



PROJECT OVERVIEW

- **Objective** of the Working Group Africa is to enhance capacities in Africa in the sector of Earth Observation (EO) from Space, **in complement** to other institutional efforts such as GMES & Africa.
- Training of trainer's program in **FR, EN and PT**:
 - Phase 1: 10 modules provided to 30 trainers
 - Phase 2: supporting the trainers to implement a training session in their local communities
- Webinars in FR, EN and PT for **wider dissemination and engagement.**



WORKING
GROUP
AFRICA

Agenda for today!

Webinar 2: Copernicus services and applications – part II

1. General introduction and webinar objectives

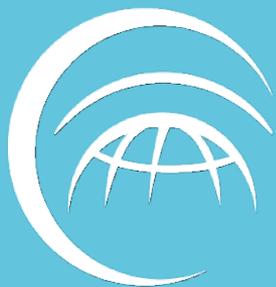
Objective: Present the Copernicus Services and Use cases

FOCUS: Copernicus Atmospheric and Climate Change Services

1. General introduction and webinar objectives (Ali Arslan, FMI)
2. The Copernicus Atmosphere Monitoring Service - CAMS (Chris Stewart, ECMWF)
3. The Copernicus Climate Change Service (Chris Stewart, ECMWF)
4. Emission Observatory - Pilot for Africa: Monitoring air pollution and greenhouse gas emissions in Africa using satellite data (Iolanda Ialongo, FMI)
5. The GMES & Africa ICPAC consortium, linking climate services to environmental monitoring: case study on protected areas. (David Ongo, ICPAC)
6. Mapping urban expansion in African cities (Marta Sapena-Moll, DLR)

The Copernicus Atmosphere Monitoring Service (CAMS)

Overview of the Service and applications



Atmosphere Monitoring

Chris Stewart

Laurence Rouil

CAMS team and contractors

May 2024



PROGRAMME OF
THE EUROPEAN UNION



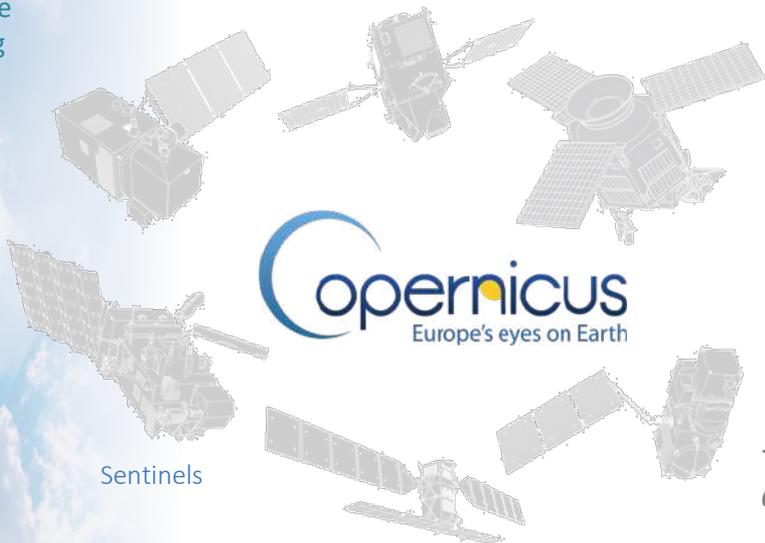
IMPLEMENTED BY





COPERNICUS

Atmosphere
Monitoring



Observations
combined with
models to provide
value-added
Services



*+ many other satellites
and non-satellite data*



Atmosphere



Climate



Land



Marine



Emergency



Security

Copernicus is the European Union's **operational** Earth Observation and Monitoring programme, looking at our planet and its environment for the ultimate benefit of everyone: **free and unrestricted data access**.



Service is implemented by ECMWF

ECWMF is contributing to the Service



PROGRAMME OF
THE EUROPEAN UNION



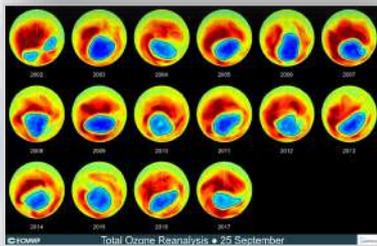
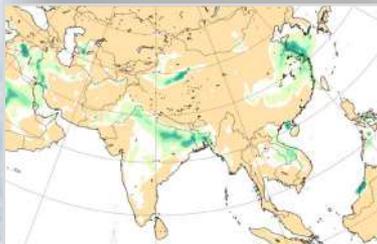
IMPLEMENTED BY

ECMWF



CAMS PORTFOLIO

Atmosphere
Monitoring



CAMS provides open & free information products based on Earth Observation about:

- past, current and near-future (forecasts) global atmospheric composition;
- the ozone layer;
- European air quality;
- emissions and surface fluxes of key pollutants and greenhouse gases;
- solar radiation;
- climate radiative forcing.

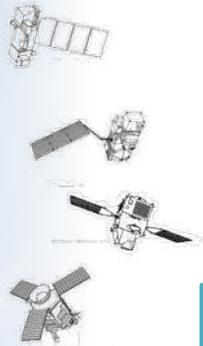
<http://atmosphere.copernicus.eu>
<http://ads.atmosphere.copernicus.eu>



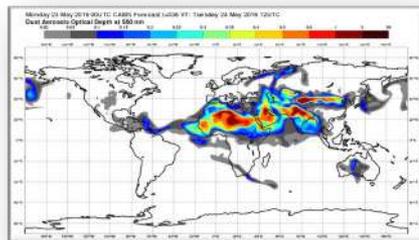


CAMS MAIN WORKFLOW

Atmosphere
Monitoring

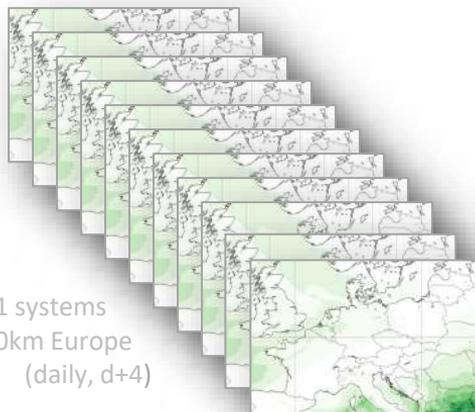


Earth Observation
See next slides



Detailed tropo. and strato. chemistry,
40km Globe (twice daily, d+5)

CAMS main operational **data**
assimilation and modelling systems

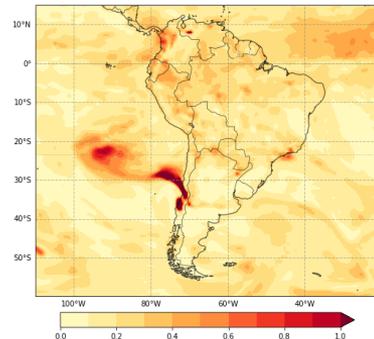


11 systems
10km Europe
(daily, d+4)

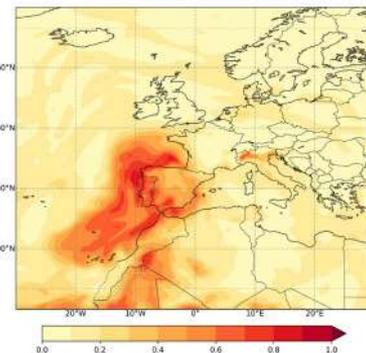


Europe's eyes on Earth

CAMS Forecast Total Aerosol Optical Depth at 550nm
20230207T00 valid for 20230207T00



CAMS Forecast Total Aerosol Optical Depth at 550nm
20230221T00 valid for 20230221T00



PROGRAMME OF
THE EUROPEAN UNION

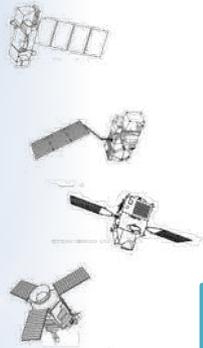
Copernicus
Europe's eyes on Earth

IMPLEMENTED BY
ECMWF

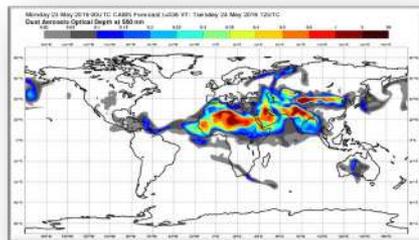


CAMS MAIN WORKFLOW... SERVING USERS WORLDWIDE

Atmosphere Monitoring

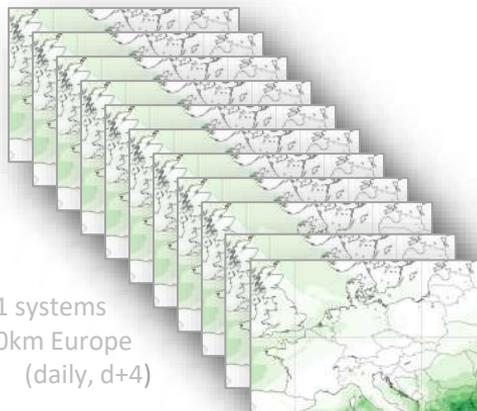


Earth Observation
See next slides

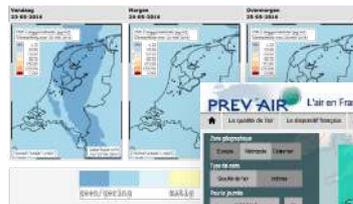


Detailed tropo. and strato. chemistry,
40km Globe (twice daily, d+5)

CAMS main operational **data assimilation and modelling systems**



11 systems
10km Europe
(daily, d+4)



Major multiplication factor
(200Mil+)



PRO GRANT OF THE EUROPEAN UNION



ECMWF



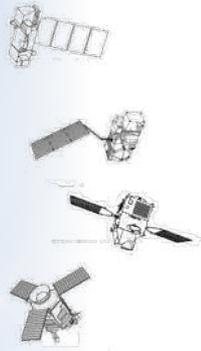
CAMS users
>33500
(~3200 routine)





CAMS USE OF EARTH OBSERVATION

Atmosphere
Monitoring



Earth Observation
from satellite (>90
instruments) and in-
situ (regulatory and
research)



Instrument	Satellite	Space Agency	Provider	Species	Status
AATSR	ENVISAT	ESA	ESA	AOD	REA(A)
AHI	Himawari-8	JMA	JMA	FRP	GFAS(P)
GOME-2	METOP-B, -C/ METOP-B, -C/ METOP-A/ METOP- A, -B	EUMETSAT-ESA	AC-SAF	O ₃ , NO ₂ , SO ₂ / HCHO/ O ₃ , NO ₂ , SO ₂ , HCHO/ O ₃ , NO ₂	GRTF(A)/ GRTF(M)/ GRTF(M)/ REA(A)
IASI	METOP-B, -C/ METOP-A/ METOP- A, -B, -C/ METOP-A, -B/ METOP-A, -B/ METOP-A, -B	EUMETSAT-CNES/ -/ -/ -/ EUMETSAT	AC- SAF/AC- SAF/ULB- LATMOS/L MD/LMD/ EUMETSAT	CO/CO/O ₃ , SO ₂ / CH ₄ /CO ₂ /CH ₄ , CO ₂	GRTF(A)/ GRTF(M)/ GRTF(P)/ GDM(A)/ GDM(P) / REA(A)
Imager	GOES-E, -W	NOAA	NOAA	FRP	GFAS(P)
MIPAS	ENVISAT	ESA	ESA	O ₃ profile	REA(A)
MLS	EOS-Aura	NASA	NASA	O ₃ profile	GRTF(A)/REA(A)
MODIS	EOS-Aqua, -Terra	NASA	NASA	AOD/AOD/FRP	GRTF(A)/ REA(A)/ GFAS(A)
MOPITT	EOS-Terra	NASA	NCAR	CO	GRTF(A)/ REA(A)
OCO-2	OCO-2	NASA	NASA	CO ₂	GDM(P)/ GHGI(A)
OMI	EOS-Aura	NASA	KNMI	O ₃ , NO ₂ , SO ₂ / O ₃ , NO ₂	GRTF(A)/ REA(A)
OMPS	S-NPP, NOAA-20	NOAA	EUMETSAT	O ₃	GRTF(A)
PMAP	METOP-A, -B/ METOP-C	EUMETSAT	EUMETSAT	AOD	GRTF(A)/ GRTF(M)
SBUV-2	NOAA-19/ NOAA- 14, -16, -17, -18 and -19	NOAA	NOAA	O ₃ profile	GRTF(M)/ REA(A)
SCIAMACHY	ENVISAT	ESA	KNMI	O ₃ , NO ₂ , CH ₄ , CO ₂	REA(A)
SEVIRI	MSG	EUMETSAT	ICARE/ EUMETSAT	AOD/FRP	GRTF(P)/ GFAS(P)
SLSTR	Sentinel-3	ESA-EUMETSAT	EUMETSAT	AOD/FRP	GRTF(P)/ GFAS(P)
TANSO	GOSAT	JAXA	SRON/ Uni. Bremen/ SRON-Uni. Bremen/S RON	CH ₄ / CO ₂ / CH ₄ , CO ₂ /CH ₄	GDM(A)/ GDM(A)/ REA(A) GHGI(A)
TROPOMI	Sentinel-5p	ESA-NSO	ESA-KNMI- DLR- / ESA- KNMI- SRON-DLR	O ₃ , SO ₂ /NO ₂ , CO, HCHO/ CH ₄	GRTF(A)/ GRTF(M)/ GDM(P)
VIIRS	S-NPP, NOAA-20	NASA-NOAA	EUMETSAT	AOD	GRTF(P)

- Only satellite data of atmospheric composition used for assimilation in the CAMS global system (*in situ* used for verification and assimilated in regional systems over Europe).
- All other data used for ECMWF NWP assimilated (about 70-75 streams) – not described here.

Status (A: assimilated; M: monitored; P: planned / research mode) depends on the different applications:

- Global real-time forecast (GRTF)
- Global delayed mode (GDM)
- Global reanalysis (REA)
- Global fire assimilation system (GFAS)
- Global surface net flux inversions of GHG (GHGI)

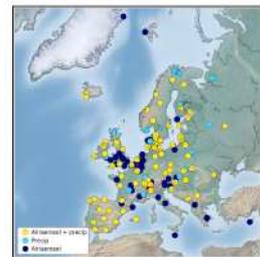


MAXIMISING USE OF IN-SITU OBSERVATIONS

Atmosphere
Monitoring



 Up-to-date air quality data



Network for the
Detection of
Atmospheric
Composition
Change

DieBilt, Netherlands (52.10°N)	Cabauw, Netherlands (51.97°N)	Valentia, Ireland (51.92°N)	Uccle, Belgium (50.8°N)
			
Villeneuve d'Ascq, France (50.61°N)	Praha, Czech Republic (50.01°N)	Heidelberg, Germany (49.0°N)	Groß-Enzersdorf, Austria (48.20°N)
			





EVOLUTION OF EARTH OBSERVATION SYSTEMS

Atmosphere
Monitoring

MetOp-SG-A

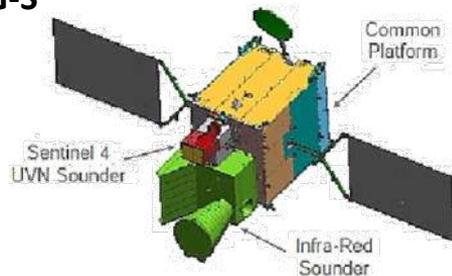


- Sentinel-5
- IASI-NG
- 3MI

Launch
end 2025

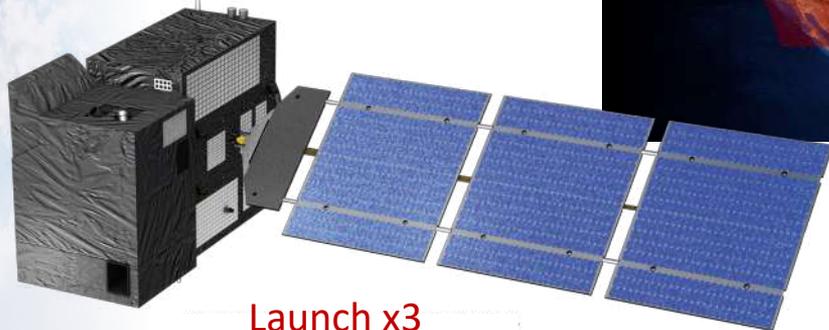


MTG-S



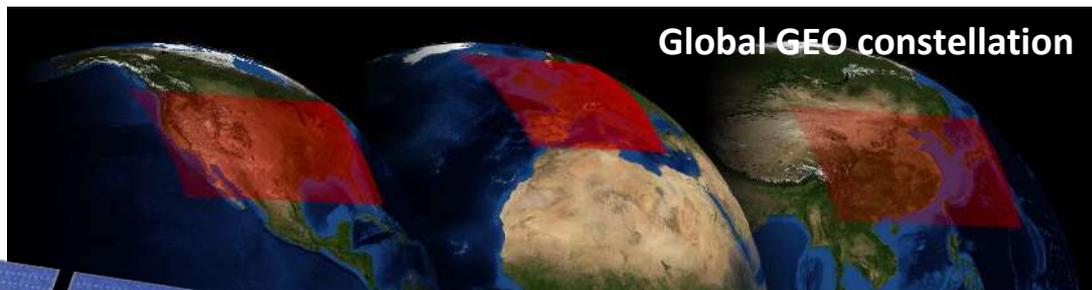
- Sentinel-4
- IRS

Launch
end-
2025/2026



CO2M

Launch x3
End-2026 to End-2027



Global GEO constellation

Use of GEMS (Asia) & TEMPO
(North America)



PROGRAMME OF
THE EUROPEAN UNION



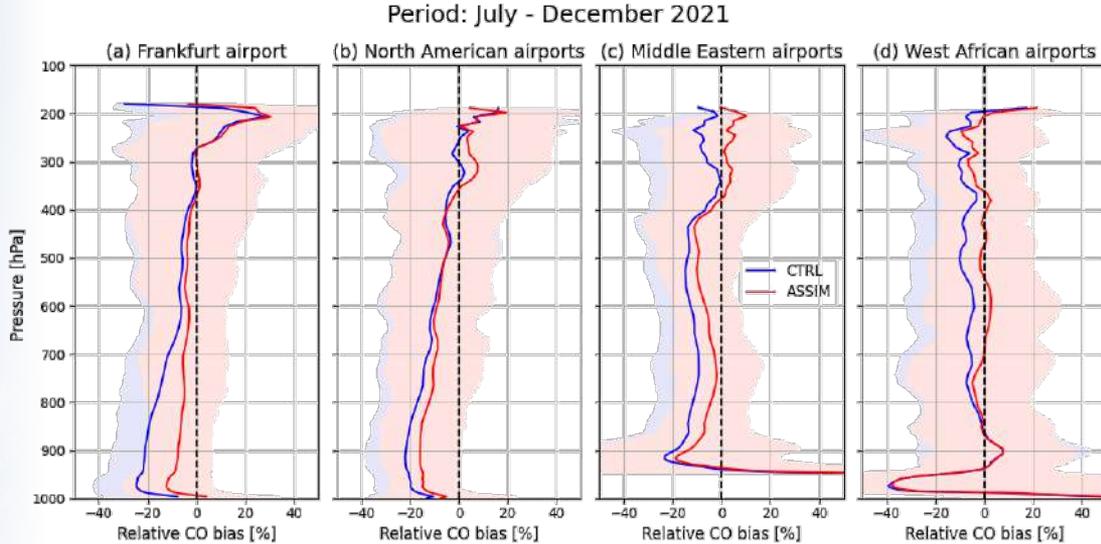
IMPLEMENTED BY





IMPACT OF SATELLITE DATA: EX. SENTINEL-5P CO

Comparison with IAGOS aircraft data



Current operations
Using Sentinel-5p

Adding new data streams is a continuous effort in CAMS. Latest example: assimilation of TROPOMI Carbon Monoxide (CO) provides additional information in the lower troposphere compared to the current CAMS global forecasting system that already assimilates MOPITT and IASI CO data. Will become operational in June.



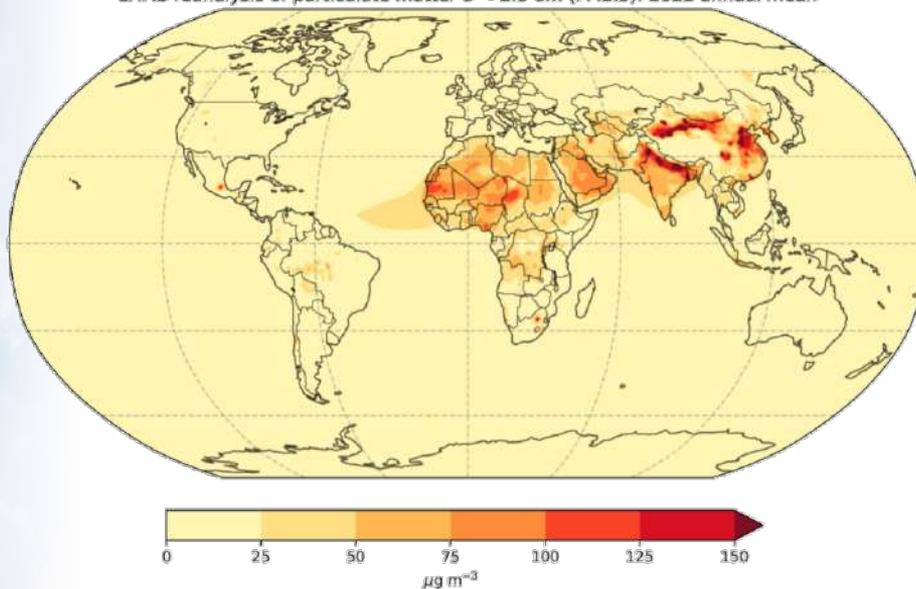
CAMS REANALYSIS (EAC4)

Atmosphere
Monitoring

The Copernicus Atmosphere Monitoring Service (CAMS) reanalysis dataset of atmospheric composition has been updated to the end of 2022 in the Atmosphere Data Store (ADS), which means that the ADS now contains a full 20-year global EAC4 reanalysis dataset.

The CAMS reanalysis dataset (EAC4) consists of three-dimensional time-consistent atmospheric composition fields, including aerosols and chemical species. A separate reanalysis dataset for greenhouse gases is published as EGG4. The dataset builds on the experience gained during the production of the earlier Monitoring Atmospheric Composition and Climate (MACC) reanalysis and CAMS interim reanalysis.

CAMS reanalysis of particulate matter $d < 2.5 \mu\text{m}$ (PM_{2.5}): 2022 annual mean



REFERENCED CONTENT

[CAMS reanalysis dataset](#) >

[Monitoring Atmospheric Composition and Climate](#) >

[CAMS interim reanalysis](#) >

[CAMS global forecasts](#) >

[AeroVal website](#) >

[Atmosphere Data Store](#) >

FURTHER READING



[CAMS releases Interim Assessment Report on air quality in Europe](#) >



PROGRAMME OF
THE EUROPEAN UNION

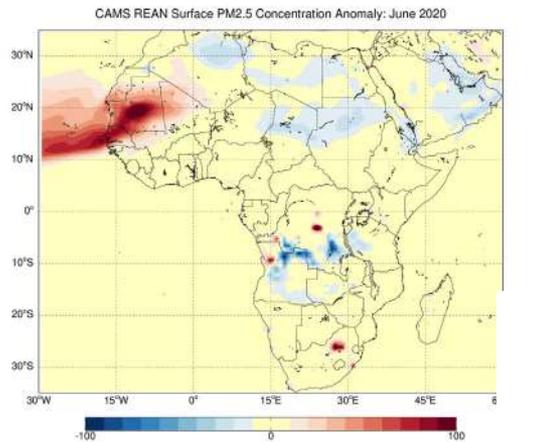
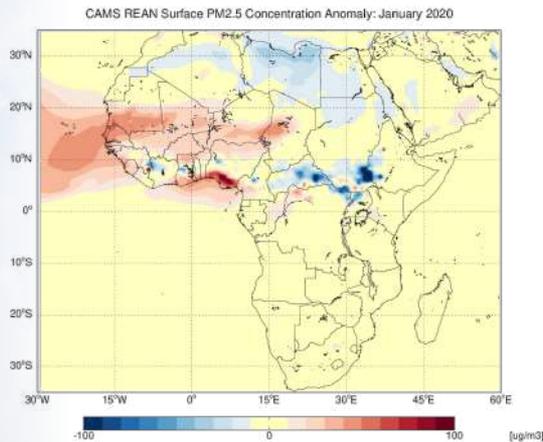
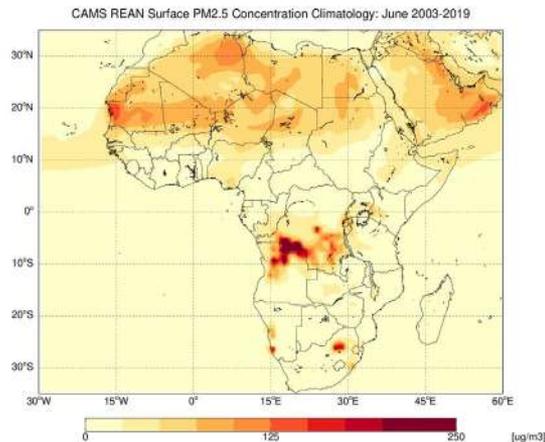
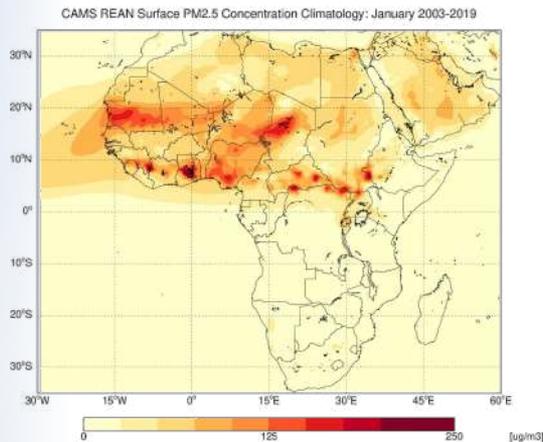


IMPLEMENTED BY





CAMS REANALYSIS: PUTTING EPISODES IN CONTEXT

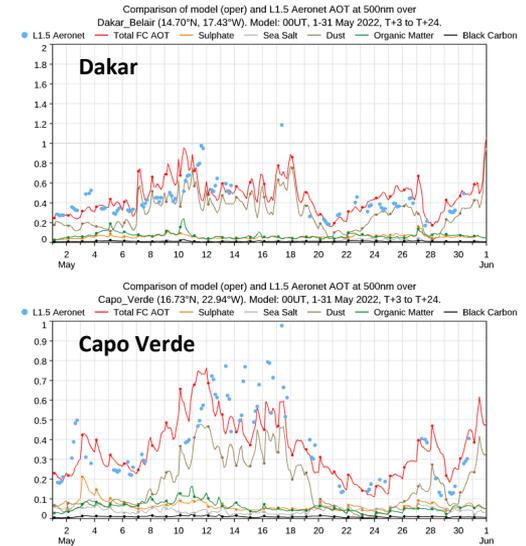
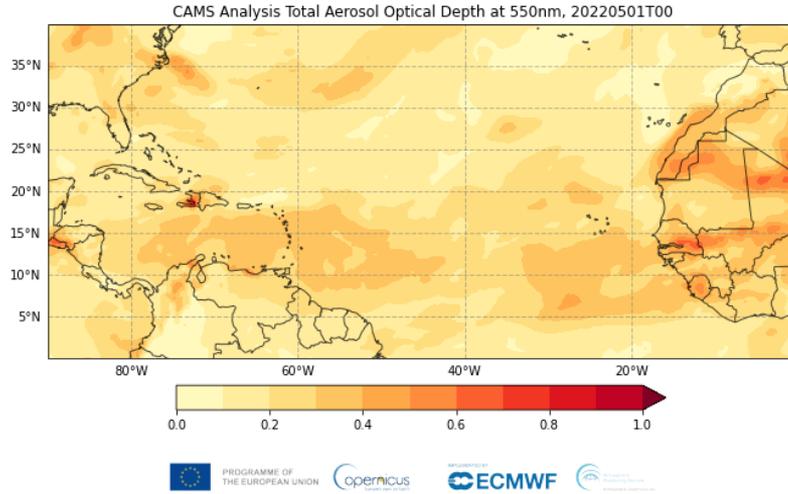
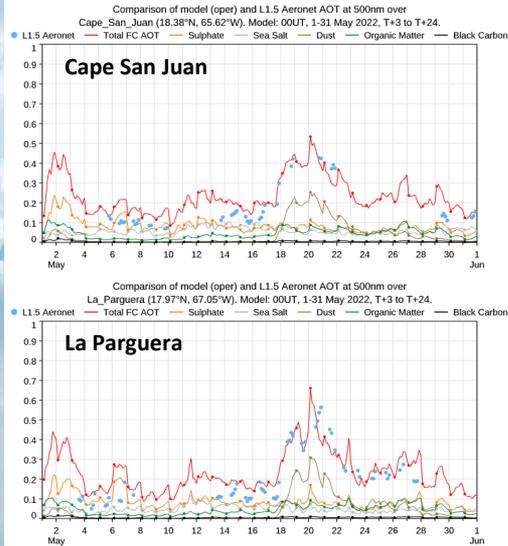


- CAMS reanalysis provides a consistent dataset for understanding long-term changes in global atmospheric composition and air quality.
- This example shows January and June monthly climatology of surface PM2.5 concentration calculated as the mean for the data from 2003-2019.
- Maps of anomalies for January and June 2020 highlight increased desert dust and decreased fire emissions.
- Support for WMO/GAW & BAMS annual bulletins.



EX. SAHARAN DUST EVENTS (MAY 2022)

Atmosphere
Monitoring

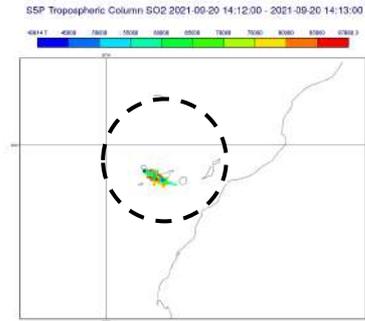
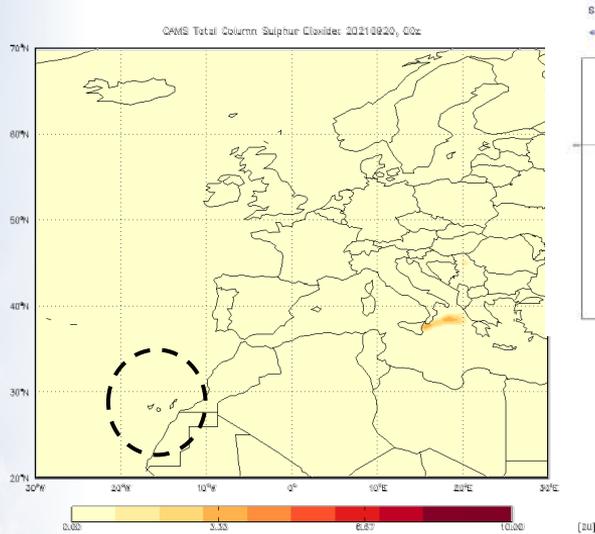


CAMS operational forecasts and air pollution cases monitored by NRT in CAMS 'Weather Room'. Information shared with users via CAMS website, social media and press.

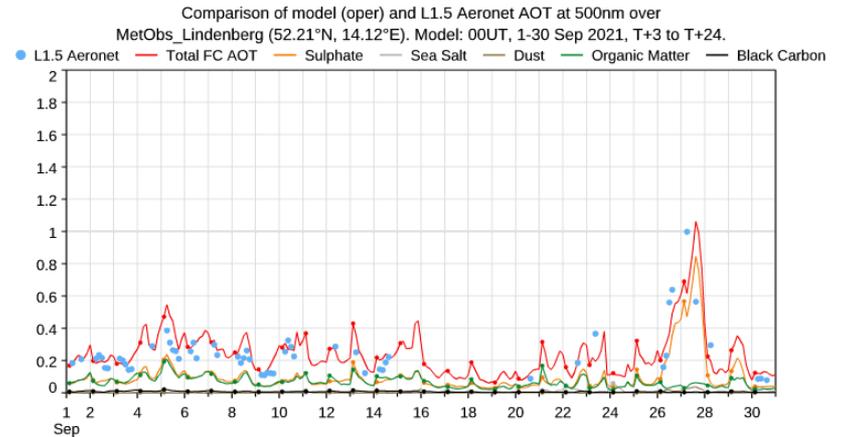


EX. VOLCANIC ERUPTIONS (SEPTEMBER 2021)

Atmosphere
Monitoring



- Cumbre Vieja volcano on La Palma erupted on 19 September 2021 for first time since 1971
- First SO₂ detections from **GOME-2 & S-5P** assimilated in IFS at 06z on 20 September (layer height ~550 hPa)
- Initial transport to the NW across N Africa, Europe and Mediterranean



PROGRAMME OF
THE EUROPEAN UNION



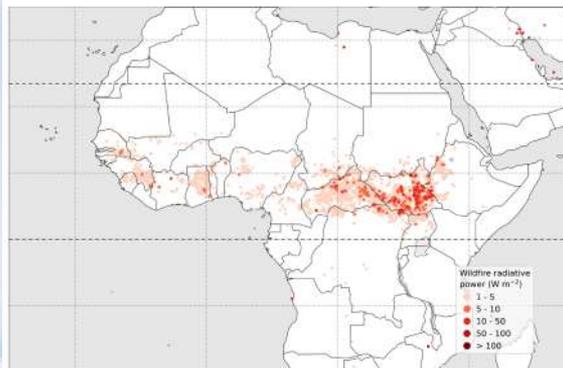
IMPLEMENTED BY



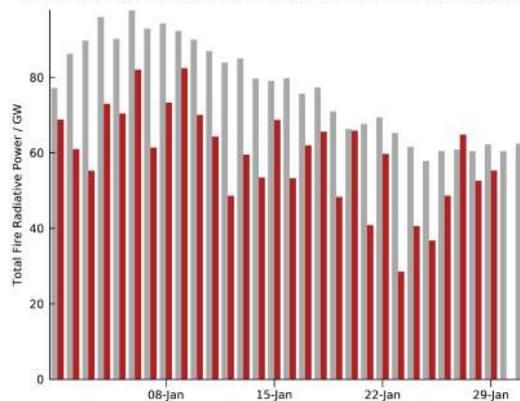


EX. WILDFIRES in Africa (January 2023)

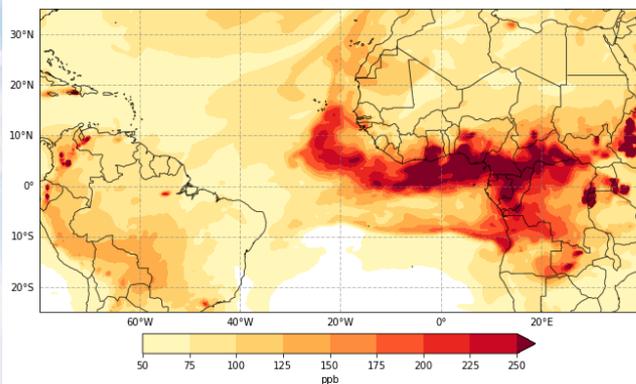
GFASv1.2 Total Fire Radiative Power: 2023-01-01 - 2023-01-29



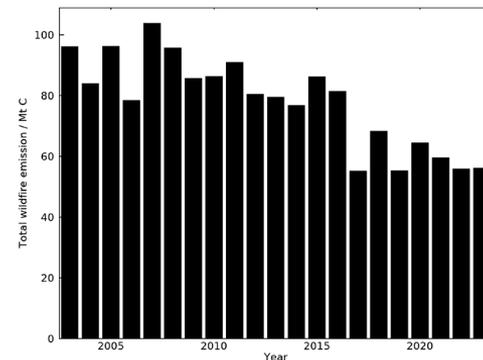
CAMS Daily Total Fire Radiative Power (GFASv1.2) for Northern Tropical Africa



CAMS Analysis carbon monoxide volume mixing ratio at 850 hPa:
20230101T00



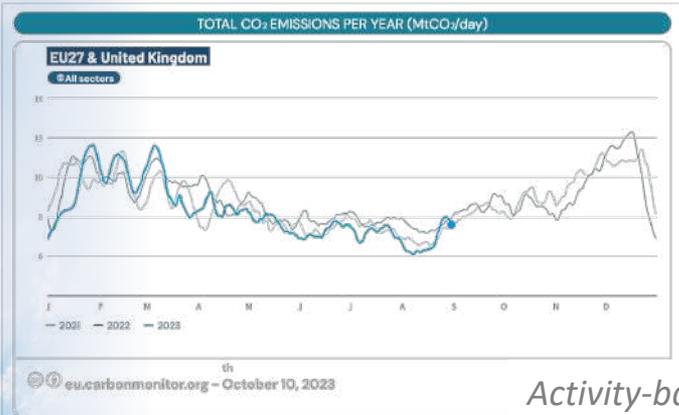
CAMS GFASv1.2 January wildfire C emissions for Northern Tropical Africa





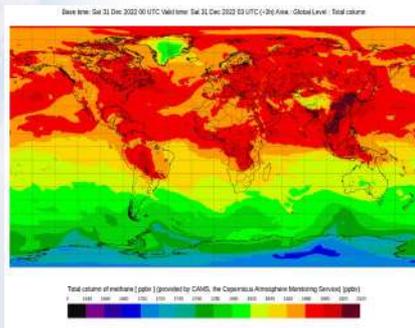
CAMS GHG INFORMATION PRODUCTS

Atmosphere
Monitoring

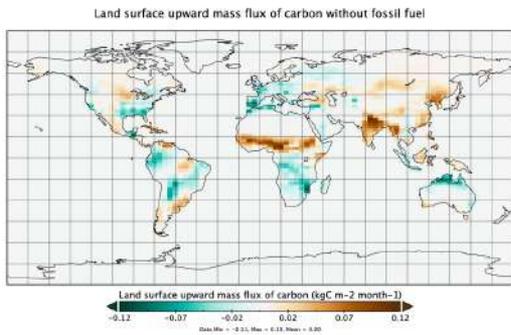
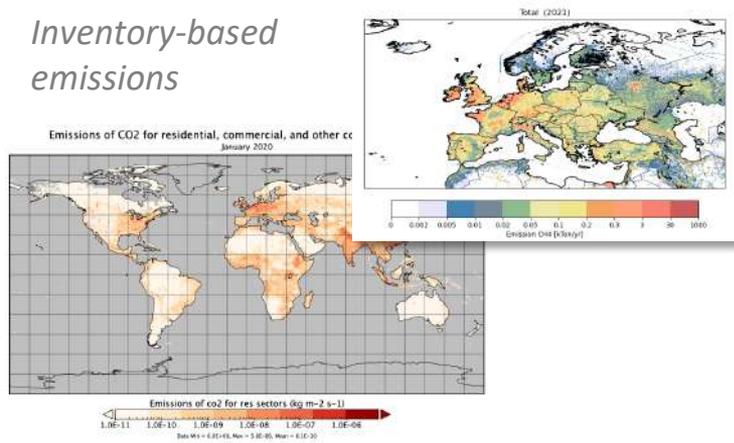


Activity-based
emissions

Daily global forecasts of atmospheric CO₂ and CH₄ concentrations at high resolution



Inventory-based
emissions

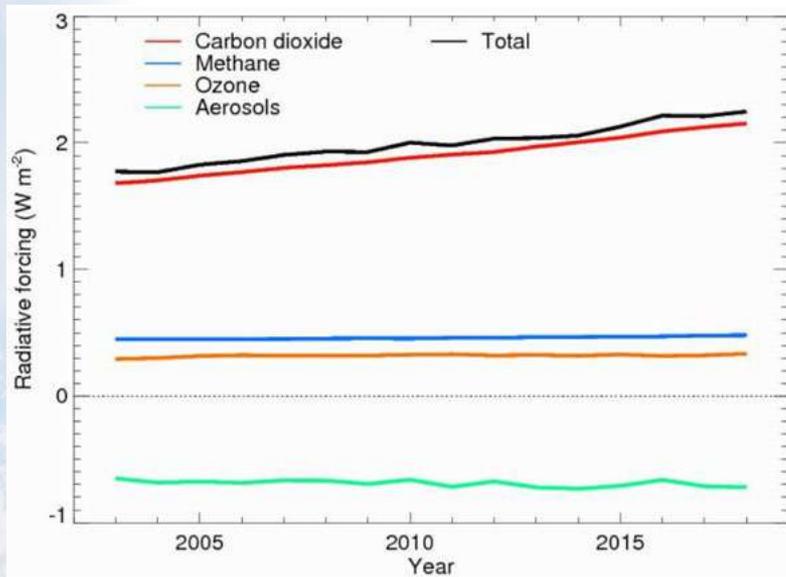


Annually updated
flux inversions
(monthly) for CO₂,
CH₄, and N₂O



CAMS CLIMATE FORCINGS

Atmosphere
Monitoring



Carbon dioxide	$+2.2 \pm 0.3 \text{ W m}^{-2}$	+1.4% in a year	
Methane	$+0.5 \pm 0.1 \text{ W m}^{-2}$	+0.5% in a year	
Ozone	$+0.3 \pm 0.1 \text{ W m}^{-2}$	+3.8% in a year	Tropospheric ozone $+0.3 \pm 0.1 \text{ W m}^{-2}$ Stratospheric ozone $-0.01 \pm 0.1 \text{ W m}^{-2}$
Aerosols	$-0.7 \pm 0.5 \text{ W m}^{-2}$	-1% in a year (became more negative)	Aerosol-radiation interactions $-0.2 \pm 0.1 \text{ W m}^{-2}$ Aerosol-cloud interactions $-0.5 \pm 0.2 \text{ W m}^{-2}$
Total	$+2.2 \pm 1.3 \text{ W m}^{-2}$	+1.7% in a year	

To slow down climate change, net radiative forcing needs to decrease towards zero. To reverse climate change, net radiative forcing would need to become negative. Over the past 16 years, the opposite has happened: net radiative forcing has become more positive, fuelling further climate changes.

