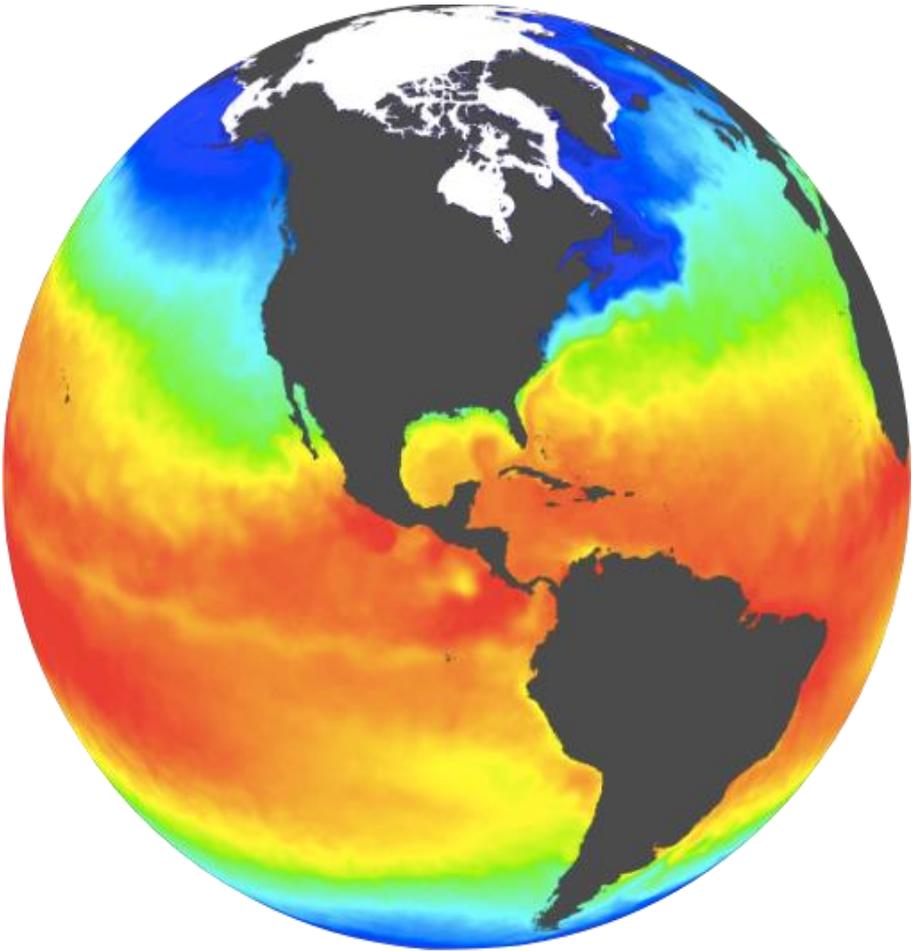
S-3 RA  
S-6 Jason

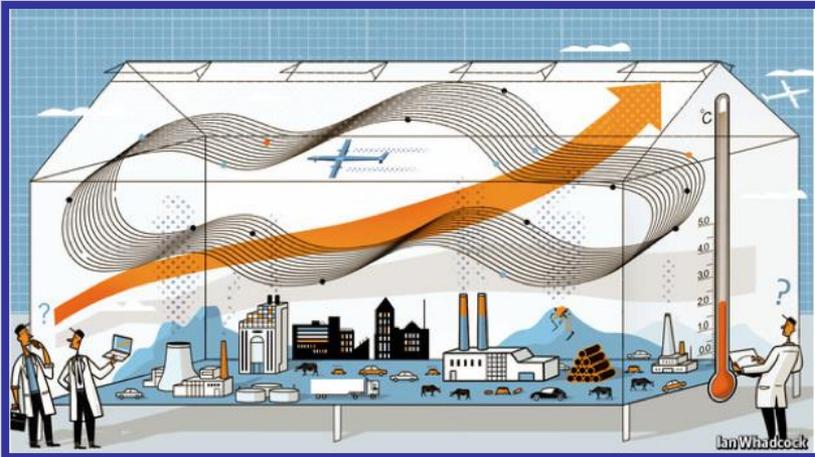
Sea Level Variations (cm) during El Niño and La Niña



Flood damage in the world's major coastal cities may top **\$1 trillion** a year by **2050** due to rising seas and subsiding land, according to a World Bank study in Nature Climate Change. Hallegatte, S. et al: Future flood losses in major coastal cities. Nature Climate Change, 2013. doi:10.1038/nclimate1979

# S-3 like Sea Surface Temperature





## Climate science

# A sensitive matter

The climate may be heating up less in response to greenhouse-gas emissions than was once thought. But that does not mean the problem is going away

imate



ESA

SPACE FOR OUR CLIMATE

OBSERVING THE EARTH

· About climate change

– Space and Earth Monitoring

+ Land

+ Oceans

+ Ice

+ Atmosphere

+ Biosphere

+ International treaties implementation

+ About Observing the Earth

EO programmes

· The Living Planet

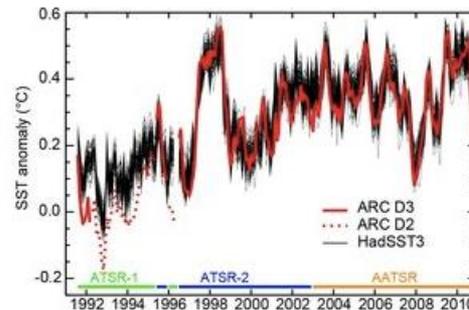
· Copernicus

ESA > Our Activities > Observing the Earth > Space for our climate



Search here

## IS GLOBAL WARMING HIDING UNDERWATER?



Sea-surface temperature

7 February 2014 Satellite observations of global sea-surface temperature show that a 30-year upward trend has slowed down within the last 15 years. Climate scientists say this is not the end of global warming, but the result of a rearrangement in the energy flow of the climate system and, in particular, how the ocean stores heat.

Like flying thermometers, some satellites carry instruments that provide a global view of the surface temperature of oceans and seas. Measuring the sea-surface temperature is important for improving weather and ocean forecasting and

climate change research.

### Related links

· ESA's Climate Change Initiative (CCI)

· Intergovernmental Panel on Climate Change (IPCC)

· UK Met Office

· University of Reading

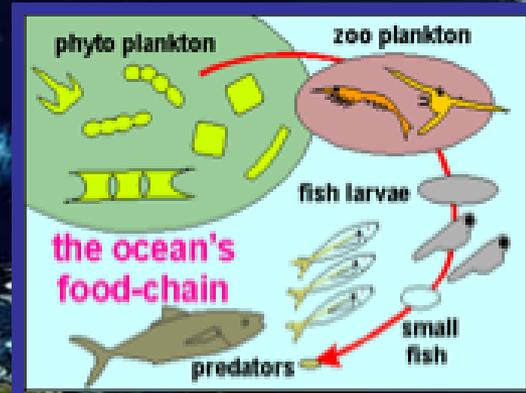
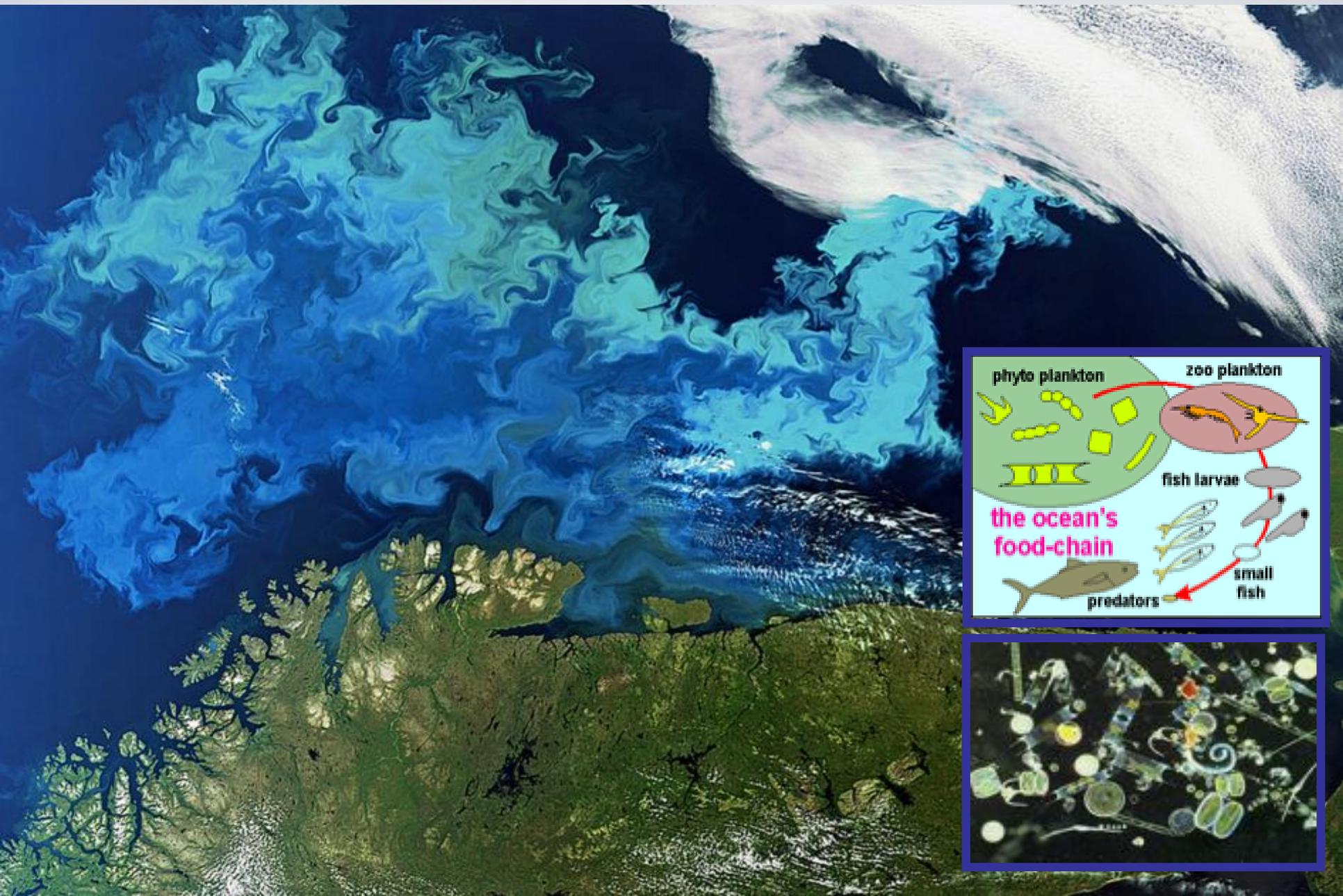
· Copernicus

