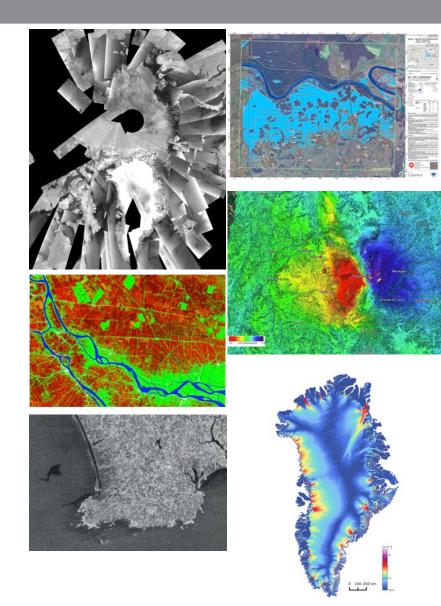
4th Advanced Course on Radar Polarimetry 2 February 2017, ESA - ESRIN





SENTINEL-1 Mission Overview

Pierre Potin Sentinel-1 Mission Manager ESA



The Copernicus Programme



Copernicus (formerly known as GMES) is a European space flagship programme led by the European Union

Provides the necessary data for operational monitoring of the environment and for civil security

ESA coordinates the space component



Copernicus Space Component – Dedicated Missions: the Sentinels





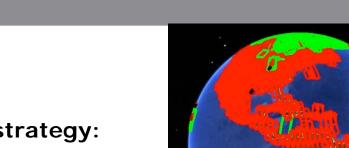
Sentinels Operations Strategy

Main objectives of the Sentinels operations strategy:

- Reliable provision of data to Copernicus users
- Ensure systematic and routine operational activities

Sentinels operations approach:

- Sentinels are operated via a pre-defined background observation and downlink plan
 - Scenario is updated on a regular basis (e.g. 6 to 12 months) taking into account the evolution of observation needs by the users
- All Sentinels acquired data is systematically downlinked and processed to generate a predefined list of core products within specific timeliness
 - Typically within 3 hrs after sensing for Near-Real Time, and within 24hrs after sensing for Non-Time Critical

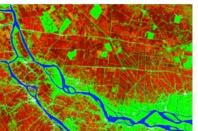


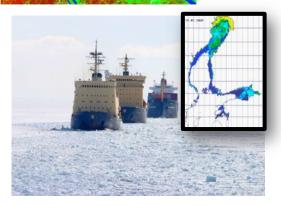


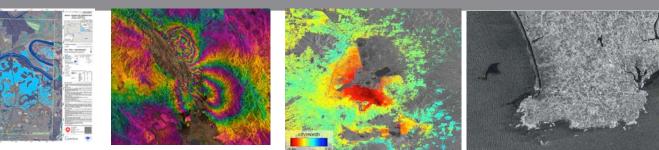
Sentinel-1: C-band SAR mission











- ✓ Data continuity of ERS and ENVISAT missions
- Copernicus radar imaging mission for ocean, land, emergency
- Applications:
 - · monitoring sea ice zones and the arctic environment
 - surveillance of marine environment (e.g. oil spill monitoring)
 - maritime security (e.g. ship detection)
 - wind, wave, current monitoring
 - monitoring of land surface motion (subsidence, landslide, tectonics, volcanoes, etc.)
 - support to emergency / risk management (e.g. flooding, etc.) and humanitarian aid in crisis situations
 - mapping of land surfaces: agriculture, forest, water and soil, etc.

Sentinel-1: Mission Profile



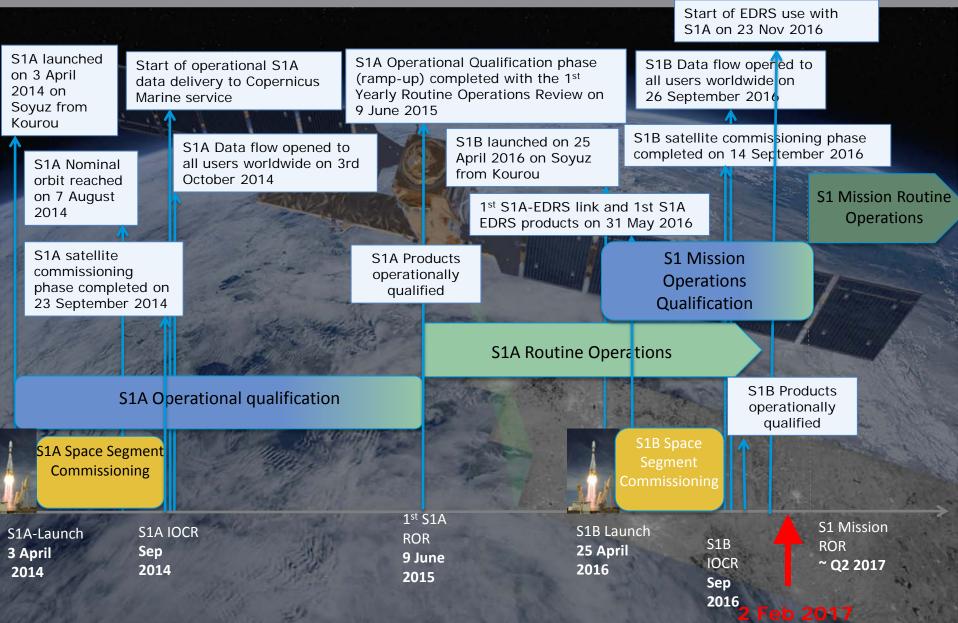
Sentinlel-1 A

Sentinlel-1 B

- Mission based on 2 satellites
- C-band Radar instrument (5.405 GHz)
- Sun-synchronous orbit at 693 km altitude
- Inclination: 98.18°
- 7 years lifetime
- Consumables for 12 years
- Mean LST: 18:00h at ascending node
- 12-day repeat cycle at Equator (6 days with 2 satellites)

Sentinel-1 Mission Operations Milestones





SAR Operational Modes



Sentinel observation scenario main objective is to establish a predefined stable conflict free observation plan

Operational Modes	GRD Level 1 product resolution	Swath Width	Polarisation
A00 Km	50m (3 ENL)	> 400 km	HH+HV or VV+VH
250 Km Interferometric Wide Swath Mode (IW)	20m (5 ENL)	> 250 km	HH+HV or VV+VH
400 Km 56 Stripme p Mode (SM) 51 Stripme p Mode (SM)	9m (4 ENL)	> 80 km	HH+HV or VV+VH
V TE Wave Mode (WV)	50m (140 ENL)	20 x 20 km ² at 100 km spacing	HH or VV
Main mode over lar coastal areas	European Space Agency		



Image Acquisition in Interferometric Wide Swath mode (IW)



<u>Terrain</u> <u>Observation</u> by <u>P</u>rogressive <u>S</u>cans (TOPS)

Sentinel-1 Operational Products available to users



LEVEL-0 PRODUCTS

Compressed, unprocessed instrument source packets, with additional annotations and auxiliary information to support the processing.

LEVEL-1 PRODUCTS

Level-1 Slant-Range Single-Look Complex Products (SLC):

Focused data in slant-range geometry, single look, containing phase and amplitude information.

Level-1 Ground Range Detected Geo-referenced Products (GRD):

Focused data projected to ground range, detected and multi-looked. Data is projected to ground range using an Earth ellipsoid model, maintaining the original satellite path direction and including complete geo-reference information.

LEVEL-2 PRODUCTS

Level-2 Ocean products Ocean wind field, swell wave spectra and surface radial velocity information as derived from SAR data.

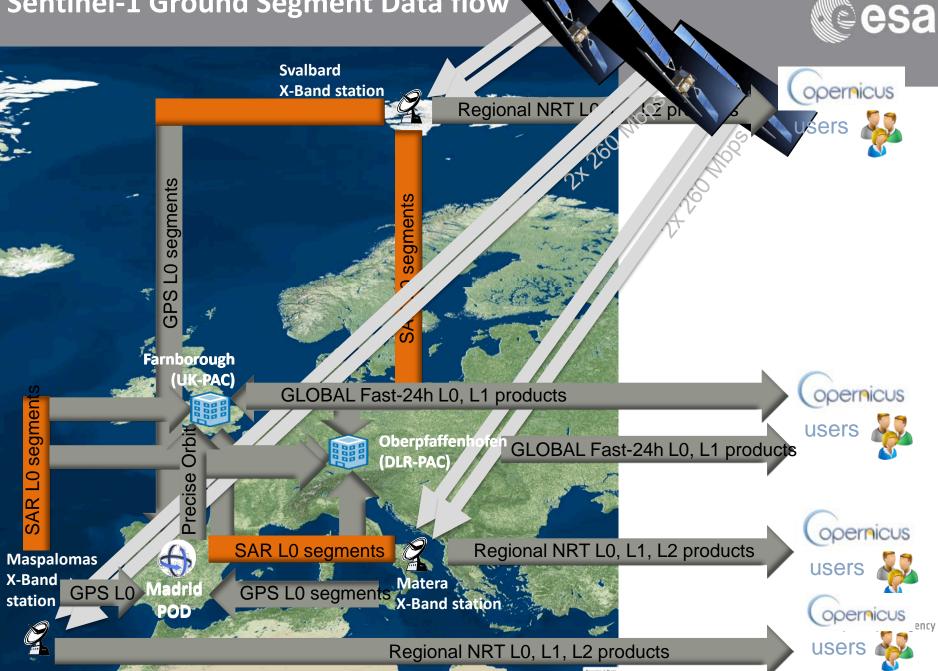
Sentinel-1 Level 1 Operational Product characteristics



Acq. Mode	Product Type	Resolution Class	Resolution [Rng x Azi] [m]	Pixel Spacing [Rng x Azi]	No. Looks [Rng x Azi]	ENL
SM	SLC	-	1.7 x 4.3 to 3.6 x 4.9	1.5 x 3.6 to 3.1 x 4.1	1 x 1	1
	GRD	FR	9 x 9	4 x 4	2 x 2	3.9
		HR	23 x 23	10 x10	6 x 6	34.4
		MR	84 x 84	40 x 40	22 x 22	464.7
			•			
IW	SLC	-	2.7 x 22 to 3.5 x 22	2.3 x 17.4 to 3 x 17.4	1	1
	GRD	HR	20 x 22	10 x 10	5 x 1	4.9
		MR	88 x 89	40 x 40	22 x 5	105.7
EW	SLC	-	7.9 x 42 to 14.4 x 43	5.9 x 34.7 to 12.5 x 34.7	1 x 1	1
	GRD	HR	50 x 50	25 x 25	3 x 1	3
		MR	93 x 87	40 x 40	6 x 2	12
			•	•	•	•
WV	SLC	-	2.0 x 4.8 and 3.1 x 4.8	1.7 x 4.1 and 2.7 x 4.1	1 x 1	1
	GRD	MR	52 x 51	25 x 25	13 x 13	139.7

