ESA Climate Change Initiative in support of Terrestrial Carbon science

→ OBSERVING | OUR CLIMATE | OUR FUTURE

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With contributions from colleagues at the ESA Climate Office
and involved in the ESA Climate Change initiative

**4th International Earth Surface Working Group
5-6 April 2022 | virtual**

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Intergovernmental Panel of Climate Change (IPCC)

Assessment Report from WG I , August 2021

"It is unequivocal that human influence has warmed the atmosphere, ocean and land. Widespread and rapid changes in the atmosphere, ocean, cryosphere and biosphere have occurred."

Warming accelerates: Each of the last four decades has been successively warmer than any decade that preceded it since 1850.

2001-2020: 0.99 [0.84 to 1.10] °C

2011–2020: 1.09 [0.95 to 1.20] °C
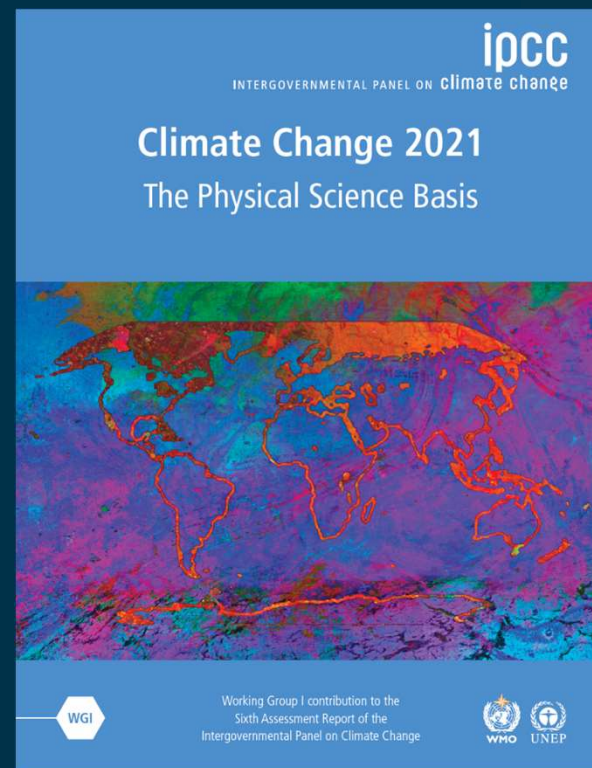
"Methodological advances and new datasets contributed approximately 0.1ºC to the updated estimate of warming in AR6."

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United Nations Framework Convention on Climate Change

UNFCCC: 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*

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ESA CLIMATE CHANGE INITIATIVE PROJECTS

