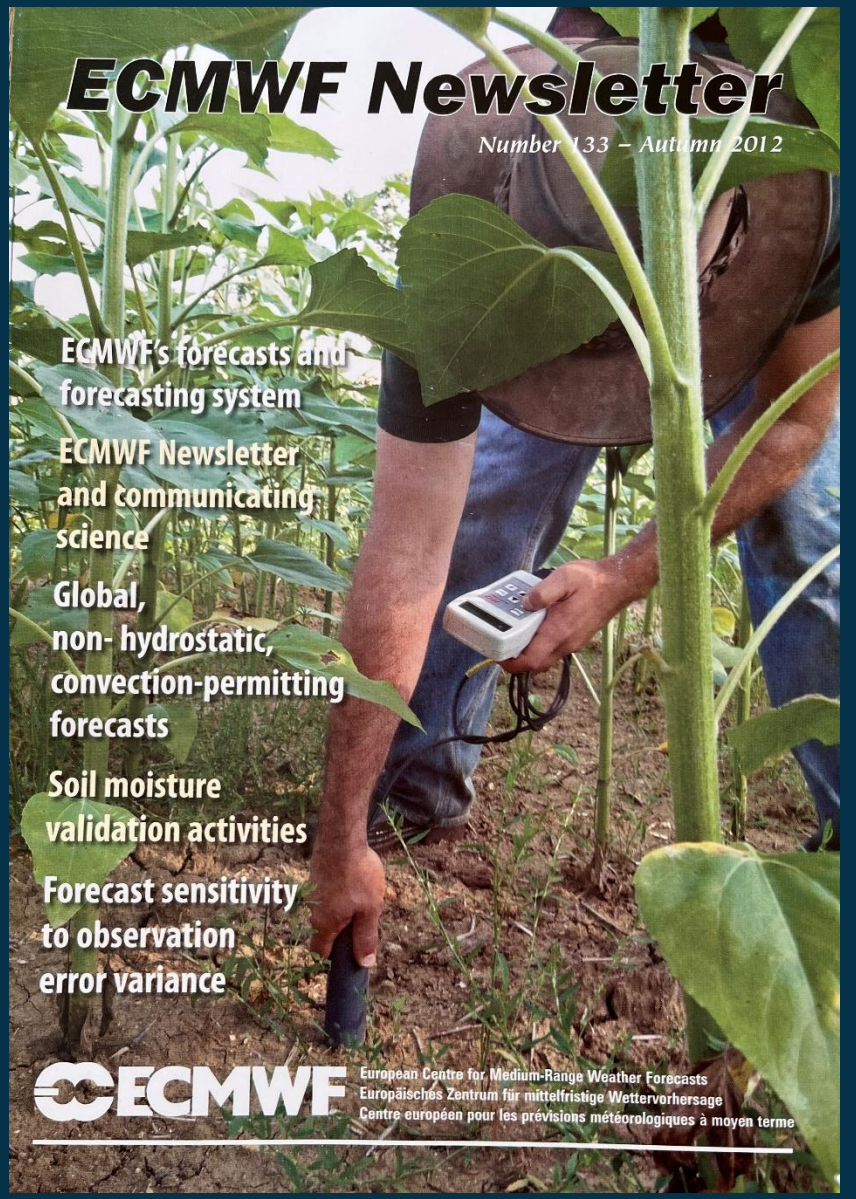
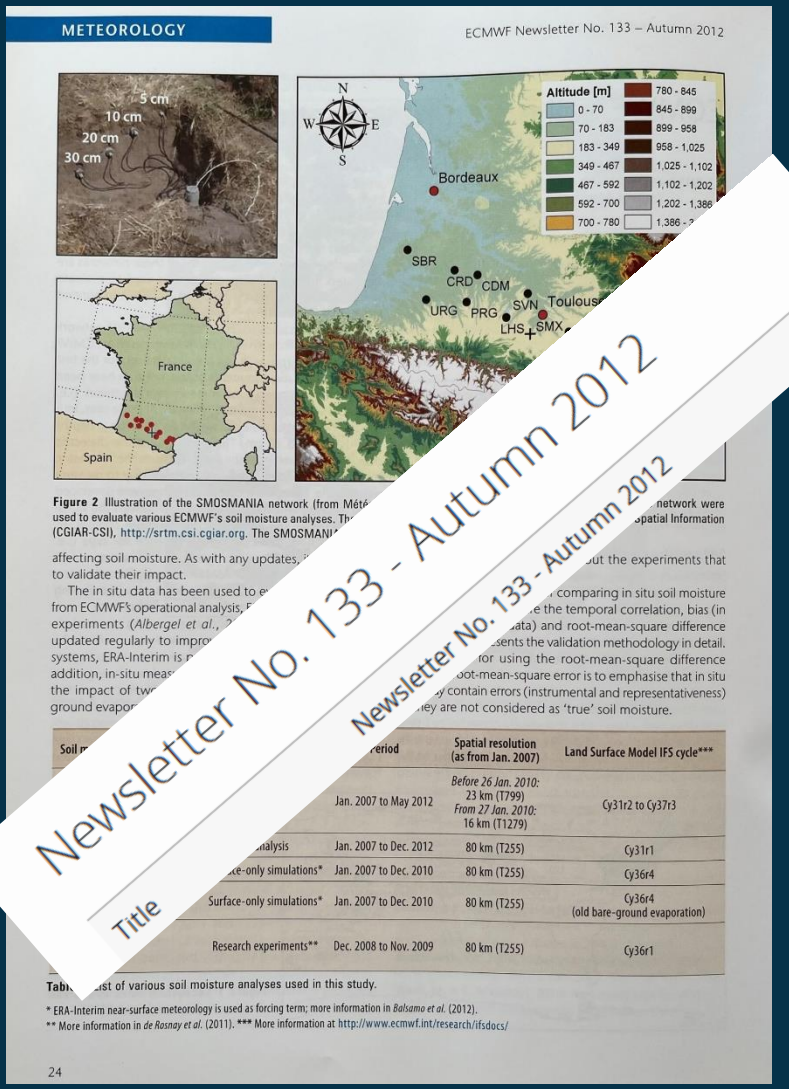
ESA’s Climate Change Initiative: how space data support our understanding of climate change

Clement Albergel, European Space Agency (ESA)
Head of ESA’s Actionable Climate Information Section

Bonn, Germany | 9-10 April 2025

Workshop on ancillary data for land surface and Earth system modelling
Part of ECMWF's 50th anniversary celebrations





Newsletter No. 133 - Autumn 2012

Title

Newsletter No. 133 - Autumn 2012

OUR FUTURE CLIMATE
SIX SCENARIOS

+1.1°C WHERE WE ARE NOW

Global warming due to increased human-driven greenhouse gases in the atmosphere

+1.4°C TAKING THE GREEN ROAD

If net zero emissions are achieved by 2050 (SSP1-1.9)

+1.5°C

PARIS AGREEMENT GOAL

+1.8°C LIMITING GLOBAL WARMING

If net zero emissions are achieved in second half of 21st century (SSP1-2.6)

+2.7°C NO EXTRA CLIMATE POLICIES

If current greenhouse gas emissions persist until mid-21st century (SSP2-4.5)

+4.4°C FOSSIL-FUELLED DEVELOPMENT

An energy and resource intensive scenario for the 21st century (SSP5-8.5)

> "It is unequivocal that human influence has warmed the atmosphere, ocean & land. Widespread and rapid changes have occurred"
>
> IPCC AR6, 2022

GLOBAL MEAN TEMPERATURE INCREASE BY 2100 (RELATIVE TO 1850-1900)
Source: IPCC Assessment report Working Group 1, Table SPM.1

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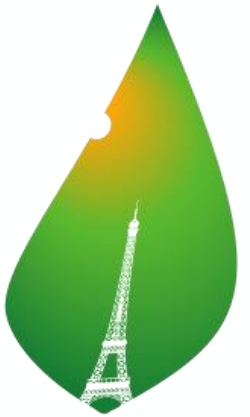
Climate Change: UNFCCC & The Paris Agreement

United Nations Framework Convention on Climate Change

Tasked with preventing *'dangerous'* human interference with the climate system

- Lead the international effort to combat climate change
- Body responsible for driving global climate action
- Make decisions on climate change mitigation and adaptation

➔ ***Requires systematic observations of the climate system***

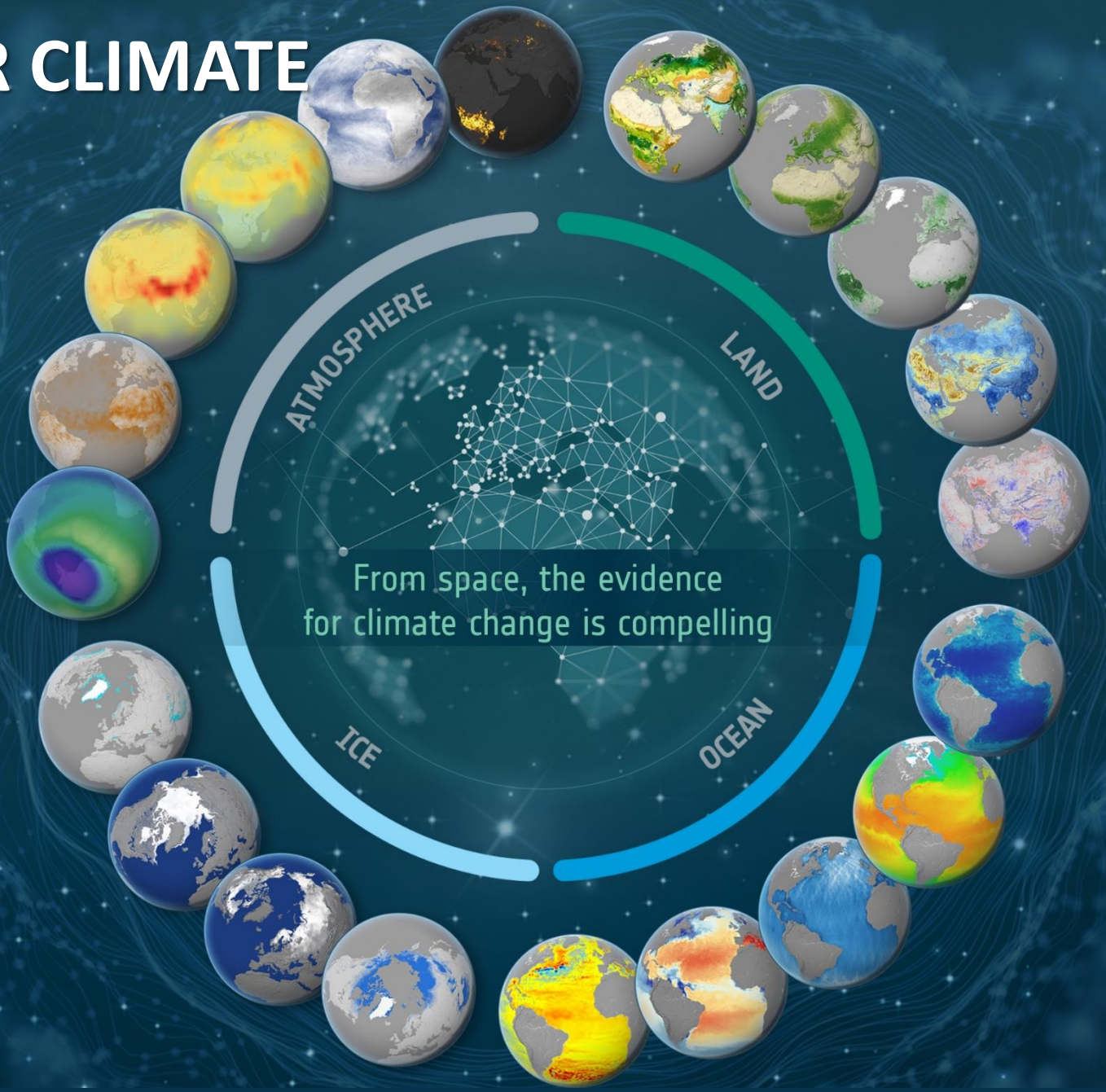


PARIS2015

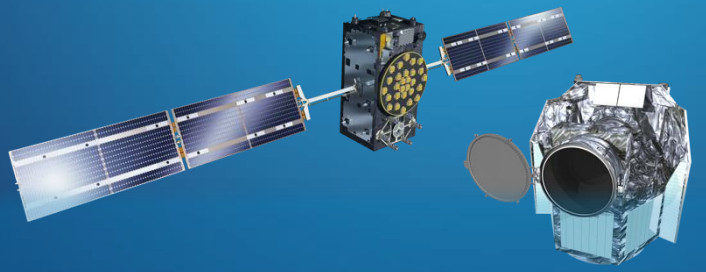
Legally-binding treaty to limit global warming to well-below 2C, and preferably 1.5C

"…to reach global peaking of greenhouse gas emissions as soon as possible … and to undertake rapid reductions thereafter in accordance with best available science...to achieve a balance between anthropogenic emissions by sources and removals by sinks of greenhouse gases in the second half of this century."

SPACE FOR OUR CLIMATE



What is the European Space Agency?