- For Ground Range Products, the resolution corresponds to the mid range value at mid orbit altitude, averaged over all swaths.
- For SLC SM/IW/EW products, the resolution and pixel spacing are provided from lowest to highest incidence angle. For SLC WV products, the resolution and pixel spacing are provided for beams WV1and WV2.
- For SLC products, the range coordinate is in slant range. All the other products are in ground range. European Space Agency

Sentinel-1 Ground Segment Data flow



Sentinel-1 observation scenario Main components & thematic domains





Sea state

ESA UNCLASSIFIED - For Official Use

Sea-ice, icebergs, lake-ice

permafrost and snow

Priorities for accessing Sentinel Resources



The priority scheme is based on the Copernicus Regulation (EU), the GSC Programme Declaration (ESA), and the EU-ESA Copernicus Agreement and is reflected in the **Sentinel High Level Operations Plan** (HLOP)

The following priorities, in descending order, are defined:

1 - Copernicus service use

Copernicus service providers, responding to the Copernicus governance, consisting of all "Copernicus services" approved by the European Commission

2 - National utilisation by Copernicus Participating States in accordance with the Copernicus Regulation and the GMES Space Component Programme Declaration and by a number of EU institutions

3 - Other use

Cooperation agreements between EU and international partners, scientific use, other use

→ Priority scheme used for managing the few potential conflicting user needs for accessing Sentinel missions resources

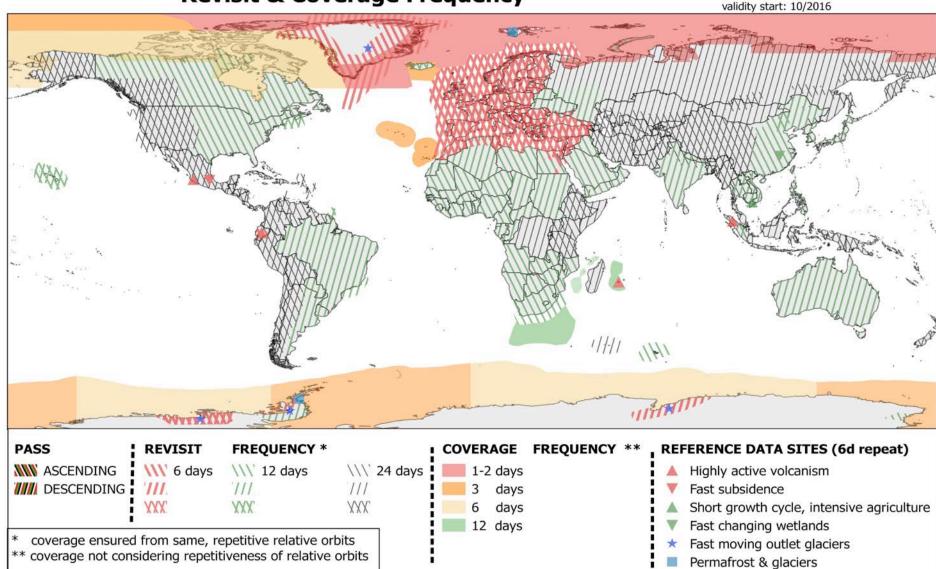
Most of the potential conflicts are in practice solved by appropriate planning of shared resources among the Sentinels two-spacecraft constellation

ESA UNCLASSIFIED - For Official Use

Sentinel-1 Constellation Observation Scenario

Sentinel-1 Constellation Observation Scenario: Revisit & Coverage Frequency

Observation plan is published on Sentinel Online portal in advance to its execution



Sentinel-1 Constellation Observation Scenario

Sentinel-1 Constellation Observation Scenario: Mode - Polarisation - Observation Geometry

HH or HH-HV



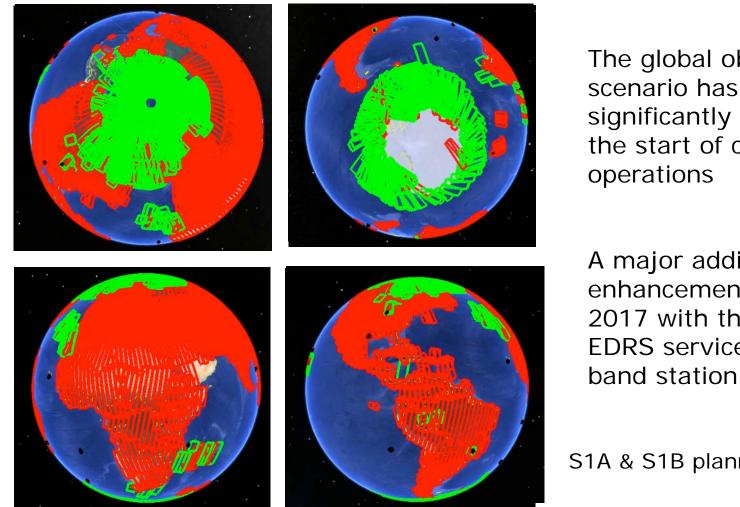
validity start: 10/2016

M Bea

VIIII IIII WHI UATT MMMMM POLARISATION SCHEMA SM mode / dual-polarisation ★ Calibration Site **MODE / POLARISATION** HH or HH-HV SM mode / single-polarisation (locally different modes or IW mode / dual polarisation polarisations possible) PASS IW mode / single polarisation VV or VV-VH EW mode / dual polarisation **ASCENDING** DESCENDING EW mode / single polarisation

Sentinel-1 Constellation Observation Scenario First operational outcome





The global observation scenario has been significantly enhanced with the start of constellation operations

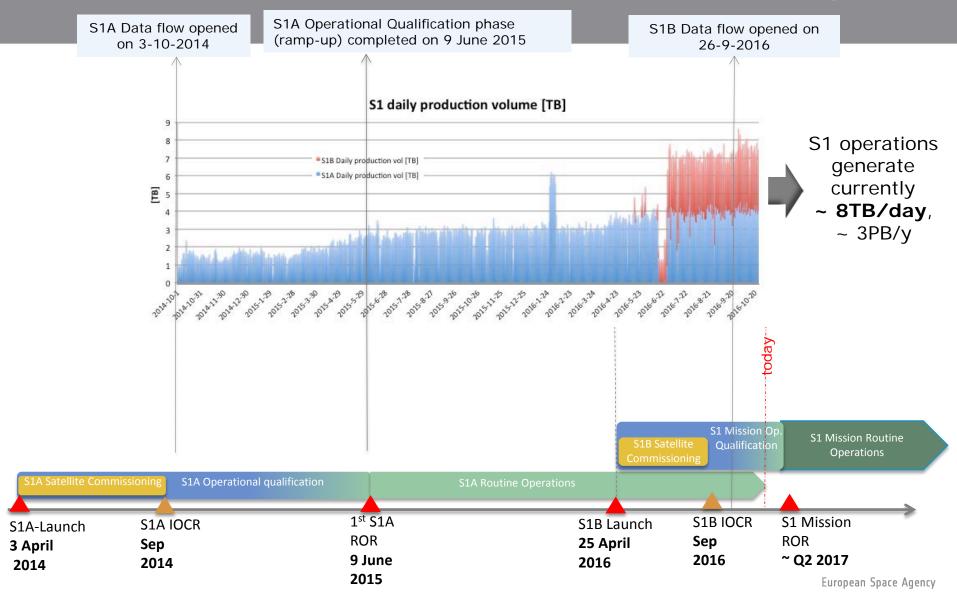
A major additional enhancement is foreseen in 2017 with the integration of EDRS service and a 4th Xband station

S1A & S1B planning Oct-Nov 2016

Sentinel-1 detailed acquisition segments provided as KML files at^{European Space Agency} https://sentinels.copernicus.eu/web/sentinel/missions/sentinel-1/observation-scenario/acquisition-segments

Sentinel-1 mission operations / data production: Status 2 years after Sentinel-1A data access opening



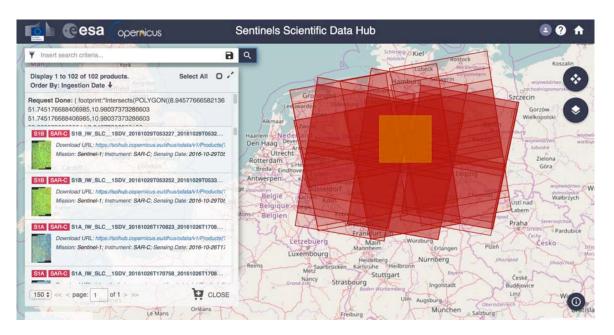


Sentinel-1 mission operations and data access concepts:
 Foster the development of many SAR-based applications

The Copernicus Sentinel data policy ensures **open and free on-line access to Sentinel-1 products**, stimulating SAR based applications in the operational and scientific domains, providing equal opportunities to all users and facilitating the undertaking of new value-added activities



- Access through self-registration
- Automated download scripting capability and dedicated API-Hub
- Restriction on concurrent downloads
- More than 62,000 users registered

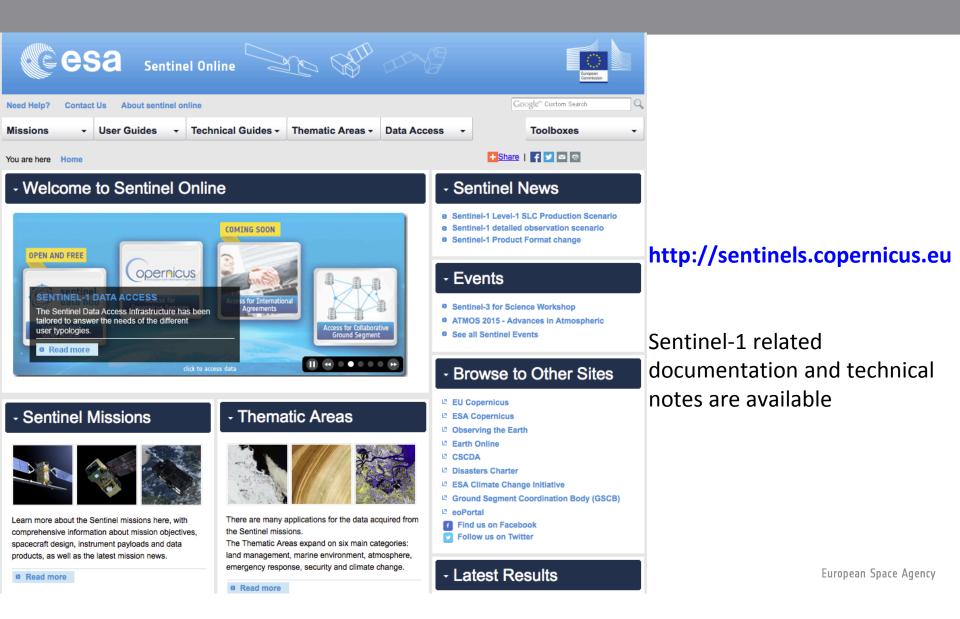


Today, more than 1 Million Sentinel-1 products are available on-line for download, representing more than 1 PB of data.