Carbon dioxide	+28% over the past 16 years
Methane	+7% over the past 16 years
Ozone	+14% over the past 16 years
Aerosols	-11% over the past 16 years (becoming more negative)
Net radiative forcing	+27% over the past 16 years

Calculated using CAMS reanalysis and pre-industrial run with the CAMS global system.
Uptake by IPCC AR6.



PROGRAMME OF
THE EUROPEAN UNION



IMPLEMENTED BY

ECMWF



Atmosphere
Monitoring

CAMS NEW FRONTIER: OBSERVATIONS BASED EMISSIONS

Main target is anthropogenic CO₂, but also CH₄ and pollutants



A European contribution to CEOS, GCOS, GEO, and WMO efforts in support of the Paris Agreement.



PROGRAMME OF
THE EUROPEAN UNION



IMPLEMENTED BY





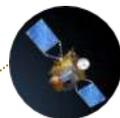
TIMELINE OF CAMS EMISSION SERVICES

Atmosphere Monitoring

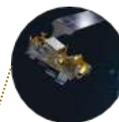
From expert groups through dedicated research funding, to operational services



Sentinel 5p



Sentinel 4



Sentinel 5



CO₂ Mission

SATELLITE MISSIONS

CO₂ TASK FORCE GUIDANCE DOCUMENTS



2015



2017



2019

2018



2017



RESEARCH AND PREPARATORY PROJECTS



2021



2022

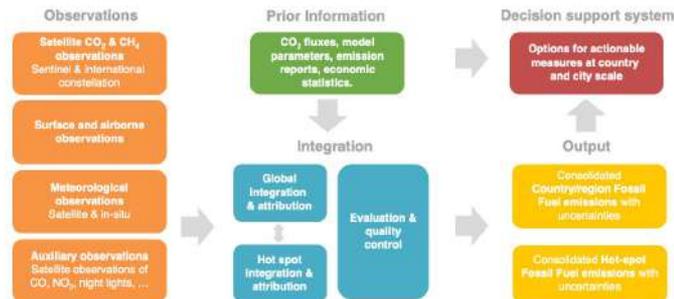
Operational ramp-up in CAMS

CO₂ Monitoring & Verification Support (CO₂MVS)

2026/27

SERVICE COMPONENTS

Air Quality emissions 2025/26



PROGRAMME OF THE EUROPEAN UNION



IMPLEMENTED BY





OPEN-DATA ACCESS POLICY

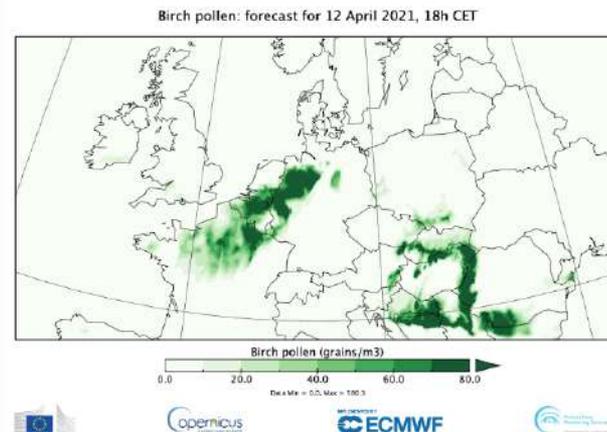
- **Data available and easily accessible** on the atmosphere/climate data store : ads.atmosphere.copernicus.eu and cds.climate.copernicus.eu
- Collaboration/contribution to the European Climate and Health Observatory <https://climate-adapt.eea.europa.eu/en/observatory>



Atmosphere Data Store API



Access the ECMWF Support Portal





Atmosphere
Monitoring

TRAINING AND USING CAMS DATA

<https://atmosphere.copernicus.eu/training>

Implemented by ECMWF as part of The Copernicus Programme

News Events Press Tenders Help & support Search

European Commission | Copernicus | Atmosphere Monitoring Service

Data About us What we do

European Commission | Copernicus | Implemented by ECMWF

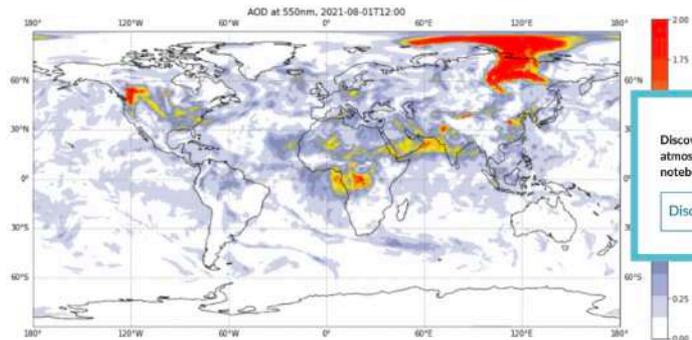
Home / Help & support / Training

Training

JUPYTER NOTEBOOK BASED DATA TUTORIALS | TRAINING EVENTS | MASSIVE OPEN ONLINE COURSES (MOOCs)

Many resources available,
most developed in
common between
EUMETSAT, ESA and ECMWF.

Jupyter notebook based data tutorials



Other Jupyter resources:

- ✓ Learning tool for Python
- ✓ Fire Applications with Next-Generation Satellites
- ✓ Dust Aerosol Detection, Monitoring and Forecasting
- ✓ Jupyter notebooks on WEKEO



GET CAMS DATA FROM THE ATMOSPHERE DATA STORE (ADS)

Atmosphere
Monitoring



Atmosphere Data Store

Welcome to the Atmosphere Data Store

Dive into this wealth of information about the Earth's past, present and future. It is freely available and functions as a one-stop shop to explore Atmosphere data. Register for free ADS and its Toolbox.

We are constantly improving the services and adding new datasets. For more information, please see our [FAQ](#) or the [CAMS forum](#).

Enter search term(s): All

Create Plot Combine Plot Open Datasets

Datasets Catalogs Bookmarks

Name

- ENS_ANALYSIS.nc
 - latitude
 - level
 - longitude
 - pm2p5_conc
 - time

- CAMS global reanalysis (EAC4)**
EAC4 (ECMWF Atmospheric Composition Reanalysis 4) is the fourth generation ECMWF global reanalysis of atmospheric composition. Reanalysis combines model r with observations from across the world in...
- CAMS global reanalysis (EAC4) monthly averaged fields**
EAC4 (ECMWF Atmospheric Composition Reanalysis 4) is the fourth generation ECMWF global reanalysis of atmospheric composition. Reanalysis combines model r with observations from across the world in...
- CAMS global inversion-optimised greenhouse gas fluxes and concentrations**
This data set contains net fluxes at the surface, atmospheric mixing ratios at model levels, and column-mean atmospheric mixing ratios for carbon dioxide (CO2), methane (CH4) and nitrous oxide (N2O)...
- CAMS solar radiation time-series**

The G of this Variable

<ul style="list-style-type: none"> Ammonia Dust Nitrogen monoxide Ozone PM2.5, anthropogenic fossil fuel carbon only Perovskite nitrate Sulphur dioxide 	<ul style="list-style-type: none"> Birch pollen Grass pollen Non methane VOCs Particulate matter < 2.5 µm (PM2.5) PM2.5, anthropogenic wood burning carbon only Ragweed pollen 	<ul style="list-style-type: none"> Carbon monoxide Nitrogen dioxide Olive pollen Particulate matter < 10 µm (PM10) PM10, wildfires only Secondary inorganic aerosol
--	---	--

Select all Clear all

Model

Ensemble median
 CHIMERE
 ENEP
 LOTOS-EUROS
 EURAD-IM

mass concentration of pm2p5 ambient aerosol in air

250
 500
 1000
 3000
 5000

Select all Clear all

Array(s) Scale Map Overlays Shading Contours Vectors Labels

Scale Range: Min: 0 Max: 30 Fit to Data Color Table: CE_RadL_08.cpt



Atmosphere
Monitoring

AND IF YOU NEED VIRTUAL MACHINES... THERE IS WEKEO

<https://www.wekeo.eu>

WEKEO

SERVICES DATA COMPUTING USE CASES SUPPORT

REGISTER SIGN IN

Copernicus and Sentinel data at your fingertips

Explore data Our services Expert support

Events

WEKEO – Hydrology studies in a Changing Climate
Mar. 14th 14:00 CET

News

How users help shape WEKEO and its products offer: an introduction to the Champion User Advisory Group (CUAG)
April 13, 2023



PROGRAMME OF
THE EUROPEAN UNION



IMPLEMENTED BY





AMS American Meteorological Society | **Journals**

JOURNALS BROWSE PUBLISH SUBSCRIBE ABOUT

Sign in Sign up

Search

< Previous Article Next Article >

Article Type: **Research Article**

Full access

The Copernicus Atmosphere Monitoring Service: from research to operations

Vincent-Henri Peuch¹, Richard Engelen¹, Michel Rixen¹, Dick... [View More +](#)

Published-online: **23 Aug 2022**

DOI: <https://doi.org/10.1175/BAMS-D-21-0314.1>

[Article History](#) [Download PDF](#) [Get Permissions](#)

Abstract/Excerpt Full Text PDF

Abstract

The Copernicus Atmosphere Monitoring Service (CAMS), part of the European Union's Earth observation programme Copernicus, entered operations in July 2015. Implemented by the European Centre for Medium-Range

BAMS Bulletin of the American Meteorological Society

Early Online Release

Metrics

	All Time	Past Year	Past 30 Days
Abstract Views	0	0	0
Full Text Views	525	525	326
PDF Downloads	471	471	266

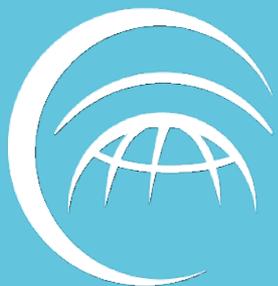
<https://doi.org/10.1175/BAMS-D-21-0314.1>





CONCLUSIONS

- As part of the European Union's Copernicus Programme, CAMS provides operational quality assured information about air quality worldwide (analyses, d+5 forecasts, reanalyses) and these are freely available
- Many ways to interact with the data, depending on needs & capacity
- There is never enough validation/verification and very open to collaborations (expertise/feedback, comparisons with local observations, support field campaigns, support downscaling and use of data in general...)
- Joint approach with EUMETSAT and ESA especially for training and engagement with users in general (how to best use available data and information)



Atmosphere Monitoring



Copernicus EU



Copernicus ECMWF



@CopernicusEU
@CopernicusECMWF
@VHPeuch
@RichardJEngelen
@m_parrington
@AntjelInness

...



@copernicusecmwf



Copernicus EU
Copernicus ECMWF



www.copernicus.eu
atmosphere.copernicus.eu



PROGRAMME OF
THE EUROPEAN UNION



IMPLEMENTED BY
 ECMWF



Climate
Change Service

climate.copernicus.eu

Copernicus Climate Change Service

May 2024

Chris Stewart

Carlo Buontempo

C3S team and contractors



PROGRAMME OF THE
EUROPEAN UNION



FULL, FREE AND OPEN
ACCESS TO DATA



-  ATMOSPHERE MONITORING
-  MARINE ENVIRONMENT MONITORING
-  LAND MONITORING
-  CLIMATE CHANGE
-  EMERGENCY MANAGEMENT
-  SECURITY

 **copernicus**
Europe's eyes on Earth

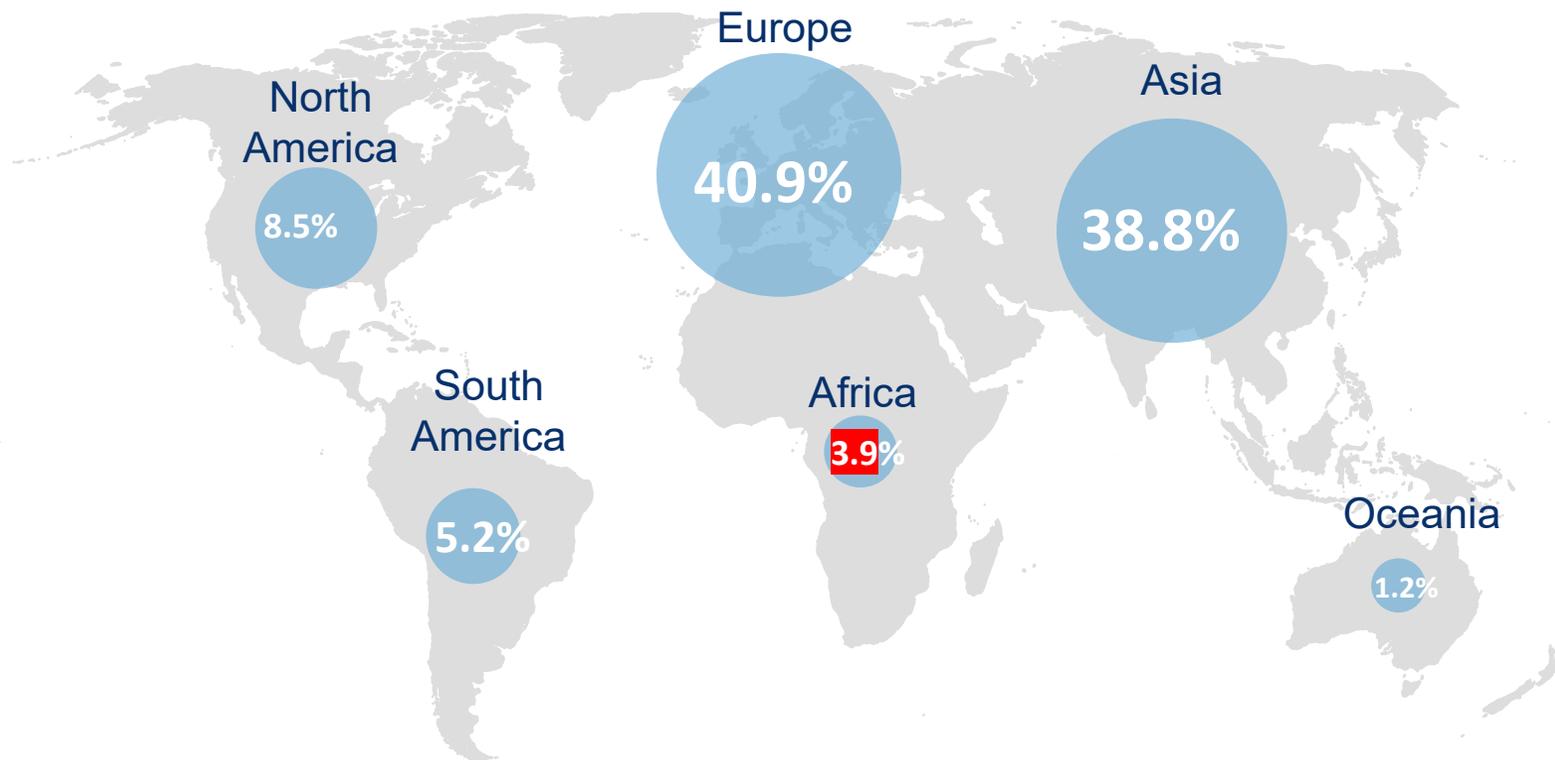


C3S: the numbers



Worldwide users

Open climate data has never been more important



Registered users
>300,000



External users
Several millions



Requests
800 million



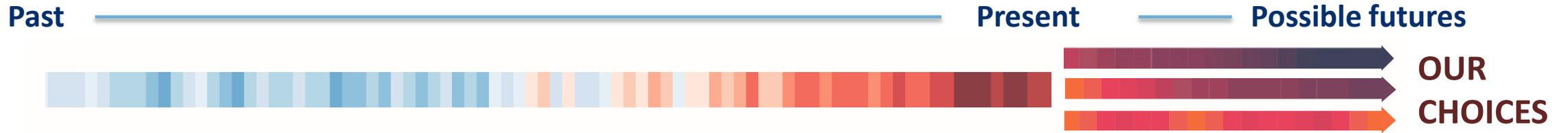
Data downloaded
>170 PB

Top 5 dataset groups
ERA5, ERA5 land, seasonal forecast, CORDEX, CARRA, CERRA, ORAS5, ECVs

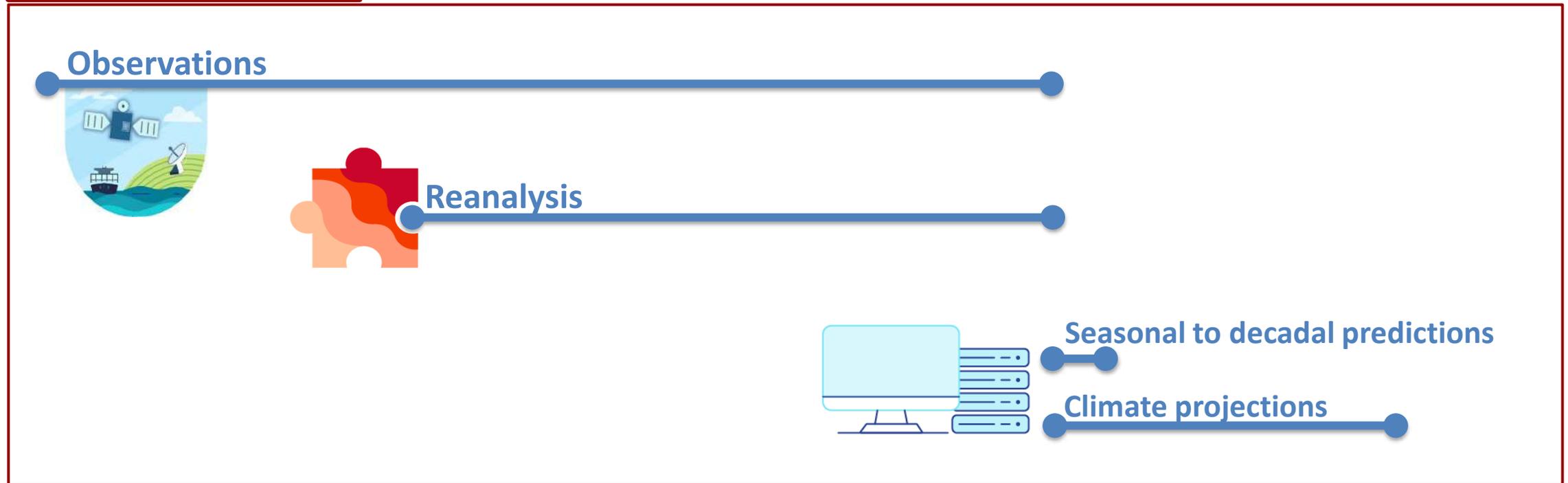




Free data for smart decisions



C3S PRODUCTS





Observations





Essential Climate Variables



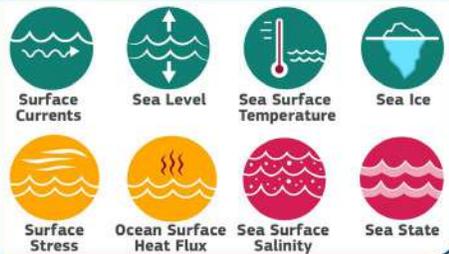
CRYOSPHERE



Legend

- Satellite ECVs
- ECVs from reanalysis
- Planned/ambition
- Unavailable

SURFACE OCEAN PHYSICS



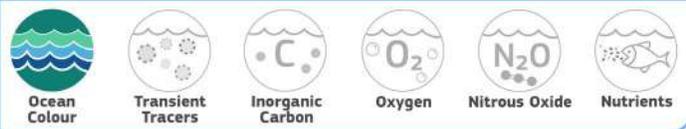
OCEAN BIOLOGY, ECOSYSTEMS



SUBSURFACE OCEAN PHYSICS



OCEAN BIOGEOCHEMISTRY



SURFACE ATMOSPHERE



UPPER-AIR ATMOSPHERE



ATMOSPHERIC COMPOSITION



ANTHROPOSPHERE



HYDROSPHERE



BIOSPHERE



*Fraction of Absorbed Photosynthetically Active Radiation

Crucial to understand changes in our climate.

C3S responds to GCOS and UNFCCC implementation needs.

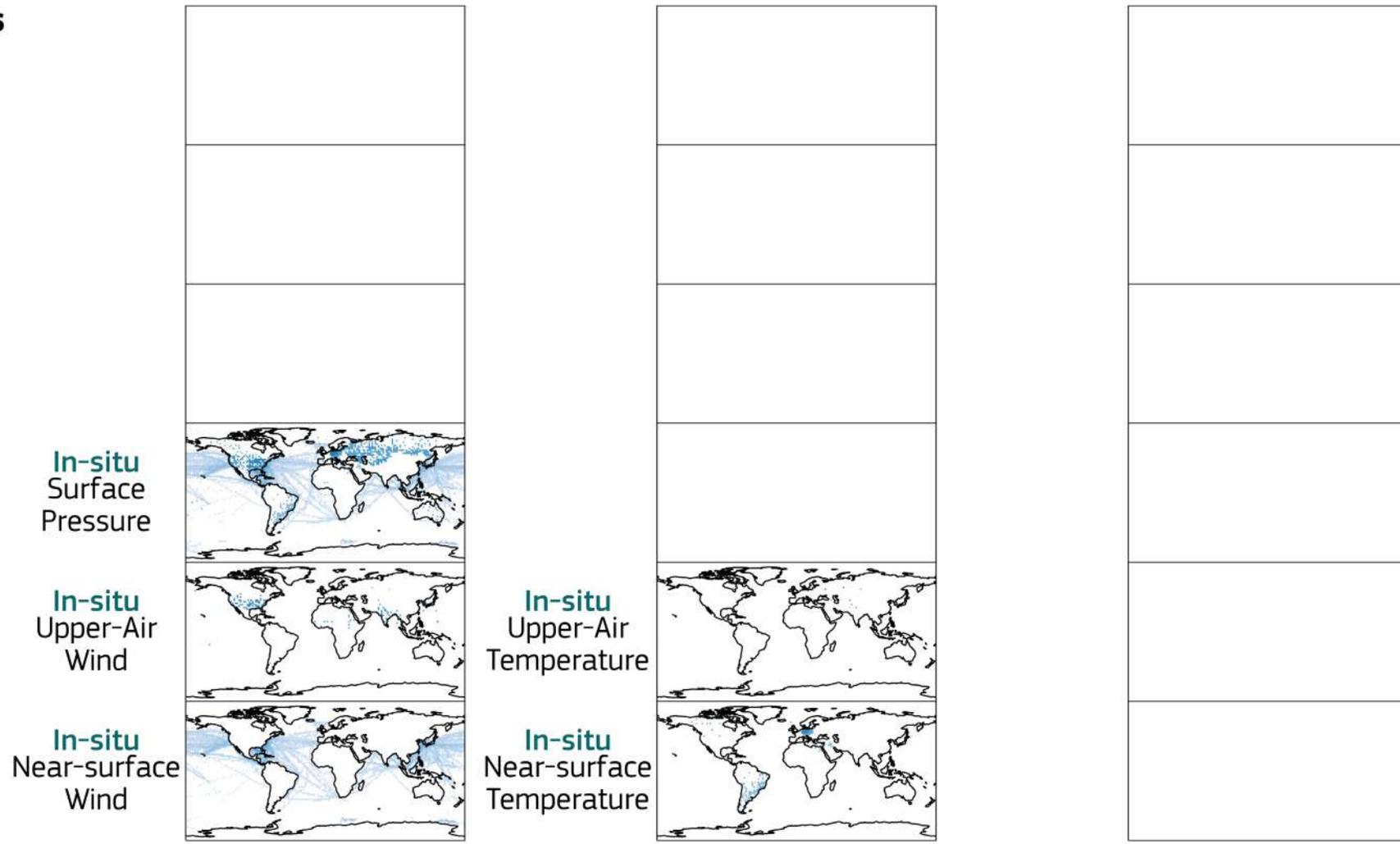
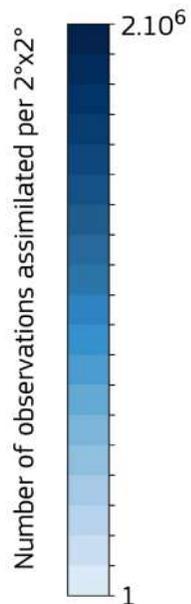




In situ observations: foundations of the climate record

Observations assimilated in ERA5

Jan 1940

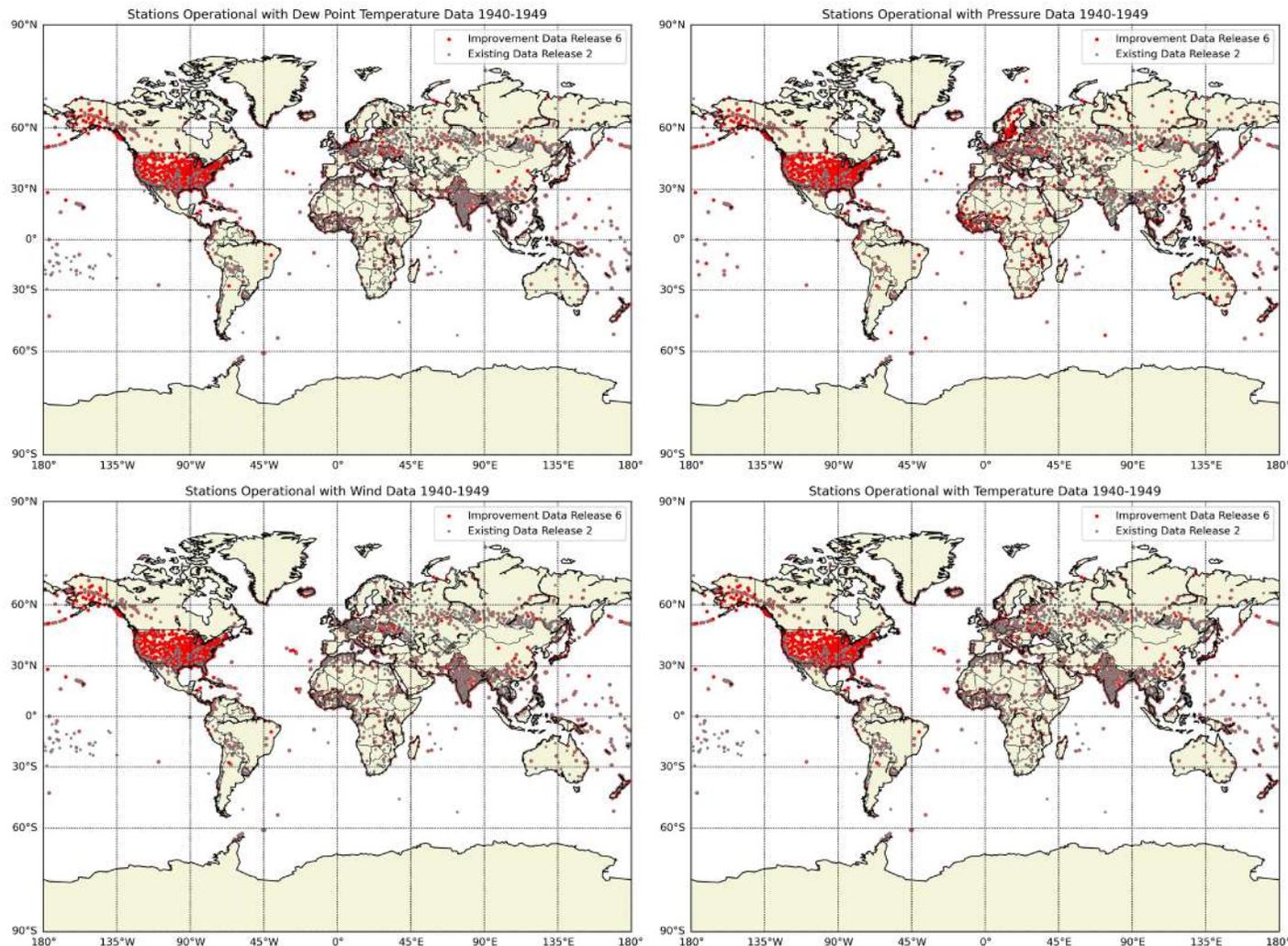




C3S expands archives of free and open in situ observations



C3S [data deposition service](#) collects rescued observations



These observations will be used in ERA6, to augment the observation coverage of ERA5

With Maynooth University, NOAA ...

<https://cds.climate.copernicus.eu/cdsapp#!/dataset/insitu-observations-surface-land?tab=overview>



PROGRAMME OF THE EUROPEAN UNION

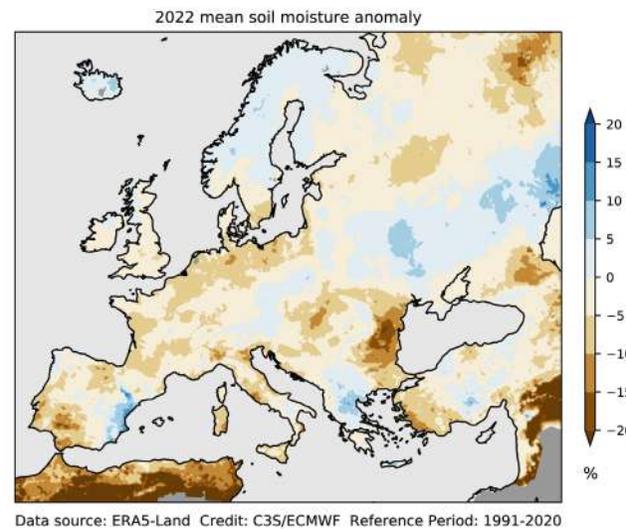
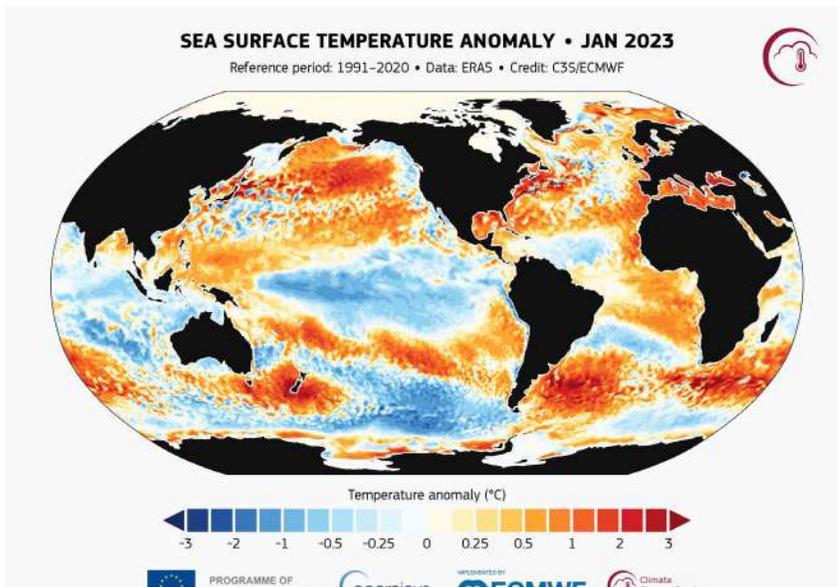


Global and regional reanalyses



Ecosystem of reanalysis products

ERA5



ERA5-Land

Product	Purpose	Time availability	Temporal resolution	Spatial resolution
ERA5	Global reanalysis for atmosphere, land and ocean waves	1940 onwards, up to 5 days behind real time	Hourly	30 km
ERA5 land	Global reanalysis for land-surface variables	1950 onwards, up to 5 days behind real time	Hourly	9 km
CERRA	European regional reanalysis	1984-2021	Hourly	5 km
CARRA	Arctic regional reanalysis	1990 onwards, up to 3 months behind real time	3-hourly analyses, hourly short-term forecasts	2.5 km



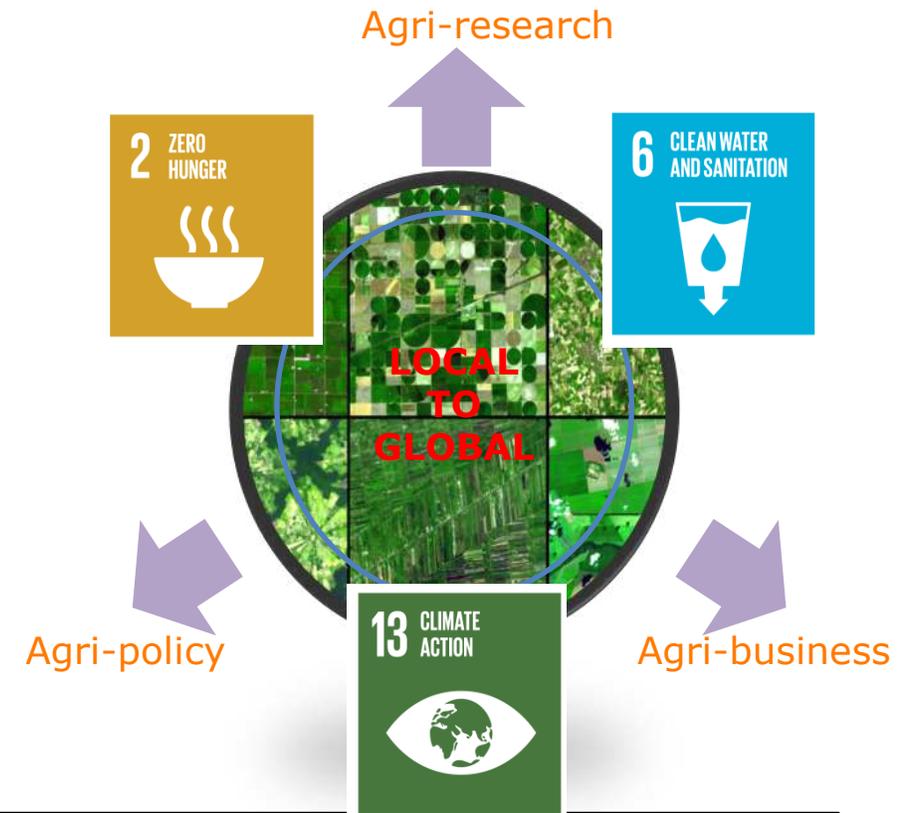


Data for Agriculture and Food Security based on ERA5

Open data products: AgERA5

- Global product derived from ECMWF ERA5 reanalysis
- Bias-corrected towards operational ECMWF forecasts
- 0.1x0.1 degree (~10 km)
- from 1979 to realtime with a delay of ~1 week
- 22 variables relevant for agricultural applications:
 - Temperature (avg, min, max, etc.)
 - Precipitation and precipitation type
 - Global radiation
 - Daily avg vapour pressure and wind speed
 - Relative humidity at specific times of the day

<https://doi.org/10.24381/cds.6c68c9bb>



Data portals using AgERA5

FAO: <https://data.apps.fao.org>

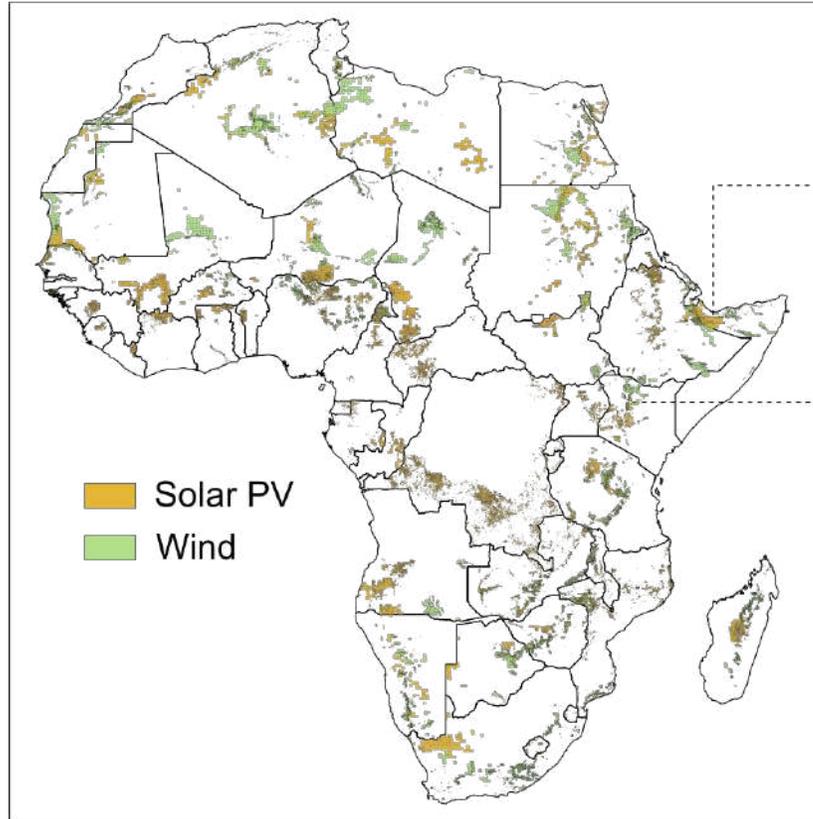
WorldCereal: <https://ceos.org/gst/agriculture.html>

openEO Hub: <https://hub.openeo.org/>

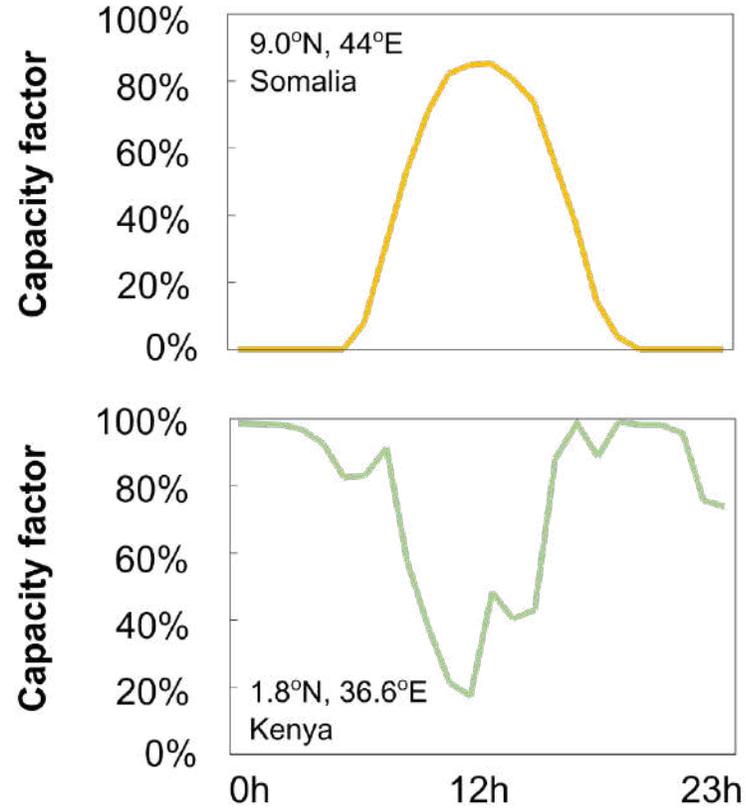


Analysing Africa's solar and wind potential

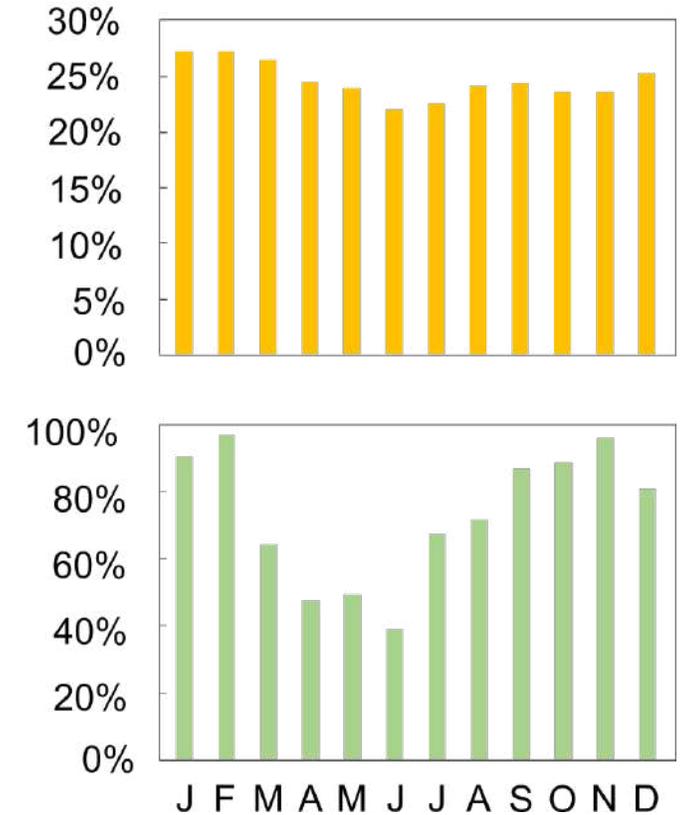
a Solar PV and wind MSR



b Diurnal profiles



c Seasonal profiles



S. Sterl, B. Hussain, A. Miketa, Y. Li, B. Merven, M. Bassam Ben Ticha, M.A. Eltahir Elabbas, W. Thiery, and D. Russo. *An all-Africa dataset of energy model "supply regions" for solar PV and wind power*. Submitted to *Scientific Data* (2022).