Make Space for Europe

6 000+
ESA Workforce

Promoting cooperation among European States in space research, technology and applications, for exclusively peaceful purposes

23
Member States

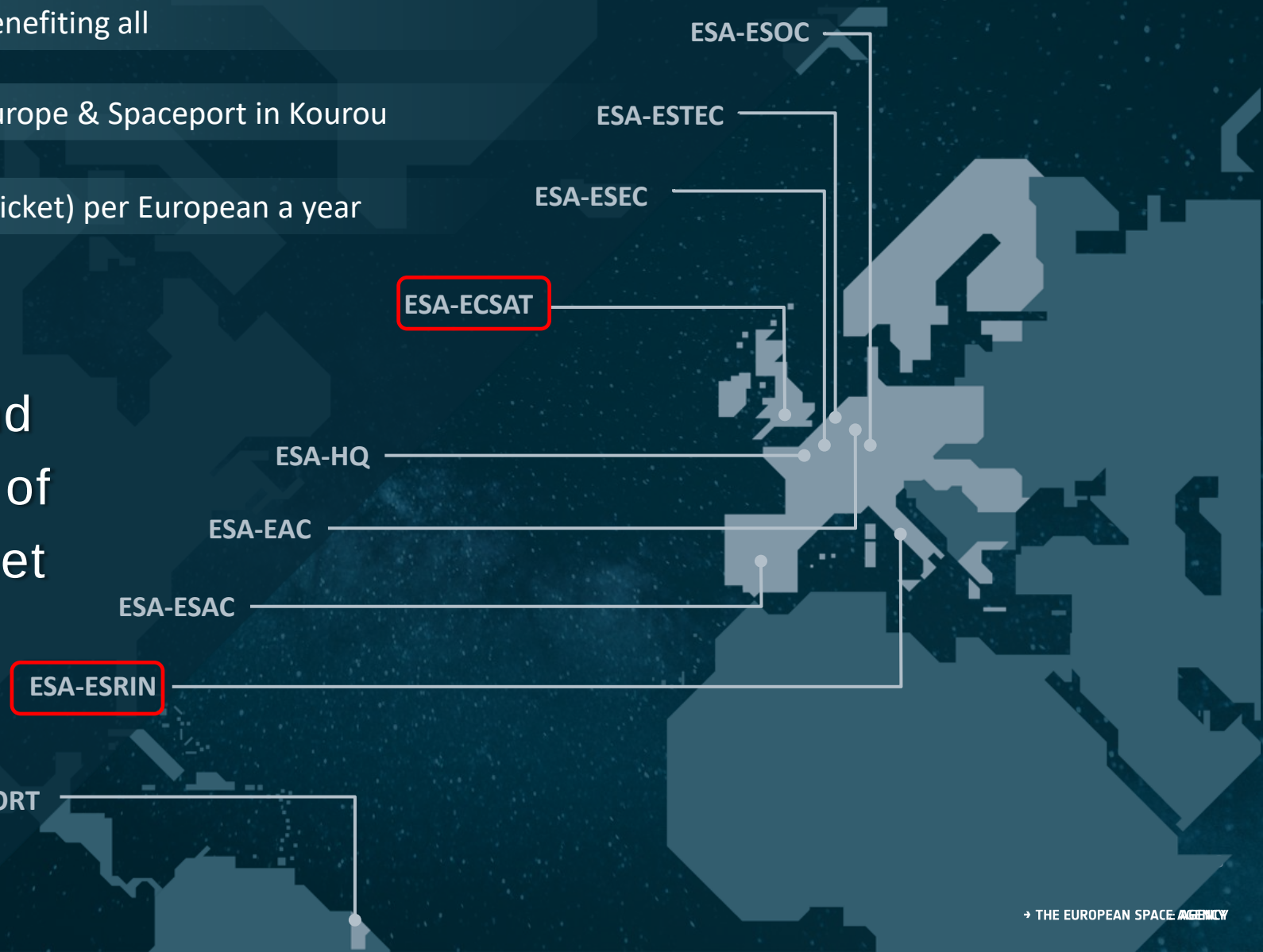
2024 Budget

7.79 billion =
15 per European

ESA in a Nutshell

WHO	22* Member States, 2500+ staff members and total workforce of 6000+
WHY	For the peaceful use of space, benefiting all
WHERE	HQ in Paris, seven sites across Europe & Spaceport in Kourou
BUDGET	€7.7 billion = €15 (one cinema ticket) per European a year

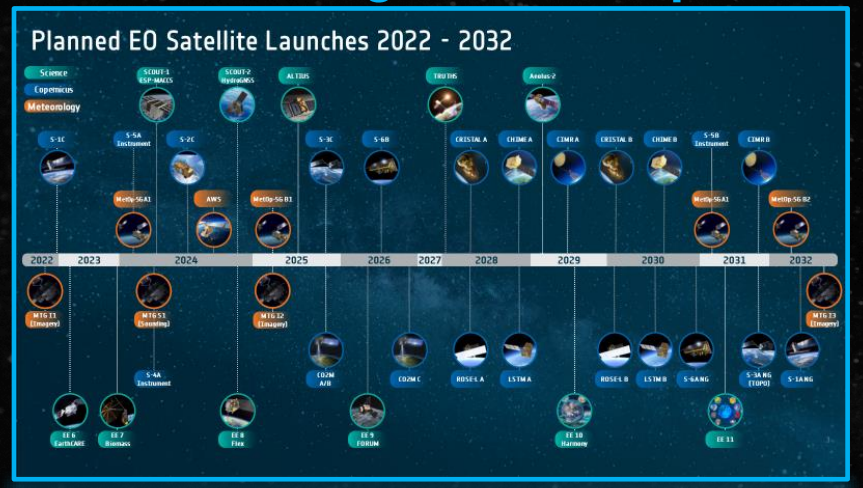
ESA is committed to the peaceful exploration and use of space for the benefit of people society and our planet



Earth Observation Activities at ESA: ESRIN, ESTEC, ECSAT

esa

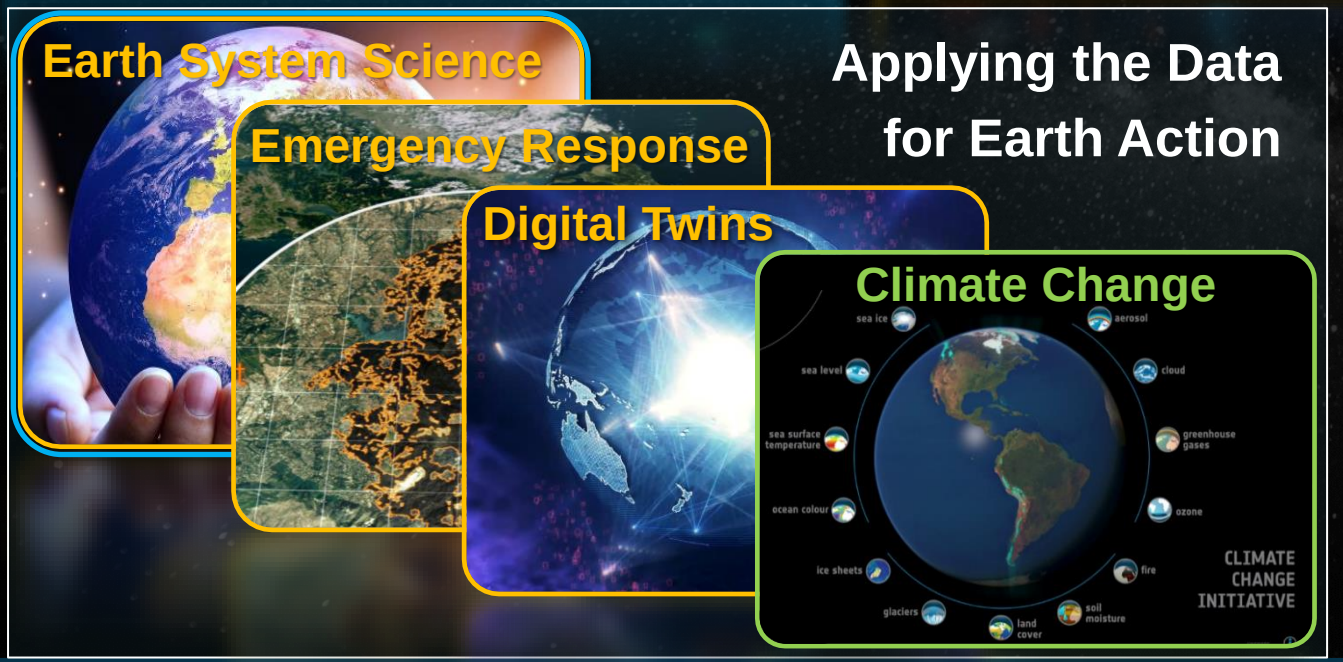
Satellite Design & Development



Missions Management

Cal/Val & Data Distribution

Applying the Data for Earth Action



Innovation

Accelerate the future of EO Via transformative innovation & commercialisation actions

Φ-lab

Future Systems & Instruments activities

Accelerate the future of EO with cutting edge research

Commercialisation

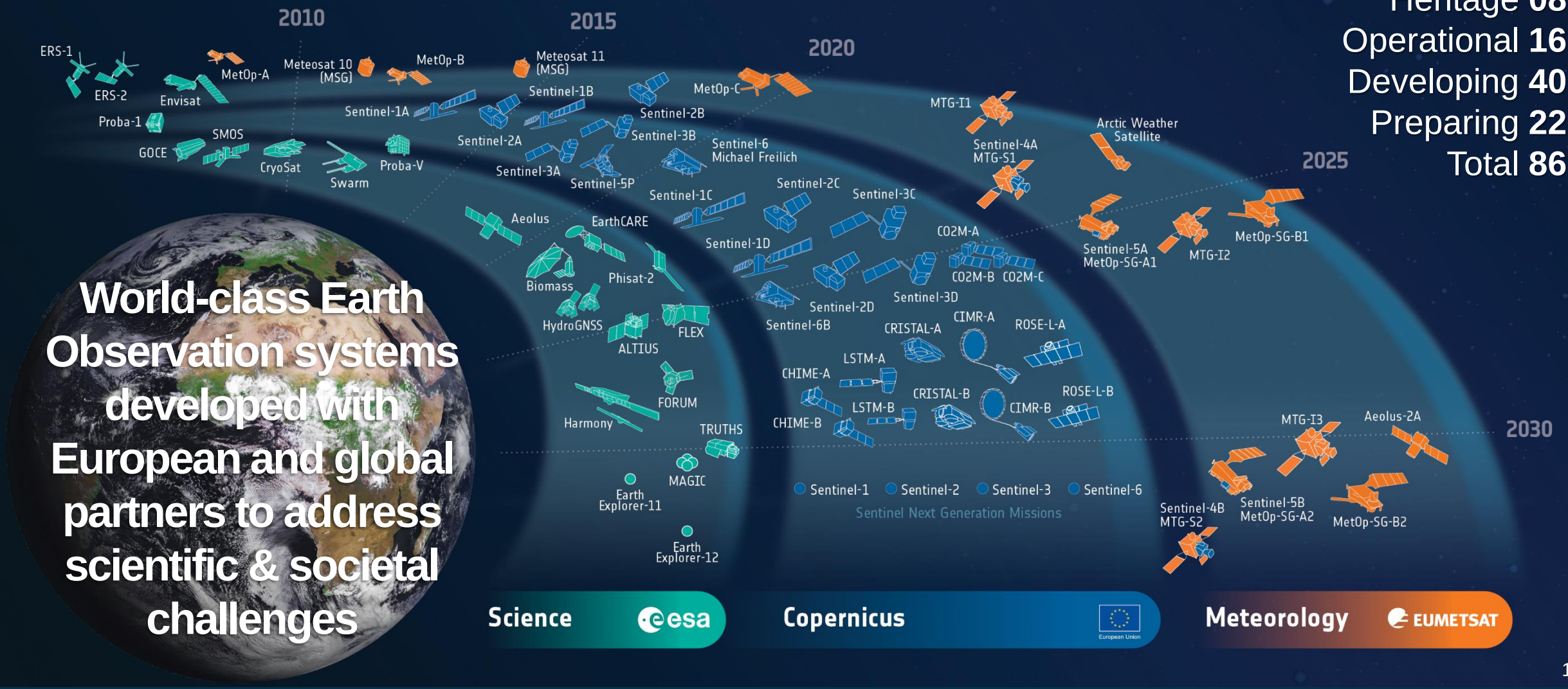
InCubed

in³

ESA's Earth Observation Missions

Satellites

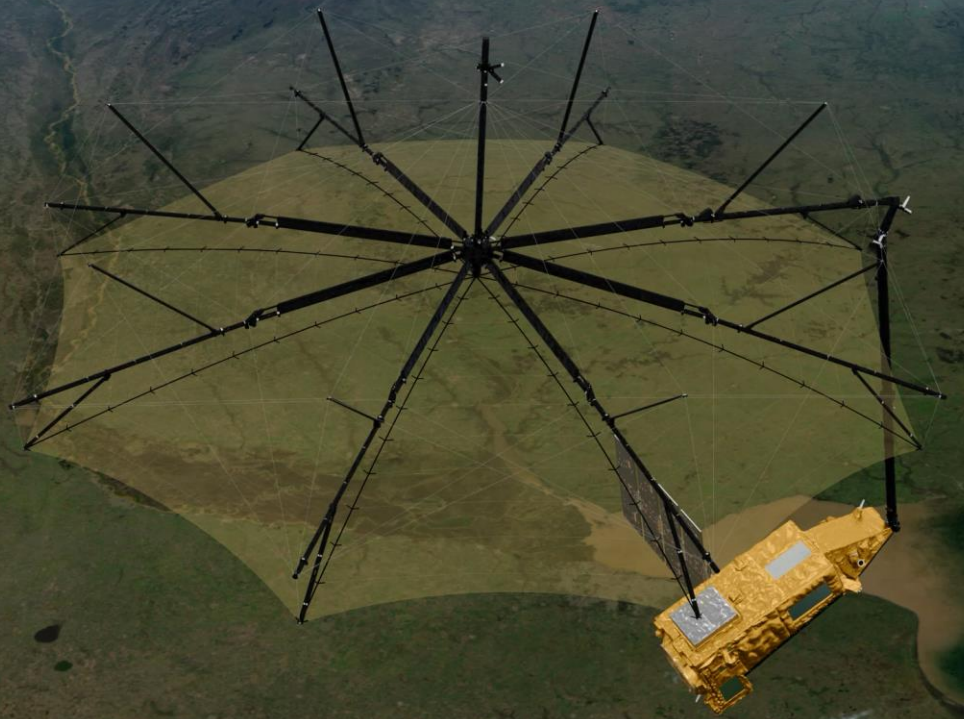
Heritage **08**
Operational **16**
Developing **40**
Preparing **22**
Total **86**