The complete mission archive has been downloaded > 7 times

Sentinel Online web portal

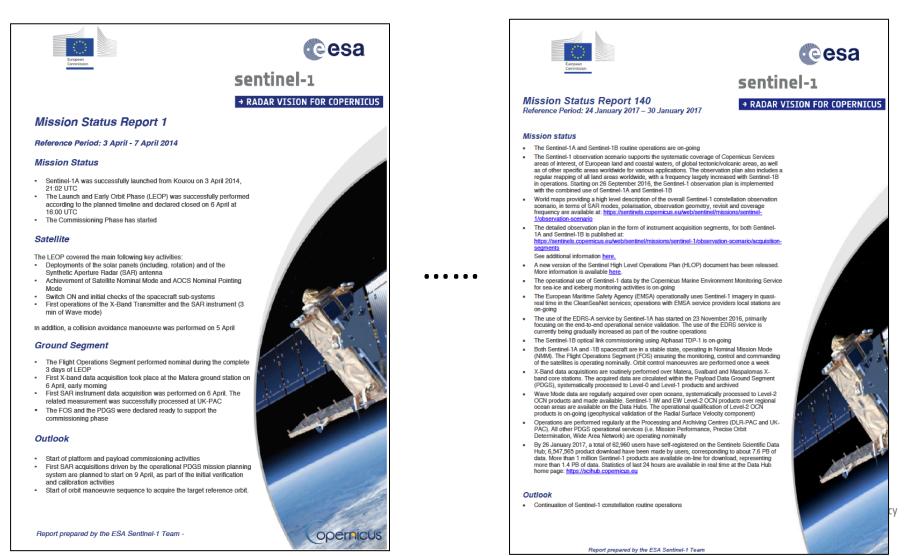




Weekly Mission Status Reports published online (140 reports issued since S1A launch)

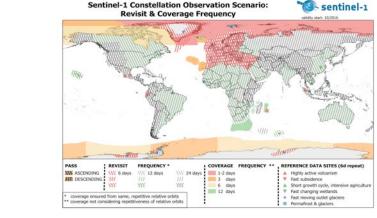


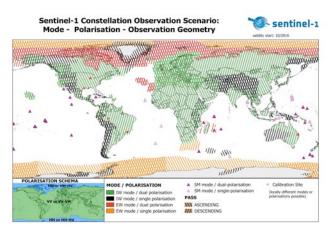
https://sentinel.esa.int/web/sentinel/missions/sentinel-1/mission-status



Sentinel-1 mission operations: concluding remarks







- The Sentinel-1 mission operations provide:
 - the technical suitability,
 - the adequate revisit and global coverage,
 - the long-term perspective,
 - the data access conditions,
 - ➔ to move SAR applications into operational domain, at continental/global scale
- The unprecedented data volume generated by the Sentinel-1 mission represents today a challenge for its massive exploitation



Examples of applications and scientific results based on Sentinel-1A data



Land cover



Crop monitoring, Forest, Food Security ... and New Promising Land Applications ...



Brussels and Surroundings







Harbour of Antwerp, Belgium

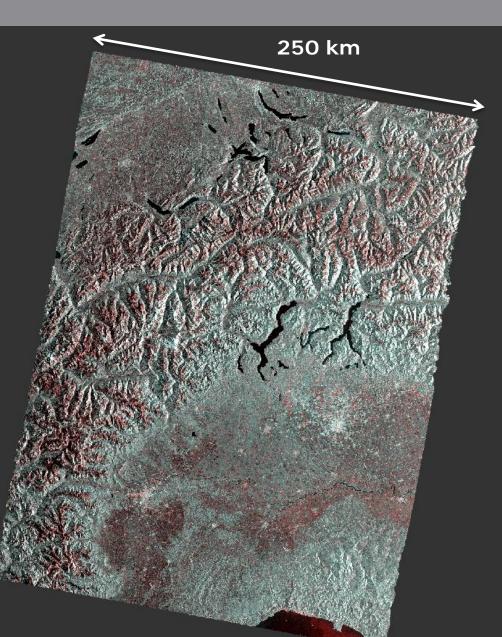






Northern Italy





RBG – VV/VH/VH Pixel spacing 10m 250x340 km Date: 15.11.2014

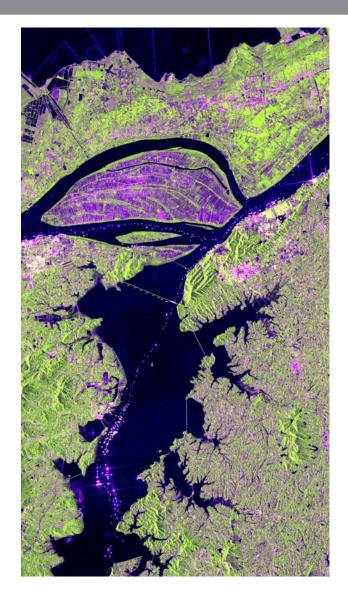


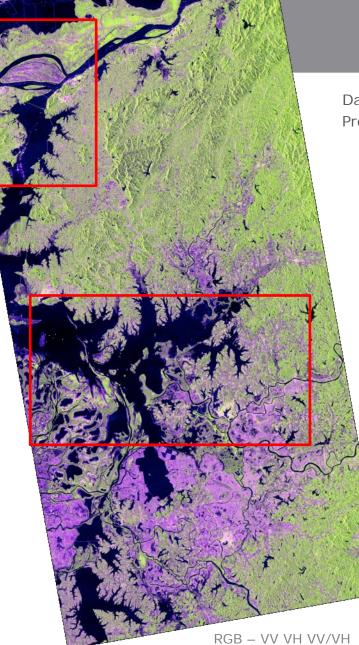
S1A Polarimetric Composition Poyang Lake, China





Data from SciHub Processed with S1TBX

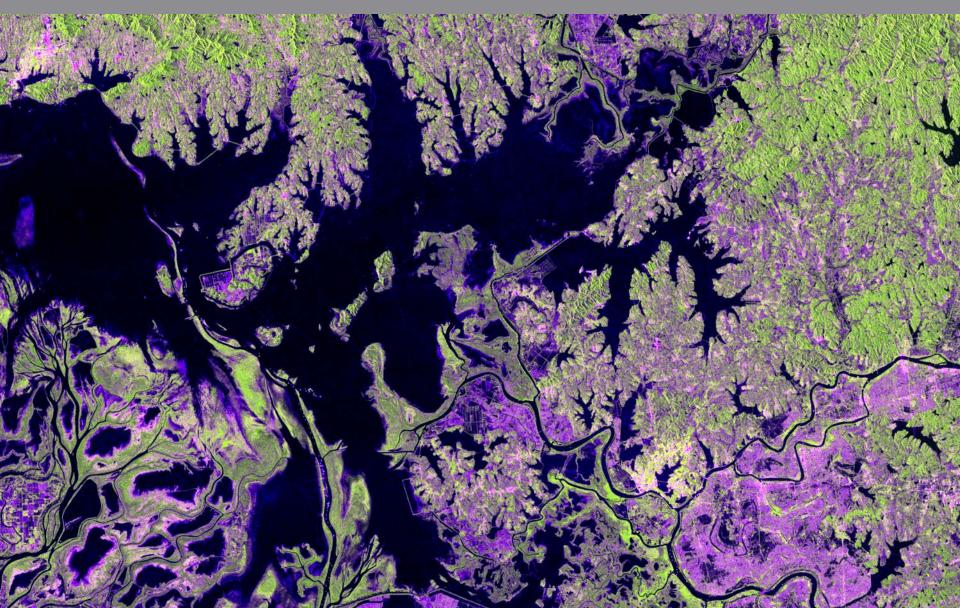






S1A Polarimetric Composition Poyang Lake









Vinter Wheat Winter Barley Spring Barley

Oilseed Rape

Sugar Beet

whole crop and gr

Maize

Other

d, winter and spring



An Annual Crop Map within the framework of the UK Land Cover Map based on Copernicus Sentinel-1 Radar Data



White areas are non-approxitanal

Key Applications

- Hydrological Modelling
- Catchment Sensitive Farming
- Plant Health and Crop Science
- Crop Areas and Statistics
- Control of Crop Subsidies and Levies
- Agri-business

www.ceh.ac.uk/crops2015



Example of Land Cover application

UK map of crop classification 2015 based on Sentinel-1A data

« ... coverage frequency compensates resolution... »

European Space Agency



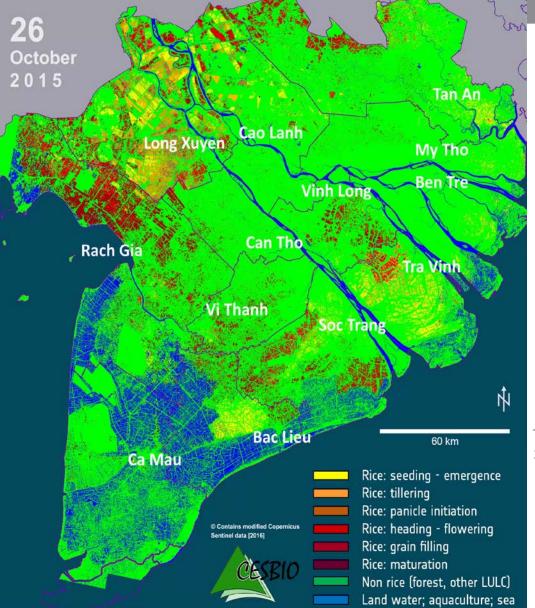
First Detailed UK Crop Map

Available March 2016

Retinues version - January 201 others instanct coming scon

S1 for Rice Monitoring innovators Monitoring of Crop Stages





georice

Winter-Spring Rice 2015/16

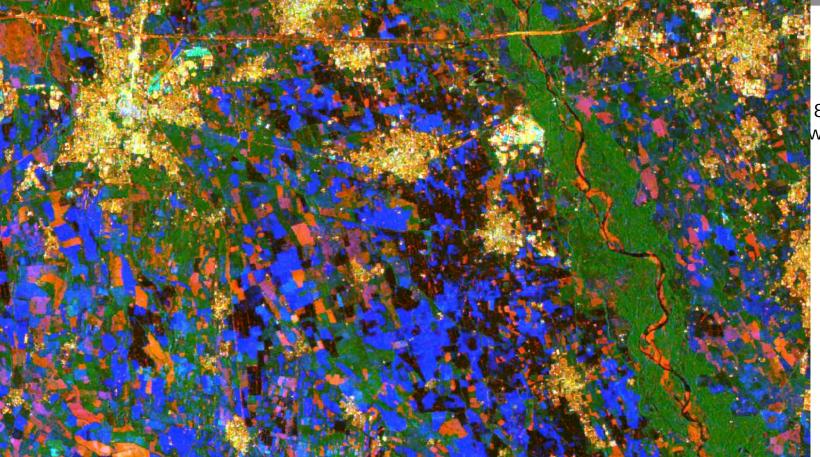
- March 2016: 1.4 Million ha rice
- March 2015: 1.7 Million ha rice
- 16.5% loss in rice area due drought and salt water intrusion caused by El Nino
- 976.000 people affected, 67 Mil. \$ estimated damage
- Based on unprecedented S1 timeseries

The Mekong Delta, Vietnam 300 km x 300 km, 20 m resolution





Great potential for rice mapping and land classification: use of coherence Demonstration North Italy



Multitemporal 8-20 Apr 2015 with coherence

> Courtesy SARMAP

RED/ORANGE:

coherence, object not changing: bare soil rough

GREEN:

average of the two sigma0 VV Forest mainly

BLUE:

difference of the two sigma0 VV objects changing within 12 days (here ploughing activities)

BLACK:

objects not reflecting: water or very smooth^{n Space Agency} bare soil areas



Marine / Oceans



Maritime Surveillance (Oil Spill Detection, Ship Detection, Illegal Fisheries monitoring, etc.)

