# Copernicus

# Copernicus – a new Phase in EO

**European Earth Observation System**

- Led by the EU
- EU-ESA Collaboration

**European response to global needs:**

- to manage the environment
- to mitigate the effects of climate change
- to ensure civil security

**European independence, contribution to global system (GEOSS)**

# Copernicus Sentinels

**> 585.000**
registered users
= tip of the iceberg

## 6 operational services

Land | Atmosphere | Ocean | Climate | Disaster | Security

**250 TB** satellite data distributed per day

**full, free & open** data policy

## 8 Copernicus Sentinels flying

S1 S2 S3 S4 S5P S5 S6

## 6 Copernicus Expansion missions

CO2M LSTM CHIME ROSE-L CIMR CRISTAL

## Preparing Copernicus 4.0

# Copernicus Sentinels: The Big-Data Revolution

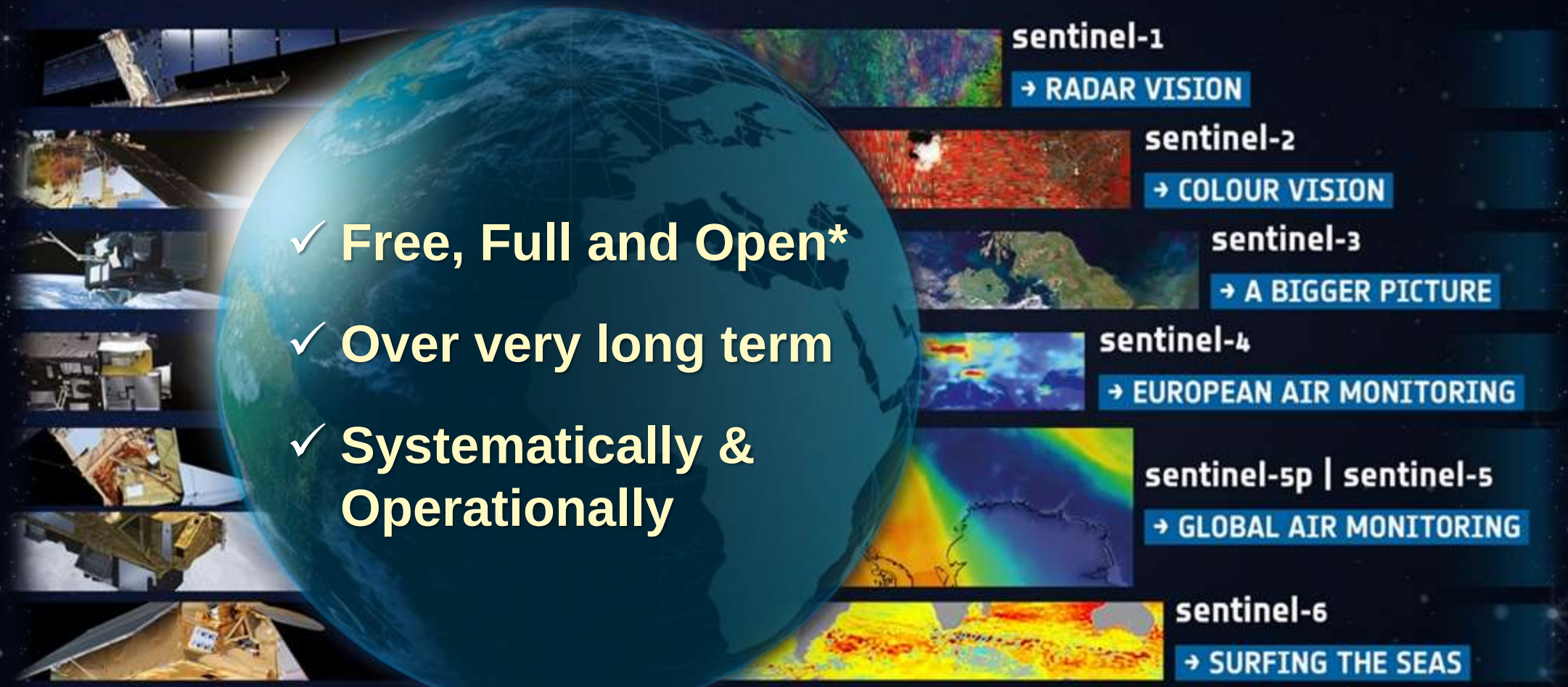
## Copernicus is the largest producer of EO data in the world

**All global landmass is observed every 5 days at 10m resolution**

**25 TB of Daily Data Production by Sentinels**

**250 TB of Daily Sentinel Products Disseminated for Services to Society**

# Sentinel Users, Data Access and (Financial) Benefits




- ✓ Free, Full and Open*
- ✓ Over very long term
- ✓ Systematically & Operationally

* ESA Sentinel Data Policy (Sep 2013) and
EU Delegated Act on Copernicus Data and Information Policy (Dec 2013)

# Copernicus Sentinel Status

## S-1

Radar

| | |
|---|---|
| A | 3 Apr. 2014 |
| B | 25 Apr. 2016 |
| C | 2022 |
| D | > 2024 |

## S-2

High Res. Optical

| | |
|---|---|
| A | 23 Jun. 2015 |
| B | 6 Mar. 2017 |
| C | 2022 |
| D | > 2025 |

## S-3

Medium Res. Optical & Altimetry

| | |
|---|---|
| A | 16 Feb. 2016 |
| B | 25 Apr. 2018 |
| C | 2023 |
| D | > 2025 |

## S-4

Atmospheric Chemistry (GEO)

| | |
|---|---|
| A | 2023 |
| B | 2030 |

## S-5P

Atmospheric Chemistry (LEO)

| | |
|---|---|
| A | 13 Oct. 2017 |

## S-5

Atmospheric Chemistry (LEO)

| | |
|---|---|
| A | 2023 |
| B | 2030 |
| C | 2037 |

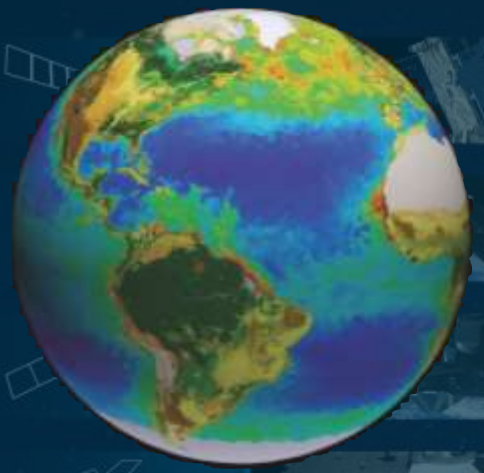
## S-6

Altimetry

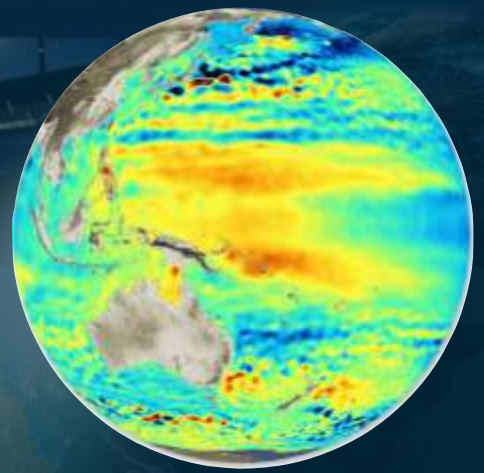
| | |
|---|---|
| MF | 21 Nov. 2020 |
| B | 2025 |

# Global & Systems View by Copernicus

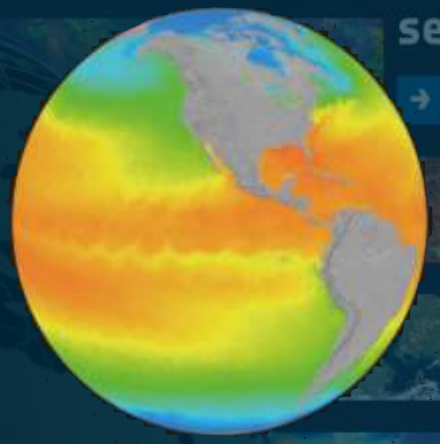
Chlorophyll



Sea Level Height



Sea Surface Temp.

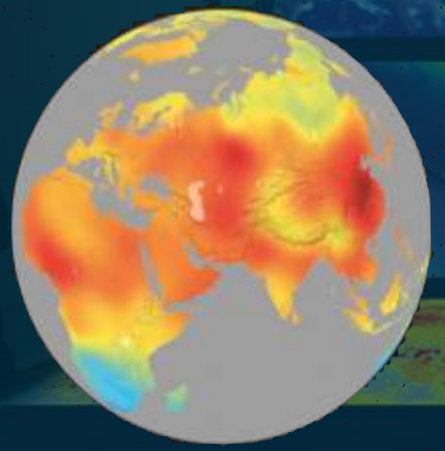


Biomass

Soil Moisture

Land cover Type

Carbon Dioxide



Nitrous Oxyde

# Copernicus Sentinel Satellites

**Sentinel 1** (A/B/C/D)
**SAR Imaging**

All weather, day/night applications, interferometry

**Sentinel 2** (A/B/C/D)
**Multispectral Imaging**

Land applications: urban, forest, agriculture, …
Continuity of Landsat, SPOT

**Sentinel 3** (A/B/C/D)
**Ocean & Global Land Monitoring**

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

**Sentinel 4** (A/B)
**Geostationary Atmospheric**

Atmospheric composition monitoring, pollution; instrument on MTG satellites

**Sentinel 5** (MF/B/C) & Precursor
**Low-Orbit Atmospheric**

Atmospheric composition monitoring; instrument on MetOp-SG satellites

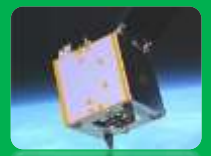
**Sentinel 6**
**Jason CS (A/B)**

Altimetry reference mission

# Contributing Missions are key to Copernicus

## Optical High & Very High Resolution

DMC



Pléiades

RapidEye

WorldView

Deimos-2

SPOT (HRS)

SkySat

Doves

## Optical Medium & Low Resolution

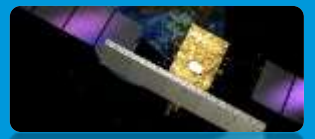
SPOT

PROBA-V

**and many more …**

## Synthetic Aperture Radar

Cosmo SkyMed



Radarsat

TerraSAR-X Tandem-X

## Altimetry

Cryosat

Jason

## Atmosphere

MetOp

MSG

**ESA buys large volumes of non-ESA EO data**

# DIAS – Creating an EO Data Ecosystem

- Copernicus **D**ata and **I**nformation **A**ccess **S**ervices
- Common DG-GROW-ESA approach to EO data exploitation with Copernicus at its core
- Create & enable European EO Data ecosystem for research & business
- Started in June 2018

# Operational Systems are Game-Changers

## Copernicus Services

Land

Atmosphere

Marine Environment

Climate Change

Emergency Management

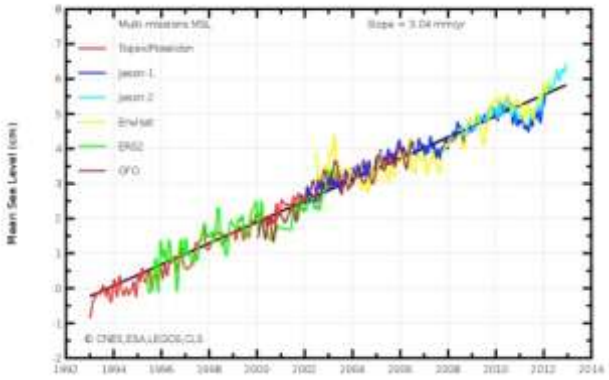
Security

**Security**

**Refugee Camp Monitoring**

# Big Data Challenges

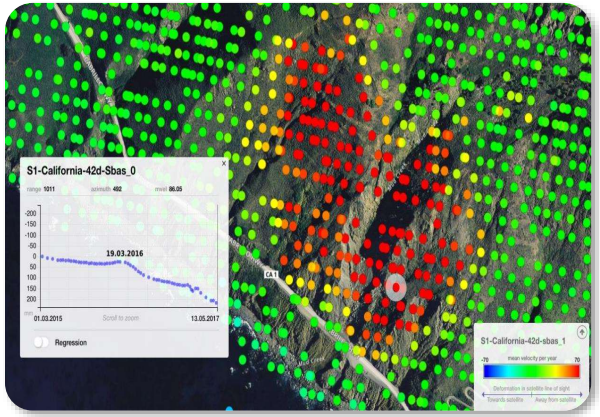
Data volume



Data continuity

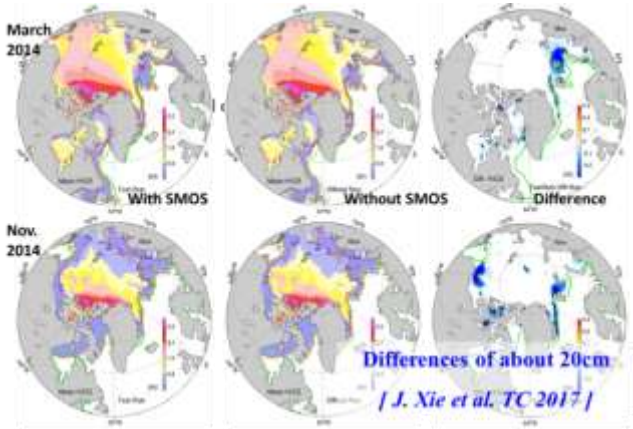
Data sharing

Data quality

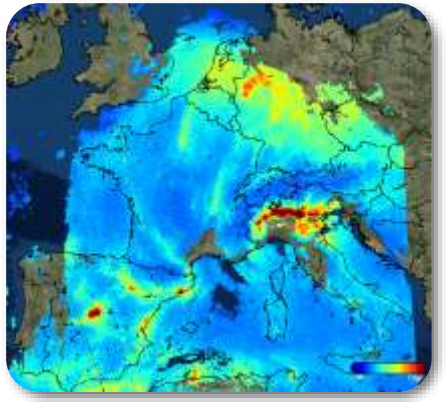



Innovation

Timeliness




Mission synergies

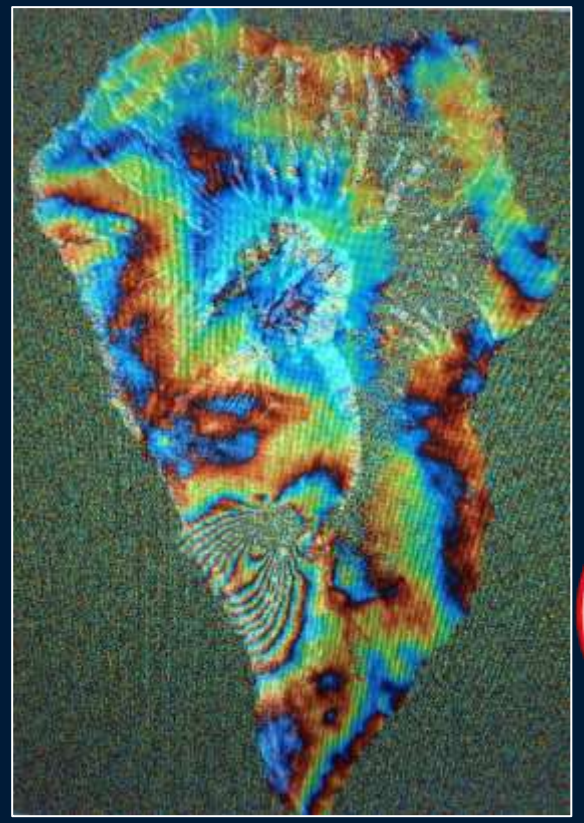


Diversity

# Copernicus' Applications

# Copernicus S-1/-2/-5P monitored La Palma eruption

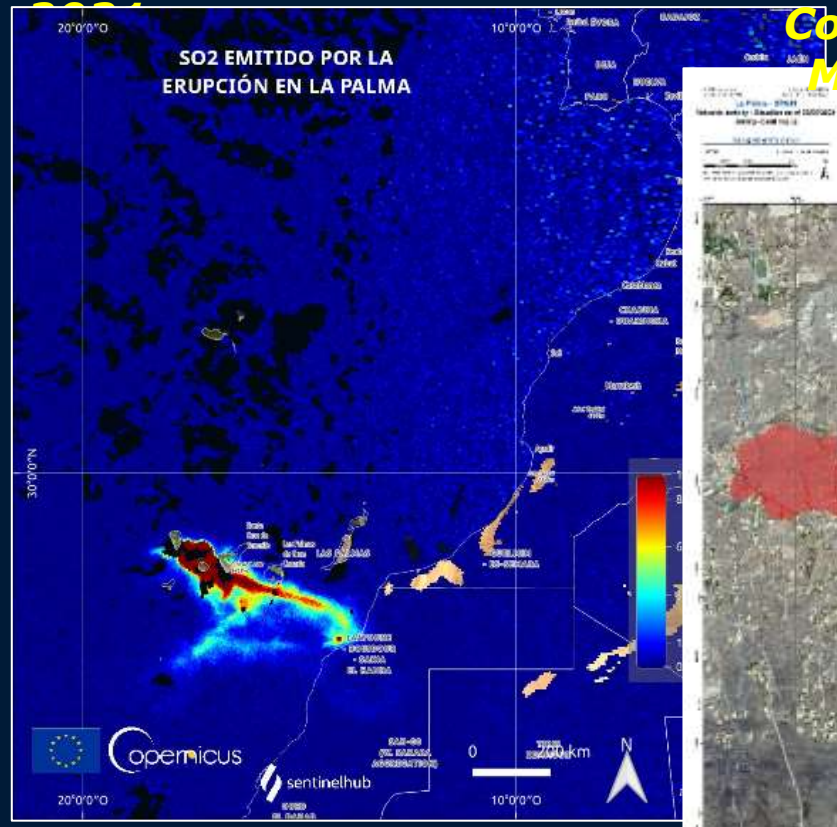
***Before the eruption***



***Sentinel-1*** *interferogram (14-20 Sep)*
*[courtesy Pablo J. González]*

***Eruption started on 19 September 2021***

***Sentinel-2*** *(20 September)*




***Sentinel-5P*** *(SO2, 20 September)*

***First lava map produced by Copernicus Emergency Management Service***

*Based on* ***Sentinel-1 and Cosmo-Skymed*** *data*

*Copyright: Contains modified Copernicus Sentinel data (2021)*

# New Validated World Settlement Footprint Products

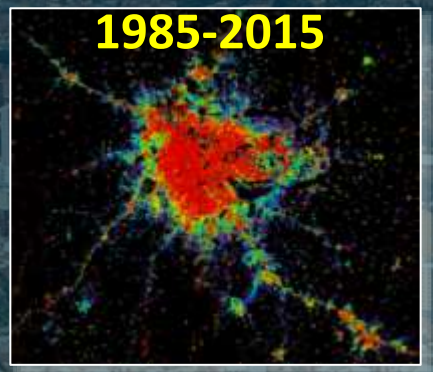
## *World Settlement Footprint (WSF) suite*

A collection of novel open-and-free global datasets produced by DLR in collaboration with ESA and Google Earth Engine for advancing the understanding of urbanization at high detail and accuracy.

**WSF 2015**

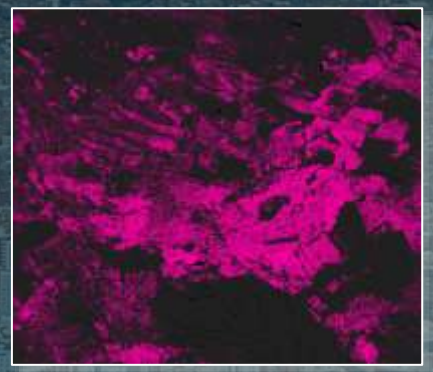
10m resolution

**WSF evolution 1985-2015**



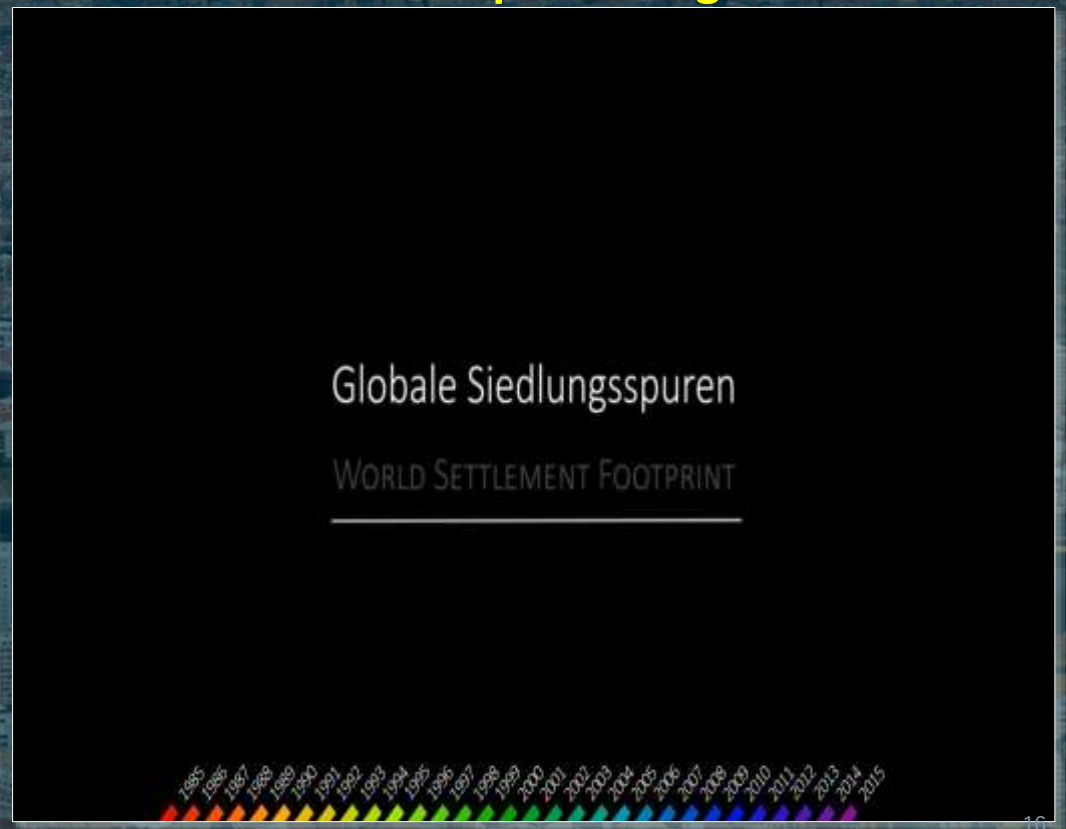
30m resolution

**WSF 2019**



10m resolution

**WSF evolution example: Shanghai 1985-2015**




30m resolution

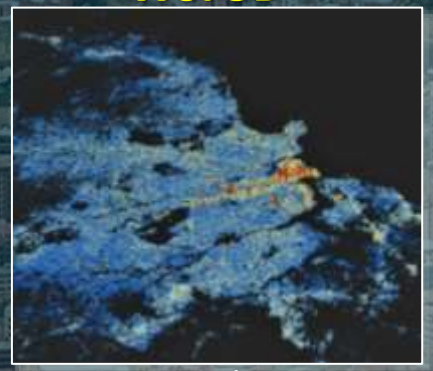
**WSF 2019 imperviousness**

10m resolution

**WSF 2019 population**

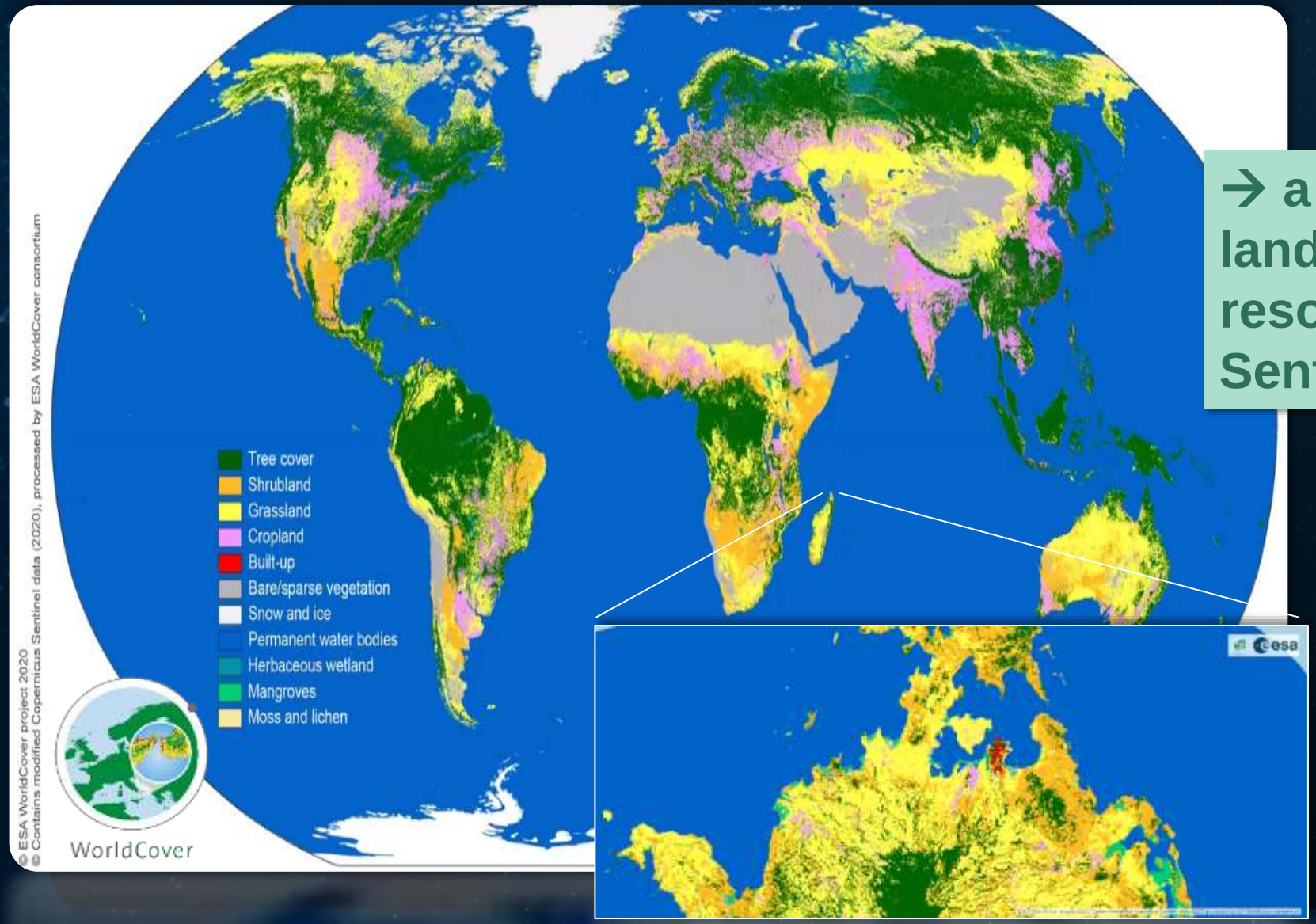
10m resolution

**WSF3D**



90m resolution

# Sentinel-1 And Sentinel-2 Applications: World Land Cover



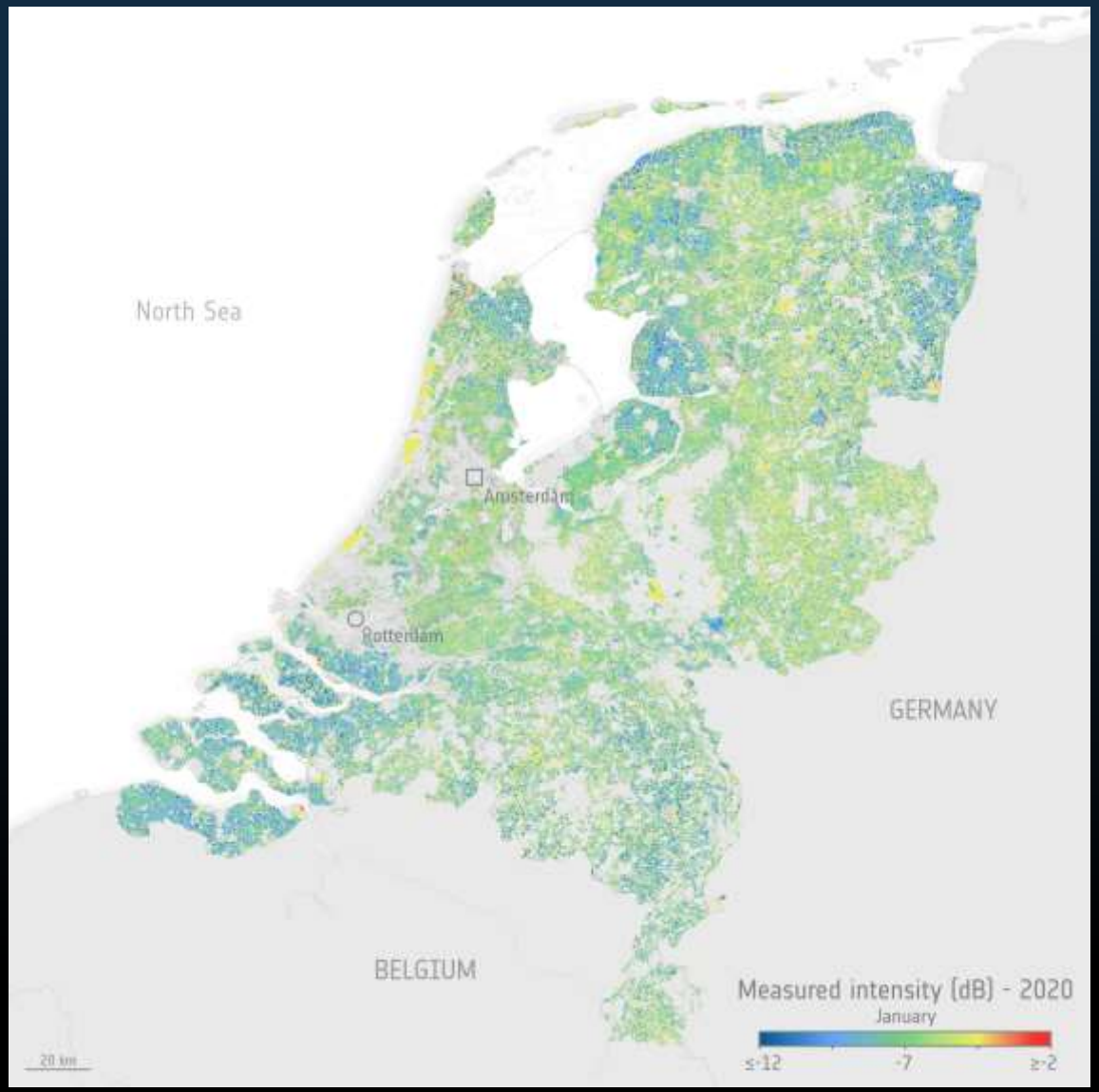

## WorldCover

**→ a freely accessible global land cover product at 10 m resolution for 2020, based on Sentinel-1 and Sentinel-2 data**

- ✓ Released on 20 Oct 2021
- ✓ **11 classes, ≈74%** overall accuracy
- ✓ Independent data validation, highly robust for phenology, Copernicus DEM used as auxiliary data
- ✓ **Part of ESA EOEP-5** (Block 4 – EO Science for Society)

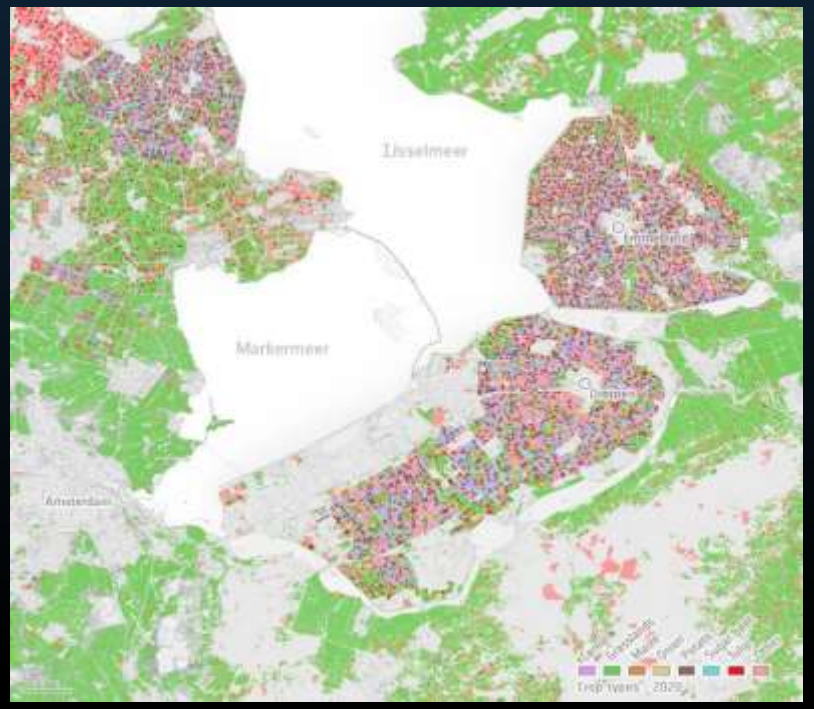
**https://esa-worldcover.org/**

# Monitoring crop health across the Netherlands




Thanks to the combination of Sentinel-1 radar and Sentinel-2 optical data and a newly developed dataset tool, called Agricultural Sandbox NL, people working in the agriculture sector, but who are not satellite data experts, can monitor the health and development of crops, right down to each crop in individual fields.