24 ECV projects, 3 budget closure projects, a data support project a climate modelling project and a fellowship call currently comprise the CCI
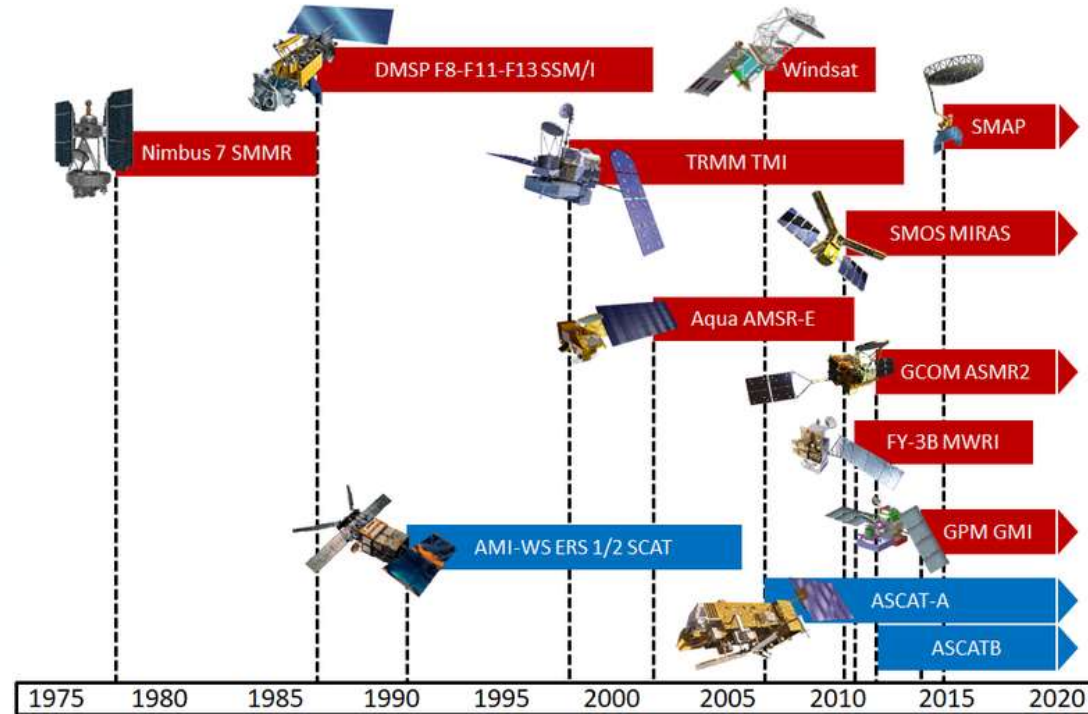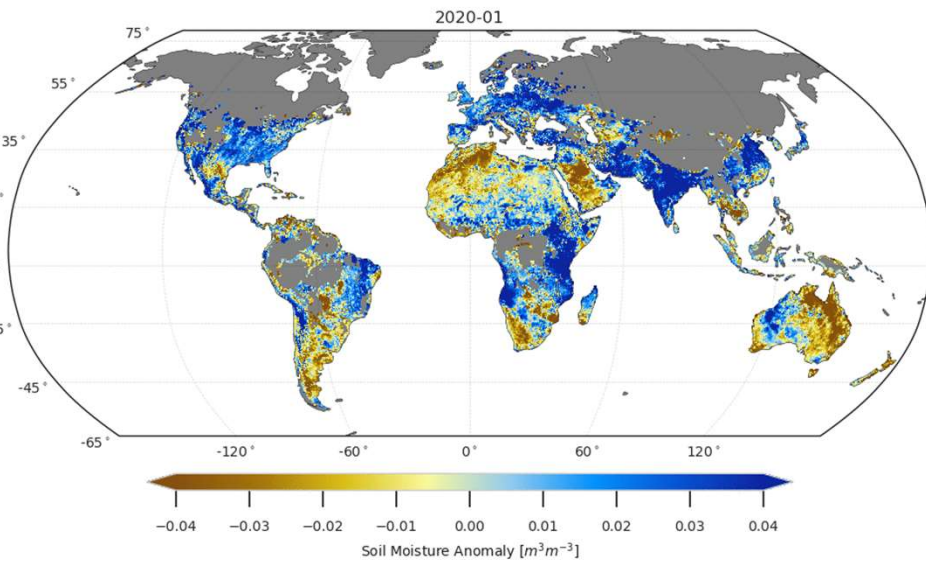
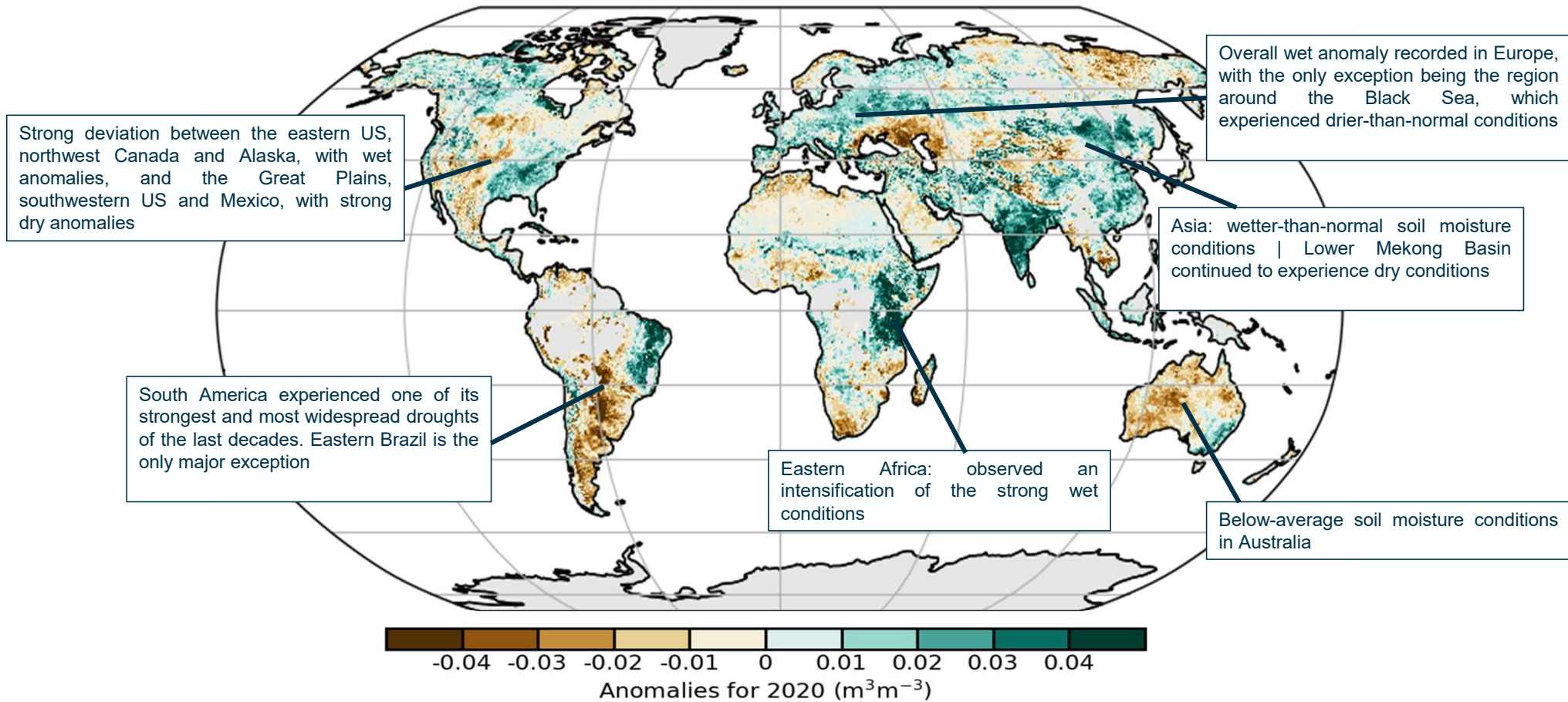esa

Climate Change Initiative: Soil Moisture

- 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
- 12 public releases to date

ESA CCI soil moisture v06.1 products utilize 4 active and 10 passive microwave sensors

Soil Moisture | BAMS State of the climate in 2020

Strong deviation between the eastern US, northwest Canada and Alaska, with wet anomalies, and the Great Plains, southwestern US and Mexico, with strong dry anomalies

Overall wet anomaly recorded in Europe, with the only exception being the region around the Black Sea, which experienced drier-than-normal conditions

Asia: wetter-than-normal soil moisture conditions | Lower Mekong Basin continued to experience dry conditions

South America experienced one of its strongest and most widespread droughts of the last decades. Eastern Brazil is the only major exception

Eastern Africa: observed an intensification of the strong wet conditions

Below-average soil moisture conditions in Australia

-0.04 -0.03 -0.02 -0.01 0 0.01 0.02 0.03 0.04
Anomalies for 2020 ($m^3 m^{-3}$)

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→ BIOMASS

Role of above Ground Biomass in global carbon cycle
➔ **Source:** loss under Land Use Change or by degradation
➔ **Sink:** forest growth