Sea State: Wind / Wave / Current

Sentinel-1 supports the EMSA CleanSeaNet service

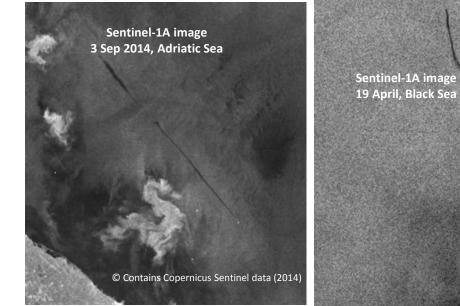


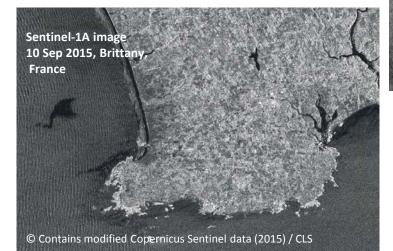


CleanSeaNet: the European satellite-based oil pollution and vessel detection monitoring system

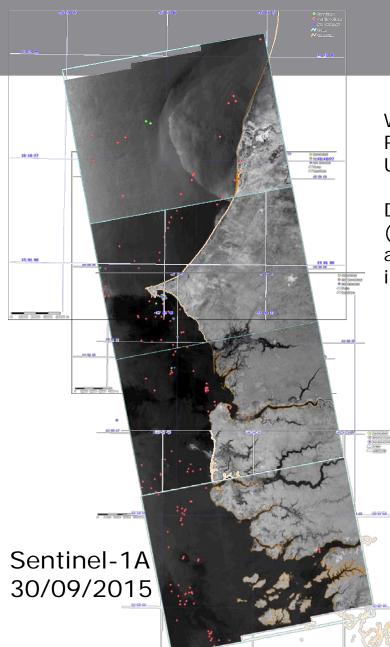
 \rightarrow Operated by the European Maritime and Safety Agency (EMSA)

EMSA operationally uses Sentinel-1 imagery in the CleanSeaNet service





© Contains Copernicus Sentinel data (2014)

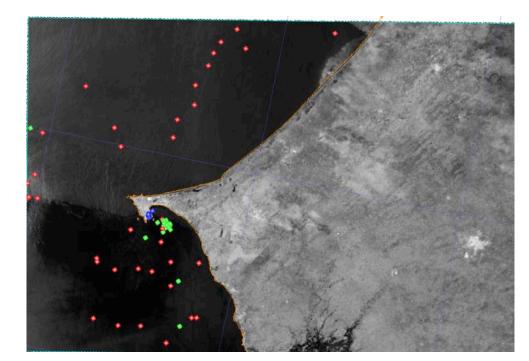


Fisheries Surveillance for WARFP



World Bank project developed within the West Africa Regional Fisheries Project (WARFP) for IUU (Illegal, Unlicensed and Unreported) fisheries detection

Detection correlated with cooperative transponder data (green) and non-cooperative data (red) usually associated with IUU activities (vessels engaged in fishing in restricted areas/EEZs without authorisation).





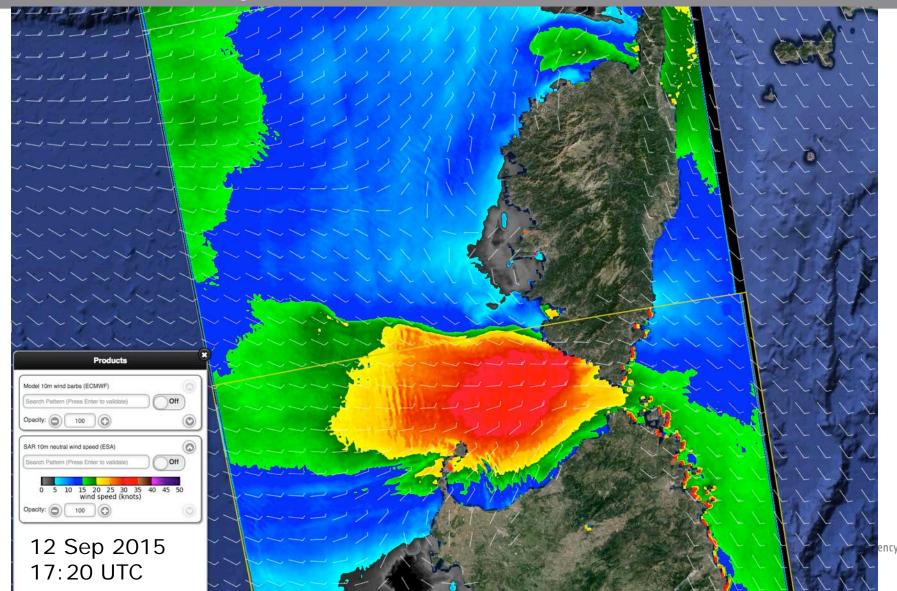


Sentinel-1A TOPS IW VV/VH GRD High 10m pixel spacing

© Copernicus Sentinel data (2014)

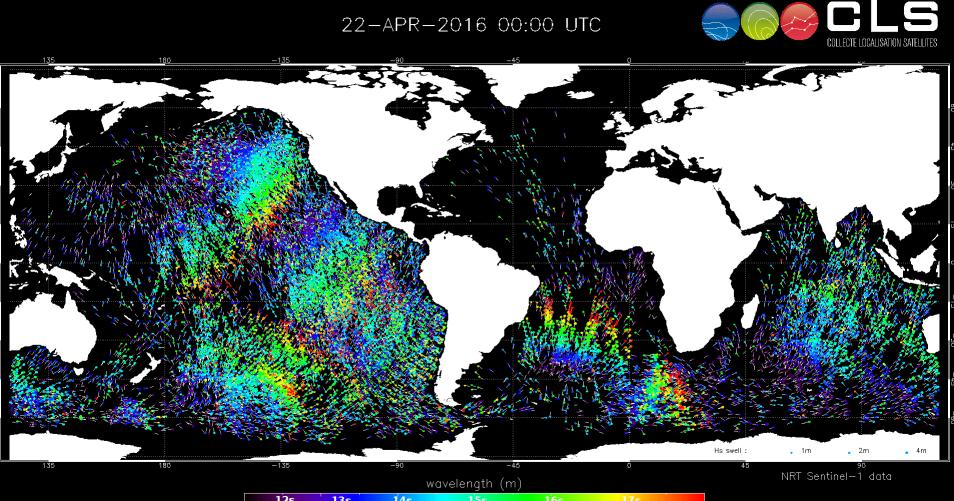
Wind fields generated from Sentinel-1 IW mode level 2 OCN data

Courtesy Oceandatalab / Ifremer / CLS / NORUT



Swell propagation fireworks derived from Sentinel-1 Wave mode level 2 data Courtesy CLS / Norut / Ifremer / Oceandatalab

Period 22 Apr 2016 – 4 May 2016



	20 <u>172</u>	145	1,35	105	1/5	1
200.0	250.0	300.0	350.0	400.0	450.0	500



Emergency Disaster Management

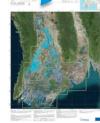


Flooding Geohazards Natural / Man-made Disasters etc

Sentinel-1 Contribution to the Copernicus Emergency Management Service

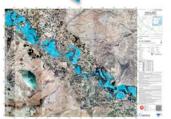


- Sentinel-1 responded to a number of activations from the Copernicus Emergency Management Service (as well as from the International Charter Space and Major Disasters):
 - ✓ EMSR87 for floods in Bosnia-Herzegovina (May 2014) -
 - ✓ EMSR100 for floods and landslides in Italy (Sep 2014)
 - ✓ EMSR107 for floods in Slovenia (Nov 2014)
 - ✓ EMSR108 for floods and landslides in Italy (Nov 2014)
 - EMSR111 related to the volcanic eruption at Fogo Island (Cape Verde) = (Nov 2014)
 - ✓ EMSR116 for floods in Malawi (Jan 2015)
 - ✓ EMSR117 for floods in Greece (Feb 2015)
 - ✓ EMSR118 for floods in Spain (Feb 2015)
 - ✓ EMSR122 for floods in Greece (Mar 2015)
 - ✓ EMSR125 for Earthquake in Nepal
 - ✓ EMSR126 for algae bloom in French Guiana (May 2015)
 - ✓ EMSR130 for major floods in Myanmar (Aug-Sep 2015)
 - ✓ EMSR147 for floods sin Cumbria UK (Dec 2015)
 ✓ EMSR151 for floods in Northern Ireland (Jan 2016)
 ✓ EMSR159 for Earthquake in Ecuador (April 2016)







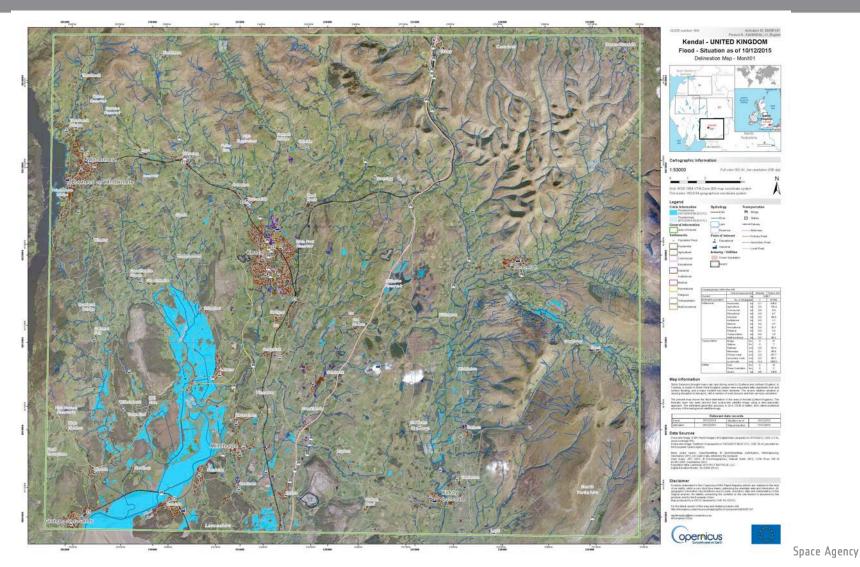






Flood delineation map based on Sentinel-1 data Copernicus Emergency Management Service Flood in Cumbria, UK, Dec 2015, CEMS activ. 147