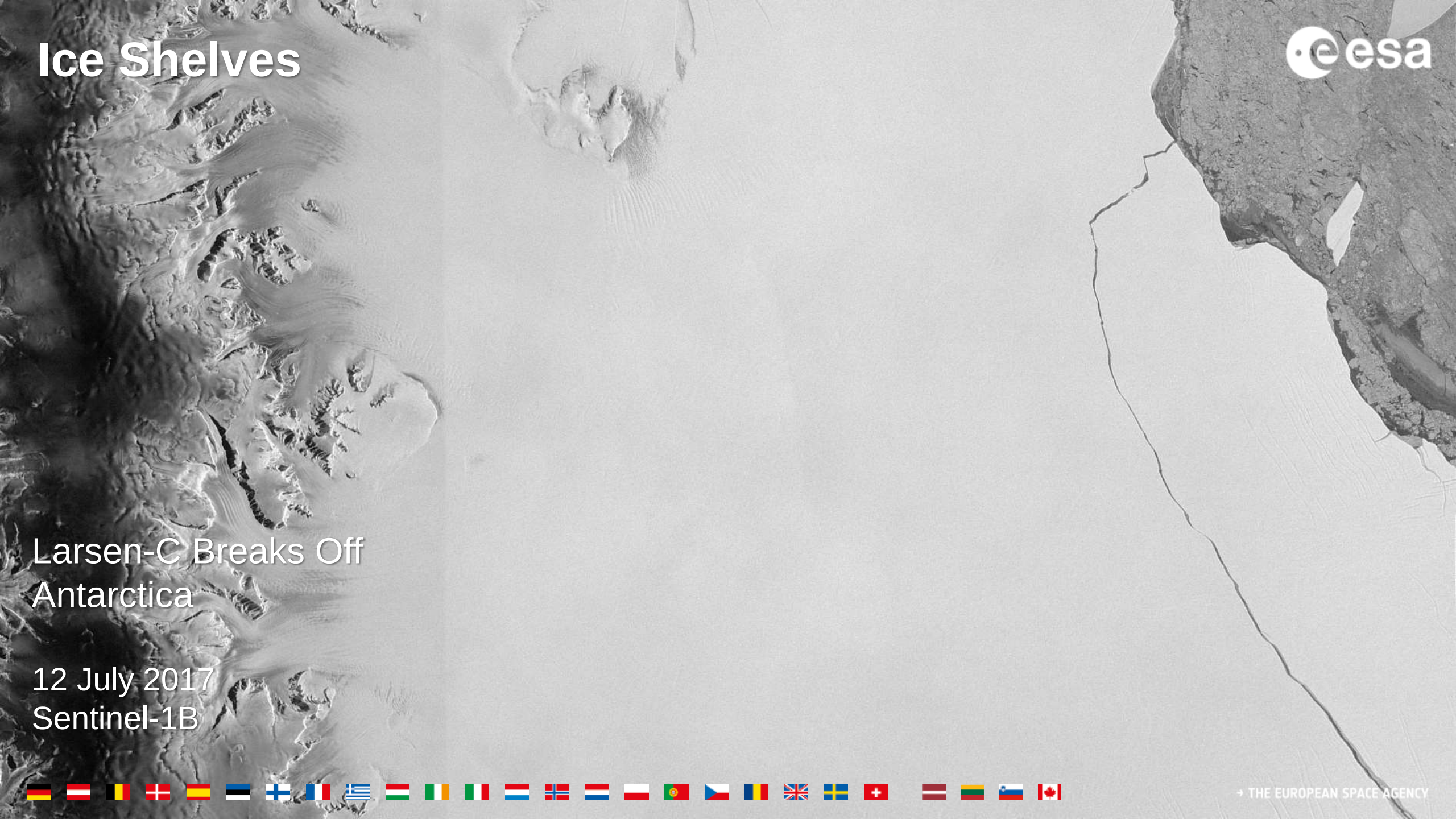
**Animation of highlighting crops between January and December 2020**




**Crop type for all agricultural parcels Flevoland in the Netherlands**

# Sentinel-1

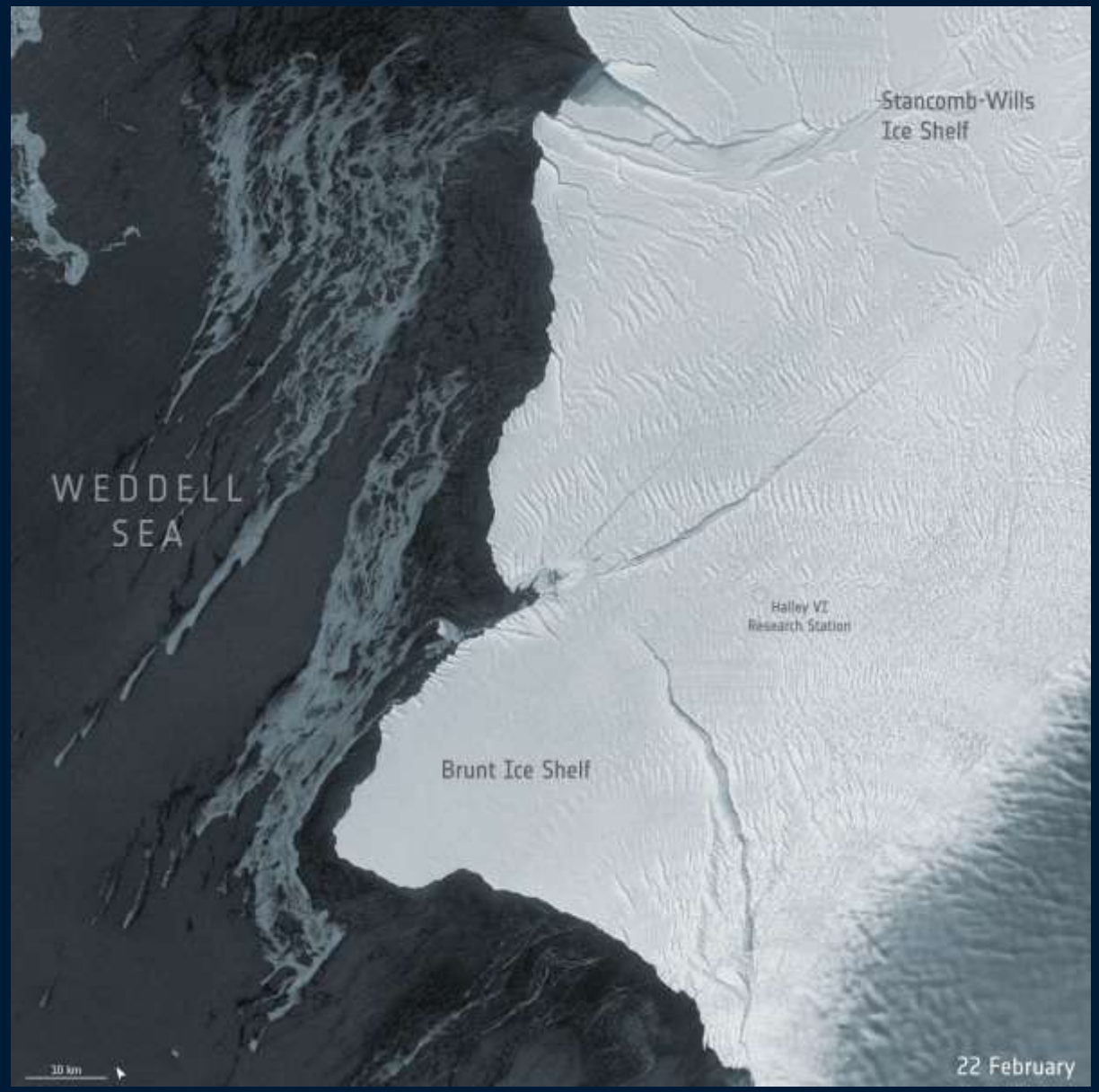
# Ice Shelves



Larsen-C Breaks Off Antarctica

12 July 2017
Sentinel-1B

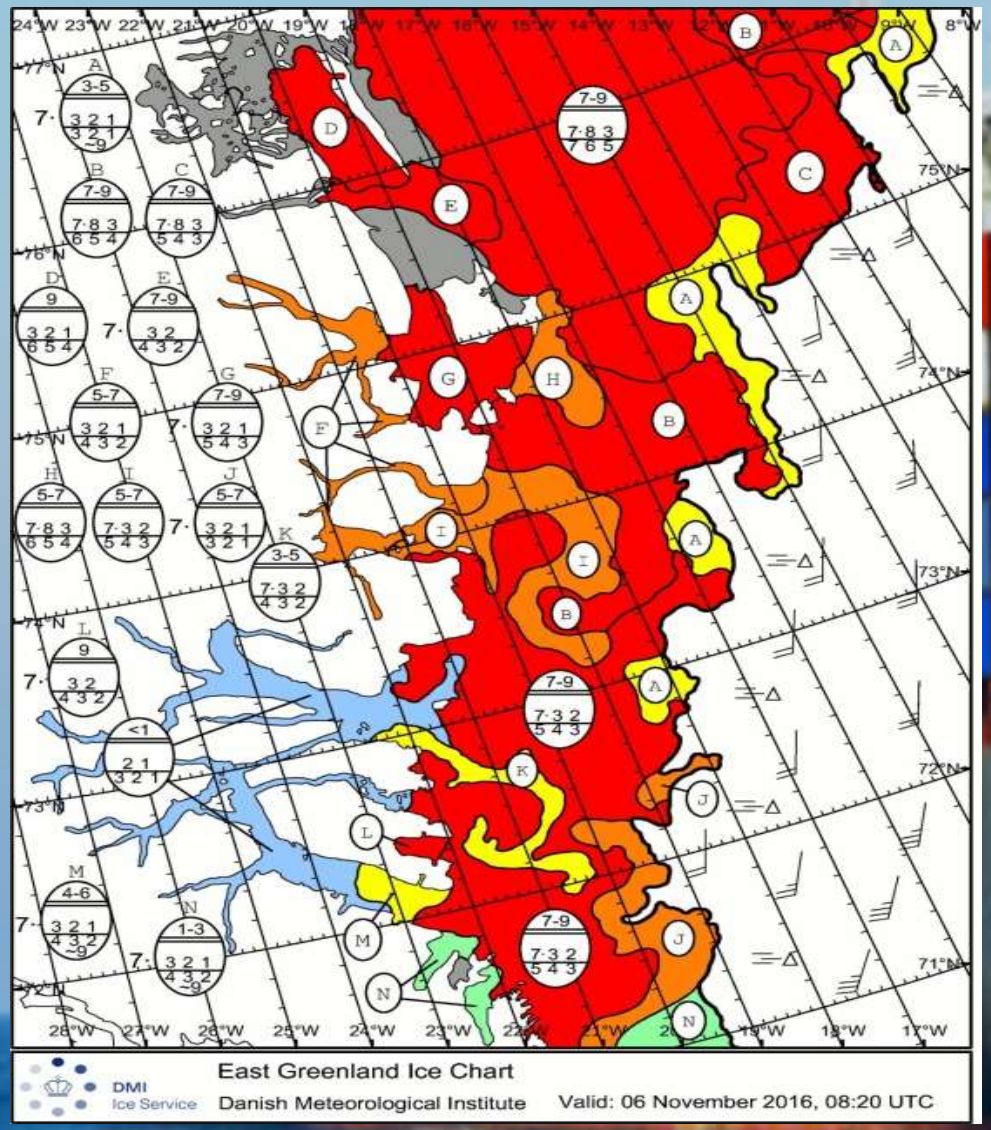
# Giant iceberg breaks off Brunt Ice Shelf in Antarctica




**22 and 28 February 2021**

**Copernicus Sentinel-1**

# Safe & Efficient Shipping




## East Greenland Ice Chart

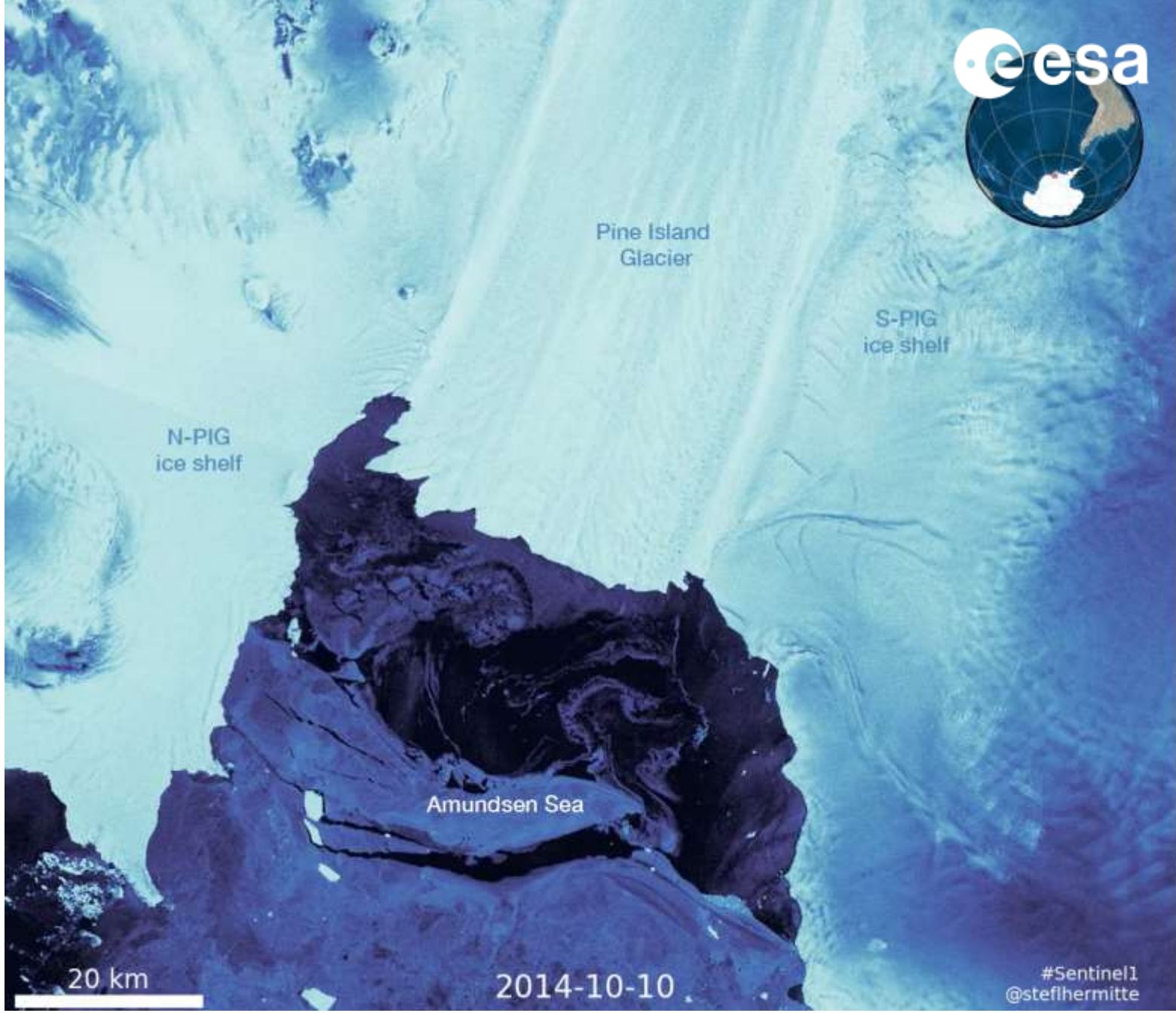
Based upon Sentinel-1 A & B data

© DMI

# Glacier Flow

Pine Island Glacier
Antarctica

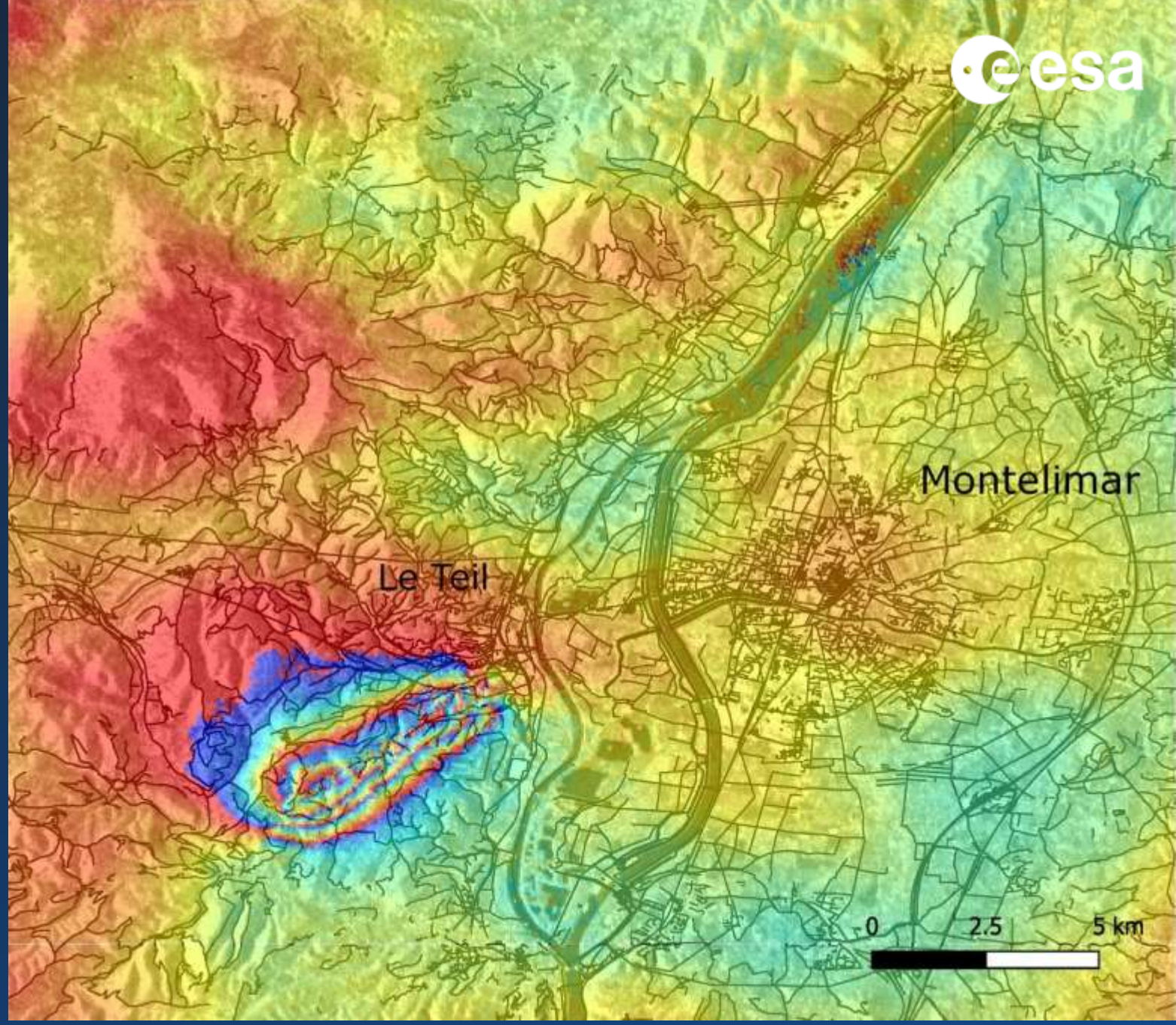
Sentinel-1
2014-2016



# Earthquake in France

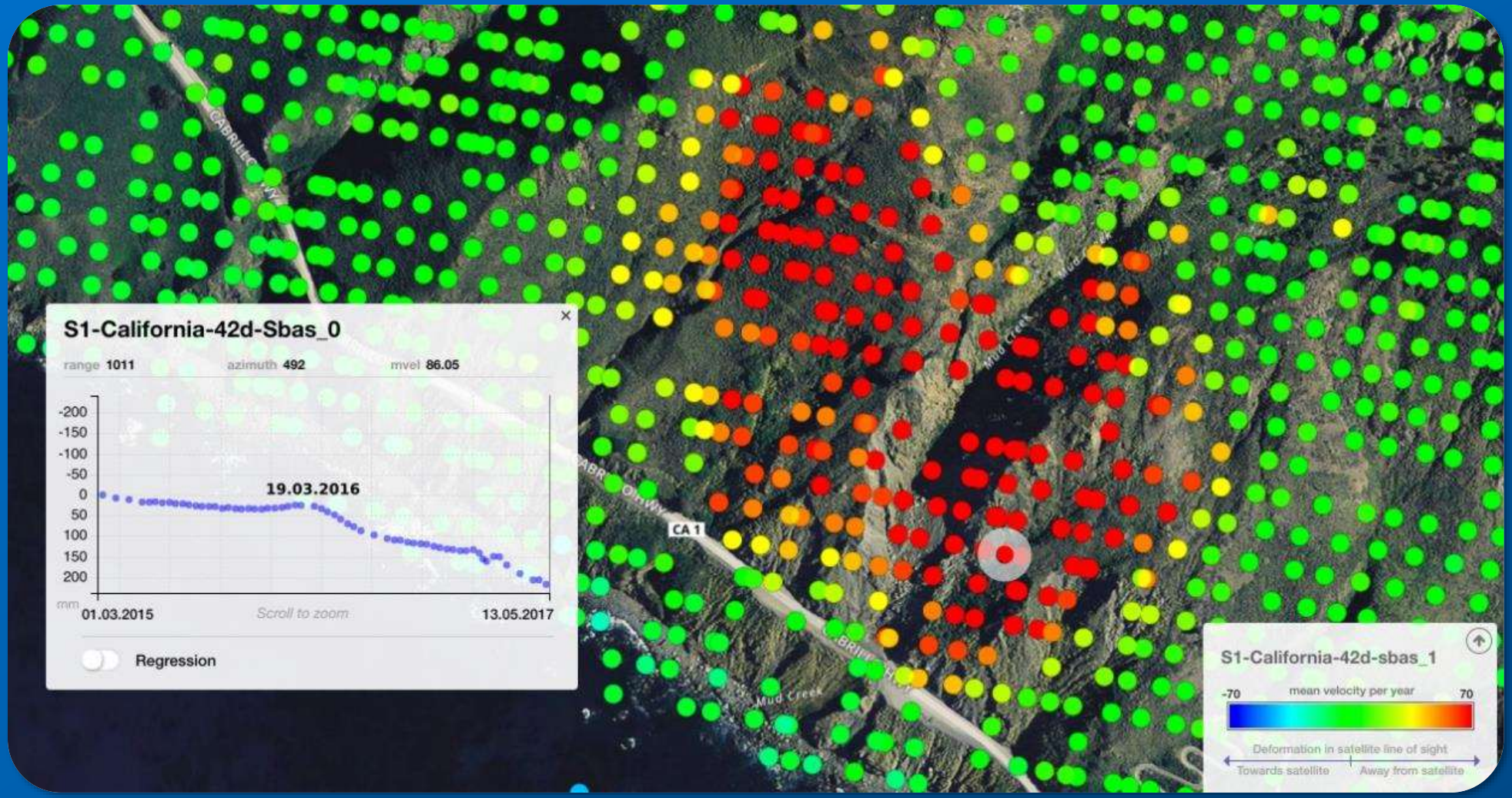
Interferogram
Based on Copernicus
Sentinel-1

6 and 12 November 2019




Contains modified Copernicus Sentinel data (2019), processed by ESA

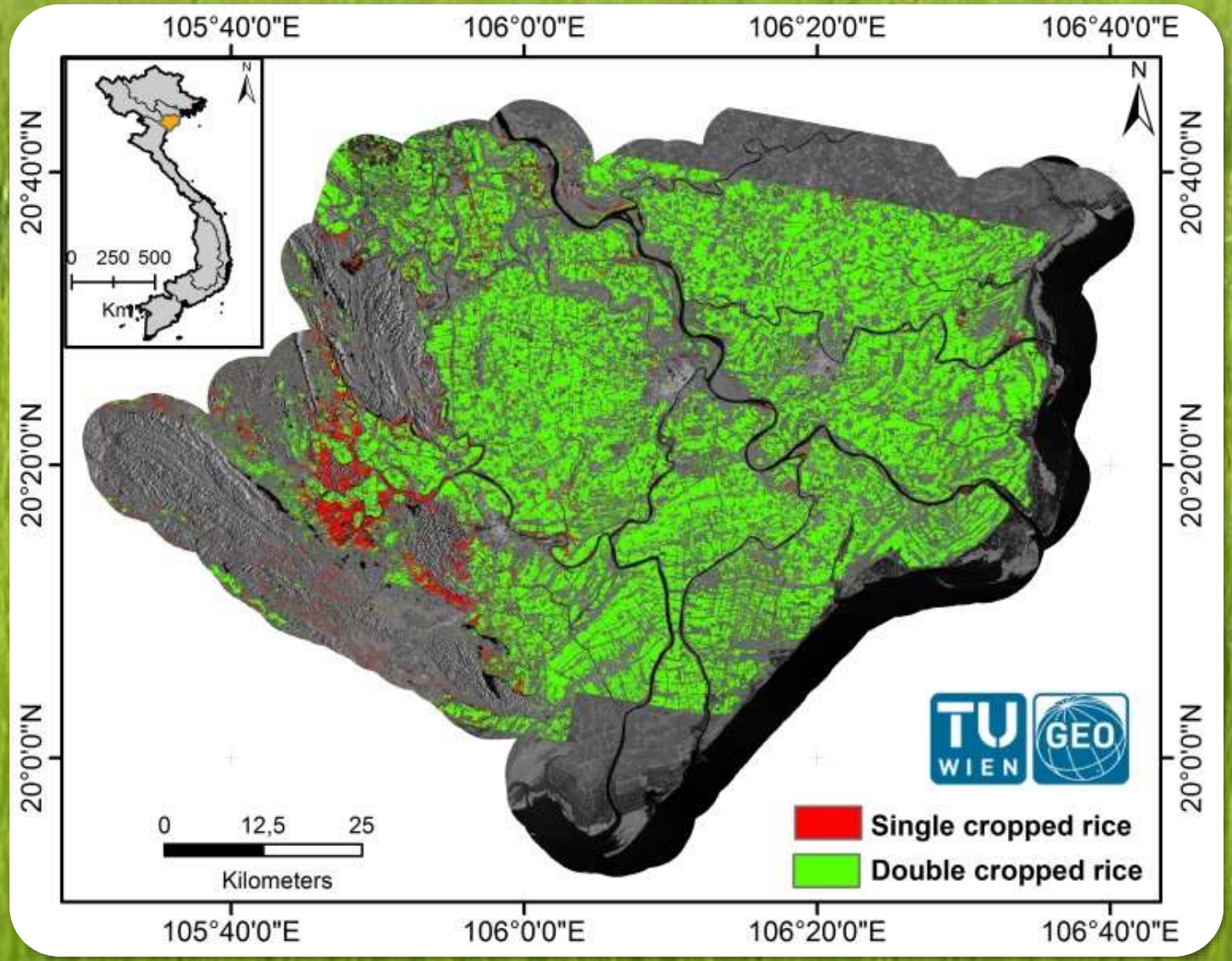
# Landslides




Highway 1
California U.S.