### Related missions

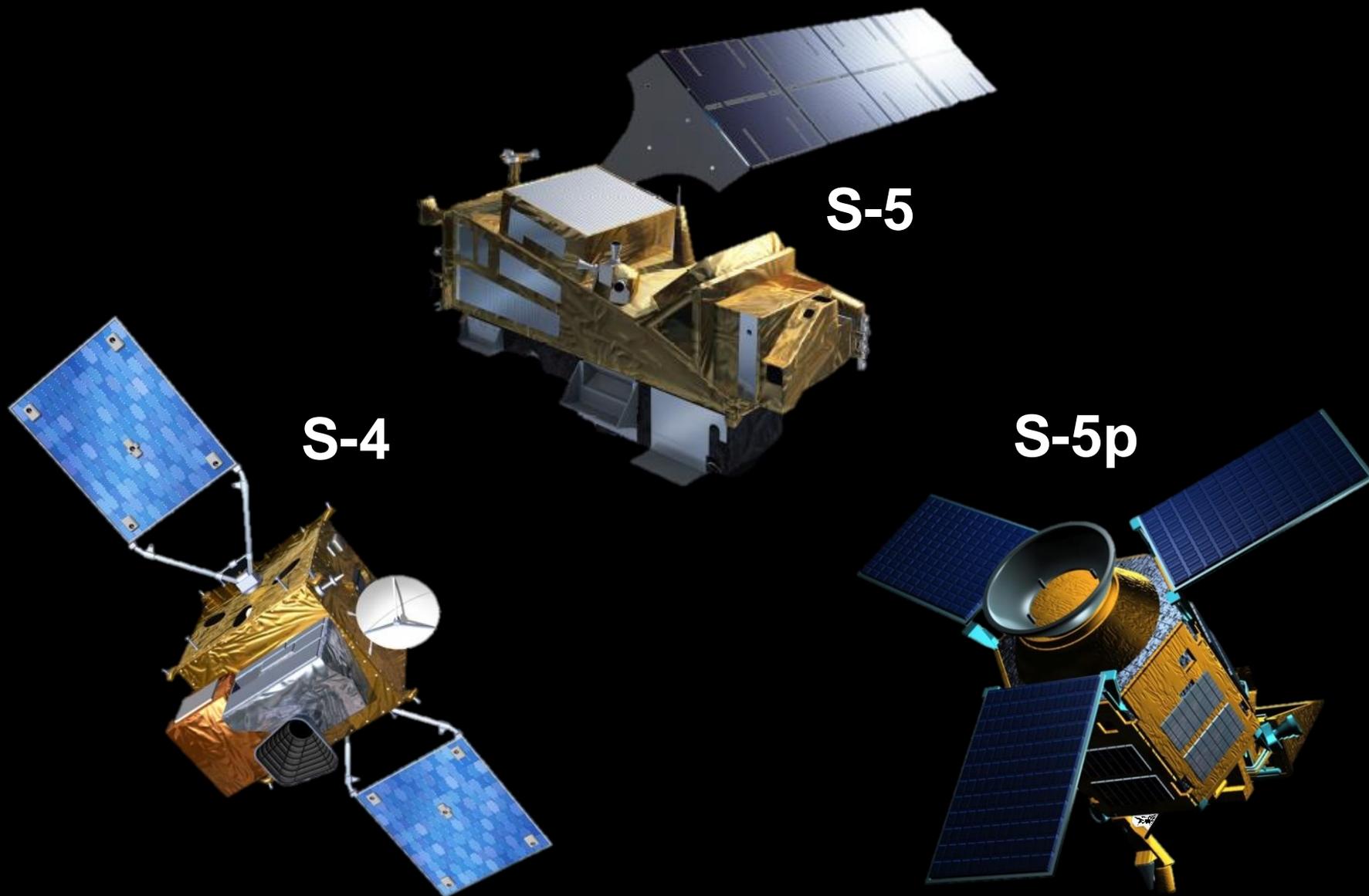
· ERS

· Envisat

· Sentinel-3



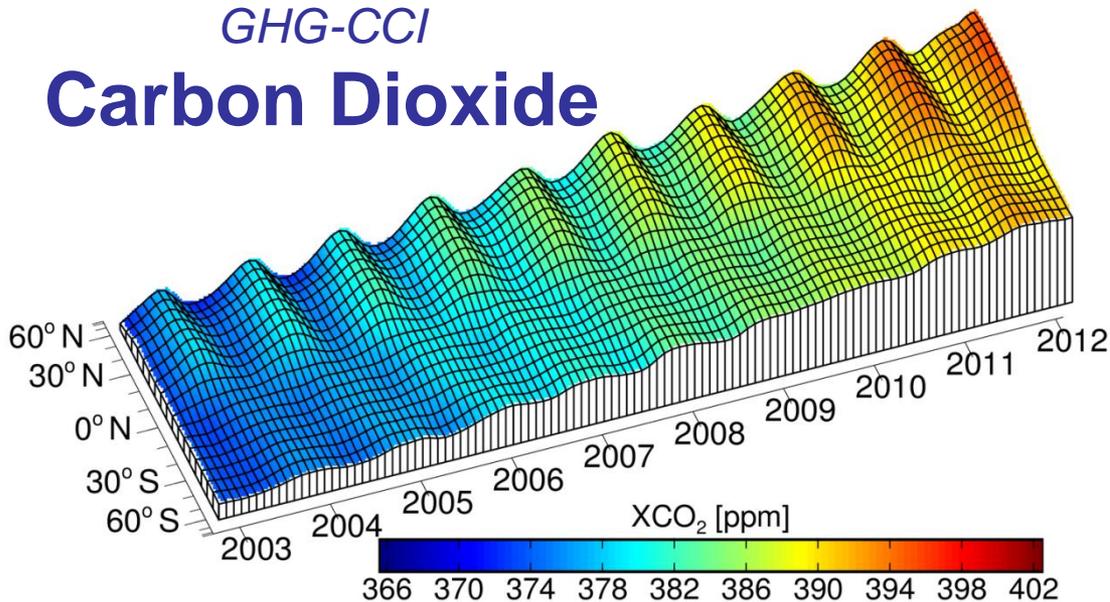




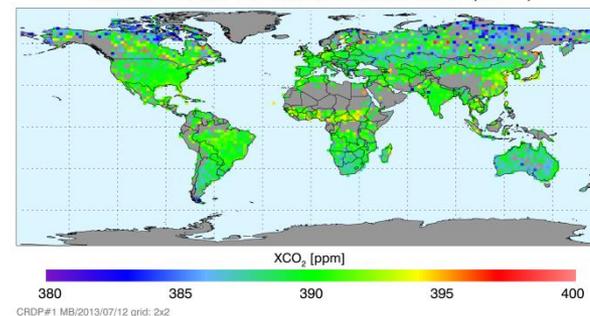
<b>Sensors</b>		Sentinel-4: UVN spectrometer aboard Meteosat Third Generation (MTG) satellites Sentinel-5: UVNS spectrometer aboard MetOp Second Generation Sentinel-5p: TROPOMI UVNS (advanced spectrometer)								
<b>Products</b>										
	<b>O3</b>	<b>NO2</b>	<b>SO2</b>	<b>HCHO</b>	<b>CO</b>	<b>CH4</b>	<b>Aerosol Optical Depth</b>	<b>Aerosol absorbing index</b>	<b>Cloud information</b>	<b>Aerosol layer height</b>
<b>S-4</b>	x	x	x	x			x			
<b>S-5</b>	x	x	x	x	x	x	x			
<b>S-5p</b>	x	x	x	x	x	x		x	x	x
<b>Spectral and temporal sampling</b>										
• S-4: 3 bands    • S-5: 7 bands    • S-5p : 8 bands							UV, VIS, NIR, [SWIR (S-5/-5p)]			
<b>S-4</b>	8 km									
<b>S-5</b>	Above 300 nm: < 8 km, below 300 nm: < 50 km									
<b>S-5p</b>	Nadir resolution: 7 x 7 km / 28 x 7 km									
<b>S-4</b>	60 minutes (fast repeat cycle over Europe and North Africa)									
<b>S-5</b>	Daily									
<b>S-5p</b>	17 days									
<b>Application areas</b>										
<b>S-4/-5:</b>	Air quality measurements, Stratospheric ozone monitoring, Solar radiation measurements, Climate monitoring									
<b>S-5p:</b>	Atmospheric composition studies, Tropospheric monitoring and air quality, Ozone monitoring, Climate monitoring, through the studies of atmospheric chemicals									
<b>Target potential ECVs</b>										
• <b>Cloud</b>			• <b>Aerosol</b>			• <b>Ozone</b>			• <b>GHG, NO2, SO2, CO</b>	
<b>Expected launch date</b>										
• S-4/-5: 2021					• S-5p: 2016					

*GHG-CCI*

## Carbon Dioxide



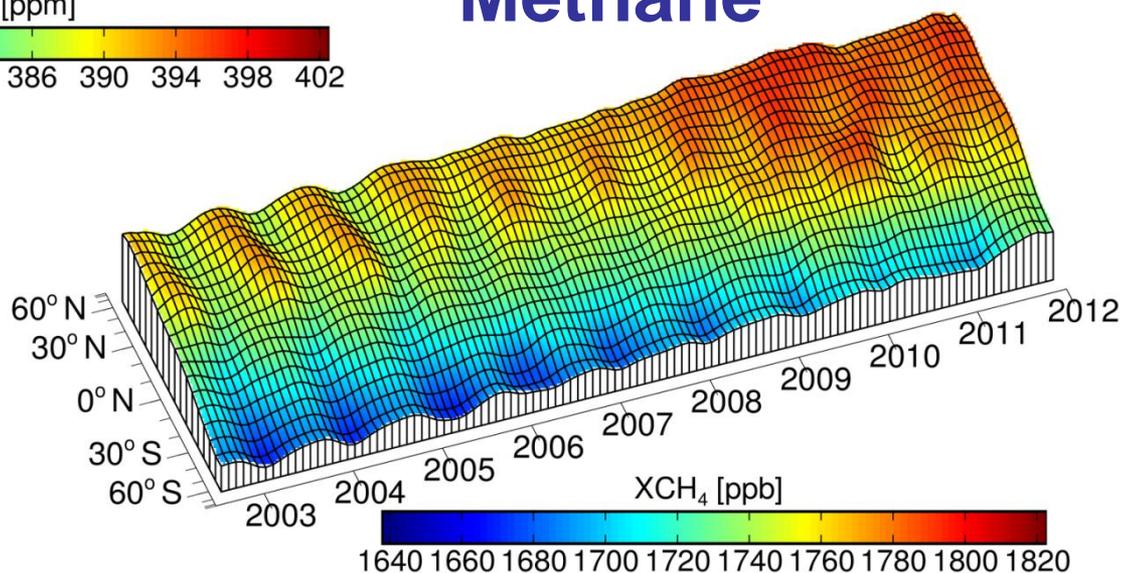
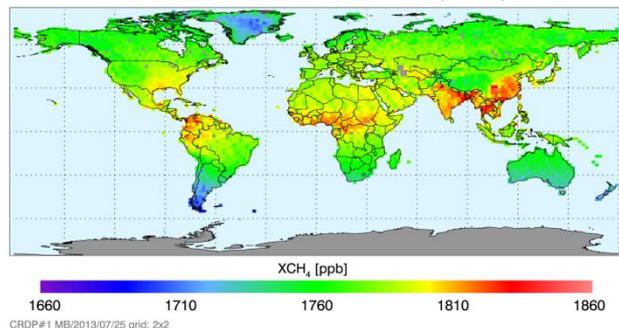
GHG-CCI  
2010-2011  
Carbon Dioxide TANSO/GOSAT/RemoTeC(SRFP)