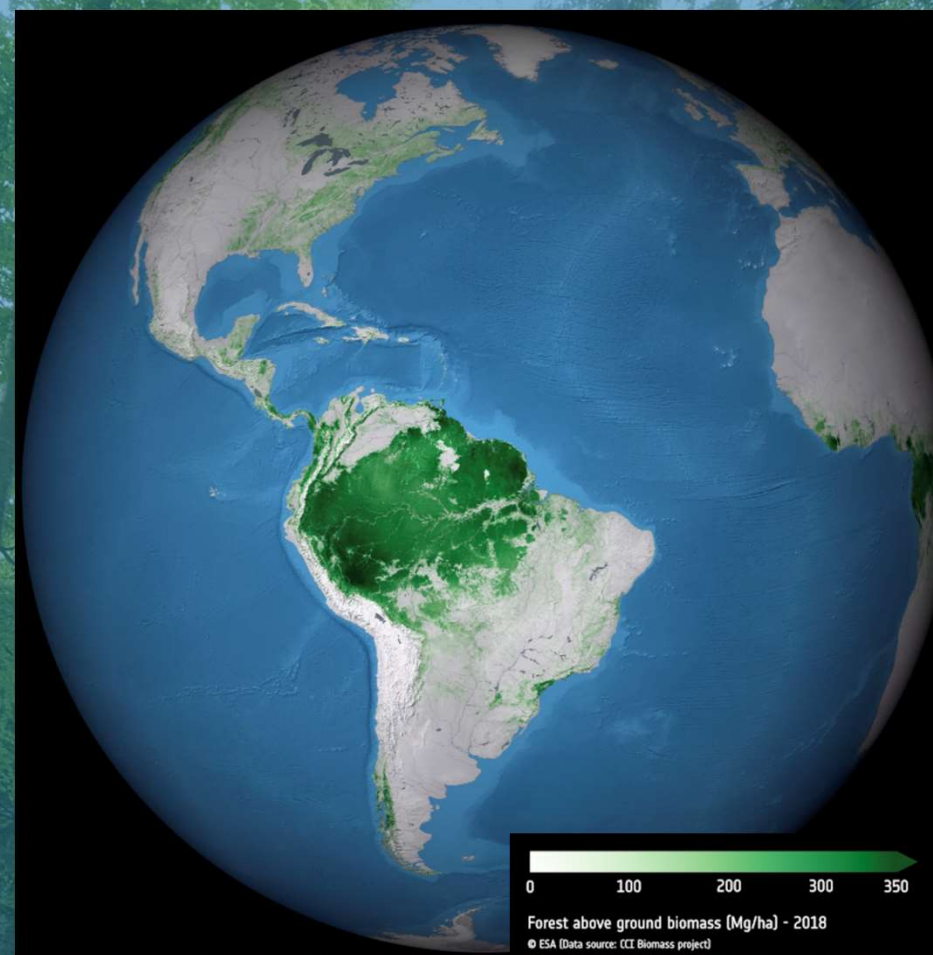**Wider role in understanding and predicting climate**
➔ Model initialisation and testing, estimation of Carbon turnover, inferring forest disturbance regime *[...]*

Contributor to the Paris Agreement GST
➔ National Determined Contributions
➔ More robust and transparent reporting in the UNFCCC
➔ Overall reliance of natural sinks for climate mitigation
➔ Carbon-Climate feedbacks, hot spots, tipping points, ecosystem collapse

biomass cci

Forest above ground biomass (Mg/ha) - 2018
© ESA (Data source: CCI Biomass project)

0   100   200   300   350

climate change initiative

→ **BIOMASS**

New maps for 2010, 2017, 2018, 2020
→ Sentinel-1, Envisat's ASAR, ALOS-1 & ALOS-2, *[...]*
→ 100 m spatial resolution, provision of standard deviation
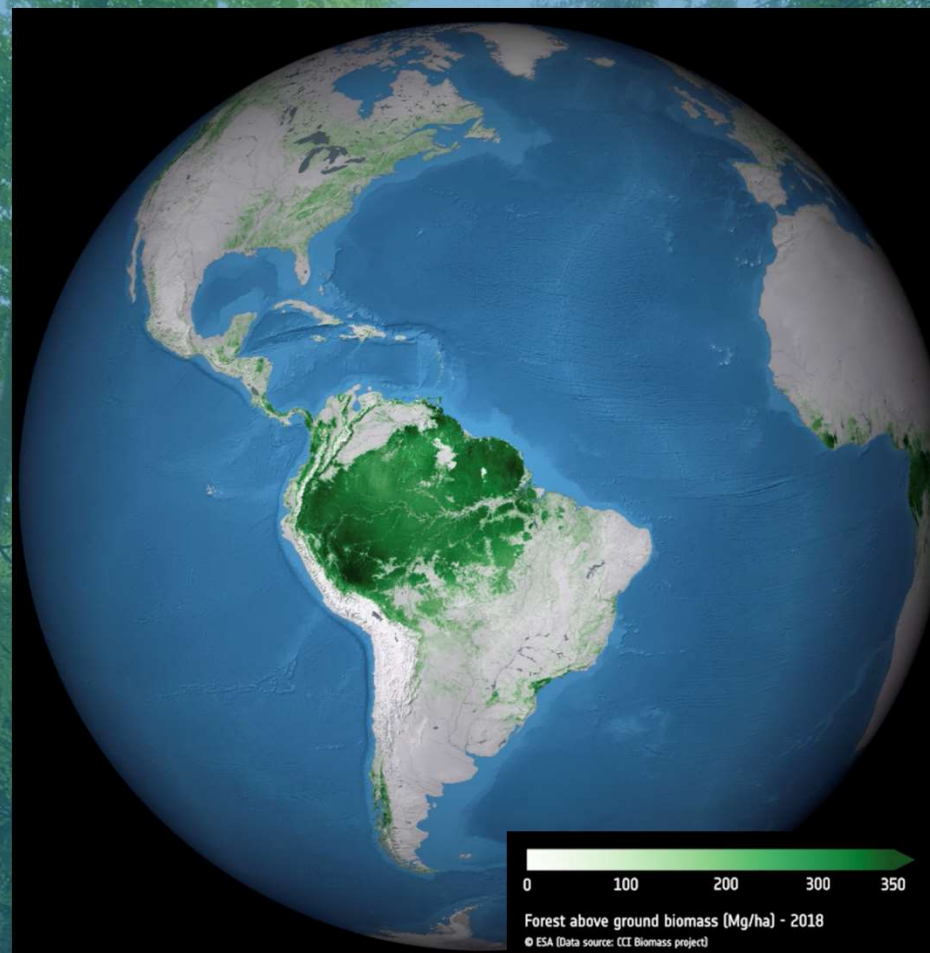
Address temporal consistency
→ integration of additional data streams
(SMOS* / ASCAT Vegetation Optical Depth)