(12th of March of met year 2018)



Climate intelligence



Implemented by Copernicus Climate Change Service C3S 



Predictions and projections





C3S seasonal prediction: components



DATA PRODUCTS

cds.climate.copernicus.eu

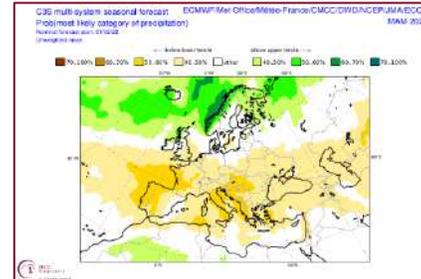


GRAPHICAL PRODUCTS

climate.copernicus.eu/charts/packages/c3s_seasonal/

- ❑ Datasets available in the Climate Data Store
 - Atmosphere
 - daily and subdaily data (6h, 12h, 24h)
 - monthly statistics (mean, max, min, standard deviation)
 - bias corrected data (monthly anomalies)
 - Ocean monthly means
- ❑ Multi-system retrospective forecasts and real-time forecasts, the latter published on 6th (ECMWF) and 10th day of month (the rest)

Products for individual contributing systems and multi-system combination



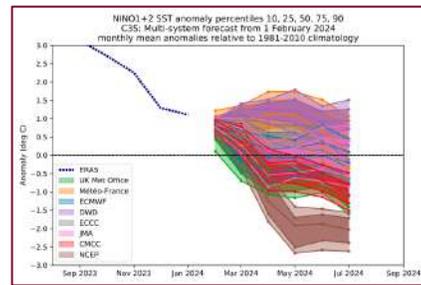
- Total precipitation
- Near-surface temperature and wind
- Mean sea-level pressure
- Sea surface temperature
- Sea ice concentration
- Geopotential height at 500 hPa
- Temperature at 850 hPa



CDS API

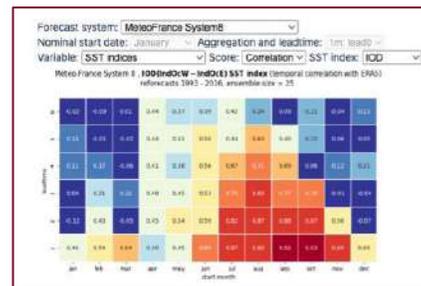
```
import cdsapi
c = cdsapi.Client()
c.retrieve(
    'seasonal-monthly-single-levels',
    {
        'format': 'grib',
        'originating_centre': 'meteo_france',
        'variable': 'total_precipitation',
        'product_type': [
            'ensemble_mean', 'hindcast_climate_mean'
        ]
    },
    {'year': '2018',
     'month': '09',
     'leadtime_month': ['1', '2', '3', '4', '5', '6'] },
    'ods_seasonal_output_grib')

```



- Sea surface temperature NINO regions
- Sea surface temperature Indian Ocean
- Zonal mean wind at 10hPa

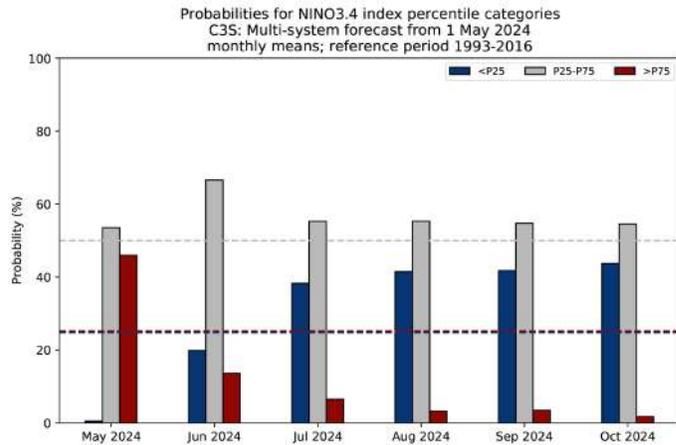
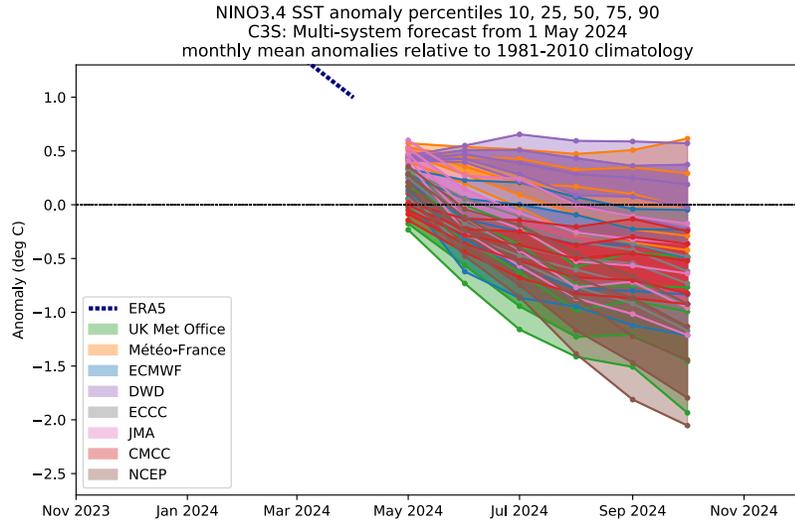
Python workflows



- Temporal correlation
- Relative Operating Characteristic (ROC) score
- Ranked Probability Score (RPS)



NINO 3.4 May 2024



C3S multi-system forecasts

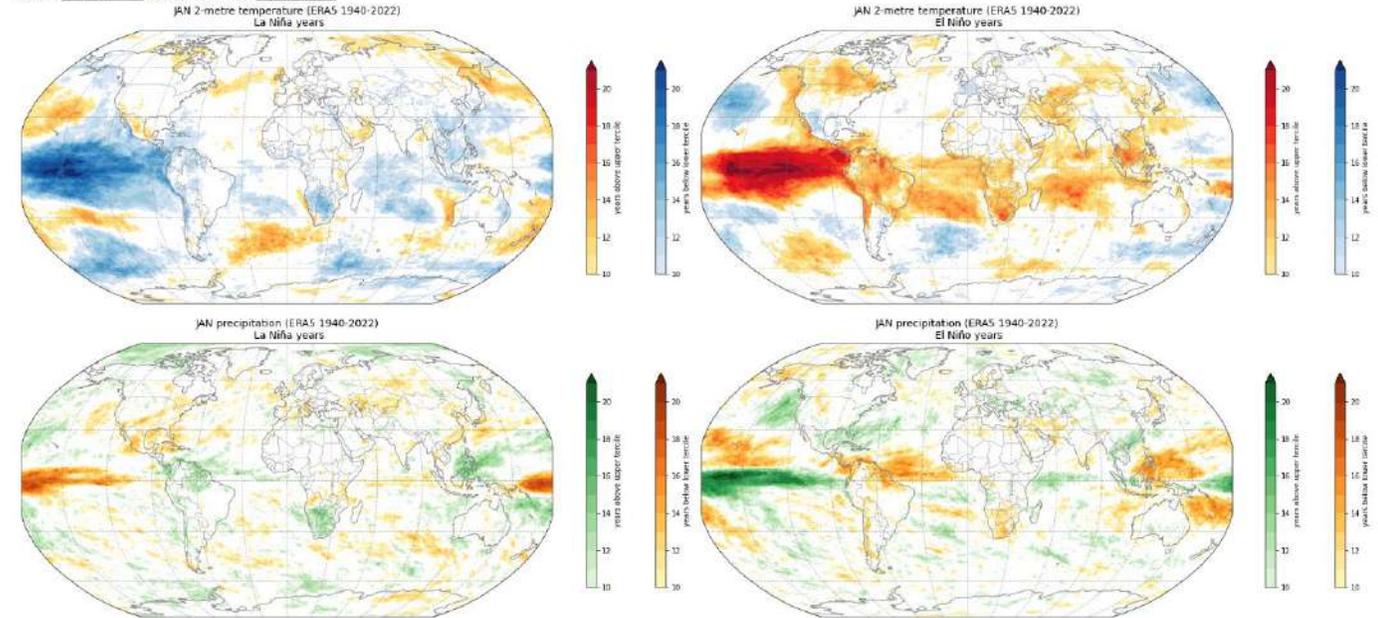
Global effects - temperature and precipitation

Using the ENSO years selection approach outlined above (here with a choice between the period 1940-2022 and 1970-2022), typical effects on temperature and precipitation are illustrated, by displaying the number of years falling into the upper or lower tercile category of the distribution of the respective variable. Colours are only shown when the number of years is statistically significant. This concept and methodology is similar to that used in Davey et al. 2014.

These charts can be used to identify regions where, according to this analysis method, there is a statistically significant ENSO teleconnection for temperature or precipitation for each calendar month. Due to the variability seen within the postage stamp charts shown above for Europe, there is not a strong signature in the composites below.

[Click here to see the selected ENSO events for each month](#)

Month: Reference period:



Investigation of ENSO teleconnections

<https://confluence.ecmwf.int/display/COPSRV/ENSO+impacts+on+Europe>

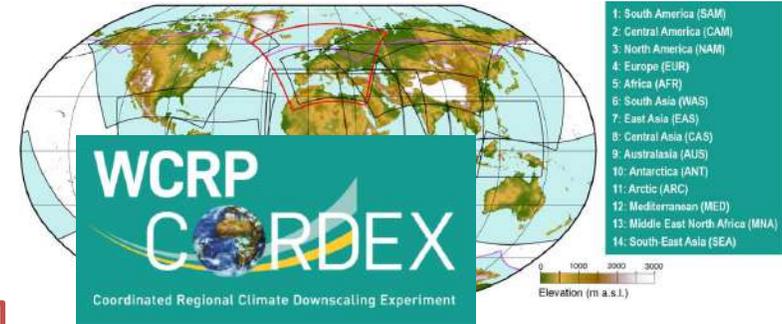


PROGRAMME OF THE EUROPEAN UNION





C3S climate prediction and projection data



- 1: South America (SAM)
- 2: Central America (CAM)
- 3: North America (NAM)
- 4: Europe (EUR)
- 5: Africa (AFR)
- 6: South Asia (WAS)
- 7: East Asia (EAS)
- 8: Central Asia (CAS)
- 9: Australasia (AUS)
- 10: Antarctica (ANT)
- 11: Arctic (ARC)
- 12: Mediterranean (MED)
- 13: Middle East North Africa (MNA)
- 14: South East Asia (SEA)

Global climate projections

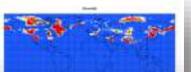
Climate Change Service
climate.copernicus.eu

- operational data access
- quality control
- data tutorials

Regional climate projections

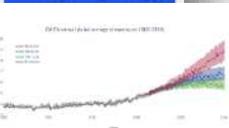
CMIP5 daily data on single levels

This catalogue entry provides daily climate projections on single levels from a large number of experiments, models, and time periods computed in the framework of the fifth phase of the Coupled Model Intercomparison Project (CMIP5).



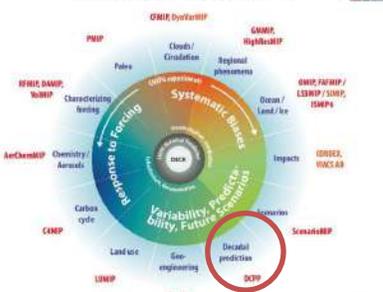
CMIP6 climate projections

This catalogue entry provides daily and monthly global climate projections data from a large number of experiments, models and time periods computed in the framework of the sixth phase of the Coupled Model Intercomparison Project (CMIP6).



CMIP6 data underpins the Intergovernmental Panel on Climate Change 6th Assessment Report. The use of these data is mostly aimed at: addressing outstanding sci...

21 CMIP6-Endorsed MIPs



Eyring et al., CMIP6 Overview, GMD, 2016

Decadal predictions

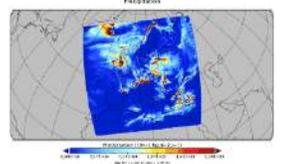
CMIP6 predictions underpinning the C3S decadal prediction prototypes

This catalogue entry provides daily and monthly global climate model data from Decadal Climate Predictions Project (DCPP) experiments, part of the sixth phase of the Coupled Model Intercomparison Project (CMIP6).

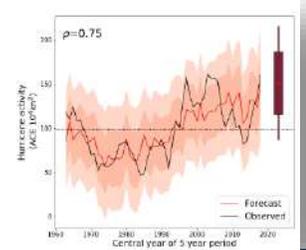
The decadal data in the Climate Data Store (CDS) are a quality-controlled subset of the full DCPP. CMIP6-DCPP data addresses the ability of the climate system to be predicted on annual, m...

CORDEX regional climate model data on single levels

This catalogue entry provides Regional Climate Model (RCM) data on single levels from a number of experiments, models, domains, resolutions, ensemble members, time frequencies and periods computed over several regional domains all over the World in the framework of the Coordinated Regional Climate Downscaling Experiment (CORDEX).



The term "single levels" is used to express that the variables are 2...





PROGRAMME OF THE EUROPEAN UNION



User guidance

Copernicus Interactive Climate Atlas

Mean temperature (°C) - CMIP6 - Change - Warming 2°C - Annual - rel. to 1850-1900

Mean temperature ▼ CMIP6 ▼

AR6 Regions ▼

Climatology and Changes ▼ Global warming levels

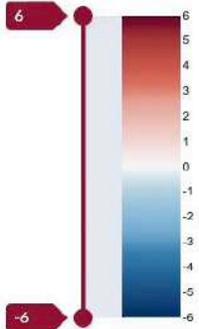


Quantity

Change ▼

Season

Annual ▼

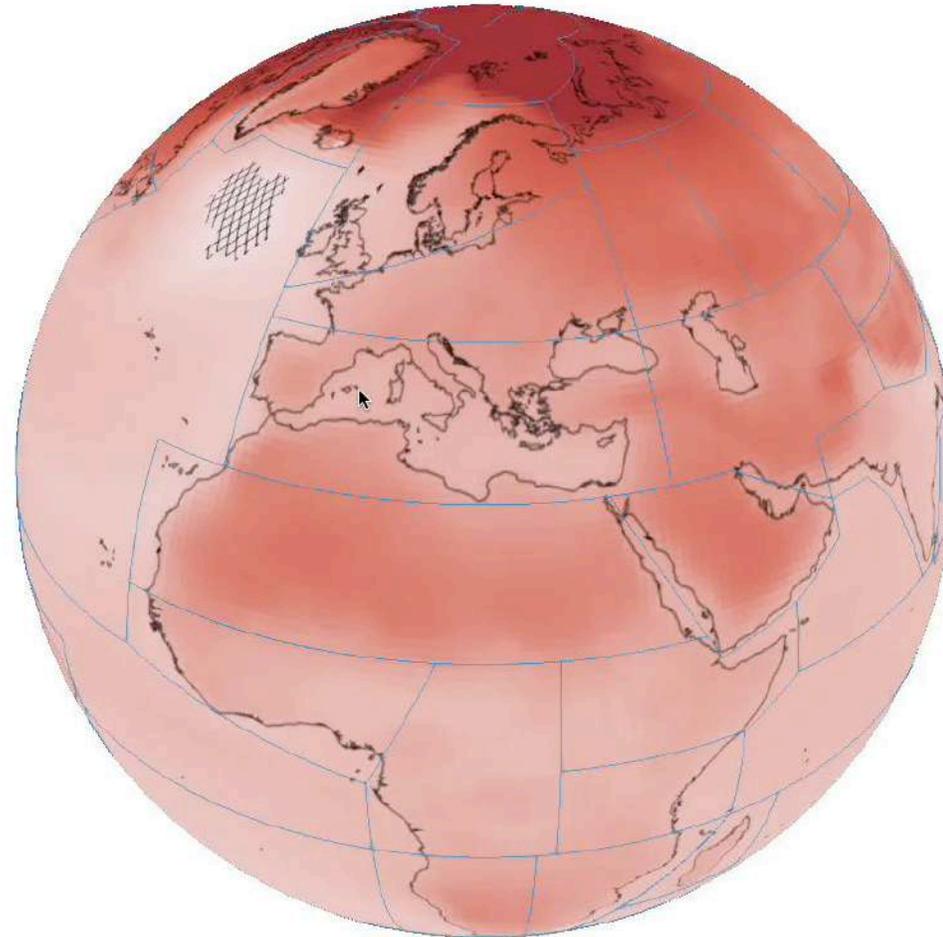


Units: °C

Robustness:

- Robust signal (original color)
- No change or no robust signal
- Conflicting signals

Palette ☰ Autofit ↻ Reset



PROGRAMME OF THE EUROPEAN UNION

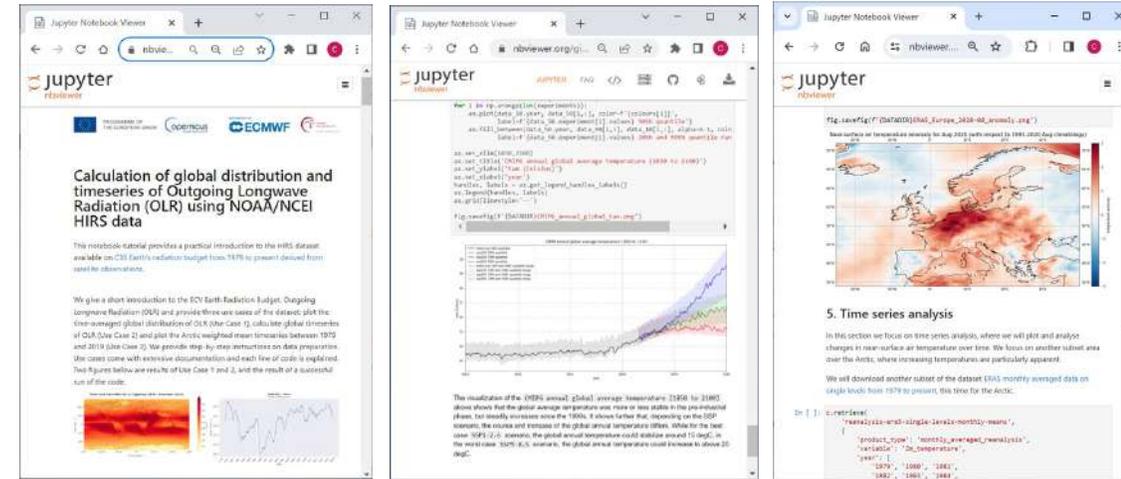
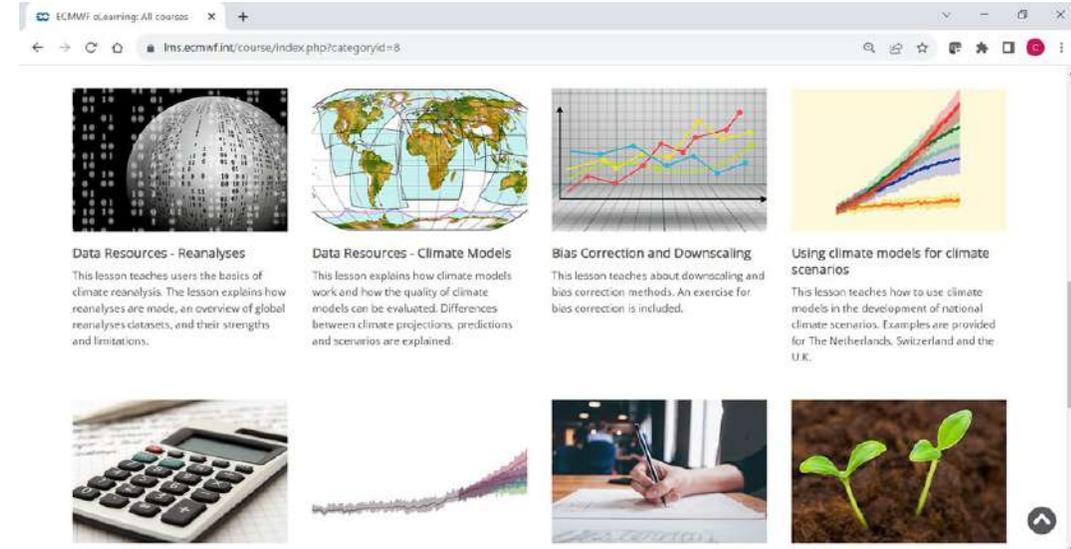


User engagement and National uptake actions



Training and knowledge transfer

- Contract on training events & resources
 - Contract started Q1 2024
 - Training events (also in context of partnerships, NCP, core & other users)
 - Curation & development of learning resources (Jupyter, elearning)
- Open Call for training experts to support with specific domain expertise
 - Launched Q3 2023
 - Trainer
 - Content Creator
 - Instructional Designer
- C3S Mini-MOOCs
 - RFP due for launch in Q1 2024
 - Series of short online courses on C3S relevant topics
 - Targeted to wider audience





Conclusion and outlook





Operational attribution: modular access to information on extremes

Prototype extreme events and attribution service

SCO FLAude: Understanding extreme hydrometeorological events in Aude and Occitanie in the context of climate change

Operational windstorm service for the insurance sector

Home / What we do / Sectoral Impacts / Sectoral specific challenges / Insurance / Operational windstorm service for the insurance sector

Facebook Twitter LinkedIn

ABOUT | DATA AND TOOLS | HOW IT WORKS | PROJECT PARTNERS

DATASETS >

SECTORAL INFORMATION

Disaster risk reduction

We provide climate information to support policies related to disaster risk reduction, as well as practices to address weather-related risks.

DEMONSTRATOR PROJECTS | SHOWCASES

Demonstrator projects

JANUARY 2020

Pluvial Flood Risk Assessment in Urban Areas

This service aims to generate the information required to assess the risks associated with extreme rainfall events in Europe. In particular, it analyses the risk of flooding caused by intense rainfall that the ground is unable to absorb.



29TH JANUARY 2021
New C3S app lets you discover current and future fire danger

28TH AUGUST 2020
Climate organisations join forces to support flood management

13TH DECEMBER 2019
From climate data to climate action

Operational access to extreme event information including:

- Long term observed changes in extremes and their attribution
- Extended information on types of events in a changing climate (e.g. factsheets or similar)
- Extend number of tools for extreme event analysis
 - Consistency with climate projections
- NRT daily suite similar to the (extended/evolved) C3S monthly bulletin suite
- Triggering mechanism via the Extreme Forecast Index (or similar)
- Fitness-for-purpose of data sets for extreme analysis
- Enhanced adoption of AI-based tools





Climate
Change

Thank you !

Carlo.Buontempo@ecmwf.int



**ECMWF
Copernicus**



@copernicusecmwf



Copernicus ECMWF



**Copernicus EU
Copernicus
ECMWF**



**@CopernicusEU
@CopernicusECMWF**



**www.copernicus.eu
climate.copernicus.eu**

Emission observatory

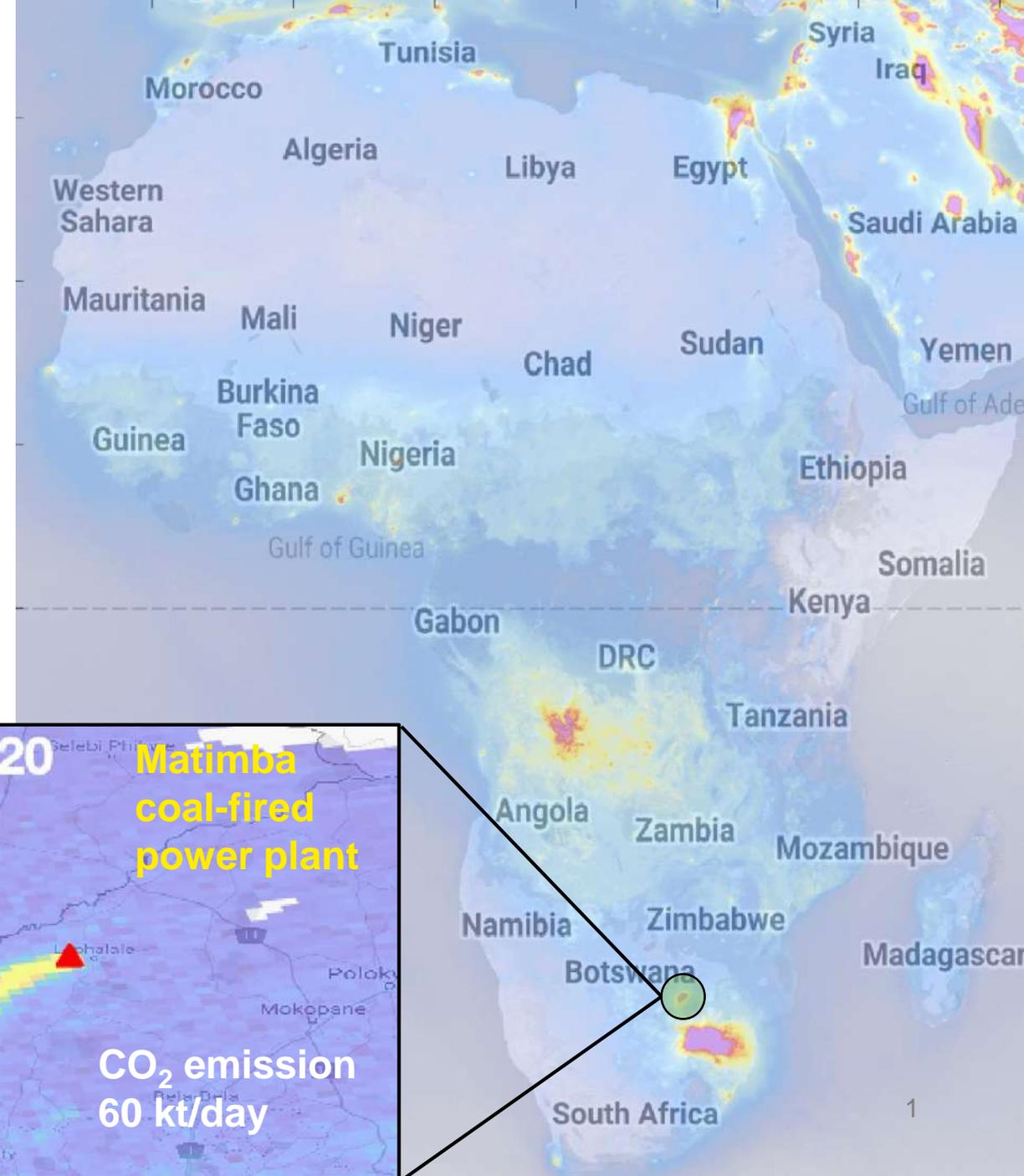
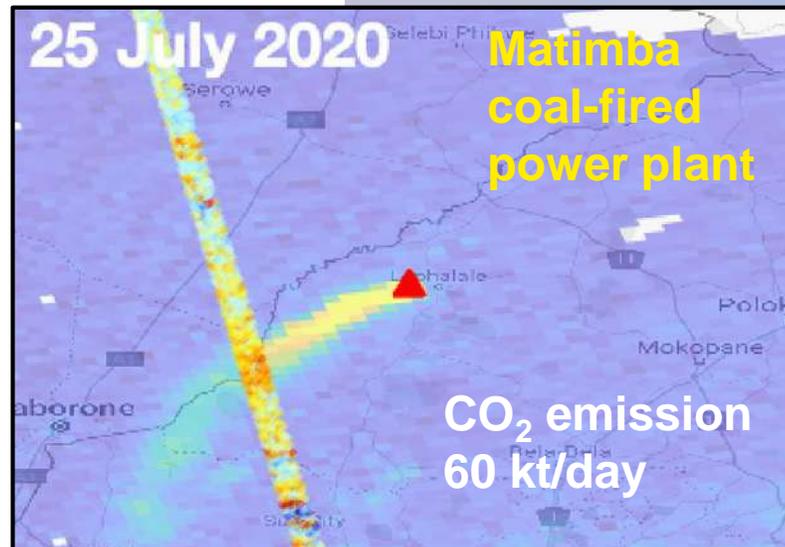
Pilot for Africa

Iolanda Ialongo, FMI

<https://www.emissionobservatory.org>

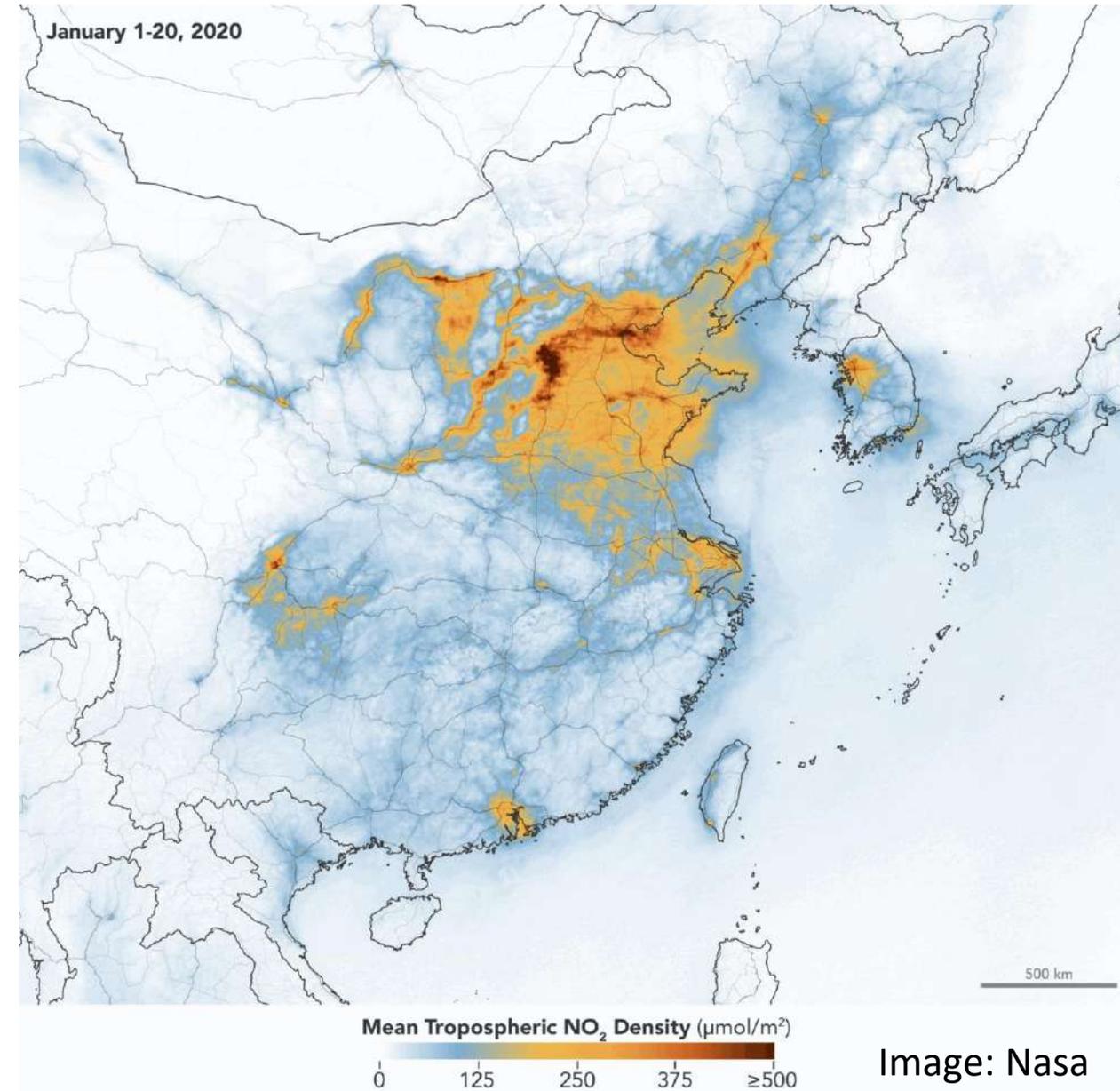
- An online interactive map service for monitoring man-made greenhouse gas and air pollution emission sources
- The service will provide improved and transparent emission information based on satellite observations
- Initial focus areas: open pit mining, energy production (e.g., coal-burning power plants), oil and gas industry (e.g., fugitive methane emissions and gas flaring) and megacities
- Target users and stakeholders: decision makers, environmental authorities, citizens and industry

The service is tailored to the users so suggestions for development are welcome



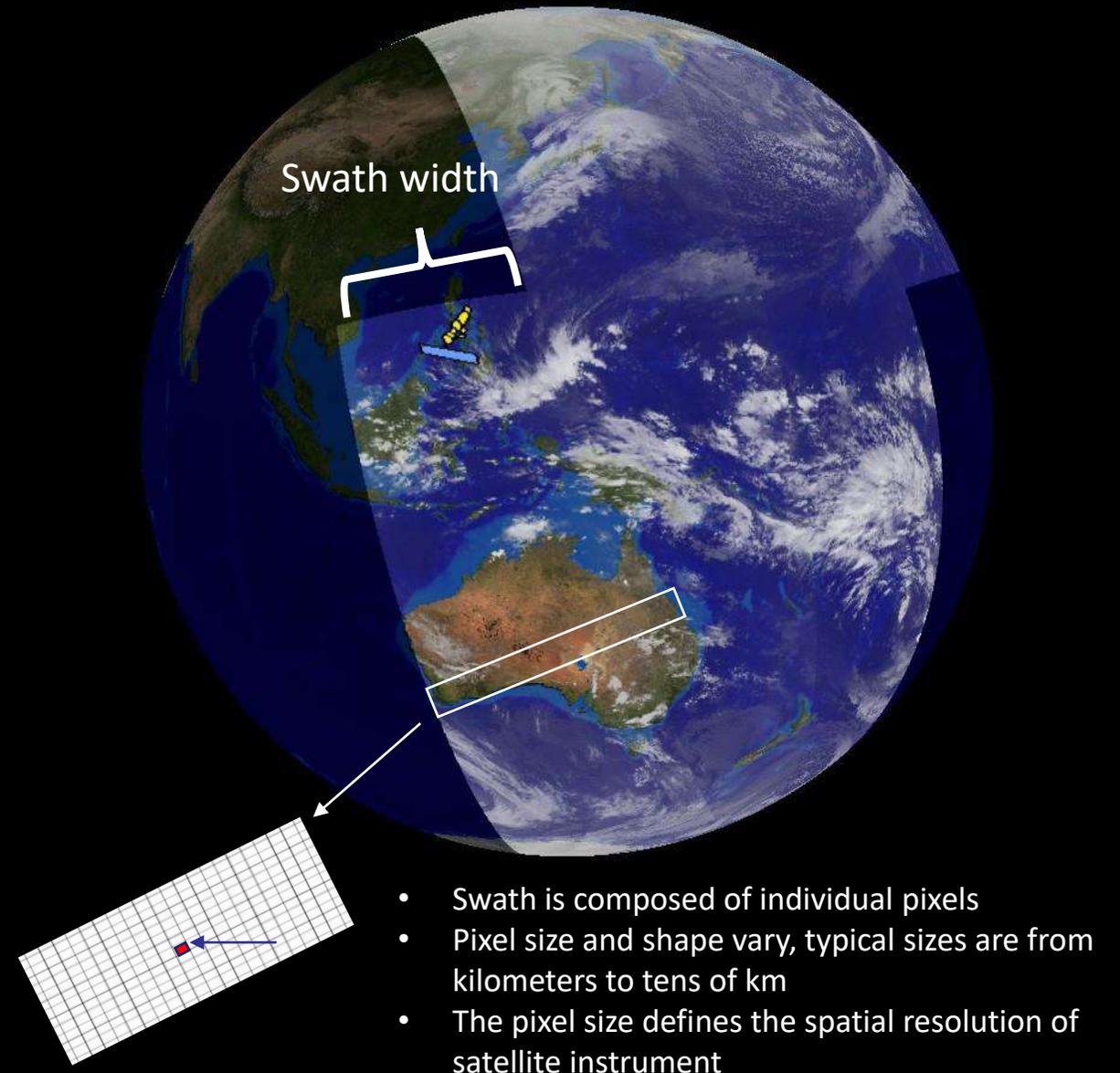
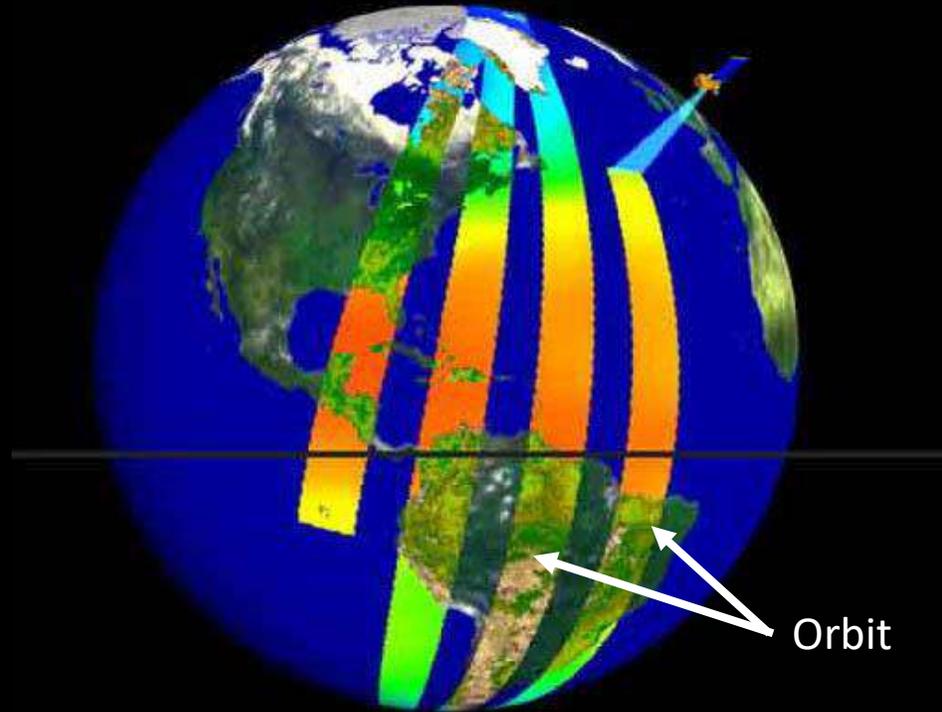
Satellite observations of atmospheric composition

- Nadir looking satellite instruments can observe air pollutants all over the globe
 - NO_2 (nitrogen dioxide), CO (carbon monoxide), CH_4 (methane), CO_2 (carbon dioxide), SO_2 (sulfur dioxide), aerosols
- These are indirect observations as satellite instruments only measure solar radiation backscattered from the Earth's surface to the satellite
- Satellites provide observations over areas where ground observations are not available or difficult to collect/maintain, or where the measurement network is sparse
- Satellite observations have been used to assess changes in human activities such as related to the implementation of new environmental policies and regulations, the global economic crisis in 2008-2009 and the Covid-19 pandemic.