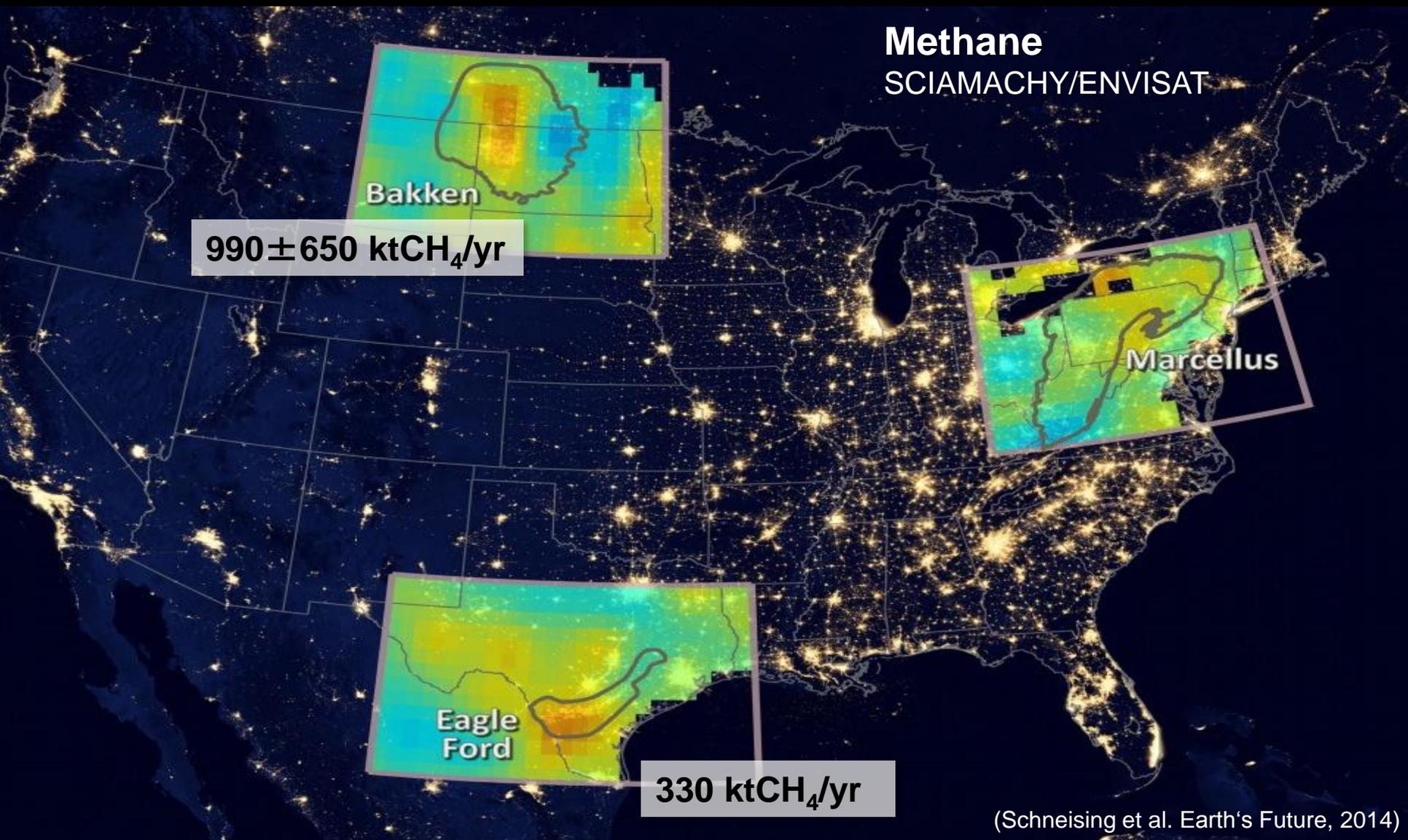
*GHG-CCI*

## Methane

GHG-CCI  
2010-2011  
Methane TANSO/GOSAT/UoL-PR(OCPR)

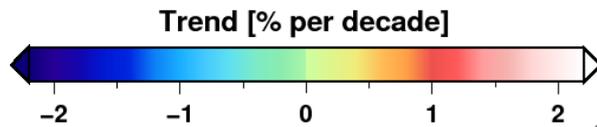
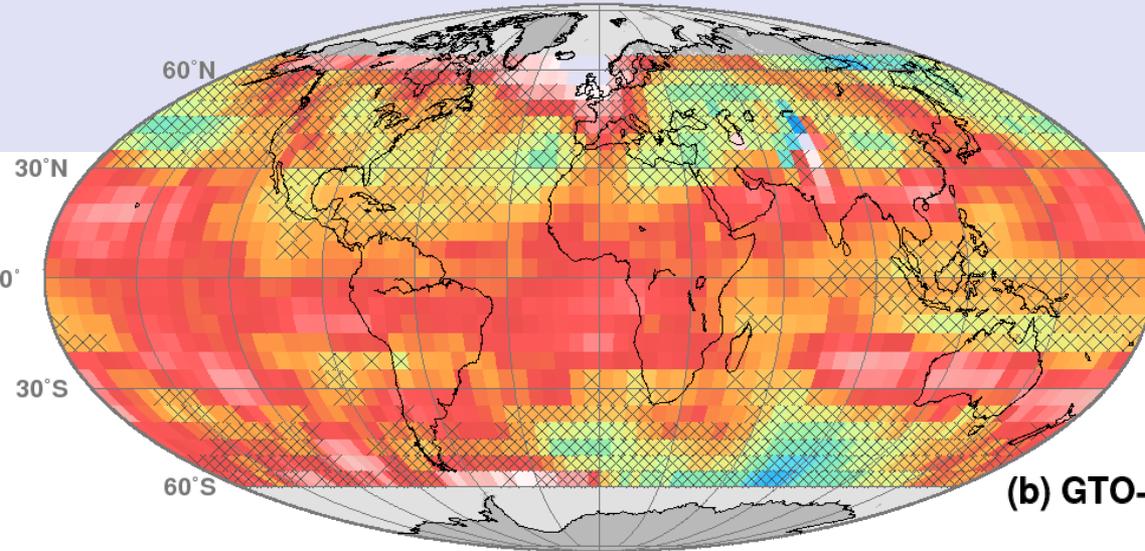


## Estimated emission increase 2009-2011 relative to 2006-2008

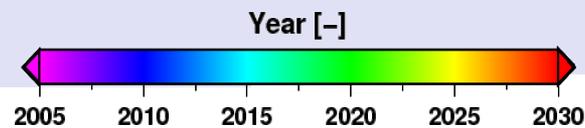
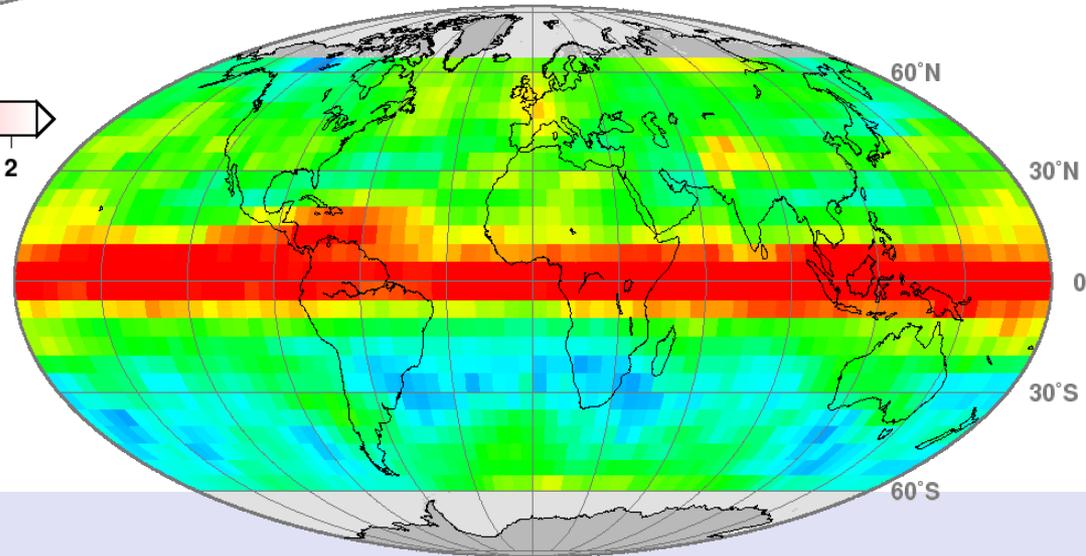


(a) GTO-ECV CCI Total Ozone

Linear total ozone trend estimates  
1995–2013 from satellite data  
GTO-ECV CCI



(b) GTO-ECV CCI Expected Trend Detection



Courtesy:  
Coldwey-Egbers et.al. JGR 2015

<http://www.esa-ozone-cci.org/>

Estimated year of expected  
ozone trend detection for the  
period 1995-2050

# NO<sub>2</sub> from OMI



OMI tropospheric NO<sub>2</sub>

December 2009 All

60 months

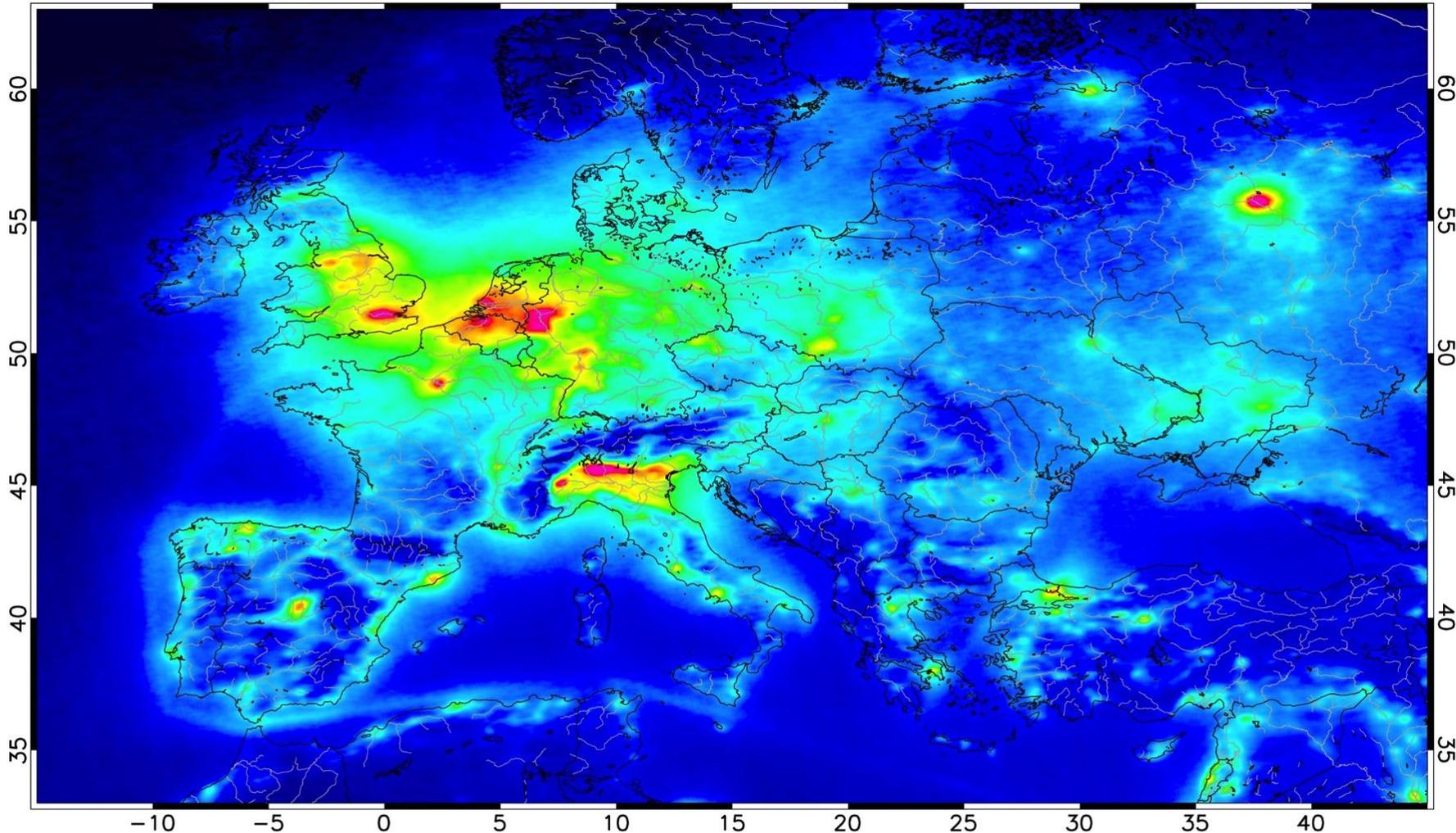
Europe

-10 -5 0

5 10 15

20 25 30

35 40



NO<sub>2</sub> tropospheric column density [ $10^{15}$  molec./cm<sup>2</sup>]

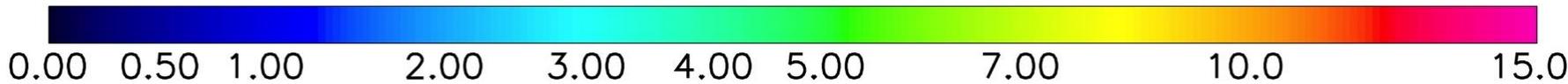


Image credits:  
Geert Vinken (TU/e) and Folkert Boersma (KNMI)

# **3. Sentinel Data Access**

The screenshot shows the Sentinel Online website with a blue header containing the ESA logo, 'Sentinel Online' text, and icons of various satellites. A navigation menu includes 'Missions', 'User Guides', 'Technical Guides', 'Thematic Areas', 'Data Access', and 'Toolboxes'. A search bar and social media links are also present. The main content area features a large banner for 'SENTINEL-1 DATA ACCESS' with sub-sections for 'Access for International Agreements' and 'Access for Collaborative Ground Segment'. Below the banner are sections for 'Sentinel Missions' and 'Thematic Areas'. On the right, there are sections for 'Sentinel News' (listing events like 'Nepal earthquake on the radar'), 'Events' (listing 'Sentinel-3 for Science Workshop'), and 'Browse to Other Sites' (listing various external resources).