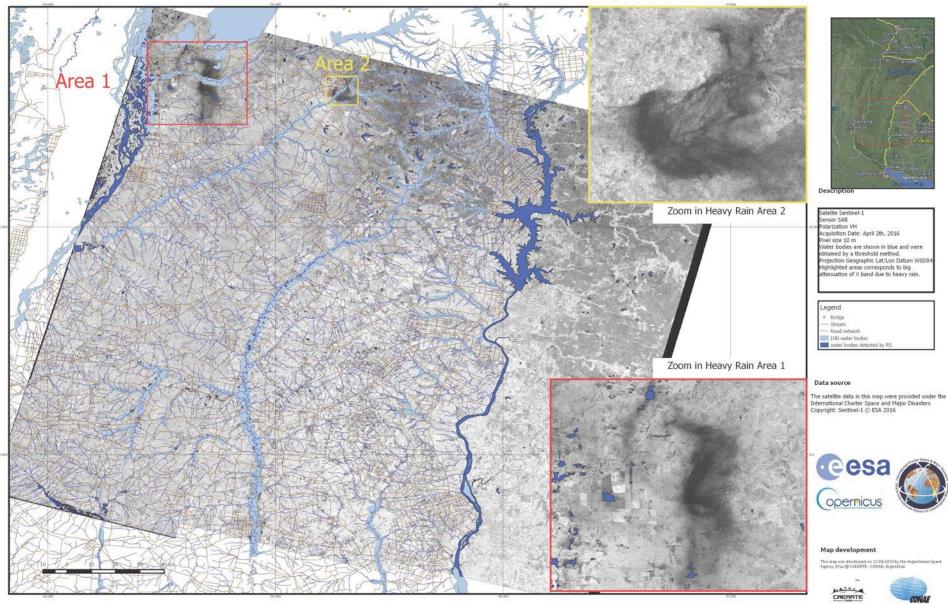


© Copernicus Service information (2015)/CEMS

Flood in Argentina, April 2016 – International Charter Space and Major Disaster

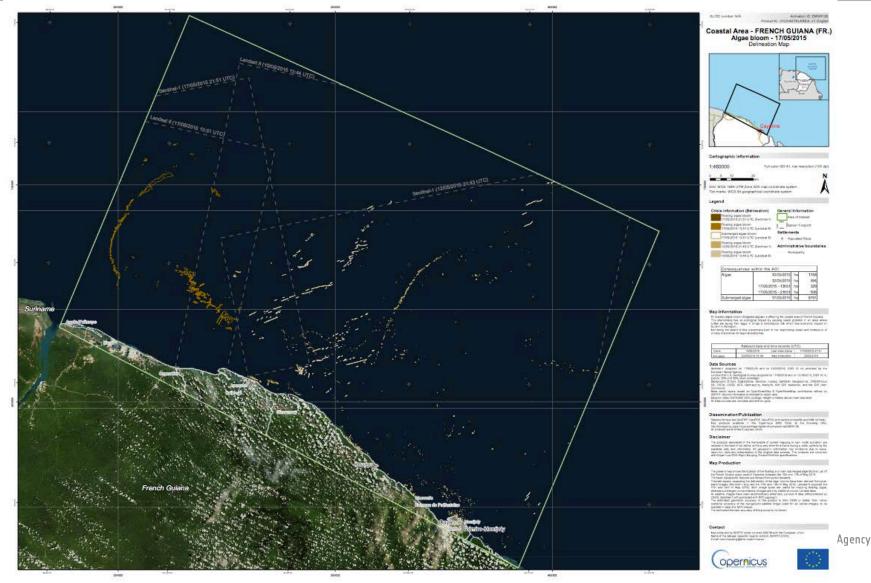
Inundaciones en Mesopotamia Abril 2016 Flooding in Argentina

April 02th, 2016 International Charter Call ID 561



Algae bloom detected by Sentinel-1, French Guiana Use by the Copernicus Emergency Management Service

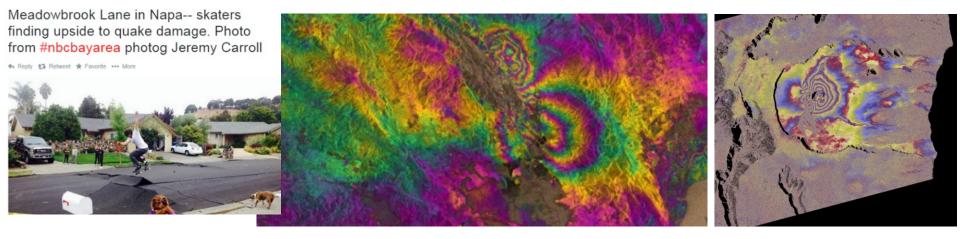








Land deformation



Interferometry Applications Ground Motion, subsidence, landslides, Earthquakes, Volcanoes, Tectonic Processes,...

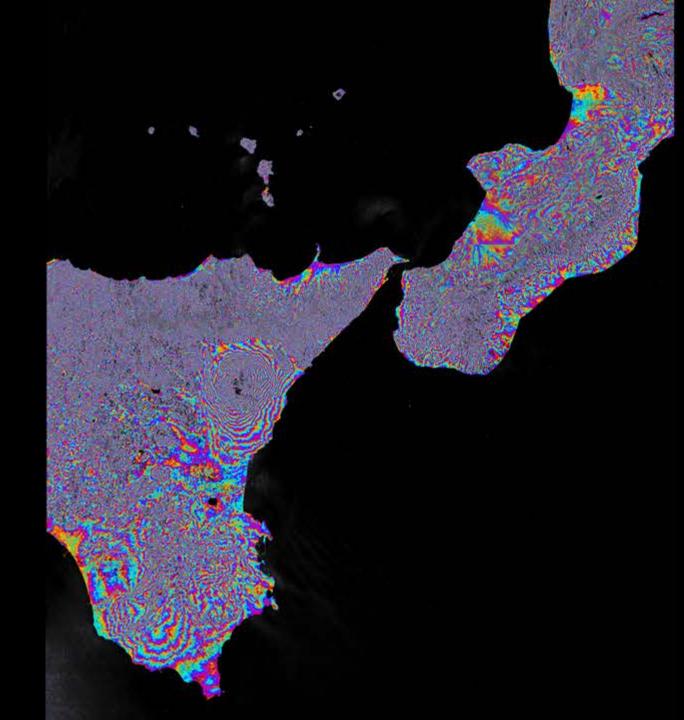


Italy 1200 Km

Large scale

Courtesy DLR

Datatake (7 slices): IW mode Vertical Polarization Dates: 9.08.2014 21.08.2014





First Capture of an Earthquake by Sentinel-1 Napa Valley (California) M6.0R



Sentinel-1 maps earthquake

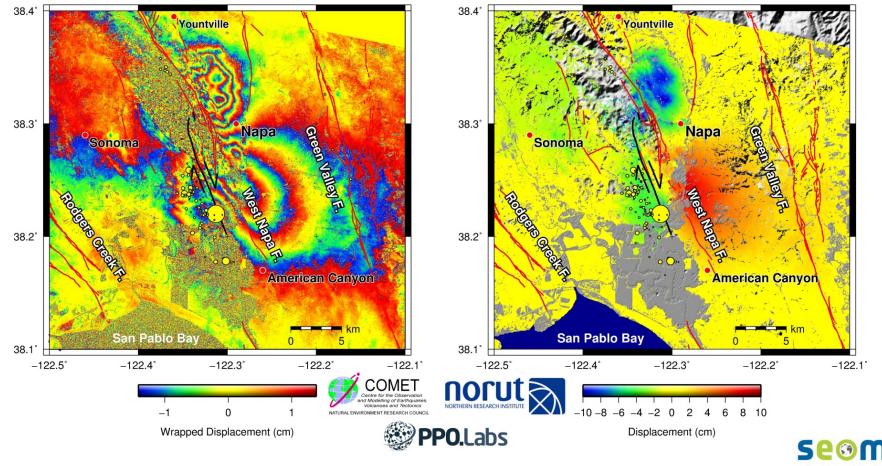
The biggest earthquake in 25 years struck California's Napa Valley in the early hours of 24 August 2014. By processing two Sentinel-1A images, acquired on 7 August and 31 August 2014 an interferogram was generated. Deformation on the ground causes phase changes in radar signals that appear as the rainbow-coloured patterns around the Napa Valley. Each colour cycle corresponds to a deformation of 28 mm deformation. The maximum deformation is more than 10 cm, and an area of about 30x30 km was affected significantly.