World-class Earth Observation systems developed with European and global partners to address scientific & societal challenges

Science esa | Copernicus European Union | Meteorology EUMETSAT

The BIOMASS Mission



ESA's 7th Earth Explorer to be deployed in 2025

An interferometric, fully-polarimetric P-band SAR

Designed to observe forest height and biomass

The Copernicus Space Component – Sentinels

PROGRAMME OF THE EUROPEAN UNION

esa

Copernicus is the largest producer of EO data in the world with a Full, Free & Open Data Policy*

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

20 TB of Daily Data Production by Sentinels

(august 2024)

> 700 PB of Sentinel Products Disseminated for Services to Society

> 200.000

Registered Users since Jan 2023

Supporting 6 operational services

Land

Atmosphere

Ocean

Climate

Disaster

Security

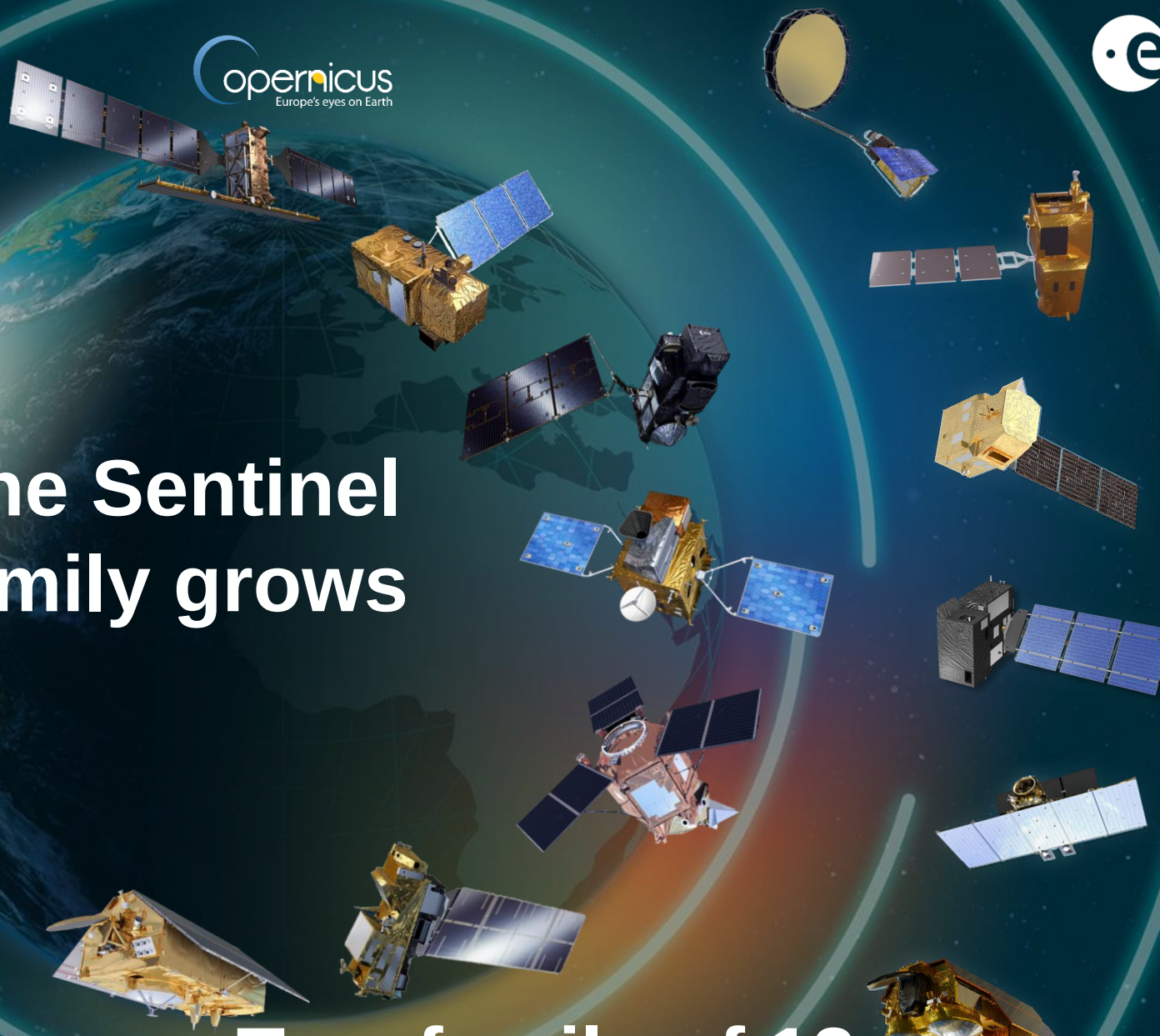
* ESA Sentinel Data Policy (Sep 2013) and
EU Delegated Act on Copernicus Data and Information Policy (Dec 2013)

PROGRAMME OF THE EUROPEAN UNION

Copernicus
Europe's eyes on Earth

esa

The Sentinel family grows



From a family of 6

To a family of 12

→ THE EUROPEAN SPACE AGENCY

PROGRAMME OF THE EUROPEAN UNION

esa

Food Security and Water Management

Monitoring Land and Natural Resources

CHIME

ROSE-L

LSTM

CIMR

Combatting Climate Change

Safeguarding the Arctic

Strengthening Copernicus Space with the Sentinel Expansion Mission observations

CO2M

CRISTAL

→ THE EUROPEAN SPACE AGENCY

ESA'S CLIMATE CHANGE INITIATIVE

Linking satellite observations and modelling communities

Crucial lines of evidence for informed decision-making

Advancing climate science

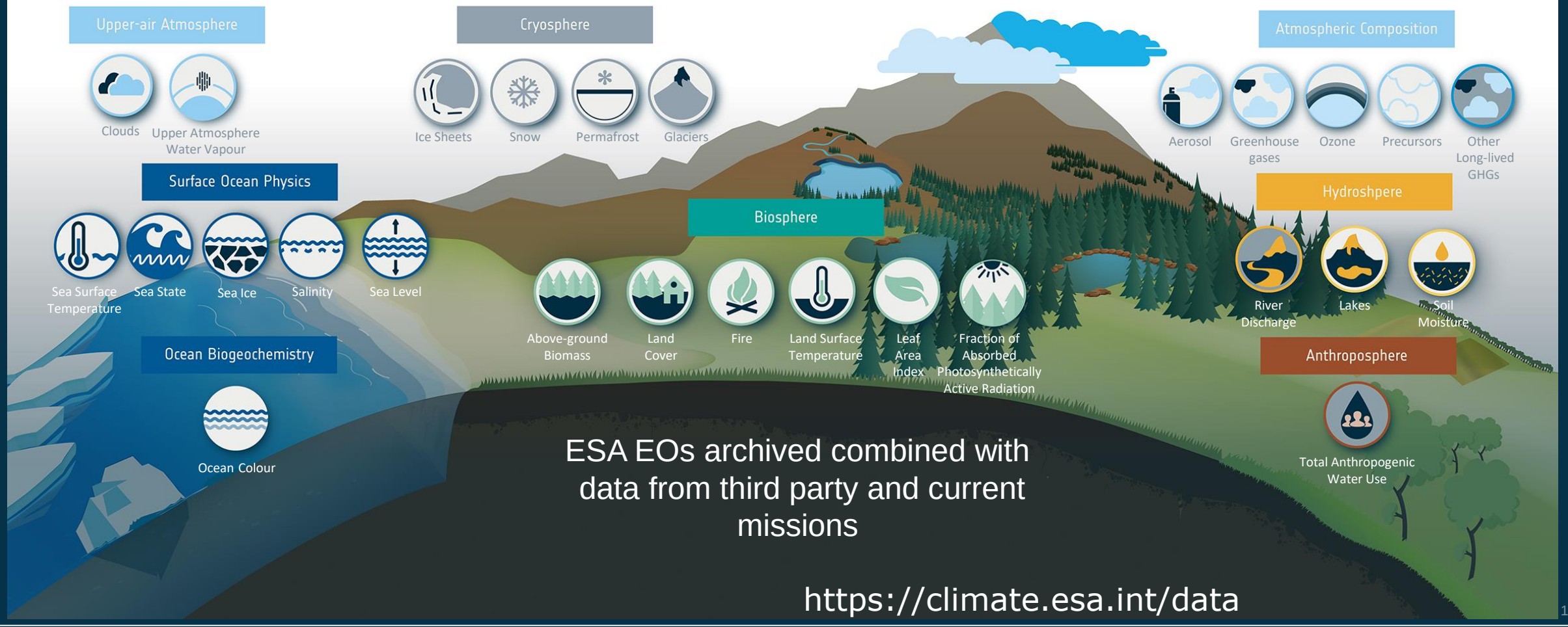
Supporting the Paris Agreement and Global Stocktake

Developing satellite-derived climate data records

Exchanging knowledge

ESA'S CLIMATE CHANGE INITIATIVE

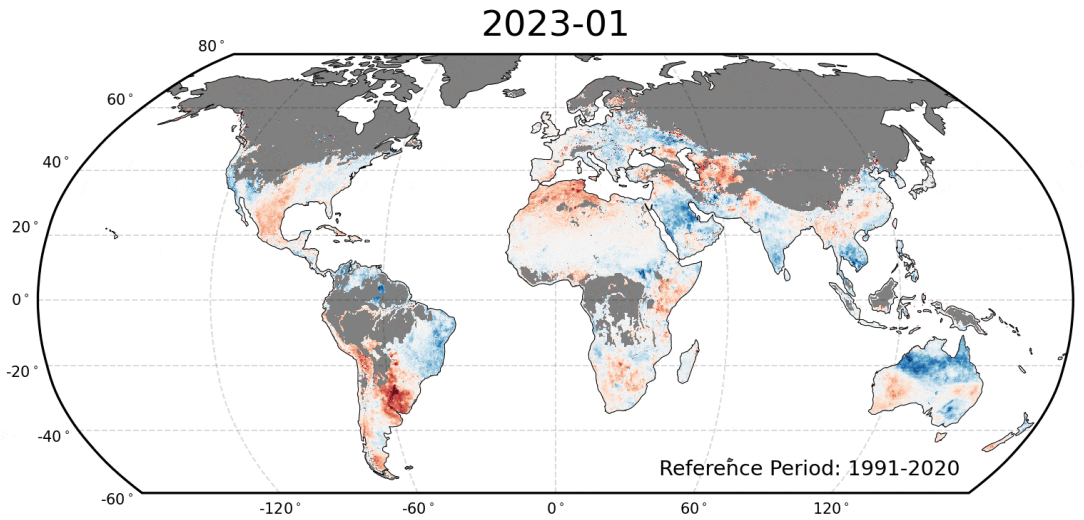
GCOS defined **55** Essential Climate Variables | **36** benefit from space observations | **27** generated by ESA's Climate Programme



