Emissions, wildfires, and monitoring atmospheric impacts

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Atmosphere Monitoring

4th Joint ESA/EUMETSAT/ECMWF Training on Atmospheric Composition

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Acknowledgements:

Sebastien Garrigues, Vincent-Henri Peuch, Melanie Ades, Anna Agusti-Panareda, Richard Engelen, Johannes Flemming, Antje Innes, Zak Kipling, Nicolas Bousserez, Ernest Koffe, Panagiotis Kountouris (ECMWF)

CAMS development teams

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Overview

- Brief introduction to emissions
- Examples of emissions inventories & surface fluxes
- Estimating wildfire emissions
- Example case studies on wildfire emissions
  - Arctic
  - California
  - Merging information from the Copernicus services
- Building a CO_2 monitoring service - improving emission estimation

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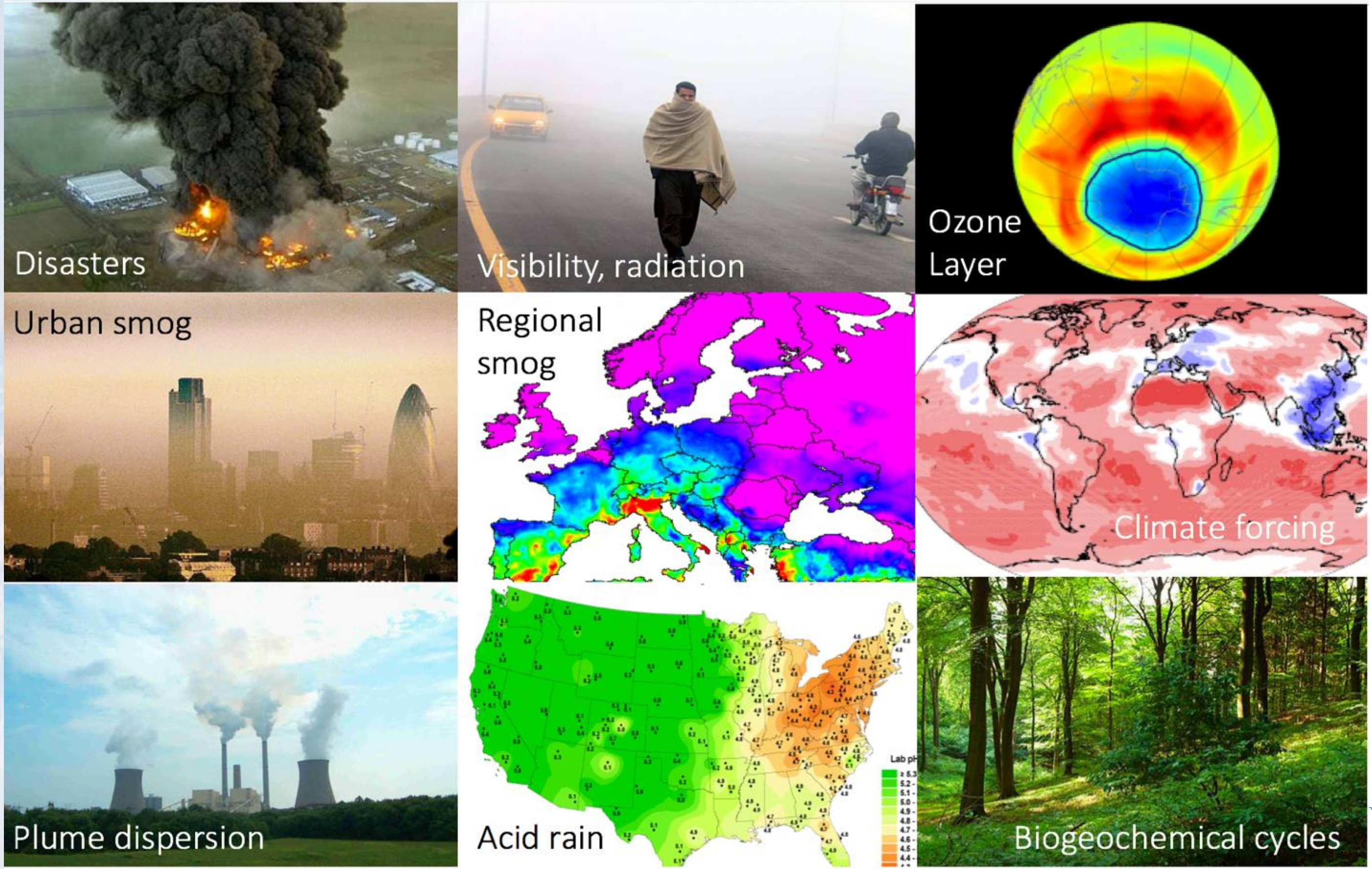
Monitoring atmospheric composition across scales



Local < 100km | Regional 100-1000km | Global > 1000km

from D. Jacob (Harvard)

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Emissions and sources

- Emissions represent the quantity of a pollutant released into the atmosphere
- Emission estimation:

$$Emission_{pollutant} = \sum_{activities} Activity\ rate_{activity} \times Emission\ factor_{activity,pollutant}$$

Certain (easy) — Uncertain (difficult)   Certain (easy) — Uncertain (difficult)

emissions factor is a representative value that attempts to relate the quantity of a pollutant released to the atmosphere with an activity associated with the release of that pollutant.

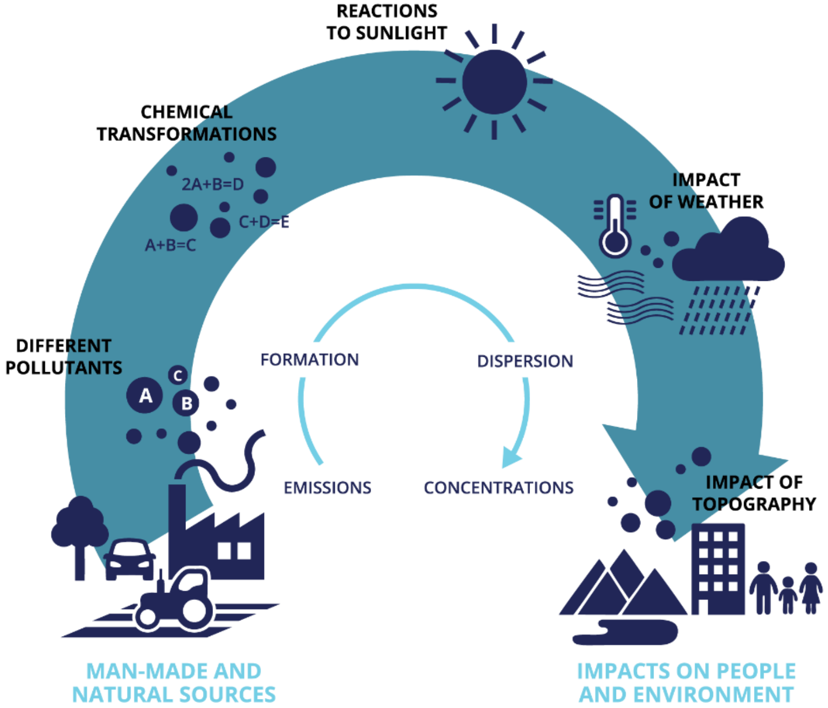
Hugo Denier van der Gon (TNO) lecture from 3rd Joint Training in Atmospheric Composition

Anthropogenic activities:
- Industrial processes
- Energy production
- Road and non-road transportation (shipping aviation)
- Agriculture
- and others…

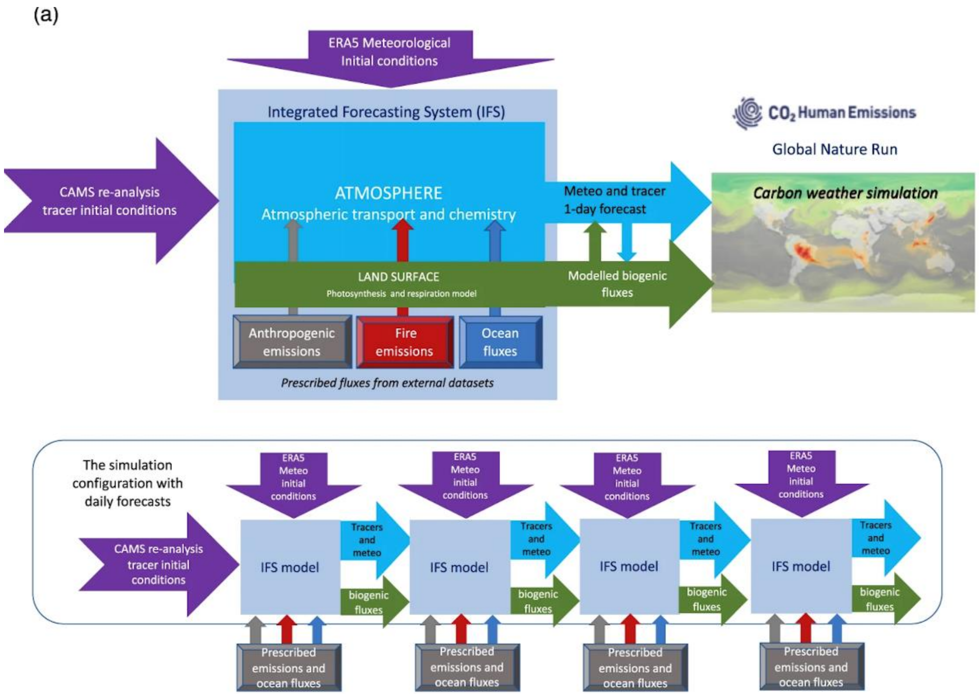
Natural activities:
- Wildfires
- Biogenic emissions from vegetation
- Oceans
- Volcanoes
- *Wind-blown: sea-salt, mineral dust*