*Qin, Y., Xiao, X., Wigneron, JP. *et al.* Carbon loss from forest degradation exceeds that from deforestation in the Brazilian Amazon. *Nat. Clim. Chang.* **11,** 442–448 (2021). https://doi.org/10.1038/s41558-021-01026-5

biomass
cci

Forest above ground biomass (Mg/ha) - 2018
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→ BIOMASS

Forest degradation has become the largest process driving carbon loss in the Brazilian Amazon

Net loss of 0.67 Pg C of above ground biomass over the last decade

Study ESA SMOS L-VOD data

Calls to strengthen forest protection policies (REDD+) and support mitigation policies (Paris Agreement)

https://www.esa.int/Applications/Observing_the_Earth/Space_for_our_climate/Forest_degradation_primary_driver_of_carbon_loss_in_the_Brazilian_Amazon

biomass cci

Map credits: ESA/CCI Biomass project and Hansen/UMD/Google/USGS/NASA

Forest loss

Above ground biomass (tonnes/ha)

200 km 0 100 200 300 ≥400

Forest loss map of the Amazon basin 2010-2019 using data from the Global Forest Change dataset (University of Maryland)

Qin, Y et al (2021).. *Nat. Clim. Chang.* doi.org/10.1038/s41558-021-01026-5

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→ FIRE

25%-35% of GHG result from biomass burning

Fire_CCI key variable is "burned area"

2 global products

➔ *Pixel products: date of detection, confidence level, land cover*

➔ *Grid product: sum of burned area, standard error, fraction of burnable area, fraction of observed area, number of patches, and sum of burned area for each land cover*

Small Fire Database over Sub-Saharan Africa, demonstrator over the Amazon, several products under development

fire cci

Product name*	Data	Period	Spatial resolution	Domain
FireCCI51	MODIS	2001-2020	250m 0.25°	Global
FireCCISFS11/20	Sentinel-2	2016 2019	20m & 0.25° 20m & 0.05°	Sub-Saharan Africa
FireCCILT11	AVHRR-LTDR	1982-2018	0.25°	Global
FireCCS1SA10	Sentinel-1	2017	40m	Demonstrator Area in the Amazon
Case Study	Sentinel-1	El Niño 2015-2016	~ 10m at the Equator	Indonesia

Additional (more recent) products*
Global product based on Sentinel-3 SYN data for 2019 (FireCCIS310)
Test sites in Africa based on Sentinel-1 and a combination of S1 & S2 data for 2019
Global products based on merged reflectance or merged burned area outputs

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

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→ FIRE

Importance of small fires and their carbon emission
→ Over Africa 90% more small fires (<100 ha) were detected with Sentinel 2 than with MODIS in 2016
→ *Contribute to 2.02 million km² of the 4.89 million km² total burned area detected*

Corresponding Fire C emission estimated are 1.44 PgC
→ *31-101% higher that previously thought*
→ *14% of global C emission from FF burning*

Critical driver of BA in Sub-Saharan Africa
→ *Raises the contribution of biomass burning to global GHG and aerosols*

fire cci

Ramo, R., et al: ***African burned area and fire carbon emissions are strongly impacted by small fires undetected by coarse resolution satellite data***, Proceedings of the National Academy of Sciences Mar 2021, 118 (9) e2011160118; DOI: 10.1073/pnas.2011160118

ESA UNCLASSIFIED - For Official Use
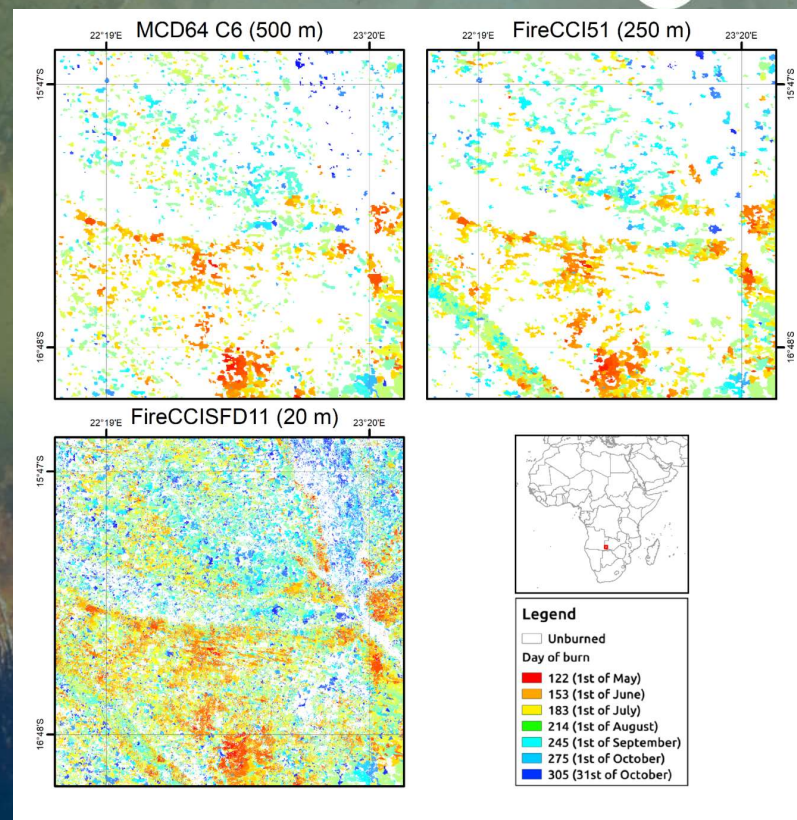
The finer resolution (20m) of the FireCCISFD11 product allows detecting much smaller burned area patches (and hence a larger total BA) compared to medium-resolution sensors (e.g. FireCCI51 at 250m)