Polar orbiting satellites

- Depending on the swath width, global coverage can be obtained in one day or in several days
- Overpass of specific locations about same local time



Examples of current operational satellite instruments monitoring atmospheric composition

OMI
NASA AURA



- Since 2004
- Polar orbit
- Trace gases, aerosols, clouds, UV- radiation
- FMI as the co-PI institute with KNMI

TROPOMI
Copernicus Sentinel 5p



- Since 2017,
- Polar orbit
- Trace gases, aerosols, clouds, UV- radiation, methane

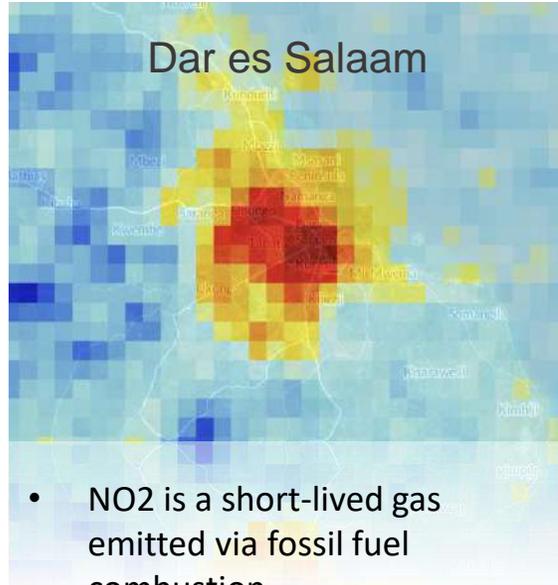
OCO-2/3
NASA



- Since 2014, and 2019
- Polar orbit
- CO₂, SIF

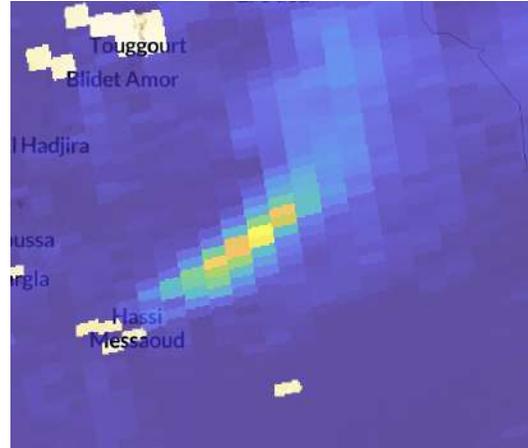
Examples of air pollutants observed from satellite

Nitrogen dioxide (NO₂)



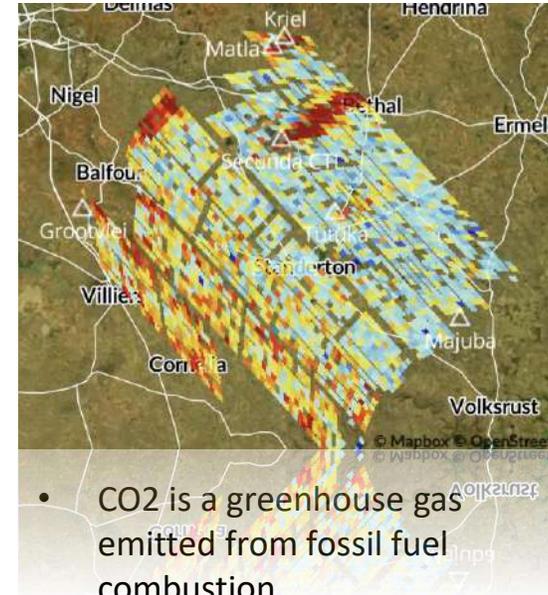
- NO₂ is a short-lived gas emitted via fossil fuel combustion
- Enhanced NO₂ levels can be found near emission sources such as cities and industrial area

Methane (CH₄)



- CH₄ is a greenhouse gas emitted from oil&gas facilities, livestock, landfills as well as natural wetlands
- CH₄ has about 7-12 years lifetime

Carbon dioxide (CO₂)



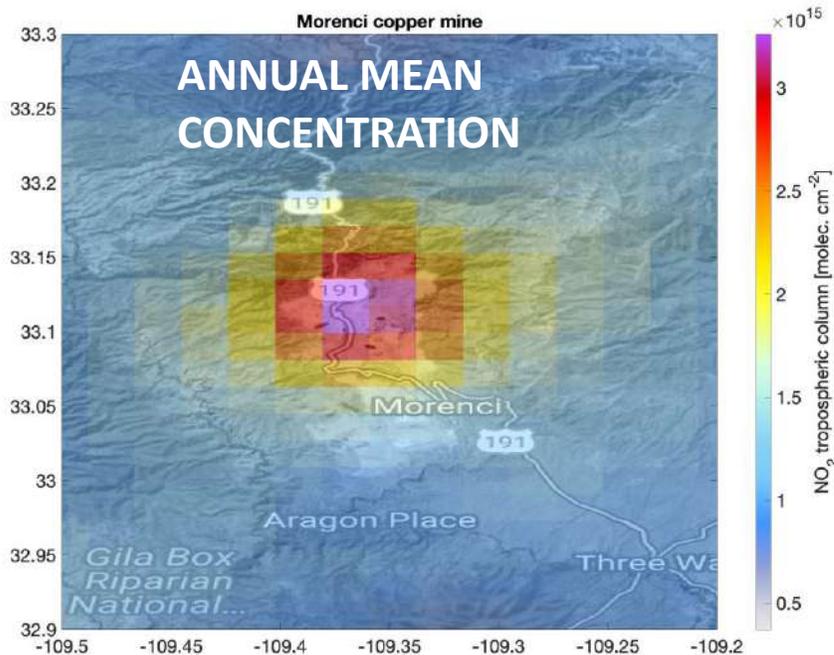
- CO₂ is a greenhouse gas emitted from fossil fuel combustion
- CO has lifetime of hundreds of years and it accumulates in the atmosphere

From concentrations to emission estimates

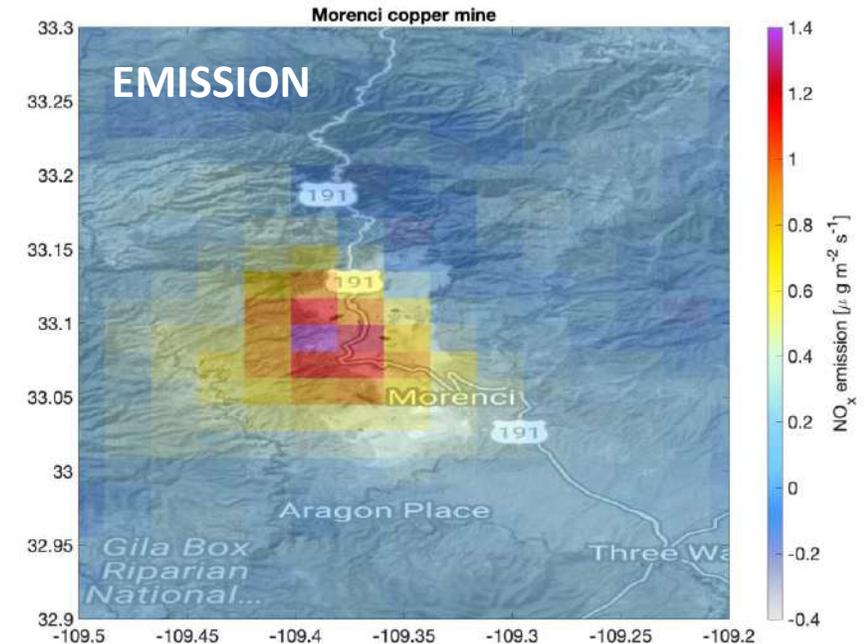
Satellite-based **CONCENTRATIONS** indicate the amount of pollutant in the whole atmosphere per surface unit

Data-driven emission estimation methods

EMISSION is the amount of pollutant released in the atmosphere from a specific pollutant source and in a specific time interval



Wind information



Focus sectors

Energy



- Coal-burning power plants
- Synthetic fuel plant

Oil&gas



- Methane leak/venting
- Gas flaring

Mining



- Open pit mining
- Metal smelting

Megacities



- Urban emissions such as traffic/residential

Emission Observatory

Pilot for Africa

<https://www.emissionobservatory.org>



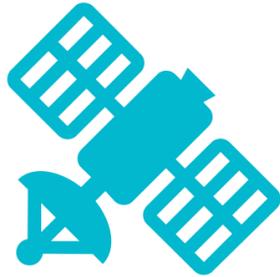
CONTACT US

emissionobservatory@fmi.fi

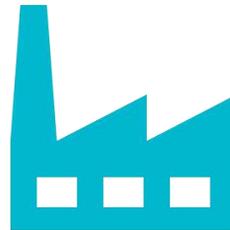


ILMATIETEEN LAITOS
METEOROLOGISKA INSTITUTET
FINNISH METEOROLOGICAL INSTITUTE

Conclusions and outlook



Satellite observations can support emission monitoring where no other info is available: how could we support your emission monitoring activities?



What could be your sectors of interest?



Do you have specific emission sources/areas you would like to monitor?



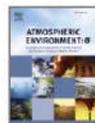
ILMATIETEEN LAITOS
METEOROLOGISKA INSTITUTET
FINNISH METEOROLOGICAL INSTITUTE

Contact

emissionobservatory@fmi.fi

31.5.2024 Nimi





Analyzing nitrogen oxides to carbon dioxide emission ratios from space: A case study of Matimba Power Station in South Africa

Janne Hakkarainen ^{a, *}, Monika E. Szilag ^a, Iolanda Ialongo ^a, Christian Retscher ^b, Tomohiro Oda ^{c, d, e}, David Crisp ^f

Show more

Share Cite

<https://doi.org/10.1016/j.aeaoa.2021.100110>

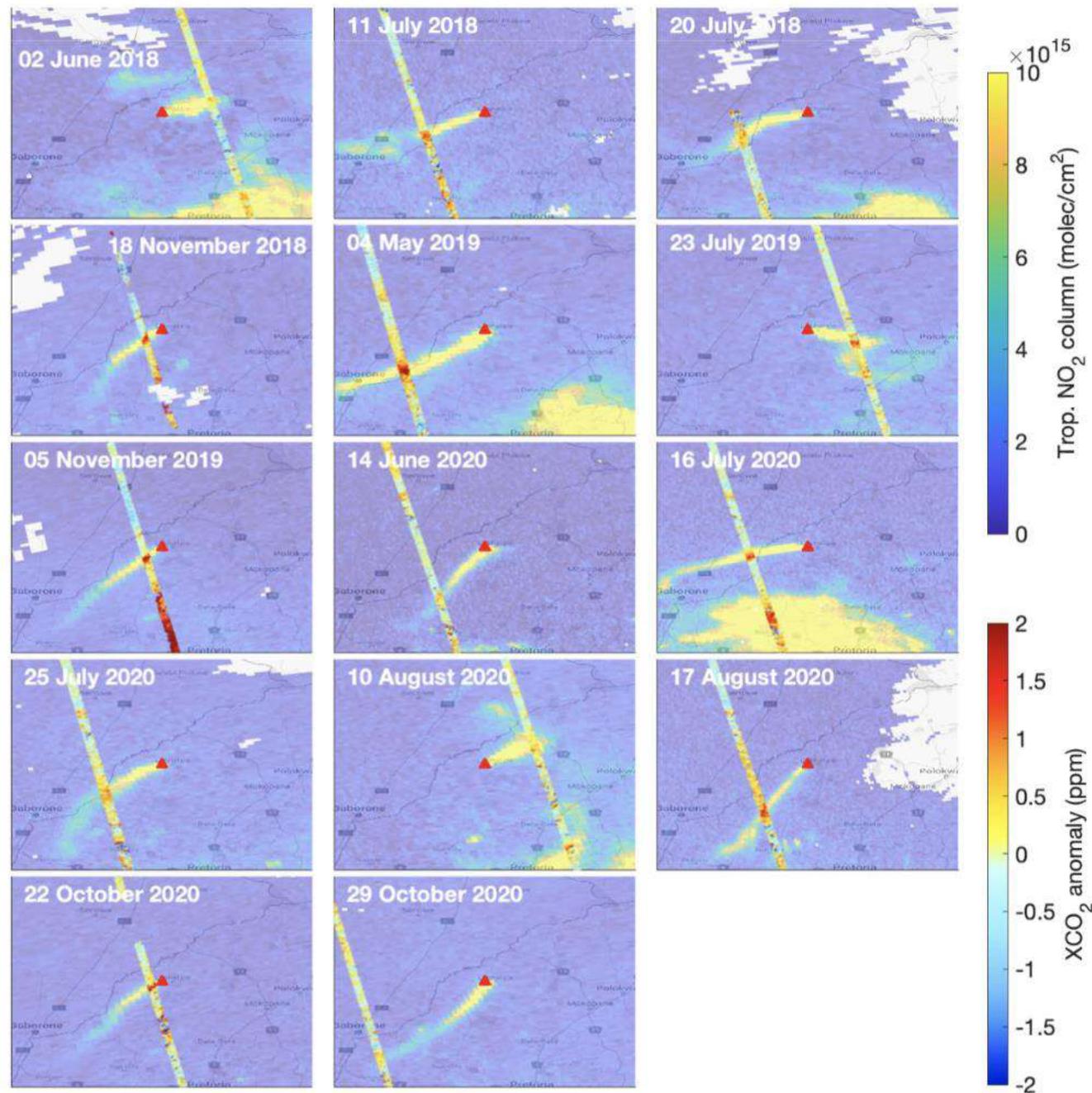
Get rights and content

Under a Creative Commons license

open access

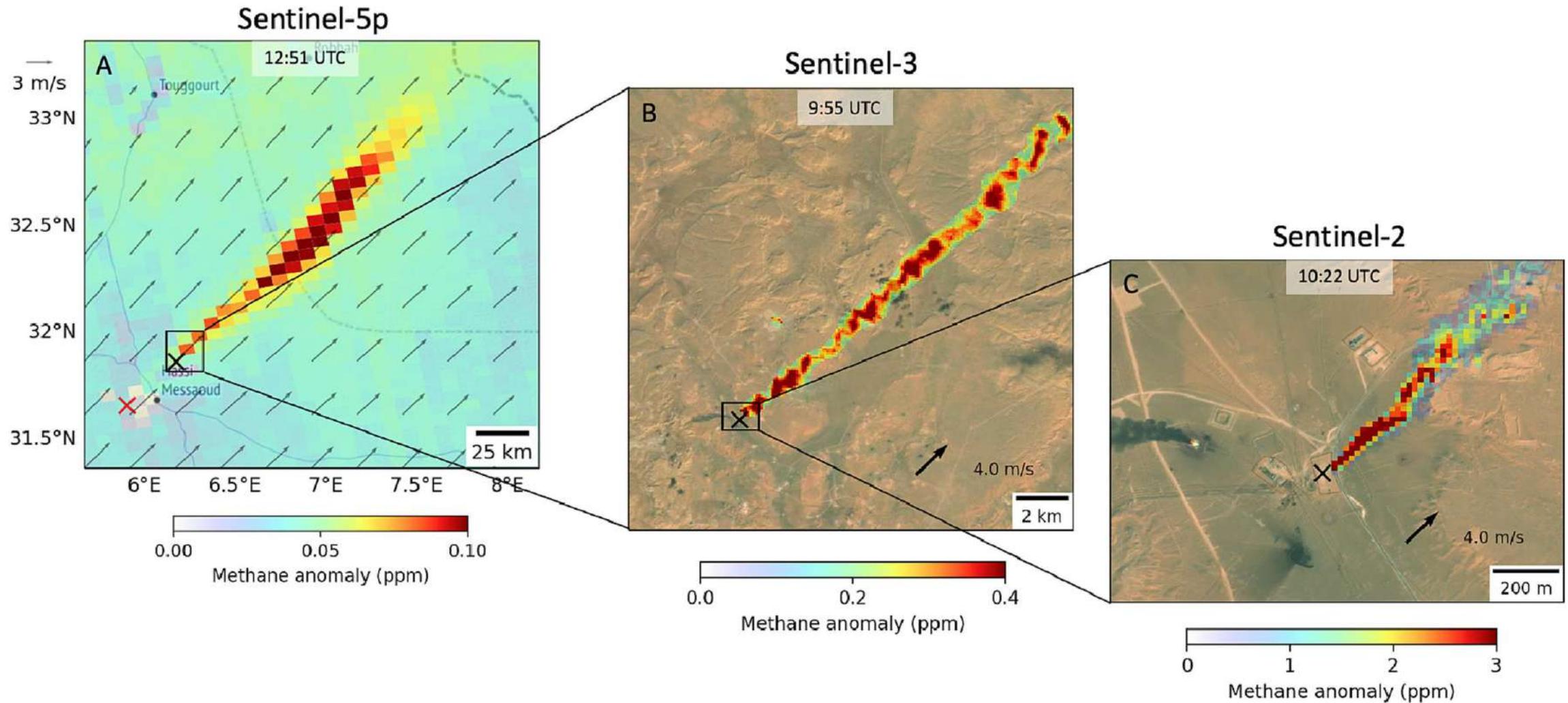
Highlights

- A new methodology to derive source-specific NO_x-to-CO₂ emission ratios.
- The method is applied for TROPOMI and OCO-2 satellite observations.
- The mean emission ratio of $(2.6 \pm 0.6) \times 10^{-3}$ is obtained for Matimba Power Station.
- The annual CO₂ emissions for Matimba are ~60 kt/d.
- The emission estimates are consistent with existing inventories such as ODIAC.



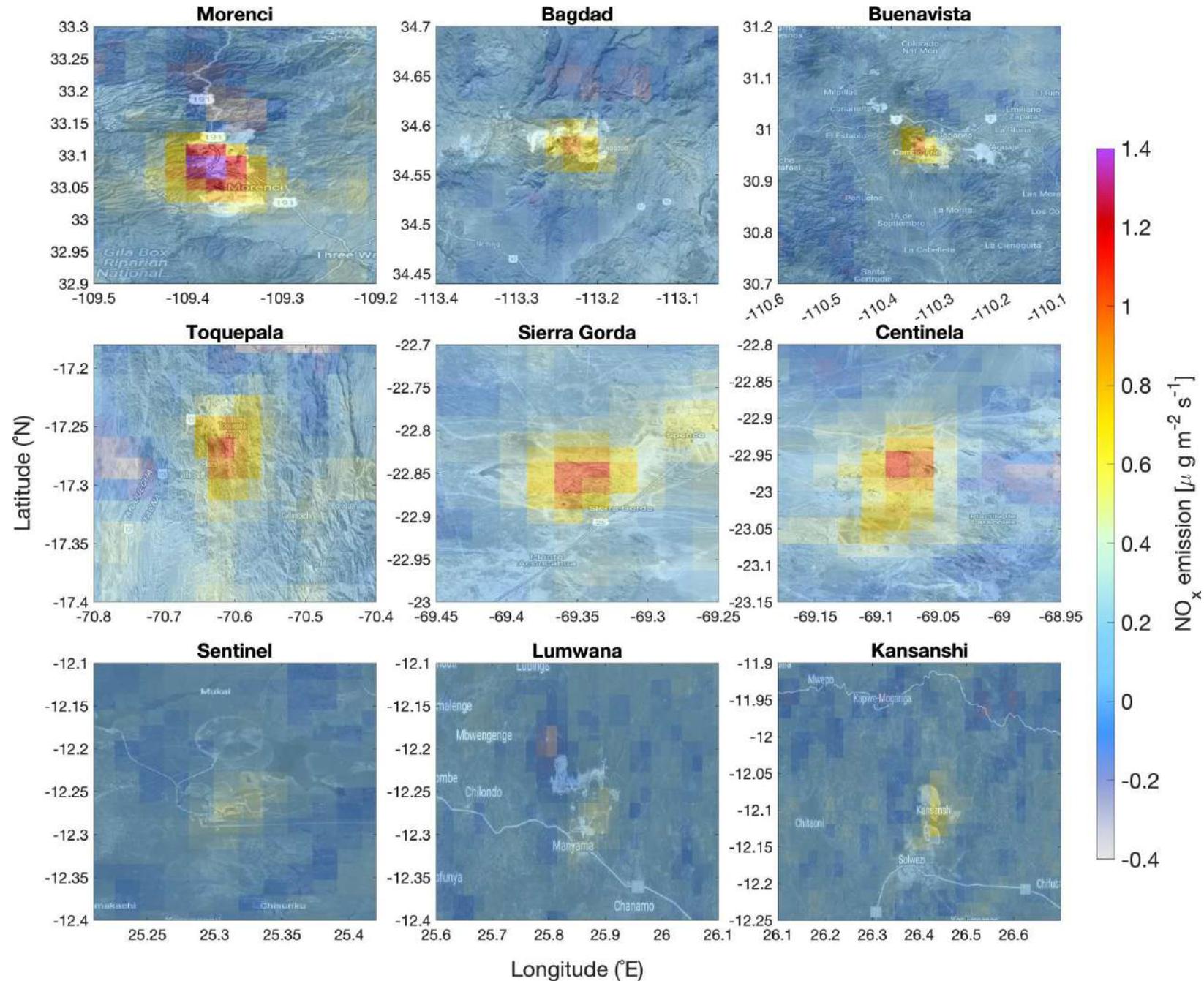
Oil&Gas

Observations of a Methane Leak in Algeria on January 4, 2020

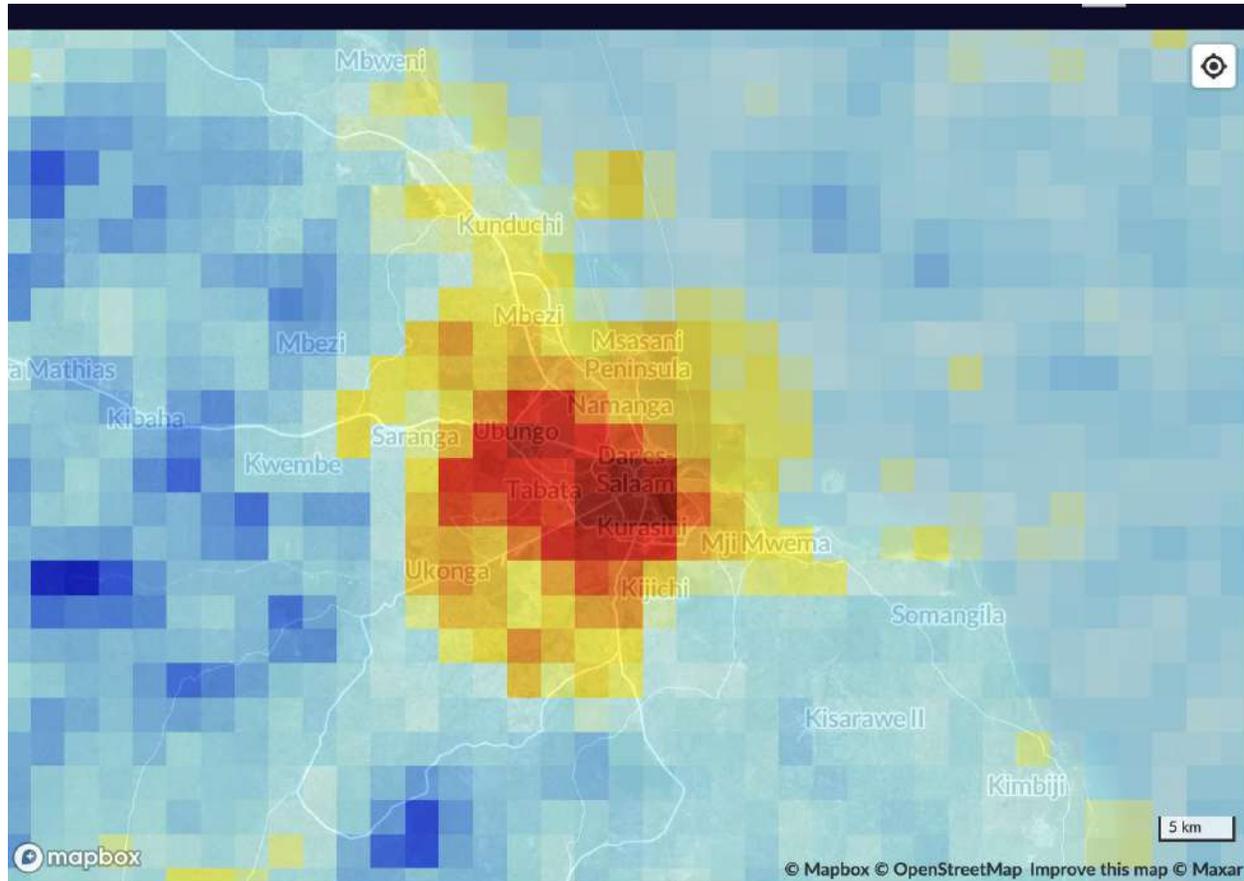


Mining

Business Finance funded **SpaceCasting** project (led by Univ. Vaasa) to find new ways of using satellite data for economic nowcasting.



Megacities



DAR ES SALAAM

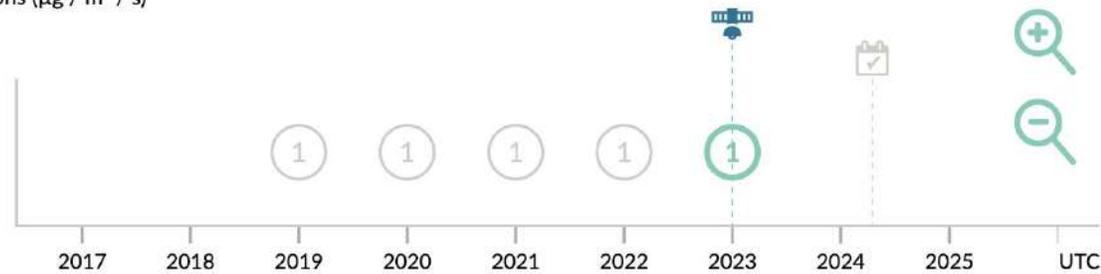
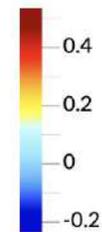
Dar es Salaam description...

Site type Megacity



SATELLITE IMAGES

NOx emissions ($\mu\text{g} / \text{m}^2 / \text{s}$)



Estimated NOx emissions

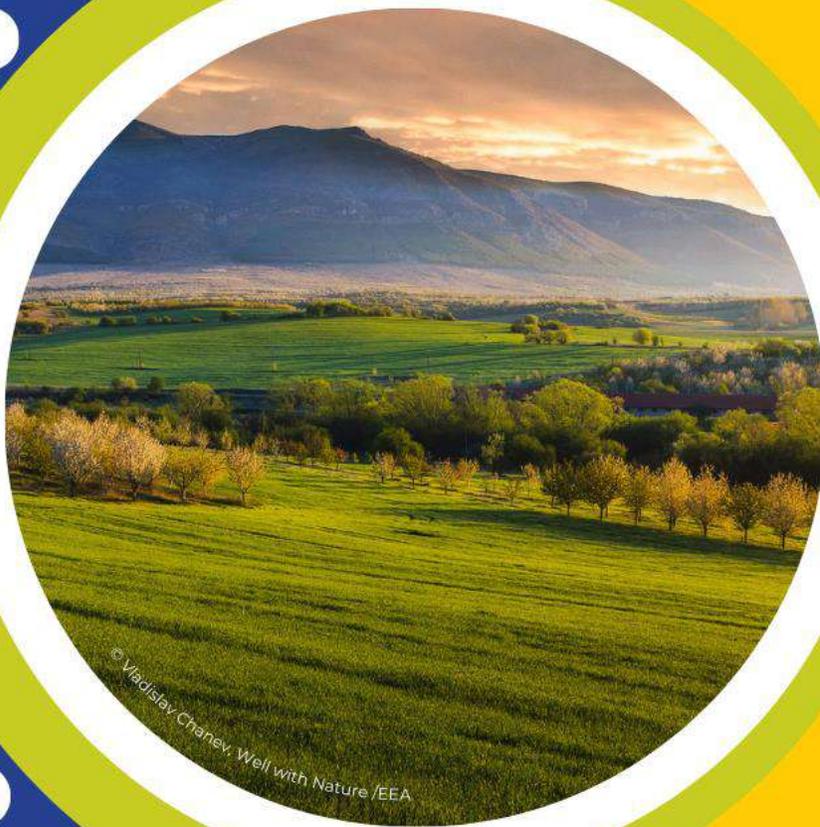
Estimated annual nitrogen oxide emissions based on TROPOMI observations of tropospheric vertical column density (VCD) of nitrogen dioxide (NO_2), calculated using the divergence method and ERA5 winds at 100 m height above the surface.

EO for Agriculture and Environmental Monitoring

Agricultural Monitoring

David Ongo – ICPAC Consortium

11th June 2024



© Vladislav Chanev, Well with Nature / EEA



PROGRAMME
OF THE EUROPEAN UNION



Implemented by



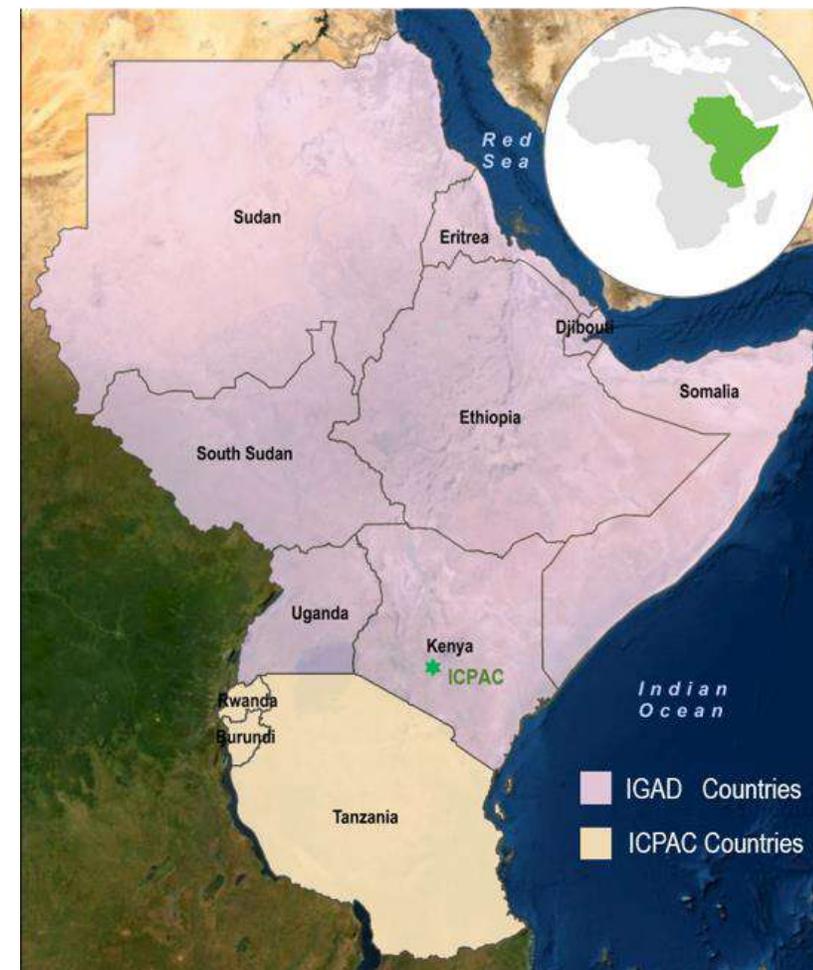
European
Environment
Agency



European
Commission

IGAD CLIMATE PREDICTION AND APPLICATIONS CENTRE

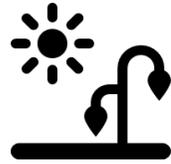
- Established in 1989 as the Drought Monitoring Centre, Nairobi (DMCN)
- 2007, the Protocol establishing the Centre signed & the name changed to **IGAD Climate Prediction and Applications Centre (ICPAC)**
- ICPAC is a **WMO Regional Climate Centre (WMO-RCC)** for Eastern Africa.
- ICPAC is a member of **AUC/NEPAD** Network for Water Centres of Excellence.
- ICPAC has an Observer Status with the **UNFCCC**
- We provide services to over 300 million people



WHAT DO WE DO? KEY PRODUCTS AND SERVICES



**Climate
Monitoring and
Forecasting**



**Disaster Risk
Management**



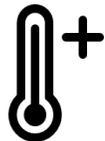
**Agriculture and
Food Security**



Water Resources



**Environmental
Monitoring**



Climate Change



**Capacity
Development**



**Climate Information
and Co-production**



PROGRAMME OF THE
EUROPEAN UNION



Implemented by



European
Environment
Agency





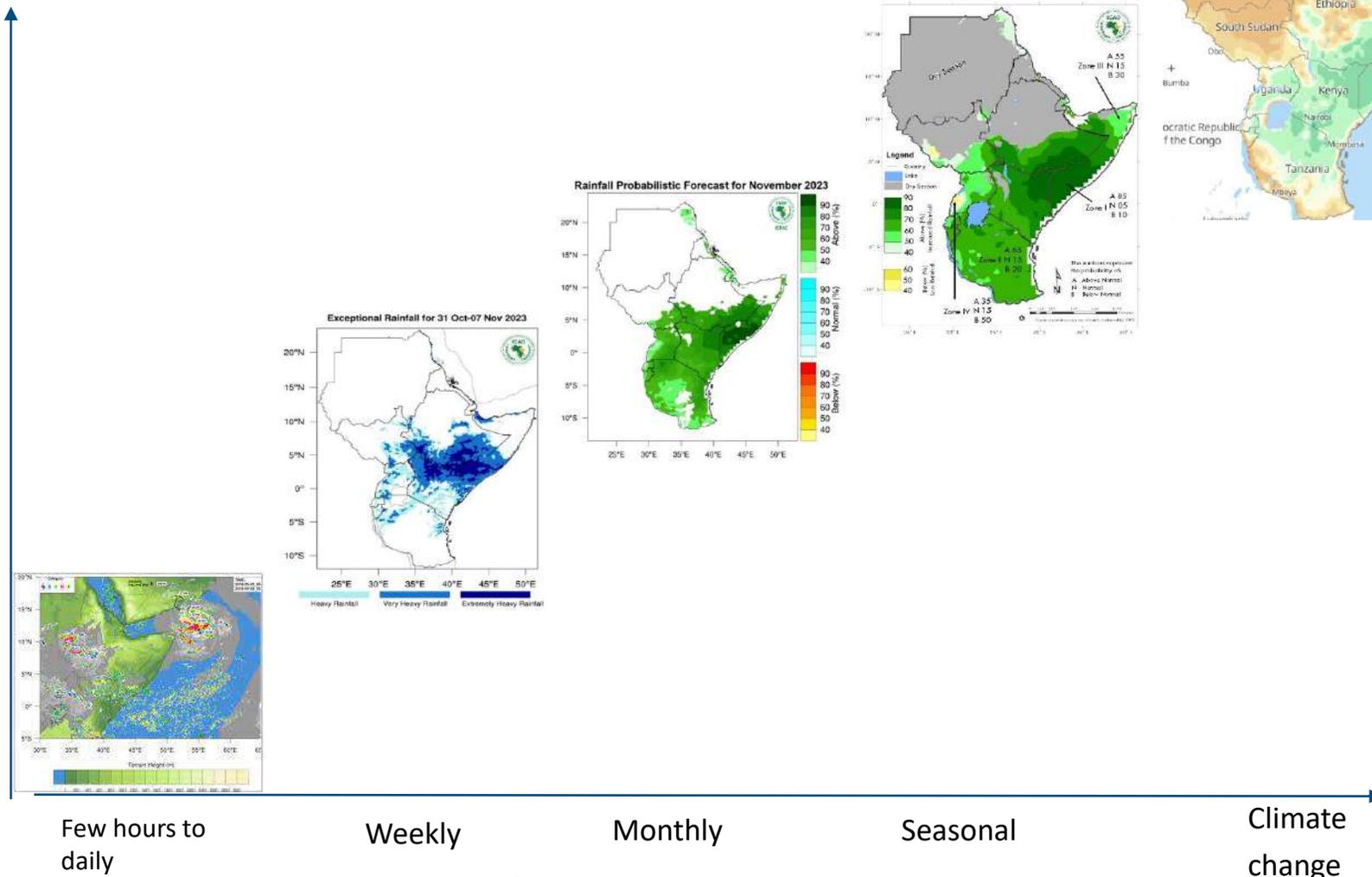
SEAMLESS early warning INFORMATION

Planning informed

Strategic planning and scenario building

Preparedness planning

Response and relief



Few hours to daily

Weekly

Monthly

Seasonal

Climate change

Timescales

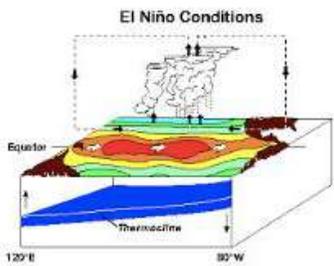


PROGRAMME OF THE EUROPEAN UNION



Implemented by





Suppressed rainfall in HOA



Extensive flooding in EA

Worst Ever Desert locust



Flooding in EA due to Elnino and IOD conditions

2015/2016

2016/2017

2018/2019

OND 2019

2019/2020

2020/ 2022

2023

El Nino one of the strongest

Tropical cyclones in Eastern and Southern Africa



Persistent LaNina Conditions leading to longest drought duration over EA



Strongest IOD



PROGRAMME OF THE EUROPEAN UNION



Implemented by

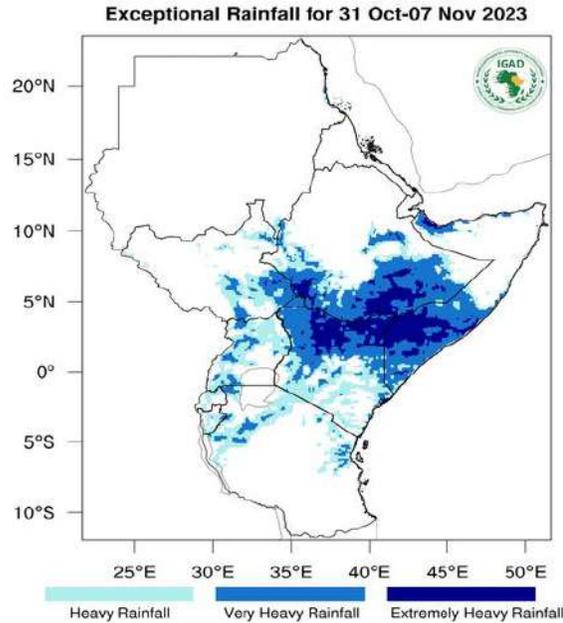


European Environment Agency

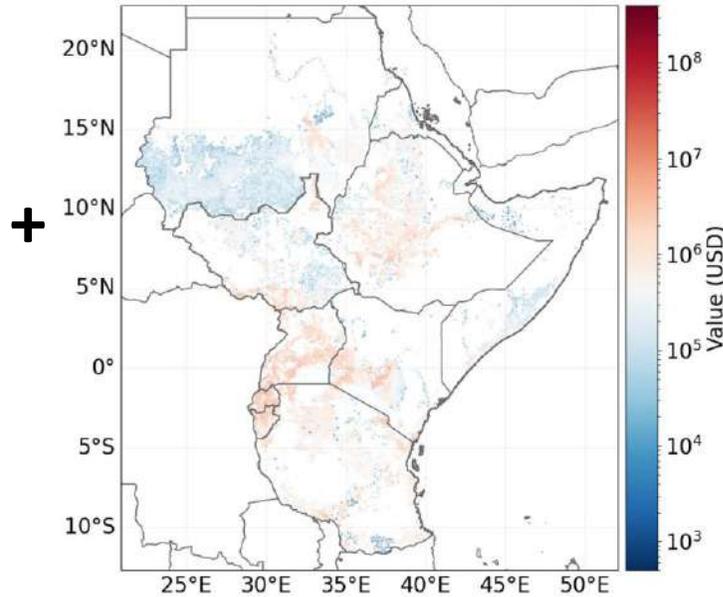


MOVING TOWARDS WHAT THE WEATHER WILL DO: IMPACT BASED FORECASTS

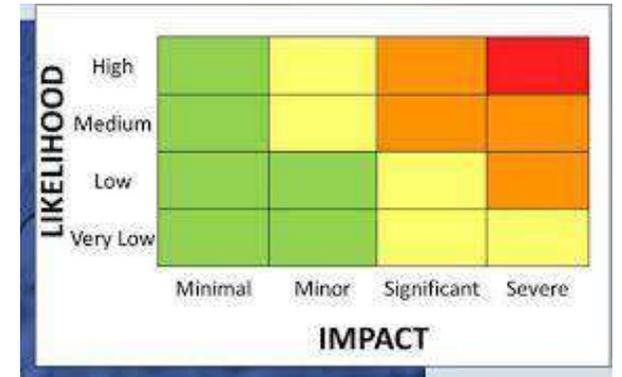
Hazard



Exposure



Vulnerability



This is being implemented in partnership with non-traditional collaborators such as Google



PROGRAMME OF THE
EUROPEAN UNION



Implemented by



European
Environment
Agency



Agriculture and Food security

- ❖ Improve Food Security and Agricultural monitoring in Eastern Africa.
- ❖ Committed to support countries and organisations to make better decisions in food security, nutrition and resilience.
- ❖ Coordinate the meetings of the Food Security and Nutrition Working Group, a network of over 80 organizations working in the region to monitor food security and send monthly food security updates.
- ❖ ICPAC hosts the [IGAD Food Security, Nutrition and Resilience Analysis Hub, IFRAH](#), which integrates the Food Security and Nutrition Working Group ([FSNWG](#)), the Resilience Analysis Unit (RAU) and the Integrated Food Security Phase Classification (IPC).



Capacity Development

We build capacity in Food and Nutrition Security analysis, reporting and advocacy for action.