- Typically estimated emissions can provided by inventories compiled from activity data, satellite/in situ observations or modelled/parameterized based on meteorology.
- Inverse methods to infer emissions based on observations also exist and are being developed for operational use

How emissions fit in



EEA, From emissions to exposure[1]



Agusti-Panareda et al., Sci Data (2022)[2]

[1] https://www.eea.europa.eu/themes/air/media/infographics/air-pollution-from-emissions-to-exposure/view
[2] https://doi.org/10.1038/s41597-022-01228-2

Bottom-up vs. Top-down emission estimation

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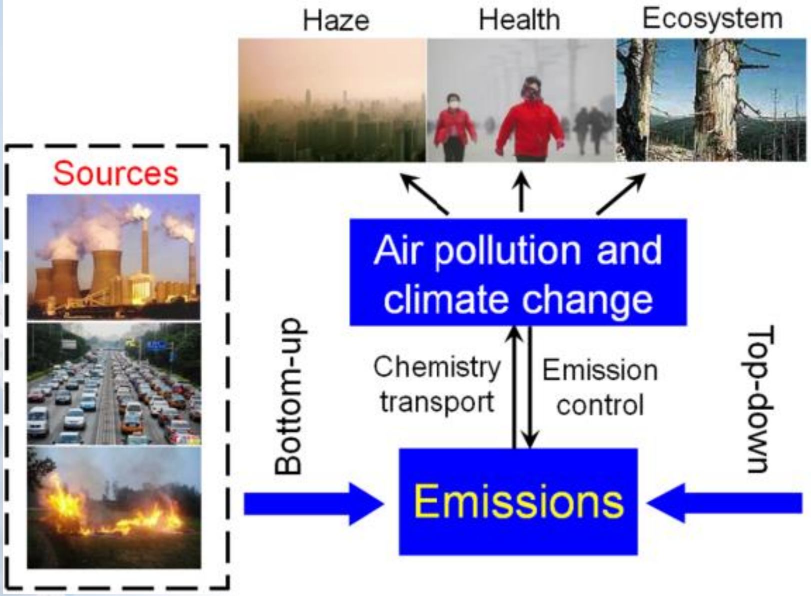
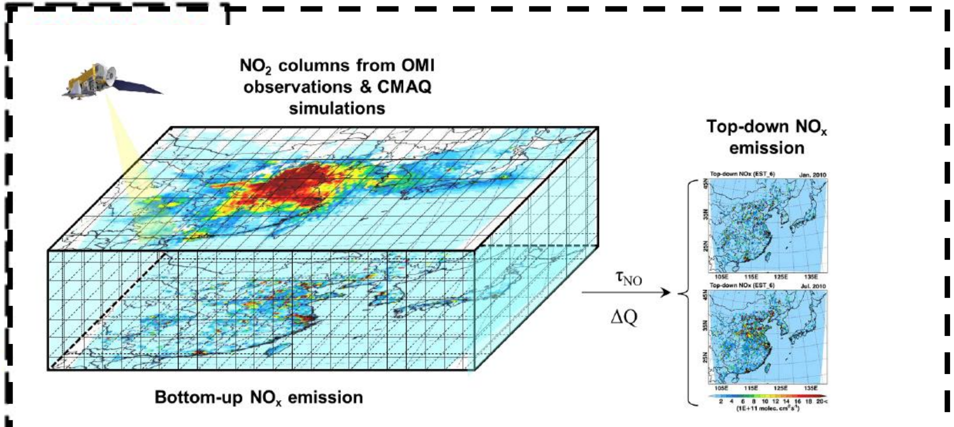
Available months-years after activity

Available within hours



Source: The Zhao Group, Nanjong University
http://www.airqualitynju.com/En/Data/List/Research%20direction



Han et al., Remote Sens (2020)
https://doi.org/10.3390/rs12122004

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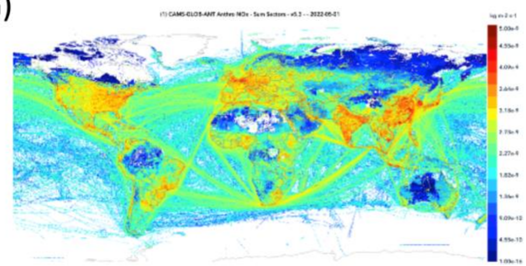
Anthropogenic emissions

CAMS-GLOB-ANT Global anthropogenic emissions already used by many global/regional modeling groups worldwide (560 downloads from the ECCAD database so far)

- Data used : combination of EDGARv5 emissions developed at JRC (Ispra, Italy) and CEDS emissions developed at PNNL (Maryland, USA)
  - EDGAR 5: 0.1x0.1 degree, monthly averages; 1970 to 2015
  - CEDS: 0.5x0.5 degree, monthly averages; 1750 to 2019

- Methodology:
  - Extrapolate the EDGAR emissions using the trends from the CEDS emissions
  - Define 17 sectors, consistent with EU CAMS emissions (CAMS-REG)
  - Use ship emissions from CAMS-GLOB-SHIP
  - Use temporal profiles from CAMS-GLOB-TEMPO



➔ CAMS-GLON-ANT_v5.3

CO_2, CH_4, N_2O, CO, NO_x, NMVOCs, NH_3, SO_2, BC, OC
and 25 speciated VOCs
2000-2022, 0.1x0.1 degree, 20 different sectors, monthly averages

Publication in preparation: Soulie et al., ESSD, 2022

c/o Claire Granier (CNRS/NOAA)

Anthropogenic Emissions Inventories

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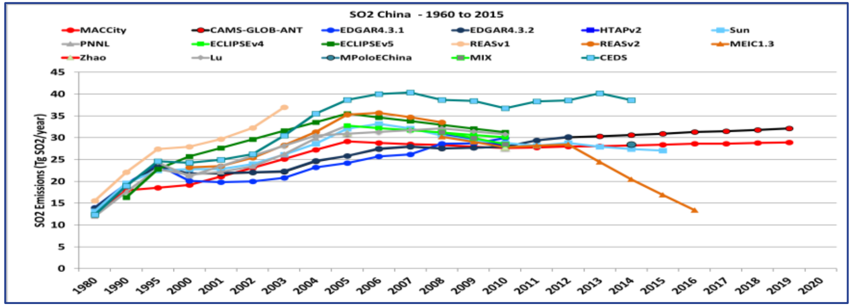
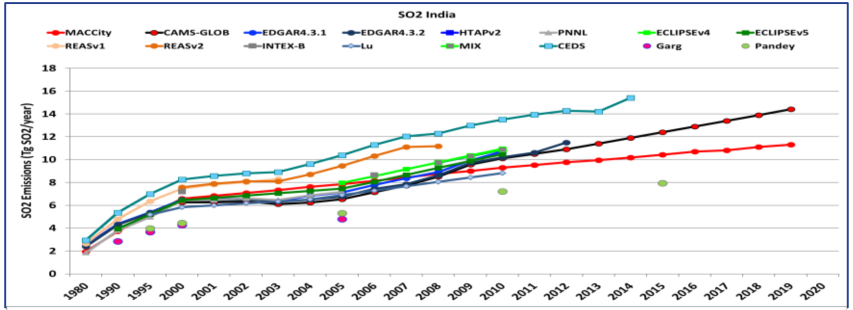
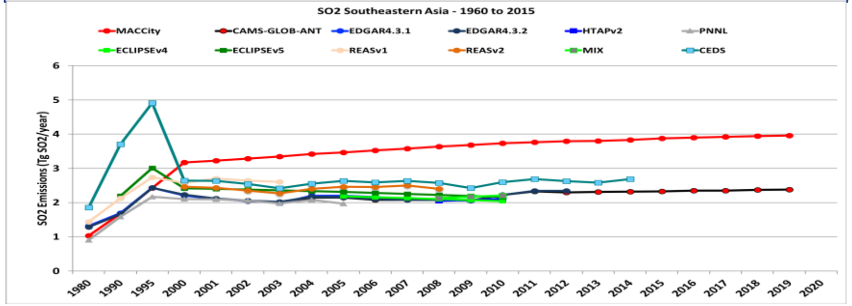
SO_2 China



SO_2 India



SO_2 SE Asia



- Global emissions inventories for anthropogenic, biogenic, shipping, volcanic outgassing, soil NO
  - Geographical and sectoral temporal profiles
- Regular updates to include, e.g., specific information on regional (including China, India, & SE Asia) emissions
- Public releases and documentation available via CAMS Atmosphere Data Store
  - https://ads.atmosphere.copernicus.eu/cdsapp#!/dataset/cams-global-emission-inventories
  - https://eccad.aeris-data.fr/