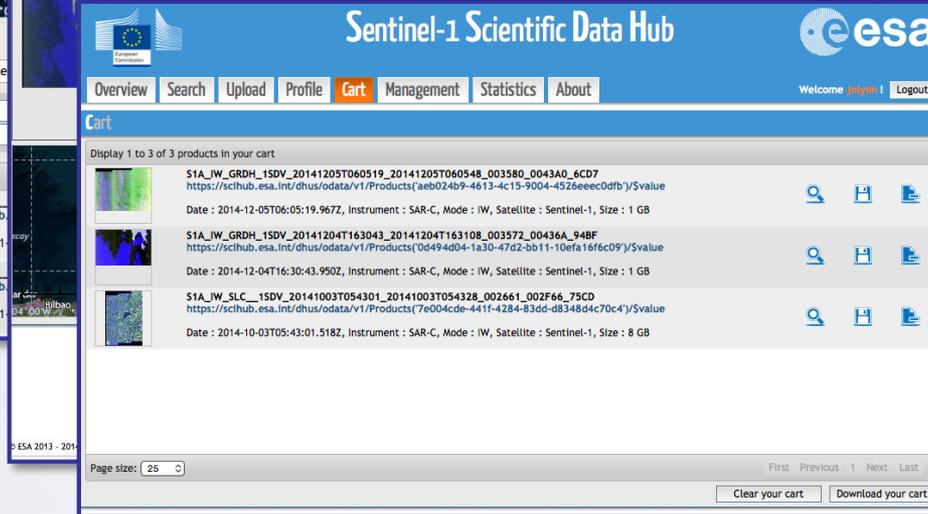
Sentinel Online - <http://sentinels.copernicus.eu>

Username   
Password  Confirm it

**Straightforward registration**



**Flexible search**



**Product inspection**

**Individual and batch download + APIs**

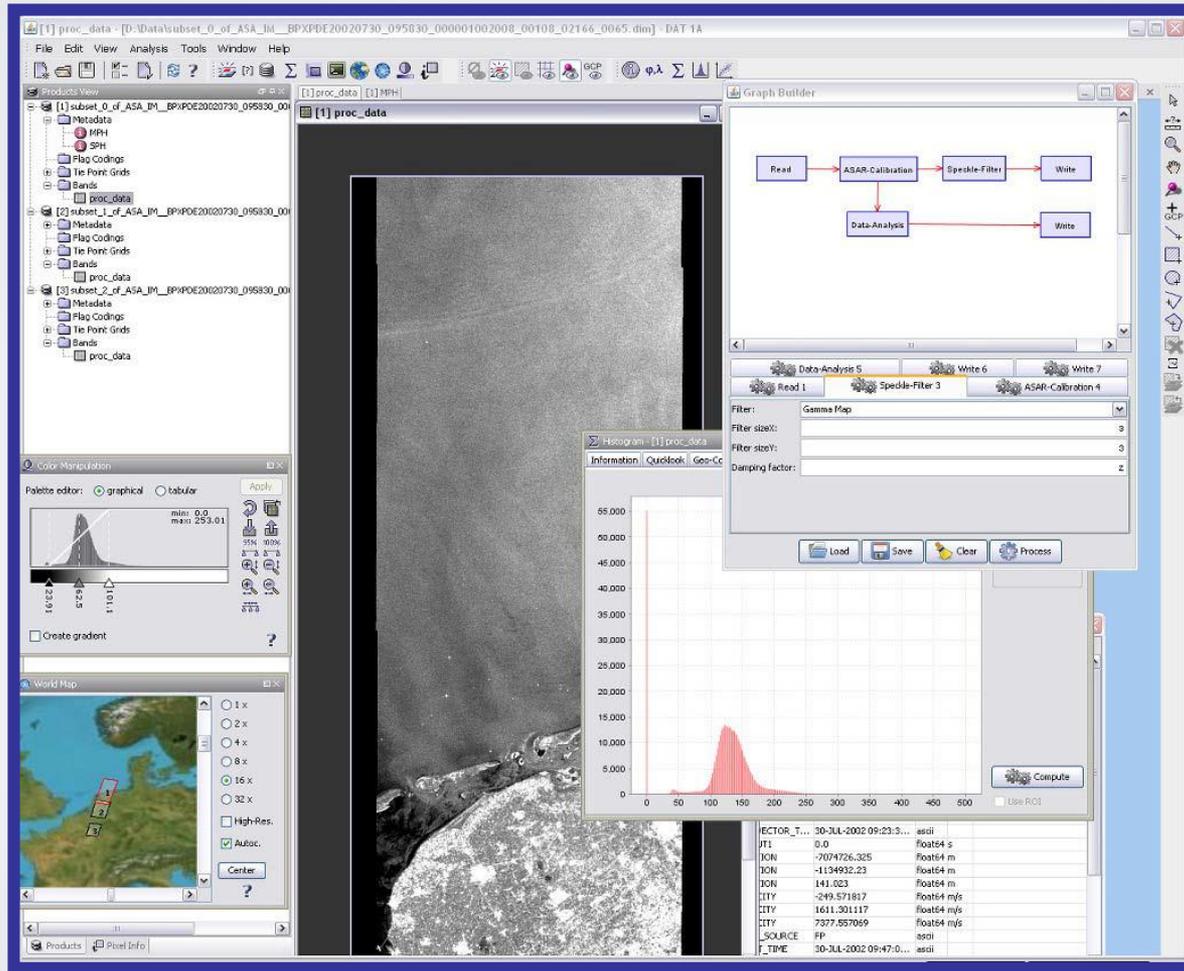
<https://sentinel.esa.int/web/sentinel/missions/sentinel-1/mission-status>

By June 2015:

- **Users: 7,500+** (mainly Europe / North America)
- **Products: 150,000+**
- **Download: 1,030,000+** products downloaded by users, representing about **1.37 PB** of data

## → SENTINEL TOOLBOX

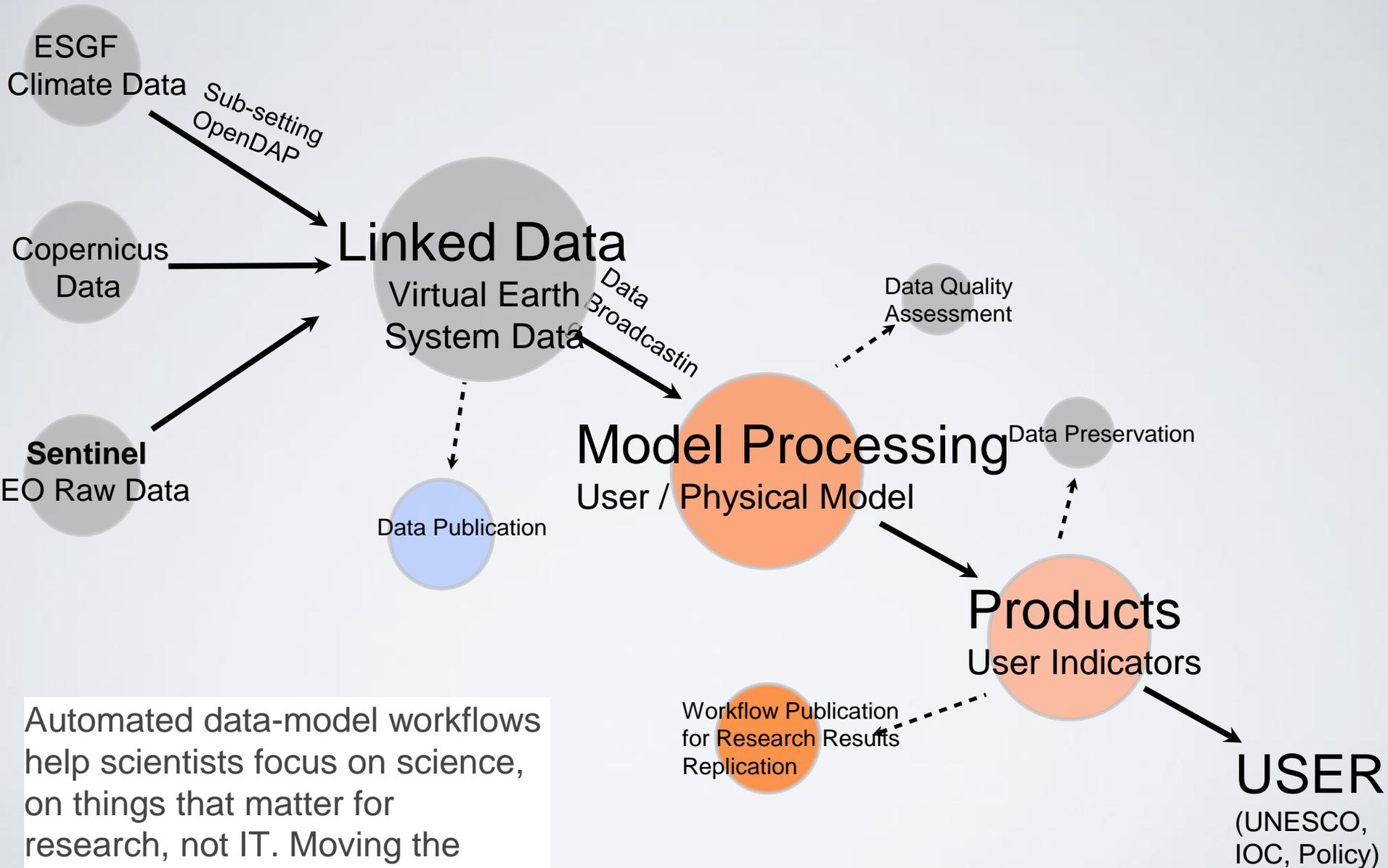
SNAP | Sentinels Application Platform



The screenshot displays the SNAP software interface with several key components:

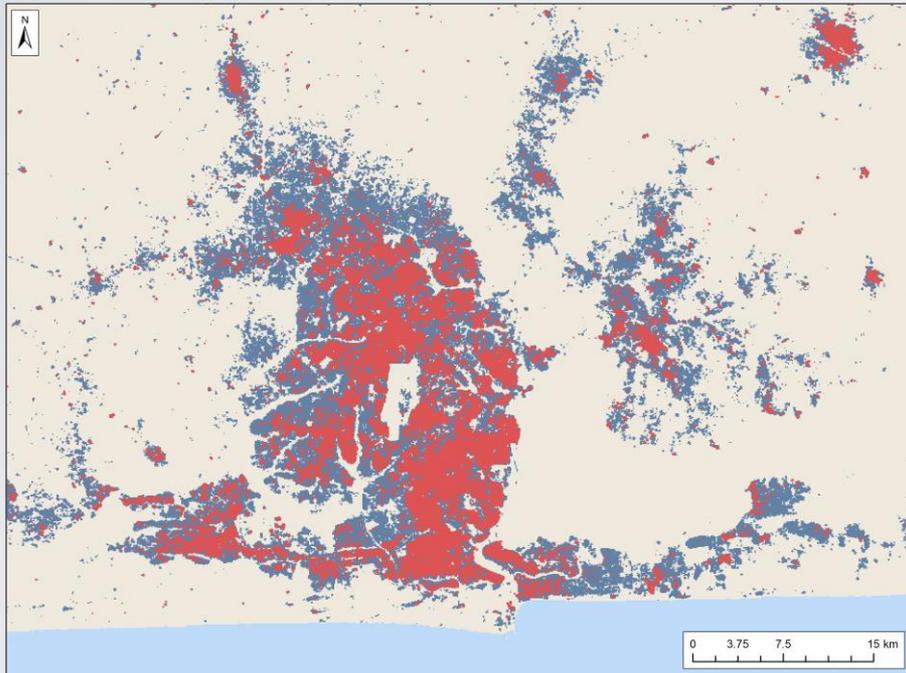
- Product View:** A tree structure on the left showing the project hierarchy, including metadata, bands, and processed data.
- Graph Builder:** A workflow diagram in the top right showing the sequence of operations: Read → ASAR-Calibration → Speckle-Filter → Write, and Data-Analysis → Write.
- Color Manipulation:** A histogram and palette editor in the bottom left, showing a distribution curve and a color gradient.
- World Map:** A small map in the bottom left showing the geographic location of the data.
- Histogram:** A histogram window in the bottom right showing the distribution of pixel values, with a red shaded area under the curve.
- Metadata Table:** A table at the bottom right listing metadata for the selected product.