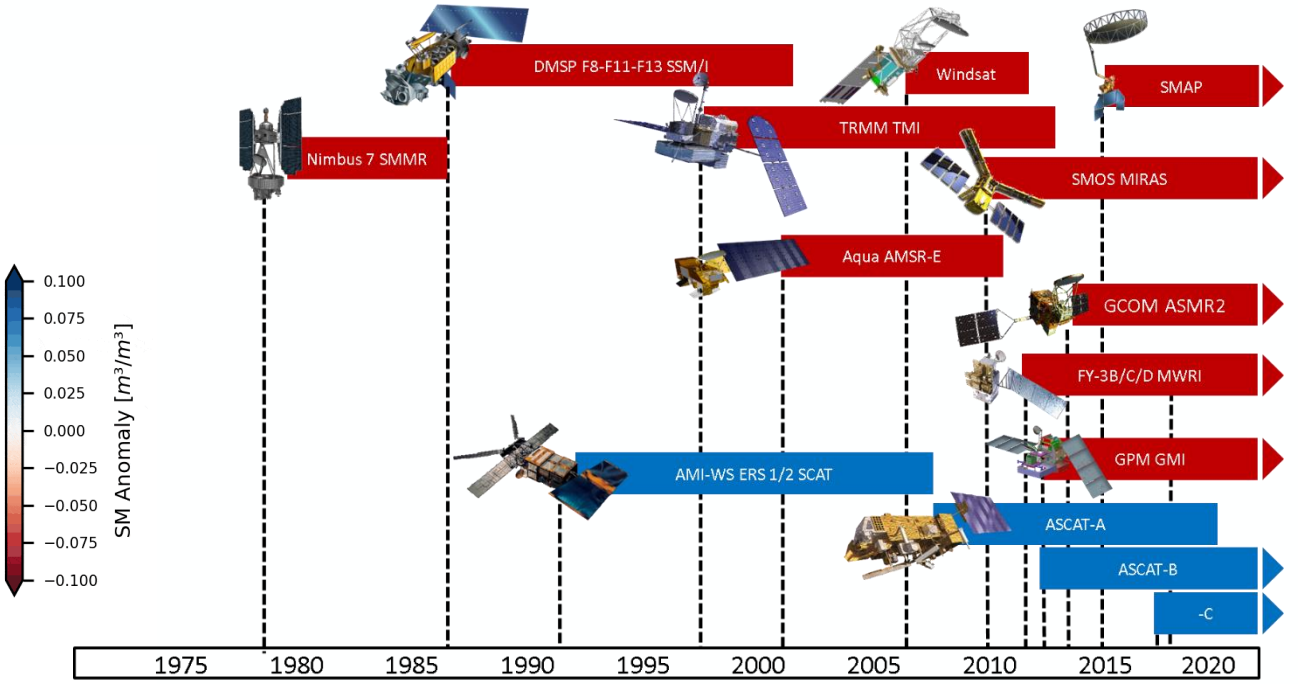
ESA'S CCI: SOIL MOISTURE ECV

- Annually algorithmically updated global climate data record of soil moisture spanning > 40-yr
- 3 separate soil moisture products derived from active, passive and combined (active + passive) sensors
- 14 public releases to date

https://climate.esa.int/en/projects/soil-moisture/



Soil moisture anomalies for the year 2023 derived from the ESA CCI COMBINED v09.0 product

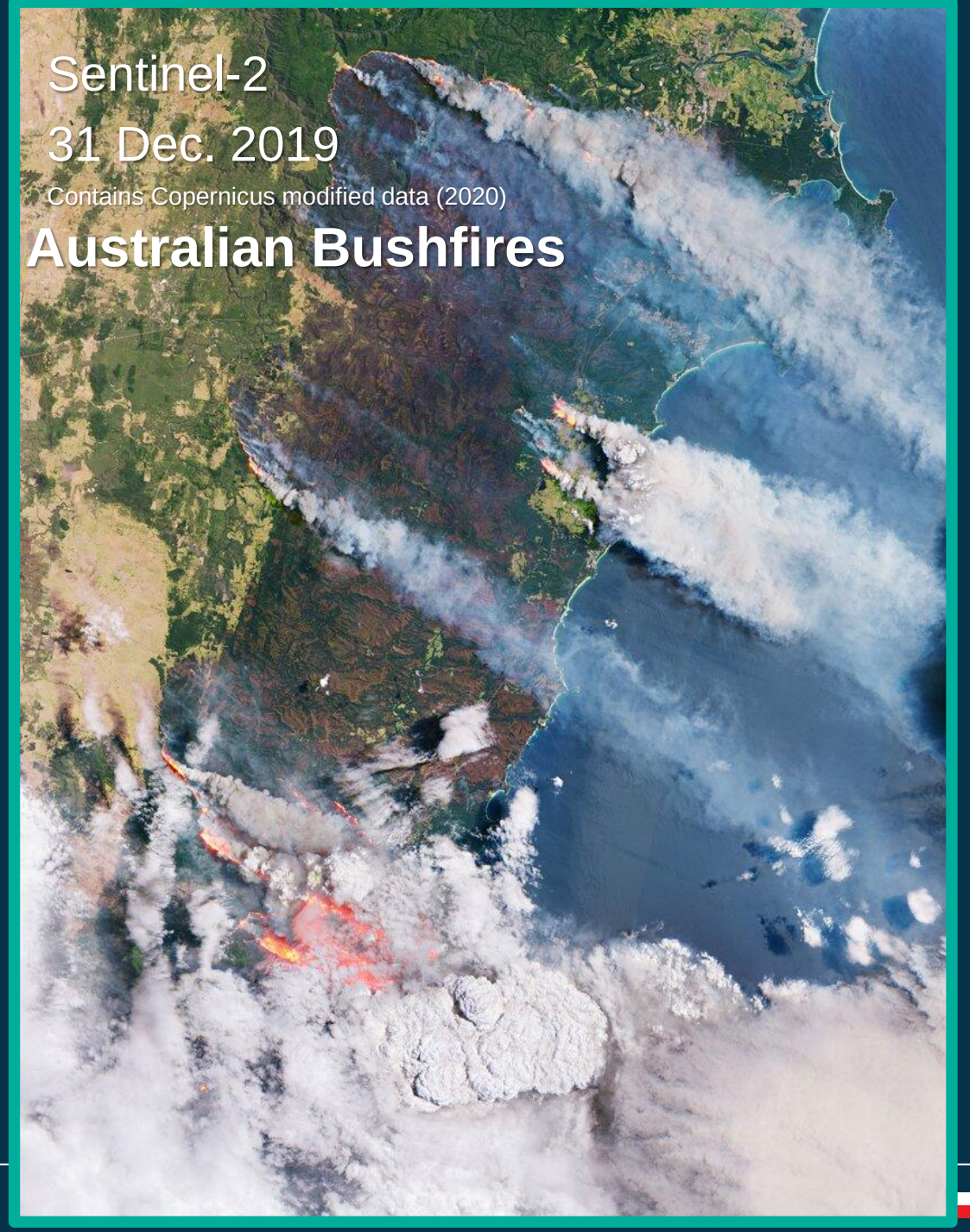


ESA CCI soil moisture v09.1 products utilize 5 active and 12 passive microwave sensors

V09.1 (1979-2023), already available at:

https://climate.esa.int/en/projects/soil-moisture/

Now generated operationally via C3S



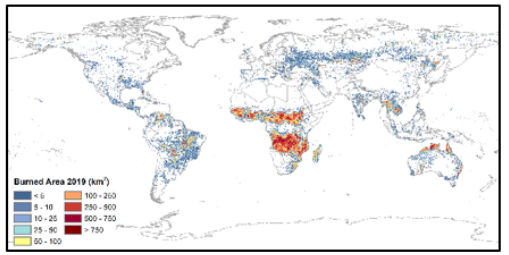
ESA CCI : Fire ECV

Satellites permit to monitor different fire characteristics: areas that are dry and prone to wildfire outbreak, actively flaming and smouldering fires, burned area, as well as smoke and trace gas emissions

2 principles: thermal anomalies and changes in surface reflectance

https://climate.esa.int/en/projects/fire/

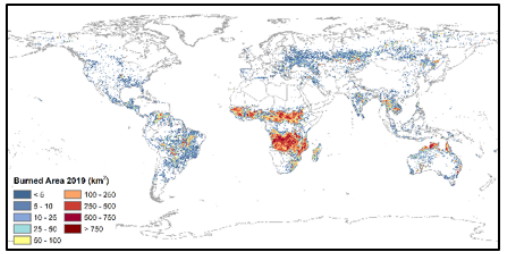
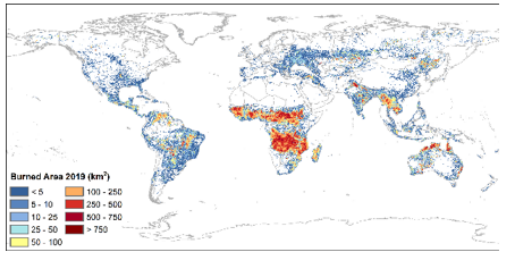
ESA'S CCI: Burned Area

	FireCCI51
	
Coverage	Global
Time series	2001-2020 (21)
Pixel resolution	250m
Grid resolution	0.25 deg.
Input information	MODIS (SR & HS)

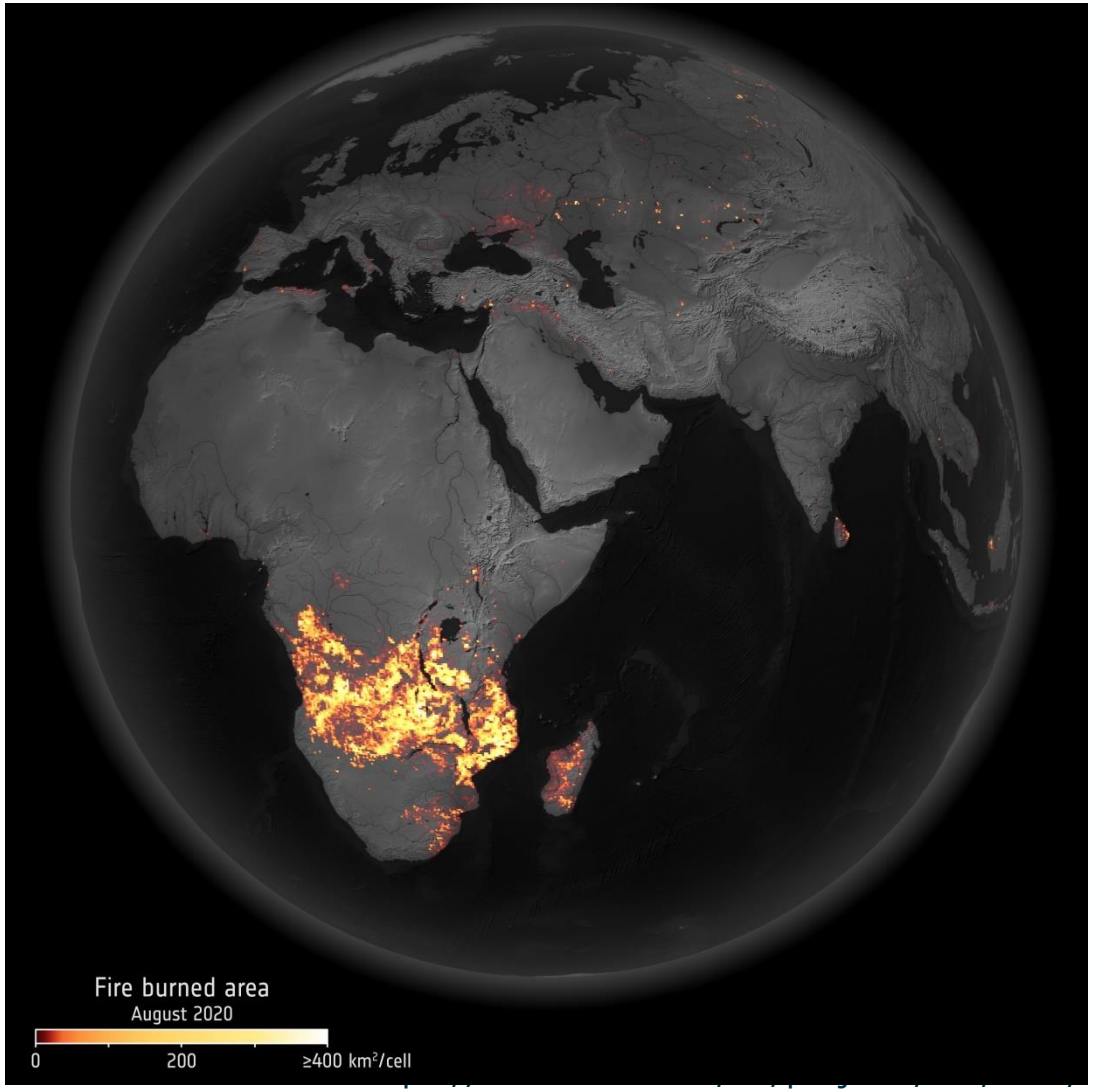
SR: Surface Reflectance
HS: Hot Spot

https://climate.esa.int/en/projects/fire/data/

ESA'S CCI: Burned Area

	FireCCI51	FireCCIS311
		
Coverage		Global
Time series	2001-2020 (21)	2019-2020 (2022...)
Pixel resolution	250m	300m
Grid resolution	0.25 deg.	0.25 deg.
Input information	MODIS (SR & HS)	S-3 SYN (SR) + VIIRS (HS)