European Space Agency
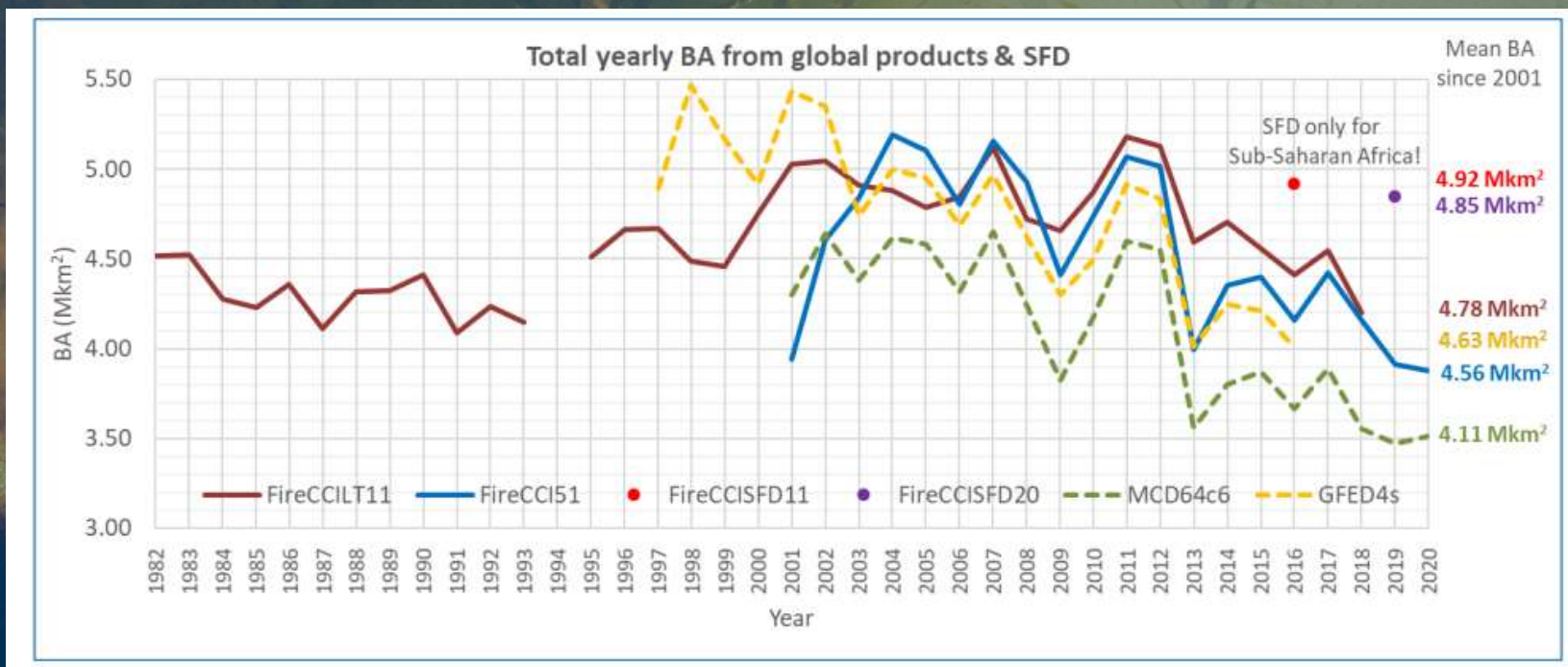
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→ PERMAFROST

Develop and deliver permafrost maps as ECV products
➔ *Depth of active layer, Permafrost temperature, Rock glacier kinematics*

Permafrost model that compute the ground thermal regime constrained by EOs such as LST, SWE, Land Cover
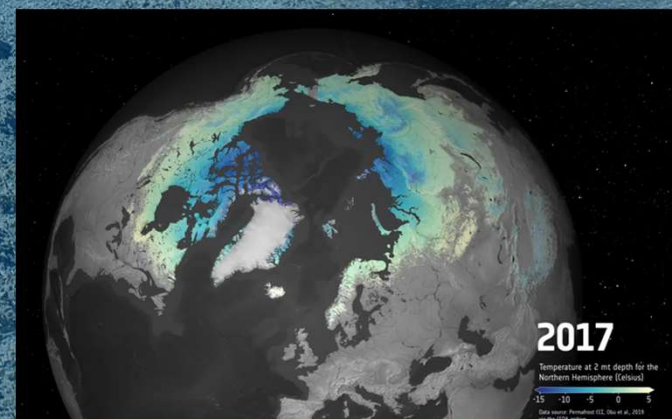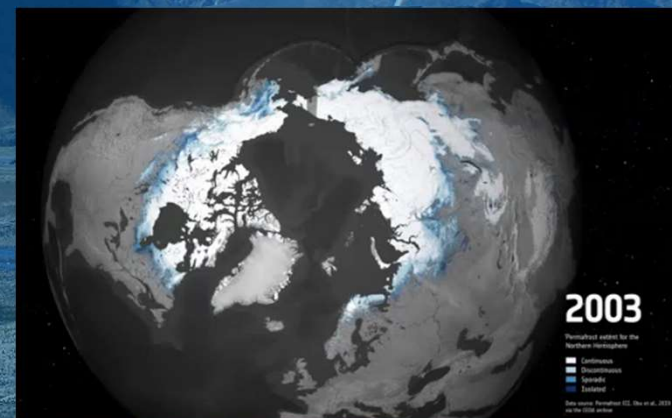➔ *Strong link to other ESA projects*

21-year satellite-derived record detailing the annual changes to the northern hemisphere permafrost soils from 1997-2020
➔ *longest satellite permafrost record currently available*

permafrost cci

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climate change initiative

→ PERMAFROST

'How microbes in permafrost could trigger a massive carbon bomb'