Based on Sentinel-1 data (2015–17), processed by Norut

# Monitoring Rice Yields



Duong Delta
Nothern Vietnam

Based on Sentinel-1 Data

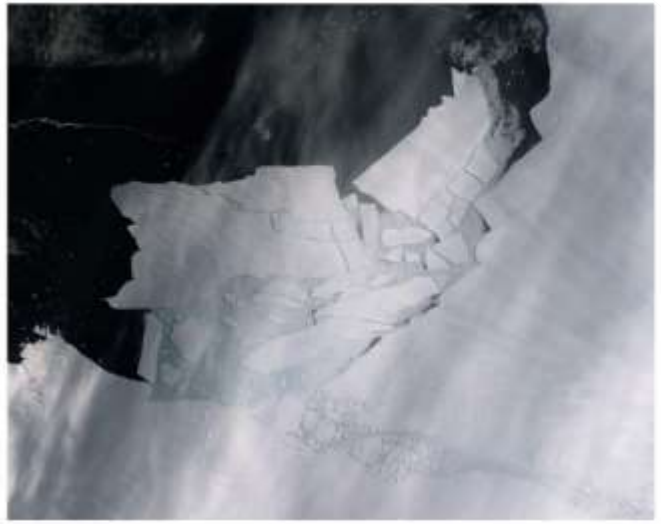
© TU Wien, GEO

# Pine Island Glacier

Sentinel-1

Feb. 2019 – Feb. 2020

Contains Copernicus modified data (2020)



This image, taken on February 11 by the Copernicus Sentinel-2 mission, shows the Pine Island Glacier's newly calved icebergs in detail.

PHOTOGRAPH COURTESY COPERNICUS SENTINEL, EUROPEAN SPACE AGENCY

SCIENCE

**A huge iceberg just broke off West Antarctica's most endangered glacier**

Huge blocks of ice regularly shear away from Antarctica's ice shelves, but the losses are speeding up.

NATIONAL GEOGRAPHIC

**760.000 views on the ESA YouTube channel and counting**

2019

10 km

N

THE EUROPEAN SPACE AGENCY

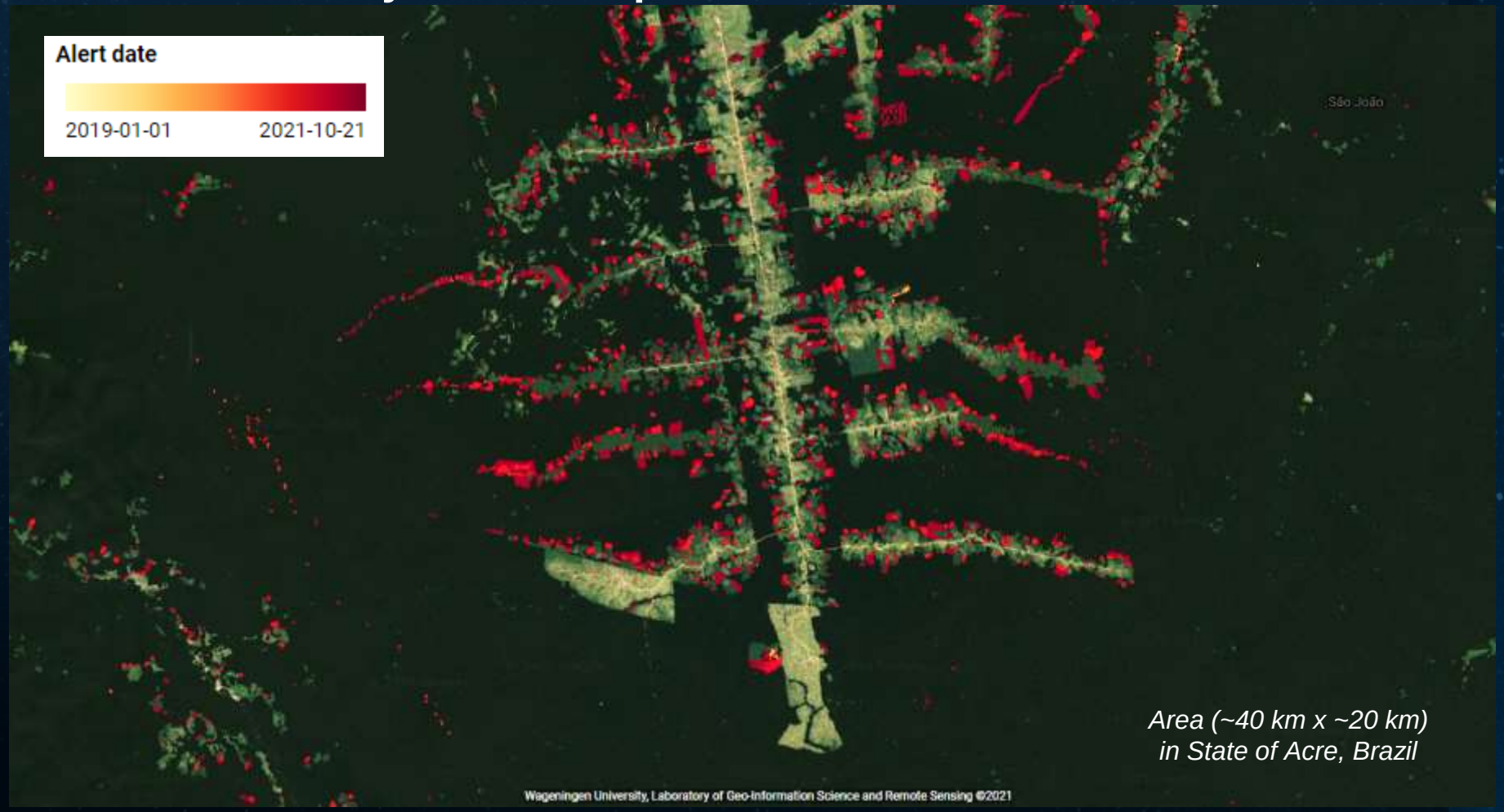
# Sentinel-1 Applications: RADD Forest Disturbance Alert

RADD (Radar for Detecting Deforestation) alerts are operational for the pan-tropics (44 countries) and are available at the Global Forest Watch platform.

Sentinel-1 data enables the rapid detection of small-scale forest disturbances, such as subsistence agriculture and selective logging.

A new forest disturbance alert is triggered based on a single observation from the latest Sentinel-1 image. Subsequent observations are used to increase confidence and confirm or reject the alert.

## RADD for Primary Humid Tropical Forests disturbance alerts




*Area (~40 km x ~20 km) in State of Acre, Brazil*

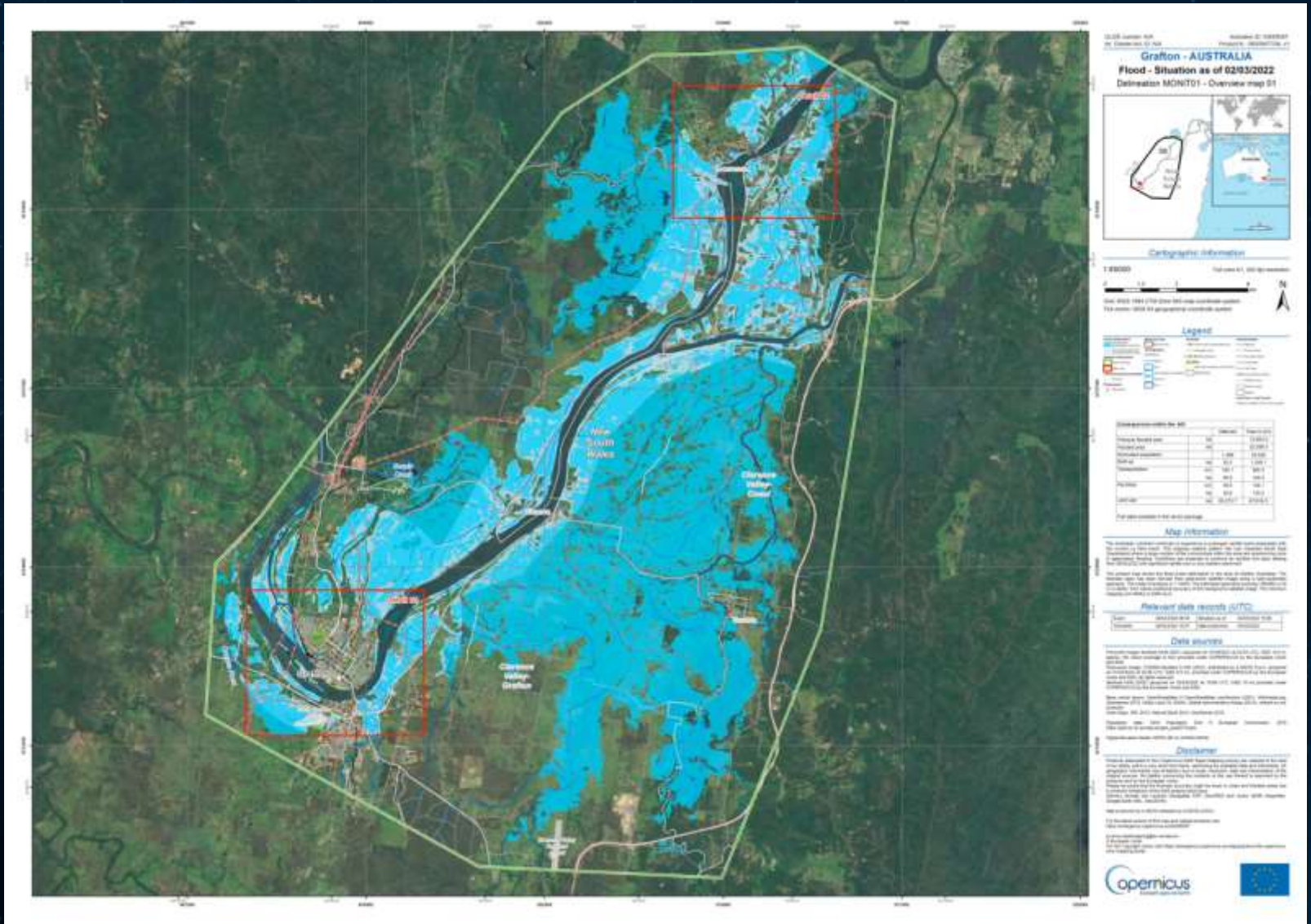
*Copyright: Contains modified Copernicus Sentinel data (2019-2021) / processed by Wageningen University*

WAGENINGEN UNIVERSITY & RESEARCH

# Major floods in Australia observed by Sentinel-1A

***Activation EMSR567 from the Copernicus Emergency Management Service***

***Example of flood map near Grafton (New South Wales) based on both Sentinel-1A imagery acquired on 02/03/2022 and COSMO-SkyMed imagery acquired on 01/03/2022***




*Copyright: Copernicus Service Information (2022) / Copernicus Emergency Management Service / processed by e-GEOS*

# Applications: Cyclone Monitoring Service (CYMS) with S-1

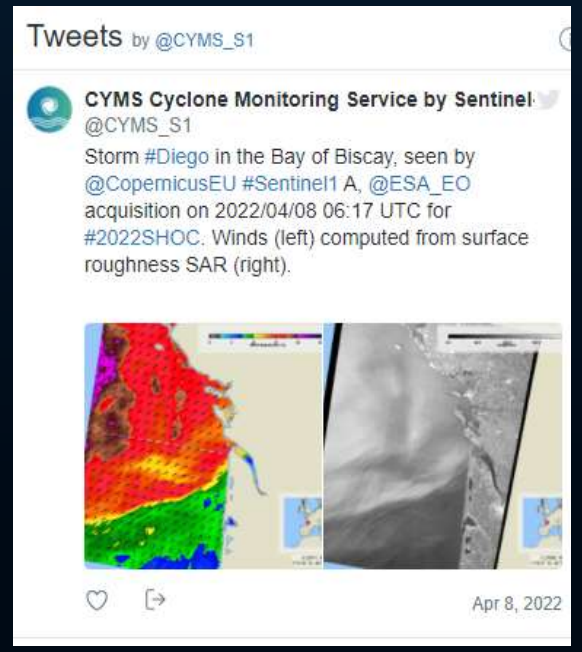
## From Open Call to preparing its integration into a Copernicus Service

*Unprecedented observations of European Waters storm events as Extra-Tropical Cyclones, Medicanes or Polar Lows*

Single Integrated Portal

www.esa-cyms.org

*Storm in the Bay of Biscay, April 2022*




## Consortium:

Ifremer CLS COLLECTE LOCALISATION SATELLITES

*Ongoing coordination with CMEMS*

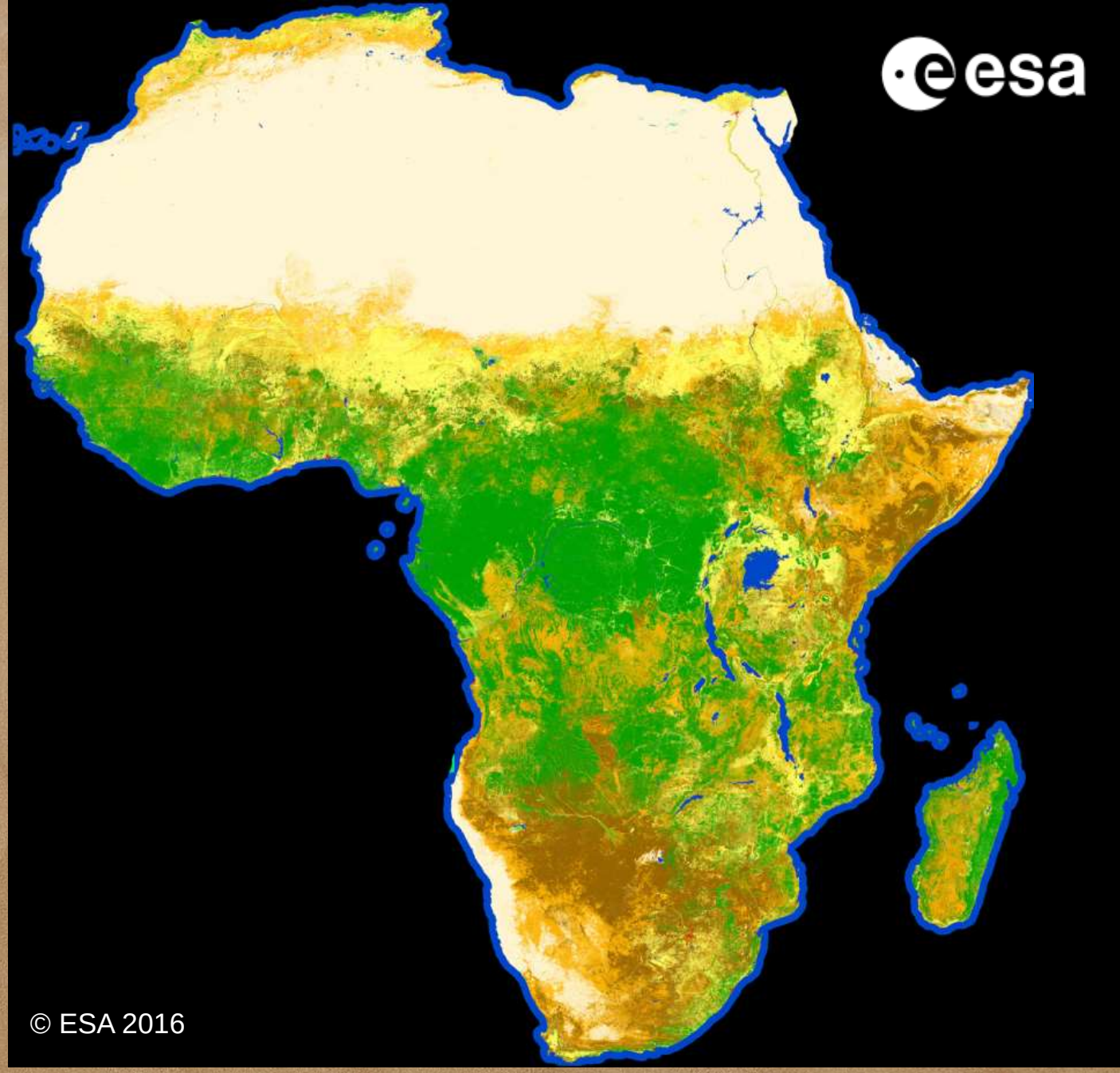
Copernicus Marine Service

PROGRAMME OF THE EUROPEAN UNION Copernicus implemented by MERCATOR OCEAN

# Sentinel-2

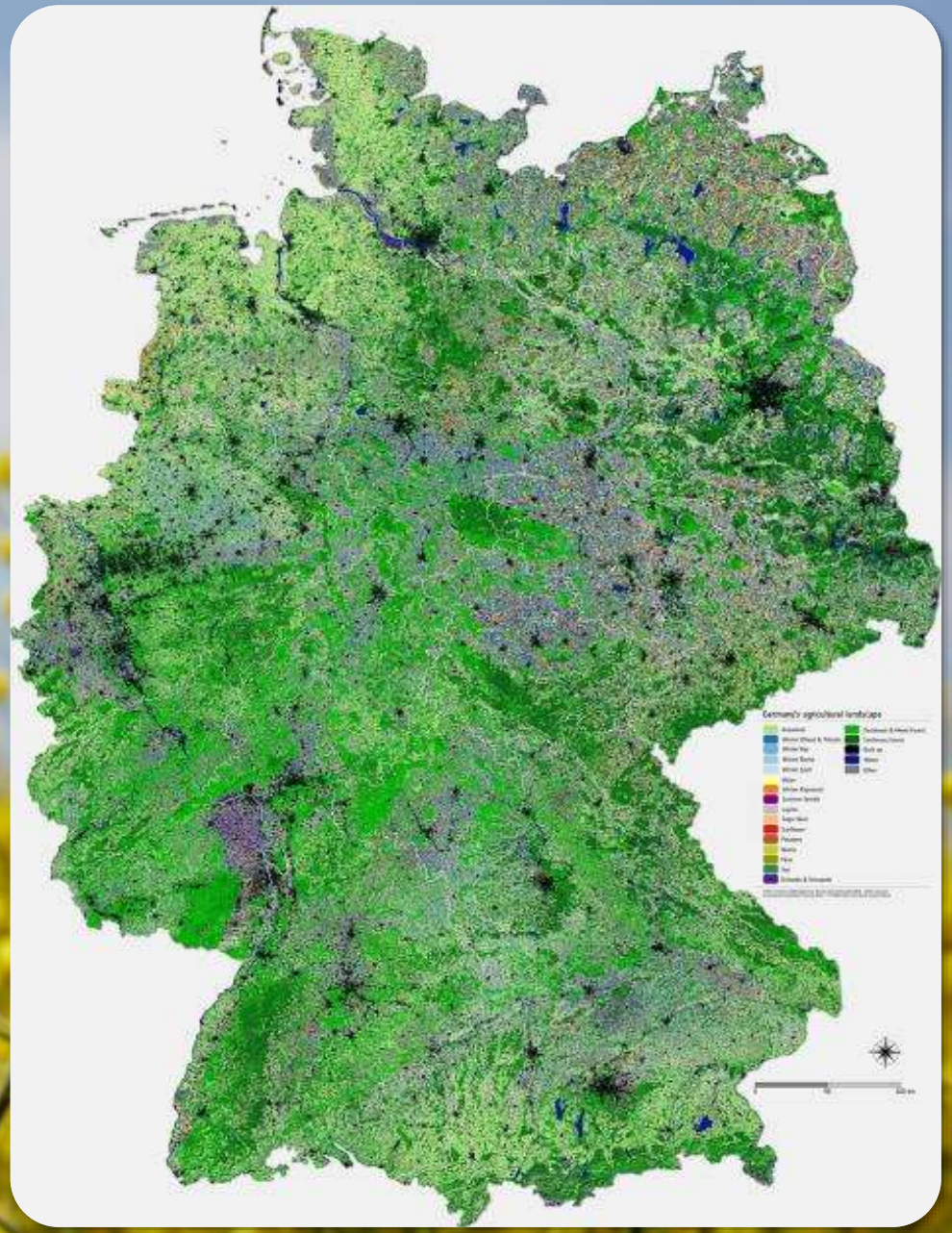
# Land Cover Typology

180.000 Sentinel-2A images
Dec. 2015 – Dec. 2016




- no data
- Trees cover areas
- Shrubs cover areas
- Grassland
- Cropland
- Vegetation aquatic or regularly flooded
- Lichen Mosses / Sparse vegetation
- Bare areas
- Built up areas
- Snow and/or Ice
- Open water

# Agricultural Land Use

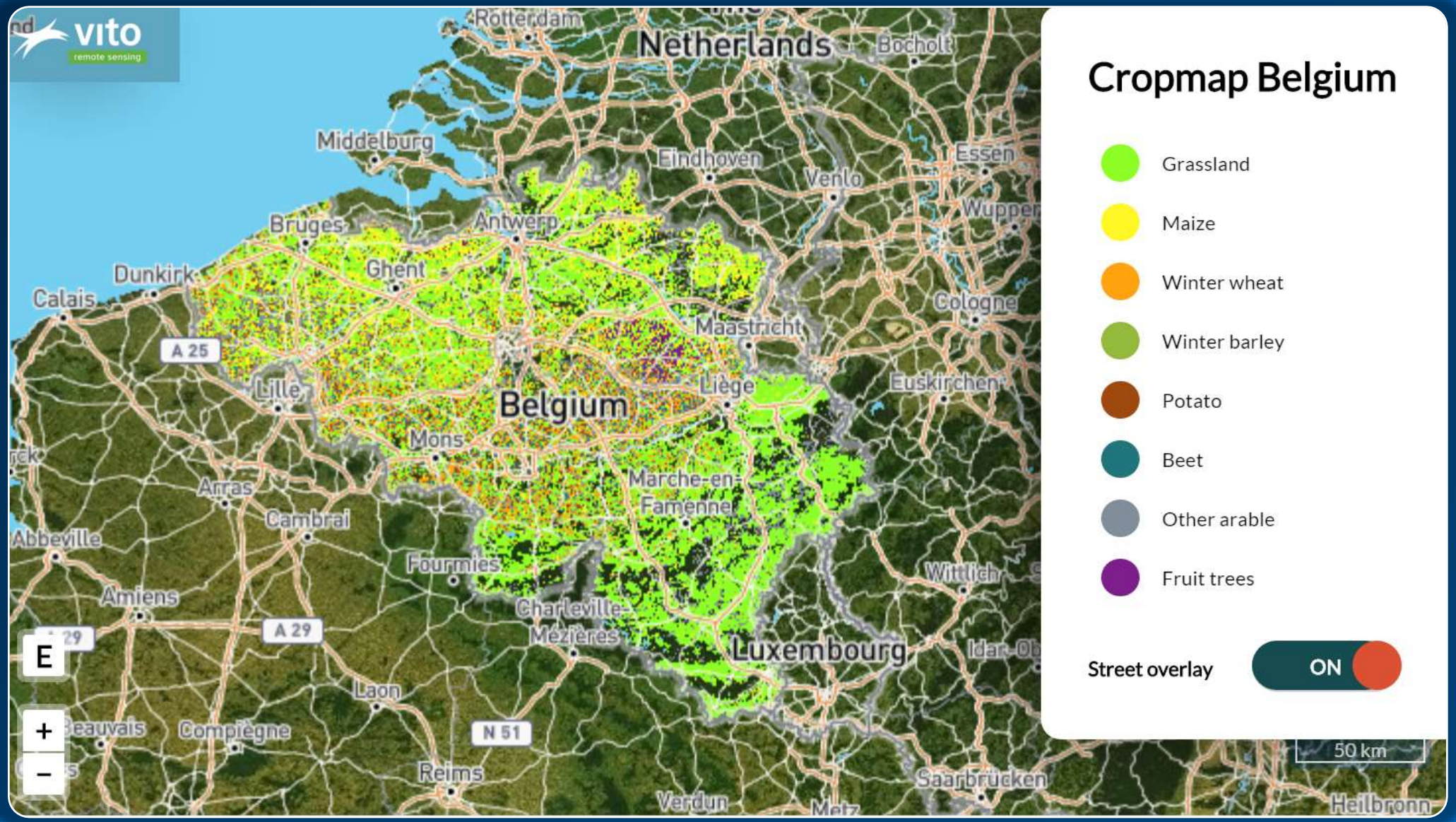


Distinguishing 15 crop types
Germany

Mixed Sentinel-2 and Landsat-8 Data

© Humboldt University Berlin
P. Griffiths

# Agricultural Landscape in Belgium

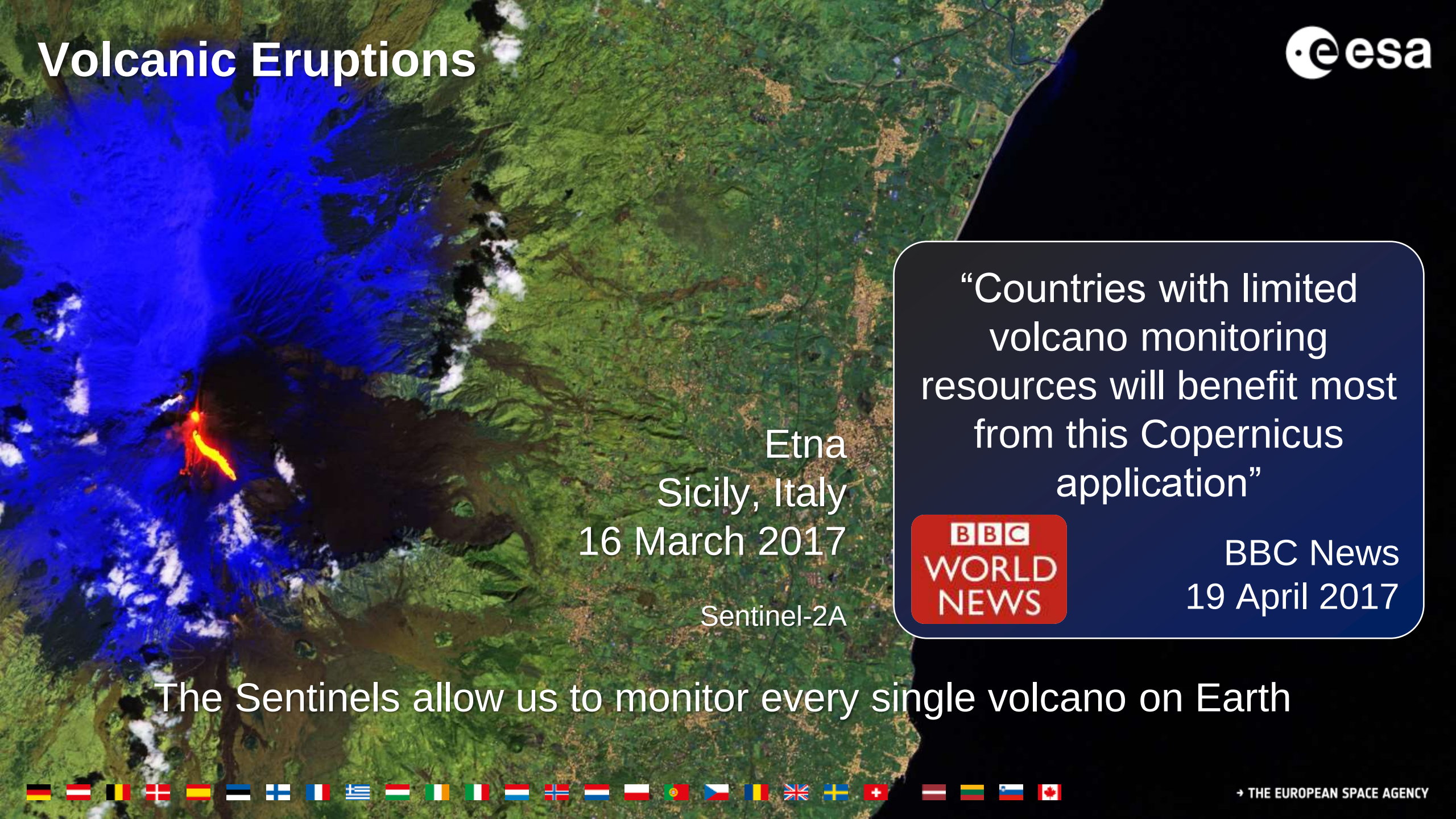



Based on Sentinel-1 & Sentinel-2 Data

1 Jan. – 15 June 2018

© VITO

# Volcanic Eruptions



Etna
Sicily, Italy
16 March 2017

Sentinel-2A

"Countries with limited volcano monitoring resources will benefit most from this Copernicus application"