SR: Surface Reflectance
HS: Hot Spot



ESA'S CCI: Burned Area

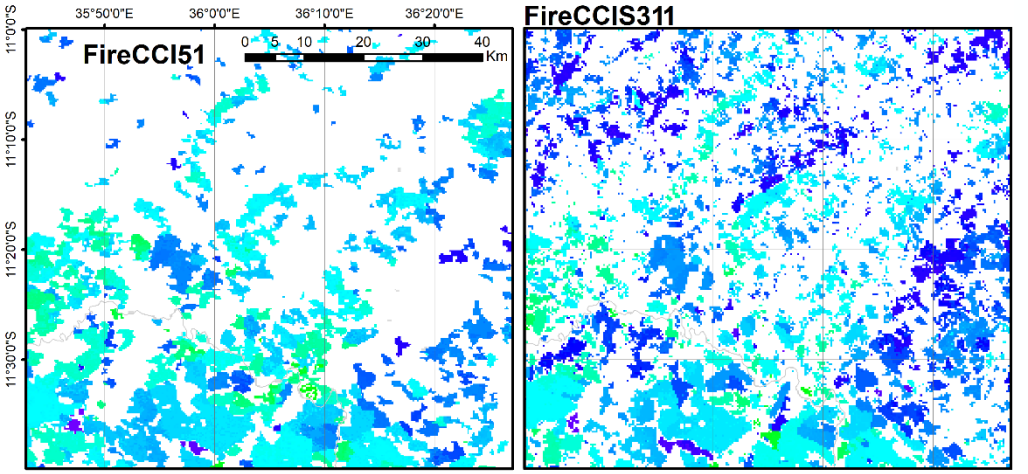
FireCCIS311

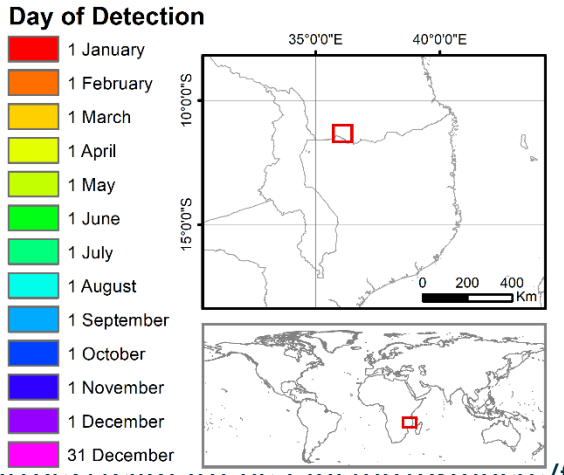
➔ Detects globally 1Mkm^2 more BA than previous products!

Table 4. Burned area (km^2) of the year 2019 for each product and biome.

	FireCCI51	MCD64A1 c6	FireCCIS310	
Boreal forest	86711	72370	87145	
Deserts & xeric shrublands	116907	176164	253192	+116%
Mediterranean	29162	32364	39765	
Temperate forest	111999	105320	165621	+48%
Temperate savanna	165610	145221	220141	
Tropical forest	433493	400165	897703	+107%
Tropical savanna	2958452	2529860	3311552	
Tundra	11531	8437	12000	
Global	3913865	3469901	4987119	+27%

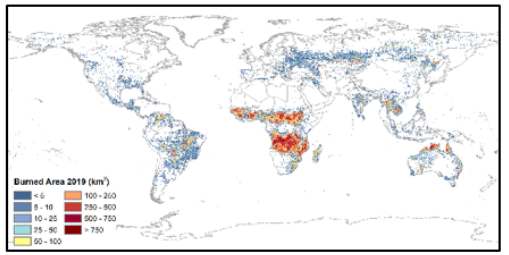
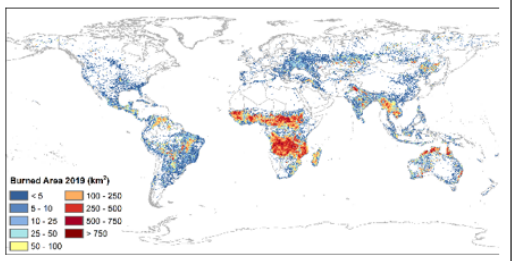
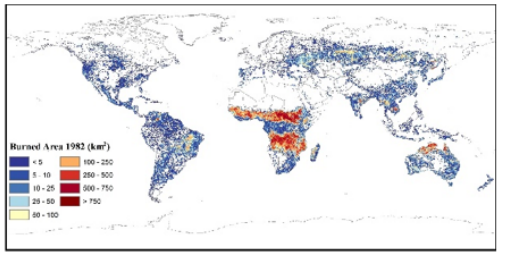
Lizundia-Loiola et al., 2022, RSE





https://climate.esa.int/en/projects/fire/data/

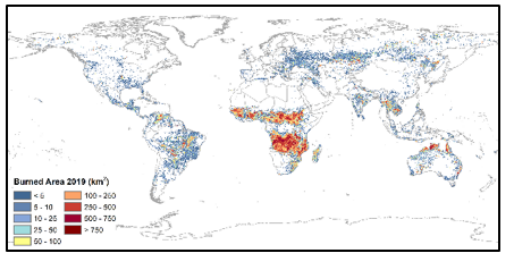
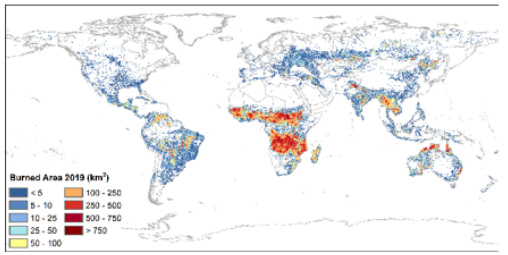
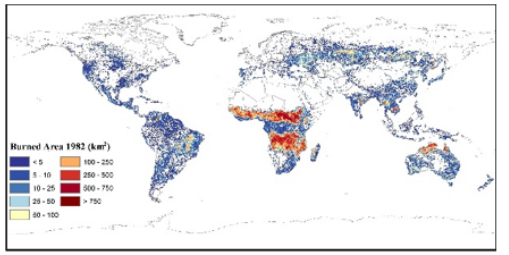
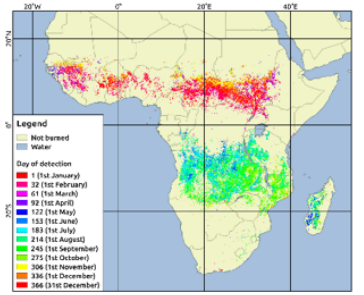
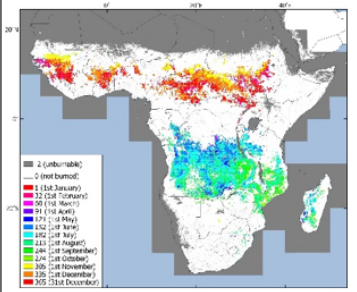
ESA'S CCI: Burned Area

	FireCCI51	FireCCIS311	FireCCILT11
			
Coverage	Global		
Time series	2001-2020 (21)	2019-2020 (2022...)	1982-2018 (gap 1994)
Pixel resolution	250m	300m	0.05 deg.
Grid resolution	0.25 deg.	0.25 deg.	0.25 deg.
Input information	MODIS (SR & HS)	S-3 SYN (SR) + VIIRS (HS)	AVHRR LTDR (SR)

SR: Surface Reflectance
HS: Hot Spot

https://climate.esa.int/en/projects/fire/data/

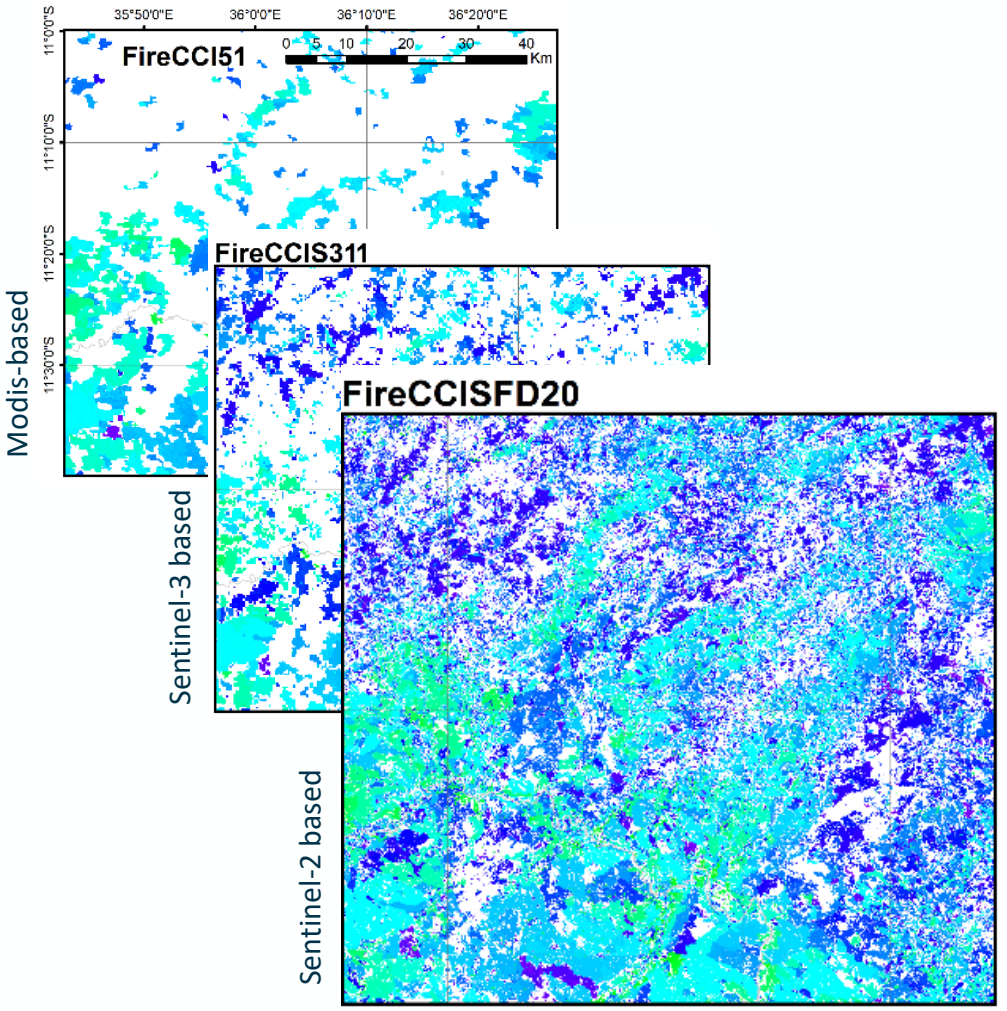
ESA'S CCI: Burned Area

	FireCCI51	FireCCIS311	FireCCILT11	FireCCISFD11	FireCCISFD20
					
Coverage	Global			Sub-Saharan Africa	
Time series	2001-2020 (21)	2019-2020 (2022...)	1982-2018 (gap 1994)	2016	2019
Pixel resolution	250m	300m	0.05 deg.	20m	20m
Grid resolution	0.25 deg.	0.25 deg.	0.25 deg.	0.25 deg.	0.05 deg.
Input information	MODIS (SR & HS)	S-3 SYN (SR) + VIIRS (HS)	AVHRR LTDR (SR)	S-2A (SR) + MODIS (HS)	S-2A&B (SR) + VIIRS (HS)

SR: Surface Reflectance
HS: Hot Spot

https://climate.esa.int/en/projects/fire/data/

BURNED AREA MAPPING: RESEARCH TO OPERATIONS & Data as a Service



Burned area map improvement
ESA Climate Change Initiative's Fire project

ESA Climate Change Initiative (CCI) high-res **prototype algorithm** has matured into a **Data-as-a-Service** to support wildfire disaster risk reduction & recovery mapping and fire-related GHG emissions assessment

fire cci

1 Research

- Prototype algorithm Based on Copernicus Sentinel-2
- Resolution 20m

(ESA CCI Fire Project)

2 Operational

- Open-source workflow developed for Disaster Risk Reduction & Management

(CopLAC consortium)

3 Service

- Burned area processing service for commercial and non-commercial use via ESA nor-discover.org

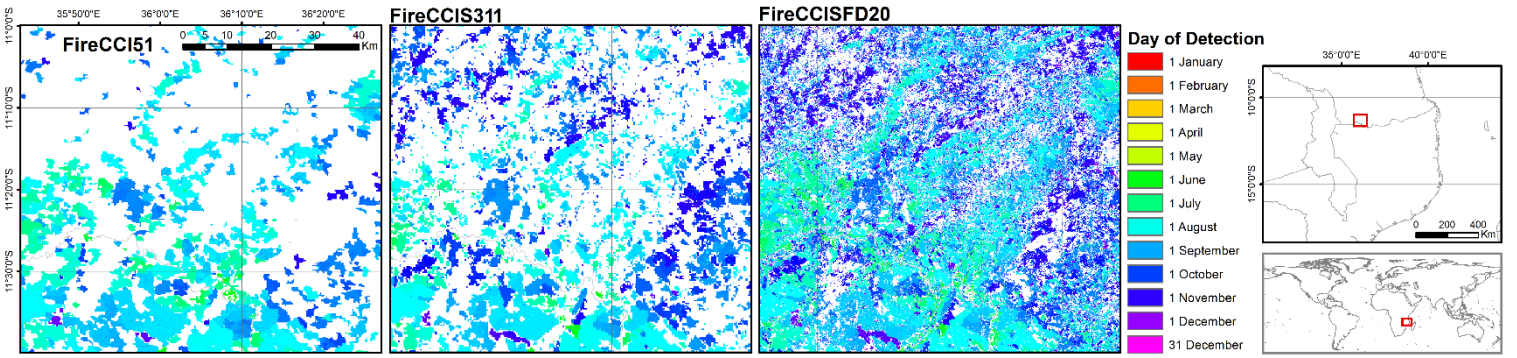
(Brockmann Consult GmbH)