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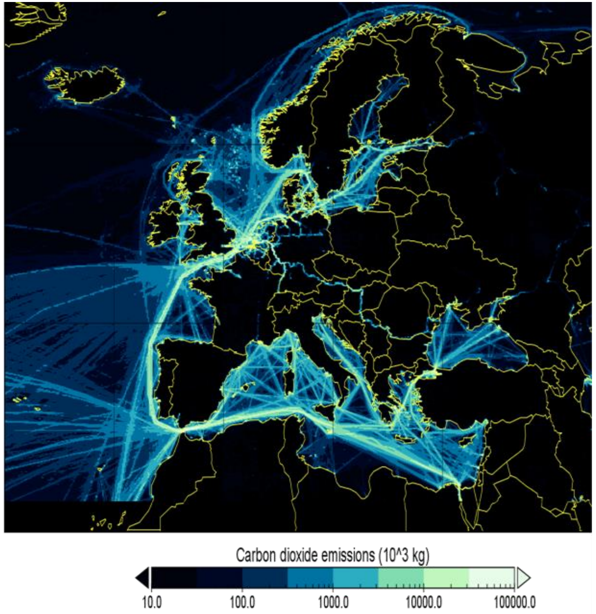
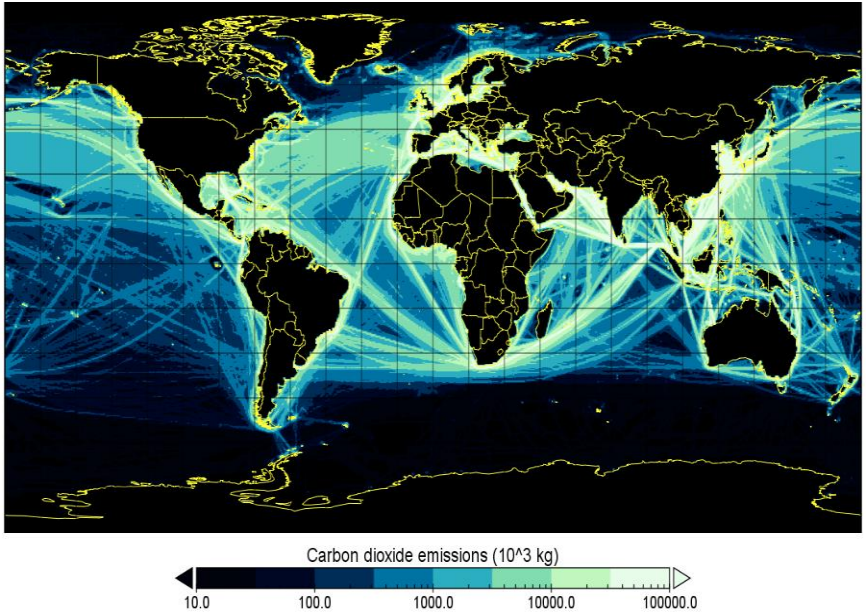
CAMS EMISSIONS INVENTORIES (BOTTOM UP)





Emissions are both an input to CAMS global and regional systems and a popular product. New datasets have been produced covering 2003 to 2020 (extrapolation). Example: CO_2 emissions from shipping activities (Provider: FMI, Finland).

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(Granier et al., doi 10.24380/d0bn-kx16)

Temporal profiles of emissions

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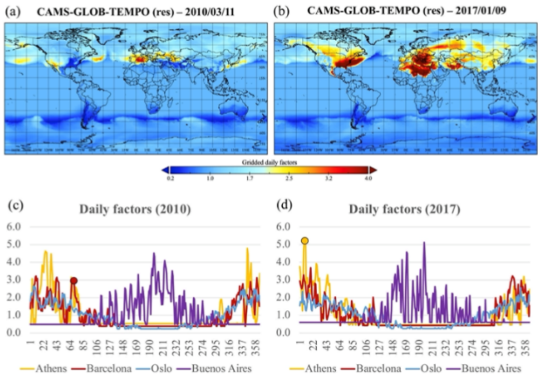
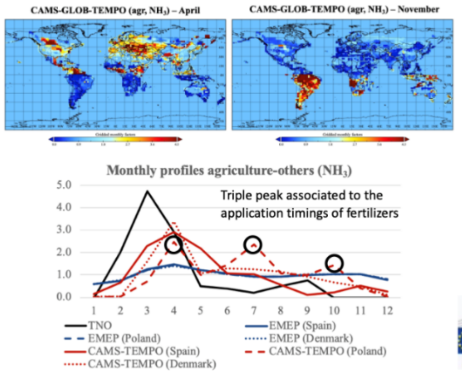
- A collection of **gridded monthly, weekly, daily and hourly temporal profiles** to be combined with the CAMS-GLOB-ANT and CAMS-REG-AP/GHG emission inventories
- Consideration of **year & pollutant-dependency, sociodemographic and meteorological influences**
- **Temporal coverage:** 2000 - 2020
- **Sectoral coverage**: energy & manufacturing industry, residential/commercial combustion, road transport, agriculture (livestock, fertilizers and agricultural waste burning), aviation, shipping
- Methods and dataset documented in detail in Guevara et al. (2021; Earth Syst. Sci. Data)

Residential combustion: Influence of temperature



Fertilizers: Influence of meteorology + crop calendars



c/o Marc Guevara (BSC)

Biogenic emissions

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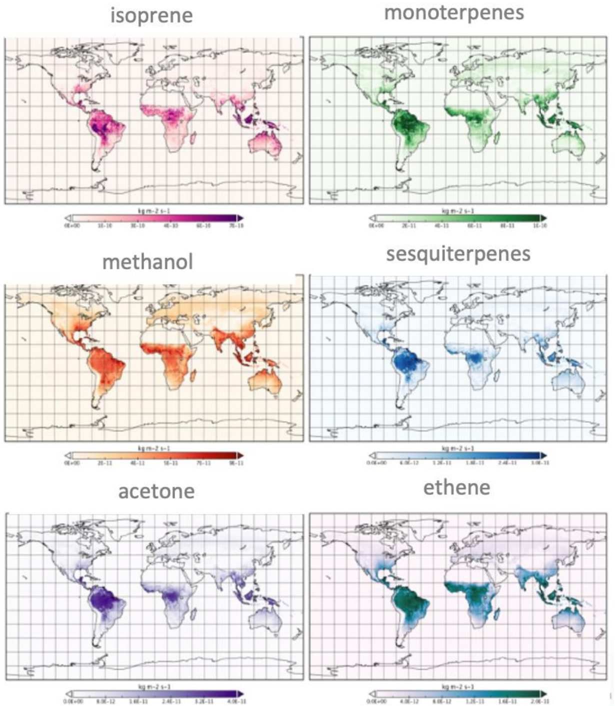
Global gridded inventory of biogenic VOC emissions from vegetation

Emissions calculated by the MEGANv2.1 model and ECMWF meteorology (published in Sindelarova et al., ESSD, 2022)

Monthly mean emissions and monthly averaged daily profiles of 25 VOC species/chem. groups for 2000 – 2020 on a 0.25x0.25 deg. grid

- **CAMS-GLOB-BIOv3.1**
  - driven by ERA5, includes update of isoprene emission factors in Europe based on the EMEP model data
- **CAMS-GLOB-BIOv3.0**
  - driven by ERA5 and by annually changing land cover from the ESA-CCI dataset
- **CAMS-GLOB-BIOv1.2**
  - driven by ERA-Interim meteorology

CAMS-GLOB-BIOv3.1
annual mean emissions [kg m^{-2} s^{-1}]



c/o Katerina Sindelarova (Charles University)

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Surface GHG fluxes

Net surface fluxes of CO_2, CH_4 and N_2O through combining accurate observations of these greenhouse gases near the ground or from space with our knowledge of atmospheric transport and chemistry

- For CH_4, distinction between wetlands, rice fields, biomass burning, and *other sources*