NAME	TYPE	UNIT	DESCRIPTION
VECTOR_T...	30-JUL-2002 09:23:3...	ascii	
JT1	0.0	Float64 s	
ICON	-7074726.325	Float64 m	
ICON	-1134932.23	Float64 m	
ICON	141.023	Float64 m	
ITY	-249.571817	Float64 m/s	
ITY	1611.301117	Float64 m/s	
ITY	7377.557059	Float64 m/s	
_SOURCE	PP	ascii	
_TIME	30-JUL-2002 09:47:0...	ascii	

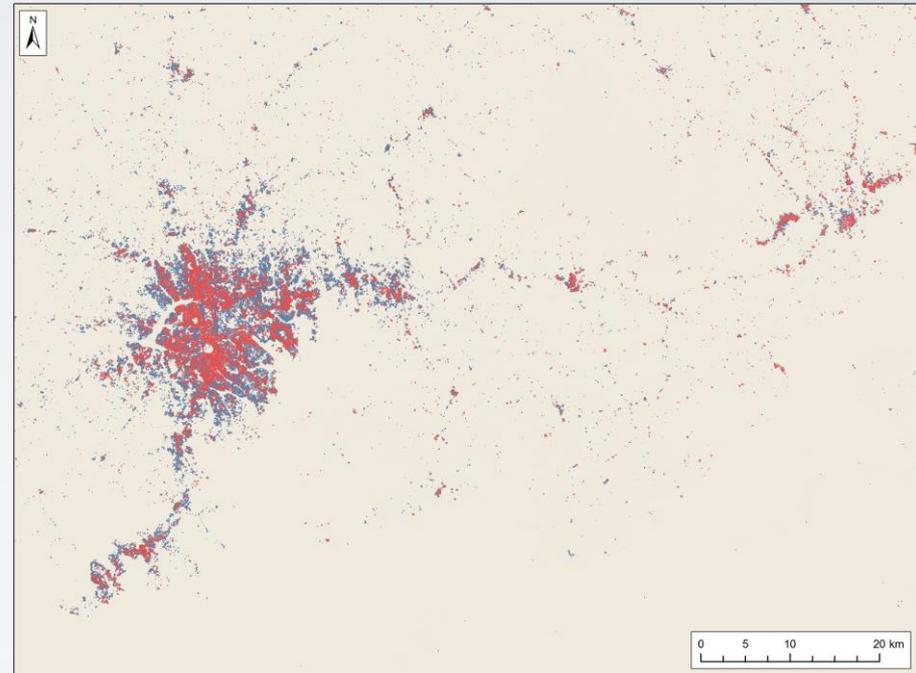


Automated data-model workflows help scientists focus on science, on things that matter for research, not IT. Moving the Calculations to the Software

 Lagos



 Kampala

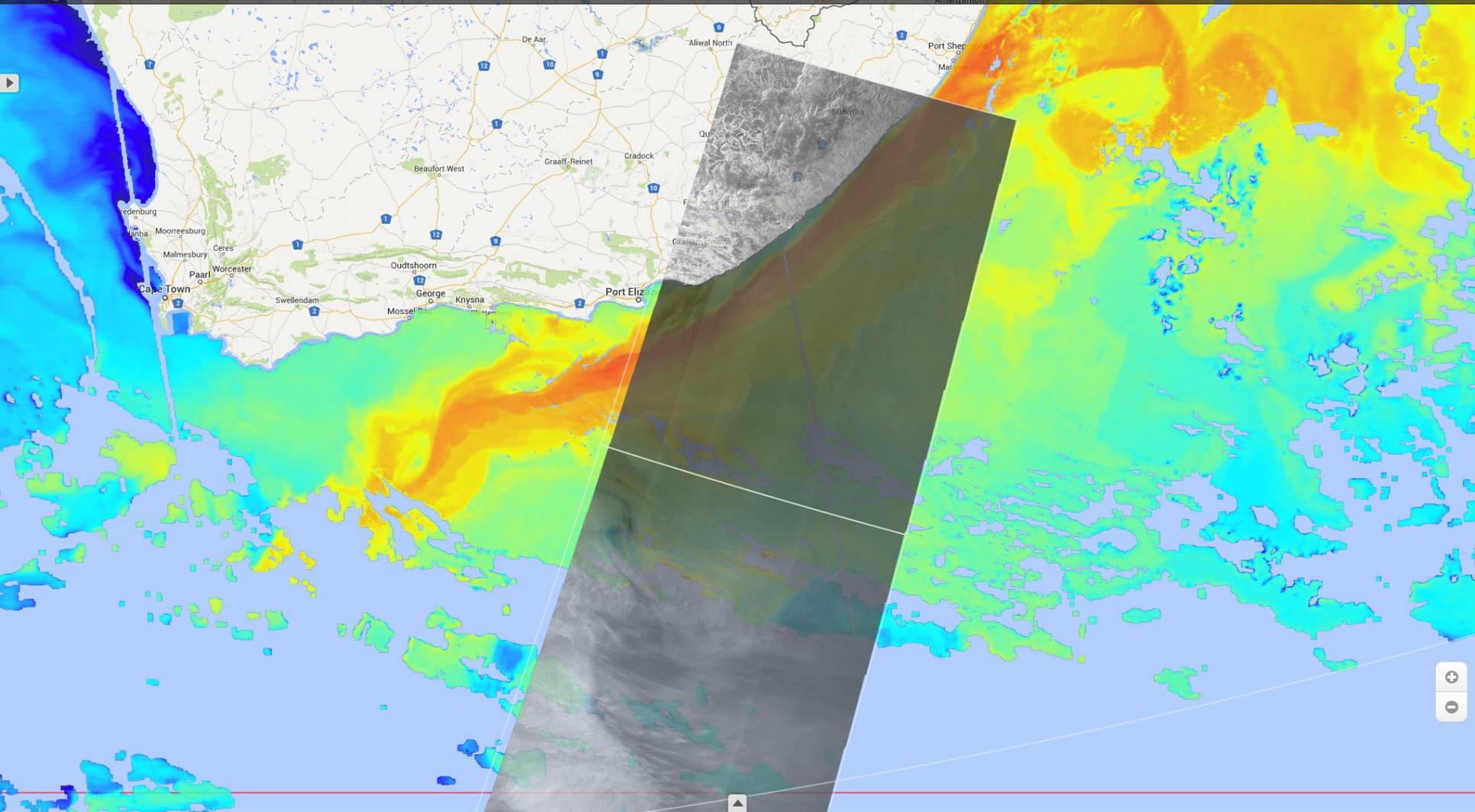


<http://oceandatalab.syntool.org/>

OCEANDATALAB Synergy Portal

Products Hotspots Share

Settings About



1x Daily 3-Day Weekly 100.0% datasets shown (4/4)

2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014

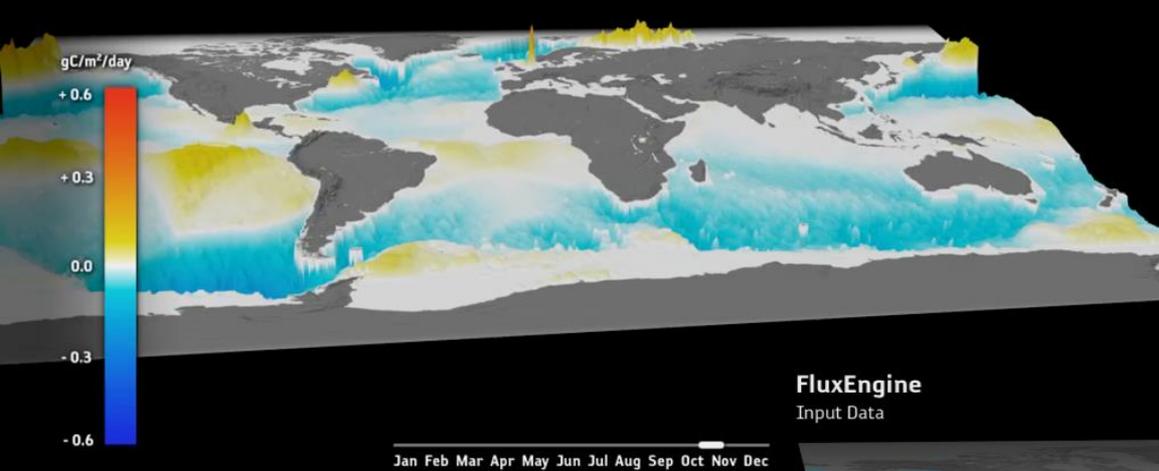
January February March April May June July August September October November December

33.75°, -39.93°

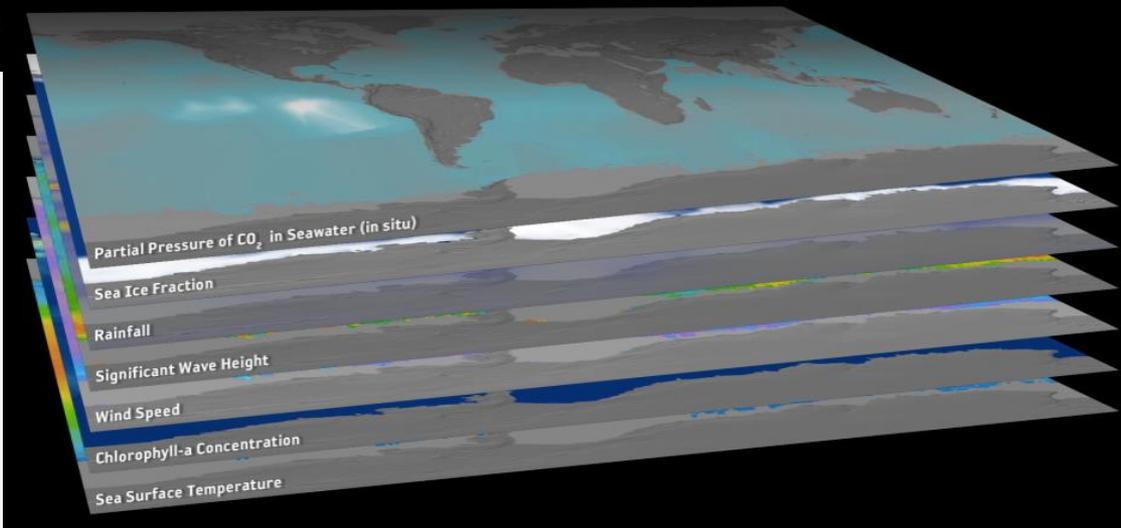
16 18 20 21 22 23 24 25 26 27 28 29 30 31