CLIMATE CHANGE INITIATIVE – FIRE EMISSIONS

From Burned Area…

ESA CCI latest fire product (FireCCISFD20 – small fires database)

- 20 m resolution using Sentinel-2 observations
- Significantly improves total burned area detection compared to medium-resolution sensors (ESA FireCCI51 at 250m)



Modis-based Sentinel-3 based Sentinel-2 based

CLIMATE CHANGE INITIATIVE – FIRE EMISSIONS

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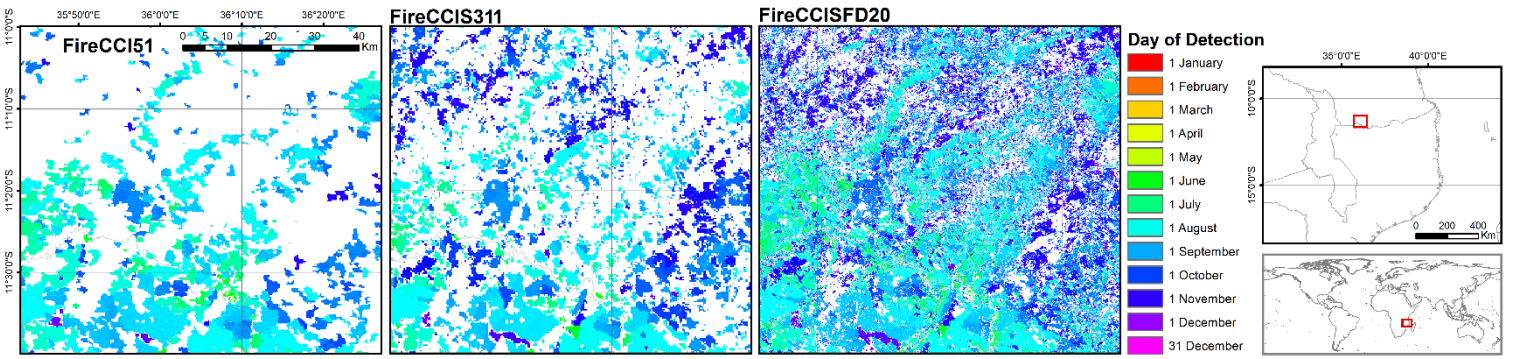


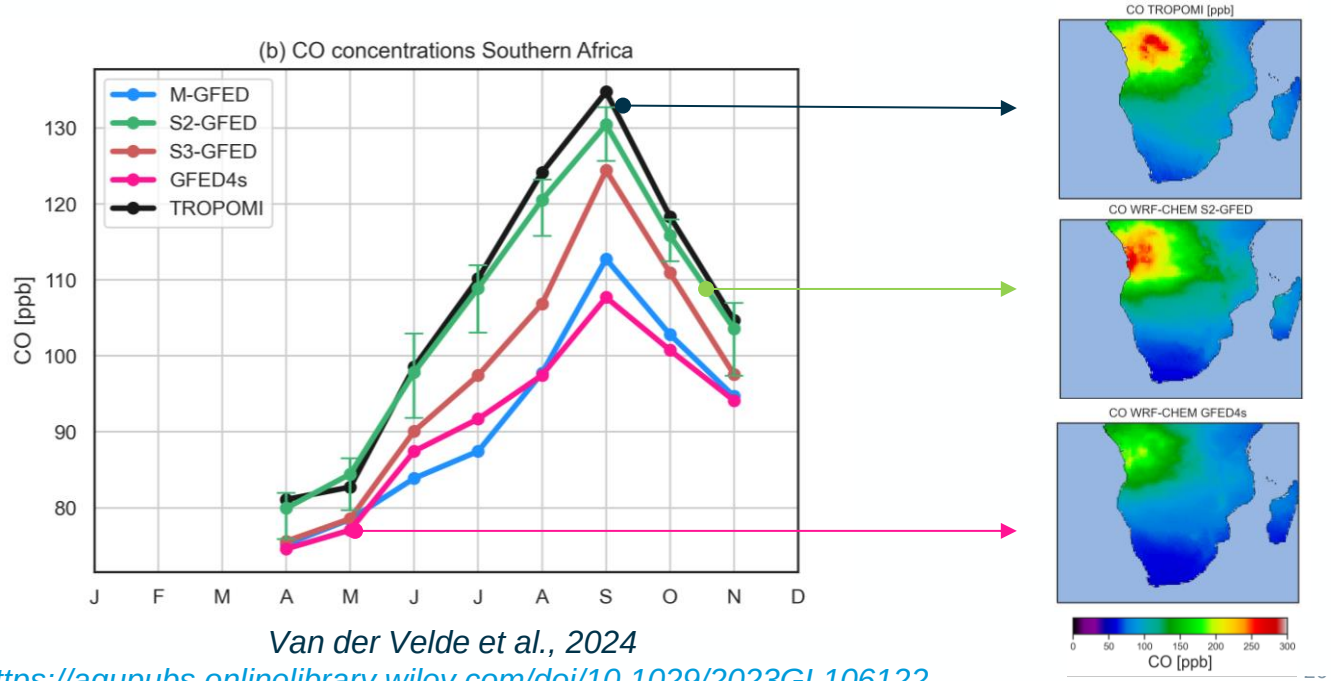
Modis-based Sentinel-3 based Sentinel-2 based

…to Fire emission

Constraining models such as the Global Fire Emission Database (GFED) with FireCCISFD20 improves analysis of fire emissions (*van der Velde et al in prep)*

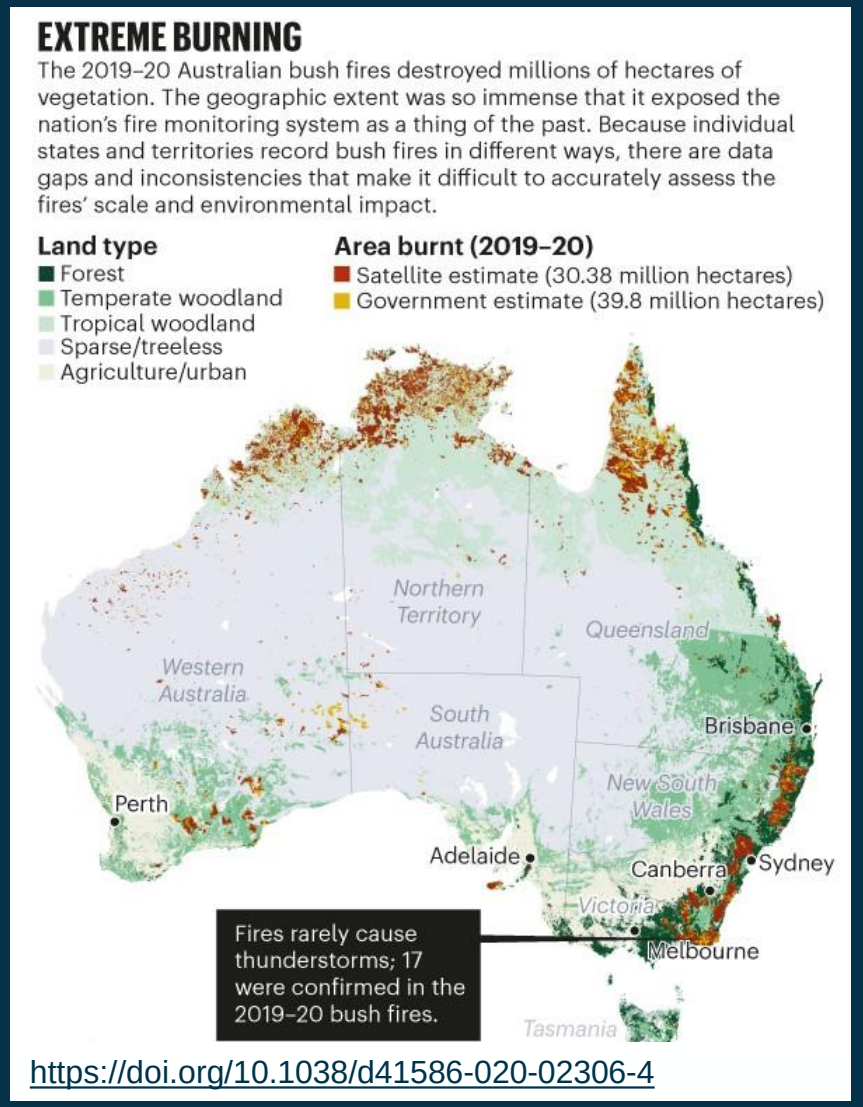
- CO emissions (a measure of fire emissions) match TROPOMI observations (2019) (**Green** vs Black) in GFED's simulations
- Aerosol optical depth results also improved

Given the impact that biomass burning aerosols have on the energy budget of the planet, this could in turn lead to improved weather forecasts and consequently better skill in downstream applications that rely on it.



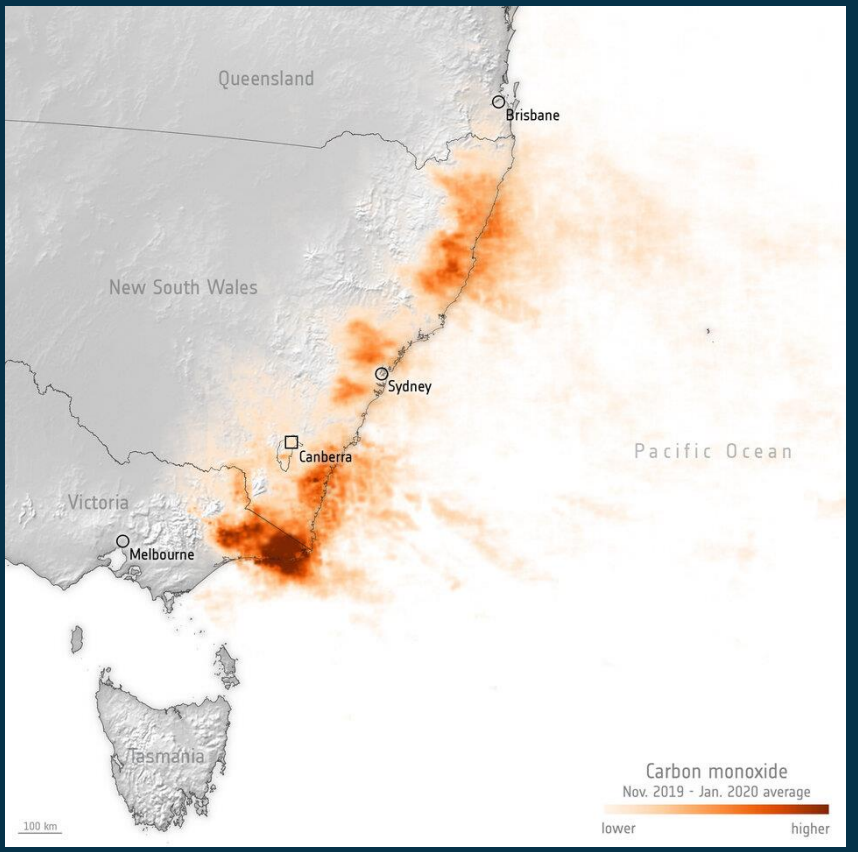
Van der Velde et al., 2024
https://agupubs.onlinelibrary.wiley.com/doi/10.1029/2023GL106122

Aerosols released from Australian bushfires triggers algal blooms

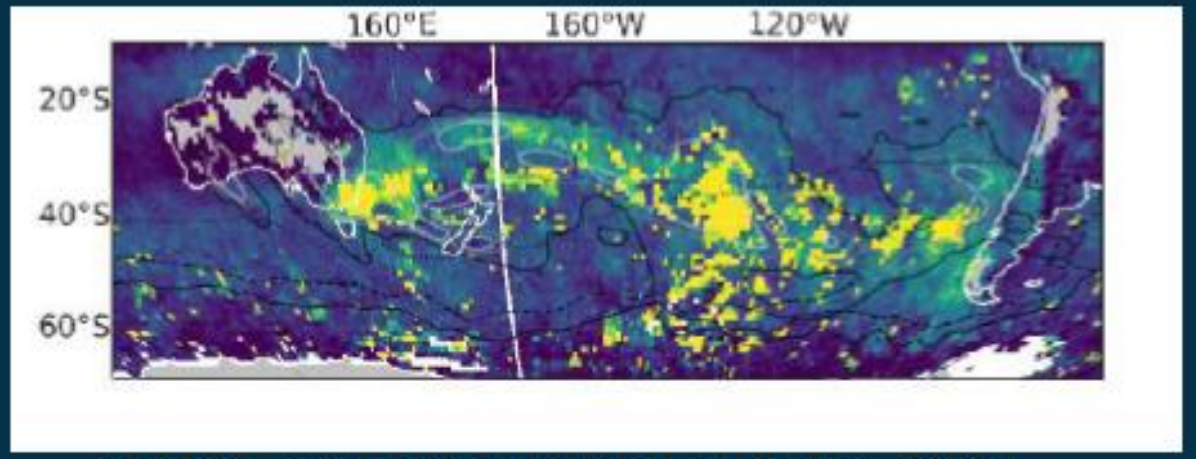


https://doi.org/10.1038/d41586-020-02306-4

- Satellite fire data and modelled quantities of standing biomass : 275 million tonnes of carbon dioxide
- Calculated from TROPOMI: 715 million tonnes