Copyright: Copernicus data (2014)/ESA/PPO.labs/Norut/COMET-SEOM Insarap study



Napa Valley Earthquake - Scientific Component





scientific exploitation of operational missions



opernicus



esa

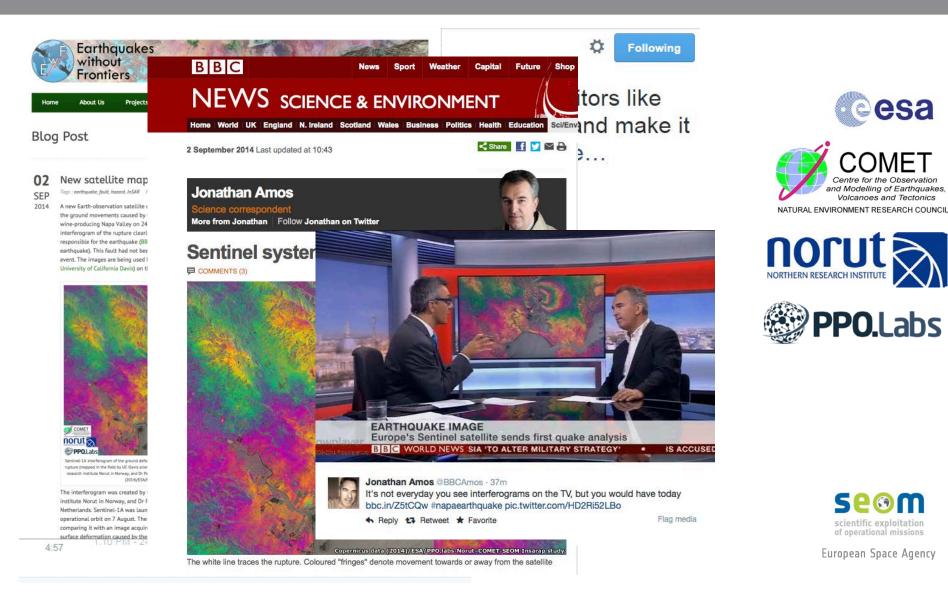
Centre for the Observation

and Modelling of Earthquakes,

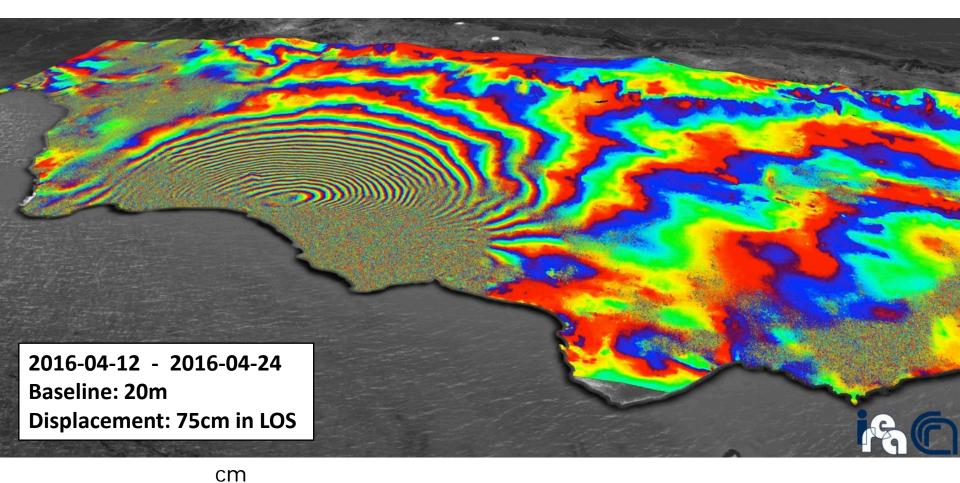
Volcanoes and Tectonics

Seom

scientific exploitation of operational missions

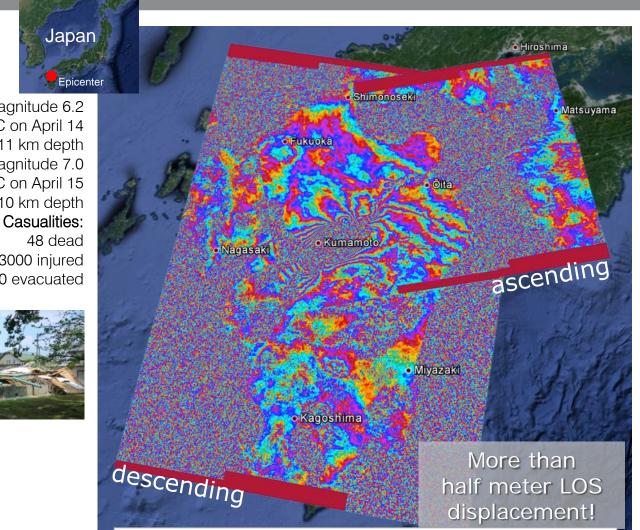


M7.8 Ecuador Earthquake, 16 April 2016 CSA (courtesy CNR IREA)



2.8

M 7.0 Kumamoto Earthquake, Japan – April 14-15 2016 (Courtesy DLR)



Sentinel-1a flattened interferograms:

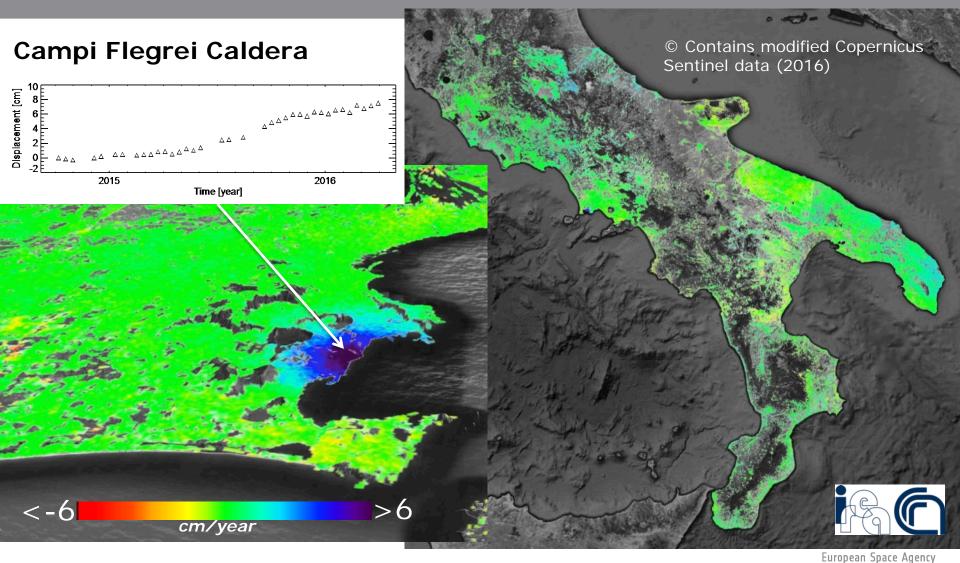
Descending configuration: March 27, 2016 – April 20, 2016 Ascending configuration: April 8, 2016 – April 20, 2016

Foreshock: magnitude 6.2 12:26 UTC on April 14 11 km depth Mainshock: magnitude 7.0 16:25 UTC on April 15 10 km depth Casualities: 48 dead 3000 injured 4000 evacuated





Sentinel-1 SBAS(*) analysis of Southern Italy (courtesy CNR IREA)

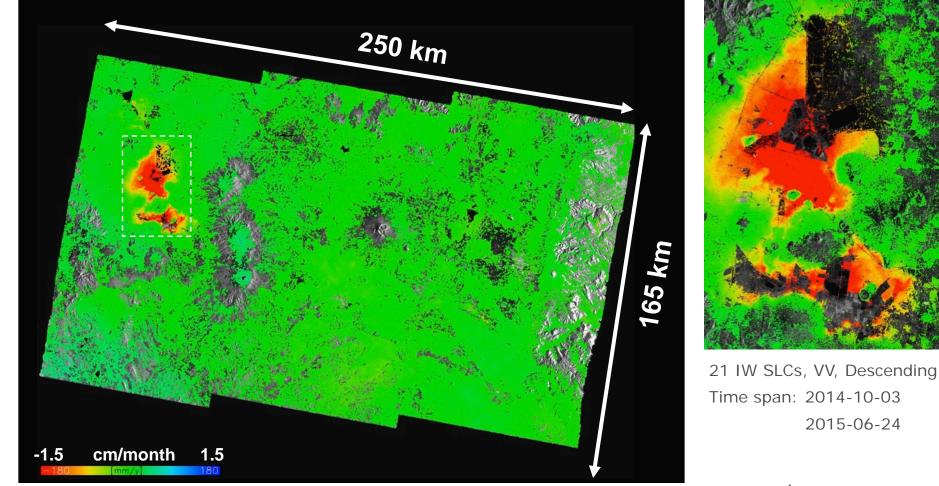


Time Interval: October 2014 – March 2016

SBAS: Small BAseline Subset technique

Sentinel-1 Wide Area PSI – Mexico Linear Deformation (courtesy DLR)





Contains modified Copernicus Sentinel data 2014-2015 / DLR



S-1 Time Series Results



NORGES GEOLOGISKE

eye alt 12.30 km 🕜

Data: 4 months of data → 13 scenes

Period: June - September 2015

SBAS: All baseline combinations utilized

© Contains modified Copernicus Sentinel data (2015)

Date: 4/10/2013 69°25'17.34" N 20°34'57.84" E elev 243 m

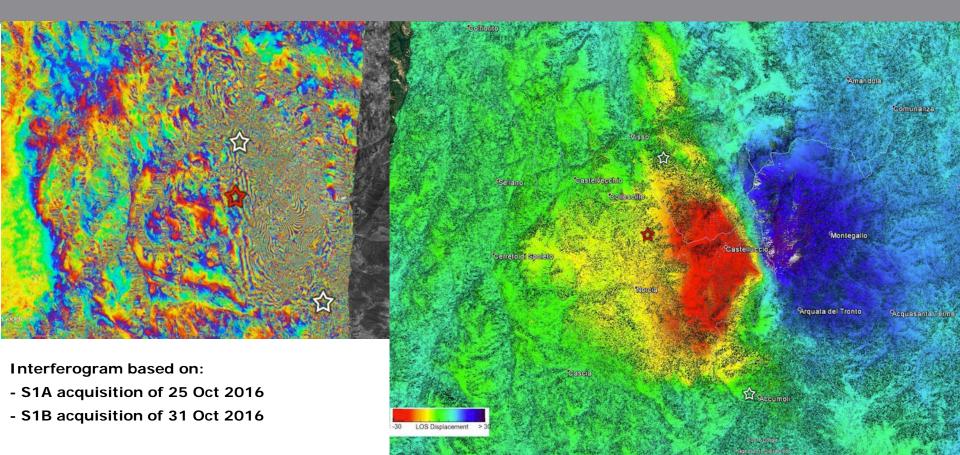


Two major earthquakes occurred in Central Italy in October 2016:

- On 26 October, magnitude Mw 5.9
- On 30 October, magnitude Mw 6.5
- All relevant acquisitions of S1A and S1B were already included in the baseline observation plan, thanks to the systematic observation scenario over Europe:
 - All potential passes of S1A and S1B (necessary at this latitude to provide full regular coverage) were already part of the plan
 - Both ascending and descending orbits
- Very rapid results related to ground deformation (both vertical and horizontal) could be generated by users worldwide



Central Italy M6.5 earthquake, 30 October 2016 Combined use of Sentinel-1A and Sentinel-1B



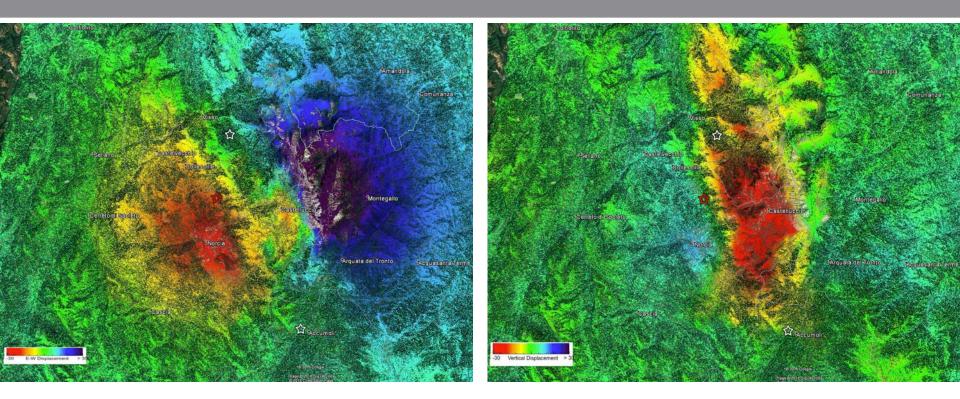
Ground deformations extending to about 130 sq. km and with a maximum LOS displacement of at least 70 cm, in the area of Castelluccio Based on interferogram generated with:

- S1B acquisition of 26 Oct 2016
- S1A acquisition of 1st Nov 2016

European Space Agency

© Contains modified Copernicus Sentinel data 2016/ESA/CNR-IREA





EAST-WEST GROUND DISPLACEMENT:

- Eastwards shift of about 40 cm in the vicinity of Montegallo
- Westwards shift of about 30 cm in the area of Norcia

VERTICAL GROUND DISPLACEMENT:

- Subsidence of about 60 cm around Castelluccio
- Uplift of about 12 cm close to Norcia

© Contains modified Copernicus Sentinel data 2016/ESA/CNR-IREA



Ice / Cryosphere / Climate

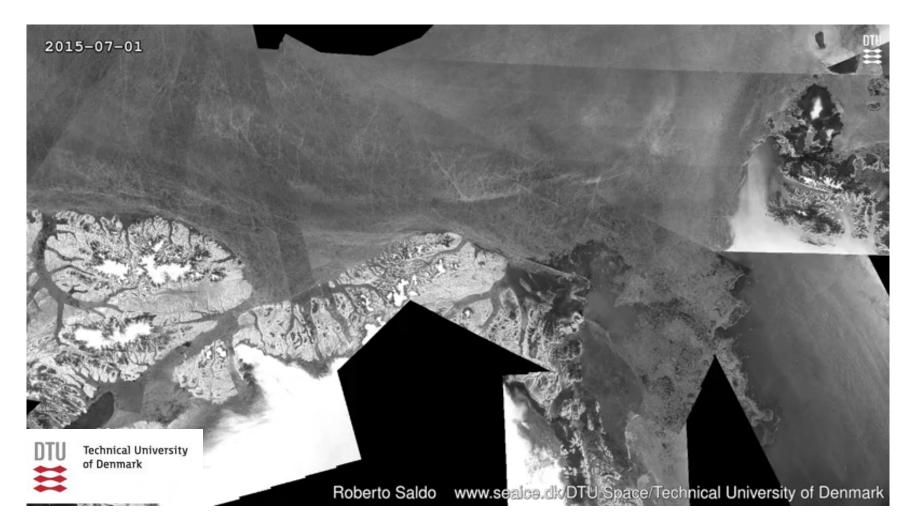


Examples of Sentinel-1 results related to:

Sea Ice / Iceberg Ice Sheets Polar Monitoring Snow

Sentinel-1 imagery from July 2015 to April 2016



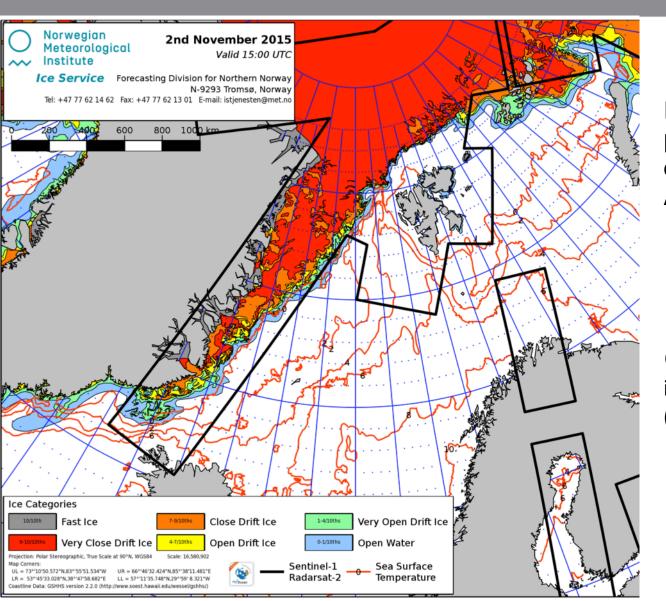


European Space Agency

© Contains modified Copernicus Sentinel data [2015-2016]

Operational Sentinel-1 data provision to CMEMS Example of daily ice chart





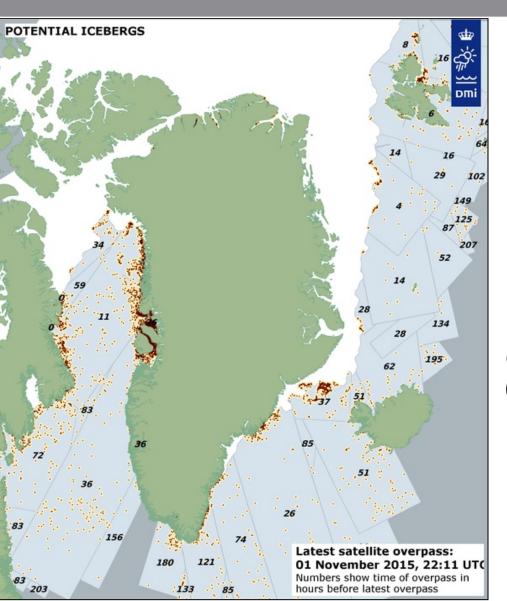
Daily Ice Charts are produced in support of navigation in the Arctic.

© Copernicus Service information (2015)/CMEMS



Operational Sentinel-1 data provision to CMEMS Example of daily maps of icebergs





Daily maps of icebergs in Greenland Waters are routinely produced

Note that some targets may be ships...

© Copernicus Service information (2015)/CMEMS



Copernicus Marine Environment Monitoring Service (CMEMS)

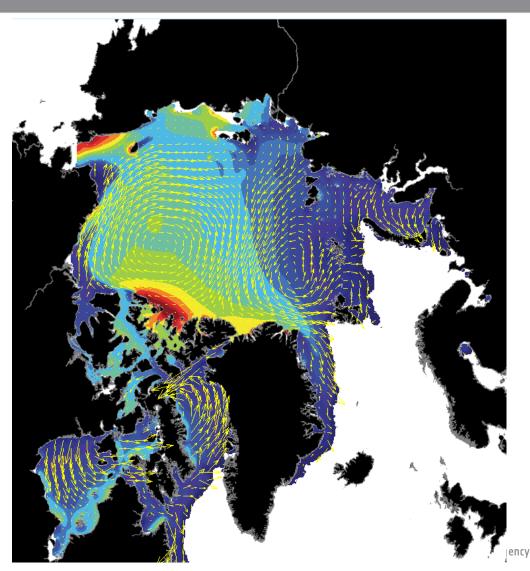


Copernicus forecasts example

3-day forecast of Ice Thickness Ice drift

From Arctic MFC (Marine Forecasting Center) in Norway

ernicus



© Copernicus Service Information [2016]

Sentinel-1A + Sentinel-1B 3-day mosaic 29-30-31 Jan 2017



3-day mosaic of S1A + S1B imagery routinely generated by the Copernicus Environment Monitoring Service (CMEMS)

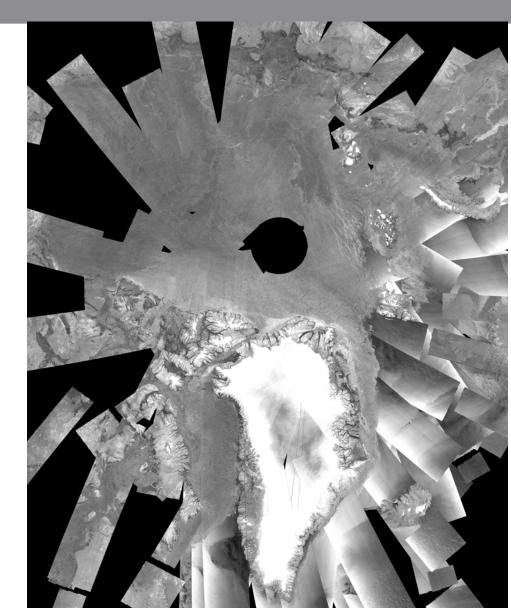
3-day mosaic 29-30-31 Jan 2017

http://www.seaice.dk/



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Monitoring ice sheets with Sentinel-1

Towards a routine observatory of ice sheet margins

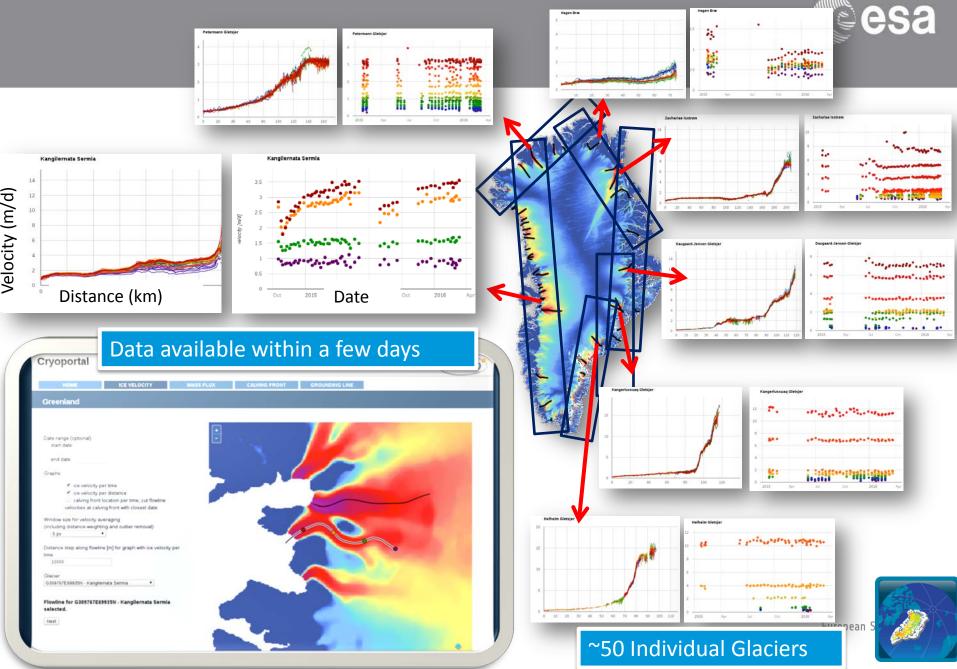
© Contains modified Copernicus Sentinel data [2015-2016]