- **Annual to quadrimester updates**, depending on observation availability

https://ads.atmosphere.copernicus.eu/cdsapp#!/dataset/cams-global-greenhouse-gas-inversion

c/o Frederic Chevallier (LSCE)
5th CAMS General Assembly

Example inverse methods for methane fluxes

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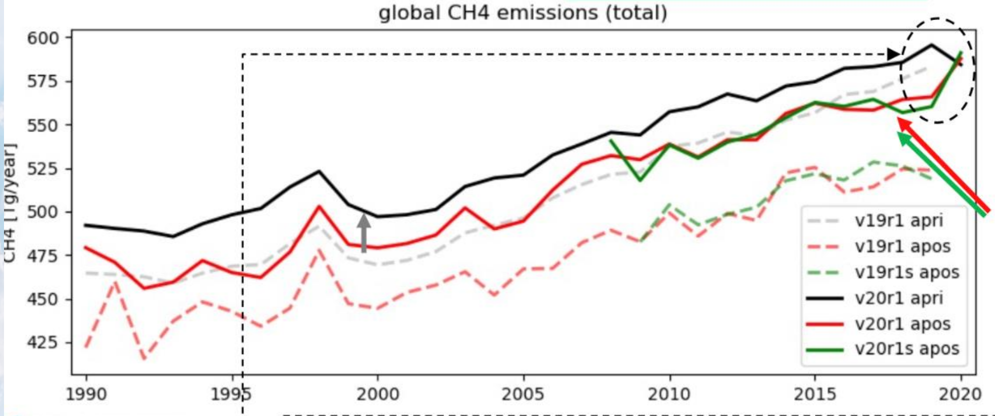
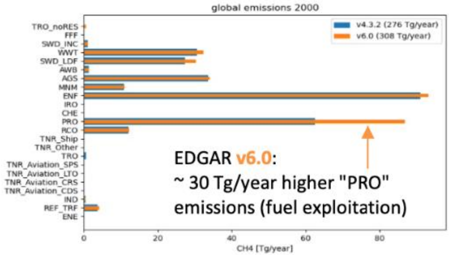
Latest **v20** release of CAMS CH_4 TM5/4D-Var emission inversions:

v20r1 (surface obs.) 1990-2020

v20r1s (sfc.+GOSAT) 2009-2020





- latest EDGAR v6.0 *a priori* emissions: ~ 30 Tg/year higher than previous inventory
- *posterior* emissions:
  - ~ 20-40 Tg/year lower than *a priori*
  - same variations as in *a priori*, except for 2020

2019 -> 2020: a priori emissions based on fossil fuel consumption proxies, lower due to lock-downs;
relatively high posteriori estimate, but inversion lacks lock-down signal in atmospherics sinks

c/o Frederic Chevallier (LSCE)
5th CAMS General Assembly

Emissions fluxes informing policy

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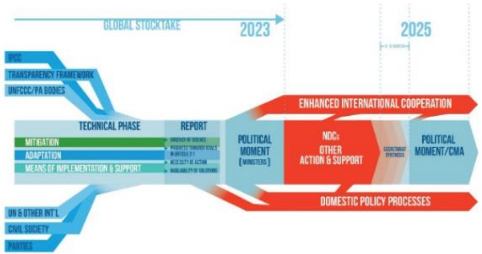
The Global Carbon Project

CO_2, CH_4 and N_2O regular global syntheses
RECCAP and RECCAP2 regional syntheses
The Assessment Reports of the IPCC

The UNFCCC, through the Global StockTake of the Paris Agreement

NEW

CoCO2 (on-going)
RECCAP2 initiative https://doi.org/10.5194/essd-14-1639-2022
CEOS initiative https://ceos.org/gst/carbon-dioxide.html



⇒ More data to assimilate
⇒ Emphasis towards country scale
⇒ Emphasis towards higher resolution

More VIP users welcome!

c/o Frederic Chevallier (LSCE)
5th CAMS General Assembly

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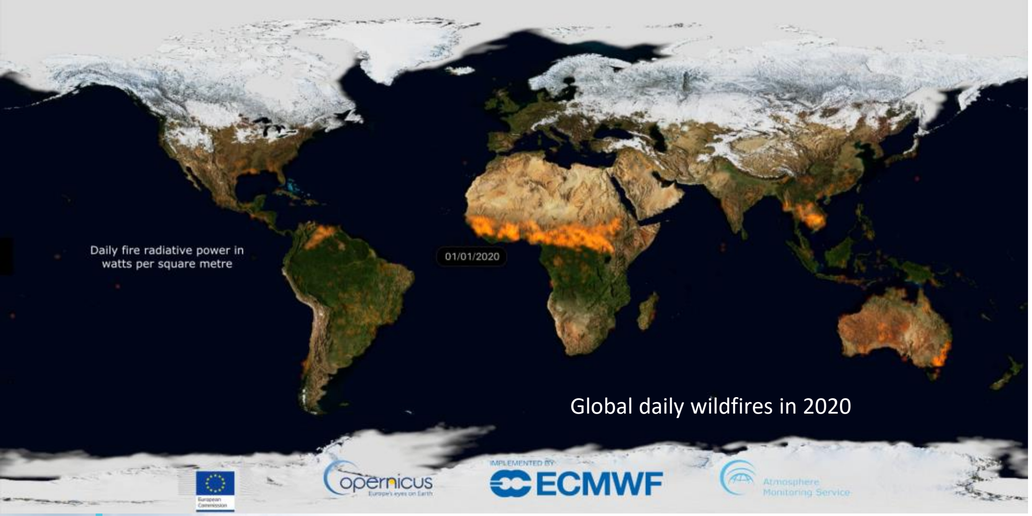
Estimating Global Wildfire Emissions



- Satellite observations of fire locations and estimated emissions available from a number of “inventories” (e.g., GFED, FINN, FLAMBE, FEER, GBBEPx, QFED).
- Based generally on similar observations but can differ in the technique used:
  - Burnt area vs. fire radiative power.

- Global Fire Assimilation System (**GFAS**); see https://ads.atmosphere.copernicus.eu/cdsapp#!/dataset/cams-global-fire-emissions-gfas?tab=overview
- Uses satellite observations of Fire Radiative Power (FRP)
  - Currently Aqua and Terra MODIS FRP observations
  - FRP from VIIRS, Sentinel-3, and geostationary satellites are being tested for future implementation
- Global Coverage at ~10km Resolution
  - *Daily Output: 1-day behind NRT*
  - Hourly Output (+24-h means): 7-hours behind NRT
- Emissions of aerosols and gases are estimated using factors dependent on vegetation type.
- Injection heights calculated with Plume Rise Model and IS4FIRES

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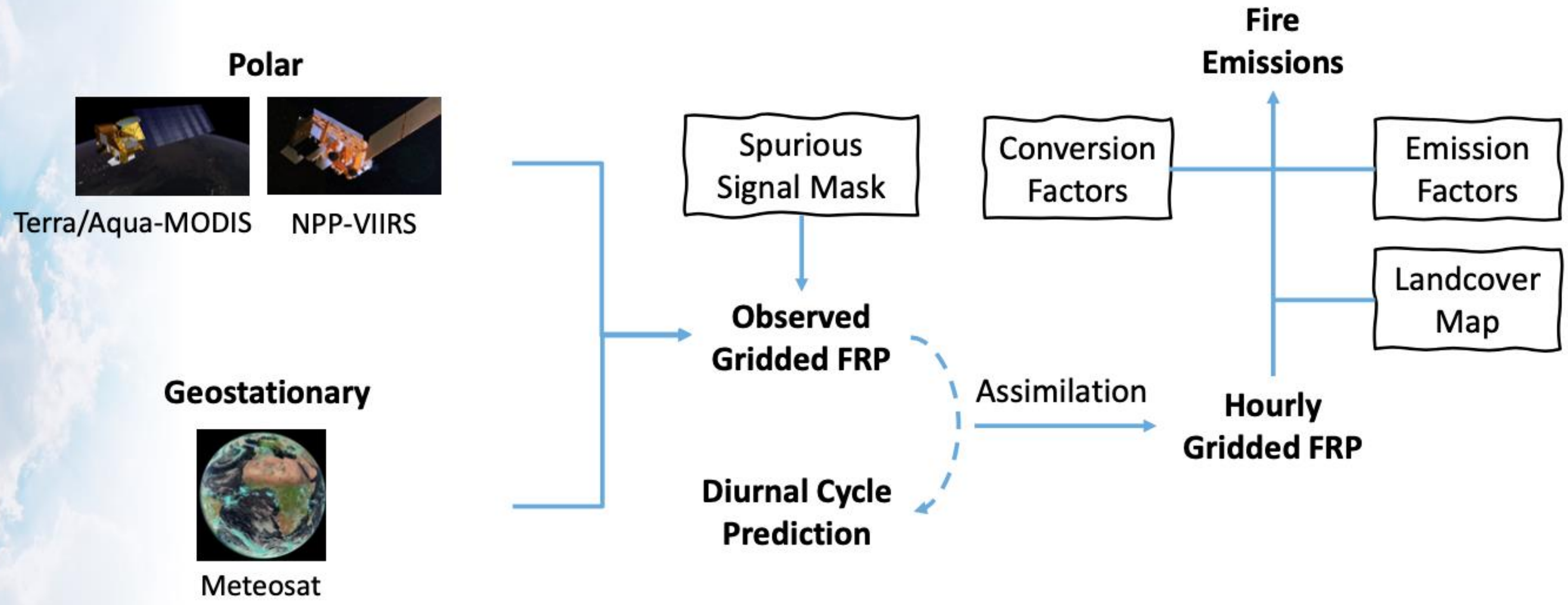
Estimating wildfire emissions