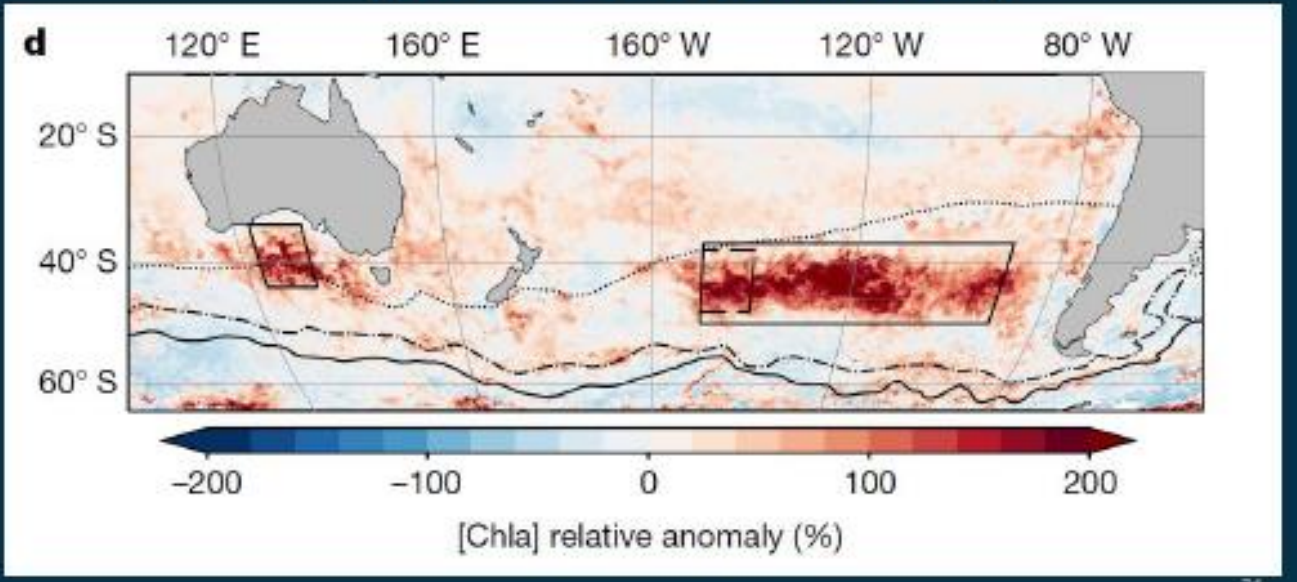
Use Multiple ECVs to Study Climate Processes



MODIS aerosol optical depth Jan.2020

Weiyi Tang *et al., 2021*
Nature, vol 597, p370
doi: 10.1038/s41586-021-03805-8

Phytoplankton Chla anomaly (ESA CCI Ocean Colour ECV)
(2019–2020 austral summer)



Increased activity of the ocean biological carbon pump might have offset some of the huge GHG emissions from the fires

Forest Degradation in Detail - Amazon

Rondonia, Brazil
Sentinel-2
29 June 2022

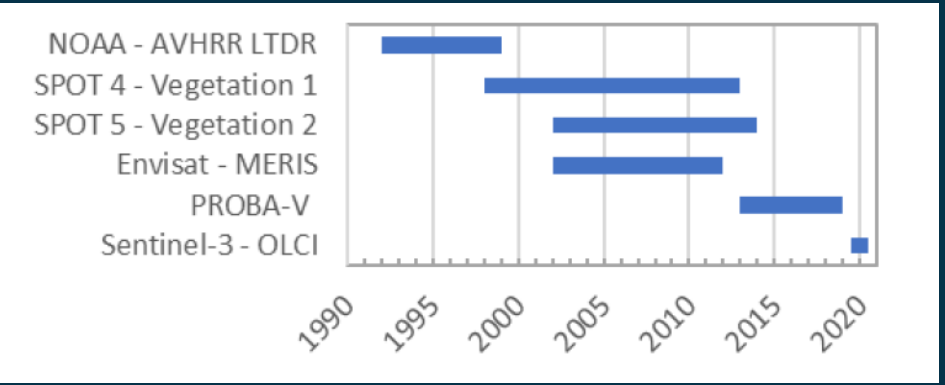
ESA Climate Change Initiative ECVs: Land Cover CCI

land cover cci

Accurate estimates of LU & LCC: crucial to support GST

➔ *Role of land for storing carbon and its future potential for offsetting carbon emissions*

**LC: series of annual maps, 300 m, 1992-2022,*
Consistent analysis-ready annual PFT maps for climate modelling



https://climate.esa.int/en/projects/land-cover/data/

* Generated operationally via C3S from 2016

ESA Climate Change Initiative ECVs: Land Cover CCI

land cover cci

high resolution land cover cci

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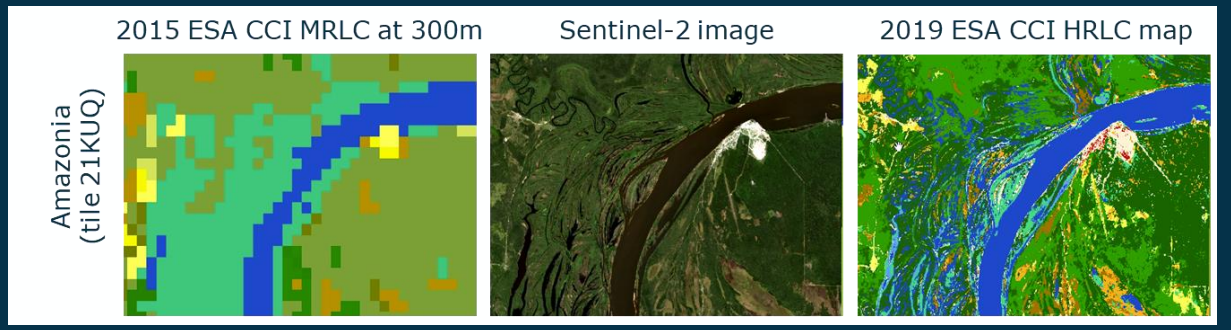

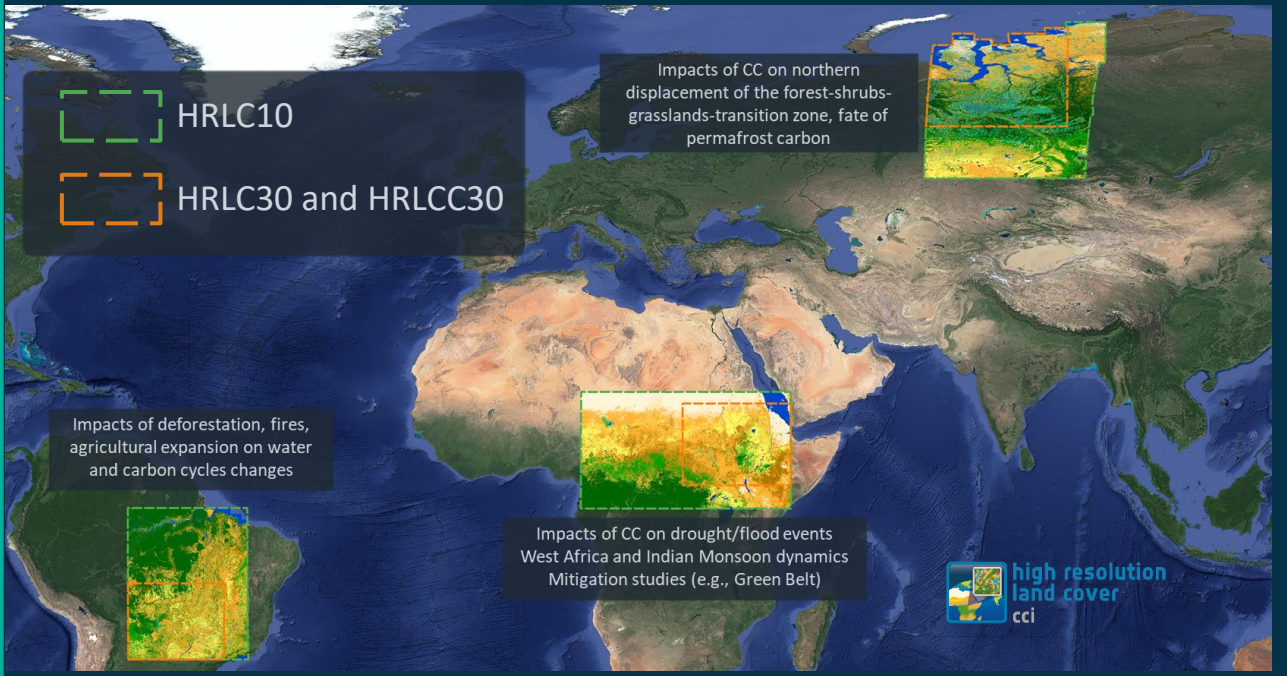

https://climate.esa.int/en/projects/high-resolution-land-cover/

* Generated operationally via C3S from 2016

ESA Climate Change Initiative ECVs: Land Cover CCI

land cover cci

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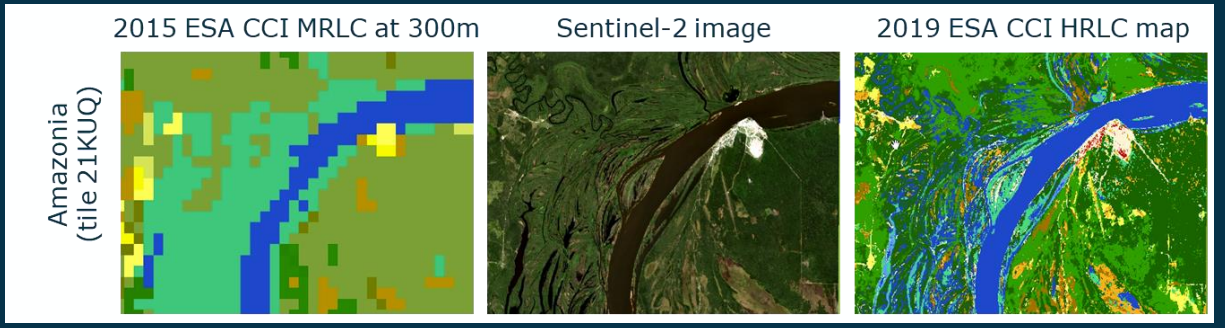
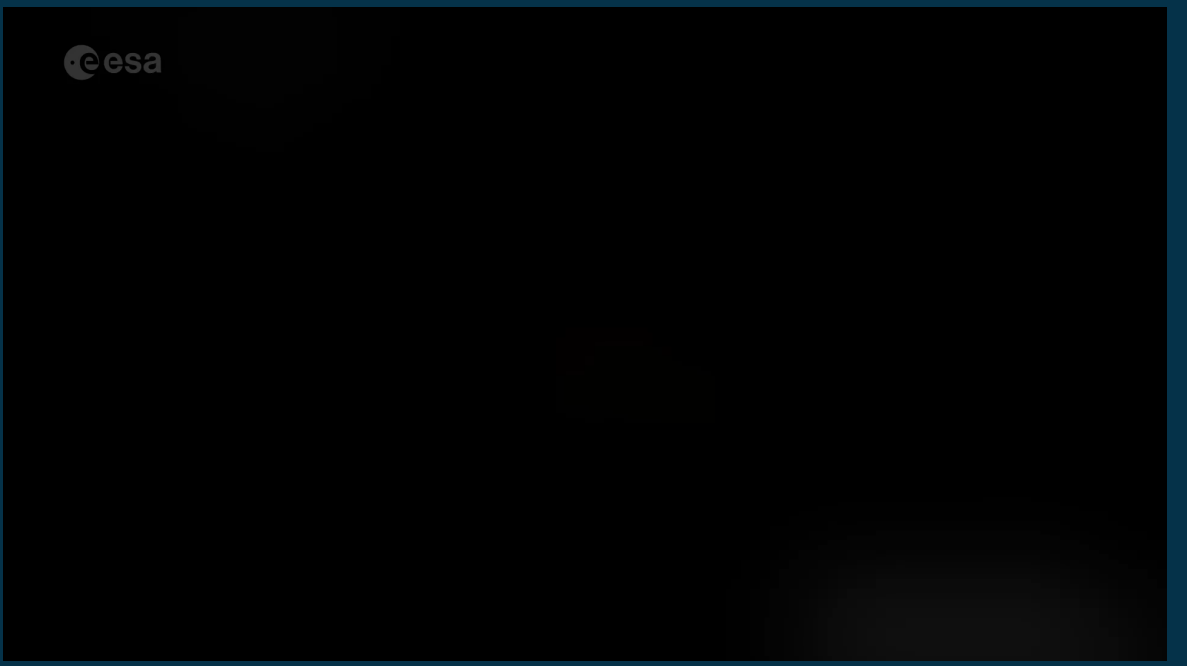




high resolution land cover cci

https://climate.esa.int/en/projects/high-resolution-land-cover/

* Generated operationally via C3S from 2016

New activities in response to UNFCCC Paris Agreement

reccap-2 cci

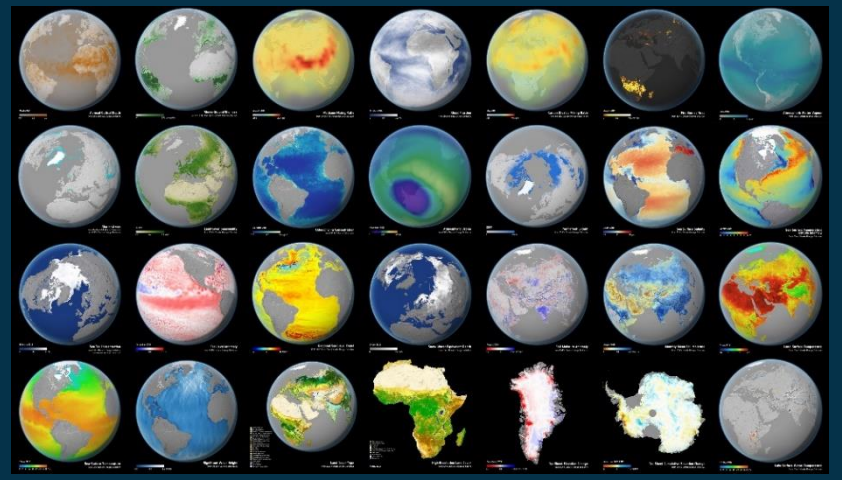
Expanding on results from RECCAP-2 and working with operational climate services