BBC News
19 April 2017

The Sentinels allow us to monitor every single volcano on Earth

# Marine Life

## Fiji – South Pacific

**Sentinel-2B**

**28 Sept. 2017**

# Forest Fires in Urban Areas

Mount Vesuvius
Naples, Italy

Sentinel-2B
12 July 2017

# Wildfires in Russia

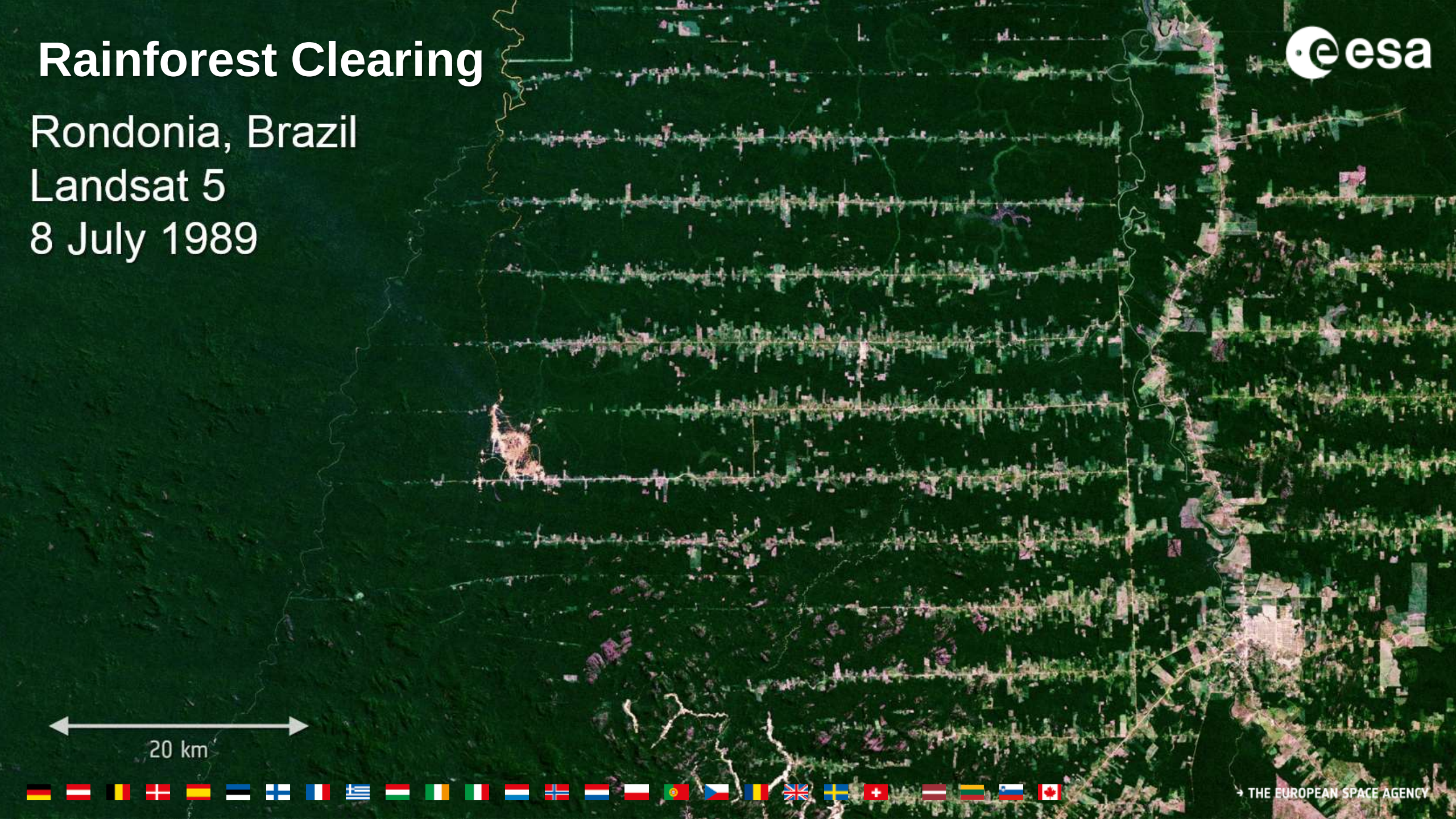
## Sentinel-2

Amur Oblast

9 May 2018

# Rainforest Clearing

Rondonia, Brazil
Landsat 5
8 July 1989



# Biodiversity: observe local rainforest clearing

# Water Level Changes

## Lake Bracciano, Italy
## Summer 2017 Drought

Based upon Sentinel-2

© BY-SA 3.0 IGO

# Floods in Greece

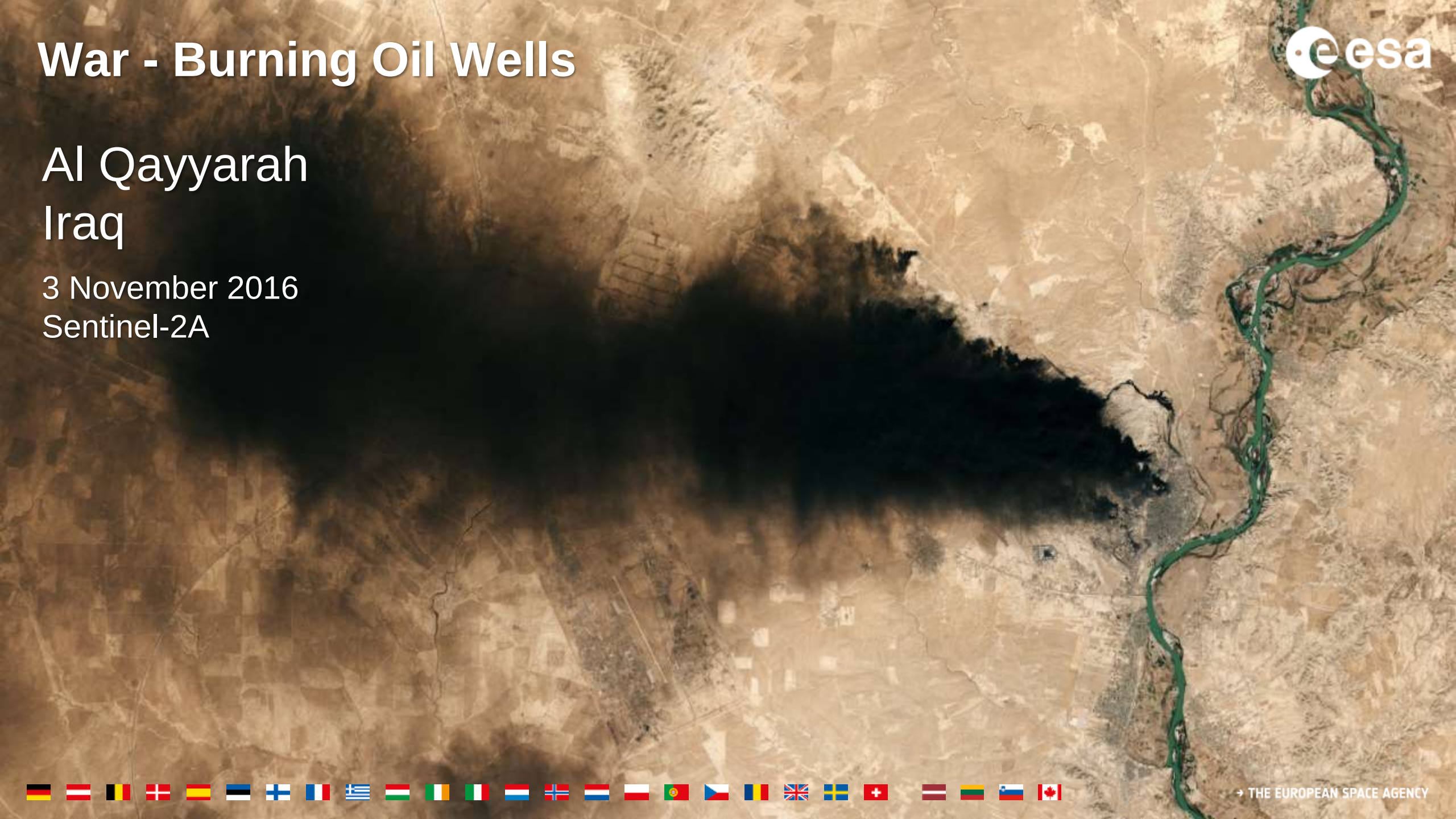
Attica before and after floods Copernicus Sentinel-2

22 and 25 November 2019

Contains modified Copernicus Sentinel data (2019), processed by ESA, CC BY-SA 3.0 IGO

→ THE EUROPEAN SPACE AGENCY

# War - Burning Oil Wells



Al Qayyarah
Iraq

3 November 2016
Sentinel-2A

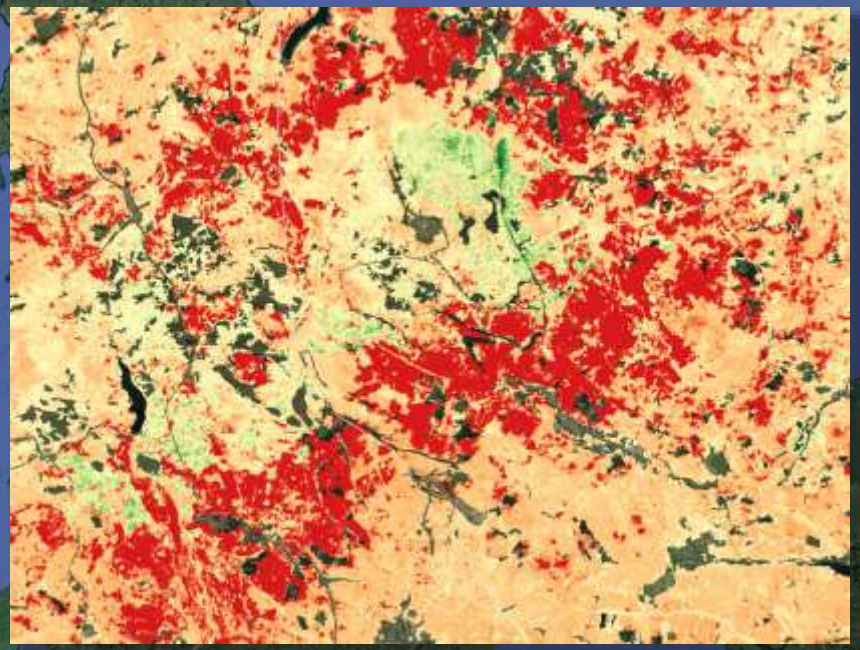
# Ecosystem Destruction

Kalimantan, Indonesia

Summer 2015

Sentinel-2A

# Sentinel-2 Supports Forest Monitoring in Germany



Forest biomass stock 2016-2020

- Biomass increase
- No change
- Vitality decrease
- Forest loss

**Waldbiomasse-Trend 2016-2020**

Wälder speichern Kohlenstoff, tragen bedeutend zur Neubildung von Grundwasser bei, spenden Kühlung und beherbergen eine große Artenvielfalt. Die letzten Dürrejahre in Deutschland haben jedoch gezeigt, wie anfällig viele Waldgebiete sind. Es sind große Schadflächen durch den Hitzeeinfluss, Schädlinge und andere

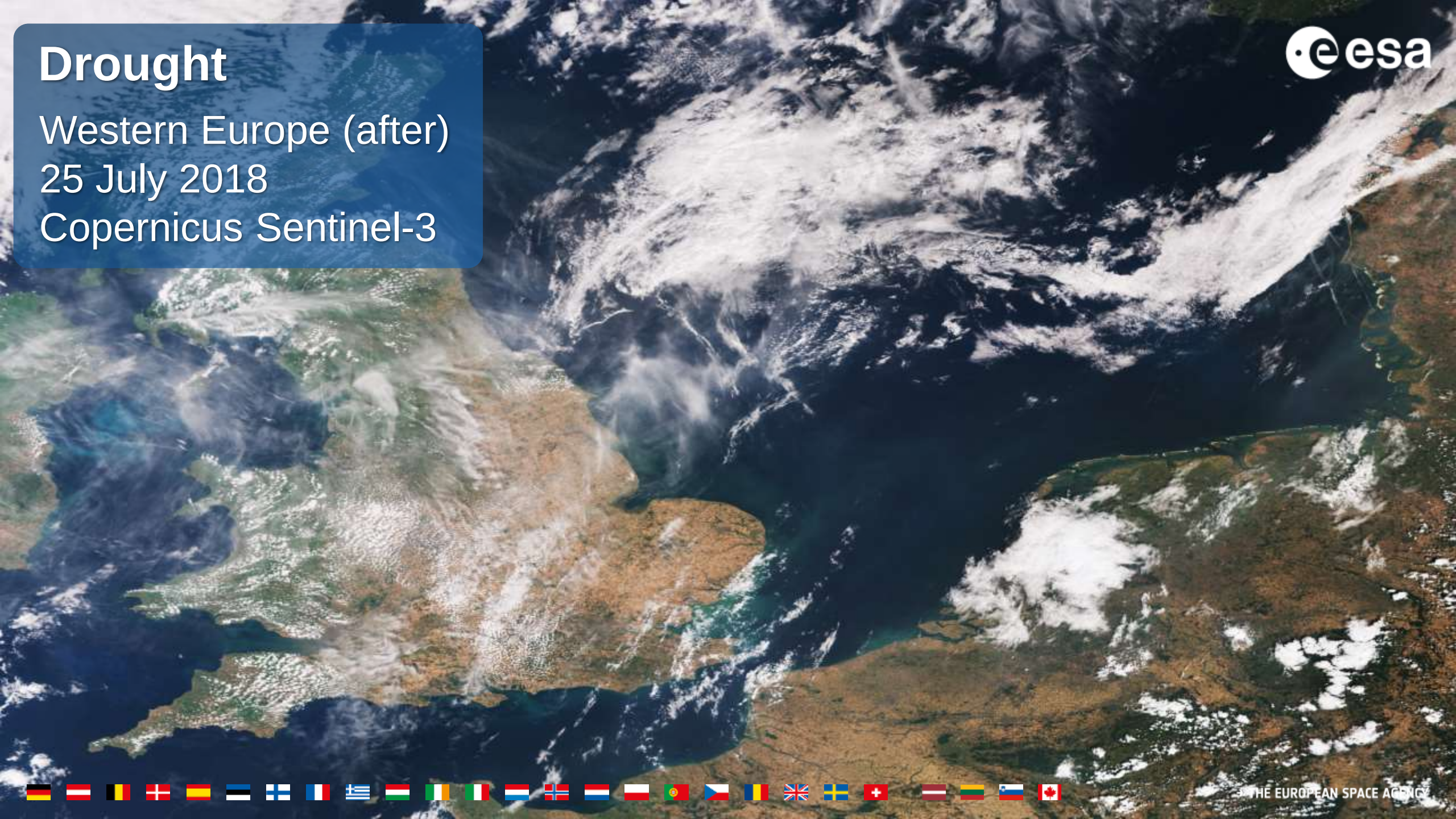
- Sentinel-2 data used to semi-automatically examine the state of the forests in Germany.
- An interactive map covering all of Germany, indicating forest vitality growth or decline or complete forest loss.
- https://map3d.remote-sensing-solutions.de/waldmonitor-deutschland/#

Transparenz

# Sentinel-3

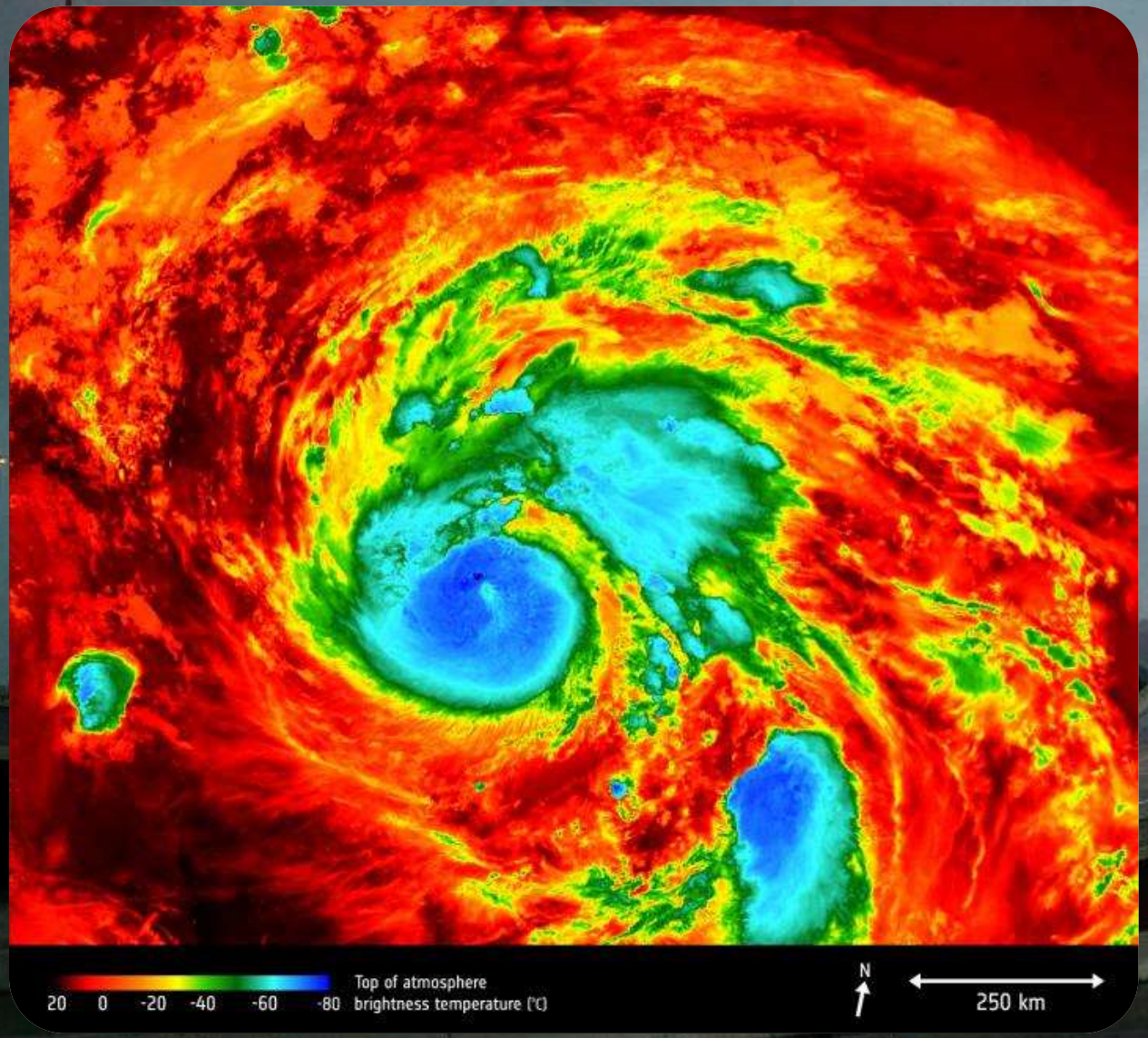
# Drought

Western Europe (after)
25 July 2018
Copernicus Sentinel-3



THE EUROPEAN SPACE AGENCY

# Hurricane Monitoring

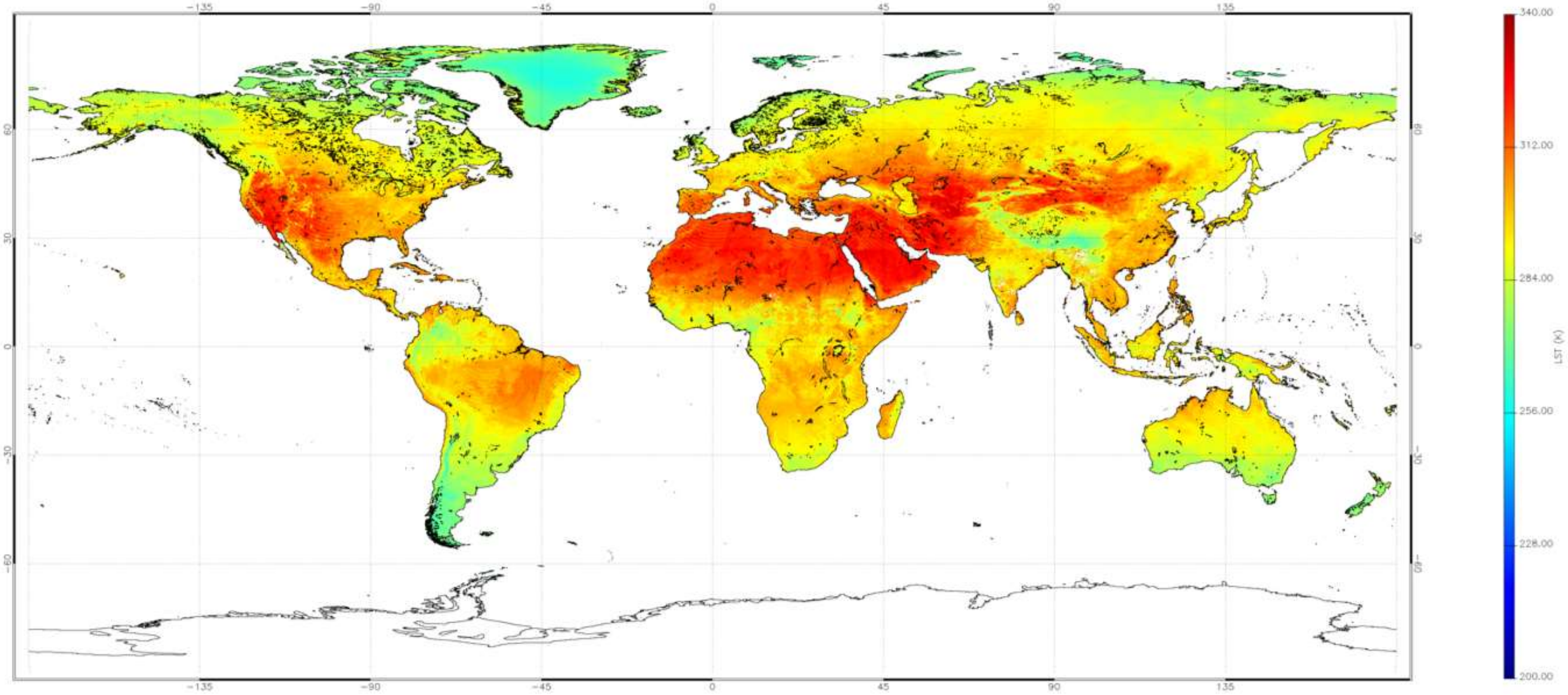



< Temperature at the top of Harvey as the storm approaches Texas

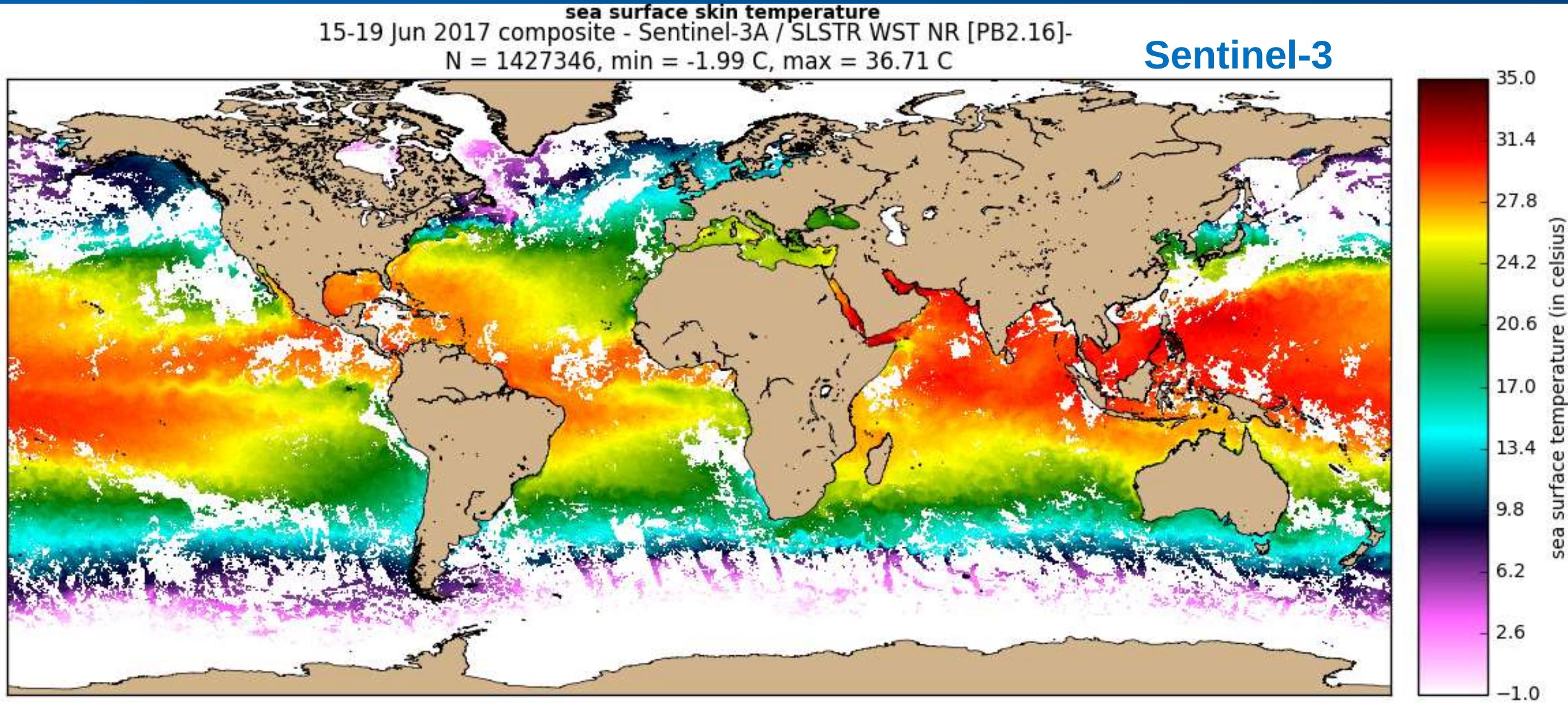
Based on Sentinel-3A data
25 August 2017