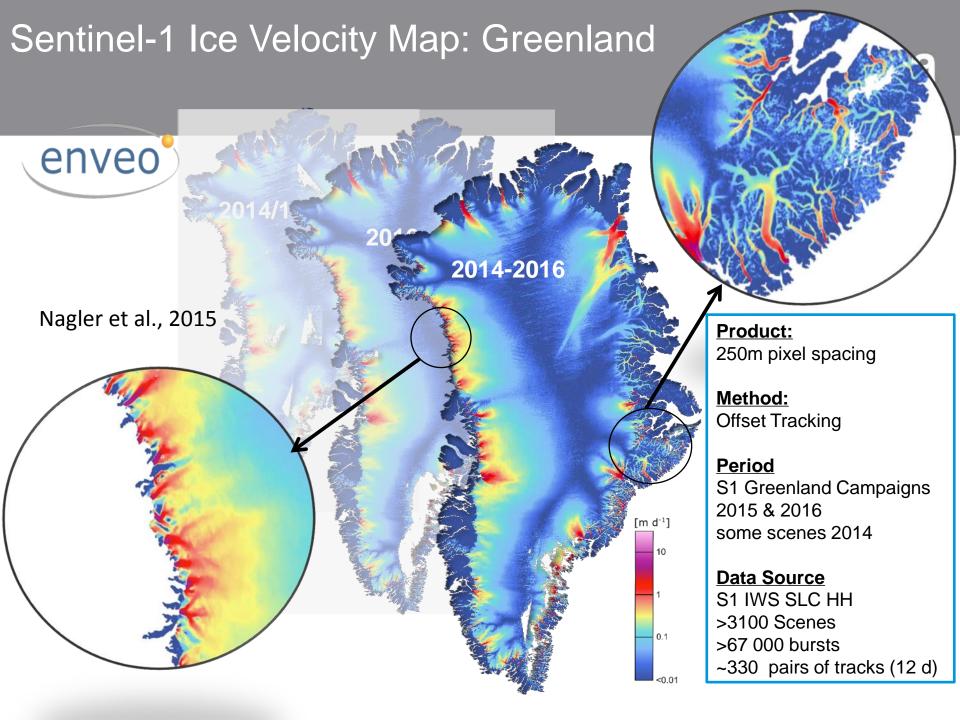
Nagler et al. 2015





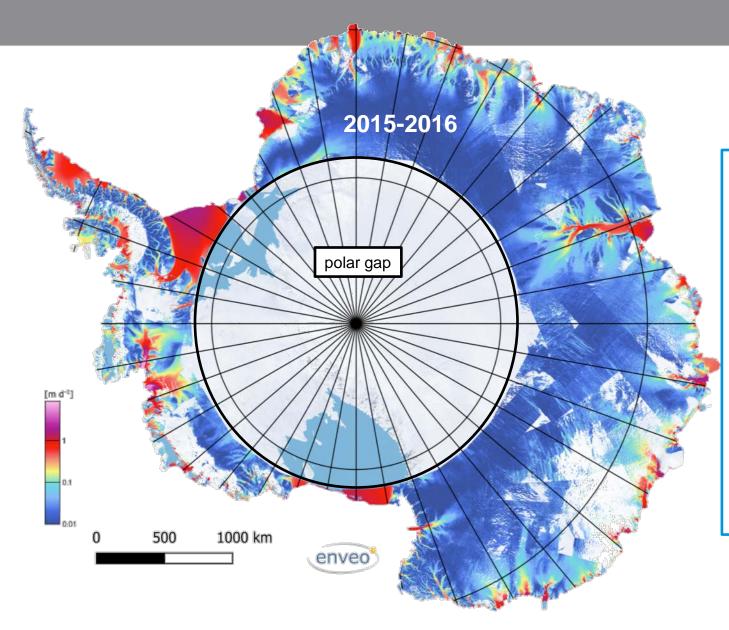
Ice Velocity Time Series: Monitoring Ice Sheet Margins





Sentinel-1 Ice Velocity Map: Antarctica





Product: 200m pixel spacing

Method: Offset Tracking

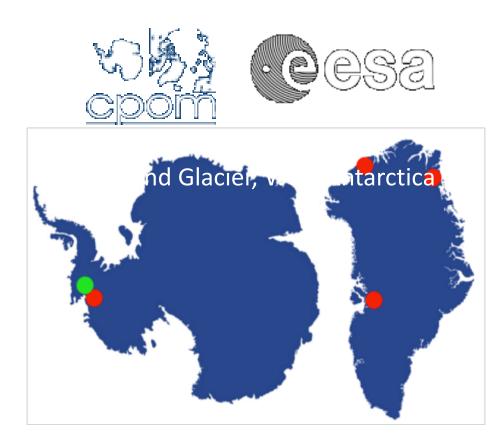
Period

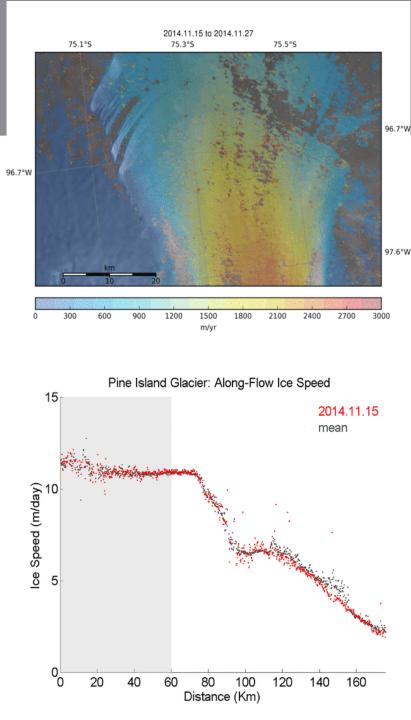
S1 Antarctic Campaign 2015/16 (some tracks started in Oct 2014)

Data Source S1 IWS SLC HH >3800 Scenes

>71800 burst pairs ~375 pairs of tracks (12d)

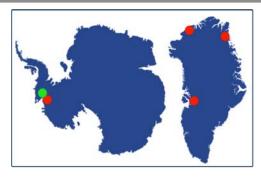
CPOM (Centre for Polar Observation and Modelling) Near Real Time Ice Velocity



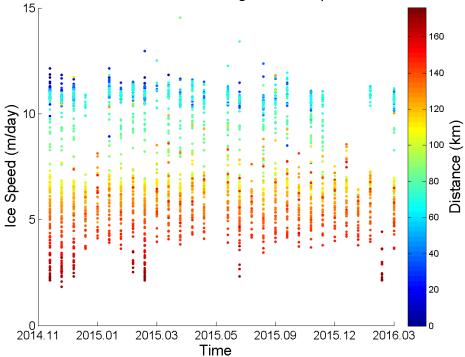


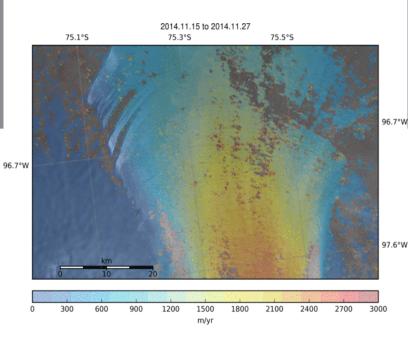


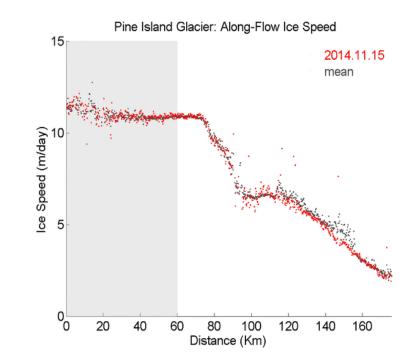
Pine Island Glacier, West Antarctica



Pine Island Glacier: Along-Flow Ice Speed







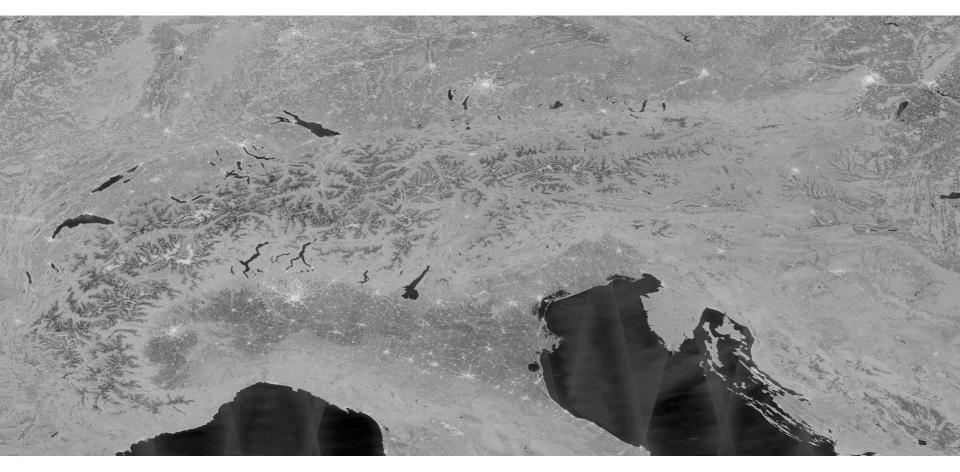


S1A Alps Backscatter Mosaic

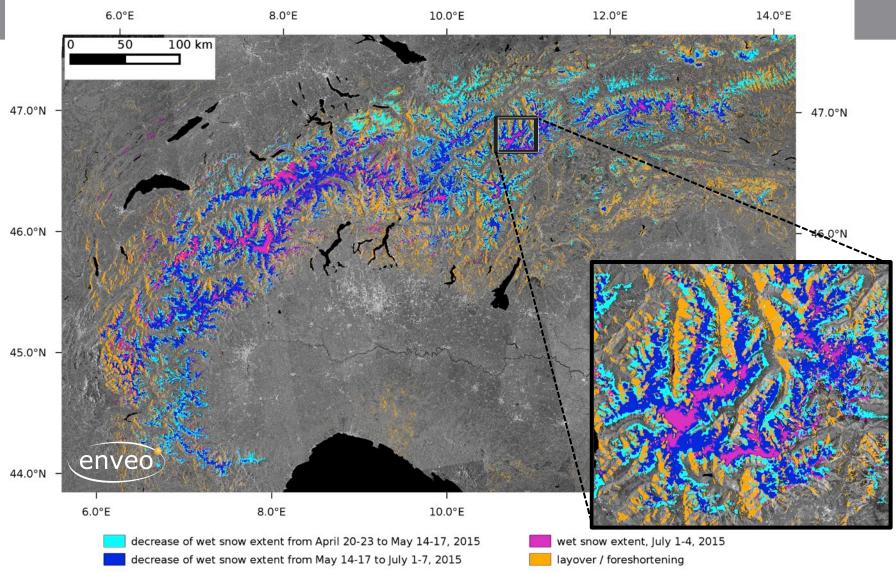
Courtesy of David Small, University of Zurich, Switzerland

Contains modified Copernicus Sentinel data (2015)

S1A IW VH & VV-pol. processed Oct. 2014 – Aug. 2016: 12d & 16d windows Jan.-Aug. 2016 VH 16d shown here



Monitoring melting snow using Sentinel-1 SAR esa



Nagler et al., Remote Sensing, 2016

Copernicus Space Component Missions Management On-Line



Copernicus Programme: copernicus.eu Sentinel Online: sentinels.copernicus.eu CSC Data Access: spacedata.copernicus.eu ESA Sentinel app: available for iOS and Android