Warnings and Advisories

We develop and disseminate a quarterly Crop Monitor and key Agro-meteorological information, warnings, alerts, scenarios, and advisories



Climate Smart Agriculture

We promote Climate Smart Agriculture and other global, continental, regional and national strategies



PROGRAMME OF THE
EUROPEAN UNION



Implemented by



European
Environment
Agency



Eastern Africa Crop Monitor



Provide an overview of the following areas

Climate: Greater Horn of Africa Climate Outlook Forum (GHACOF), NCOF

Crops: Different crop stages;

Trade: Regional Trade outlook



PROGRAMME OF THE
EUROPEAN UNION



Implemented by

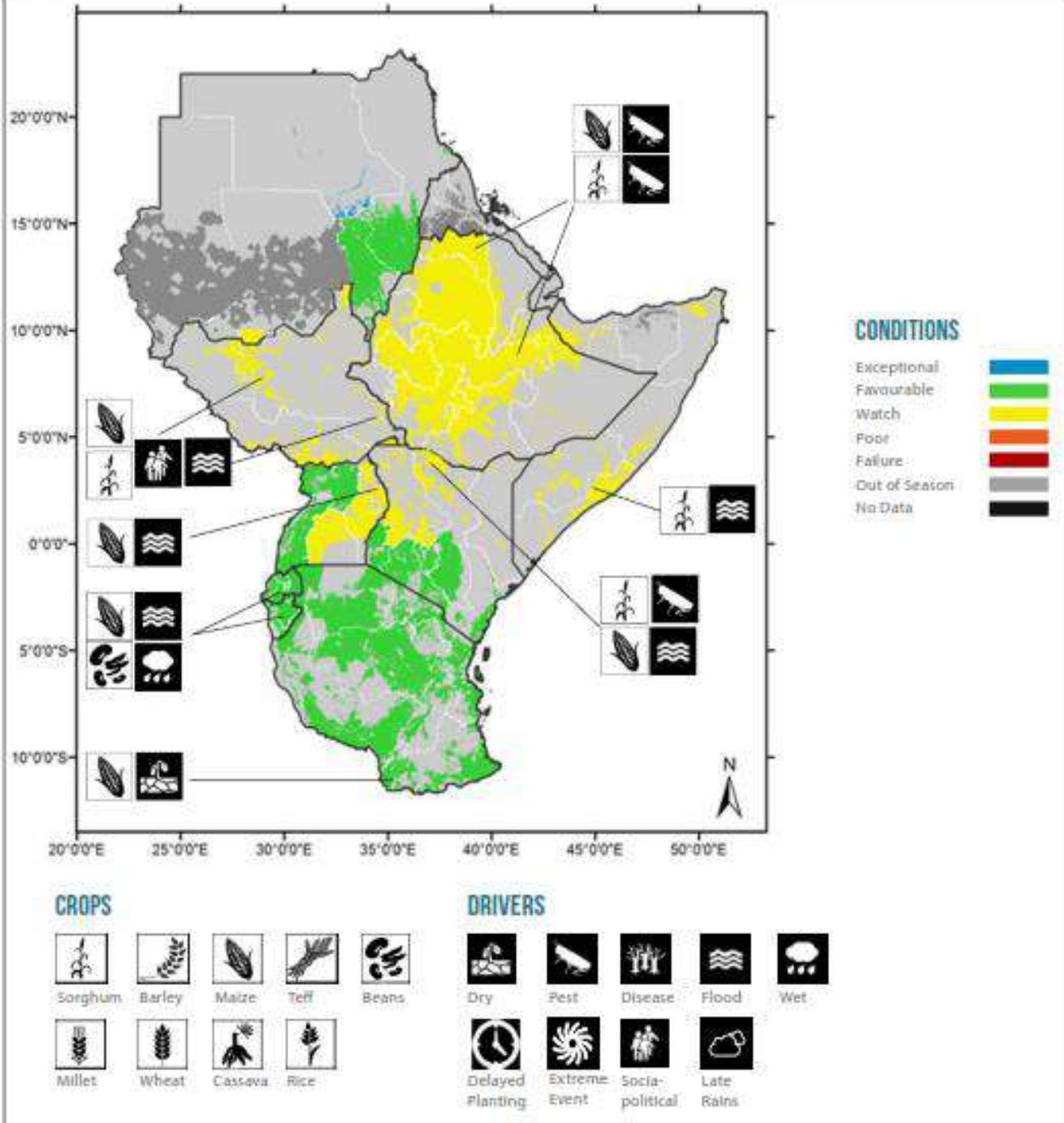


European
Environment
Agency



Crop Condition

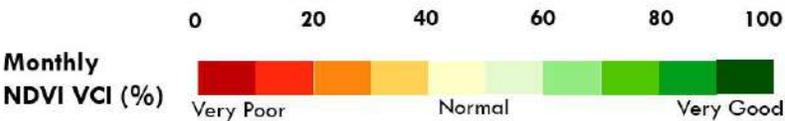
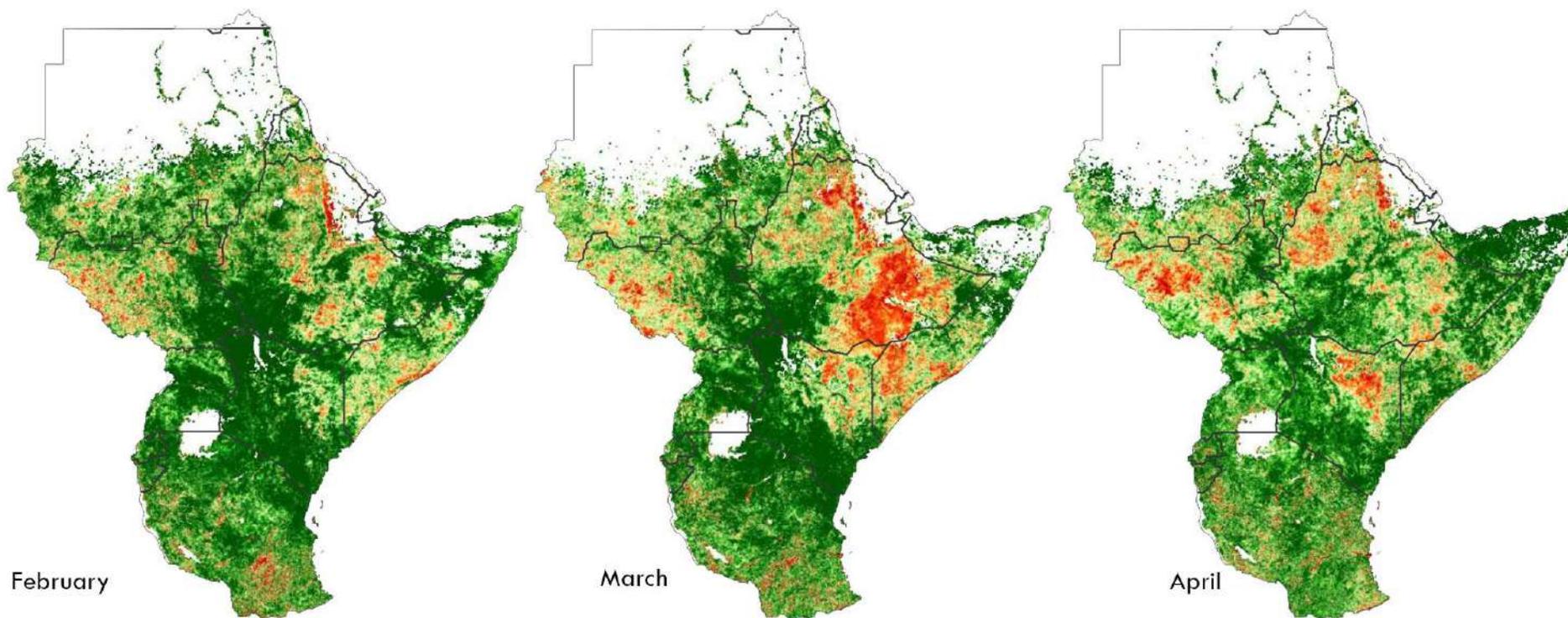
- Season Characterization, Rainfall onset
- Planting Calendar expectation
- Pest and Disease any other conditions – Desert Locust
- Country Summaries (Burundi, Rwanda, Kenya, Tanzania, Uganda, Somalia, Ethiopia, Sudan, South Sudan)



VEGETATION CONDITIONS

Progress of Vegetation Conditions

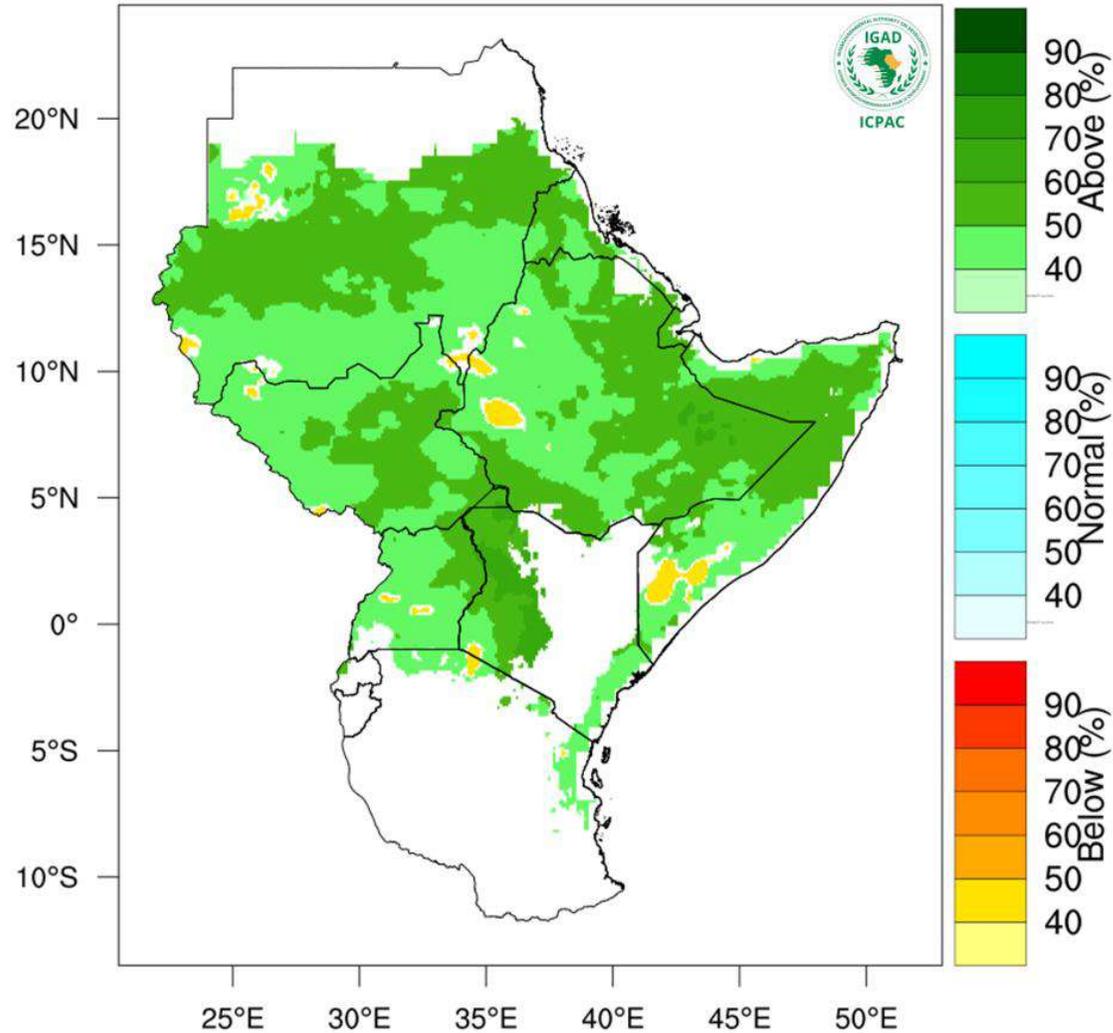
Data Source: SPOT
VGT/PROBA V NDVI



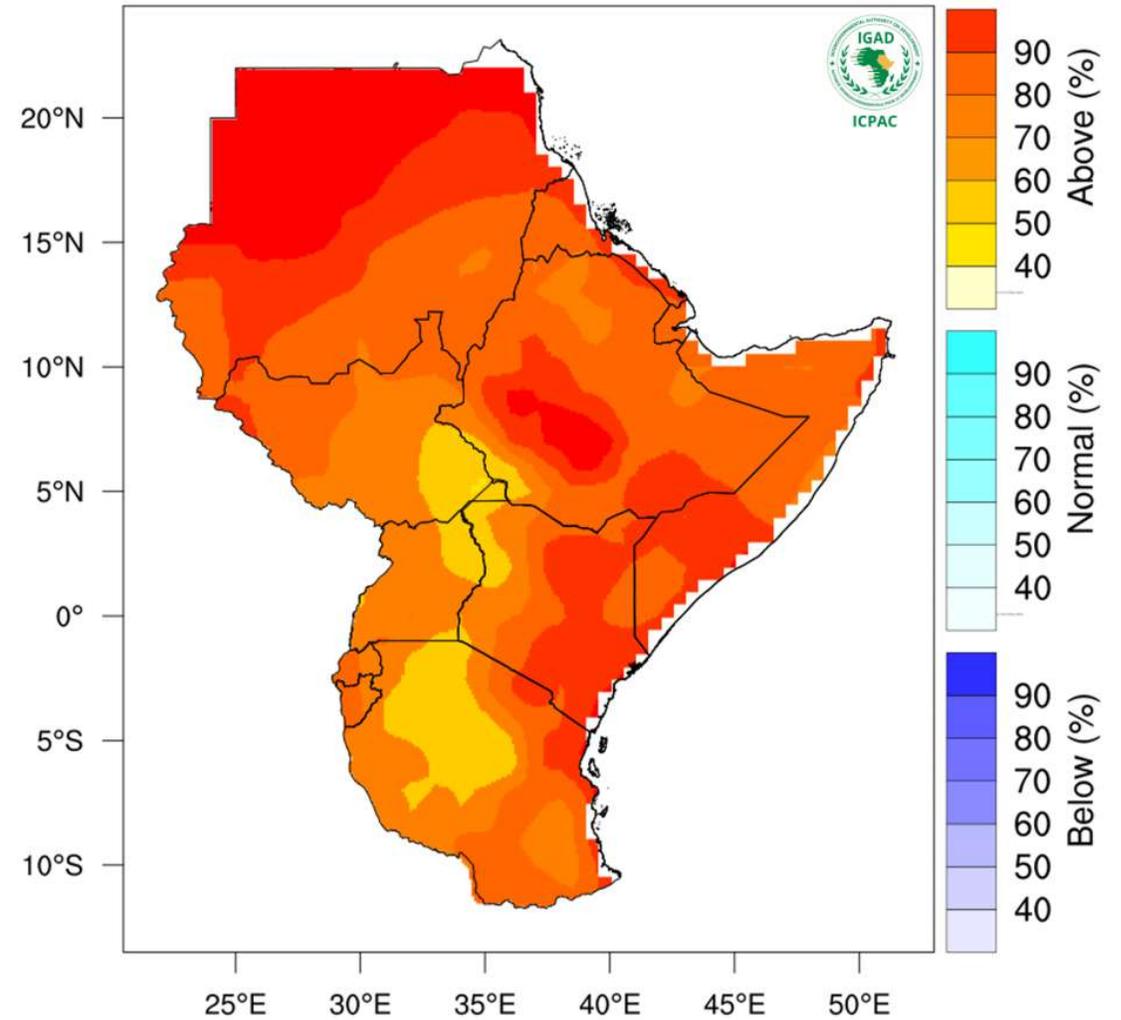
Mixed conditions due to varying rainfall distribution in March to May in most parts of Eastern Africa
Monthly assessments of Vegetation

SEASONAL FORECAST FOR MAY-JULY 2024

Rainfall Probabilistic Forecast for May-July 2024



Temperature Forecast for May-July 2024

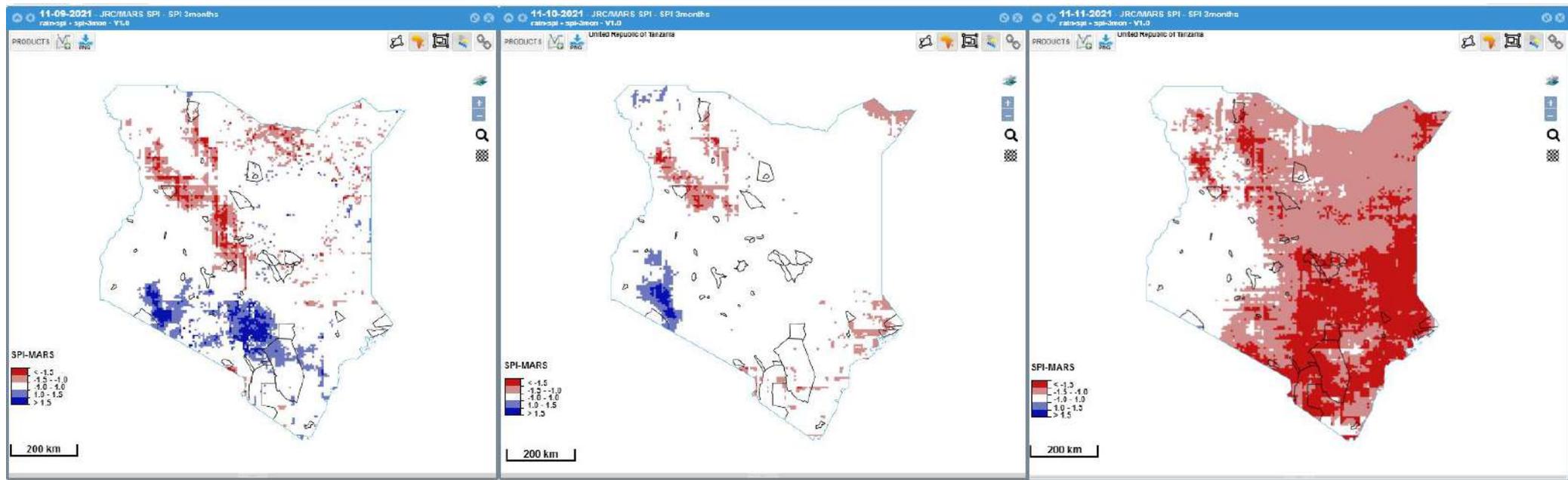
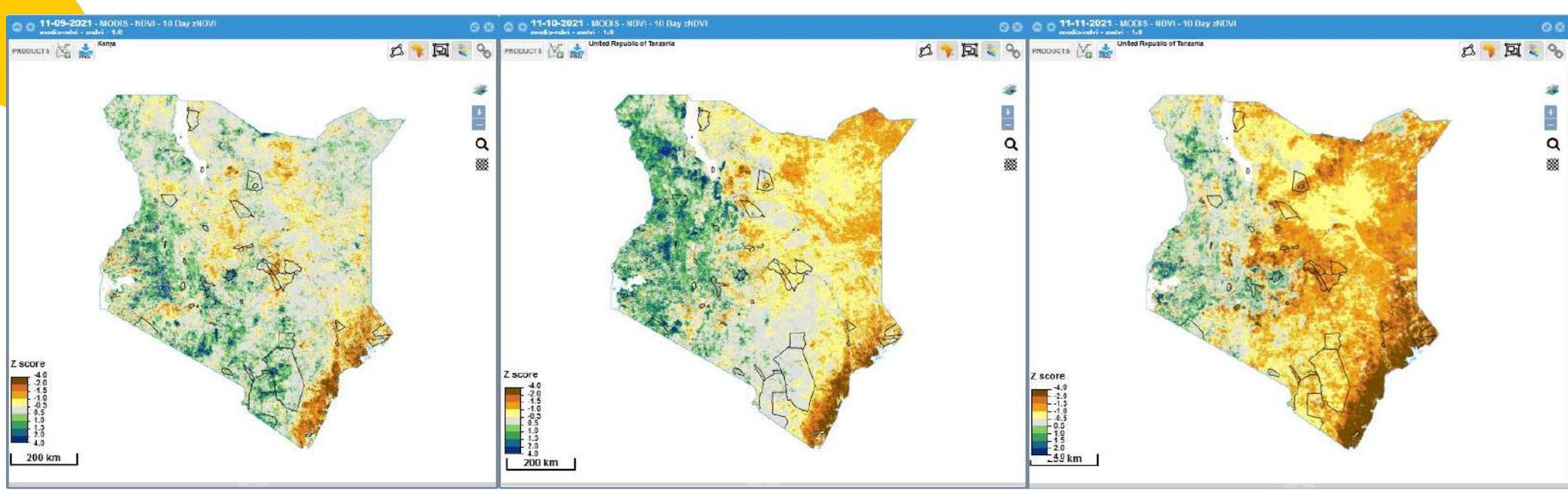




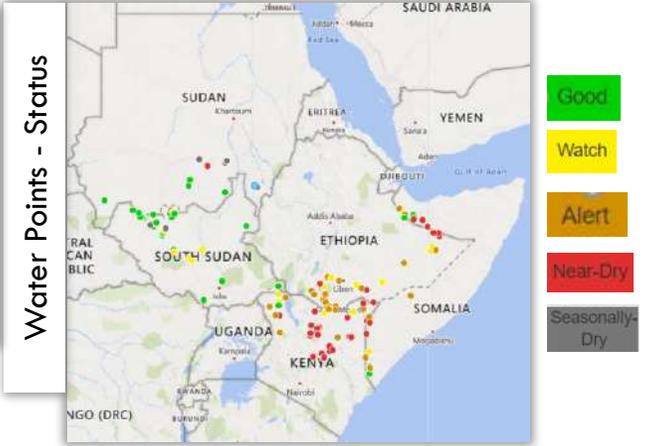
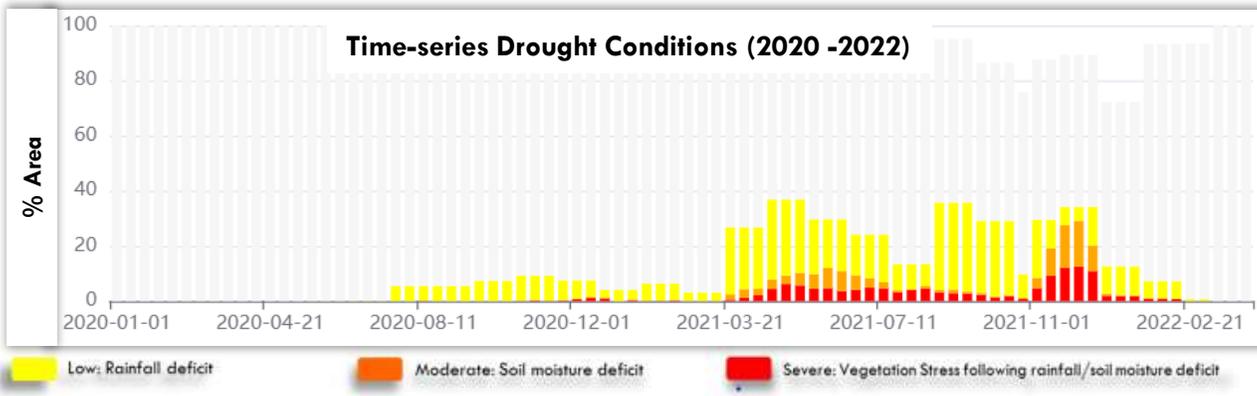
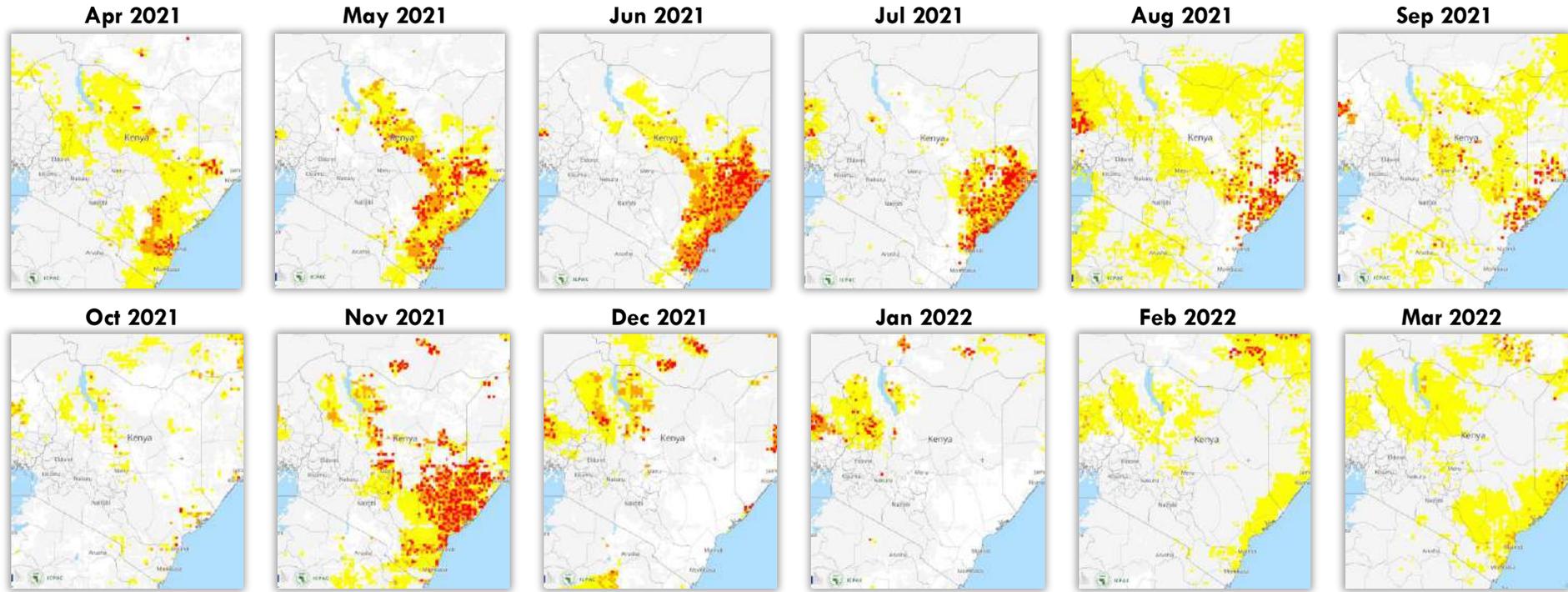
REGIONAL GRAIN MARKETS AND TRADE

- Knowing where to find customers, what and when to sell to them, and at what price.
- Provides real time grain market prices, cross border trade volumes, food stocks and climate information

- Vegetation/Drought
- National monitoring
- Hotspot Monitoring
- Drought Condition
- Regional Analysis

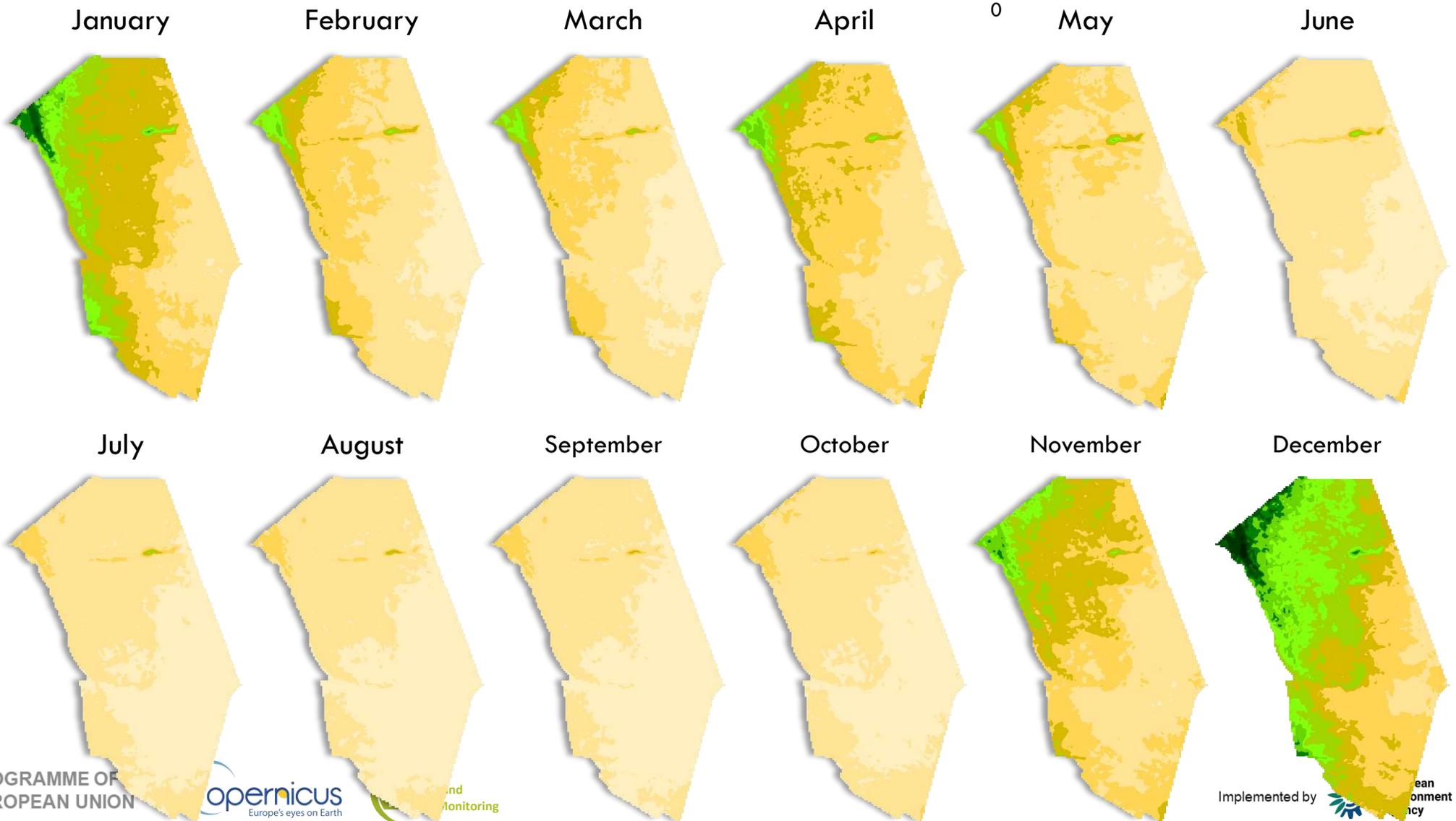
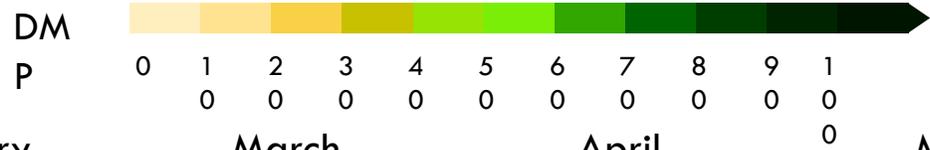


Drought Conditions – National Level Analysis



Tsavo East Biomass Distribution

Biomass Persistence (Monthly Long Term Average DMP 2011-2017)



PROGRAMME OF EUROPEAN UNION



and Monitoring

Implemented by



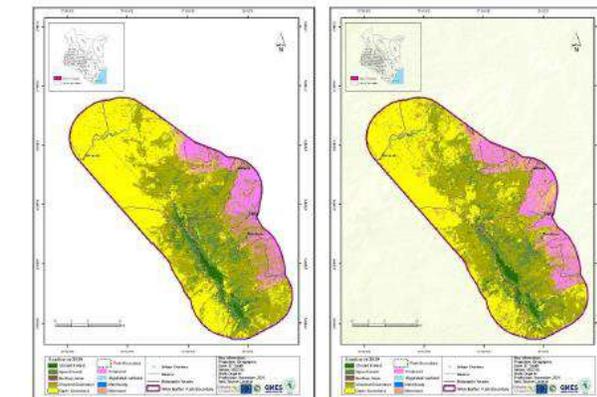
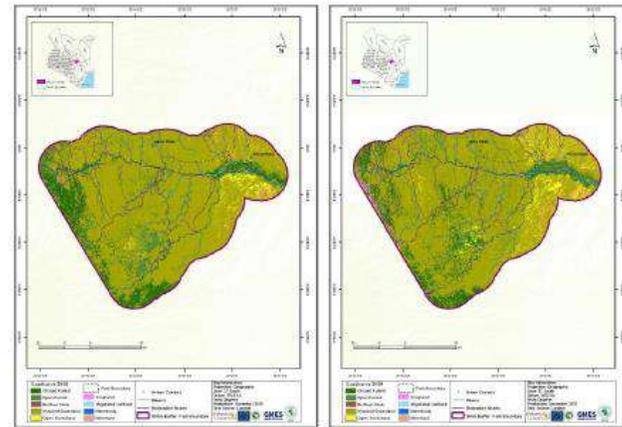
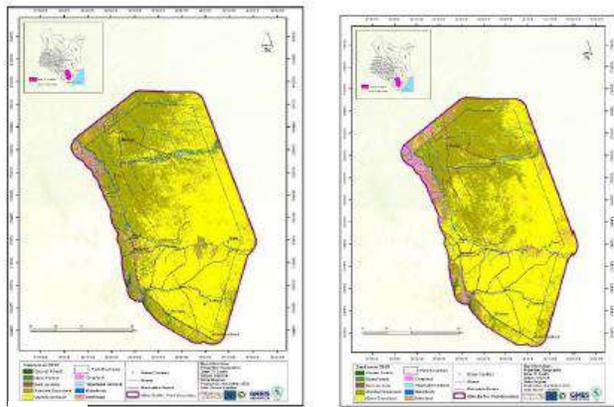
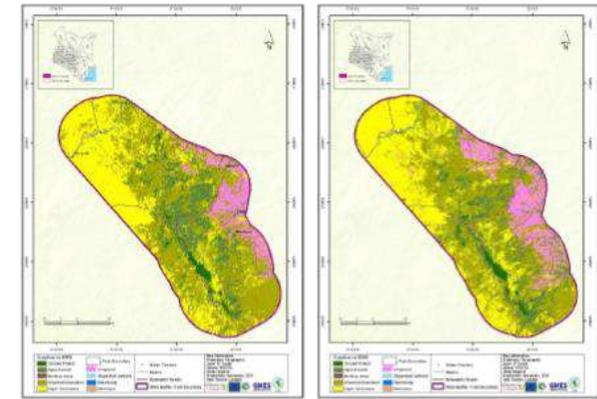
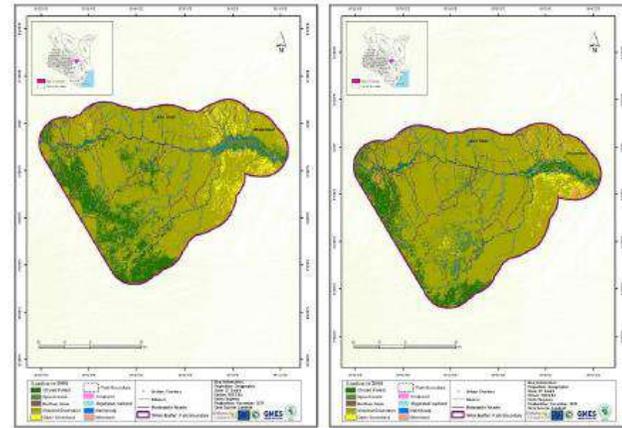
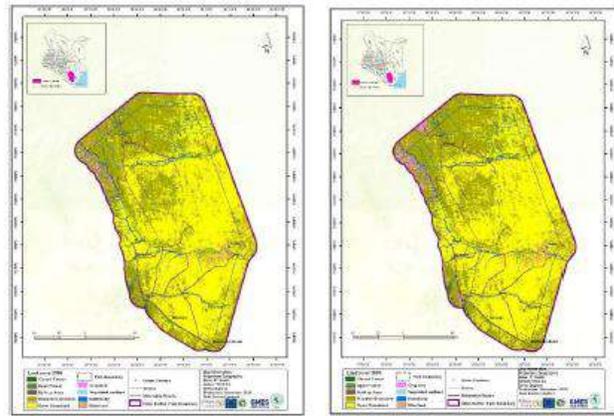
Environment Agency



Land use and land cover

LC/LCC – ecological integrity – habitats pressure and change

Land Use Land Cover: Nairobi NP, Marsabit NP, L. Nakuru, Losai, Tsavo East, Tsavo West, Maasai Mara, Mt Kenya, Ruma, Hell's Gate, Mt Elgon, Kora, Chyulu NP.