© BY-SA 3.0 IGO

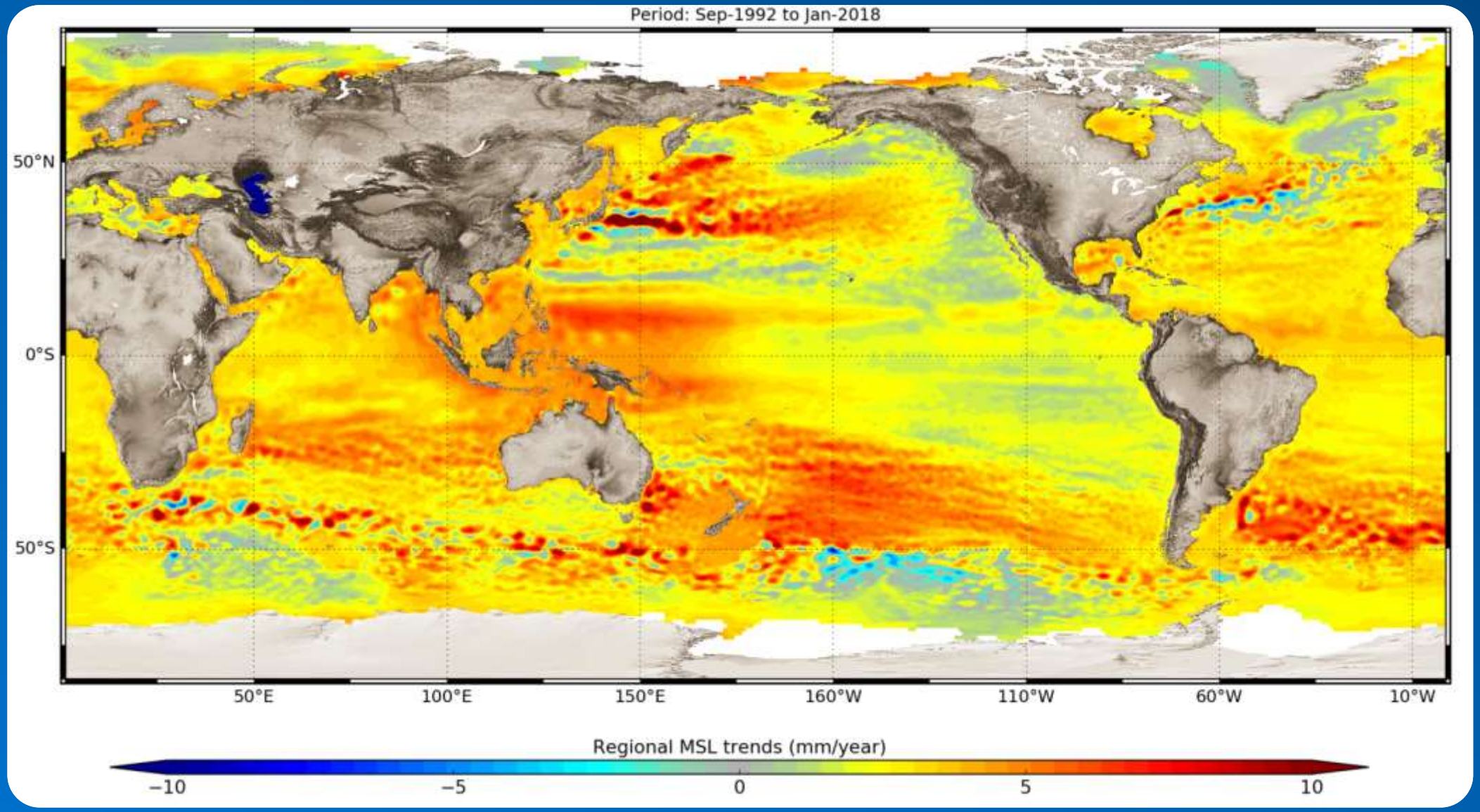
# Earth Surface Heat



# Sea Surface Temperature

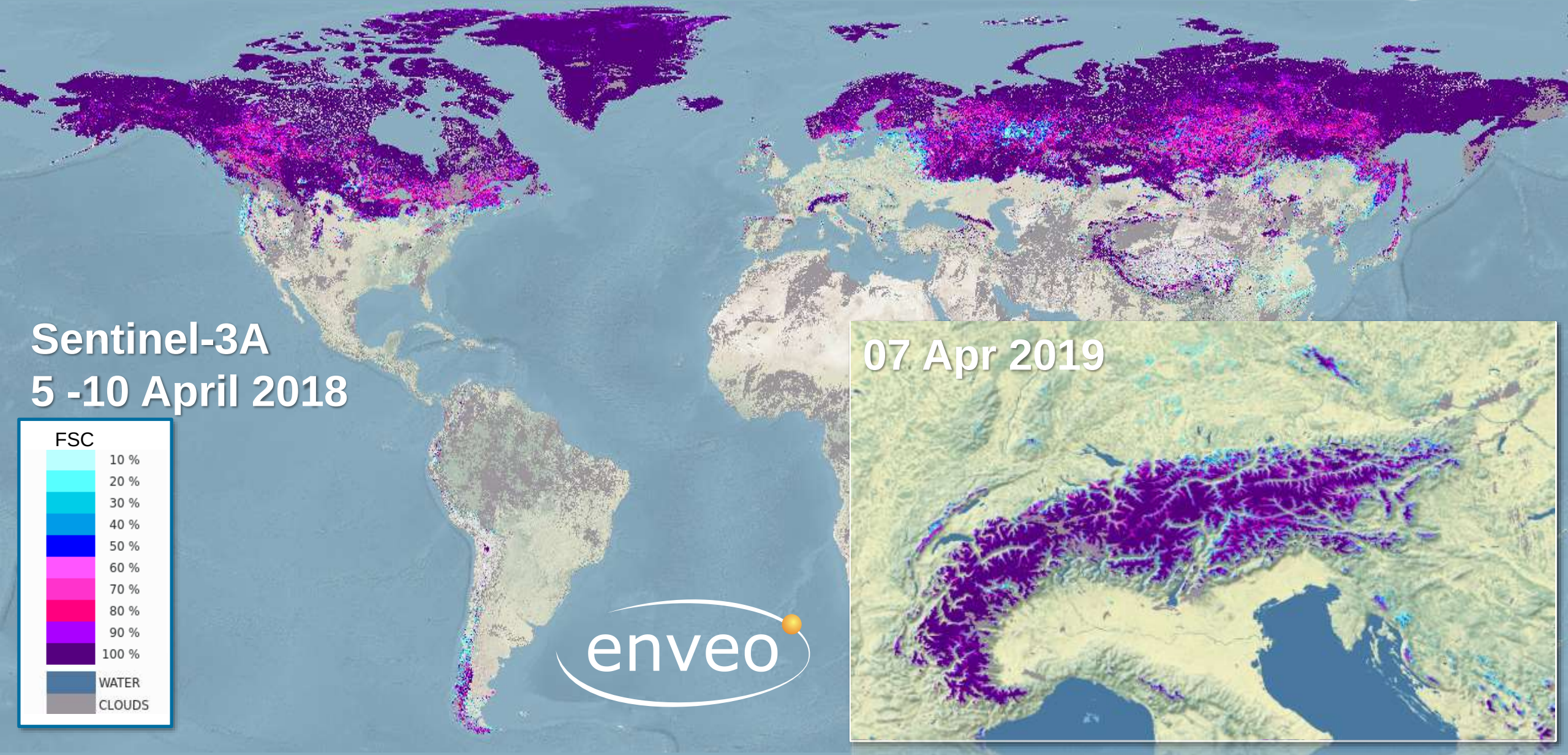


# Sea Level Trends (1992 - 2018)

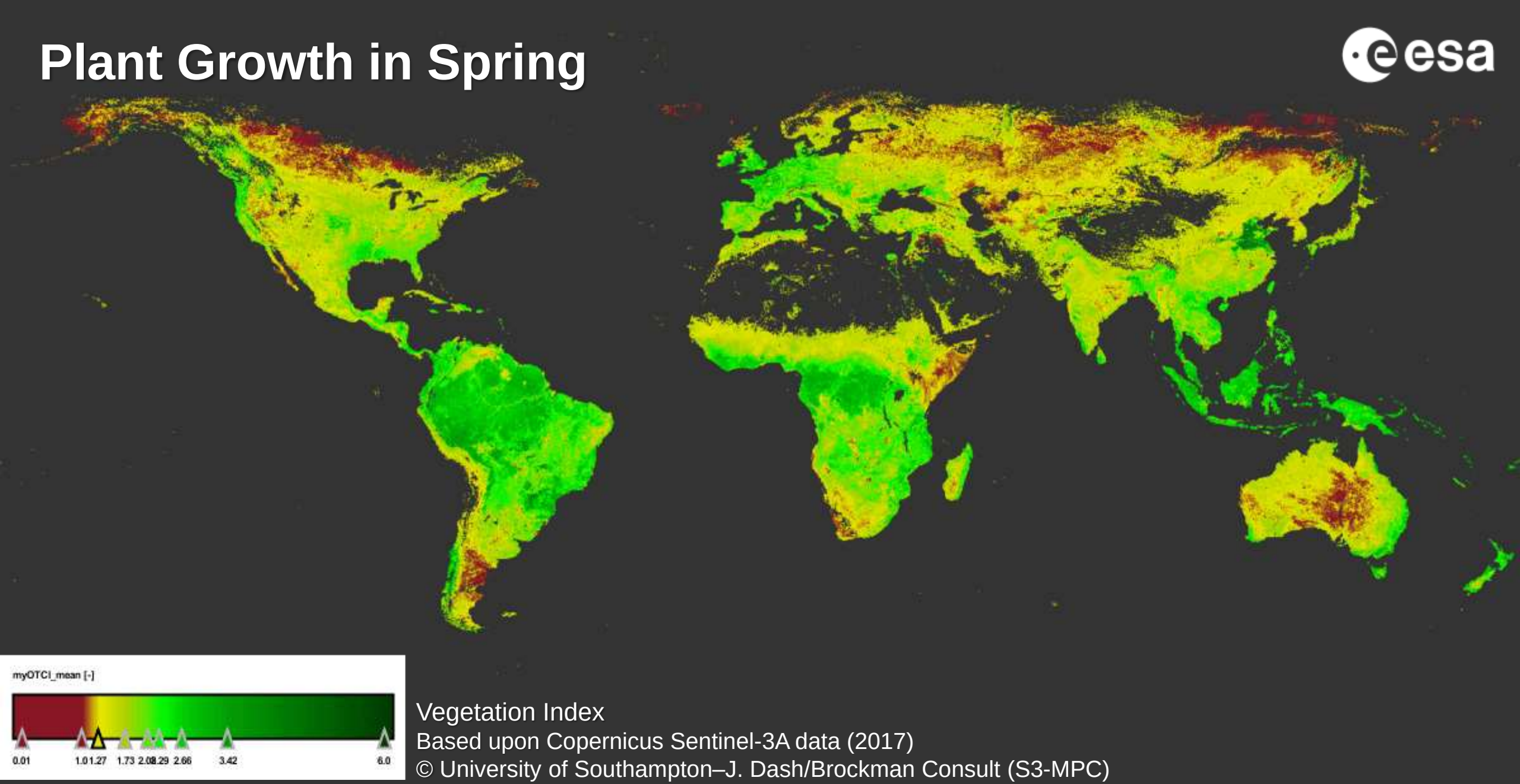



© CNES/LEGOS/ CLS/EU Copernicus Marine Service Contains modified Copernicus Sentinel data (2018)

# Snow Extent


Sentinel-3A
5 -10 April 2018
FSC
10 %
20 %
30 %
40 %
50 %
60 %
70 %
80 %
90 %
100 %
WATER
CLOUDS
07 Apr 2019
enveo

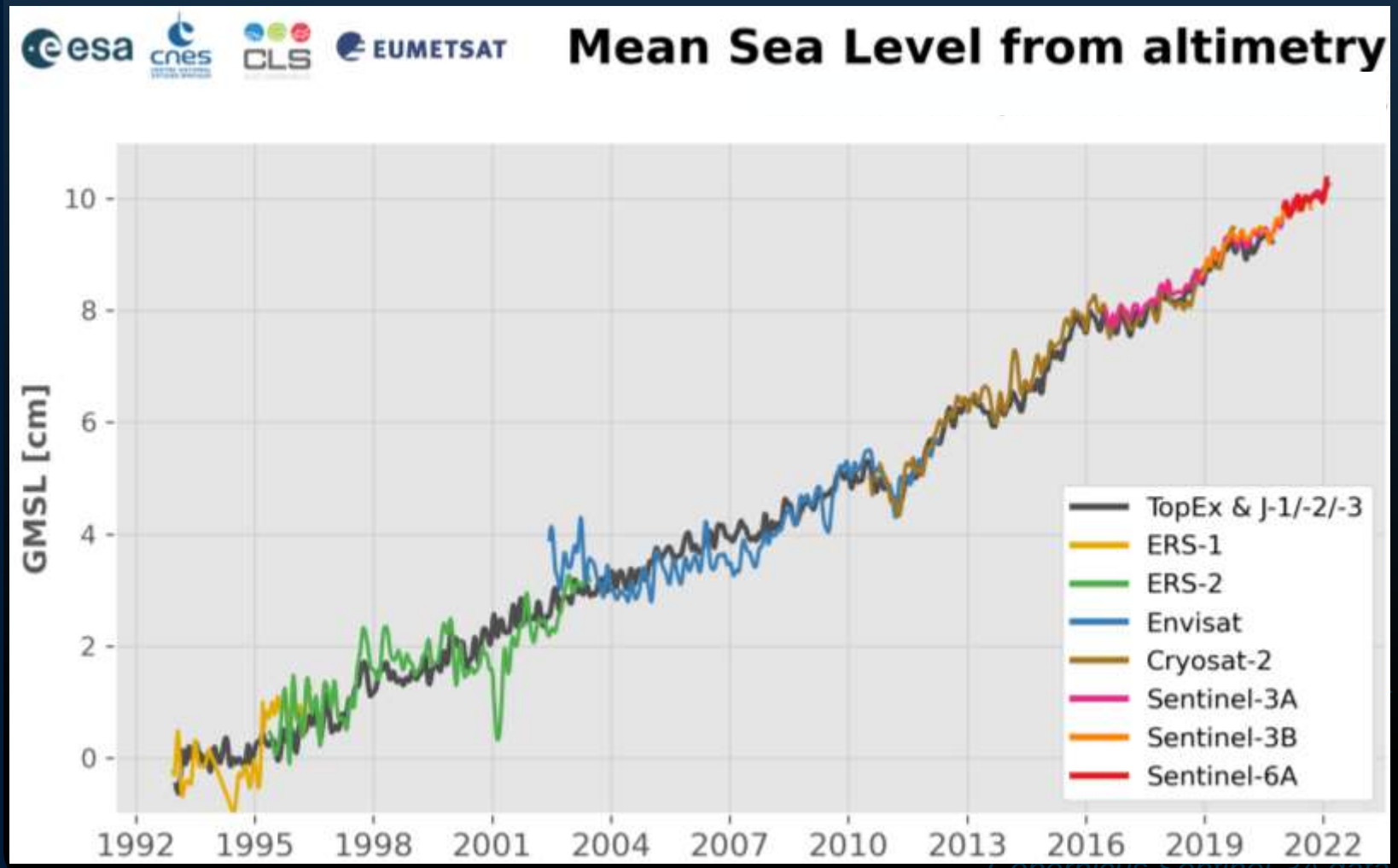
# Plant Growth in Spring




Vegetation Index
Based upon Copernicus Sentinel-3A data (2017)
© University of Southampton–J. Dash/Brockman Consult (S3-MPC)

# Applications: Sentinel-3

## Nominal operations with Sentinel-3A and Sentinel-3B




*Copernicus Sentinel-3A data*

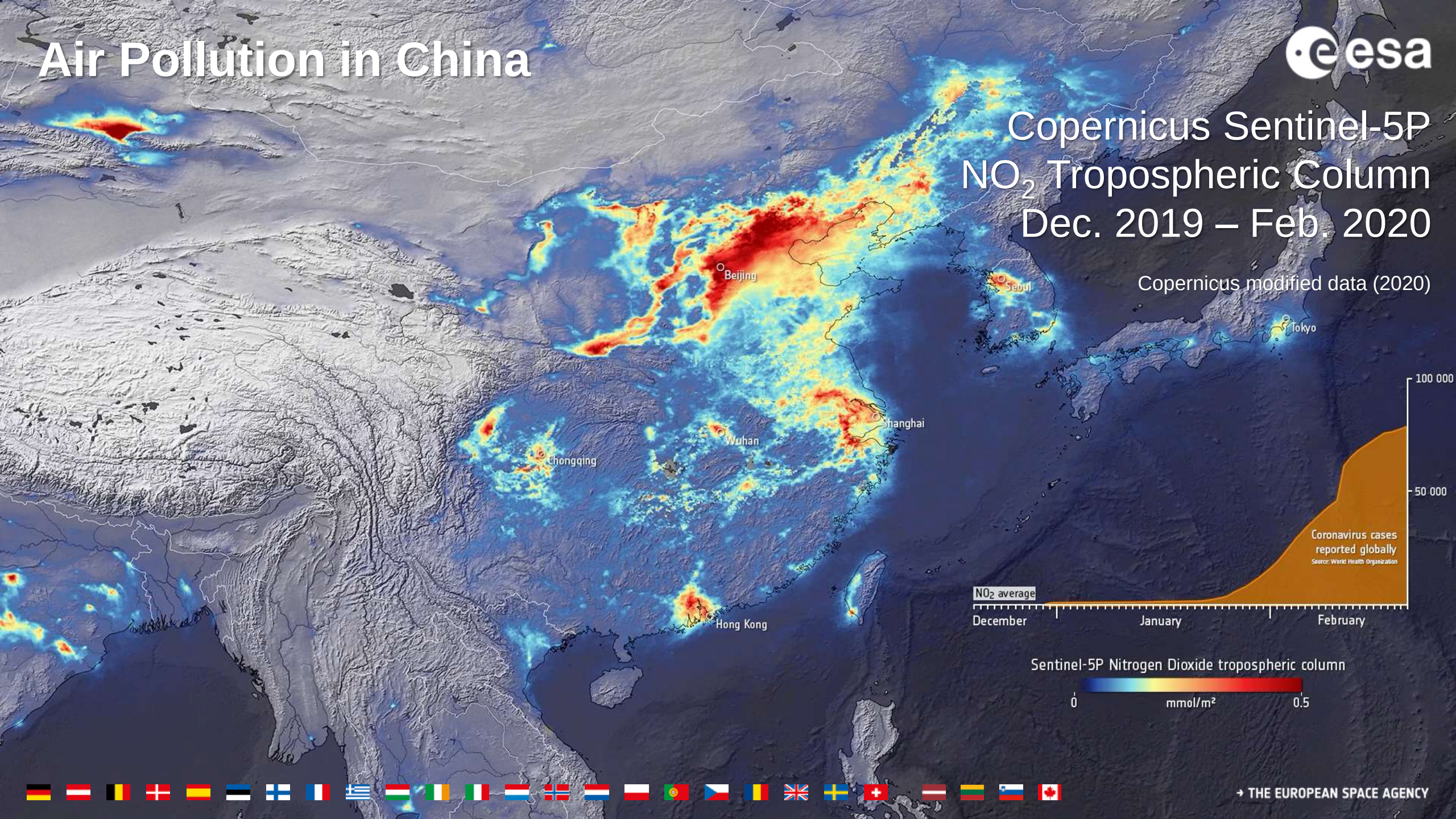
**Excellent performance of Sentinel-3 altimeters, providing continuity to the heritage missions, and in good synergy with the Jason reference measurements**

**Time-series of Mean Sea-Level Rise**

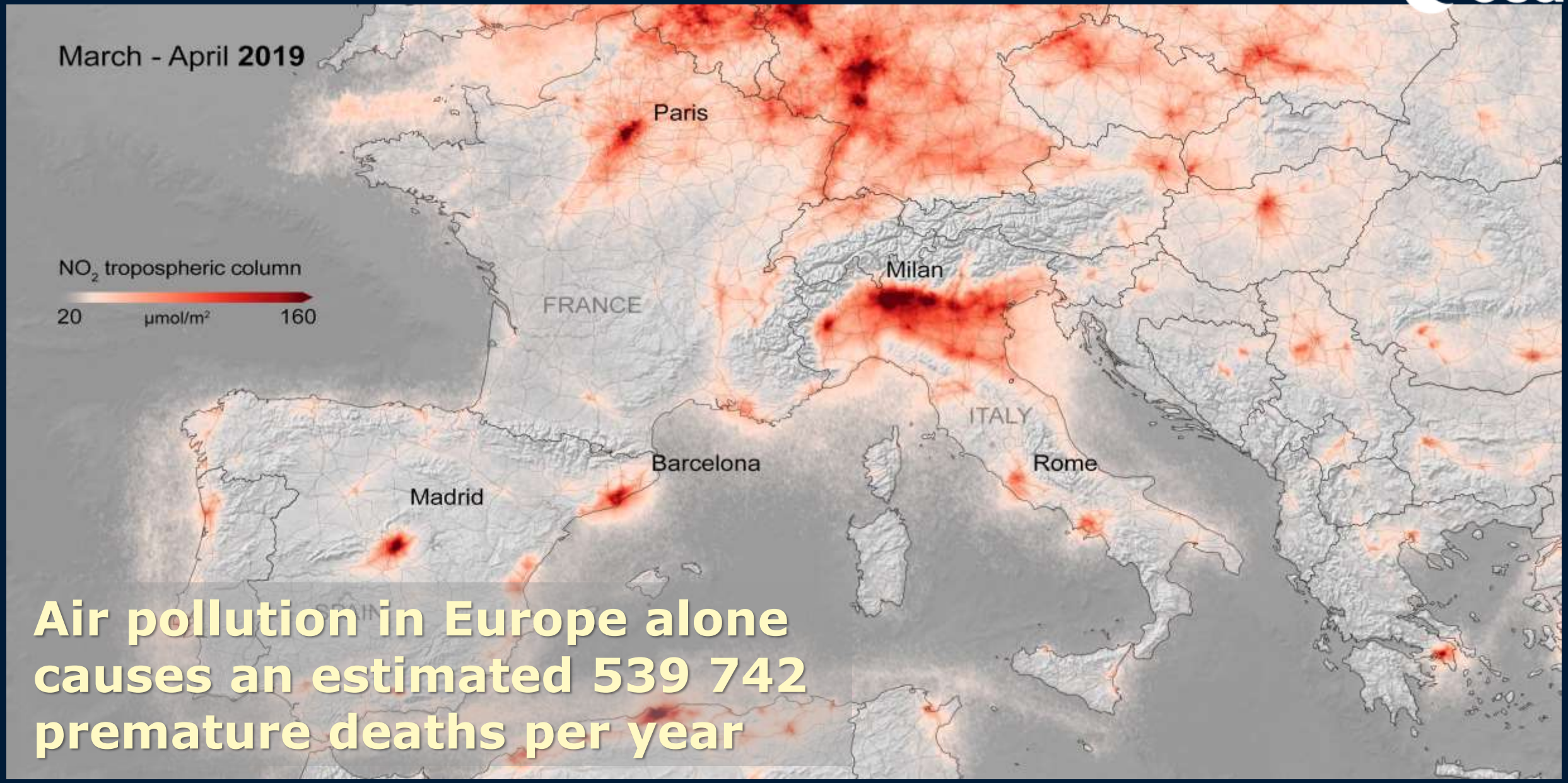
- The average rise is estimated 3.3 +/- 0.3 mm/yr over the full era (1993 - 2021)

# Sentinel-5P

# Air Pollution in China

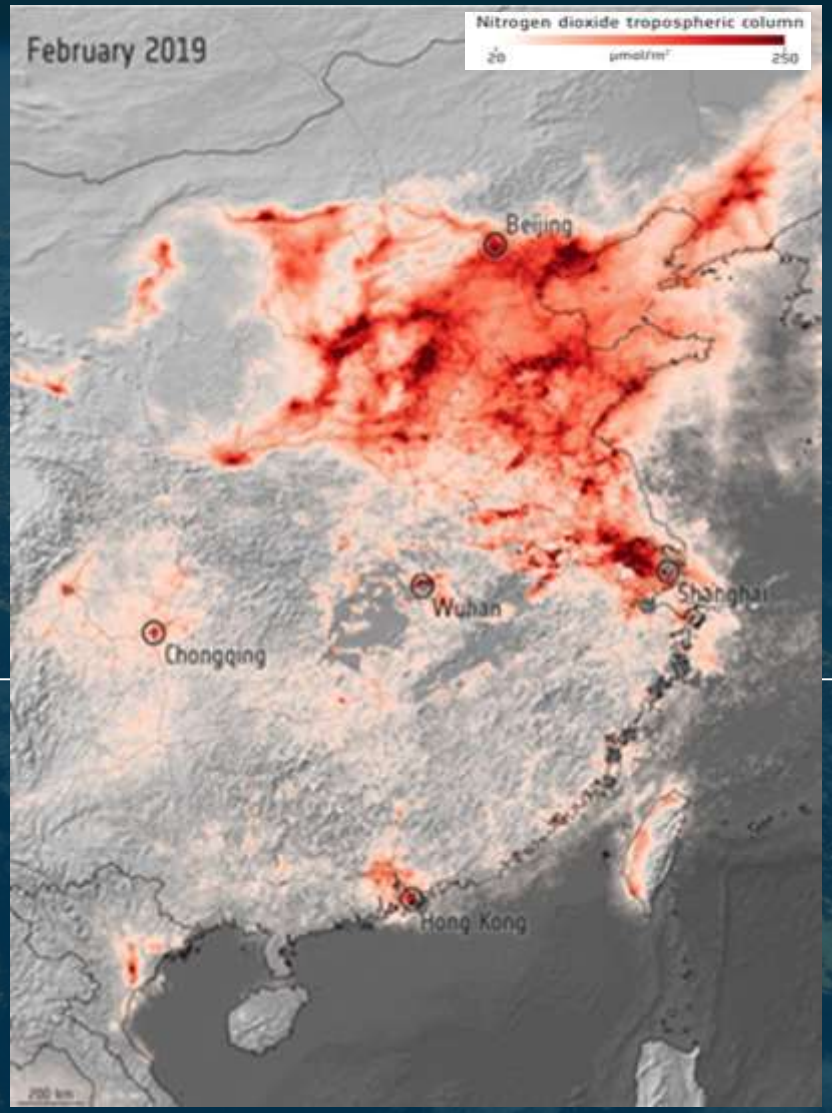


# AIR POLLUTION




**Air pollution in Europe alone causes an estimated 539 742 premature deaths per year**

# Pollution: pre, during, and post lock-down



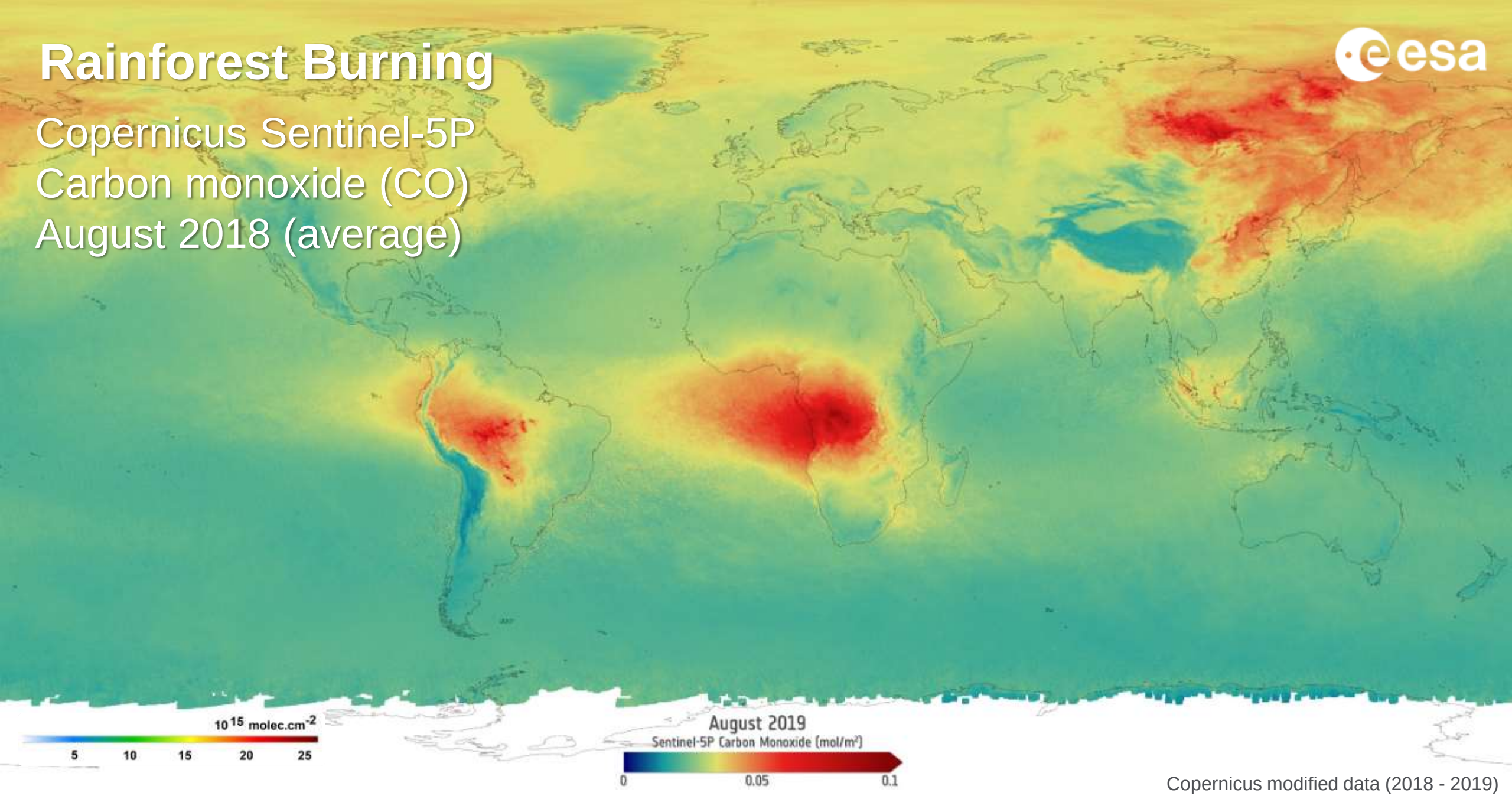

**Feb 2019 - Feb 2021**

**Copernicus Sentinel-5P**

ESA UNCLASSIFIED – For ESA Official Use Only

# Rainforest Burning

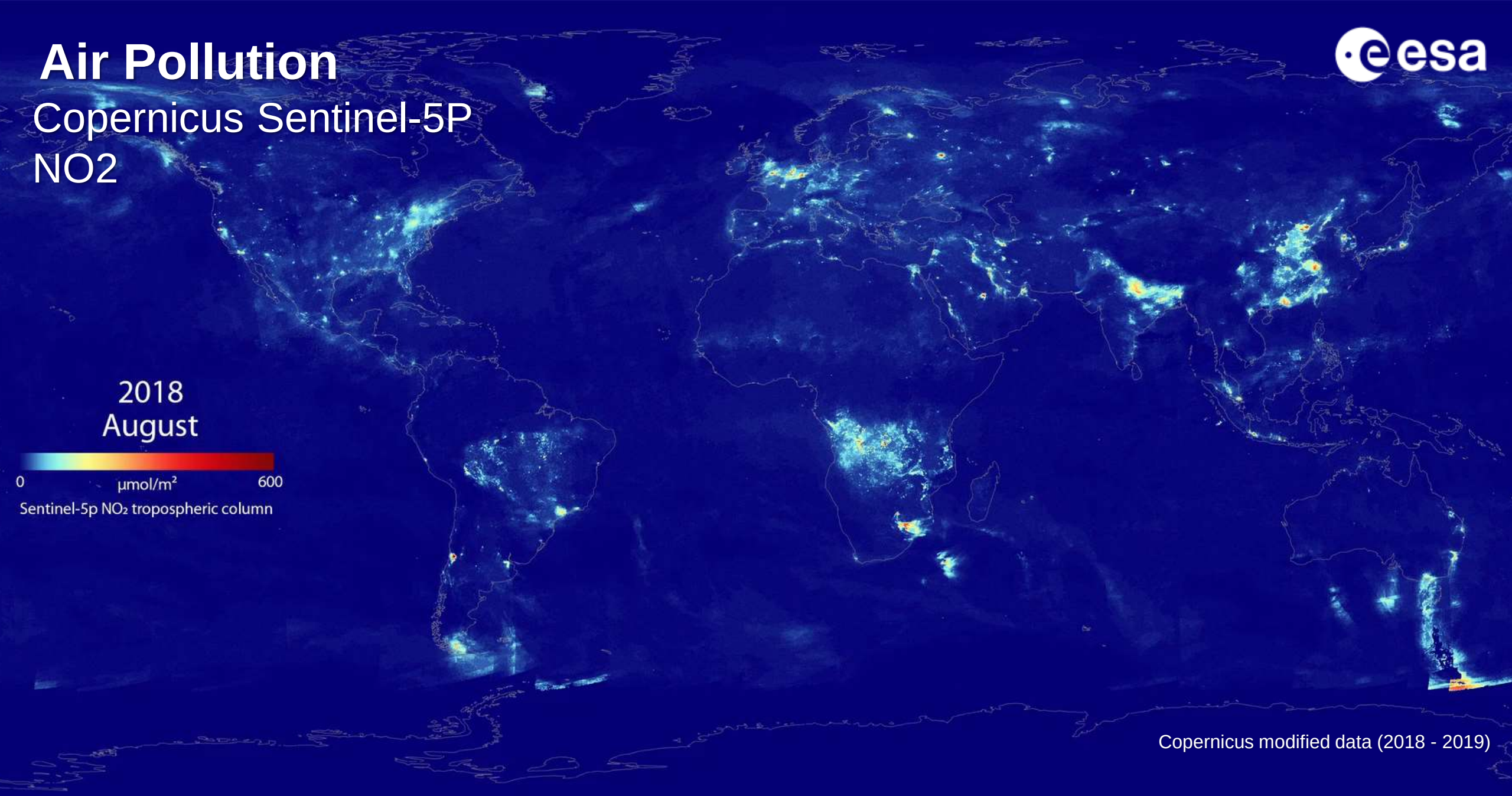
Copernicus Sentinel-5P
Carbon monoxide (CO)
August 2018 (average)