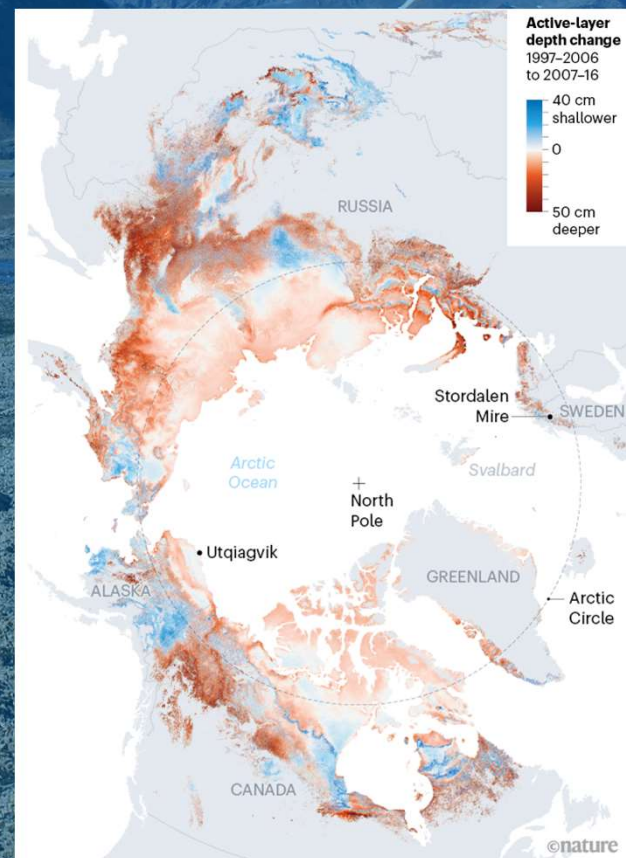**Tracking the loss of permafrost using satellite data**

North Hemishpere active layer thickness deepened by 2.5cm (2007-2016) compared to previous decade, 5% NH area by 30cm
➔ *Destabilizes the landscape*
➔ *Makes more carbon available to microbes in the soil, producing carbon dioxide and methane*

permafrost
cci

Active-layer depth change
1997–2006 to 2007–16

40 cm shallower

0

50 cm deeper

RUSSIA

Stordalen Mire — • SWEDEN

Svalbard

Arctic Ocean

+ North Pole

• Utqiagvik

GREENLAND

ALASKA

— Arctic Circle

CANADA

©nature

Data from Permafrost_cci; Obu et al

Nature *591*, 360-362 (2021)

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eesa

land cover cci
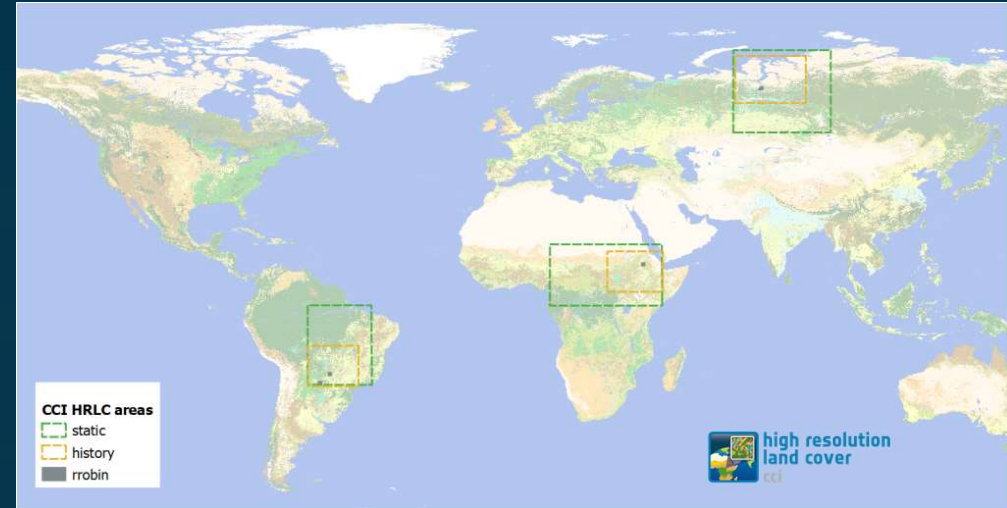
high resolution land cover cci

LU & LCC are 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, 1992-2020, Consistent analysis-ready annual PFT maps for climate modelling*

* Generated operationally via C3S from 2016

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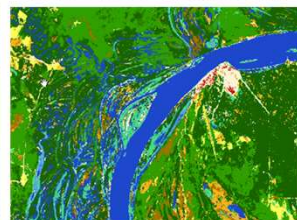

CCI HRLC areas
- static
- history
- rrobin

high resolution land cover cci

| 2015 ESA CCI MRLC at 300m | Sentinel-2 image | 2019 ESA CCI HRLC map |

Amazonia (tile 21KUQ)

* Generated operationally via C3S from 2016

Tree cover broadleaved deciduous

Tree cover broadleaved evergreen

Broadleaved evergreen Shrubland

Mosaic tree and shrub

Shrub or herbaceous cover flooded

Mosaic herbaceous cover

Mosaic natural vegetation
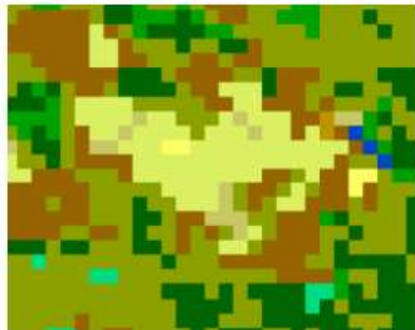
Grassland
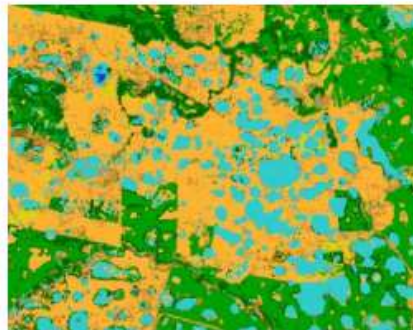
Cropland

Urban areas

Water bodies

CCI medium resolution
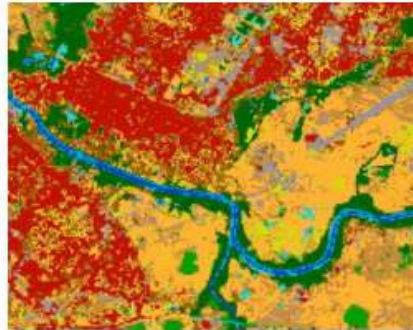
CCI high resolution