Land Cover Classes 1986, 2000, 2010 and 2019

Land Cover Classes 1990, 2000, 2010 and 2019



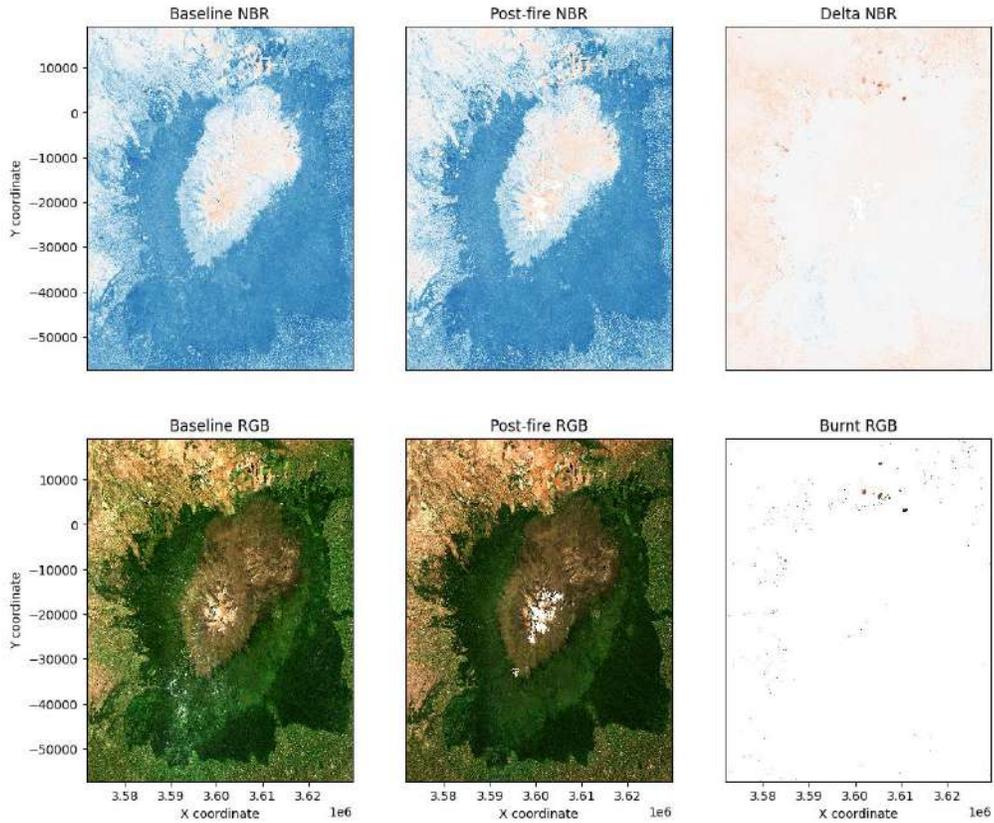
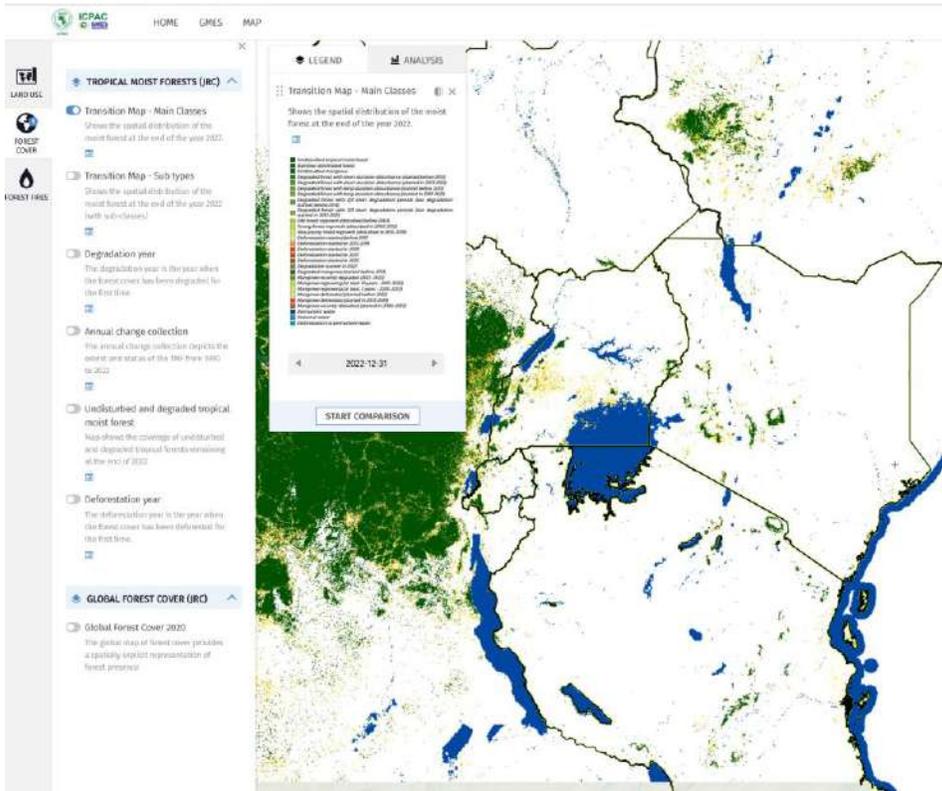
PROGRAMME OF THE
EUROPEAN UNION



Implemented by



East Africa Forest Watch



East Africa Forest Watch Fire Monitoring

2019

Unburnt area: 4399.48 km²

Burnt area: 12.38 km²

Total area (no nans): 4411.86 km²

Total area (with nans): 4432.24 km²

Percentage of total area burnt: 0.28%



PROGRAMME OF THE
EUROPEAN UNION

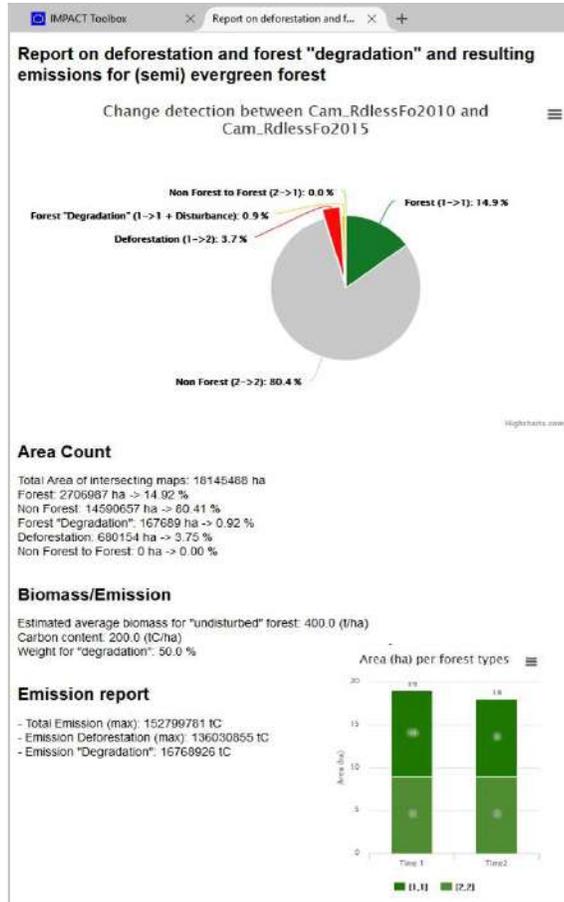


Implemented by

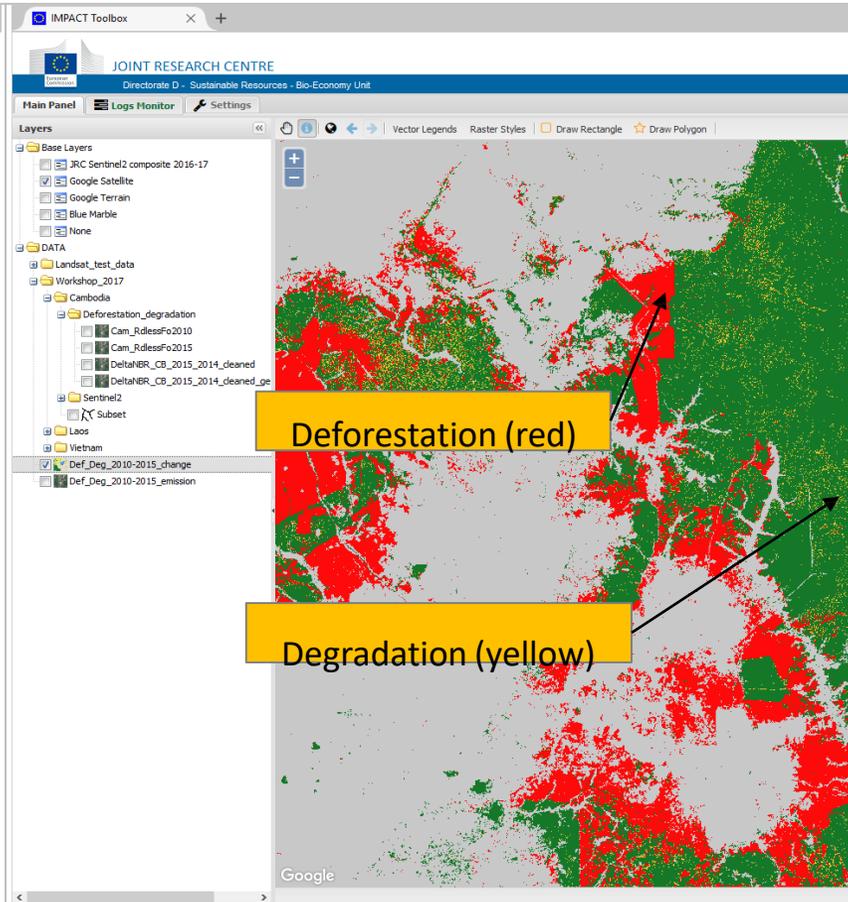


Carbon Emissions reporting tools

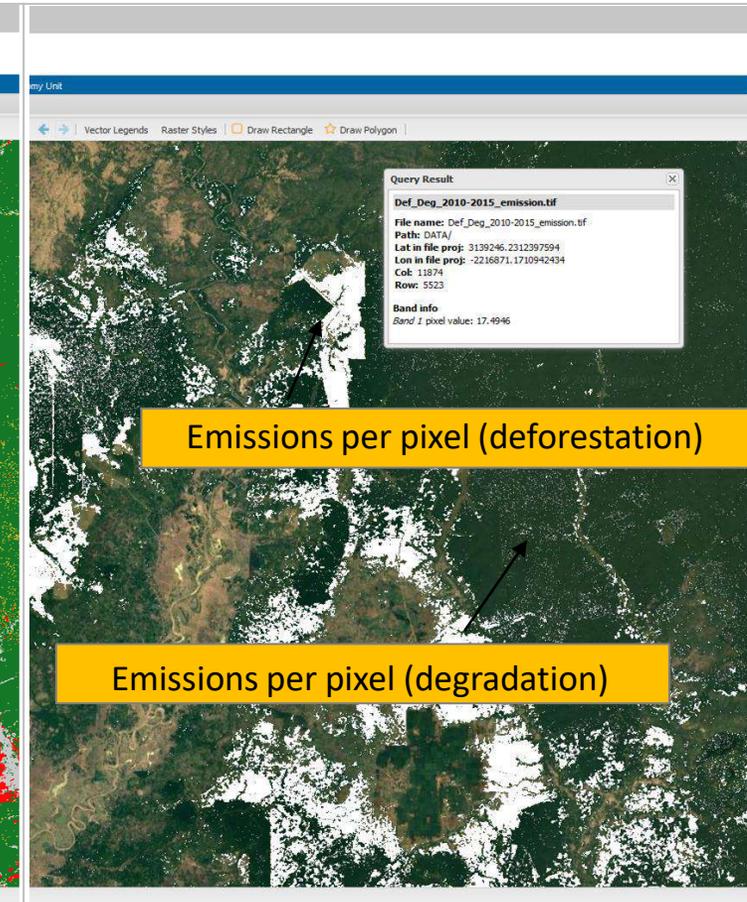
Stats

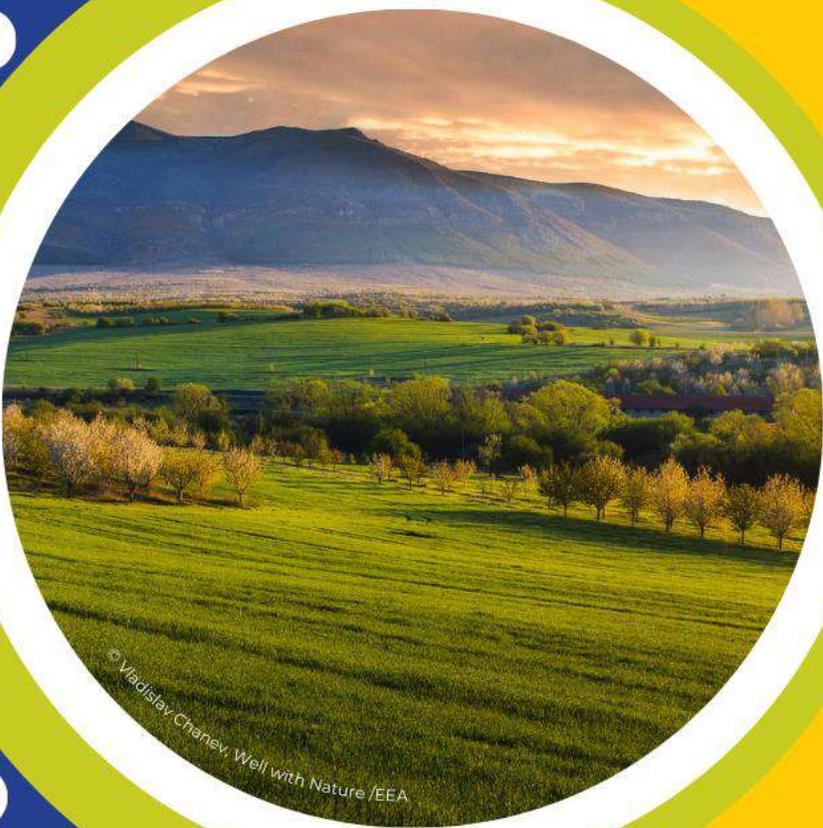


Map of deforestation and degradation



Map of emissions





© Vladislav Chanev, Well with Nature / EEA

THANK YOU

david.ongo@lgad.int

+254726613962



PROGRAMME
OF THE EUROPEAN UNION



Implemented by



European
Environment
Agency



European
Commission

Webinar FPCUP - Training of Trainers
W3# Copernicus Services and Use Cases (CAMS and C3D)

Mapping urban expansion in African cities

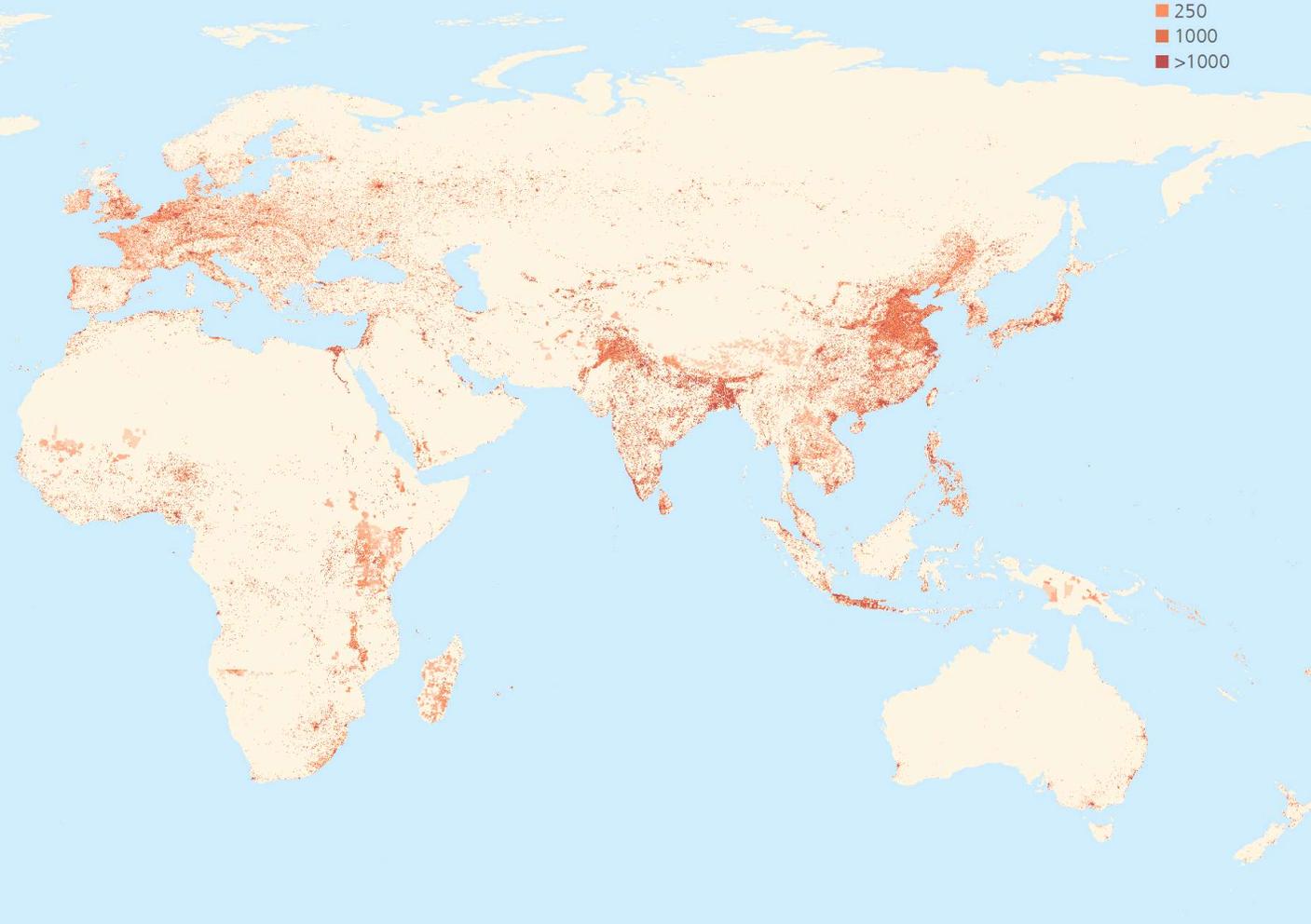
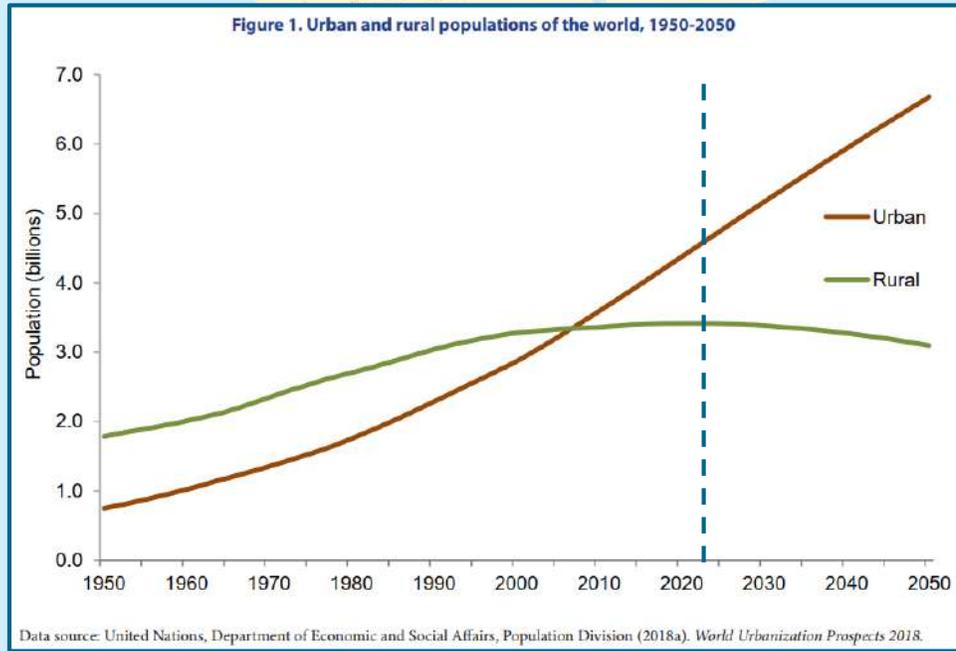
Dr. Marta Sapena-Moll, 27.05.2024



Introduction

Population/km²
(GHS POP, 2015)

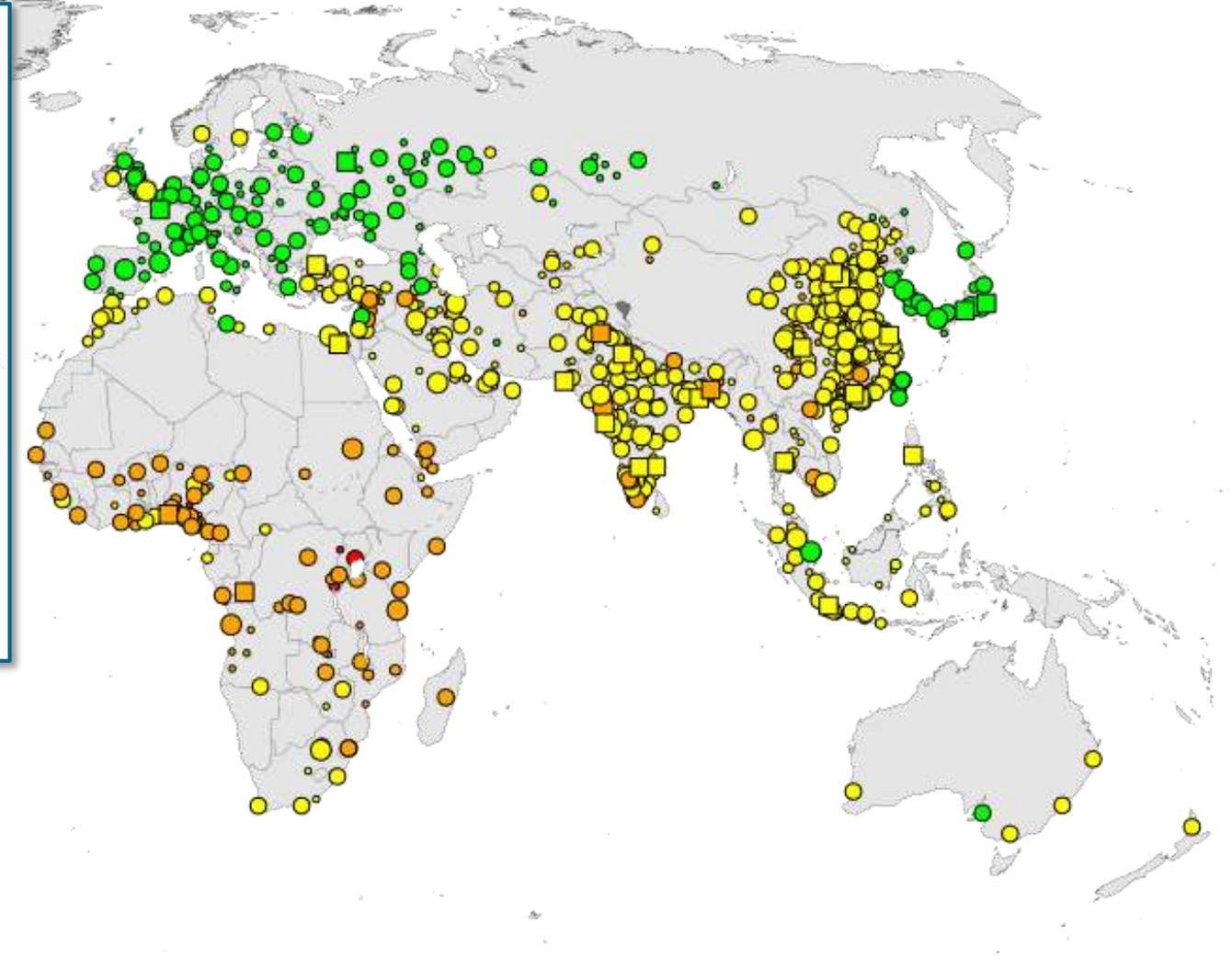
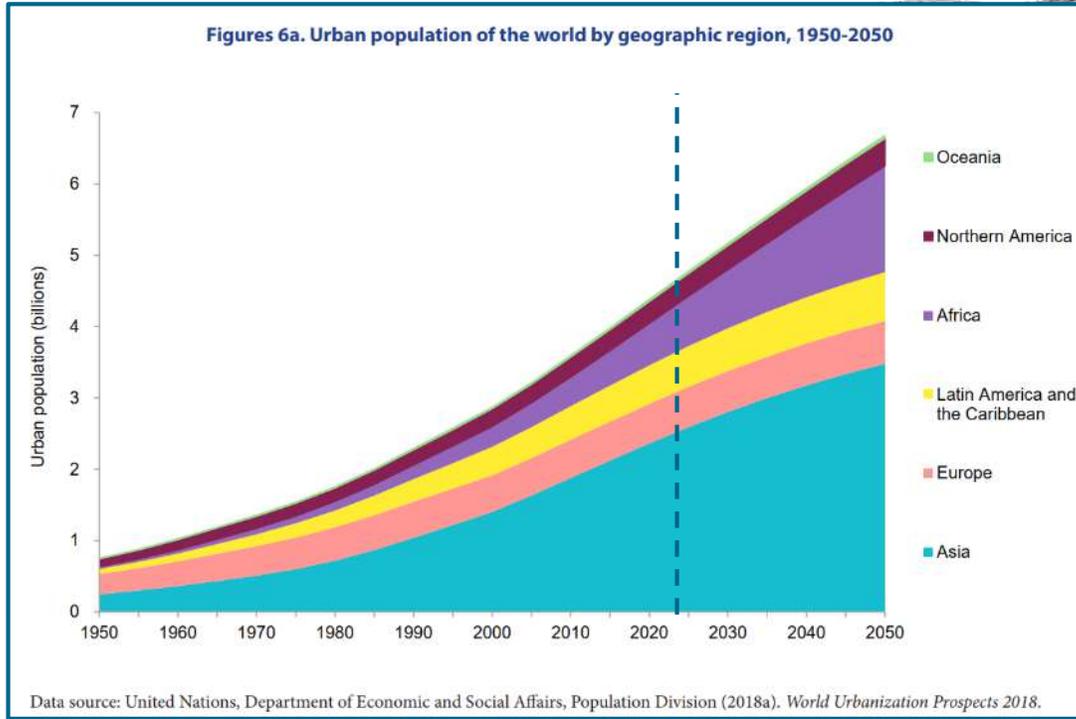
- < 1
- 5
- 25
- 250
- 1000
- >1000



Introduction



2018-2030



Growth Rate

- < 1%
- 1-3%
- 3-5%
- 5%+

City Population in 2018

- 500 to 750 thousand
- 750 to 1000 thousand
- 1 million to 5 million
- 5 million to 10 million
- 10 million or more

- **Challenges** related to the **urbanization process** are reflected by the **Sustainable Development Goals (SDGs)**. E.g., ‘**To end poverty**’ and ‘**to build sustainable cities**’ (SDG 1 & 11).



Introduction

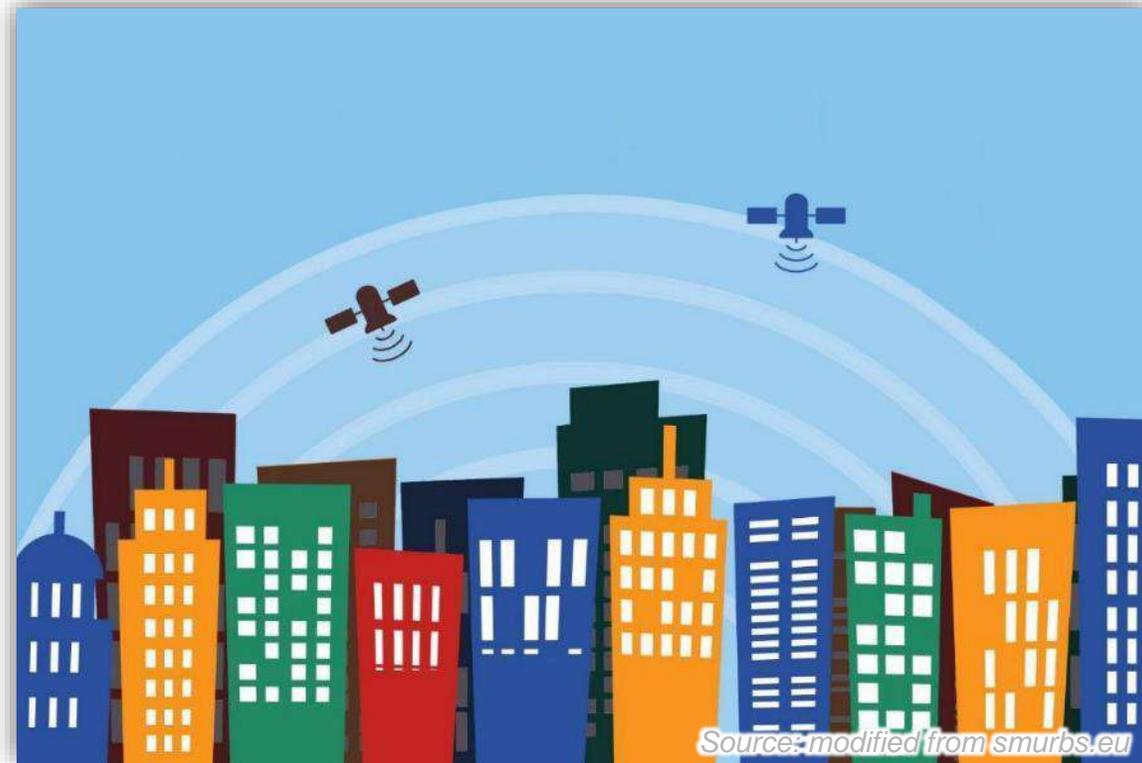
- Studying **urbanization** in the context of **climate and atmospheric pollution** is relevant for several reasons:
 - Greenhouse gas emissions, heat island effect, air quality, energy consumption, water consumption, deforestation, etc.



Introduction



- The Copernicus Sentinel data brings the opportunity to have **large-area**, **cost-free** and **consistent coverage** of **high-resolution** satellite **data** to define useful indicators for localizing and characterizing human settlements.



Source: modified from smurbs.eu

DIY-BU-mapping tool

using Sentinel to map built-up areas over time in Africa

Pre-print (under peer review)



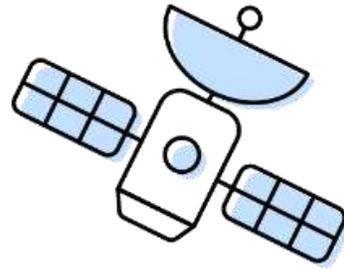
Sapena, M., Mast, J., Schoepfer, E., and Taubenböck, H.: Do-it-Yourself Built-Up Mapping Tool: A Practical Cloud-Based Solution Using Sentinel Imagery for Mapping Urban Expansion in Africa. Available at SSRN: <https://ssrn.com/abstract=4762416>

Objective: to produce 10m-resolution annual maps of built-up areas in Africa using Sentinel-1 and Sentinel-2 data.

Characteristics:

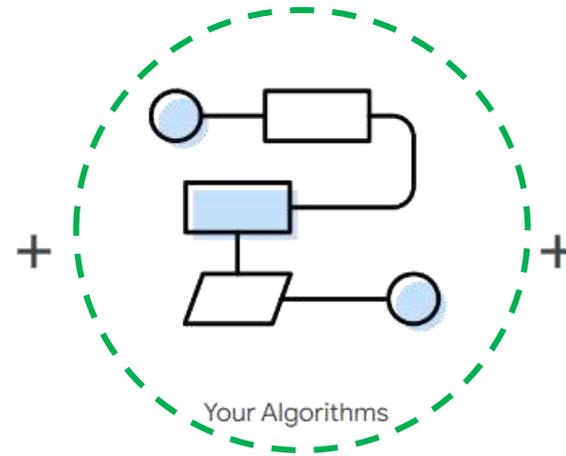
- Cloud computing.
- Application in any area of interest within Africa.
- Automatic (2-step).
- A local model is trained and evaluated for each application (site-specific).
- The results are a map and its accuracy assessment.
- The result can be fine-tuned.

Google Earth Engine: A cloud computing platform

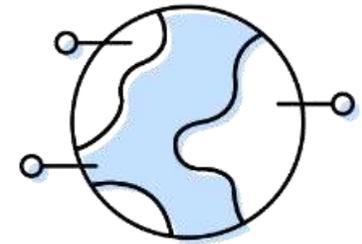


Satellite Imagery

DIY-BU-mapping tool



Your Algorithms



Real World Applications

- The only requirement is to have a google **Gmail account**

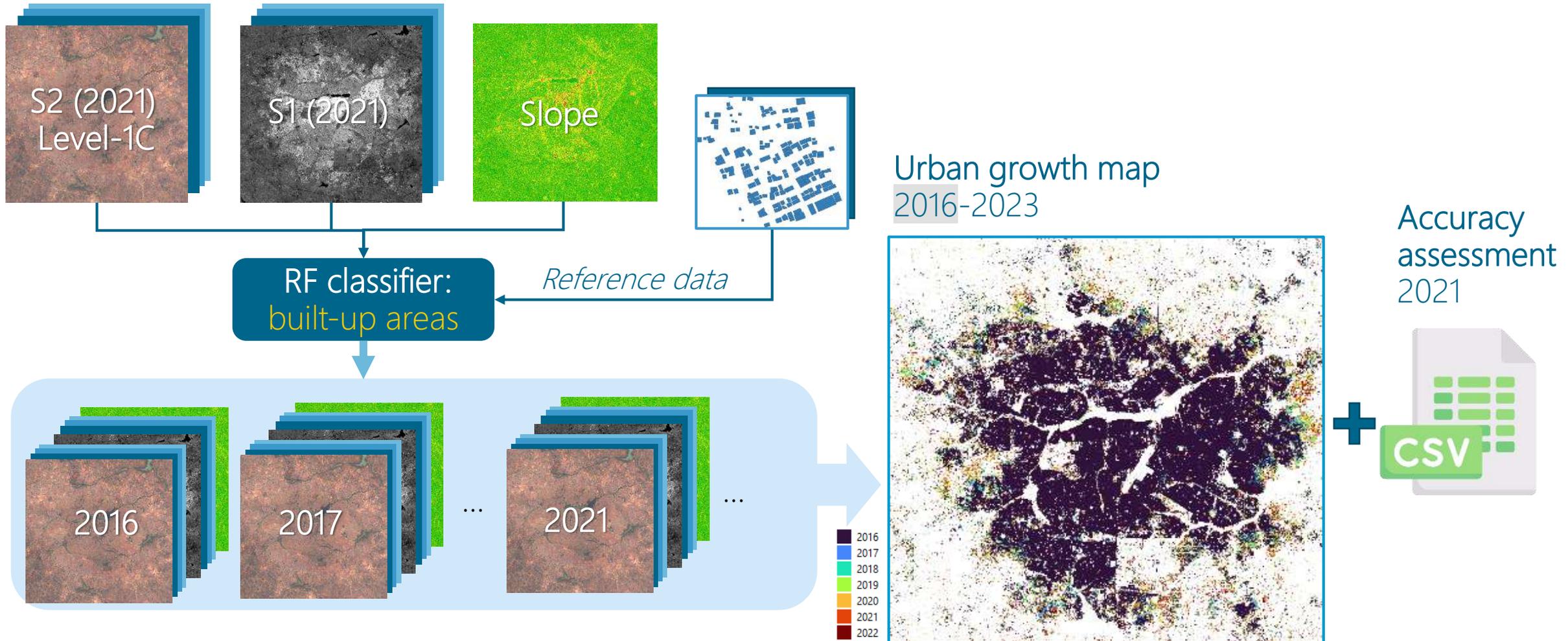


Learn More: <https://earthengine.google.com/>

Methodology



Google Earth Engine



Google Earth Engine: A cloud computing platform



The screenshot shows the Google Earth Engine interface. On the left, a sidebar lists scripts under the user 'diybuiltupmapping'. A red box highlights the script 'DIY_step1_sampling_data'. The main editor displays the code for this script, which includes imports, a description, and a citation. A red box highlights the code area with the label '(2) DIY-BU-mapping tool code'. On the right, the console shows a 'Welcome to Earth Engine!' message. A red box highlights the console area with the label '(3) Running tasks'.

Google Earth Engine

Search places and datasets...

ee-diybuiltupmapping

Scripts Docs Assets

Filter scripts... NEW

Owner (5)

- users/diybuiltupmapping/calibration
- users/diybuiltupmapping/diy_bu_tool
 - DIY_step1_sampling_data
 - DIY_step2_mapping_builtup
 - DIY_viewer

Archive

Examples

DIY_step1_sampling_data

Imports (4 entries)

```
1 //
2 /*
3 Do-It-Yourself Built-Up Mapping Tool (DIY-BU-mapping tool).
4
5 This code belongs to the paper with DOI: http://dx.doi.org/10.2139/ssrn.4762416.
6
7 Citation:
8 Sapena, M., Mast, J., Schoepfer, E., and Taubenböck, H., Do-it-Yourself Built-Up Mapping Tool: A Practical
9 Cloud-Based Solution Using Sentinel Imagery for Mapping Urban Expansion in Africa.
10 Available at SSRN: https://ssrn.com/abstract=4762416
11
12 Please, cite the paper if any part of the code is used or adapted.
13
14 Description
15 -----
16 Part 1: this component allows creating a site-specific sample dataset with built-up/non-built-up areas
17 in Africa using existing datasets ('Open buildings' from Google or 'Building Footprints' from Microsoft
18 depending on the availability).
19 The approach can be transferred to other regions, but it is not the purpose of this code,
20 it is up to the user to test its viability in other regions.
21
22 Optional (fine-tuning): It is possible to add more samples in a selected area to fine-tune
23 the classification if certain areas are not well represented in the maps or the classification is
24 poorly performed.
```

(2) DIY-BU-mapping tool code

Inspector Console Tasks

Use print(...) to write to this console.

Welcome to Earth Engine!
Please use the help menu above (?) to learn more about how to use Earth Engine, or [visit our help page](#) for support.

(3) Running tasks

The screenshot shows a map of the United States and Mexico in Google Earth. The map is centered on the United States, showing major cities and state boundaries. A red box highlights the map area with the label '(4) Map'.

Geometry Imports

Map Satellite

(4) Map

Google

Keyboard shortcuts | Map data ©2024 Google, INEGI | 500 km | Terms

Google Earth Engine: running DIY-BU-mapping



1 . Generating sample data - AOI

The screenshot shows the Google Earth Engine interface. The top navigation bar includes the Google Earth Engine logo, a search bar, and the user profile 'ee-diybuiltupmapping'. The left sidebar shows a tree view of scripts, with 'DIY_step1_sampling_data' highlighted in a red box. The main editor displays a script titled 'DIY_step1_sampling_data *' with the following content:

```
1 // -----  
2 /*  
3 Do-It-Yourself Built-Up Mapping Tool (DIY-BU-mapping tool).  
4  
5 This code belongs to the paper with DOI: http://dx.doi.org/10.2139/ssrn.4762416.  
6  
7 Citation:  
8 Sapena, M., Mast, J., Schoepfer, E., and Taubenböck, H., Do-it-Yourself Built-Up Mapping Tool: A Practical  
9 Cloud-Based Solution Using Sentinel Imagery for Mapping Urban Expansion in Africa.  
10 Available at SSRN: https://ssrn.com/abstract=4762416  
11  
12 Please, cite the paper if any part of the code is used or adapted.  
13  
14 Description  
15 -----  
16 Part 1: this component allows creating a site-specific sample dataset with built-up/non-built-up areas  
17 in Africa using existing datasets ('Open buildings' from Google or 'Building Footprints' from Microsoft  
18 depending on the availability).  
19 The approach can be transferred to other regions, but it is not the purpose of this code,  
20 it is up to the user to test its viability in other regions.  
21
```

The right sidebar shows the 'Inspector' and 'Console' tabs. The console displays the output of the script:

```
Use print(...) to write to this console.  
  
AOI, and CRS: JSON  
CapeTown JSON  
EPSG:4326 JSON
```

The screenshot shows the Google Earth map interface. A red polygon is drawn over the Cape Town area, representing the Area of Interest (AOI). The map shows various geographical features and labels, including Philadelphia, Wellington, Worcester, Rawsonville, Nuy, Koo, Goedgemoed, Paarl, Brandvlei, Voorspoed, Robertson, Montagu, Ashton, Spes Bona, Goedgeloof, Scheepersrus, Bonnivaale, Bruintjiesrivier, Swellendam, Suurbroek, Stormsvlei, Greyton, Riviersonderend, Proteem, Klipdale, Spitskop, Malgas, Ouplaas, Pringle Bay, Kleinmond, Hermanus, and False Bay. The AOI is a red polygon covering the Cape Town area, with labels for Cape Town, Stellenbosch, Raithby, and False Bay. The map is titled 'cape_town (1 poly)' and 'Rectangle drawing.' is visible in the top right corner. A red box highlights the map area.

Drawing an Area of Interest (AOI)
or uploading a .shp file with the AOI

Google Earth Engine: running DIY-BU-mapping



1. Generating sample data

The screenshot shows the Google Earth Engine interface. The main editor displays a JavaScript script for generating sample data. The script includes comments and code for setting variables like `aoi_geom`, `aoi_name`, `country`, and `aoi_crs`. The `Run` button is highlighted in red. To the right, the `Tasks` panel shows two submitted tasks: `aoi_CapeTown` (completed in <1m) and `sample_bu_lc_CapeTown` (completed in 10m). Red annotations highlight the `Run` button and the task list, with text explaining the actions: "Run the code!", "Set the geometry and a name to your AOI", "Reference data created...", "OP: Set the country", and "OP: Set the CRS".

```
45 /* Change the 'aoi_geom' name if necessary based on the given name of the new geometry, and set a label to 'aoi_
46
47 var aoi_geom = cape_town;
48 var aoi_name = 'CapeTown';
49
50 /*
51 OPTION 2 Loading the AOI from shape file in 'Assets'
52 Change the variables "shp_name", "feature_id", and "feature_name" to match the shape file.
53 Where "shp_name" is the name of the file in Assets with the AOI, "feature_id" is the field name with th
54 and "feature_name" is the id or name of the geometry with the AOI within the shape file.
55 Uncomment lines by removing "/*"
56 */
57
58 //var shp_name = "AOI_test_sites_100";
59 //var feature_id = "IDEN";
60 //var feature_name = "ID_057";
61 //var feature_aoi = ee.FeatureCollection(ee.data.listBuckets('projects/earthengine-legacy').assets[0].id + "/" +
62 //var aoi_geom = feature_aoi.geometry();
63 //var aoi_name = feature_name;
64
65 /* Note: if the country is one of following, copy and paste as it is in "country" field. Otherwise leave it emp
66 | | | (These countries do not have data from Google Building but have data from Microsoft buildings).
67
68 Countries: "Chad", "Libya", "Mali", "Morocco"
69
70 */
71
72 var country = "";
73
74 /* Coordinate reference system (default: 4326 WGS89)*/
75 var aoi_crs = 'EPSG:4326';
76
```

The screenshot shows the Google Earth map interface. A red polygon is drawn over the Cape Town area, labeled "cape_town (1 poly)". The map shows various geographical features and place names, including Cape Town, Stellenbosch, and False Bay. The interface includes a toolbar with drawing tools and a search bar.

Google Earth Engine: running DIY-BU-mapping



2. Mapping

The screenshot displays the Google Earth Engine web interface. The main editor shows a JavaScript script named `DIY_step2_mapping_builtup`. A red box highlights the `Run` button in the top toolbar, with the text "Run the script!" next to it. Another red box highlights the line `var aoi_name = 'CapeTown';` in the script, with the text "Set the same name as before" next to it. The left sidebar shows a tree view of scripts, with `DIY_step2_mapping_builtup` selected. The right sidebar shows the `Tasks` panel, which lists submitted tasks. A red box highlights the task `diy_bu_map_CapeTown` with a status of "Completed" and a runtime of "2h". Below this, a blue box highlights the task details, including the ID `36K2NITUYPOLIIZ77DC5WAD`, phase `Completed`, runtime `2h` (started 2024-05-24 11:03:06 +0200), and batch compute usage `4208891.0000`. Two buttons, `Source Script` and `Open in Drive`, are also highlighted with red boxes. At the bottom of the interface, a map of Cape Town and Stellenbosch is visible, showing the geographical context of the mapping task.

Google Earth Engine: running DIY-BU-mapping



3 . Download results

The screenshot shows the Google Drive interface. The file 'diy_bu_map_Cape_town.tif' is selected. A context menu is open over the file, with the 'Descargar' (Download) option highlighted by a red box. The word 'Download' is written in red text to the right of the box. The file name 'diy_bu_map_Cape_town.tif' is also highlighted in red in the file list. The word 'Map' is written in red above the file name, and 'Accuracy' is written in red below it. The context menu options include: Vista previa, Abrir con, Compartir, Obtener enlace, Añadir acceso directo a Drive, Mover a, Añadir a Destacados, Cambiar nombre, Ver detalles, Gestionar versiones, Hacer una copia, Descargar, and Quitar.