<http://www.ifremer.fr/cersat1/exp/oceanflux/>

**FluxEngine**  
Air-Sea Flux of Carbon Dioxide

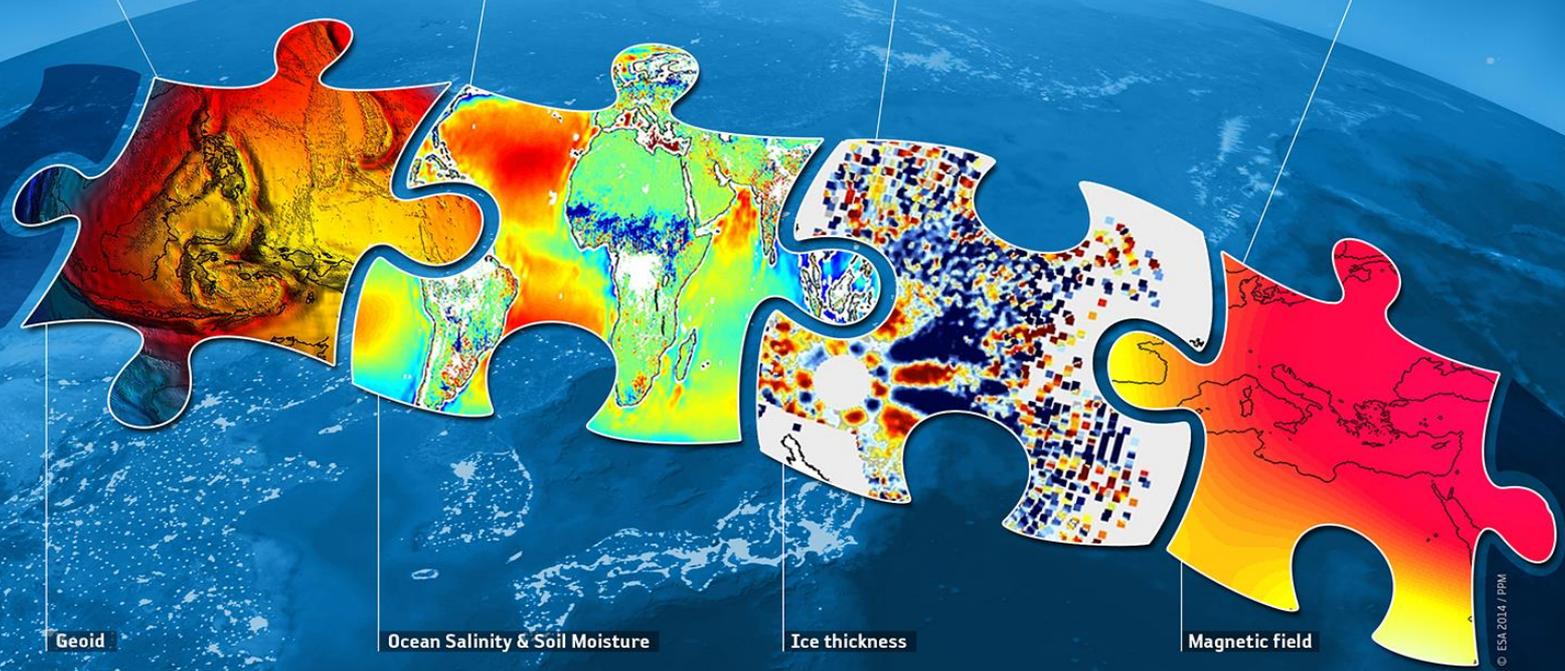


**FluxEngine**  
Input Data



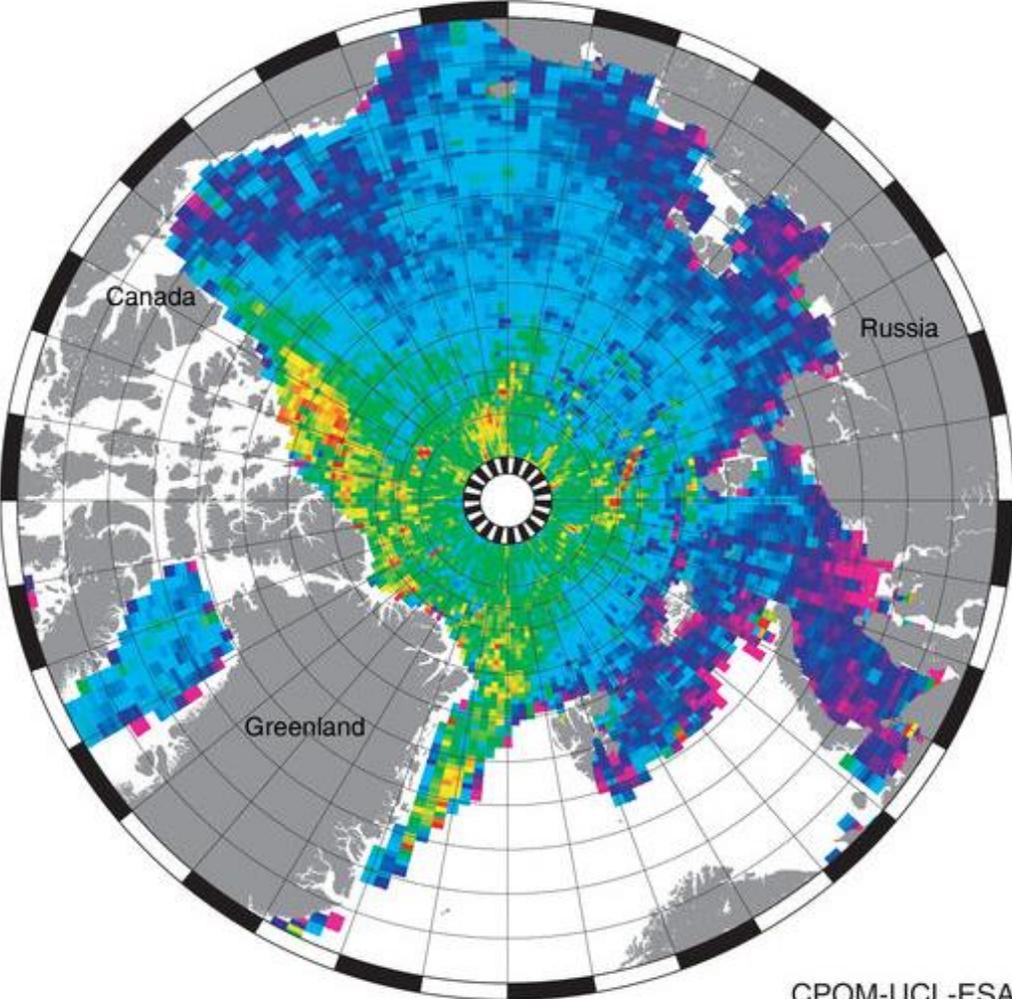
# **4. Synergy with Exploratory Measurements from Space**

# Integrated Observing System



# Sea-ice Thickness in the Arctic ocean

(January/February 2011)