c/o Mark de Jong/Martin Wooster (KCL)
5th CAMS General Assembly

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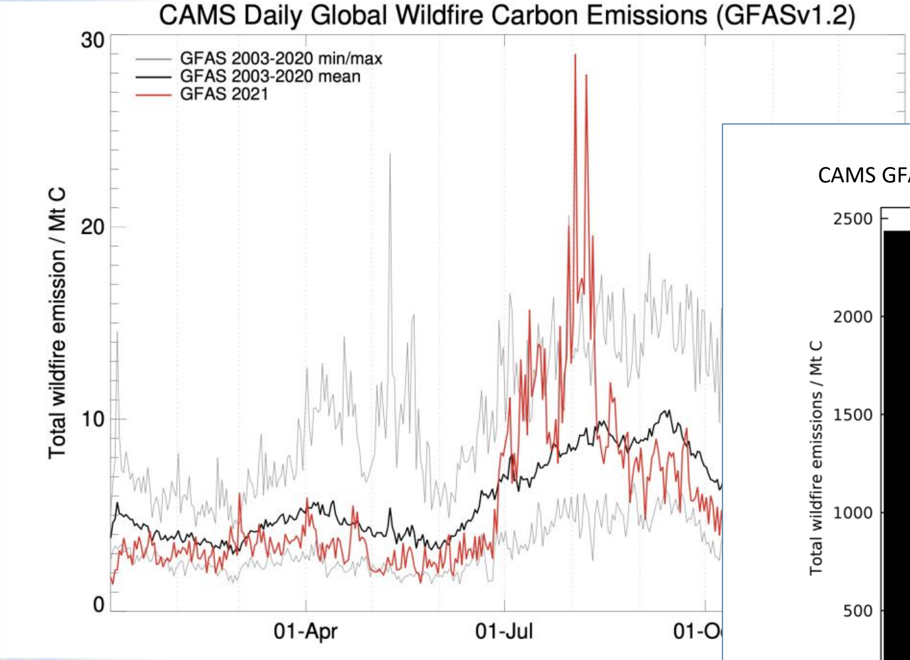
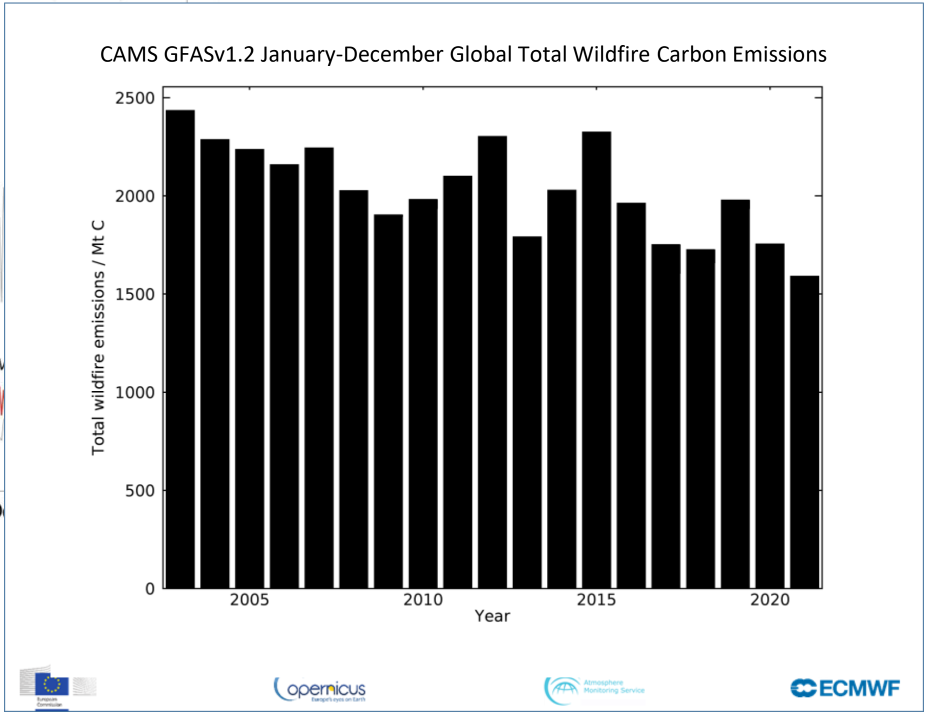
Global Wildfire Activity and Emissions in 2021



Estimated emissions reflect the scale and intensity of active fires.



- Radiative energy of fires can be observed by satellites and can be used to estimate emissions of pollutants.
- 2021 has generally been below average at the global scale apart from July and August (related to large-scale boreal wildfires in Siberia and N America).
- General downward trend in global annual total emissions due to declining savannah fires in the tropics.

CAMS GFAS: 19 years of Africa fire activity

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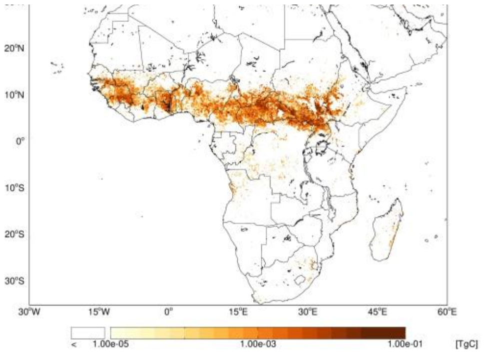
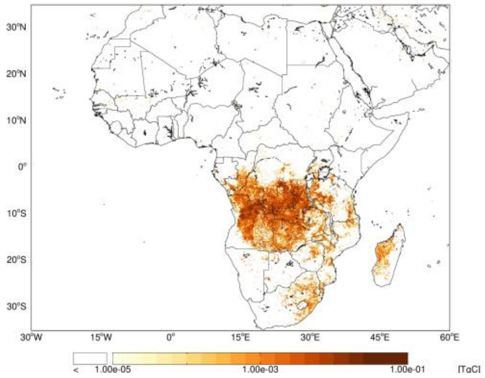
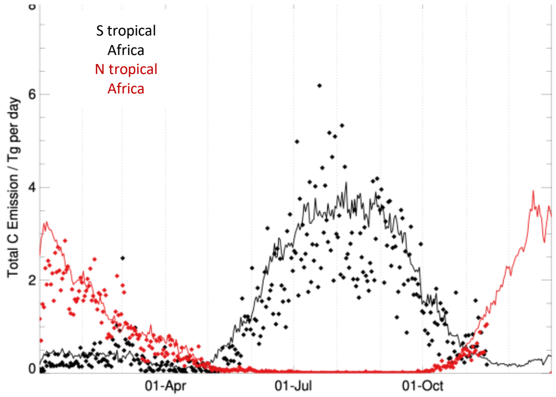
Total estimated carbon emission: January 2021



Total estimated carbon emission: July 2020

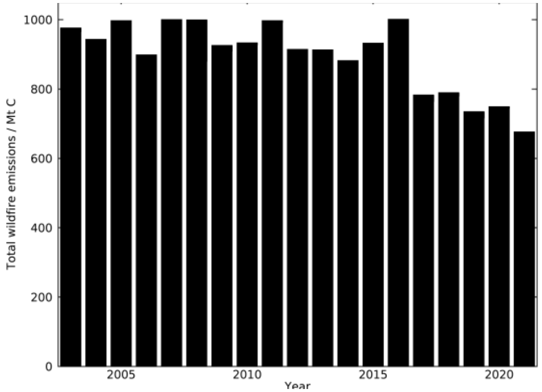


Daily total estimated carbon emissions



Mean daily total Fire Radiative Power for northern and southern tropical Africa

Total estimated annual carbon emission for Africa



Annual total estimated wildfire carbon emissions for Africa (up to 15 Nov for 2021)

- NRT estimates of emissions from fires are an essential component of CAMS atmospheric composition forecasts.
- The 19-year dataset also provides valuable context and information on fire activity at daily, monthly and yearly scales.
- These examples show how fire emissions change seasonally across across Africa, and how the annual total emissions have changed between 2003 and 2021.

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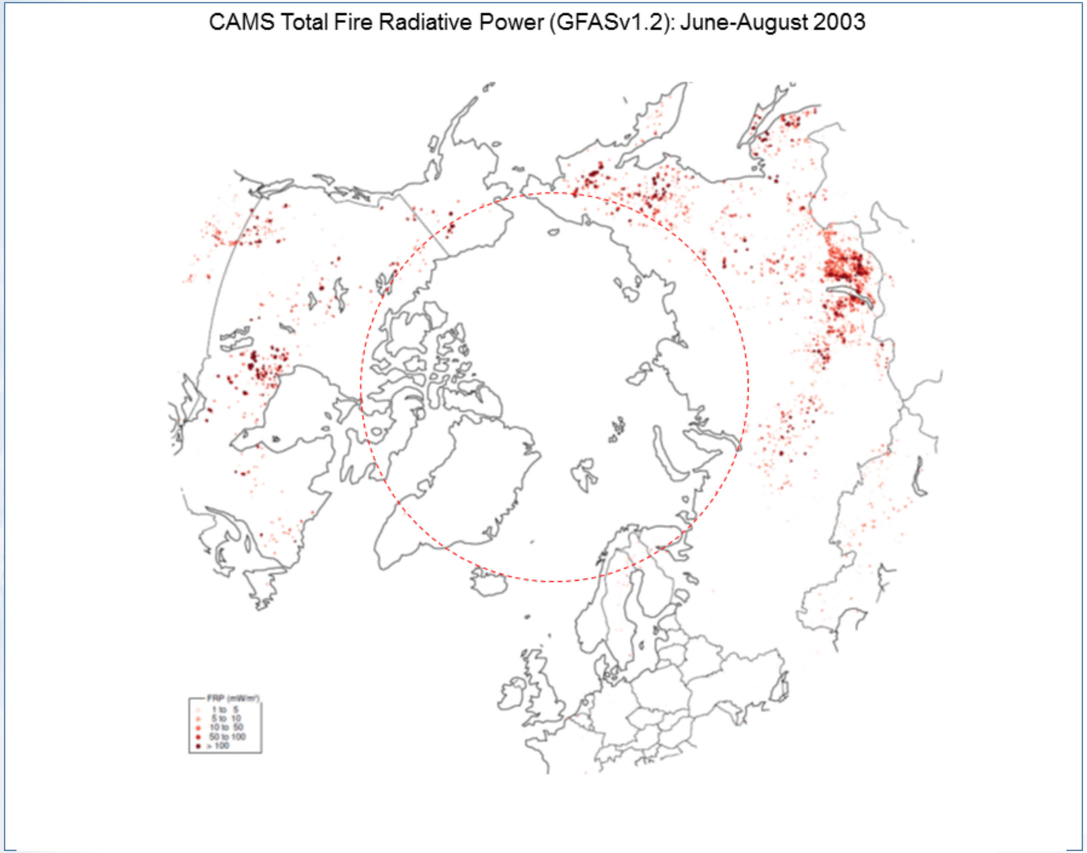
Interannual variability of Arctic wildfires