Nombre	Última ...
diy_bu_map_Cape_town.tif	22:33
RF_summary_AOI_Cape_town.csv	21:17

Map
Accuracy

Download

Open map in QGIS:
A Free and Open Source Geographic Information System



Google Earth Engine: running DIY-BU-mapping



4 . Open result in GEE

The screenshot illustrates the workflow in Google Earth Engine (GEE) to upload and run a script. It is divided into four numbered steps:

- 1**: In the top-left navigation menu, the **NEW** button is highlighted in yellow.
- 2**: The **Upload a new image asset** dialog is open. The **SELECT** button is highlighted in yellow.
- 3**: The **SUBMITTED TASKS** panel shows a task named **Ingest image: "projects/eart..."** with a status of **<1m**.
- 4**: The **Scripts** panel shows a tree view of folders. The folder **DIY_viewer** is highlighted with a red box. Below it, the script editor for **DIY_viewer** is open. The line `var map_name = 'diy_bu_map_CapeTown';` is highlighted with a red box, with the text **Set the name** next to it. At the bottom of the script editor, the **UPLOAD** button is highlighted in yellow.

```
10 Available at SSRN: https://ssrn.com/abstract=4762416
11
12 Please, cite the paper if any part of the code is used or adapted.
13
14 Description
15 -----
16 This script is use to visualize the result from the second component 'DIY_step2_mapping_builtup'.
17 First, download the map, and second, upload it as an Asset.
18
19 Author: Marta Sapena
20
21 Contact: diybuiltupmapping@gmail.com
22
23 Last modified: 11/01/2024
24
25 */
26 //-----
27
28 // Background
29 Map.setOptions('Satellite');
30
31 // Load map
32 var map_name = 'diy_bu_map_CapeTown';
33
34 var diy_bu_map = ee.Image(ee.data.listBuckets('projects/earthengine-legacy').assets[0].id + "/" + map_name);
35
36 // Color pallete for urban growth
37 var urban_growth = {min: 2016 , max : 2022, palette : [
38 'b10026', // 2016
```

Google Earth Engine: running DIY-BU-mapping



4 . Open result in GEE

5





Built-up

- 2016
- 2017
- 2018
- 2019
- 2020
- 2021
- 2022



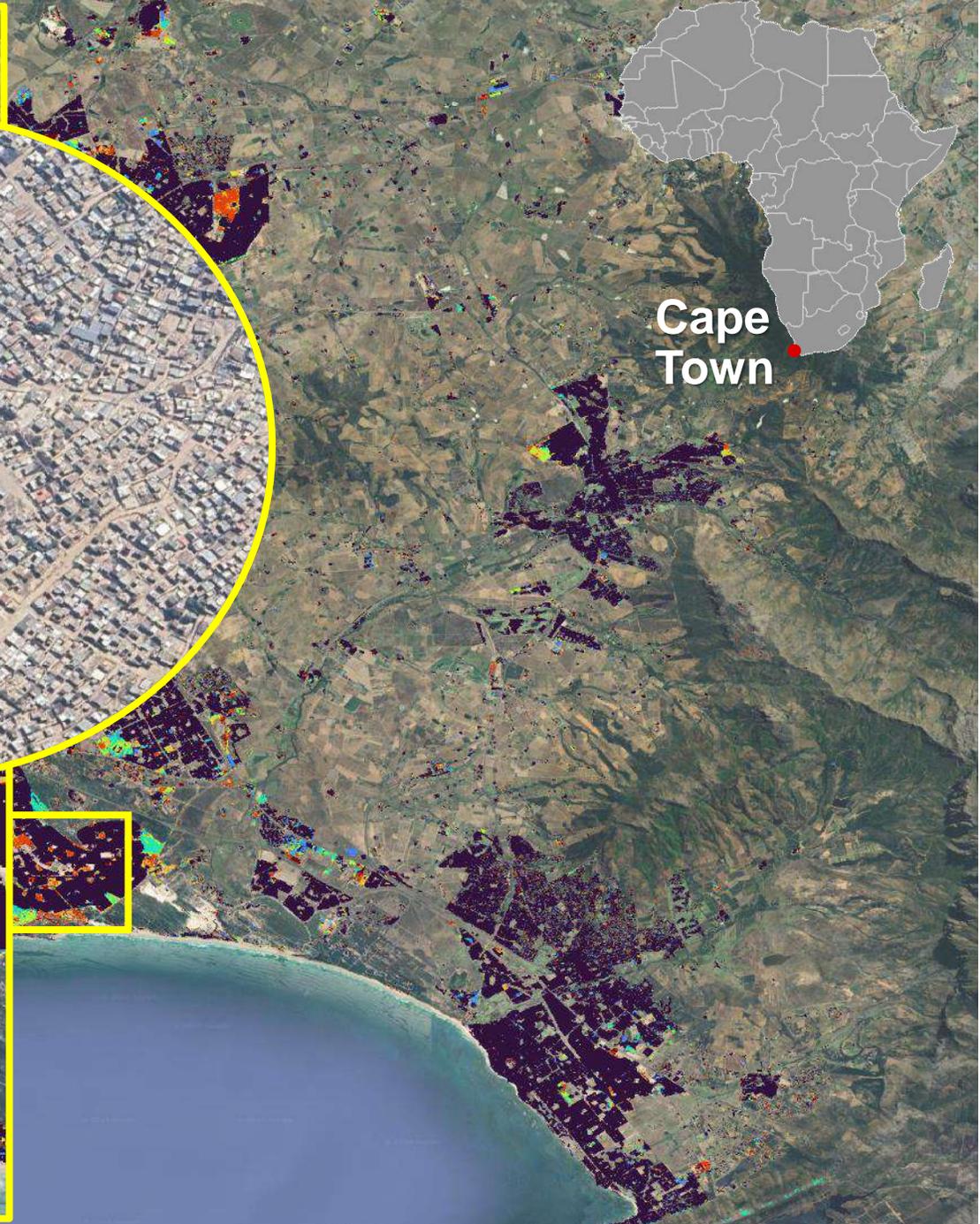
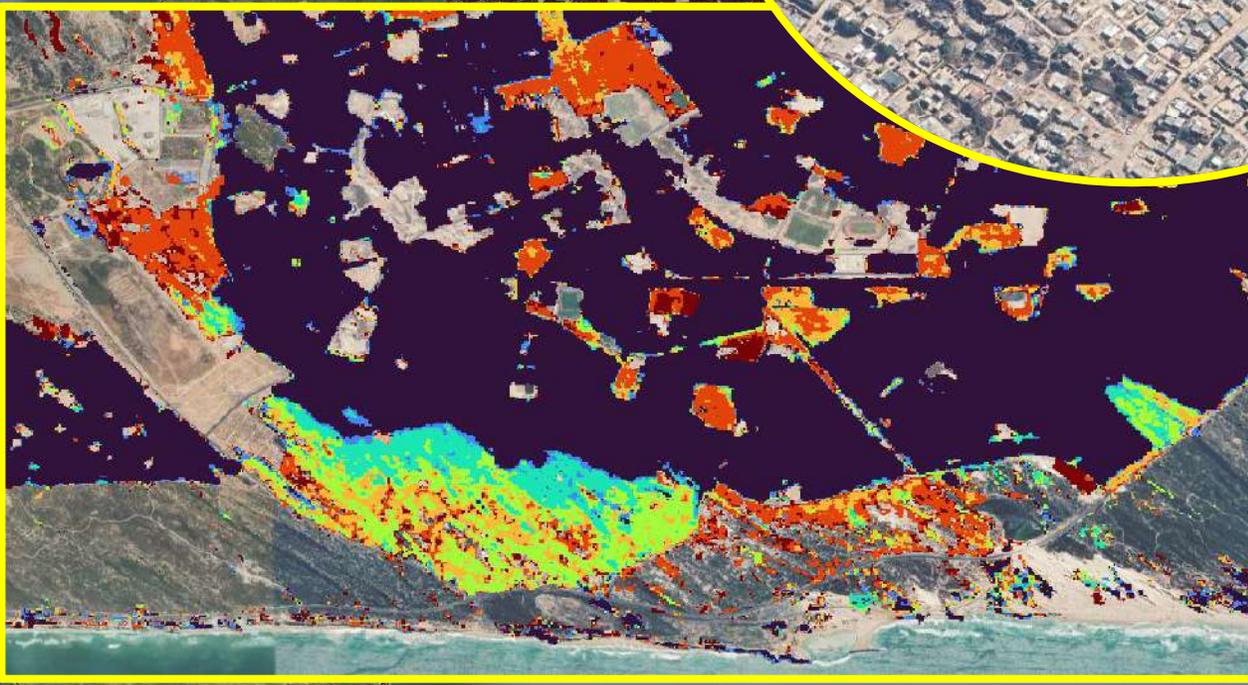
Cape
Town

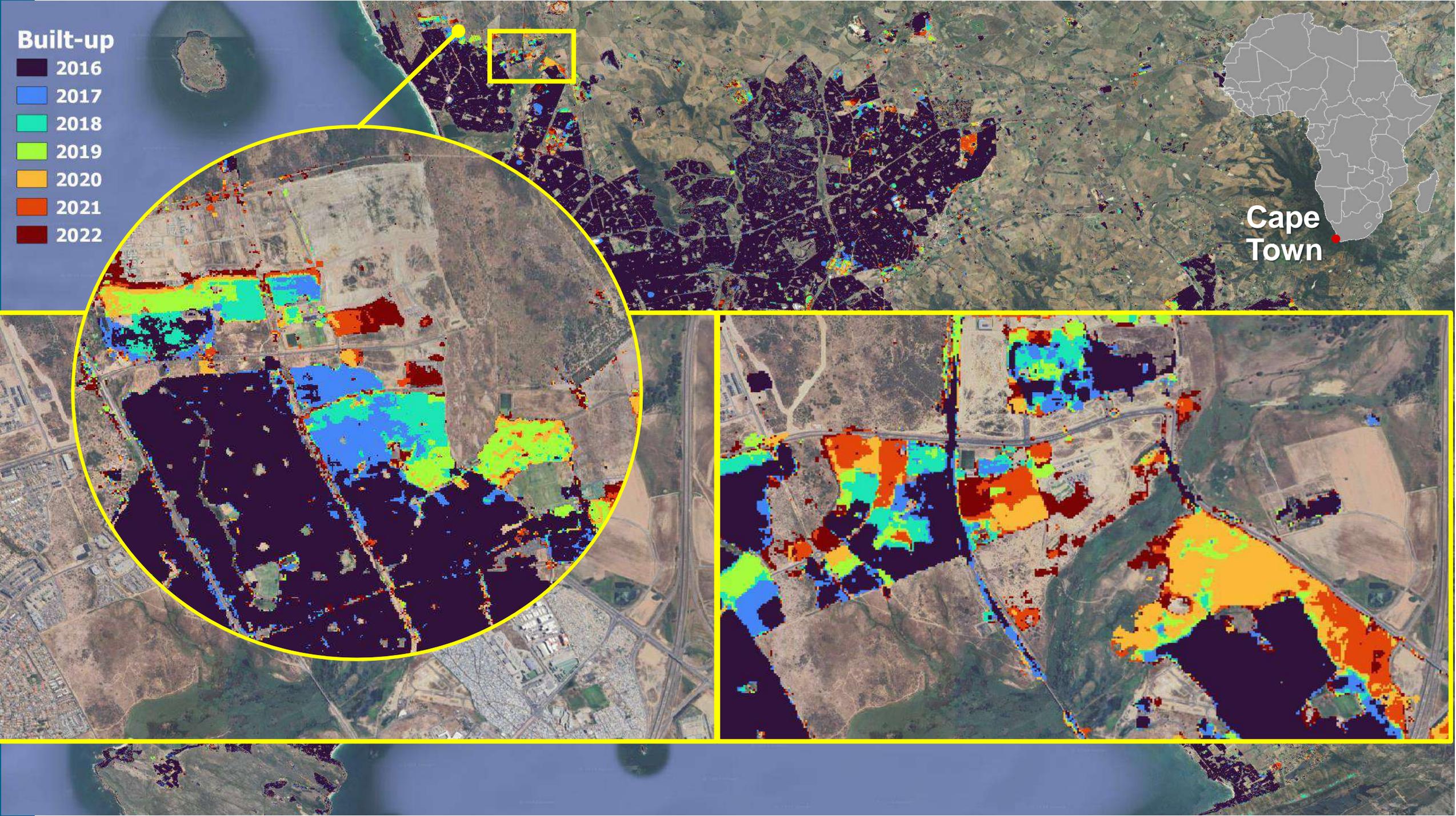
Built-up

- 2016
- 2017
- 2018
- 2019
- 2020
- 2021
- 2022



Cape
Town





Built-up

- 2016
- 2017
- 2018
- 2019
- 2020
- 2021
- 2022



Cape
Town

Google Earth Engine: running DIY-BU-mapping



5. Improving results

The screenshot displays the Google Earth Engine web interface. The top navigation bar includes the Google Earth Engine logo and a search bar. Below the navigation bar, there are tabs for 'Scripts', 'Docs', and 'Assets'. The 'Scripts' tab is active, showing a script named 'step1_sampling_data'. The code editor displays the following code:

```
54 var crs_aoi = 'EPSG:4326';
55
56 /* 4. Optional: Fine-tuning. Set the name of the fine-tuning polygons in li
57
58 // set the name of the fine-tuning polygons if drawn, otherwise leave the lin
59 //var geometry_FT = ee.Geometry.MultiPolygon();
60 var geometry_FT = geometry_FT;
61
62 /*Other parameters: */
63 var n_samples = 50000;
64 var n_samples_FT = 10000;
65
66
```

The line `var geometry_FT = geometry_FT;` is highlighted with a red box and labeled 'Activate line'. The right sidebar shows the 'Inspector' and 'Console' tabs. The 'Console' tab displays the message: 'Search or cancel multiple tasks in the Task Manager'. Below this, there is a list of 'SUBMITTED TASKS' with columns for task name, status, and duration:

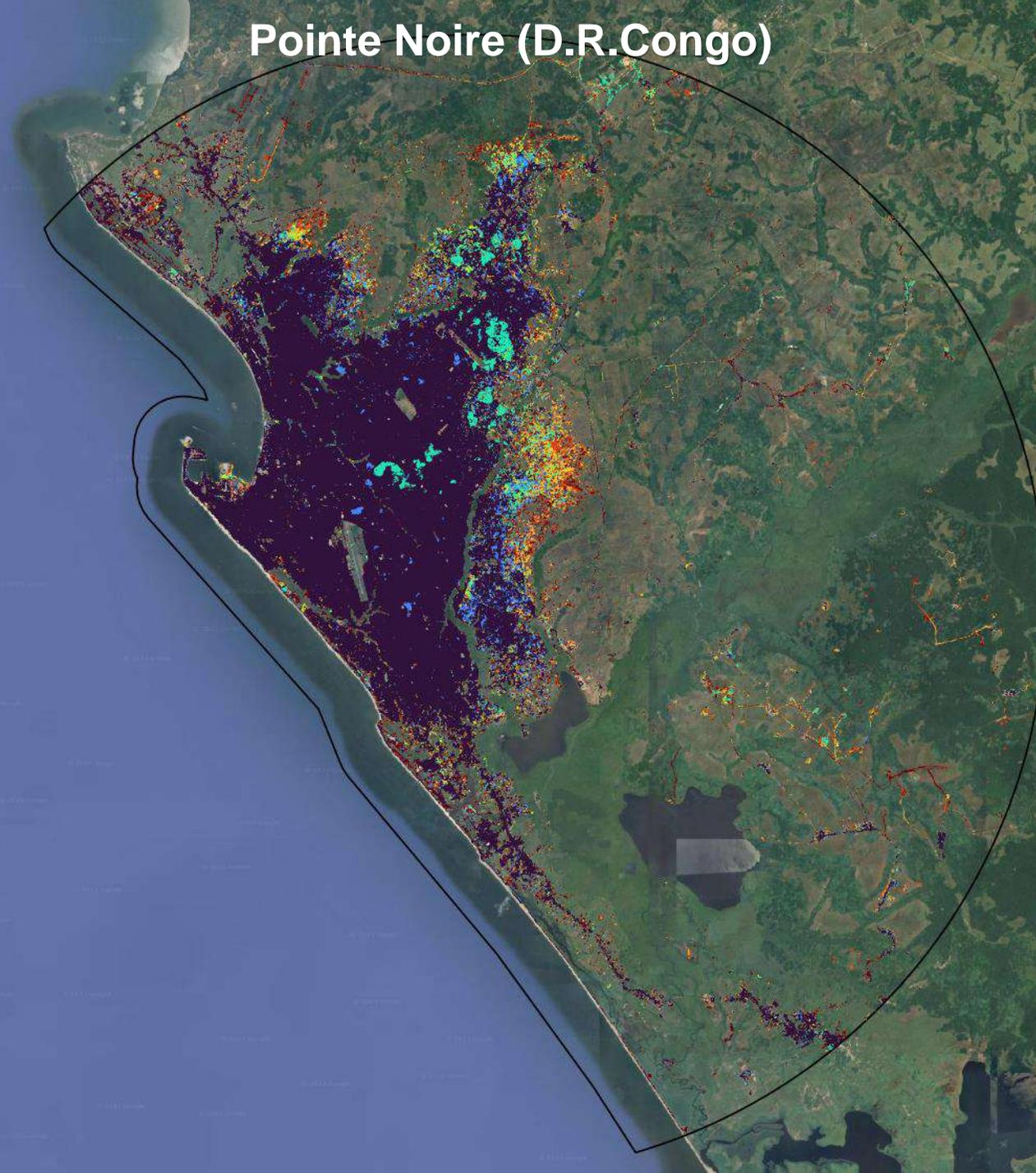
Task Name	Status	Duration
sample_bu_lc_Cape_to...	Running	1m
diy_bu_map_Cape_town	Completed	2h
RF_summary_AOI_Cape...	Completed	42m
diy_bu_map_Cape_town	Completed	2h

The bottom part of the screenshot shows a satellite map of Cape Town, South Africa. A 'Layers' panel is open on the left, showing a list of layers under 'Geometry Imports':

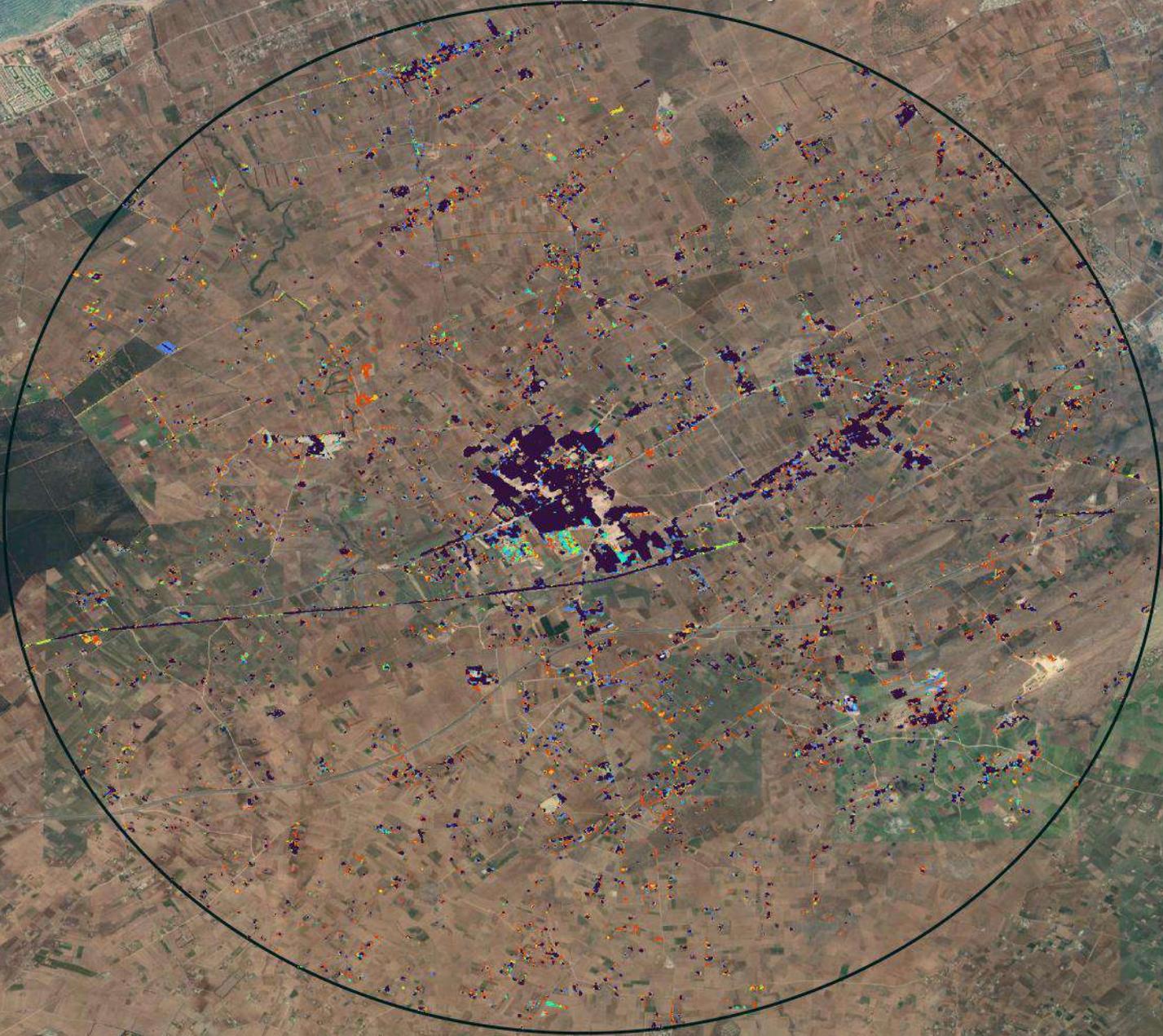
- geometry (1 poly)
- geometry_FT (5 polys)

The 'geometry_FT (5 polys)' layer is highlighted with a red box. Below the map, there is a red text annotation: 'Draw polygons to improve'. The bottom status bar shows 'Google', 'Keyboard shortcuts', 'Imagery ©2023 TerraMetrics', '20 km L', and 'Terms of Use'.

Pointe Noire (D.R.Congo)



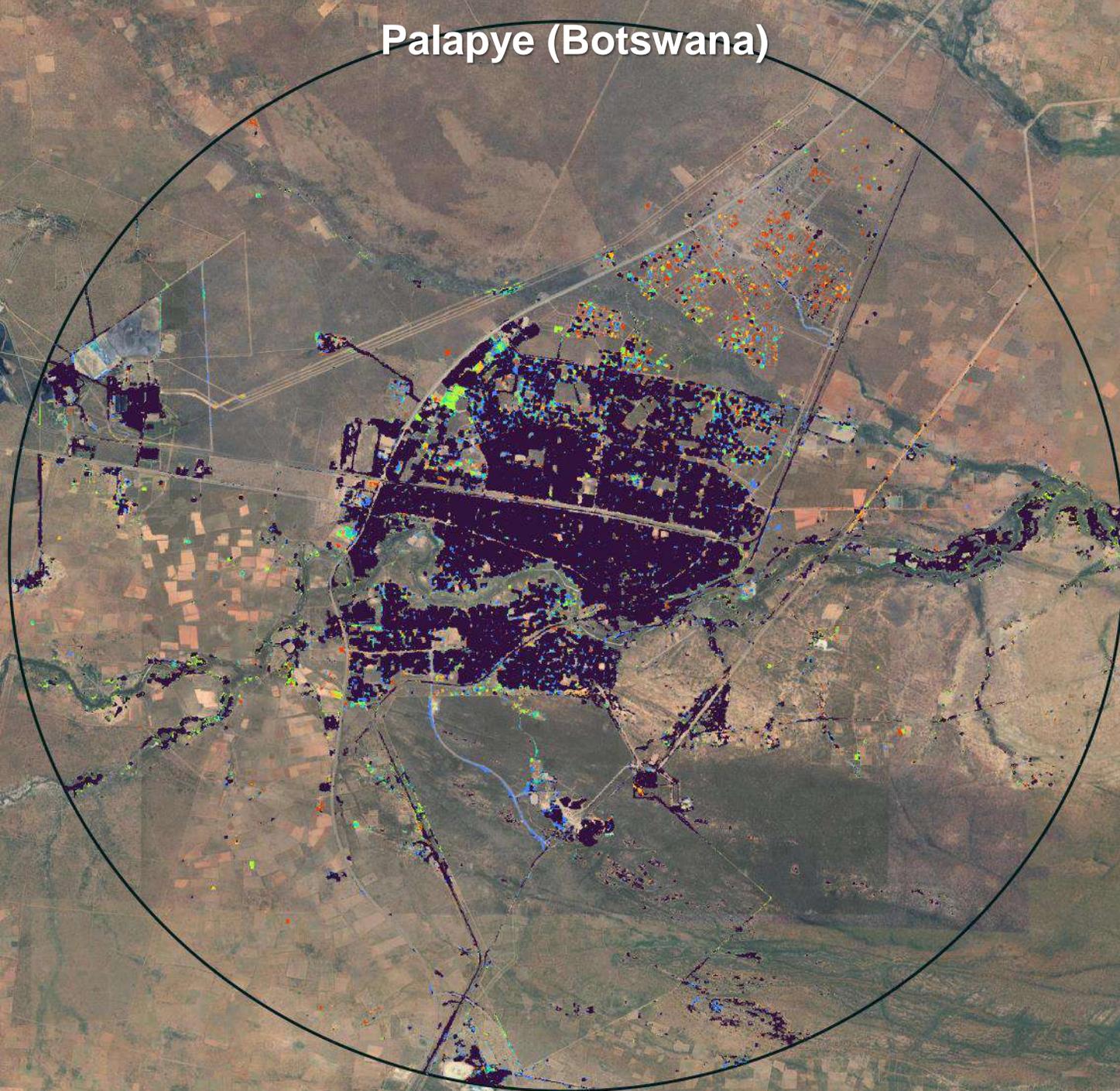
Bir Jdid (Marocco)



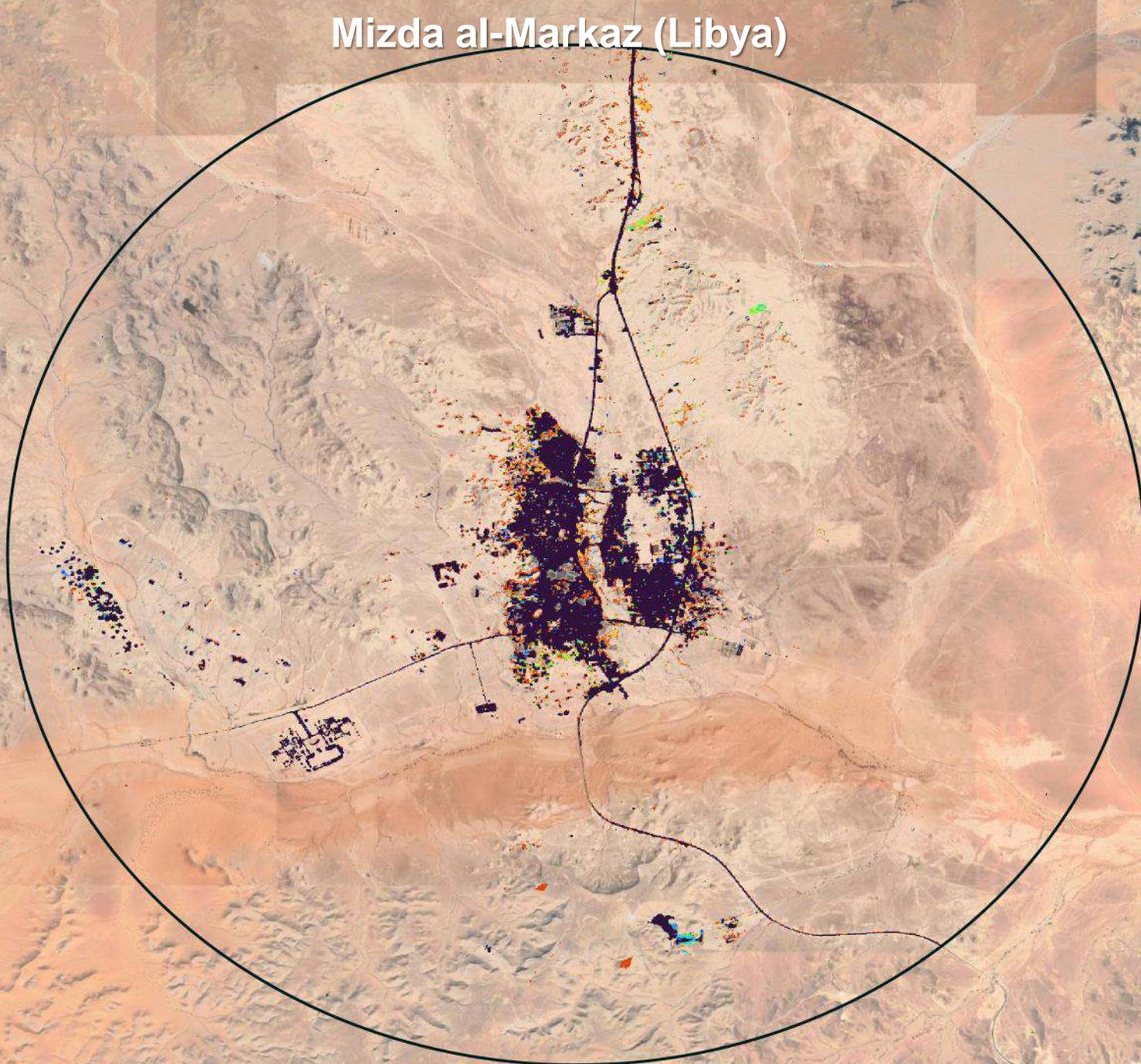
Palapye (Botswana)



- 2016
- 2017
- 2018
- 2019
- 2020
- 2021
- 2022



Mizda al-Markaz (Libya)



- 2016
- 2017
- 2018
- 2019
- 2020
- 2021
- 2022

Applications

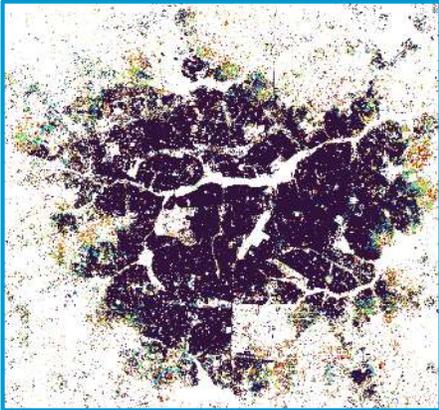
using the DIY-BU-mapping tool

- (1) Long-term urban growth mapping
- (2) Comparison of urban expansion in 300 cities (2000-2021)

(1) Long-term urban growth mapping



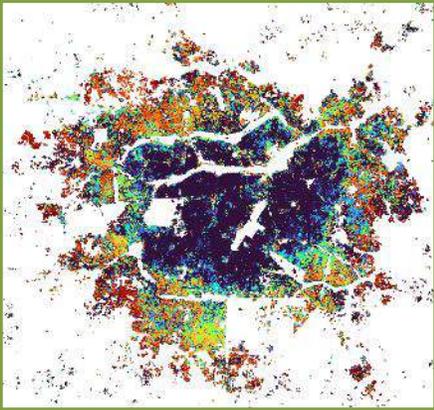
Urban growth
2016-2022



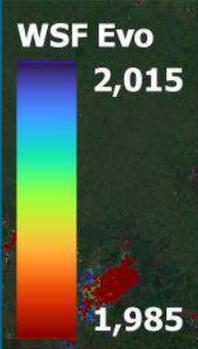
2016 2022



WSF Evo
1985-2015



1985 2015

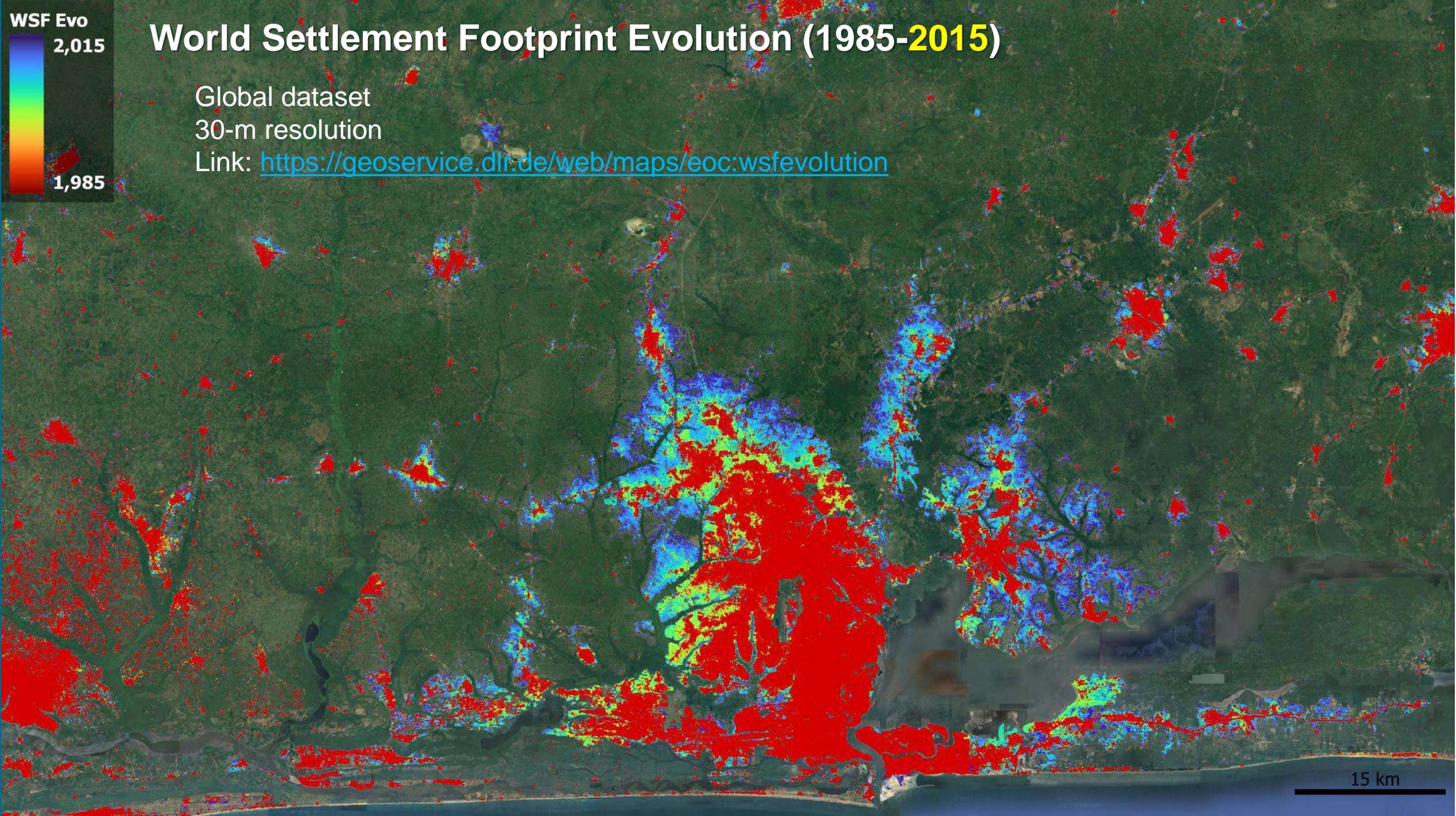


World Settlement Footprint Evolution (1985-2015)