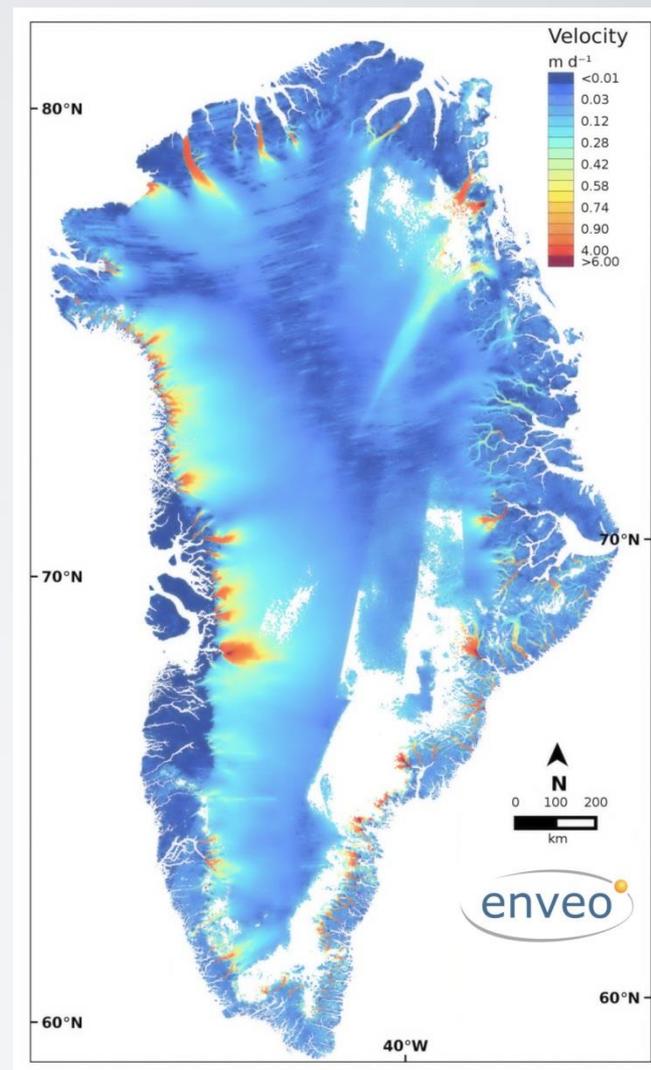


CPOM-UCL-ESA

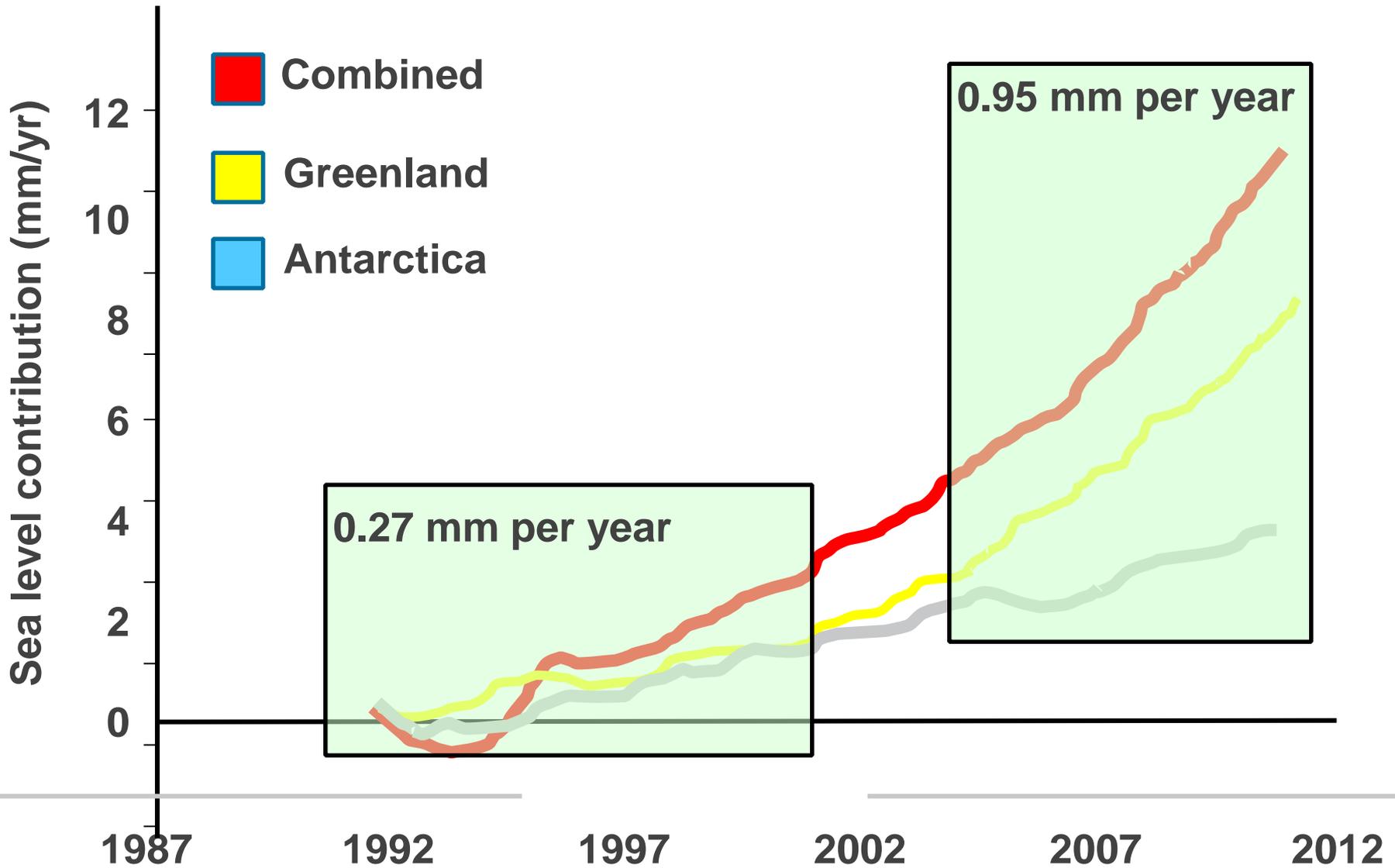


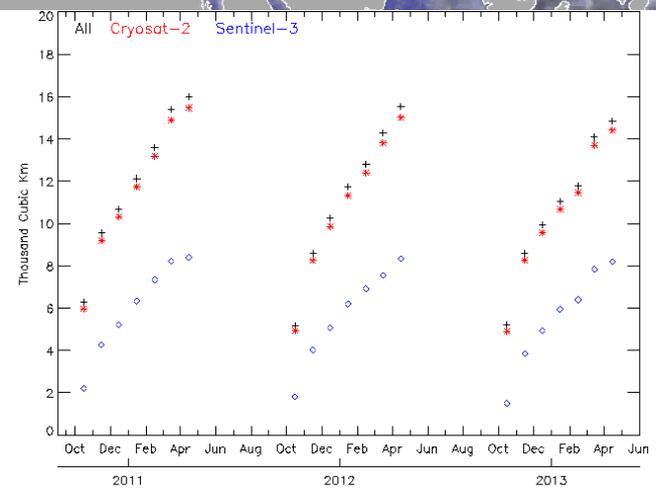
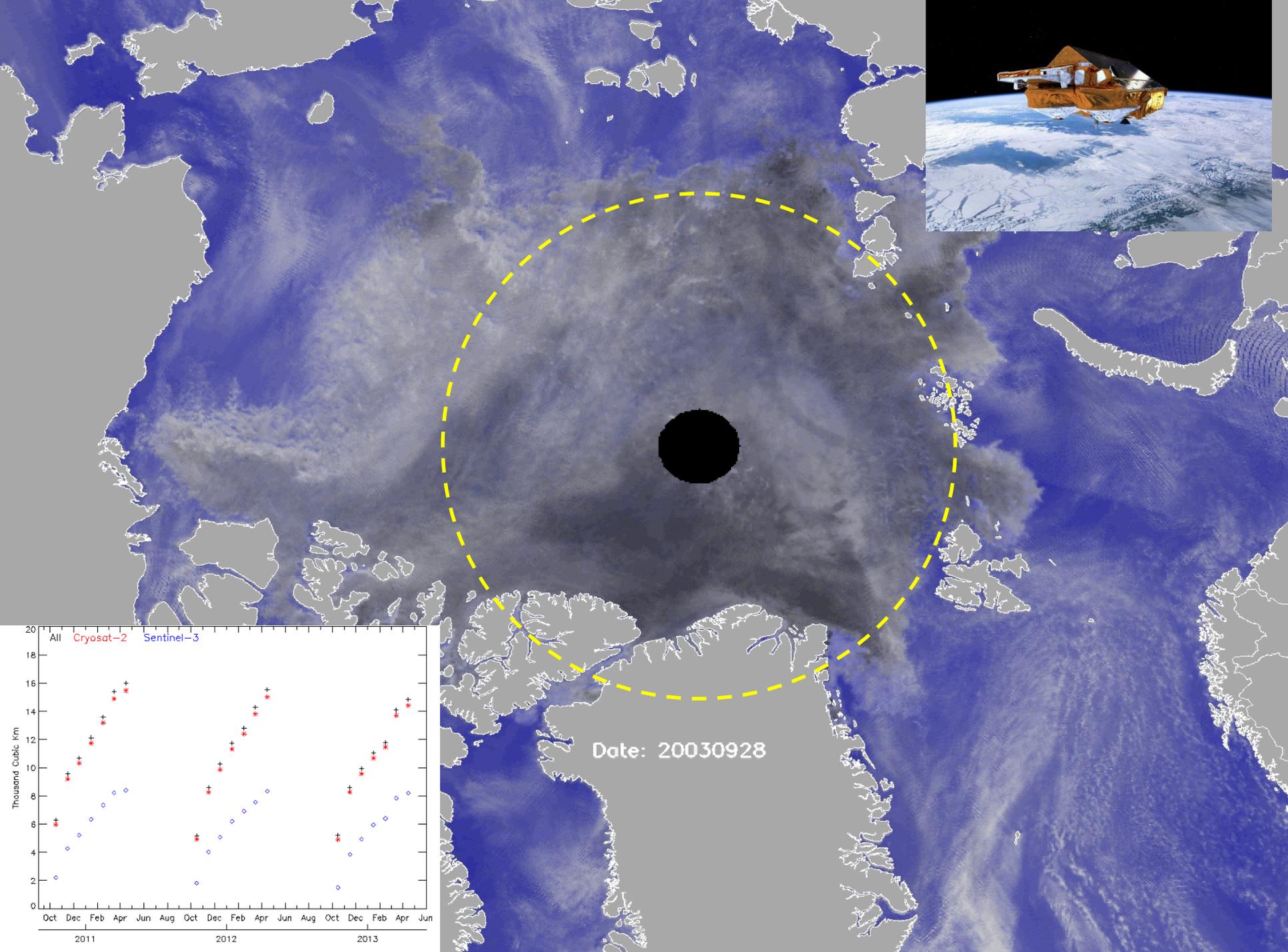