Google Image

CCI medium resolution

CCI high resolution

Google Image

Evergreen broadleaved

Deciduous broadleaved

Shrub evergreen

Shrub deciduous

Grassland

Cropland

Herbaceous Vegetation aquatic or regularly flooded

Bare areas

Build up

Open water seasonal

Open water permanent

ESA CCI RECCAP2 Cross-ECV project

Reconciling UNFCCC National GHGs inventory & atmospheric inversions

A comprehensive framework to process the results of atmospheric inversions to make them suitable for evaluating the estimates of anthropogenic emissions and removals of GHGs made by UNFCCC national inventories (Deng et al., 2022)

- *Boxplots: inversions for different time periods*

- *Black horizontal lines: net CO_2 fluxes for inversions (fossil fuel and cement emissions + land flux)*

- *Circles: mean of UNFCCC NGHGI data*

- Consistency between means for each period of NGHGI land carbon sinks and inversions, for all major emitters

➜ *Many underlying assumptions but a step toward policy implementation monitoring*

CO$_2$ fluxes for land sinks and fossil emissions
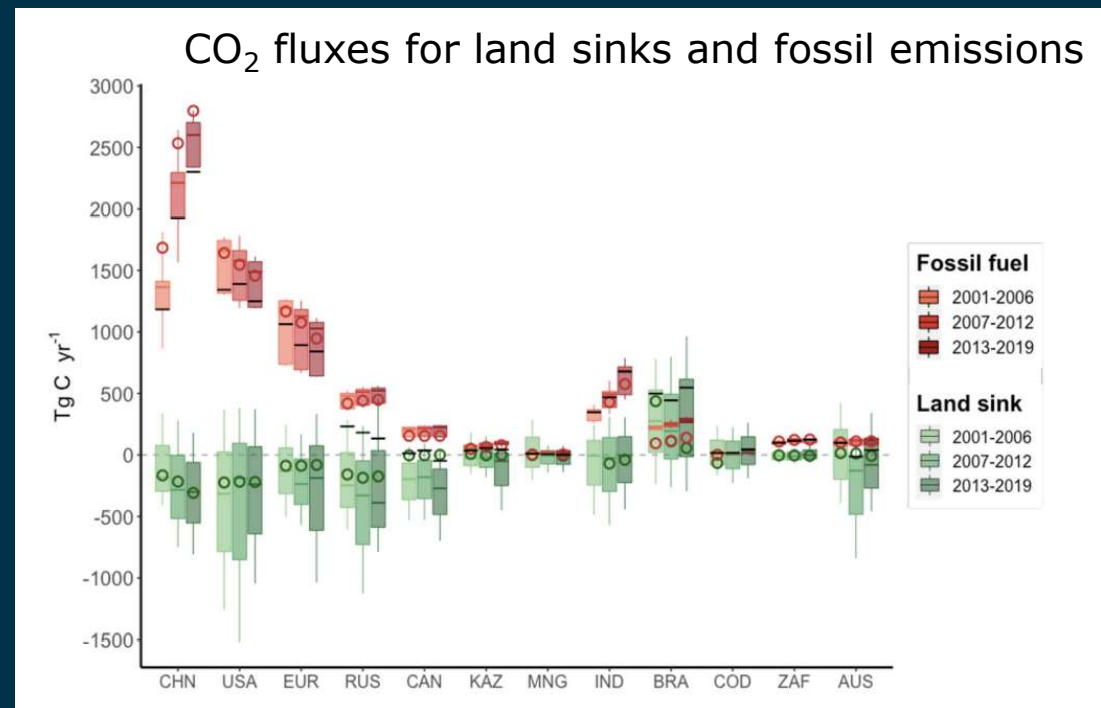
ESSDD - Comparing national greenhouse gas budgets reported in UNFCCC inventories against atmospheric inversions (copernicus.org)

Aerosols released from Australian bushfires triggers algal blooms
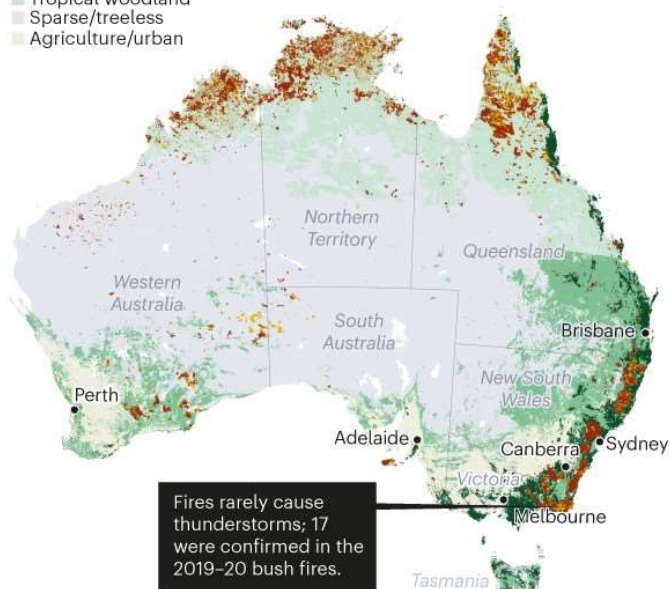

EXTREME BURNING

The 2019–20 Australian bush fires destroyed millions of hectares of vegetation. The geographic extent was so immense that it exposed the nation's fire monitoring system as a thing of the past. Because individual states and territories record bush fires in different ways, there are data gaps and inconsistencies that make it difficult to accurately assess the fires' scale and environmental impact.