Animation of June-August total MODIS active fire observations from 2003 to 2021.

High degree of interannual spatial variability of boreal forest fires, and fires in the Arctic Circle, driven by surface hydrology (e.g. soil moisture) and meteorology.

More on recent trends in Siberian & high latitude fires:

- *Ponomarev et al. (2021), MDPI Atmosphere*
- *Conard & Ponomarev (2021), IAWF* *https://www.iawfonline.org/article/fire-in-the-north-the-2020-siberian-fire-season/*
- *McCarty et al. (2021), BGS* *https://bg.copernicus.org/articles/18/5053/2021/*

Monitoring daily and seasonal Arctic wildfires

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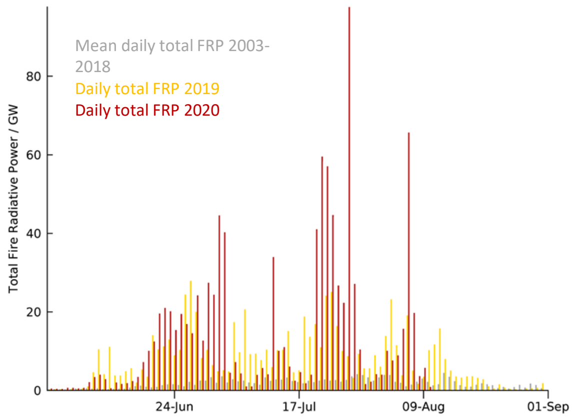
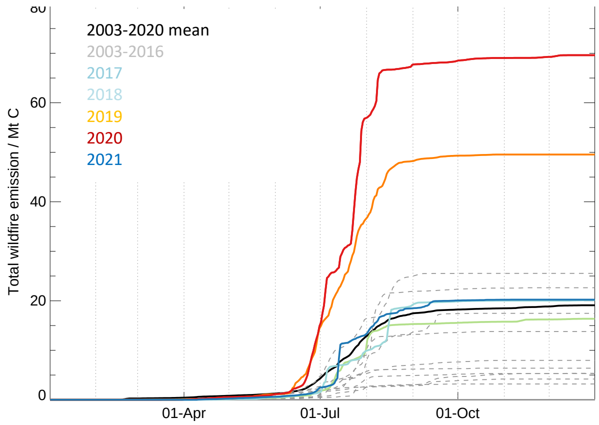
Daily total Fire Radiative Power



Cumulative daily total carbon emissions

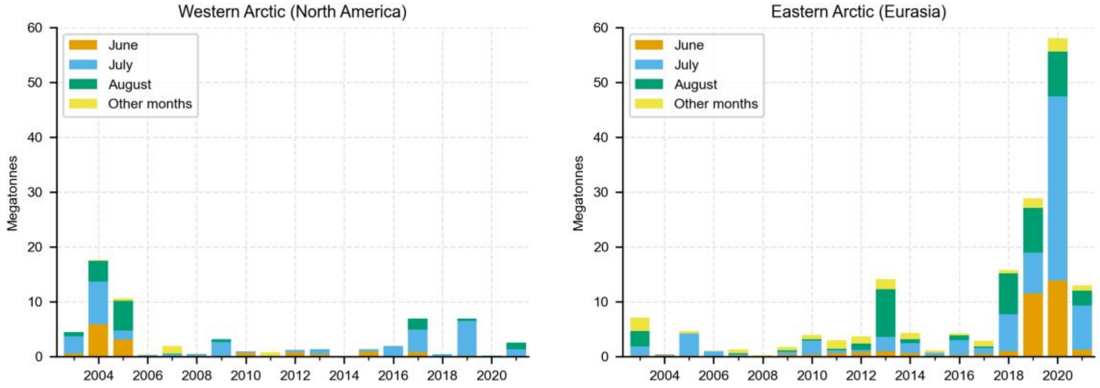


Data: Copernicus Atmosphere Monitoring Service/ European Centre for Medium-Range Weather Forecasts

Daily totals of Fire Radiative Power and estimated carbon emissions monitored in near-real-time.

Comparison against mean of previous years provides context on how 'normal' the fire activity is.

Cumulative daily total carbon emissions



Data: GFAS • Credit: CAMS/C3S/ECMWF

Routine evaluation of monthly and seasonal total estimated emissions provides larger-scale context for interannual variability over last two decades of active fire observations.

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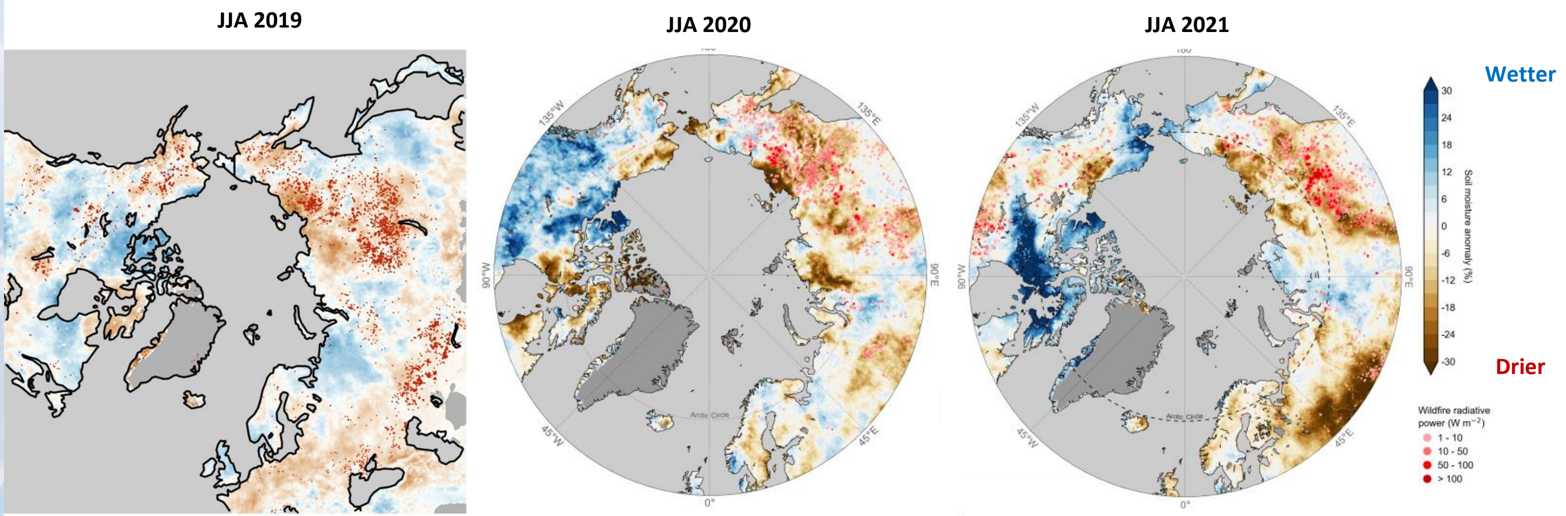
Climatological background 2019-2021

June-August soil moisture anomaly & fire locations

Active fire observations throughout the summer of 2019, 2020 and 2021 corresponded with areas of negative (drier) soil moisture anomalies (relative to 1981-2010 climatology) from the Copernicus Climate Change Service (C3S).



https://www.copernicus.eu/en/news/news/observer-copernicus-services-enable-civil-authorities-anticipate-spread-wildfires-and
https://climate.copernicus.eu/esotc/2020/heat-siberia
https://climate.copernicus.eu/esotc/2021/arctic-wildfires