Copernicus modified data (2018 - 2019)

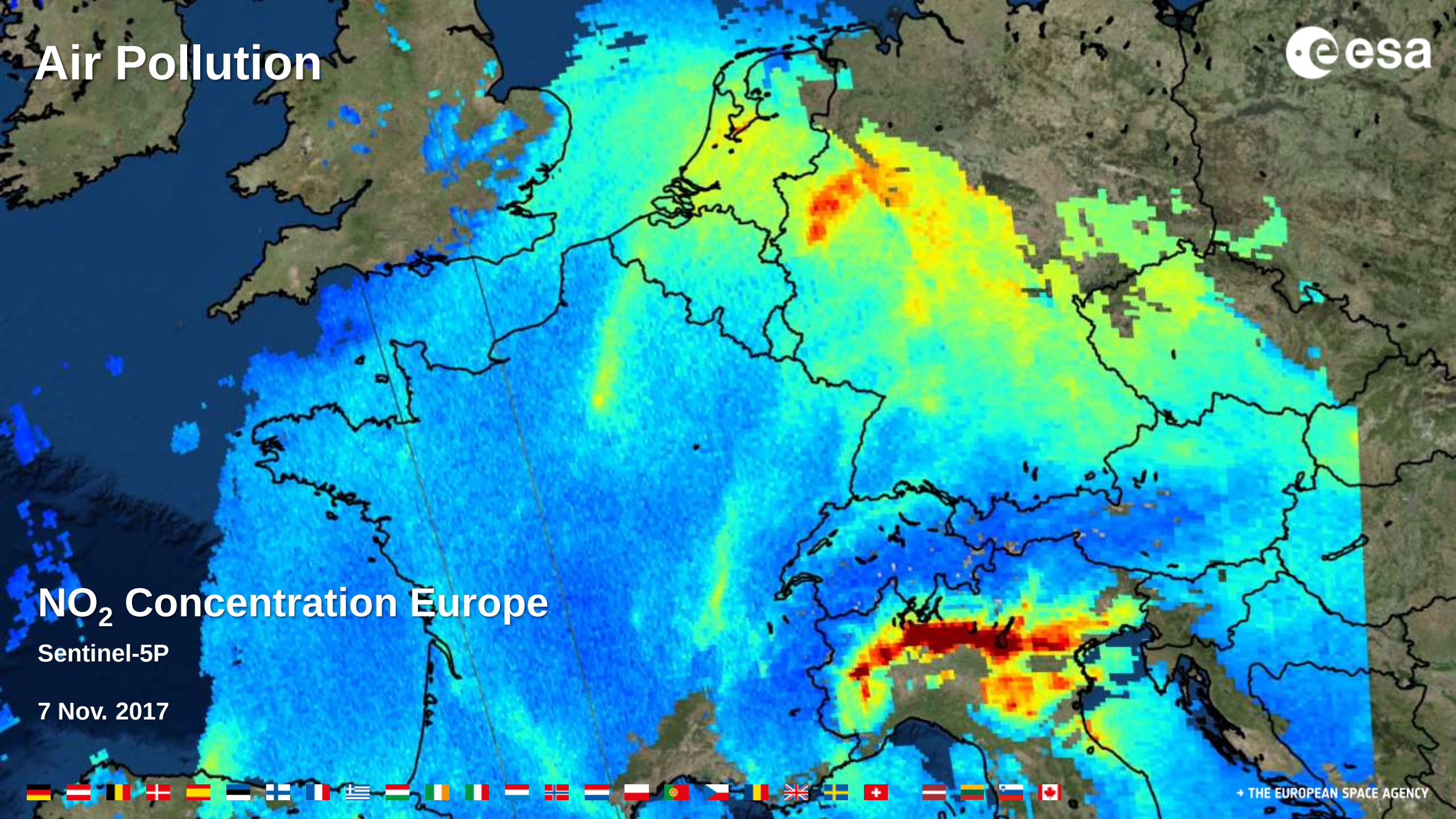
# Air Pollution

## Copernicus Sentinel-5P
## NO2




Copernicus modified data (2018 - 2019)

# Air Pollution



## $NO_2$ Concentration Europe

**Sentinel-5P**

**7 Nov. 2017**

# Air Pollution Monitoring

## Sentinel-5P

$NO_2$ Concentrations
Europe

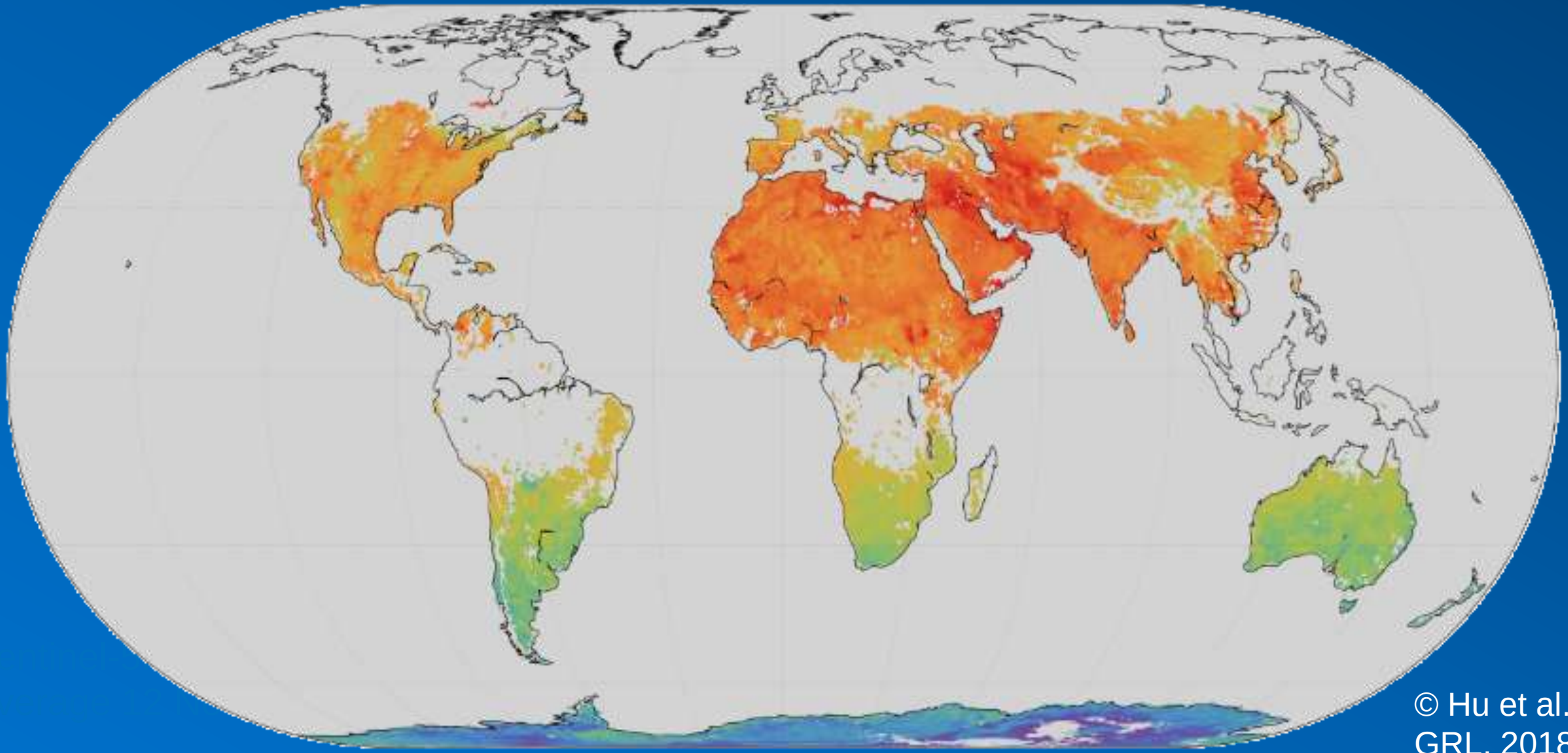
19 April 2018

© KNMI / ESA

Air pollution causes around
467,000 **premature deaths** in Europe
every **year**

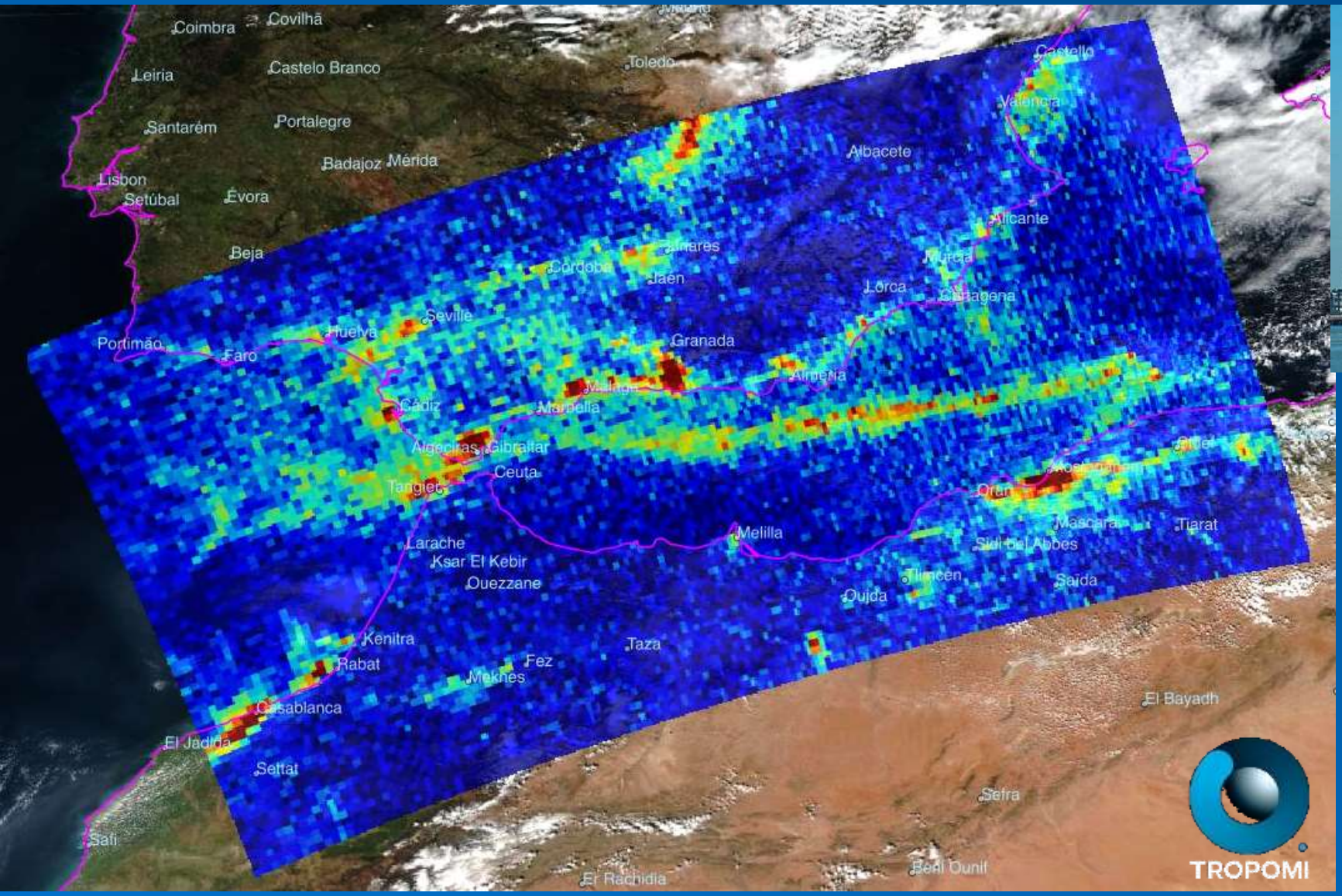
EEA 2016 Report

# Methane – Global View



© Hu et al., GRL, 2018

# Shipping Lanes: Air Pollution

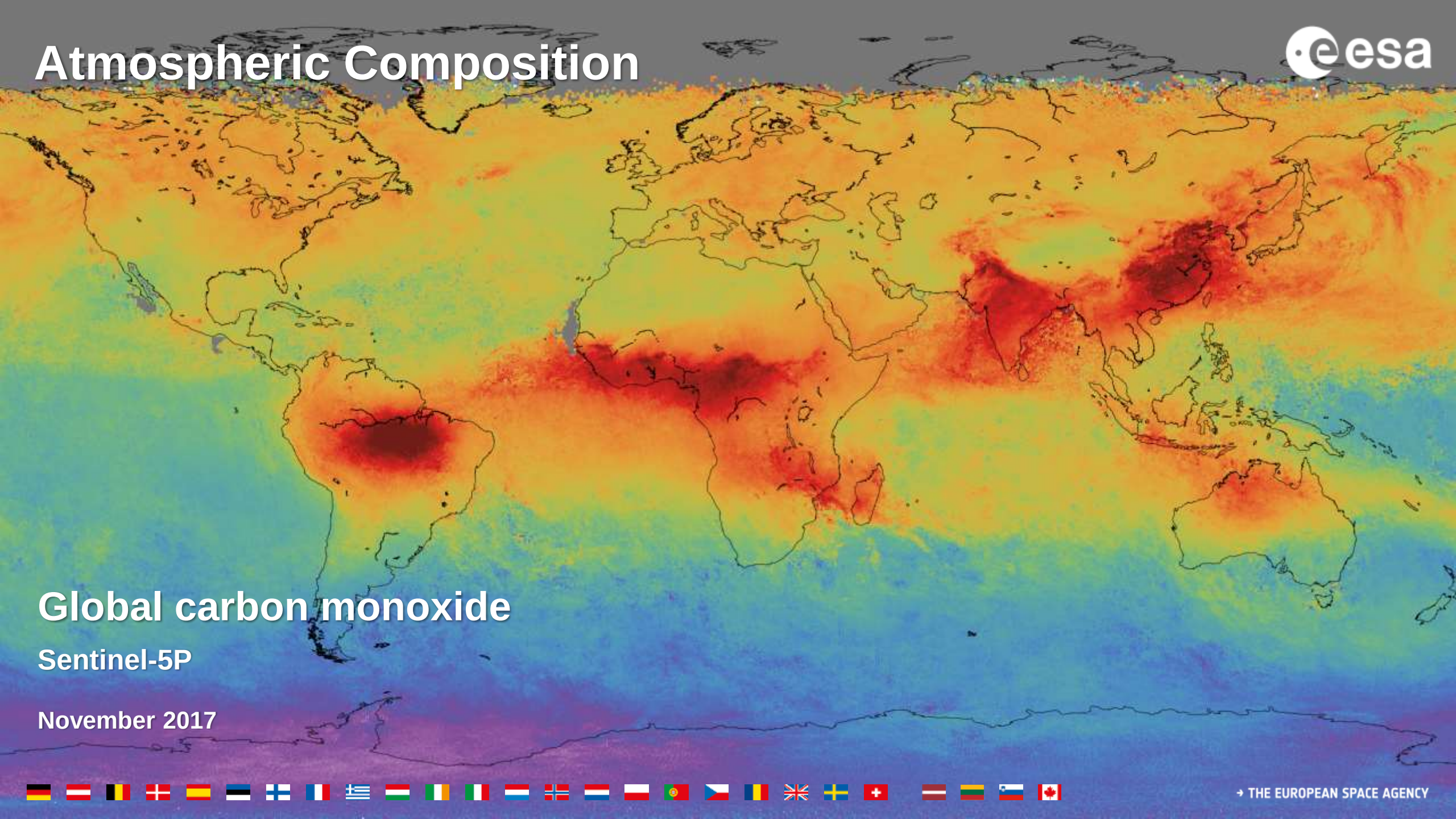


## Sentinel-5P

Street of Gibraltar
20 February 2018

© KNMI / NSO / ES

# Atmospheric Composition

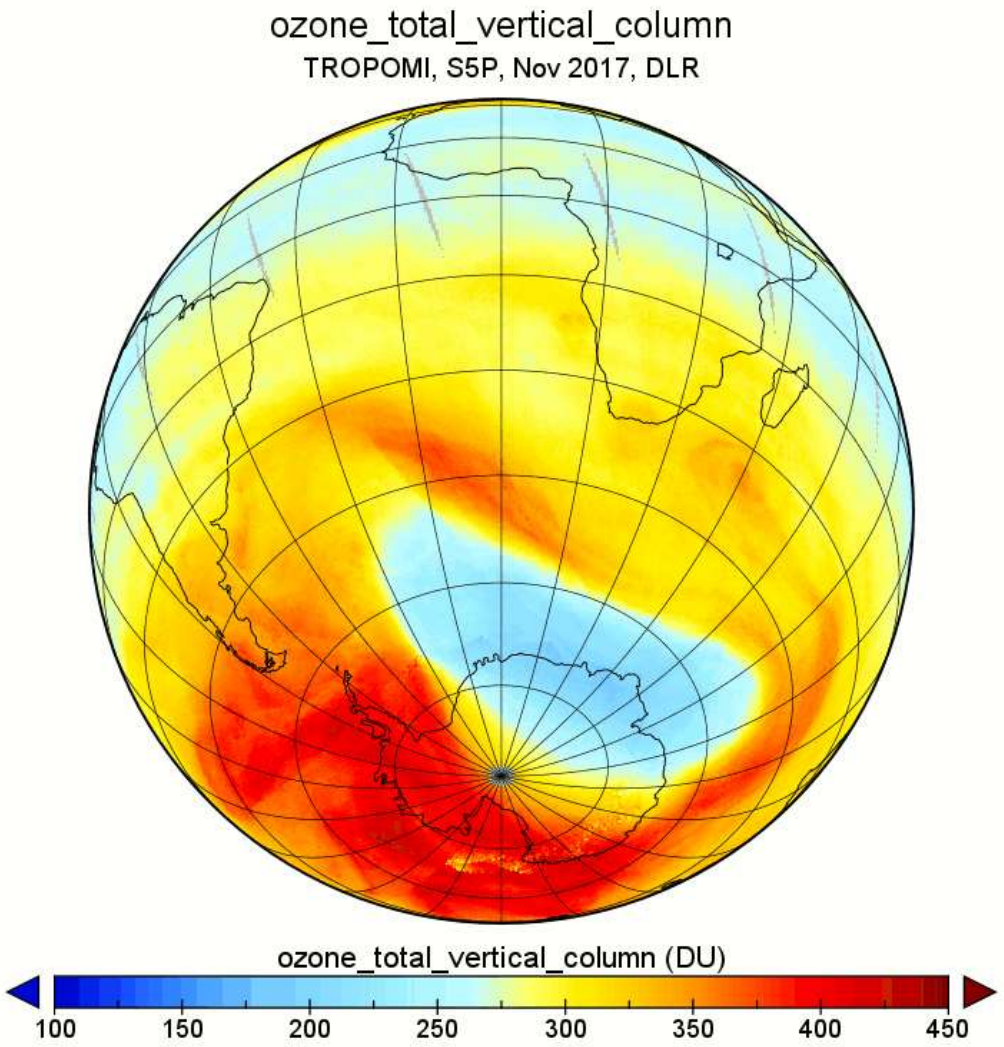


## Global carbon monoxide

**Sentinel-5P**

**November 2017**

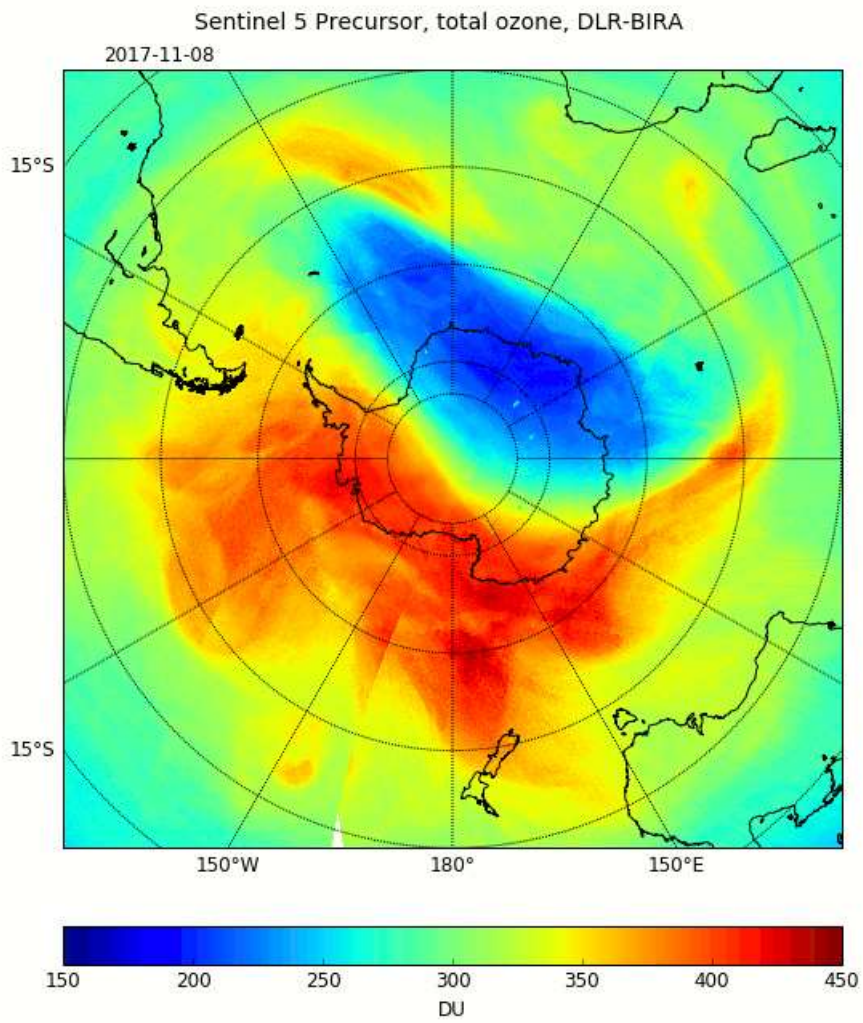
# Low Ozone Concentrations over Antarctica