Land type
- Forest
- Temperate woodland
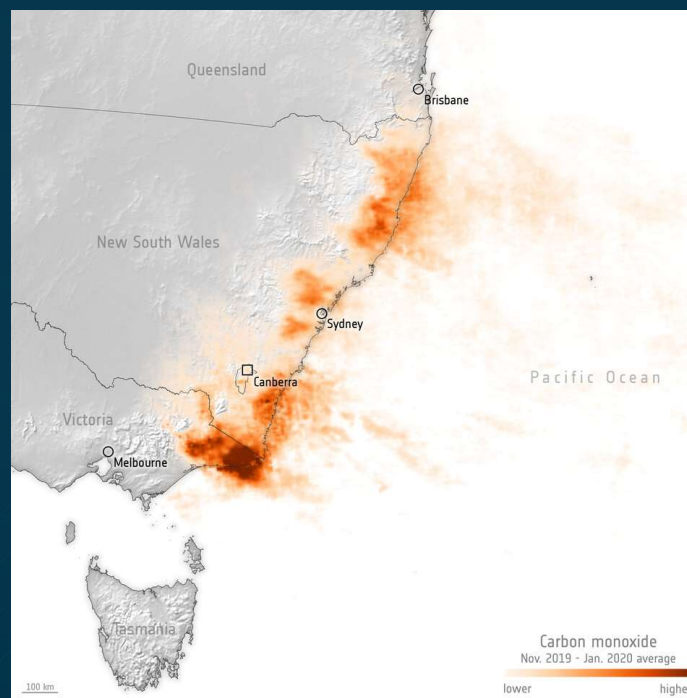- Tropical woodland
- Sparse/treeless
- Agriculture/urban

Area burnt (2019–20)
- Satellite estimate (30.38 million hectares)
- Government estimate (39.8 million hectares)

Fires rarely cause thunderstorms; 17 were confirmed in the 2019–20 bush fires.

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

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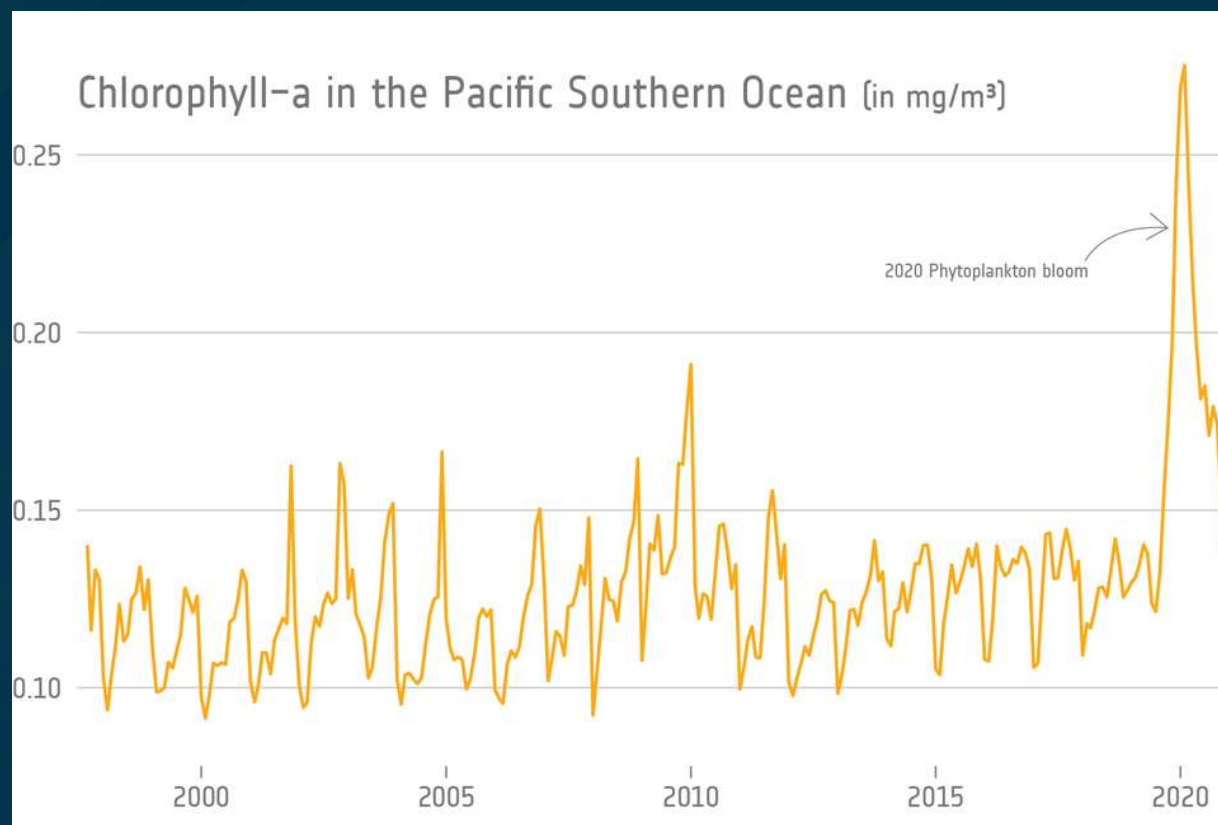- Calculated from TROPOMI: 715 million tonnes

Carbon monoxide
Nov. 2019 - Jan. 2020 average

lower — higher

Aesols released from Australian bushfires triggers algal blooms

Vast plumes of smoke which are rich in nutrients, were swept away over the ocean

These aerosols had infused the waters with iron, nourishing phytoplankton which then absorbed carbon dioxide equivalent to as much as 95% of the emissions from the fires

Chlorophyll−a in the Pacific Southern Ocean (in mg/m³)

2020 Phytoplankton bloom

https://www.esa.int/Applications/Observing_the_Earth/Aerosols_released_from_Australian_bushfires_triggers_algal_blooms

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land cover cci

high resolution land cover cci

greenhouse gases cci

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*Further develop retrieval algorithms needed to generate new high quality satellite-derived CO2 and NH4 atmospheric data products
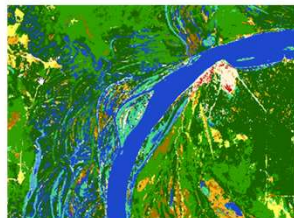➔ *column-averaged dry-air mole fractions (molecular mixing ratios) of CO2 and CH4*

lakes cci

2015 ESA CCI MRLC at 300m | Sentinel-2 image | 2019 ESA CCI HRLC map

Amazonia (tile 21KUQ)

* Now generated operationally via C3S

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lakes cci

Lake Water Level*, Lake Water Extent, Lake Surface Water temperature*, Lake Ice Cover and Lake Water-Leaving Reflectance
- *Several user cases studies (incl. brownification in Scandinavian Lakes)*
- *Potential to investigate methane emission from Lakes*
➔ *New dataset released > 2000 lakes, data from the 90's*

* Now generated operationally via C3S

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