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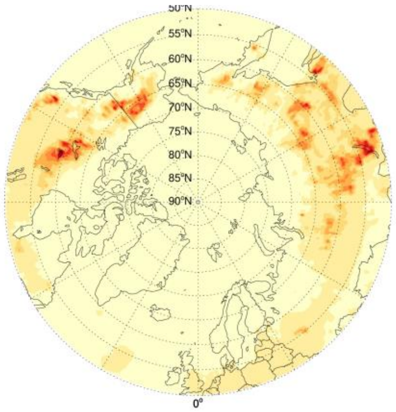
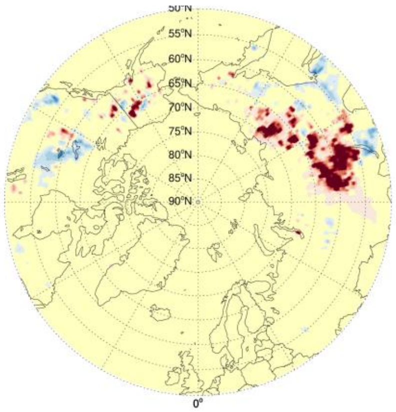
Air quality impacts of high latitude wildfires

CAMS global reanalysis of atmospheric composition:
https://ads.atmosphere.copernicus.eu/cdsapp#!/dataset/cams-global-reanalysis-eac4?tab=overview

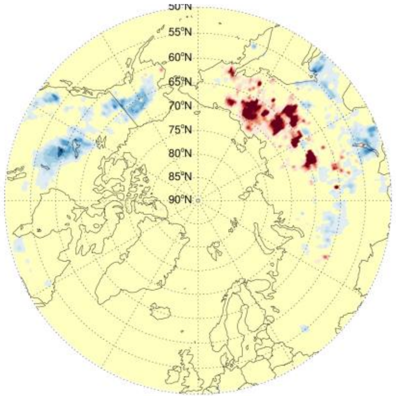
2003-2018 climatology



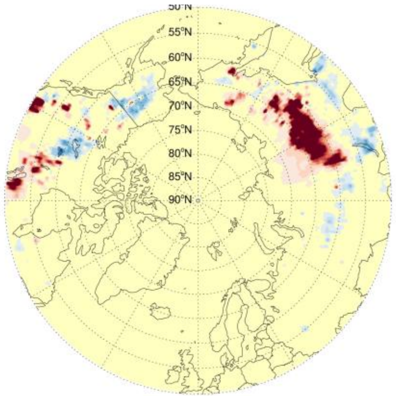
2019 anomaly



2020 anomaly



2021 anomaly



- Climatology of surface PM2.5 concentration shows limited impact of wildfires on air quality in Siberian Arctic.
- Anomalies for 2019 and 2020 show direct impact of high latitude wildfires on surface air quality as activity increases and expands poleward.
- 2021 anomaly shows air quality impacts in Siberia and North America localised to fires.

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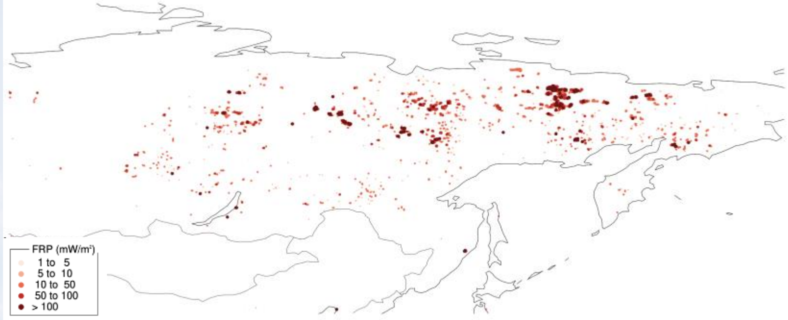
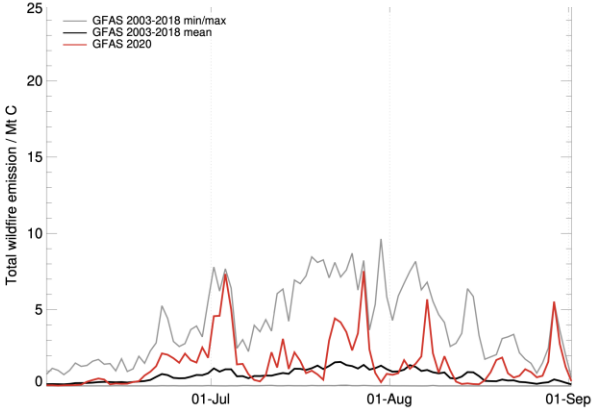
Evaluating Siberia wildfires in 2020

Fire Radiative Power: JJA 2020

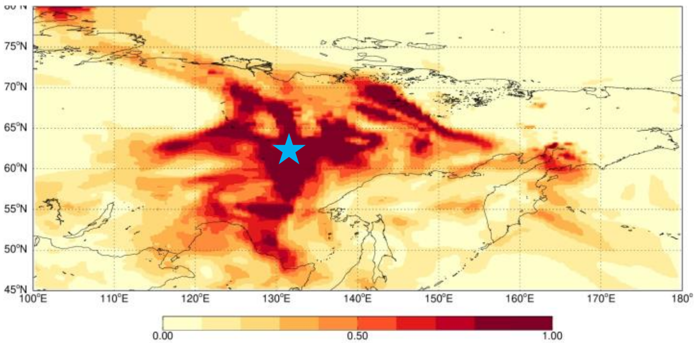


Daily total wildfire carbon emissions for Siberia*

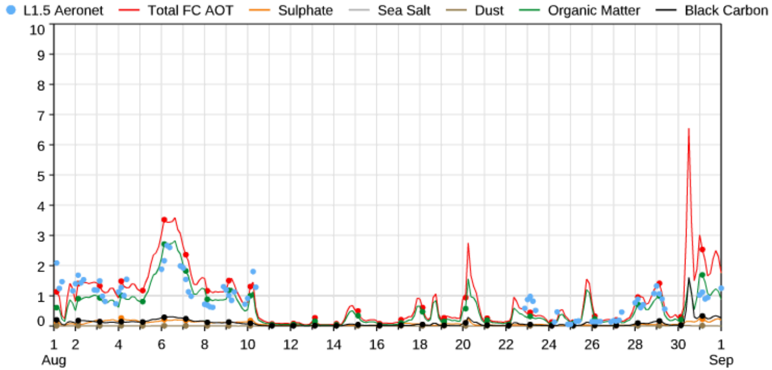


*Main contributing regions: Sakha Republic, Chukotka, Irkutsk

Organic Matter AOD analysis: 20190708, 12z



Aerosol Optical Depth comparison vs Aeronet at Yakutsk



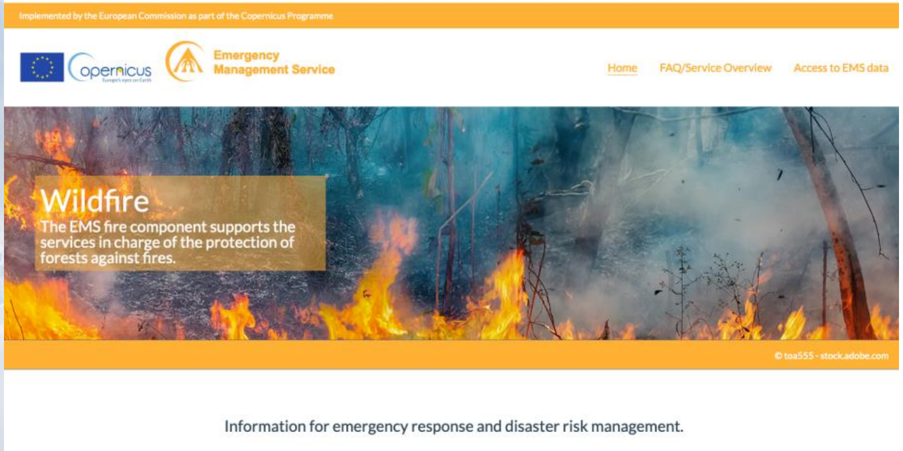
Linking Copernicus Services: From fire monitoring to fire forecasts

CAMS | **Copernicus Emergency Management Service**

Global Fire monitoring

Global fire evolution forecasting (d+5)

Global fire danger forecasting (d+10)