November 2017
Sentinel-5P

© DLR

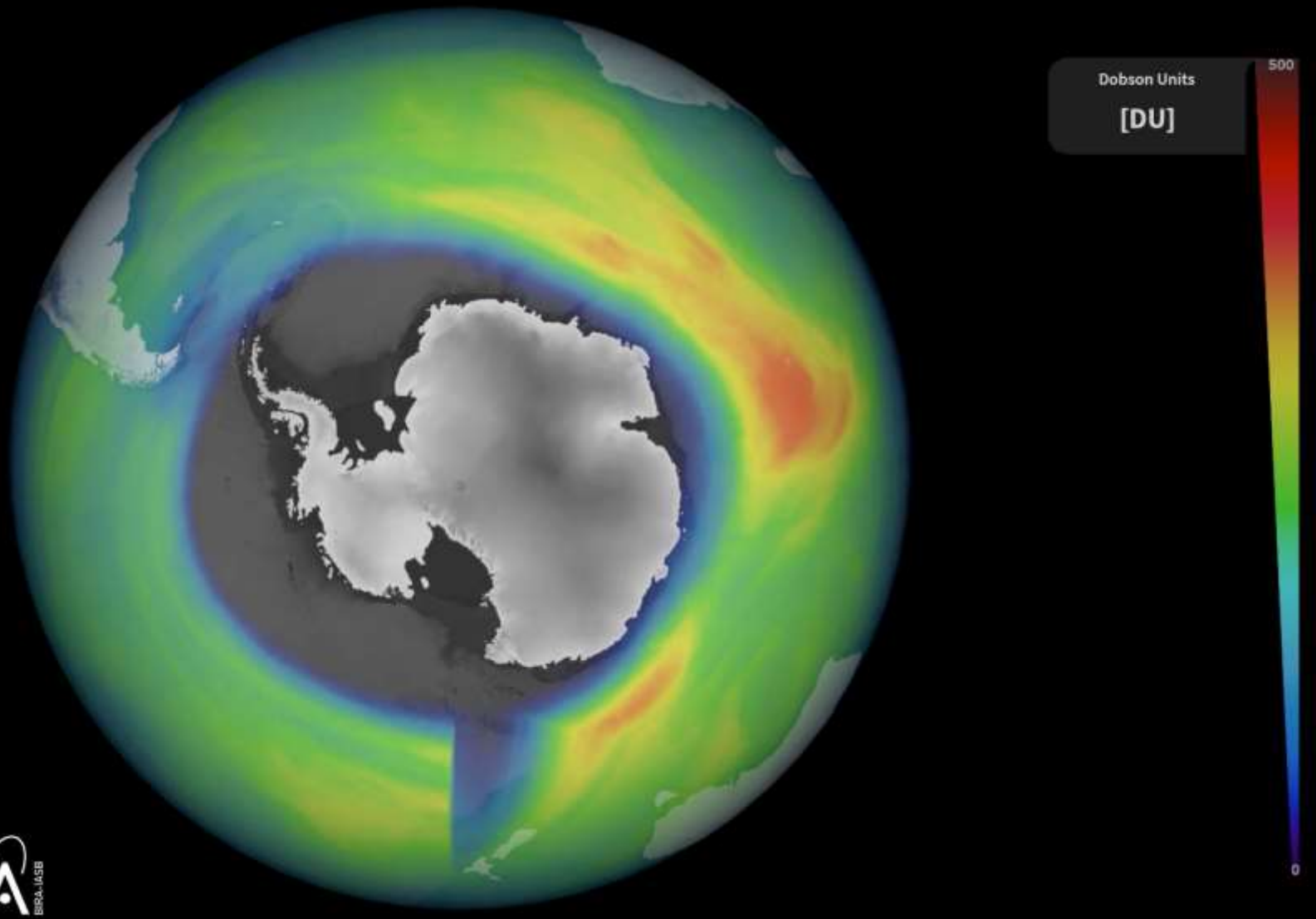
# Closing of the Ozone Hole




Released 11 July 2018

November 2017 data
Sentinel-5P

# Energy: Large ozone hole over the Antarctic

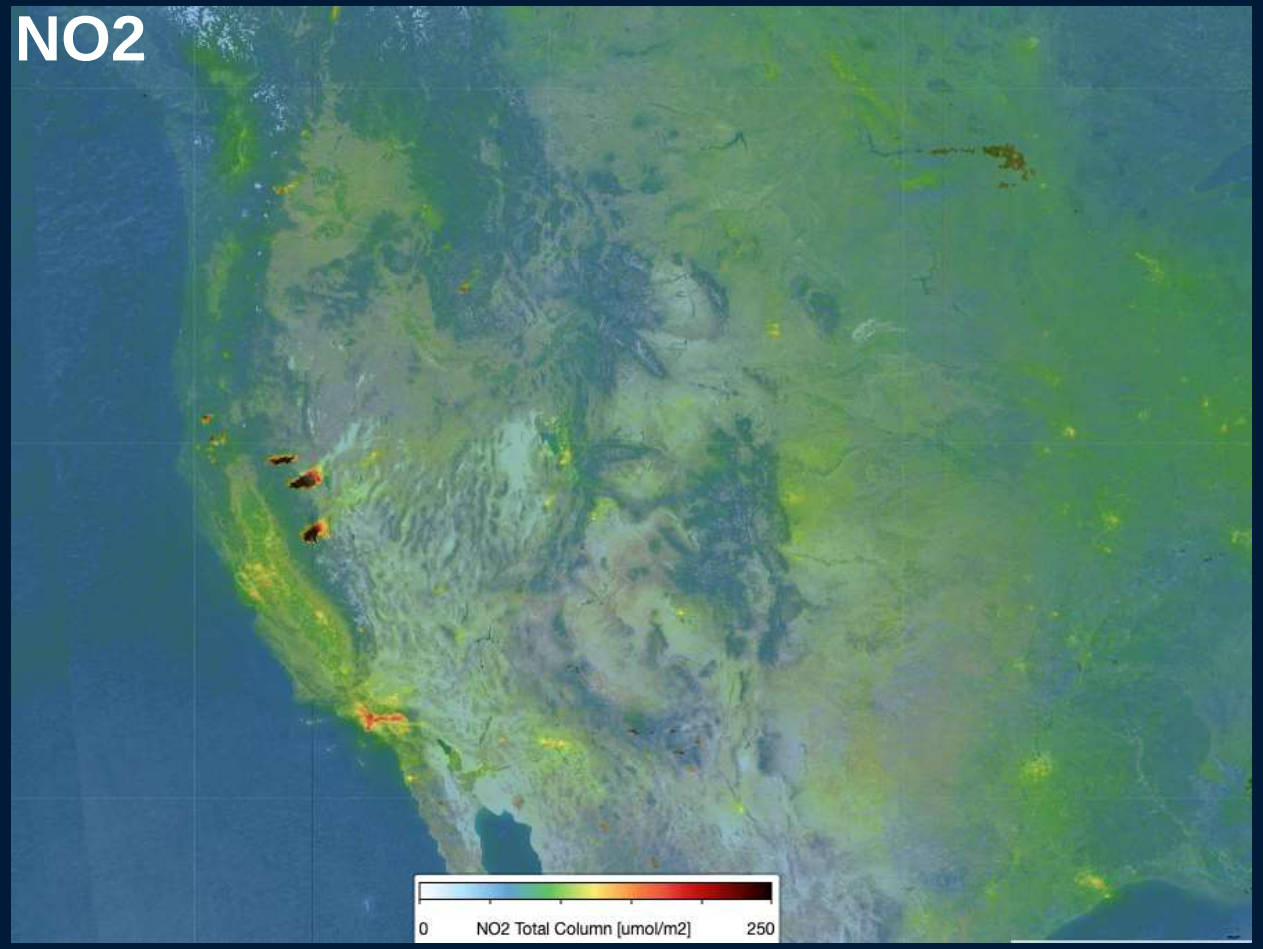


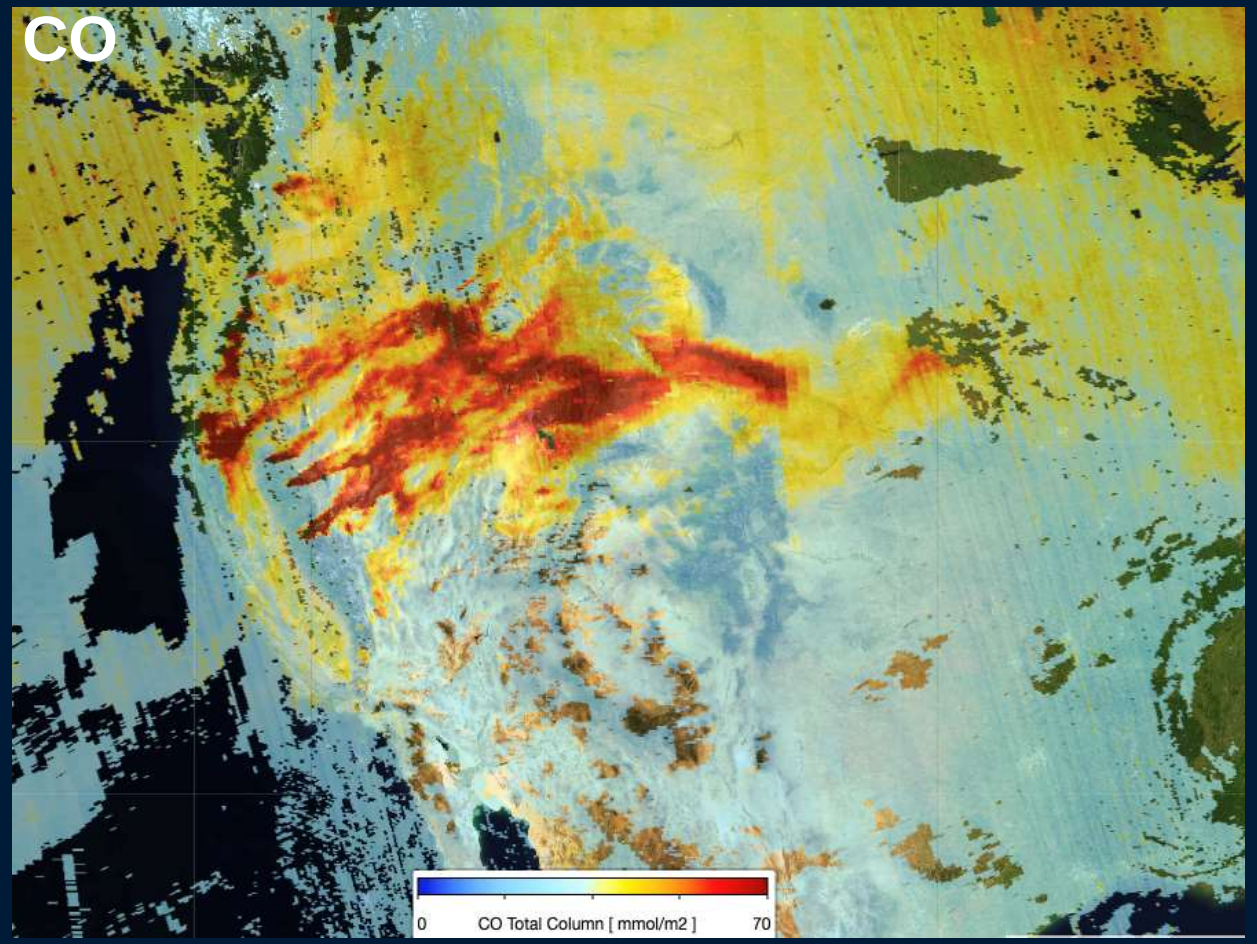

**Sentinel-5P**

DLR – Earth Observation Center (EOC)

# Sentinel-5p Applications during wildfires

## Wildfire emission measurements over Western USA (30 Aug 2021)




*Copyright: contains modified Copernicus Sentinel data (2021), processed by KNMI*

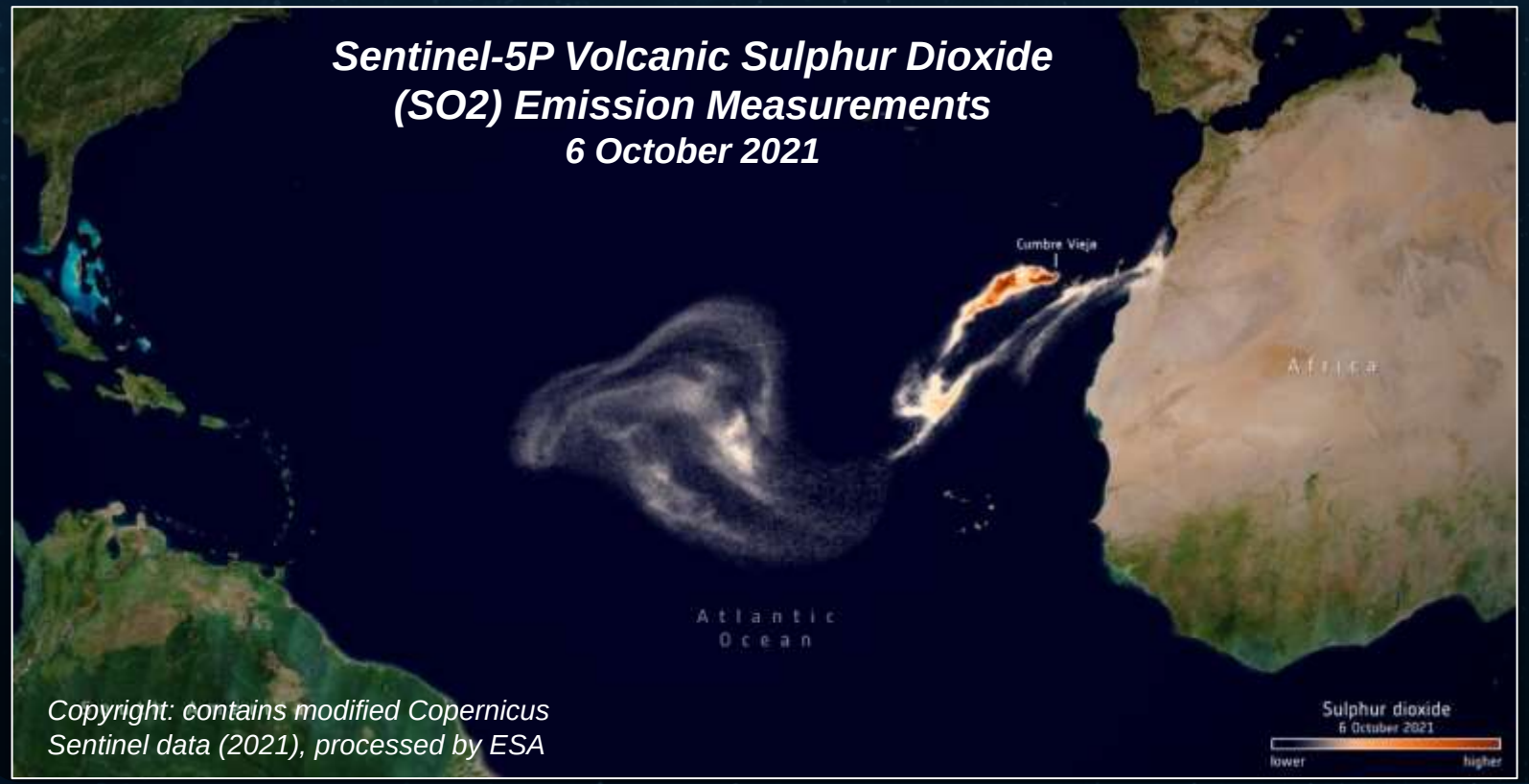
# Sentinel-5p Applications: Measuring Volcanic SO2 Emission

## *Mission Status Highlights*

- A **new Level 1 product version** (that takes into account an offset in the low UV wavelength range and corrects for degradation in irradiance measurements) was successfully implemented in July 2021 (also including upgrades of all Level 2 products)

## *Mission Outlook*

- During November 2021 will be released a new Sentinel-5P product, the **Ozone Profile product**, as well as an **improved Methane product** (providing also measurements over the sea)



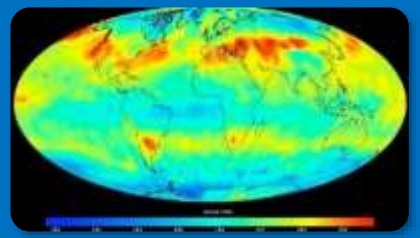

*Copyright: contains modified Copernicus Sentinel data (2021), processed by ESA*

***La Palma volcano: How satellites help us monitor eruptions***

https://www.esa.int/Applications/Observing_the_Earth/Copernicus/La_Palma_volcano_How_satellites_help_us_monitor_eruptions

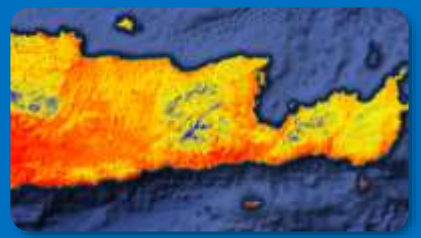
# Copernicus: Sentinel Expansion Missions

## CO2M - Anthropogenic $CO_2$ Monitoring



Causes of Climate Change

## LST – Land Surface Temperature Mission



Agriculture & Urban Management

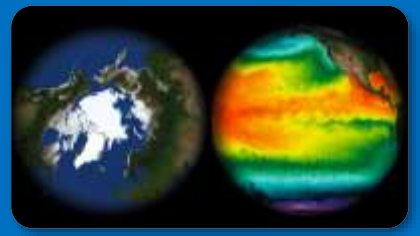
## CRISTAL – Polar Ice & Snow Topography

Effects of Climate Change

## CHIME – Hyperspectral Imaging Mission

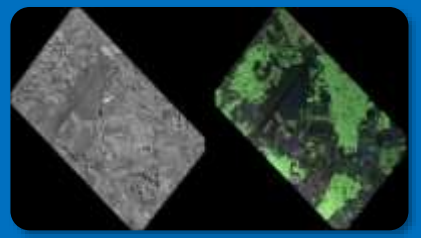
Food Security, Soil, Minerals, Biodiversity

## CIMR – Passive Microwave Radiometer



Sea: Surface Temp. & Ice Concentration

## ROSE-L – L-band SAR Mission

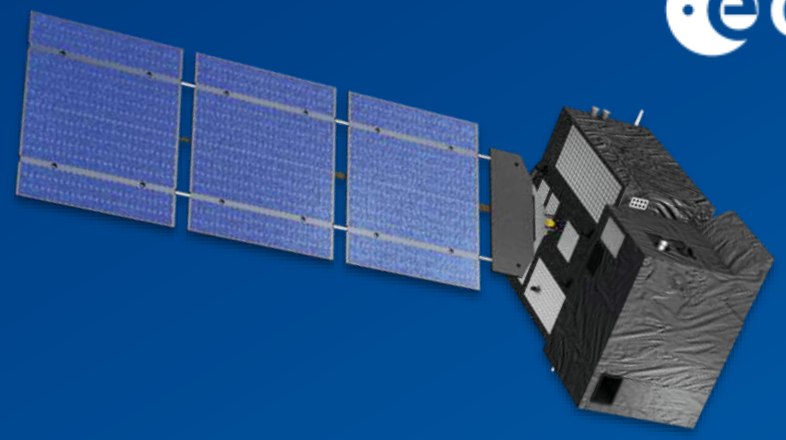


Vegetation & Ground Motion & Moisture

# CO2M

## Anthropogenic $CO_2$ Monitoring Mission

# CO2M – Science and Applications

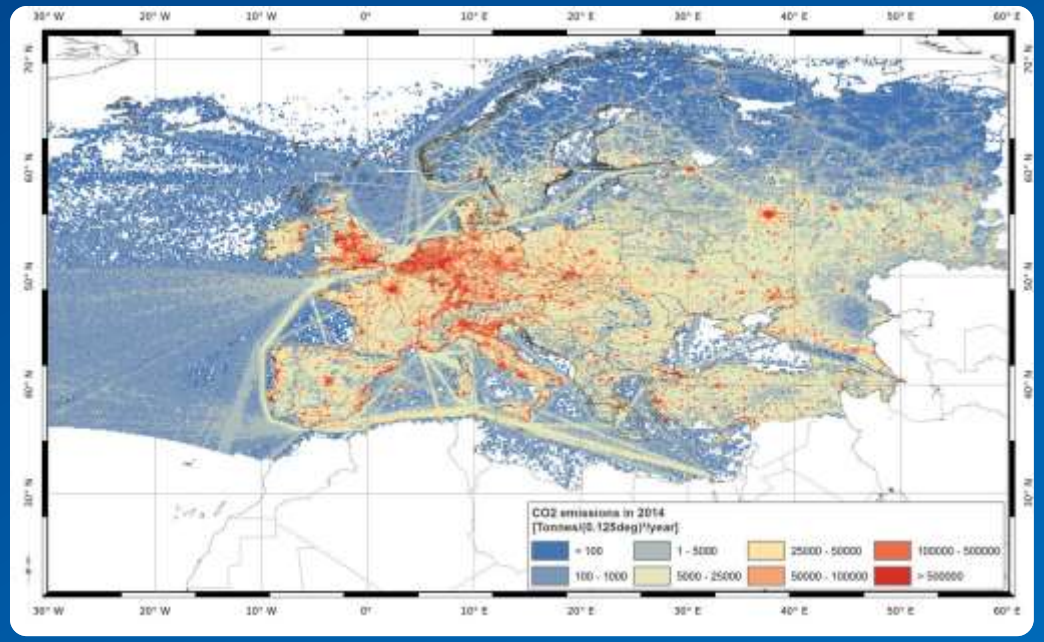


## Europe's first operational $CO_2$ mission

- Analyse man-made $CO_2$ emissions and overall $CO_2$ budget
- At country and regional/megacity scales

## Support Paris Agreement Implementation

- Assess the effectiveness of the relevant COP21 decisions
- Support global stocktake from 2023

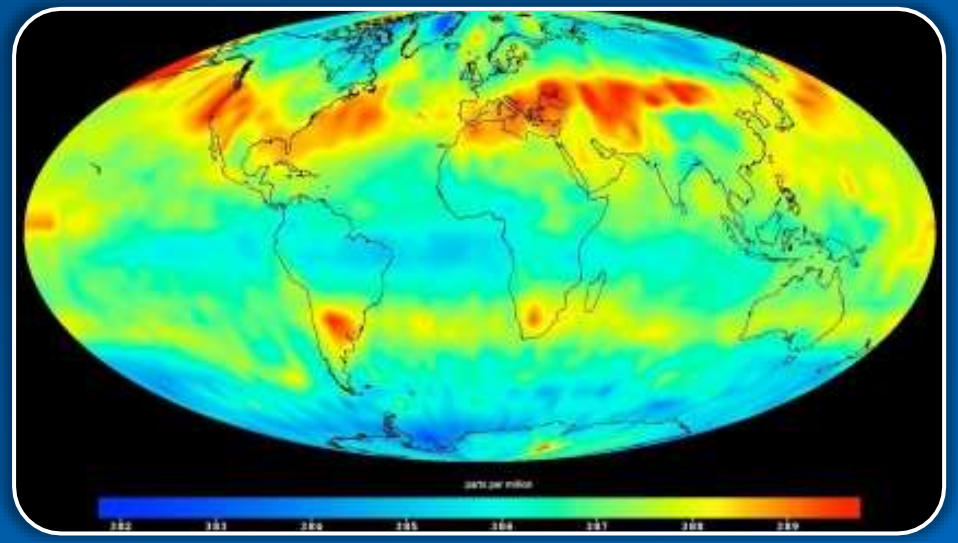


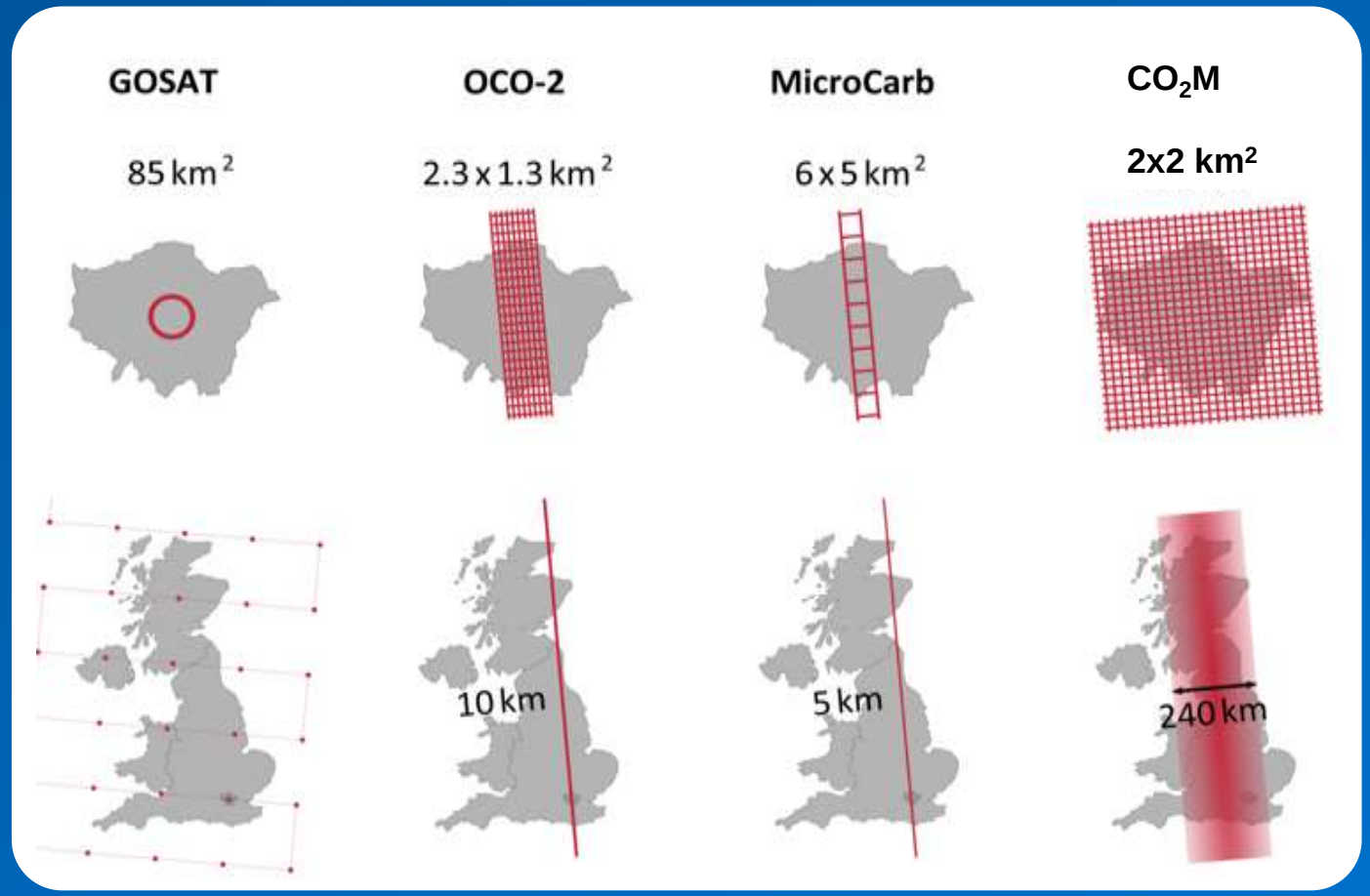

European total $CO_2$ emissions - Kuenen et al., 2014 and 2015

# CO2M

## Designed to measure anthropogenic $CO_2$ emissions

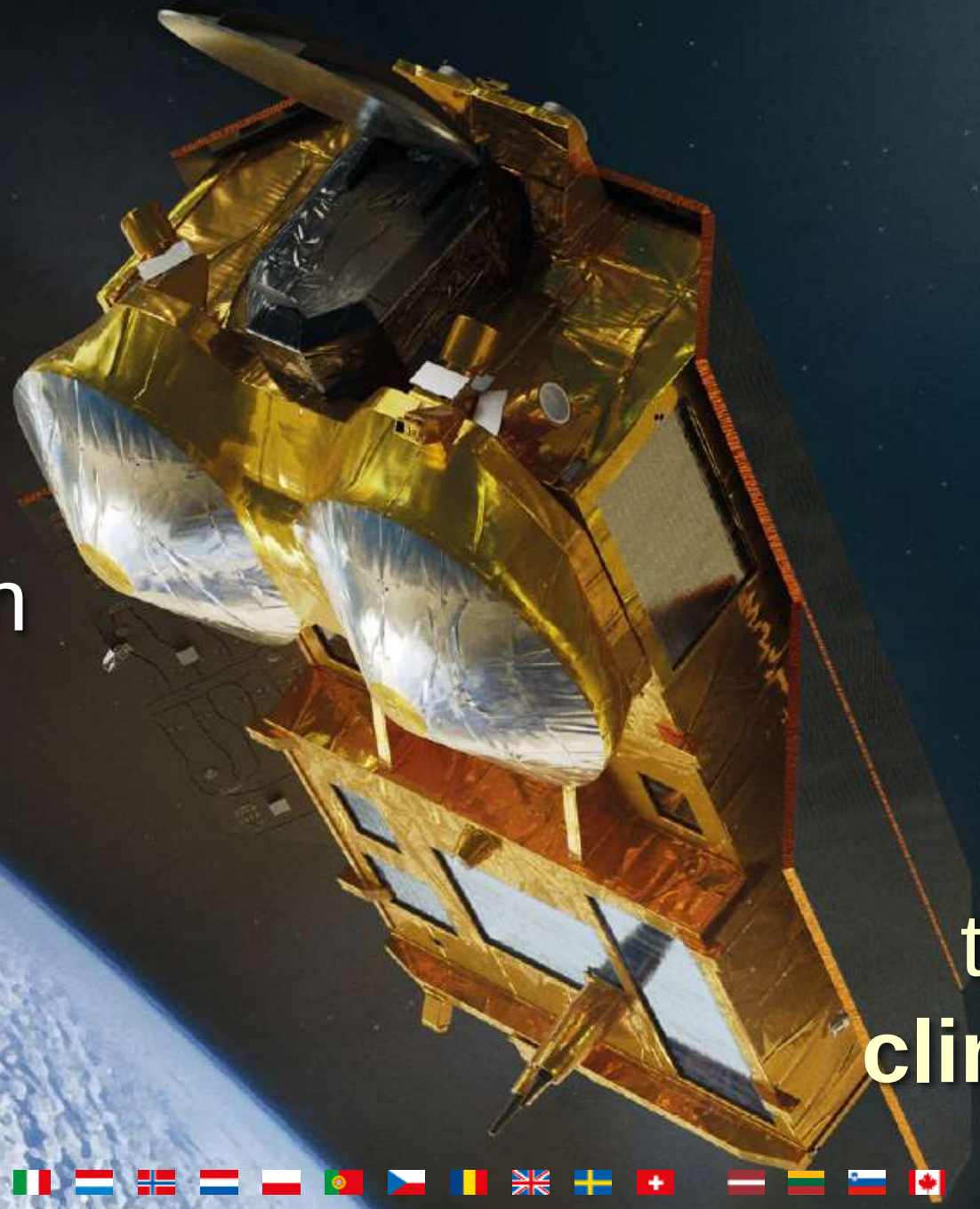
- 4 km² spatial sampling
- Global coverage - revisit time 2-3 days @40°N
- XCO2 precision 0.5 – 0.7 ppm
- Systematic bias < 0.5 ppm





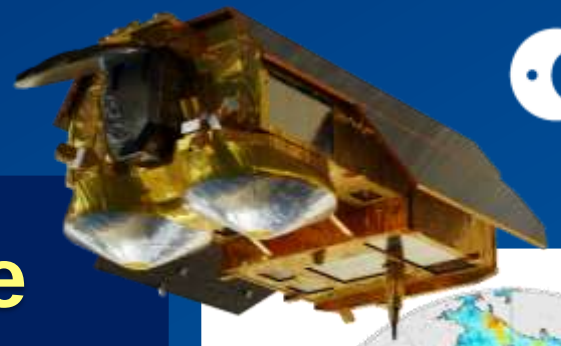
# CRISTAL

Copernicus polaR Ice and Snow Topography Altimeter Mission



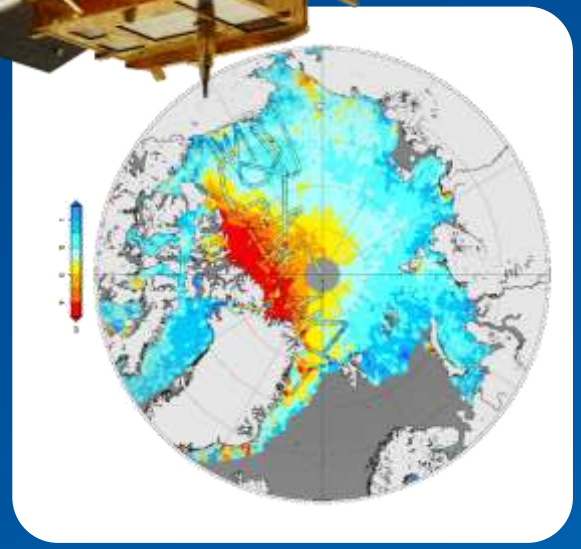
Monitoring the **effects of climate change**