CryoSat-2



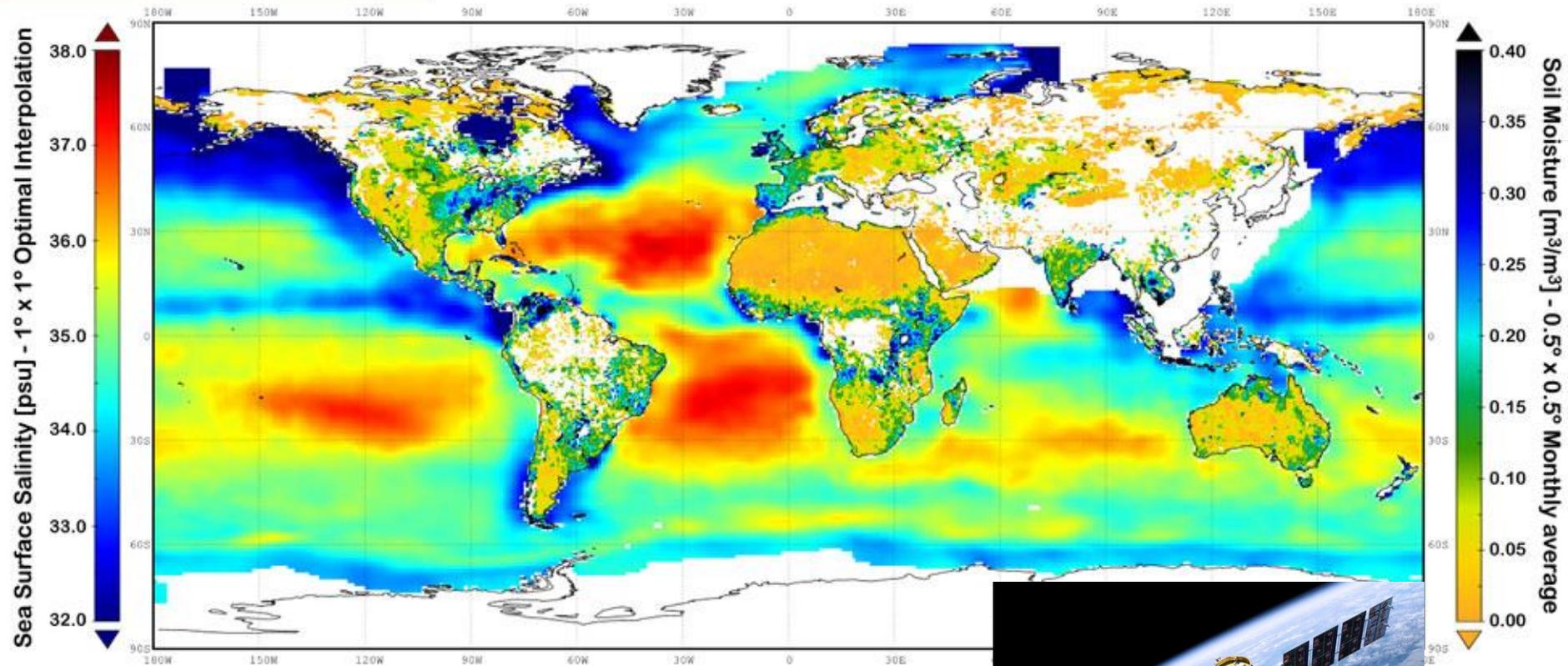
Sentinel-1





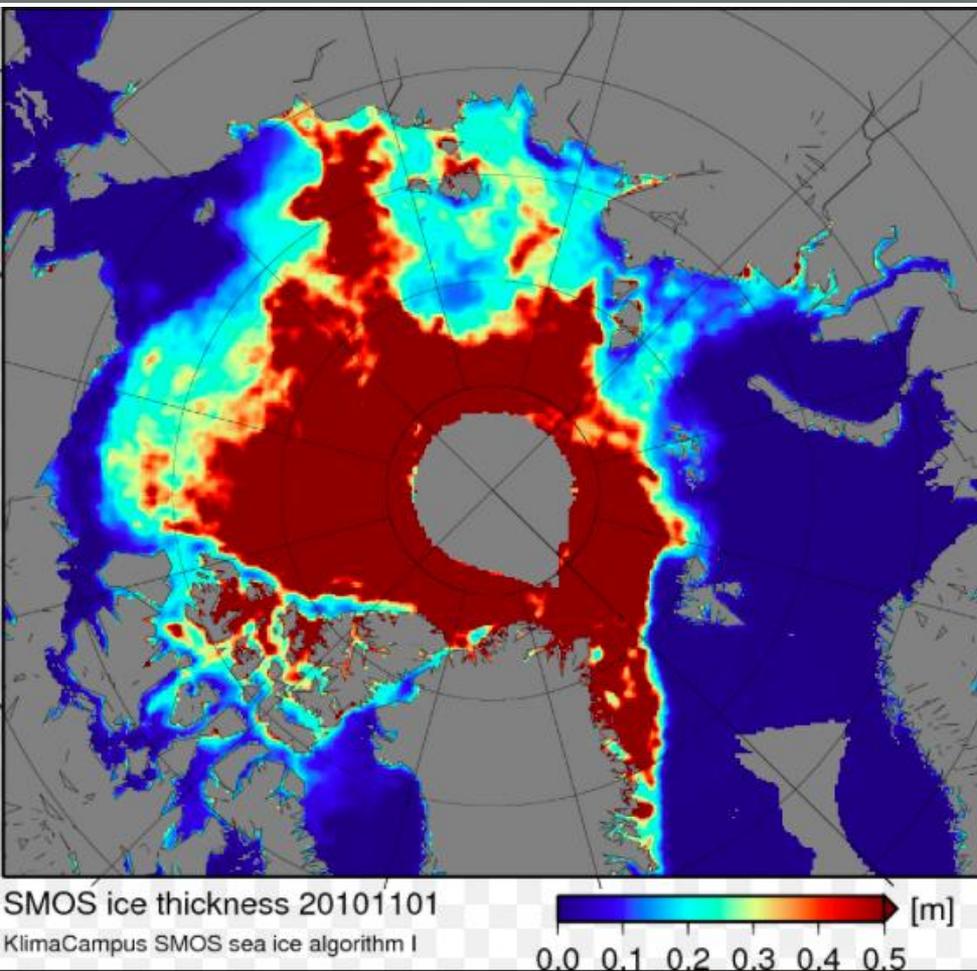


## Sea Surface Salinity and Soil Moisture November 2011

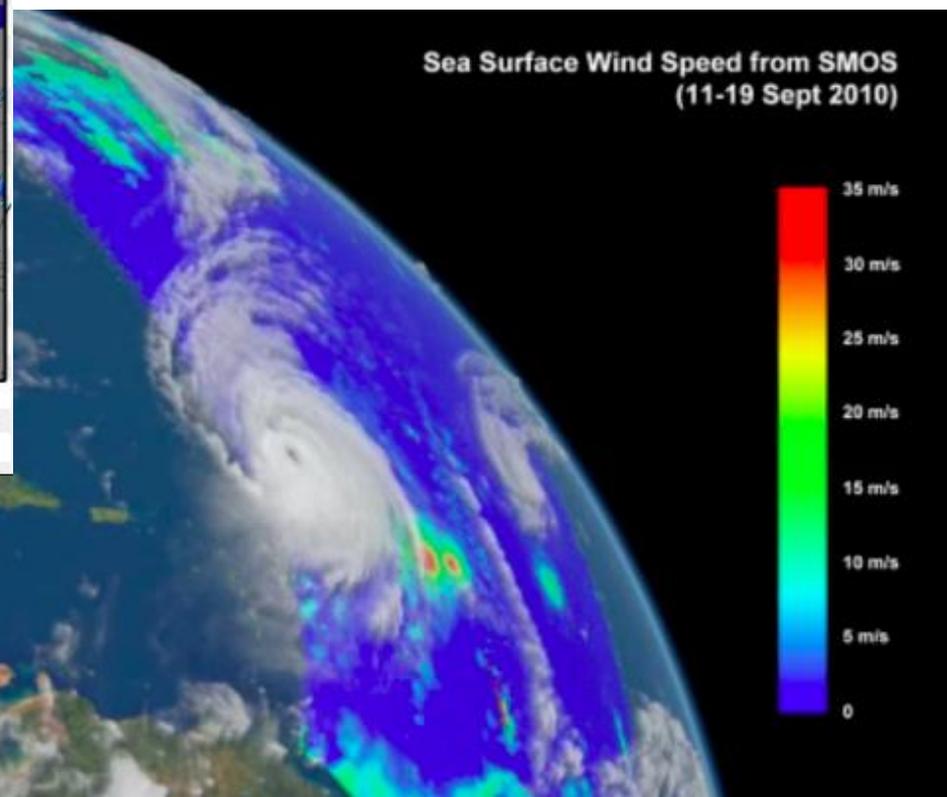


Equirectangular projection centered on 0.00°E





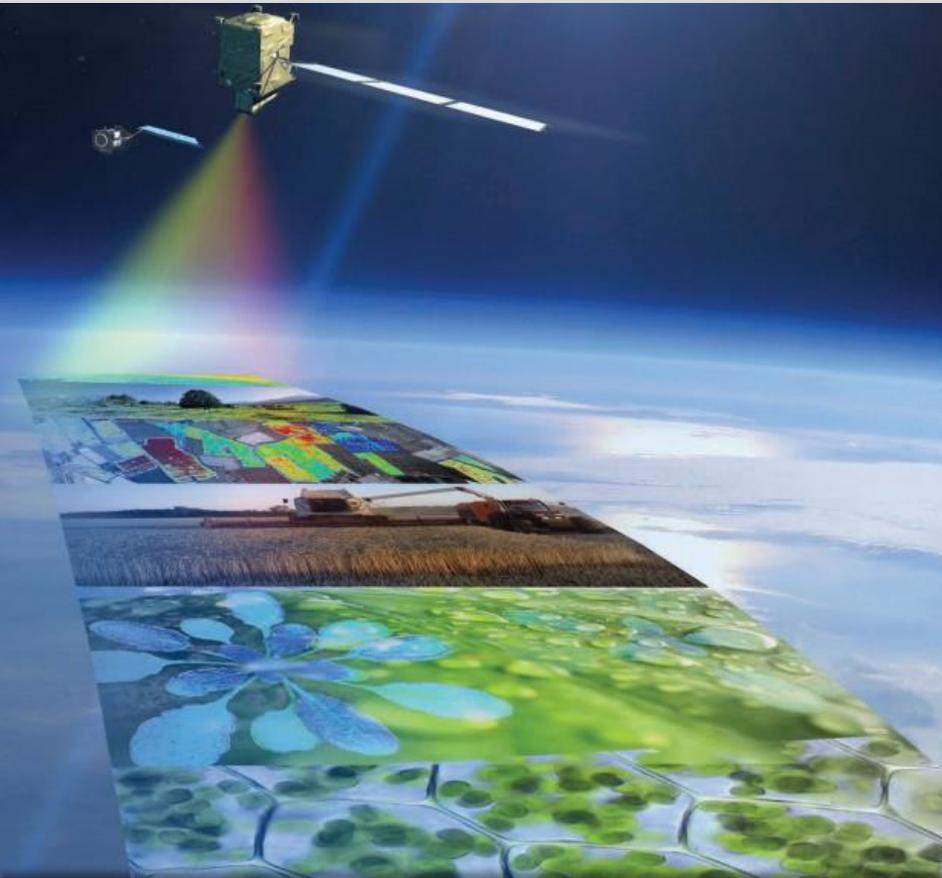
## SMOS+ Surface Wind Research & Operations



SMOS+  
Ice Thickness

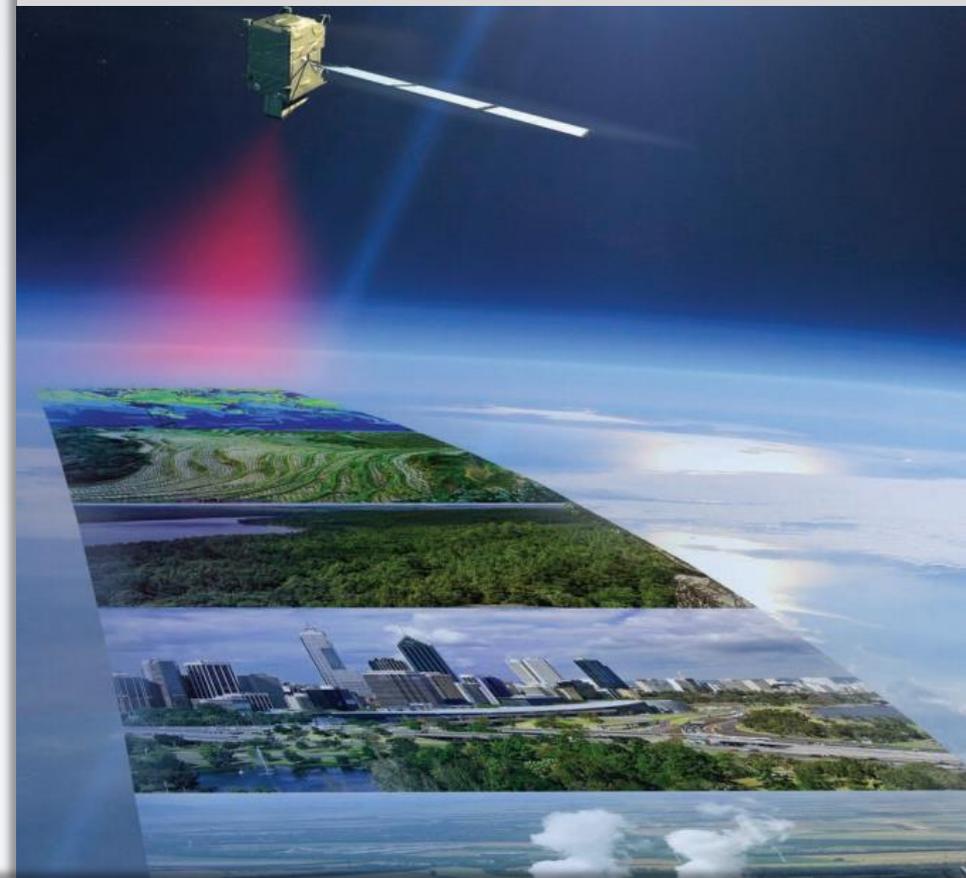
## Flex

An Earth Explorer to observe  
vegetation fluorescence



## CarbonSat

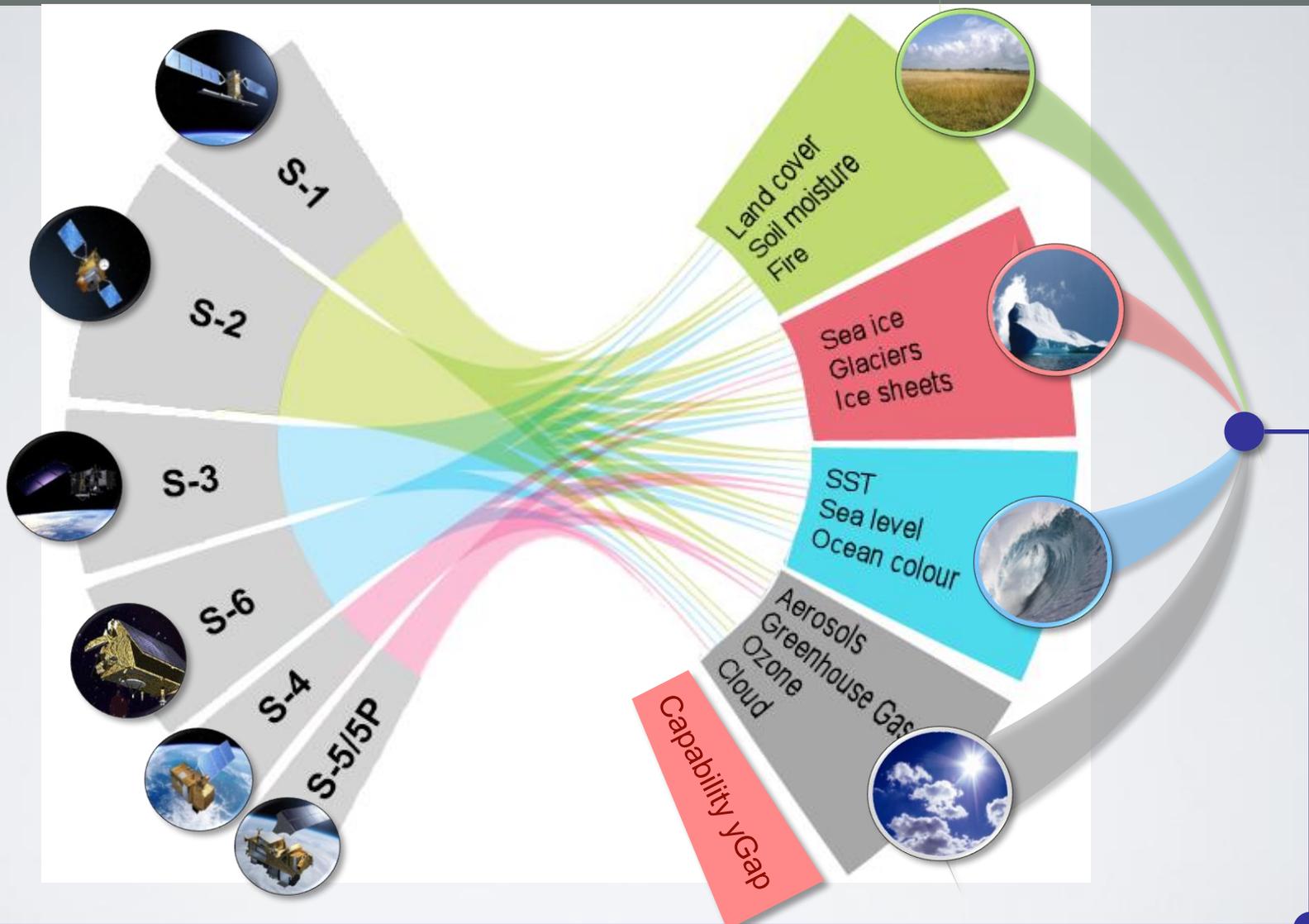
An Earth Explorer to observe  
Greenhouse Gases



**User consultation meeting:  
15-16 September 2015, Krakow, Poland**

# 5. Concluding Remarks

# All Sentinels for Climate Services



Monitoring

Prediction

Projection

Re-analysis

Informing  
Decision

Understanding

<https://www.futurelearn.com/courses/climate-from-space>



## Monitoring Climate Change from Space

Explore our planet from Space and learn how we can monitor climate change through Earth observation techniques.

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We are now at a time on planet Earth where significant and rapid changes to the climate are taking place. It is becoming increasingly essential for us to study the climate and observe changes all across the planet at the highest level of detail possible. But how can we achieve such a comprehensive

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1.17

## Remote sensing techniques



### Q2

#### What is passive remote sensing

- Passive sensing is used during the day when the sun is illuminating the earth.
- Passive sensing detects energy reflected or emitted radiation from the earth.
- Passive sensing detects infrared radiation.
- Passive sensing detects energy which is scattered by the atmosphere.



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Earth-observation satellites

## Something to watch over us

The Earth should be monitored more carefully

May 12th 2012 | From the print edition

 Timekeeper

 Tweet 86



ON APRIL 8th Envisat, Europe's largest Earth-observing satellite, unexpectedly stopped talking to its users on the Earth below. Since then those users have been frantically trying