Global dataset

30-m resolution

Link: <https://geoservice.dlr.de/web/maps/eoc:wsfevolution>

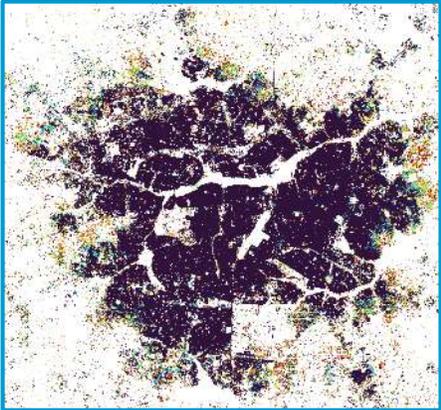


15 km

(1) Long-term urban growth mapping



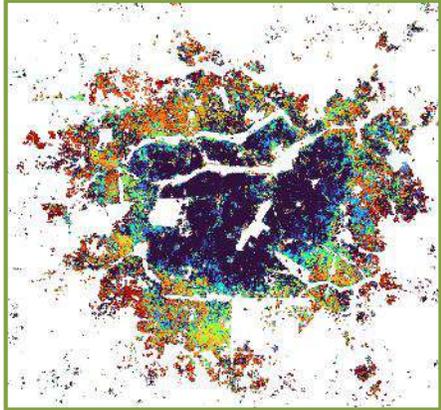
Urban growth
2016-2022



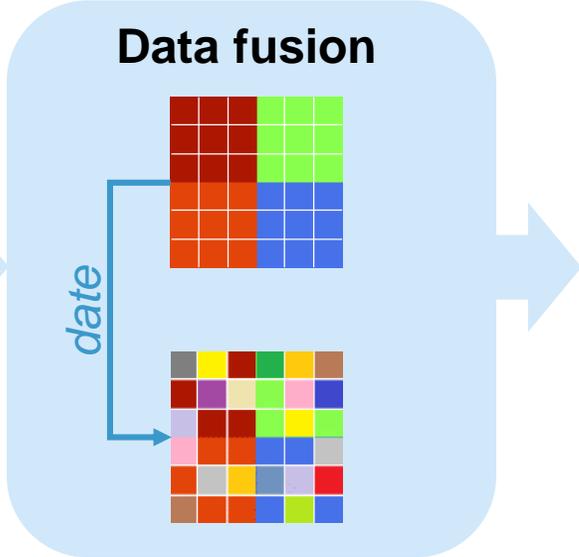
2016 2022



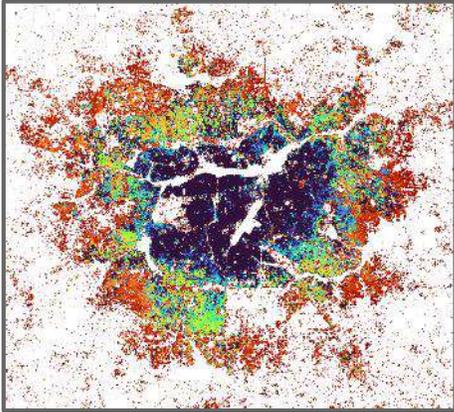
WSF Evo
1985-2015



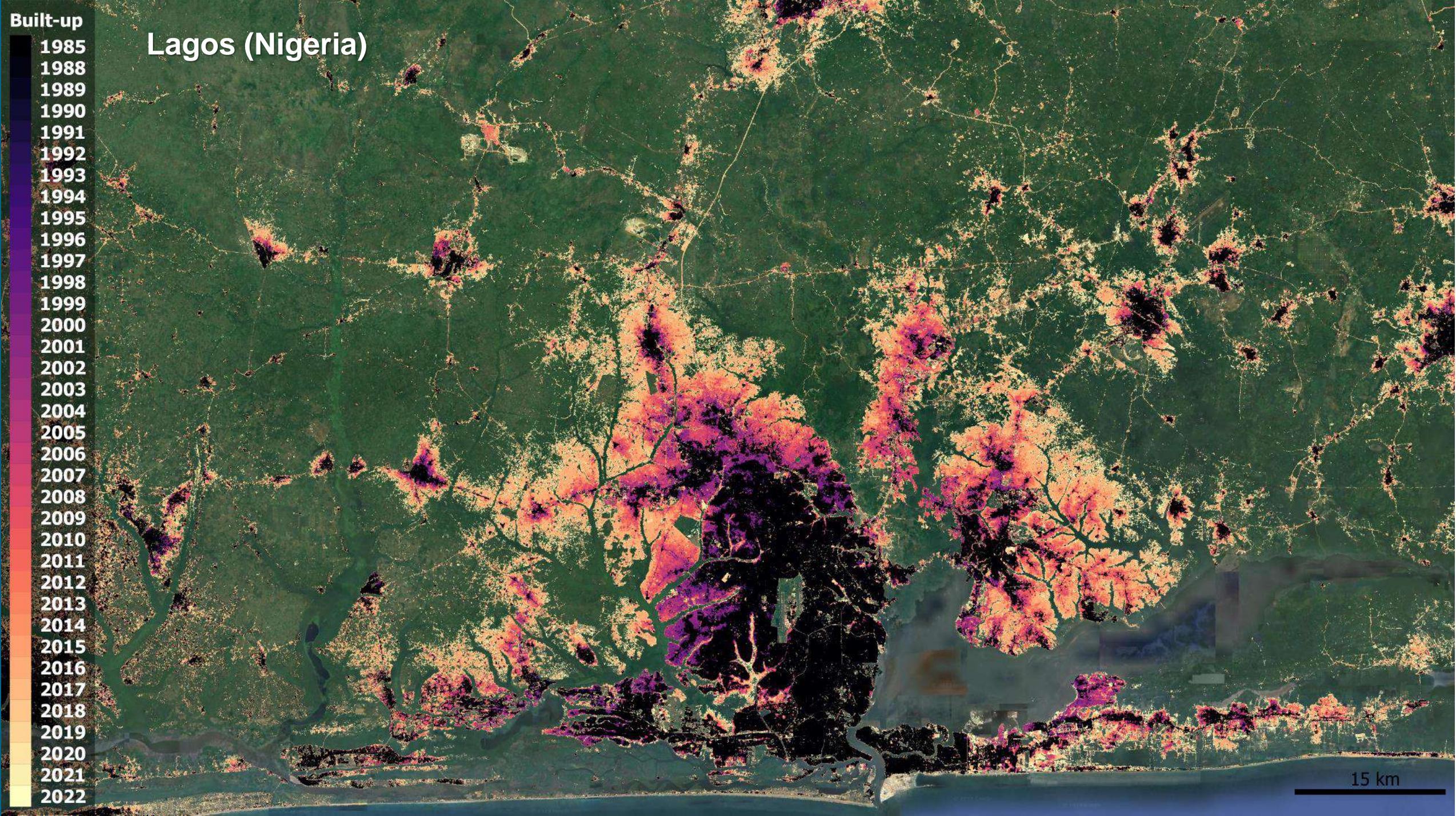
1985 2015



Long-term
urban growth
1985-2022



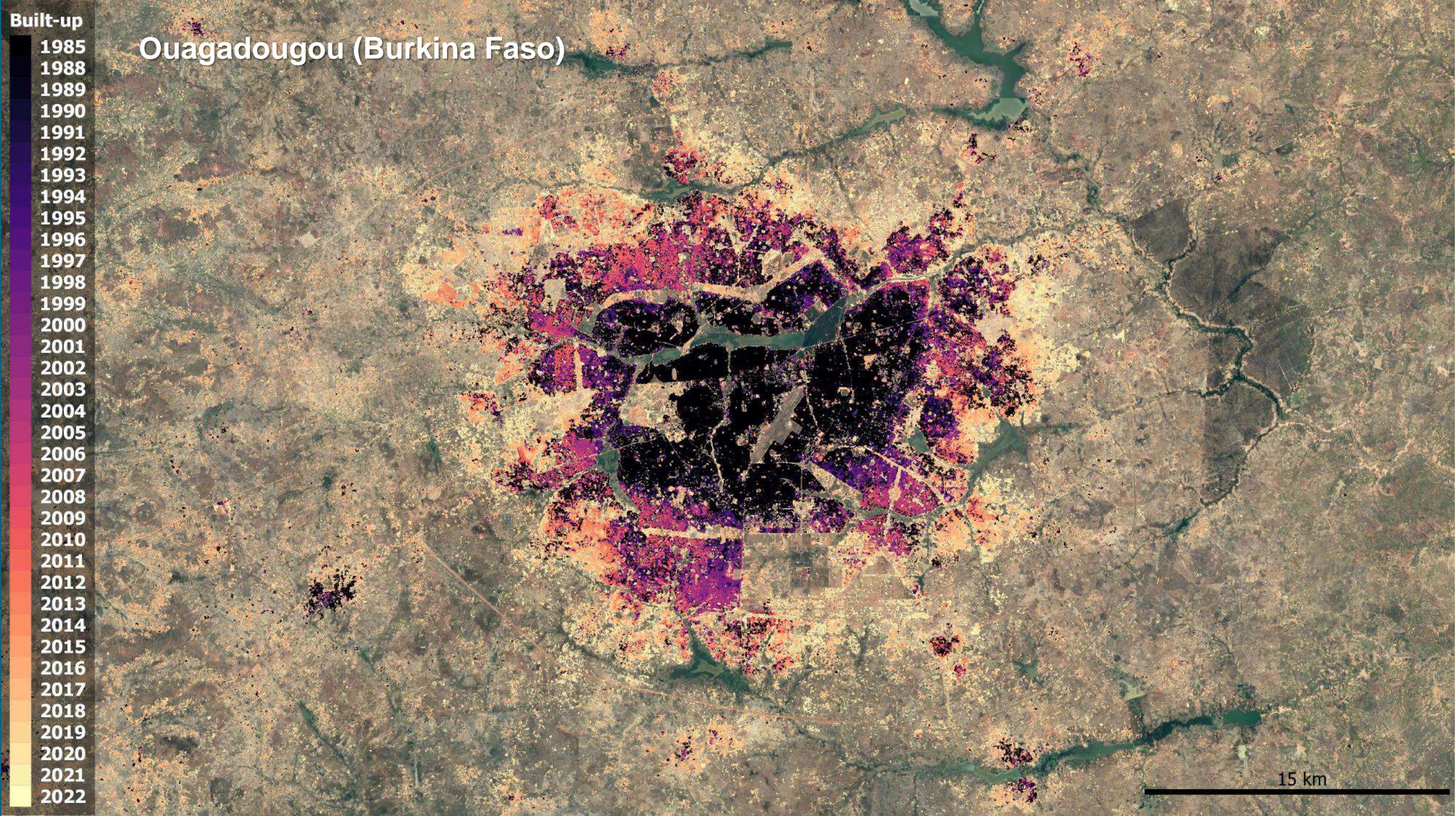
1985 2022



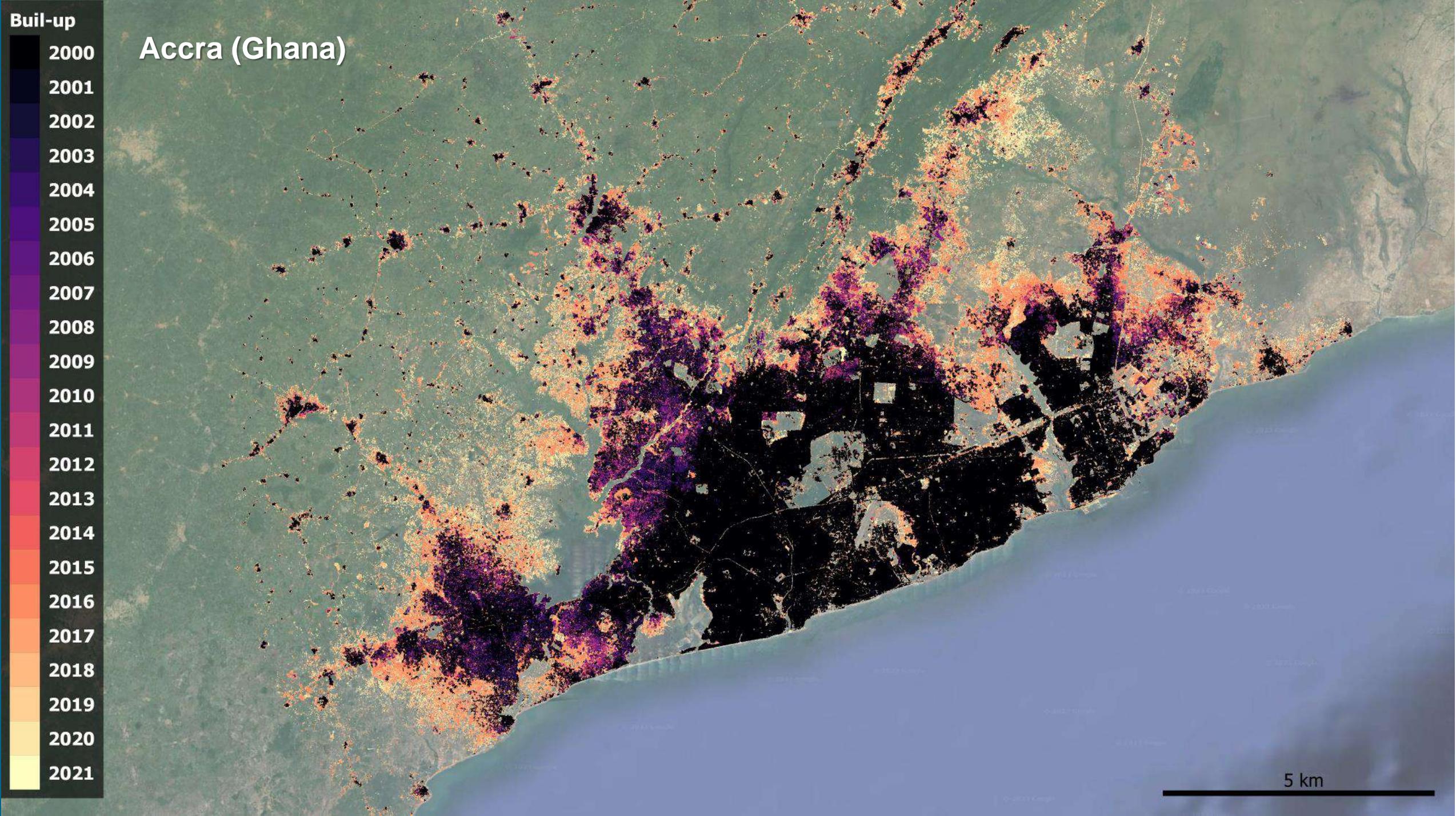
Built-up

Ouagadougou (Burkina Faso)

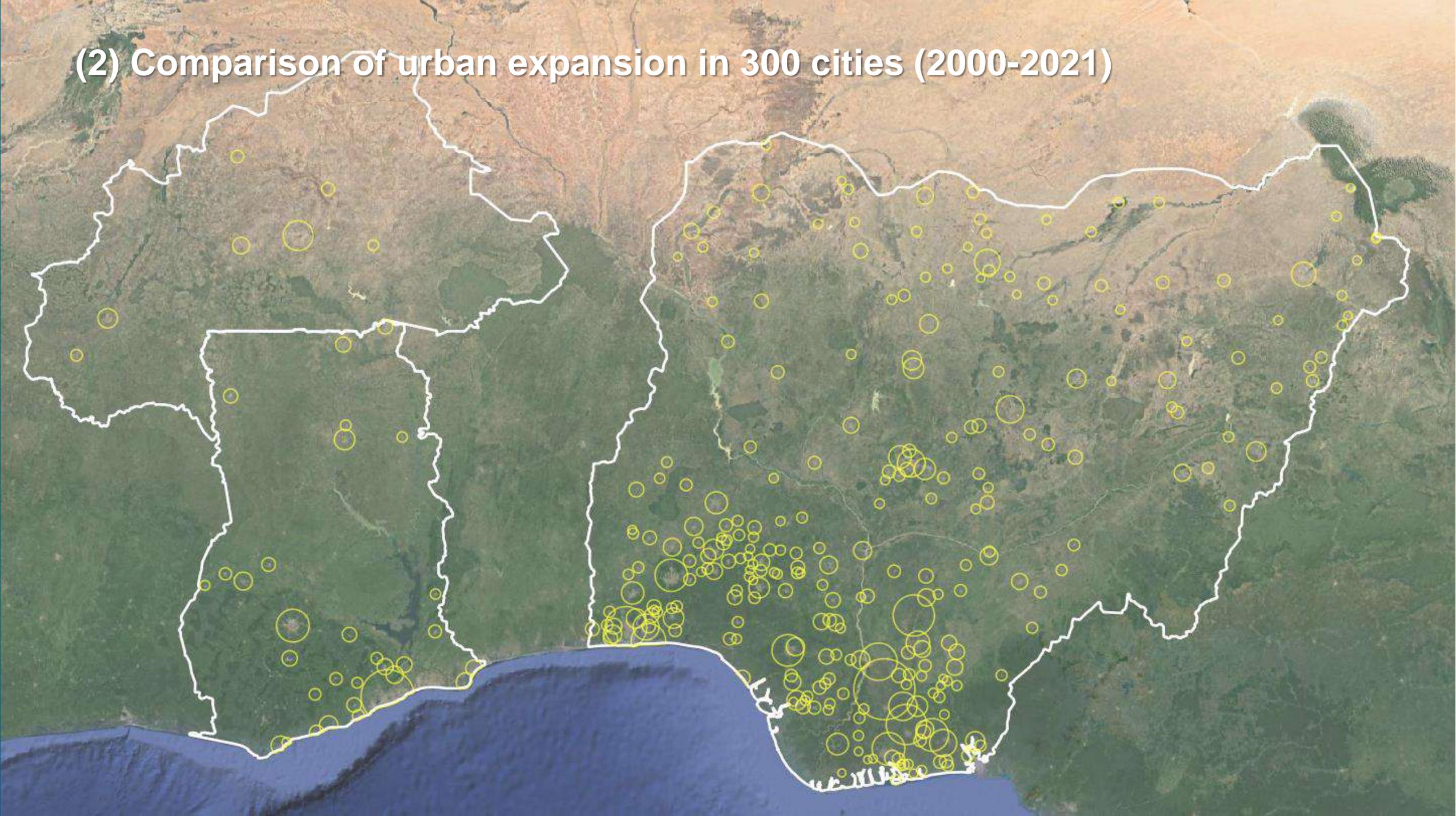
- 1985
- 1988
- 1989
- 1990
- 1991
- 1992
- 1993
- 1994
- 1995
- 1996
- 1997
- 1998
- 1999
- 2000
- 2001
- 2002
- 2003
- 2004
- 2005
- 2006
- 2007
- 2008
- 2009
- 2010
- 2011
- 2012
- 2013
- 2014
- 2015
- 2016
- 2017
- 2018
- 2019
- 2020
- 2021
- 2022



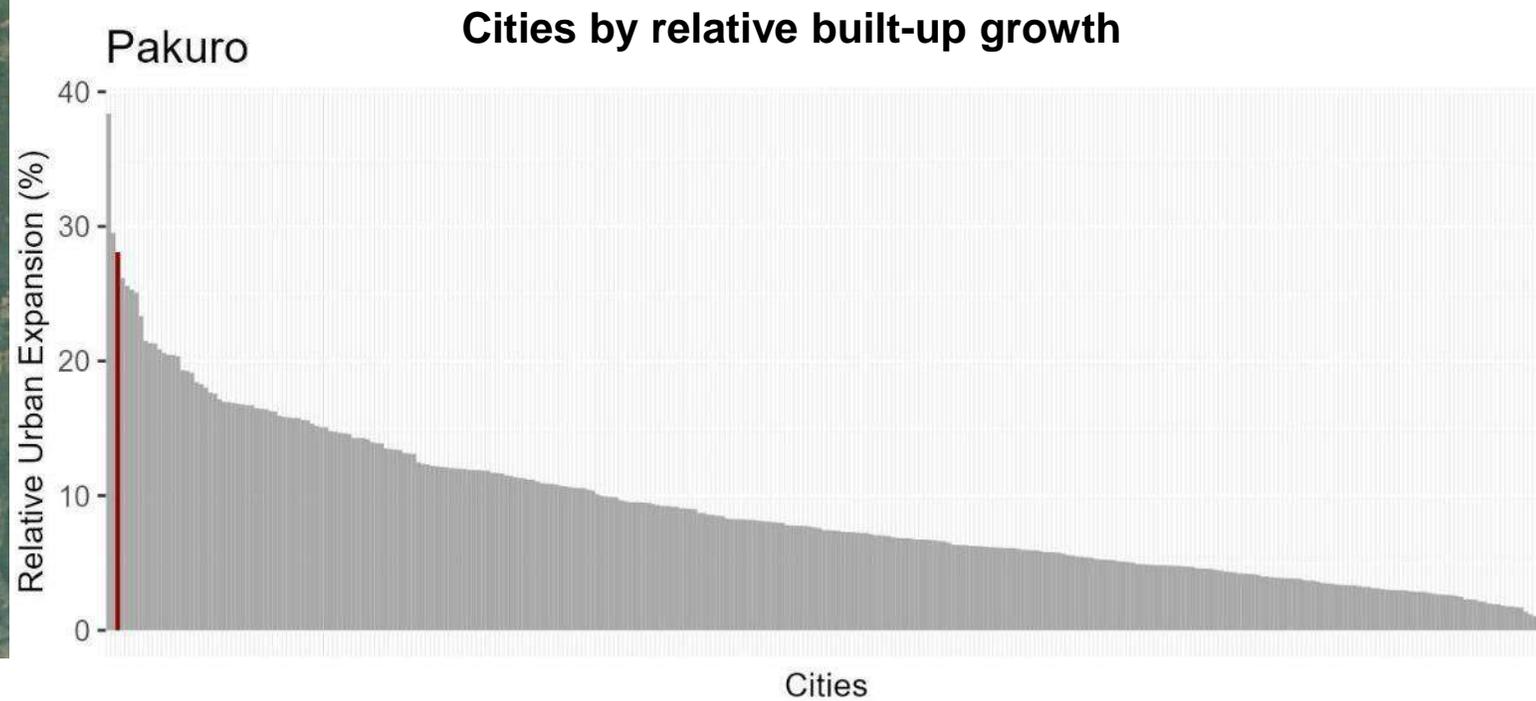
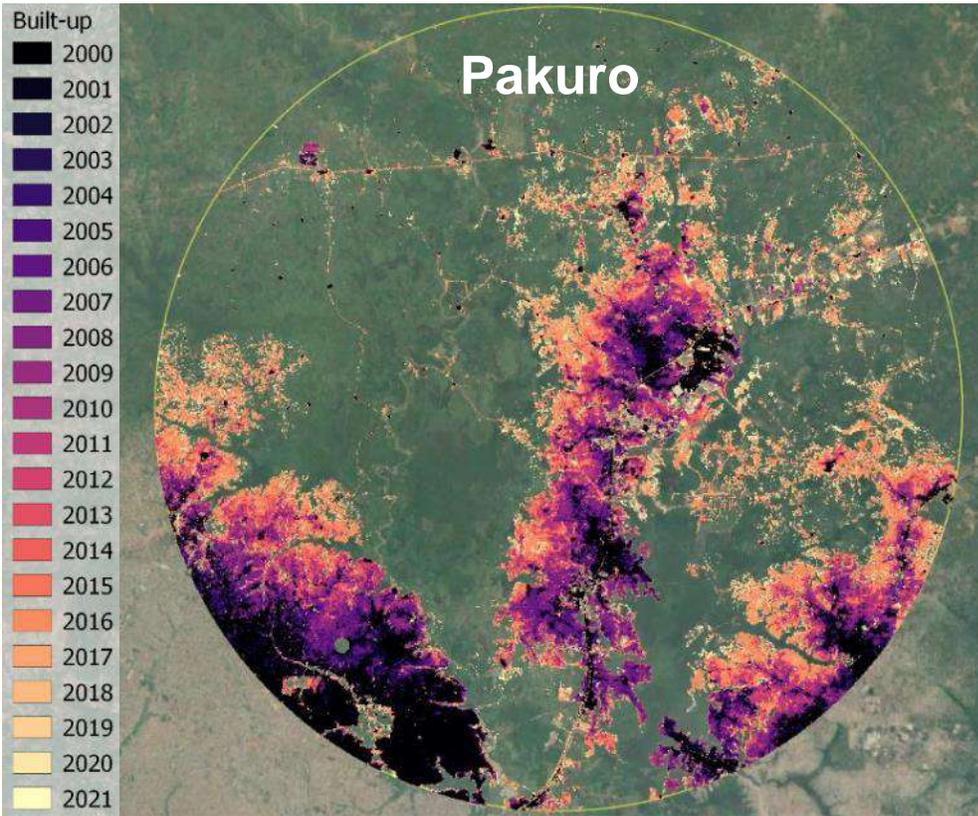
15 km



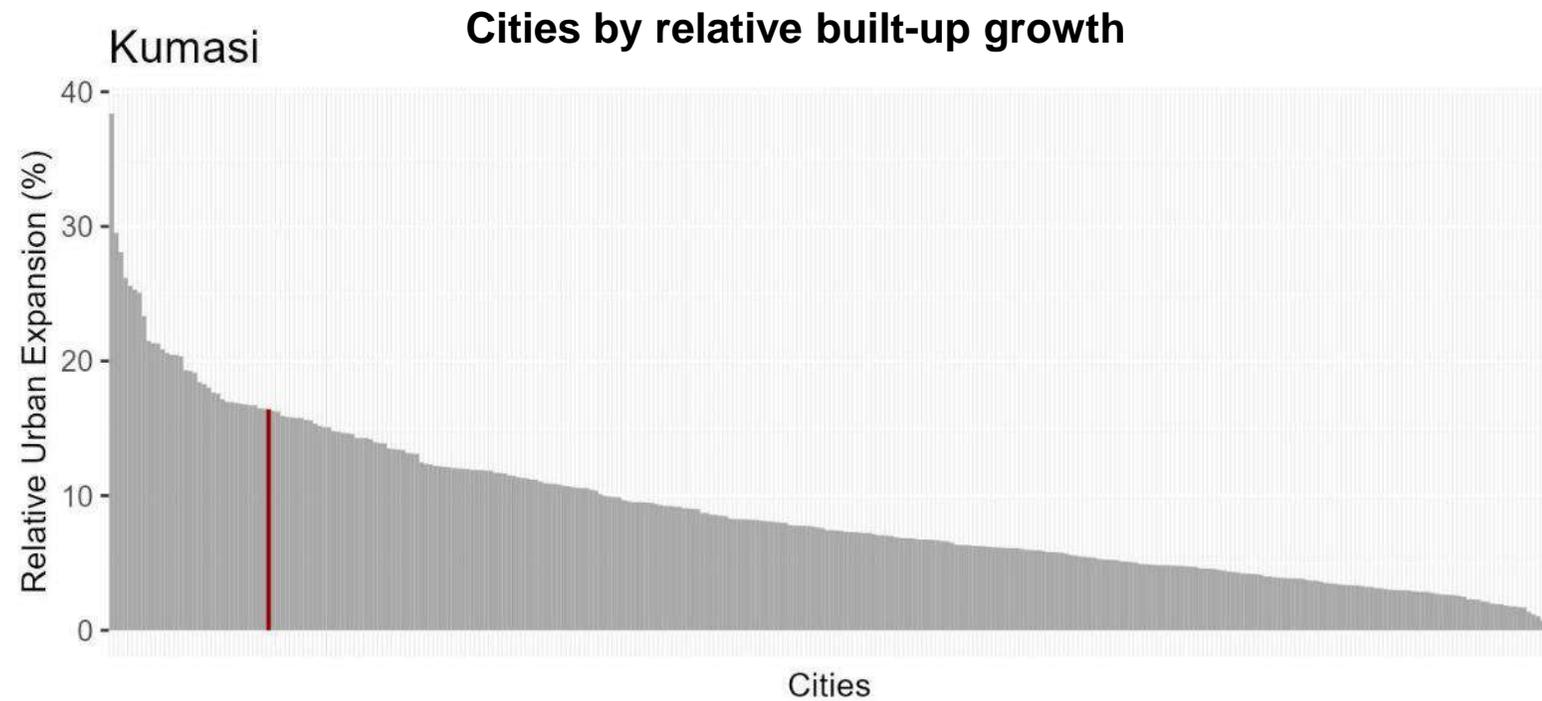
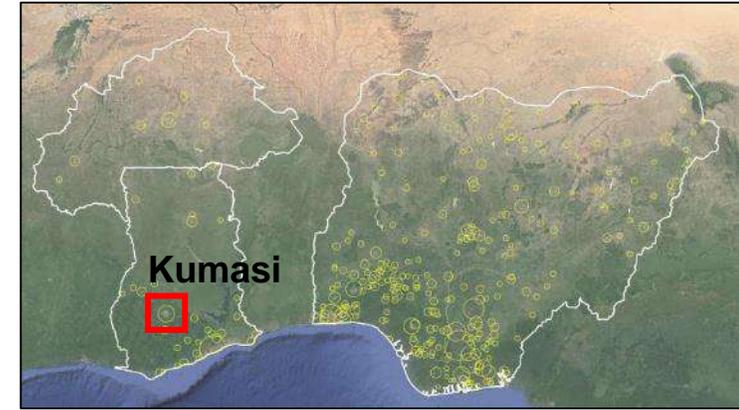
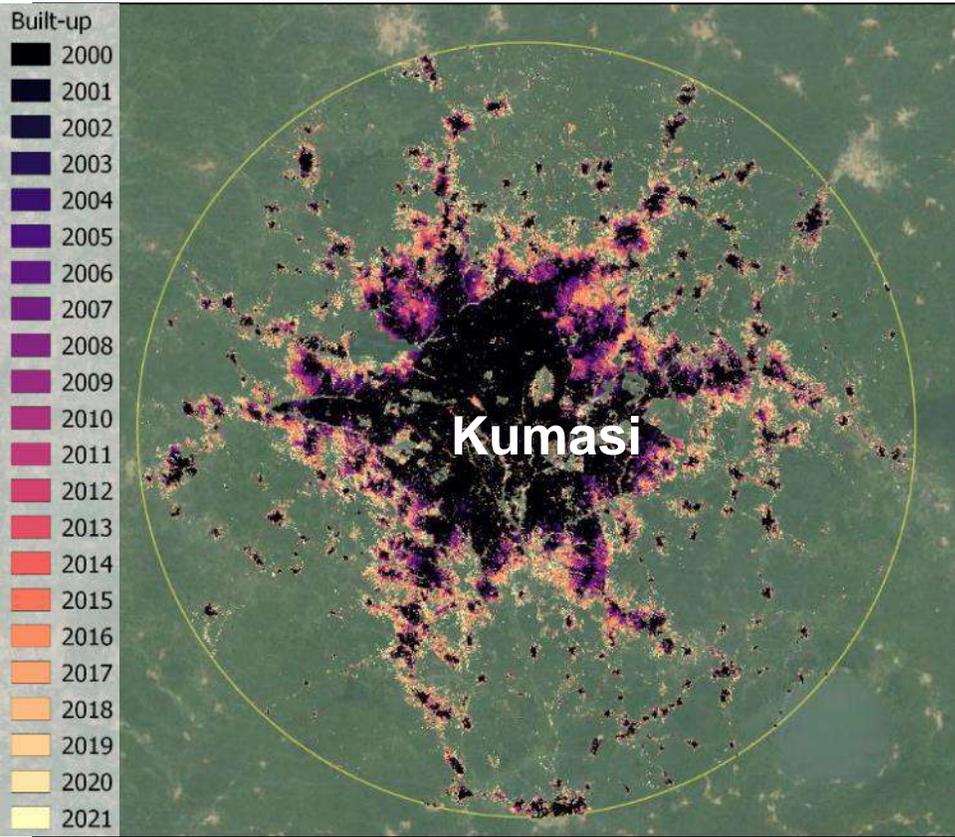
(2) Comparison of urban expansion in 300 cities (2000-2021)



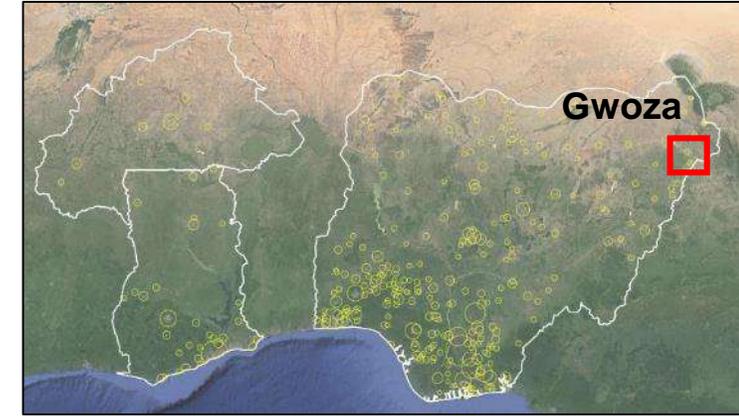
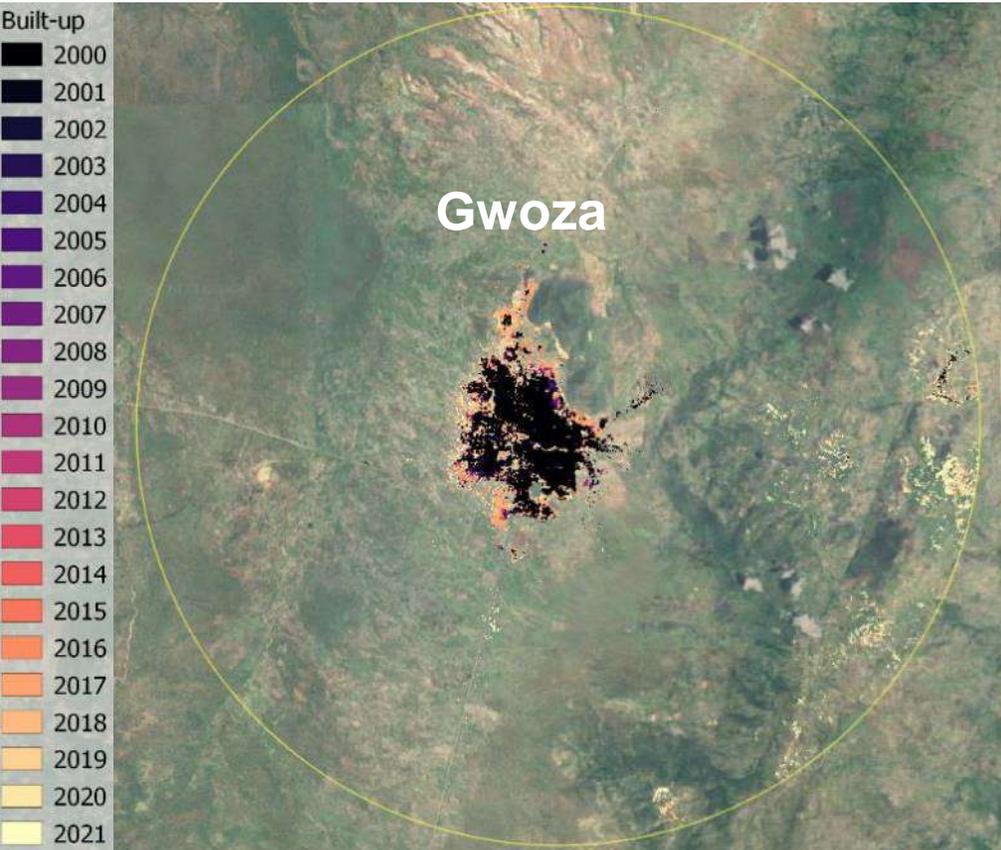
(2) Comparison of urban expansion in 300 cities (2000-2021)



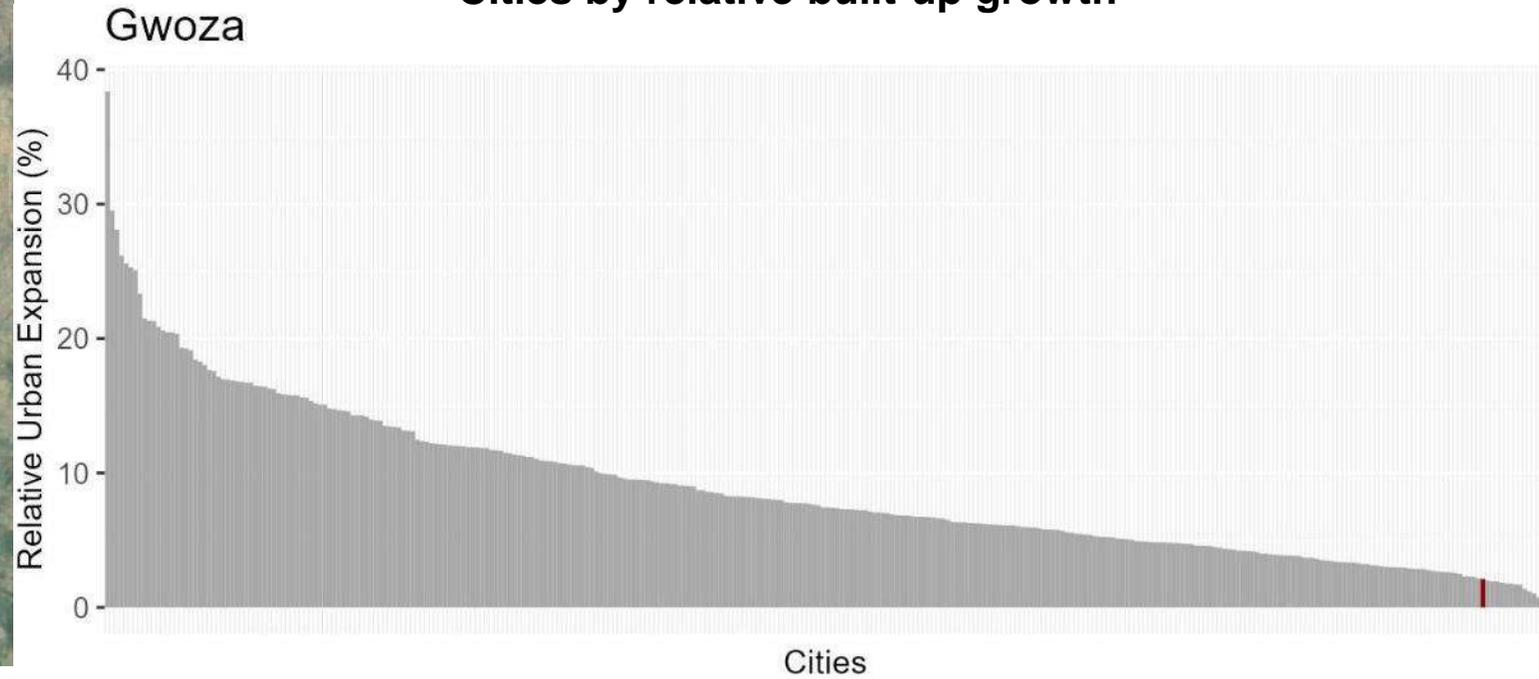
(2) Comparison of urban expansion in 300 cities (2000-2021)



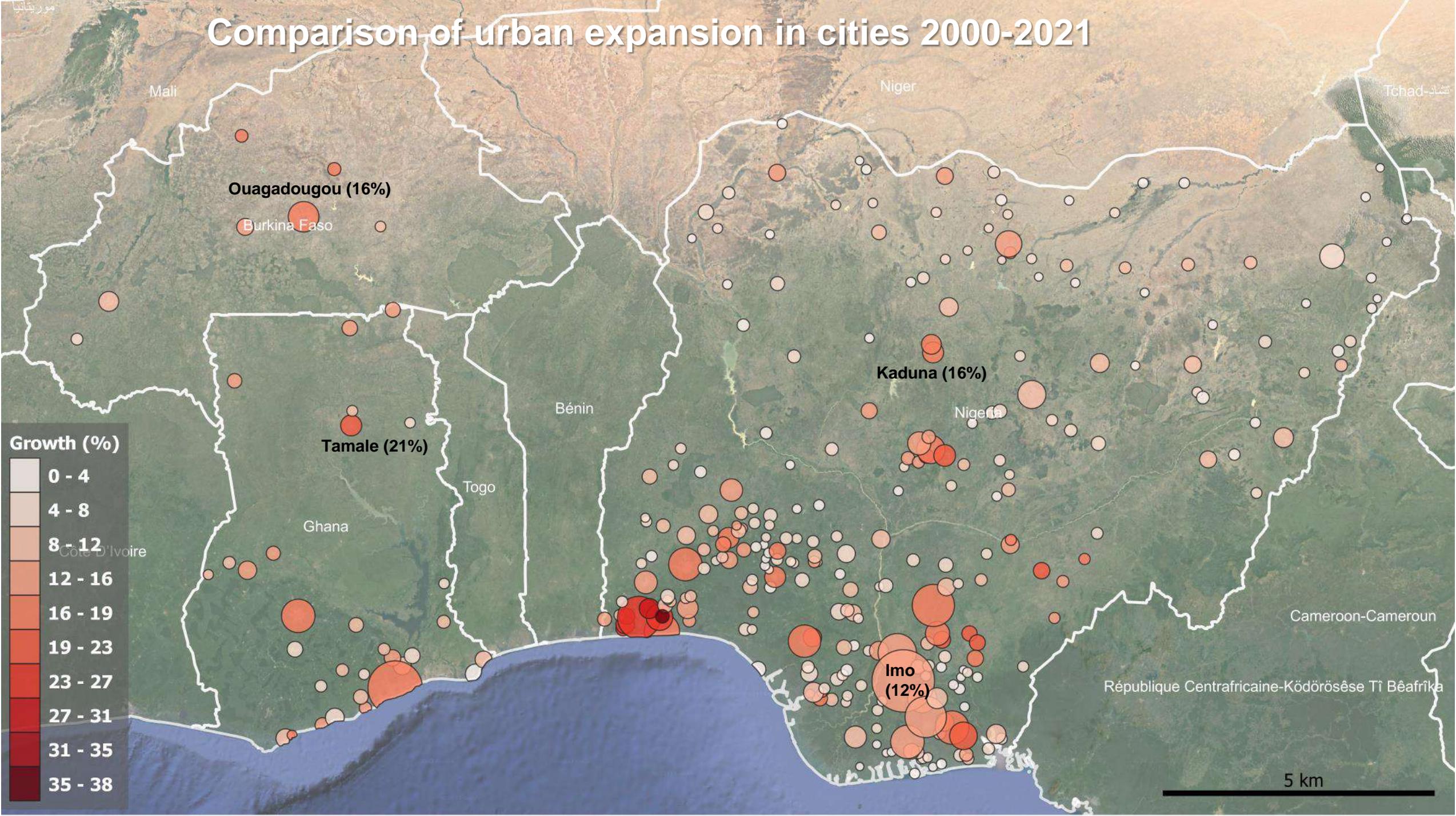
(2) Comparison of urban expansion in 300 cities (2000-2021)



Cities by relative built-up growth

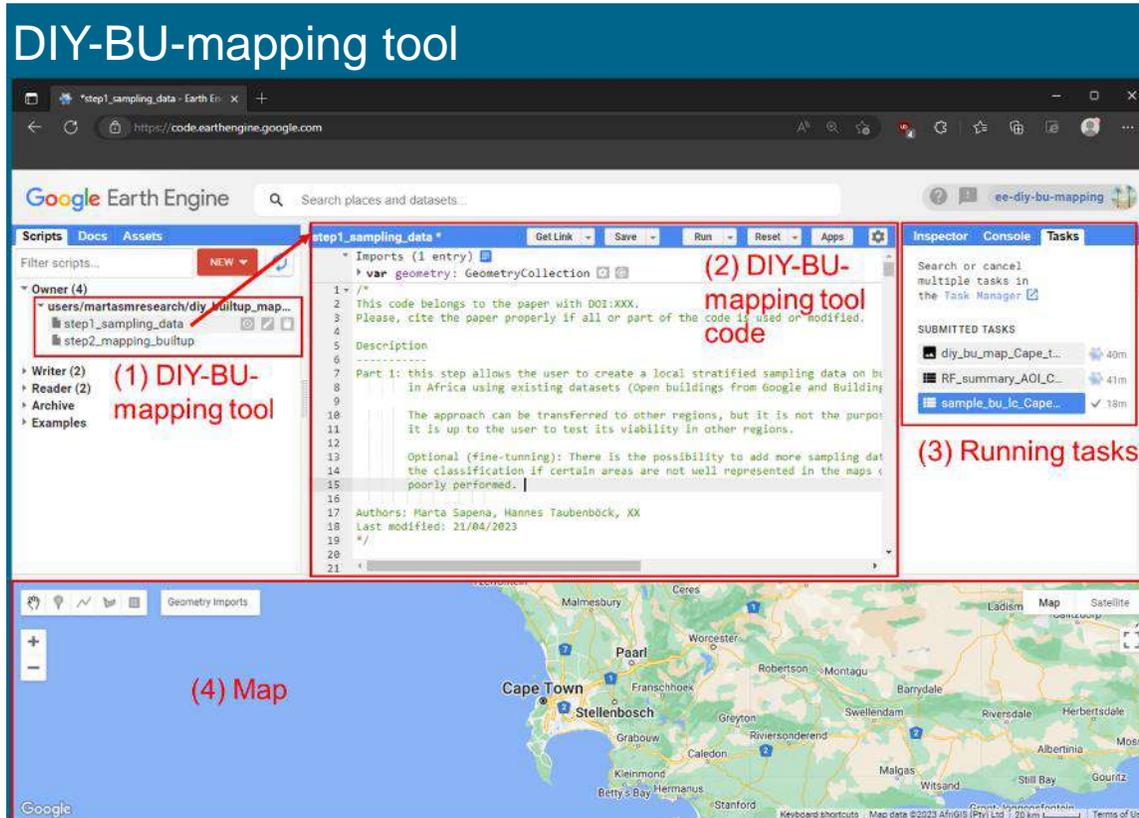


Comparison of urban expansion in cities 2000-2021



Summary and conclusion

We offer an open tool to monitor fast urbanization processes in African cities, aimed at supporting decision-making.



Transferability



Scalability in time



Multifunctional



Open source



Heterogeneity

Webinar FPCUP - Training of Trainers
W3# Copernicus Services and Use Cases (CAMS and C3D)

Mapping urban expansion in African cities

Dr. Marta Sapena-Moll, 27.05.2024

marta.sapena-moll@dlr.de