# CRISTAL – Science and Applications



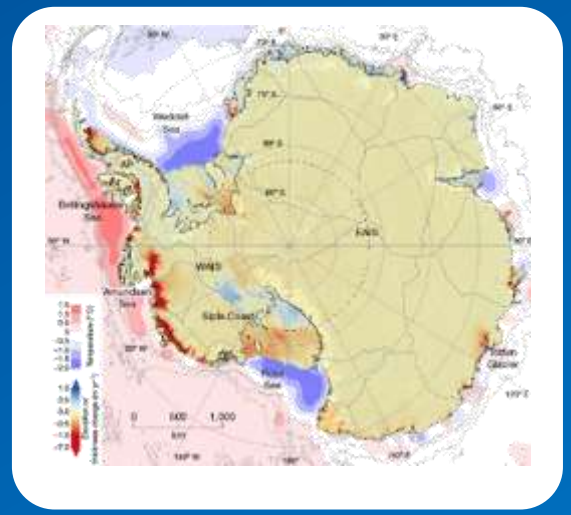
## Mapping the Effects of Climate Change

- Variability of Arctic and Southern Ocean sea-ice thickness and snow depth
- Surface elevation: changes of glaciers, ice caps and the Antarctic and Greenland ice sheets



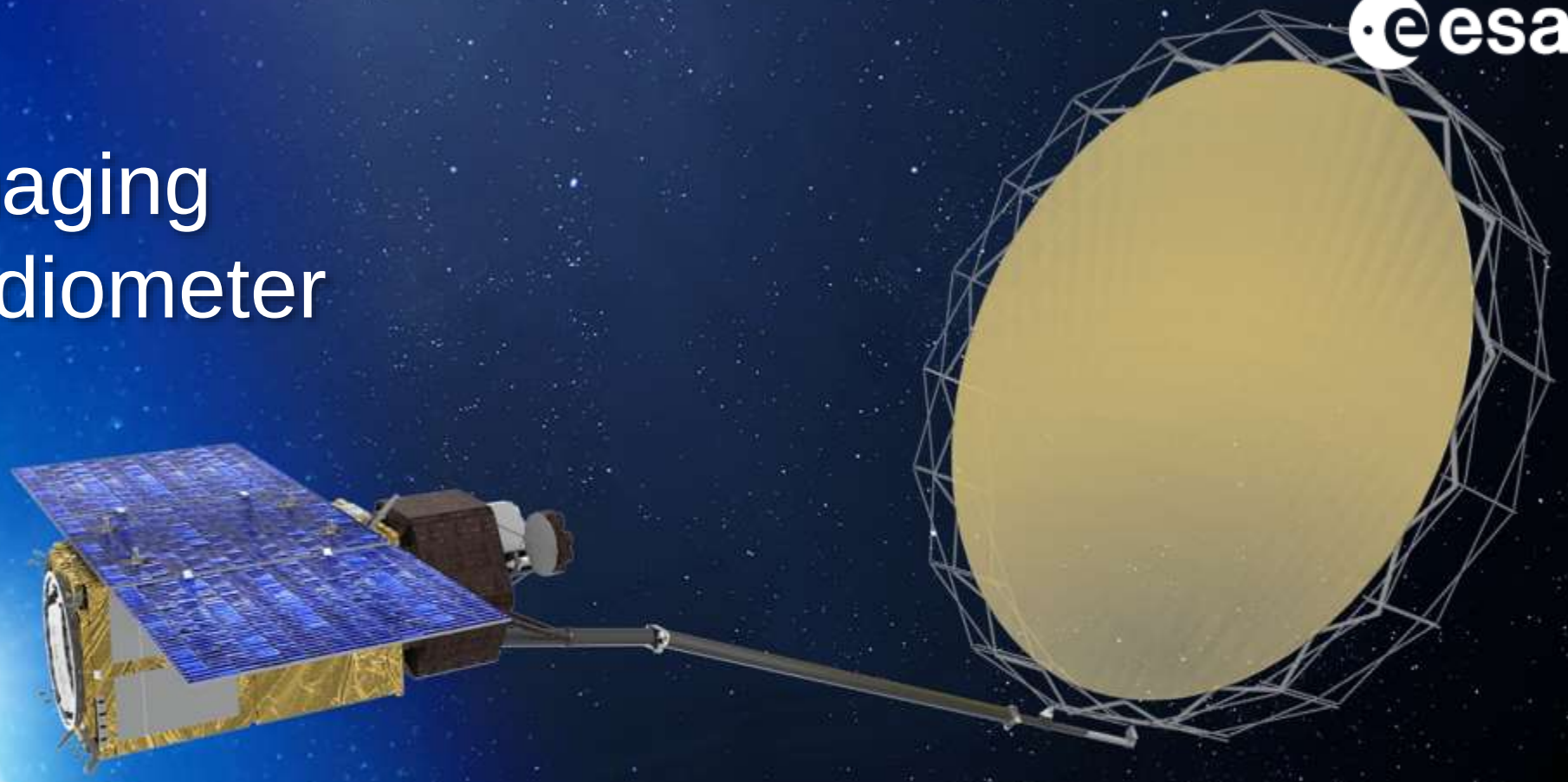
## Other Science Contributions

- Observation of global ocean topography as a continuum up to the polar seas
- Coastal and inland waters applications
- Snow cover and permafrost applications



# CIMR

## Copernicus Imaging Microwave Radiometer



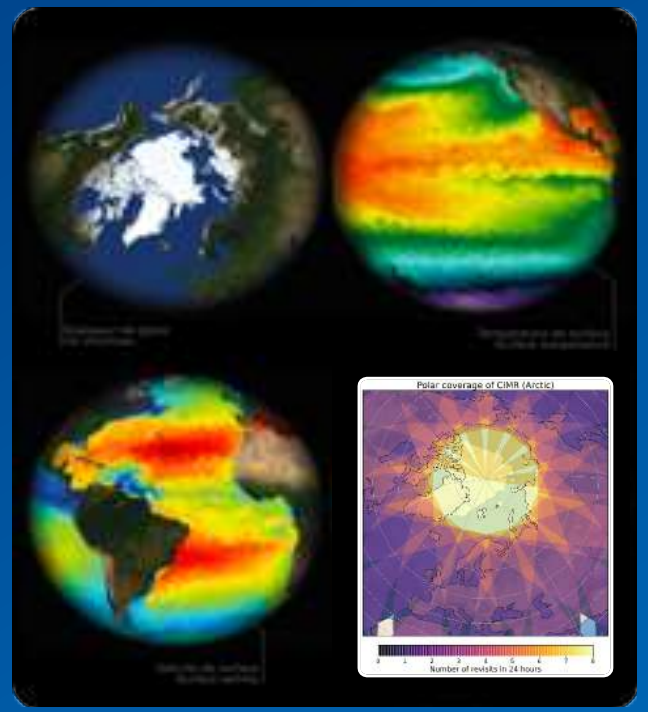
Understanding the polar oceans and their impact on our changing world

# CIMR – Science and Applications

## Polar Oceans are fundamental to understanding the global environment

### Support the EU Arctic Policy

- Measure the Polar regions every ~6 hours with 95% global daily coverage
- Enhance all Copernicus Services

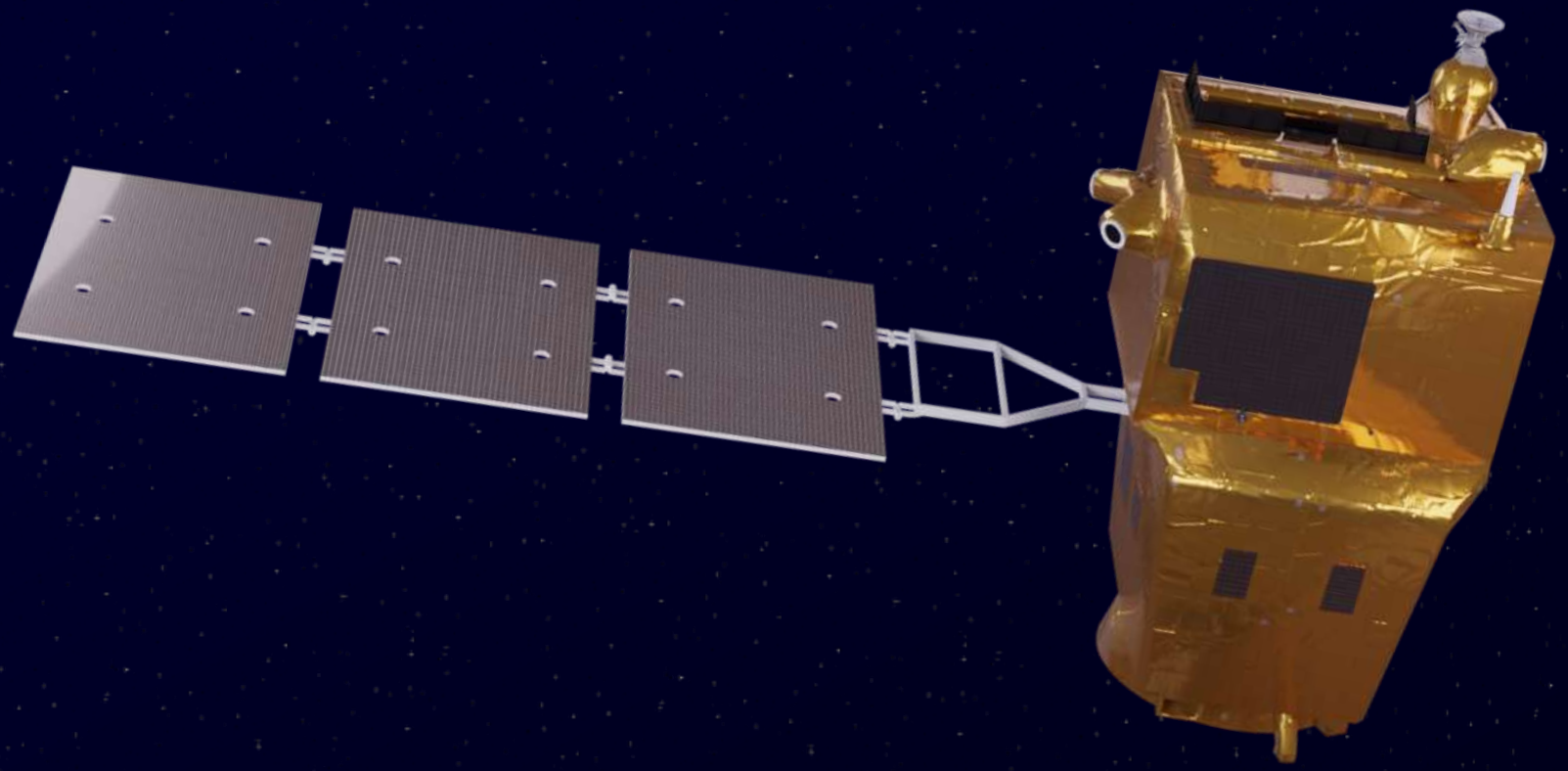



### Monitoring many polar ocean parameters

Sea Ice Concentration, Sea Surface Temperature, thin Sea Ice Thickness, Sea Surface Salinity, Wind Speed, Snow Water Equivalent, Soil Moisture

# LSTM

Land Surface Temperature Monitoring Mission

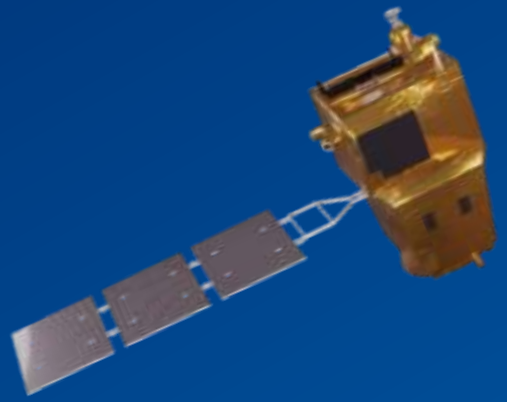


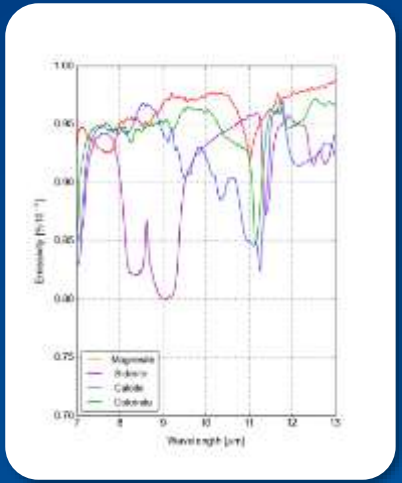
Support agriculture management services, water and food security

# LSTM – Science and Applications

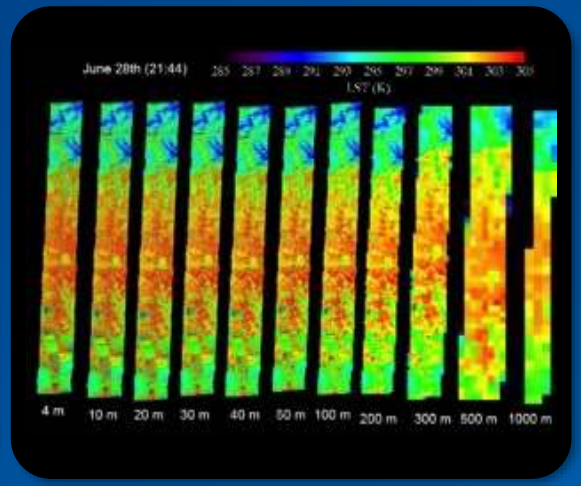
Land surface temperature observations support scientific research and applications for society

- Thermal Infrared observations over land & coastal regions
- Complement current S-2 and S-3 observations with high spatial and temporal resolution

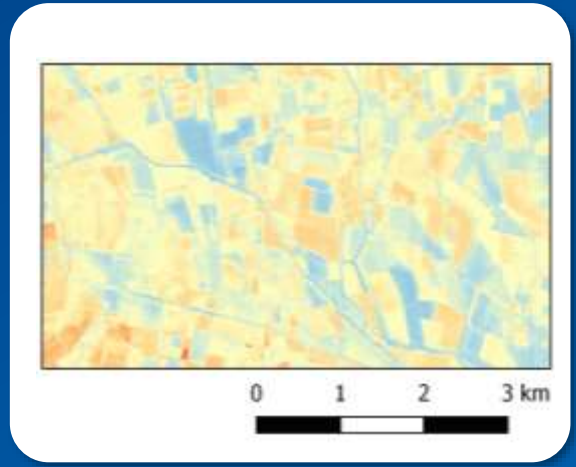




Mineralogy




Urban Heat

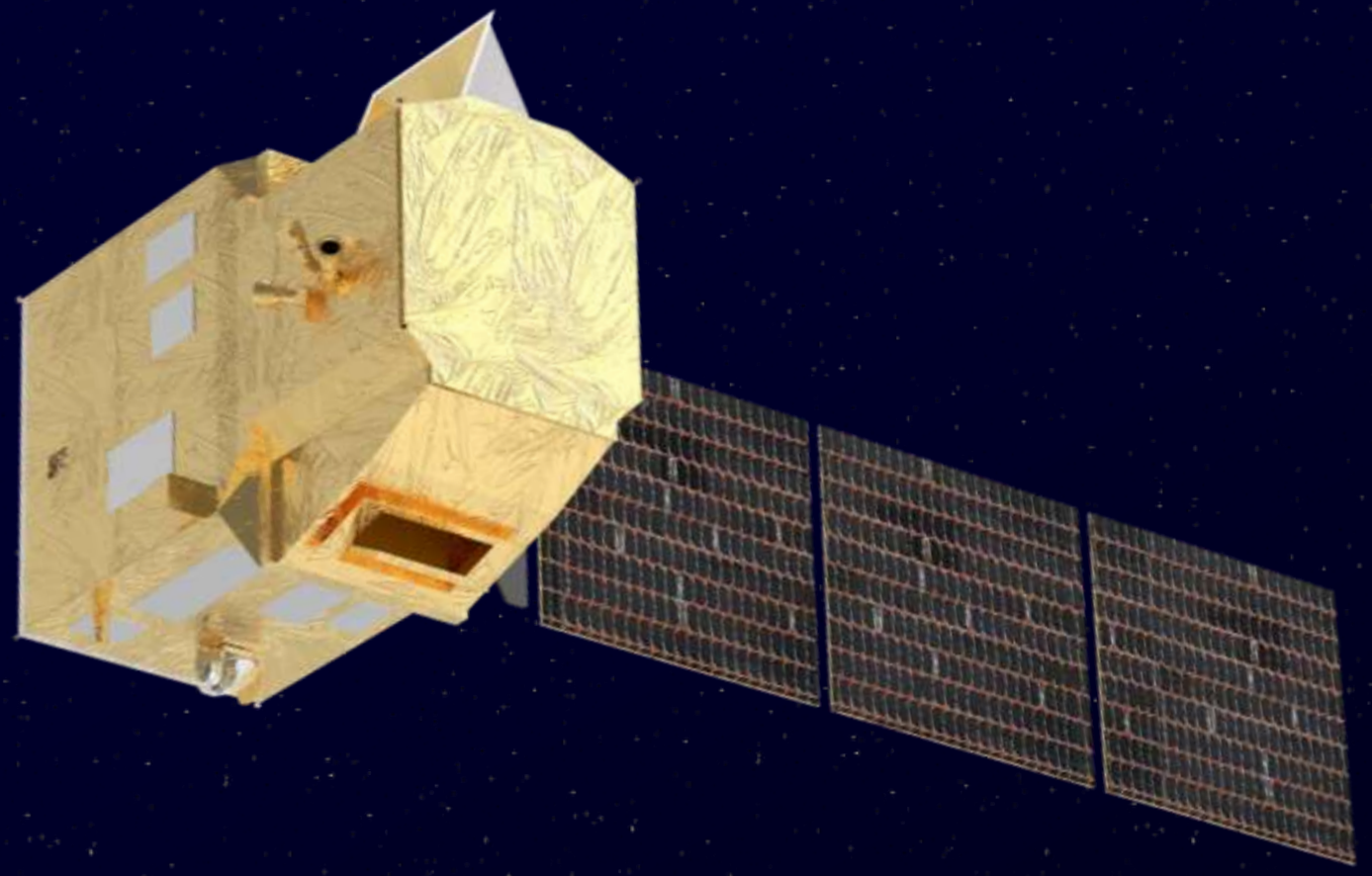



Water Stress

Permafrost Thaw Monitoring

# CHIME

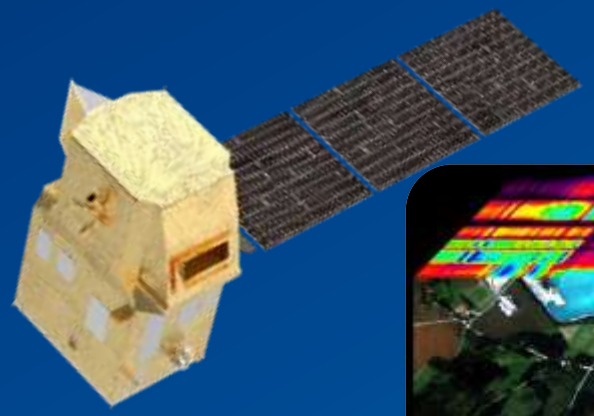
## Copernicus Hyperspectral Imaging Mission



Support the European Green Deal and management of natural resources

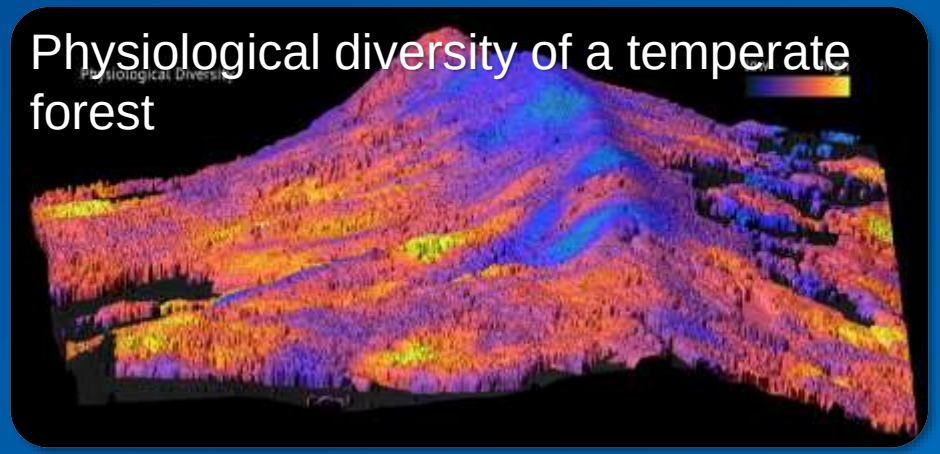
# CHIME – Science and Applications

## Support the **European Green Deal** and EU environmental policies



- Sustainable agricultural and biodiversity management, sustainable mining and environmental preservation
- Through routine hyperspectral measurements
- Support food security, agriculture, raw materials and soil management

Hyperspectral data cube
(courtesy DLR)



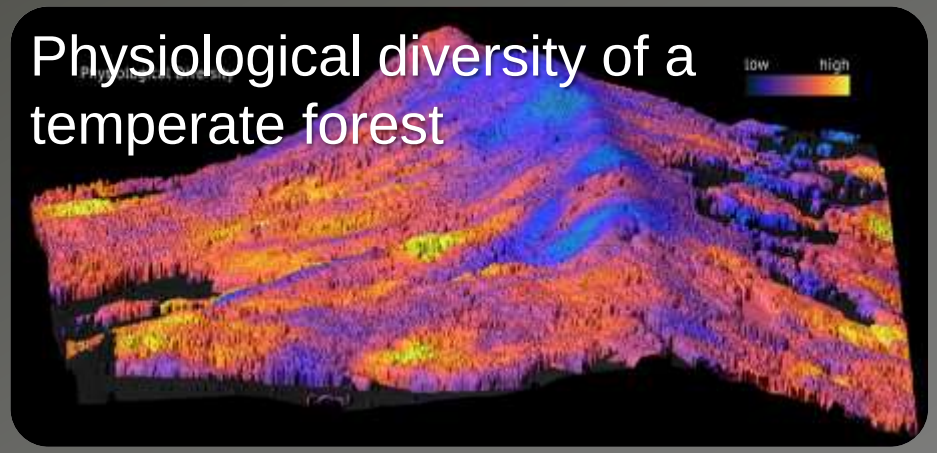

(Airborne imaging spectroscopy APEX data - Schaepman, Jehle et al. 2015)

# Copernicus Hyperspectral Imaging Mission (CHIME)

Provide routine hyperspectral measurements in support of EU- and related policies for the management of natural resources & assets

- Applications for biodiversity and ecosystem sustainability, forestry management, environmental degradation, lake/coastal ecosystems and water quality, snow grain size/albedo, snow impurities)
- Support food security, agriculture and raw materials, soil properties

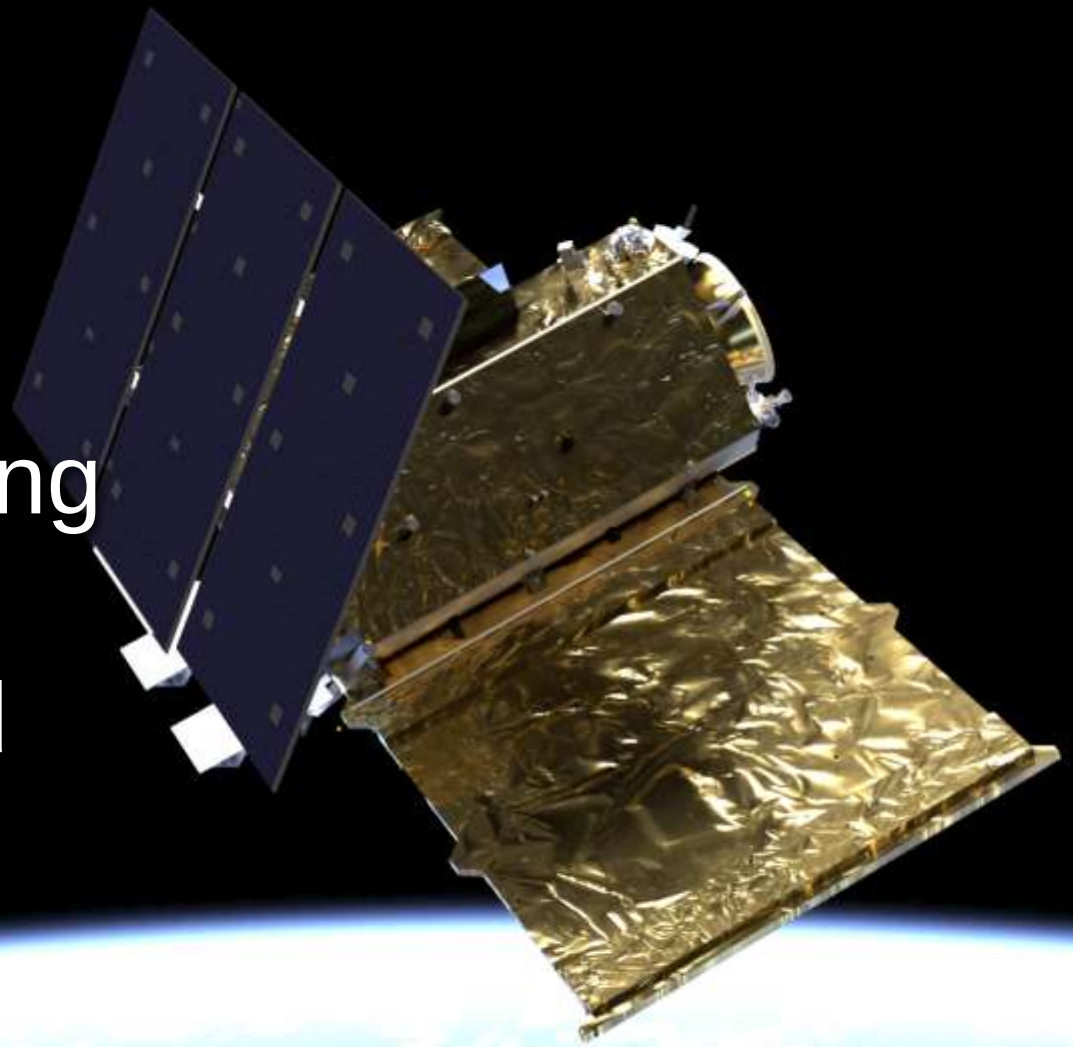
Hyperspectral data cube
(courtesy DLR)




(Airborne imaging spectroscopy APEX data - Schaepman, Jehle et al. 2015)

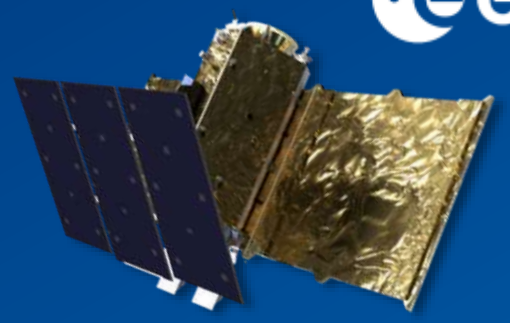
# ROSE-L

Radar Observing System for Europe L-band



Better services for disasters & geohazards, forests & agriculture management

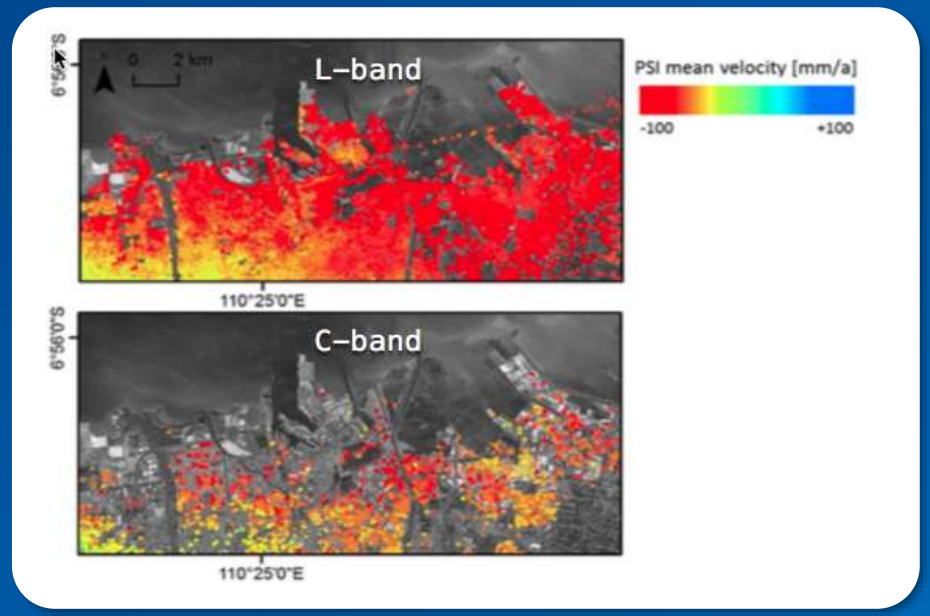
# ROSE-L – Science and Applications



## Improve services for Disasters & Geohazards, Forests, Agriculture and high-resolution monitoring of Arctic & Cryosphere

- L-band SAR has strong all-weather capabilities
- Improve disaster mitigation: earthquakes and volcanoes, landslides, flooding etc.
- Land use and agriculture as well as snow and ice applications

Temporal variations in Soil moisture & Crop type




Mapping fast subsidence rates of Semarang (Indonesia) using point scatters at L-band & C-band