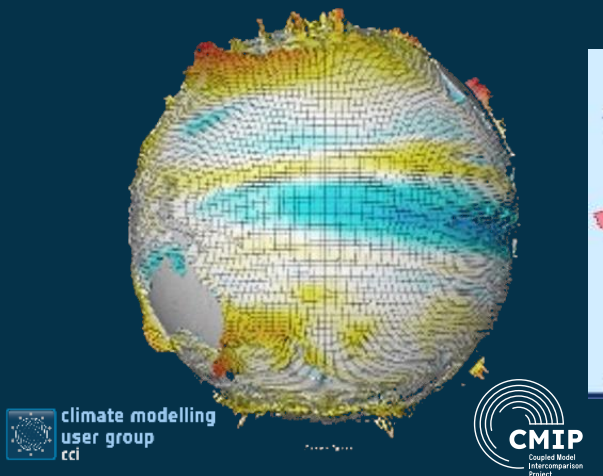
Bastos, A., Ciais, P., Sitch, S. et al. On the use of Earth Observation to support estimates of national greenhouse gas emissions and sinks for the Global stocktake process: lessons learned from ESA-CCI RECCAP2. Carbon Balance Manage 17, 15 (2022). https://doi.org/10.1186/s13021-022-00214-w

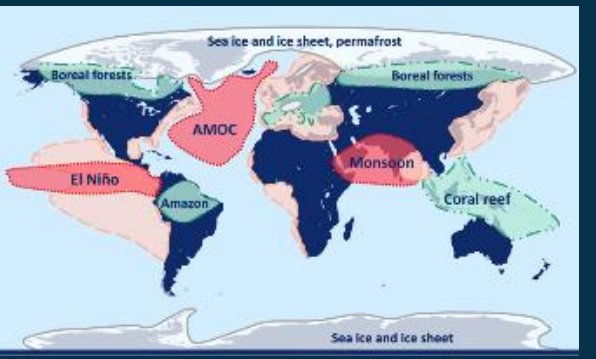
https://climate.esa.int/en/supporting-the-paris-agreement/reccap2-climate-space/

EXPANDING ESA's CLIMATE CHANGE INITIATIVE

Duration: 2023-2029 | Funding: phase 1 ~90 Meuro ; phase 2 – TBD at CMIN 2025







- Providing **physical evidence** for a changing climate, R&D for **operational climate services**
- Earth observation data support and verify the **UNFCCC Paris Agreement** pledges
- **Linking observations with modelling** provides trustworthy climate predictions and projections
- **Cross-ECVs and Tipping Points**

+ **Knowledge Exchange** (data management and curation, comms, outreach, education)

Policy drivers for CLIMATE-SPACE

- GCOS & WCRP requirements
- UNFCCC Paris Agreement
- IPCC Assessment Reports
- New users: tipping points, biodiversity & ecosystems, health

ECMWF Newsletter 171

news

Use of ESA Climate Change Initiative data in ECMWF's Earth system model

Angela Benedetti, Gianpaolo Balsamo, Souhail Boussetta, Francesca Di Giuseppe, Antje Inness, Kenta Ochi, Patricia de Rosnay, Hao Zuo

Climate change and consequent changes in weather patterns are among the greatest environmental challenges of the 21st century. The implications of a warming climate are widespread, affecting fresh water resources, global food production and sea levels.

The need for systematic observations of climate over a significant timescale has never been greater than today. To respond to this need, in 2012 the European Space Agency (ESA) launched the Climate Change Initiative (CCI) programme, which is currently in its third phase. The objective of CCI is to realise the full potential of the long-term global Earth observation archives that ESA has established over the past 30 years. For more information, see https://climate.esa.int/en/.

At ECMWF, several CCI datasets are used for various applications within our Earth system model. Here we briefly present some examples.

Ocean CCI datasets

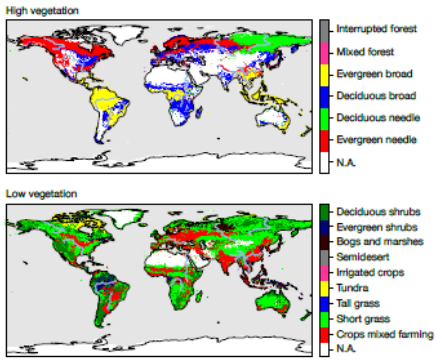
Various ocean-related climate data records have been developed during the last two phases of ESA-CCI projects. These include L4 gridded sea-level (SL) anomalies, sea-surface temperature (SST) analysis, sea-surface salinity (SSS) analysis, and sea-ice data (concentration and thickness). These CCI climate data were developed with a focus on reconstructing accurate and homogenous long-term climate signals by using consistent reference satellite instruments throughout the full reprocessing period. As a result, these CCI datasets are commonly used for monitoring and tracking climate change signals related to the ocean.
At ECMWF, they have been used for verification of seasonal forecasts and for evaluation of the performance of ocean and sea-ice reanalysis systems. Research activities to investigate direct assimilation of CCI ocean data, such as SST and sea-ice thickness data, in the ECMWF ocean reanalysis system are ongoing as well.

Land CCI datasets

An upgrade to more accurate and up-to-date land use and land cover (LU/LC) maps is being tested within the ECMWF system. This uses a new software framework to generate the model physiography for the ECMWF land surface modelling system (ECLand). The new maps are based on the ESA-CCI LU/LC, which provides consistent maps at 300 m spatial resolution on an annual basis from 1992 to the present. A total of 22 land cover classes are represented, based on the land cover classification system developed by the United Nations Food and Agriculture Organization, and adapted to the Biosphere-Atmosphere Transfer Scheme classes used in ECLand. The introduction of ESA-CCI maps will increase low vegetation and bare ground covers and reduce high vegetation cover. These differences will have a substantial impact on energy, carbon and water fluxes, which are currently being evaluated for future operational implementation.

Snow CCI dataset

ECMWF is part of the Snow CCI Climate Research Group. Preliminary investigations have shown a good level of consistency between the prototype snow cover CCI products and the IMS (Interactive Multisensor snow and ice mapping System) snow cover from the United States National Ice Center that is currently assimilated at ECMWF for numerical weather prediction and reanalysis. However, IMS high-resolution snow cover is available from 2004 only. This results in a discontinuity in snow cover and snow mass in ECMWF's ERA5 reanalysis in 2004. The quality of the CCI snow cover product from the early 1980s opens up possibilities to



ESA-CCI vegetation type maps adapted to ECLand. The charts are for high vegetation (upper panel) and low vegetation (lower panel).

ESA-CCI Essential Climate Variables in the Climate Data Store

Carlo Buontempo, Chiara Cagnazzo, Joaquin Muñoz Sabater, André Obregón, Iryna Rozum, Freja Vamborg

The Copernicus Climate Change Service (C3S), implemented by ECMWF on behalf of the EU, delivers open and free access to state-of-the-art climate products and information, building upon the latest science. Among different climate data, C3S provides operational services for 22 satellite-based essential climate variables (ECVs). This includes access to derived products, generally in the form of global gridded Climate Data Records (CDRs) through the cloud-based Copernicus Climate Data Store (CDS). A subset of them is delivered in coordination with the European Space Agency Climate Change Initiative (ESA-CCI), where C3S operationalises the ESA-CCI production chains to generate seamless temporal extensions of CDRs. An interactive application displaying variables from ESA-CCI CDRs together with reanalysis variables is under development in the CDS Toolbox. Selected ECVs from ESA-CCI are already routinely used, while others are planned to be used, in the C3S European State of the Climate report and other C3S monitoring activities. They include concentration of greenhouse gases, sea-ice thickness, sea level, sea-surface temperature and ocean colour.

C3S quality control

Together with access to the data, C3S has developed an Evaluation and Quality Control (EQC) framework to assess the technical and scientific quality of different service components, including datasets, applications and tools, with special attention to their value to the users.

The EQC function includes independent scientific assessment of ECV products from satellite observations available through the CDS, including CDRs from ESA-CCI. Those independent assessments are made by scientific experts and complement the evaluations prepared by data providers, by focusing on several aspects such as documentation, data accessibility, usability and dataset maturity.

EQC reports include, for each evaluated dataset: (i) an evaluation of technical characteristics (such as metadata standards, data format, space-time resolution and coverage (an example of coverage is given in the figure); (ii) a section on dataset maturity, focusing on data documentation and uncertainty characterisation and based on a substantial literature review by the evaluators; (iii) a fitness for purpose analysis in the context of specific scientific applications, including dataset homogeneity, its capability to reproduce known climate extremes, and its ability to estimate linear trends.

CCI R&D in Operational Services

CCI Project	GCOS ECVs		Operational Service
	GCOS 245		
	Atmospheric ECVs		
Water Vapour CCI	Upper-Air Water Vapour	→	C3S Water Vapour & **SAF**
Cloud CCI	Cloud Properties	→	C3S Cloud Properties
Greenhouse Gases CCI	Greenhouse Gases	→	C3S CO2
LOLIPOP CCI*			C3S Methane
Ozone CCI	Ozone	→	C3S Ozone
Precursors CCI & MEDUSA**	Precursor ECVs***	→	CAMS Precursors
Aerosol CCI	Aerosol Properties	→	C3S Aerosol
	Ocean ECVs ****		
Sea Surface Temperature CCI	Sea-Surface Temperature	→	C3S SST & CMEMS
Sea Level CCI	Sea Level	→	C3S Sea Level & CMEMS
Sea Ice CCI	Sea Ice	→	C3S Sea Ice
Ocean Colour CCI	Ocean Colour	→	C3S Ocean Colour
	Terrestrial ECVs		
Lakes CCI	Lakes	→	C3S Lakes
Glaciers CCI	Glaciers	→	C3S Glaciers
Antarctic Ice Sheet CCI	Ice Sheets and Ice Shelves	→	C3S Ice Sheets
Greenland Ice Sheet CCI			
Landcover CCI	Landcover	→	C3S Land Cover
High Resolution Landcover CCI			
Fire CCI	Fire	→	C3S Fire Disturbance
Soil Moisture CCI	Soil Moisture	→	C3S Soil Moisture
Vegetation Parameters CCI	FAPAR	→	C3S FAPAR
	Leaf Area Index	→	C3S LAI

Climate Change Service

Copernicus Marine Service

Atmosphere Monitoring Service

SAF
The EUMETSAT Network of Satellite Application Facilities

*LOng-LIved greenhouse gas PrOducts Performances
** Precursors for aerosols and ozone CCI
Methane Emissions Detection Using Satellites Assessment
*** Precursors supporting the aerosol and ozone ECVs
**** In discussion with CMEMS re. Sea State

The R&D of **21** CCI projects has been taken up by operational services.

Working with operational services

- Provision of CDRs
- Coordination of R&D activities
- Collaboration on pre-operational developments

CCI-C3S dedicated cooperation agreement

- Regular interactions with C3S, CAMS, (CMEMS and CGLS) providing R&D and pre-ops support
- ESA presentations at C3S and CAMS general assemblies
- C3S and CAMS presentations at CCI colocation
- Membership on science advisory boards (CSAB, MEDUSA)
- Coordination as part of 4Es meeting on European Capacity for Climate Observations – LPS2 agora
- As part of CEOS/CGMS WGClimate: collaboration and coordination internationally
- Common topics
  - Supporting DG-CLIMA
  - CMIP: prep for AR7 and forcing data provision
  - Adaptation and health

Thanks!

Clement Albergel, European Space Agency (ESA)
Head of ESA's Actionable Climate Information Section

Clement.albergel@esa.int

Bonn, Germany | 9-10 April 2025

Workshop on ancillary data for land surface and Earth system modelling
Part of ECMWF's 50th anniversary celebrations