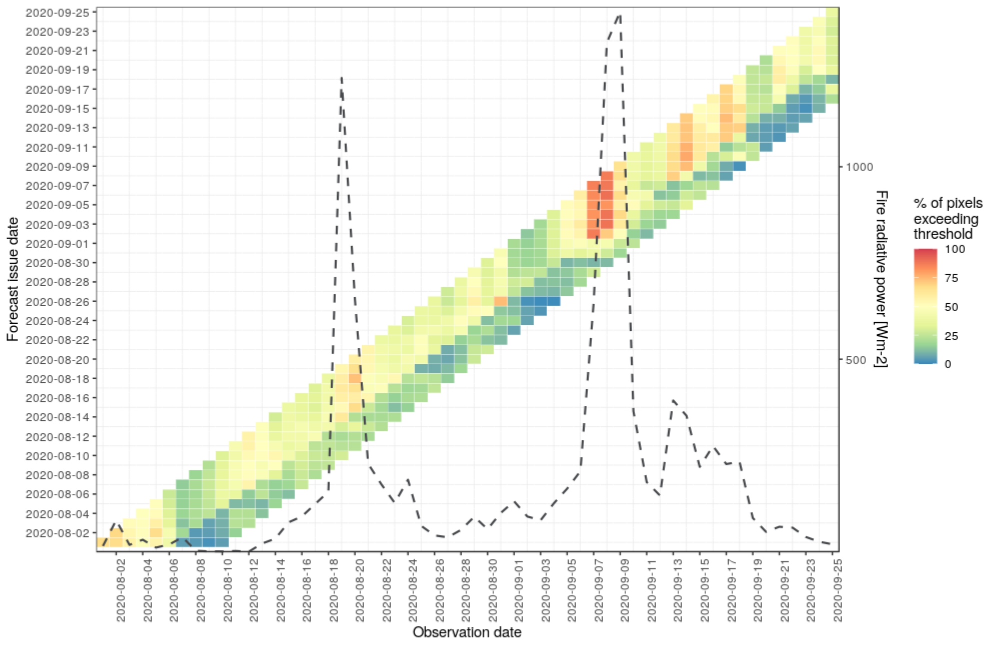
https://emergency.copernicus.eu/

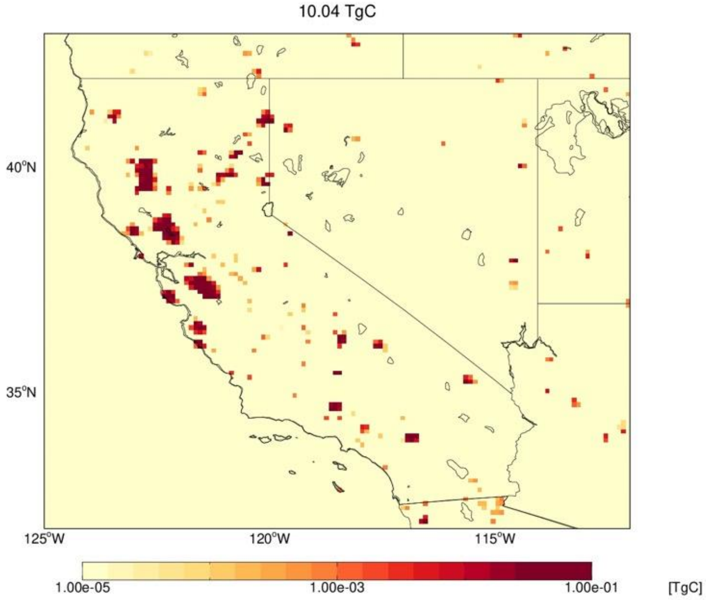
The European Forest Fire Service (EFFIS) is implemented by the EU Joint Research Centre

Flood and fire danger forecasts are provided by ECMWF.

Atmosphere Monitoring

California fires in August-September 2020

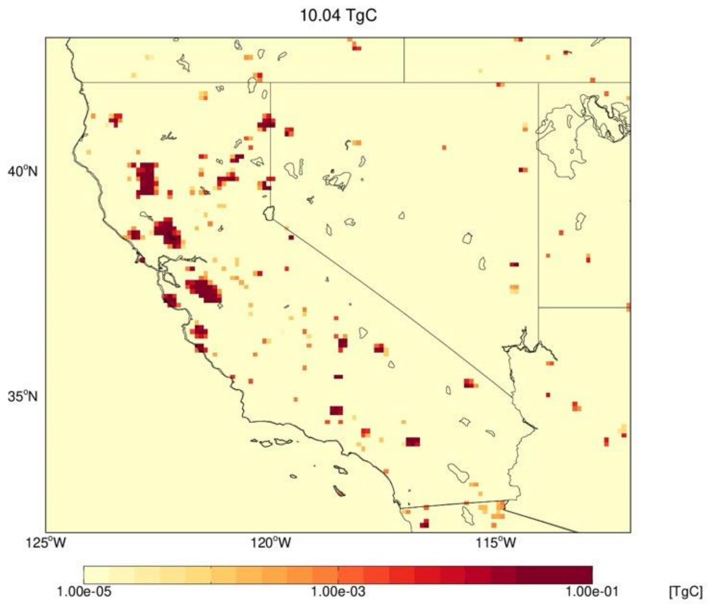


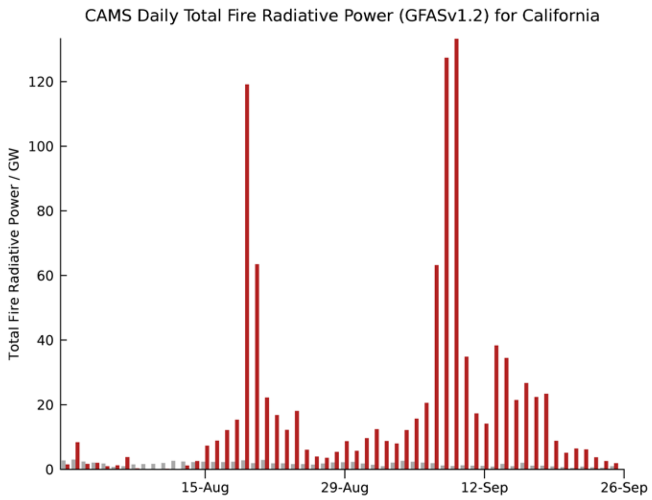


- As in previous cases, highest % of pixels exceeding very high fire danger rating in California forecast 6-8 days ahead of fire activity between 18-22 August and 5-10 September.
- Strong correspondence with highest % and observed active fire emissions.
- Air quality impacts of smoke persisted across California (and the western states) for many days and eventual long-range transport to the North Atlantic and as far as Europe.

Atmosphere Monitoring

CAMS in action: California fires in August-September 2020



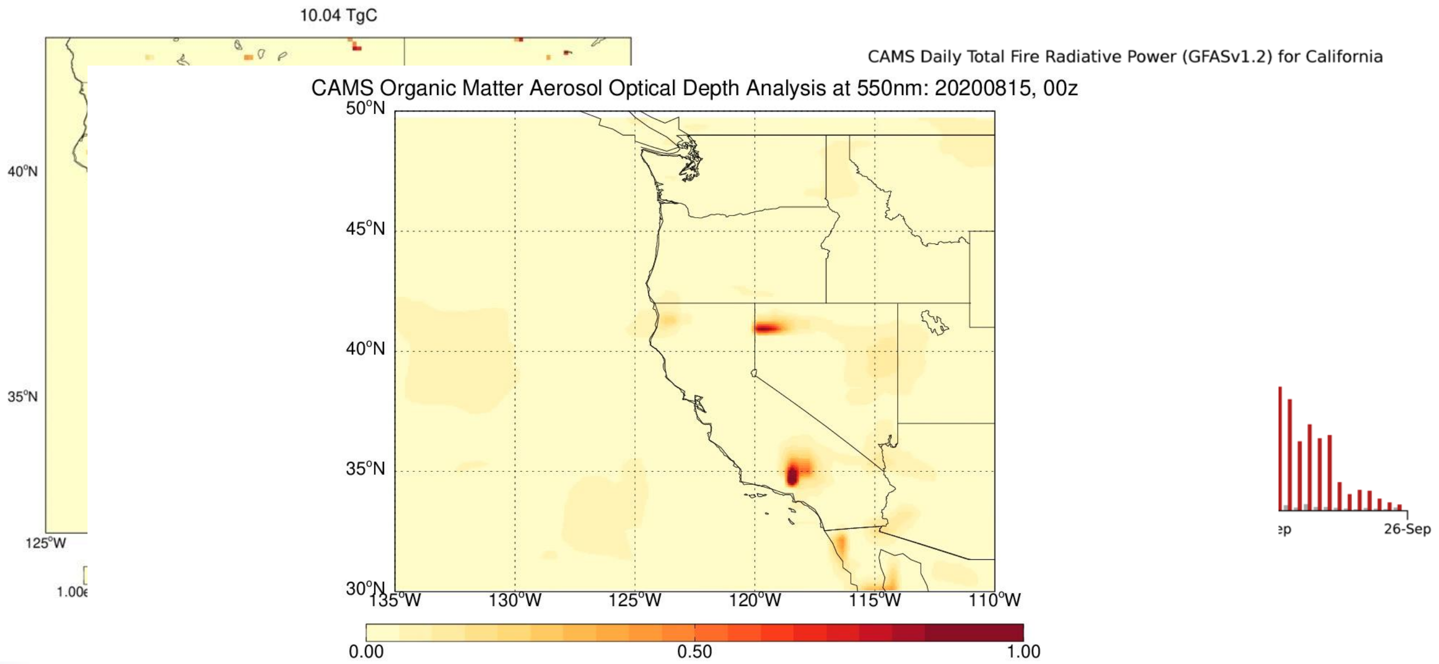


- Widespread wildfires across California and western states through August and September 2020.
- GFAS data used to monitor state-level active fires location and intensity.
- CAMS global analyses and forecasts of aerosol optical depth and total column carbon monoxide used to monitor local and long-range smoke transport.

ECMWF Copernicus Europe's eyes on Earth European Commission

CAMS in action: California fires in August-September 2020

Atmosphere Monitoring



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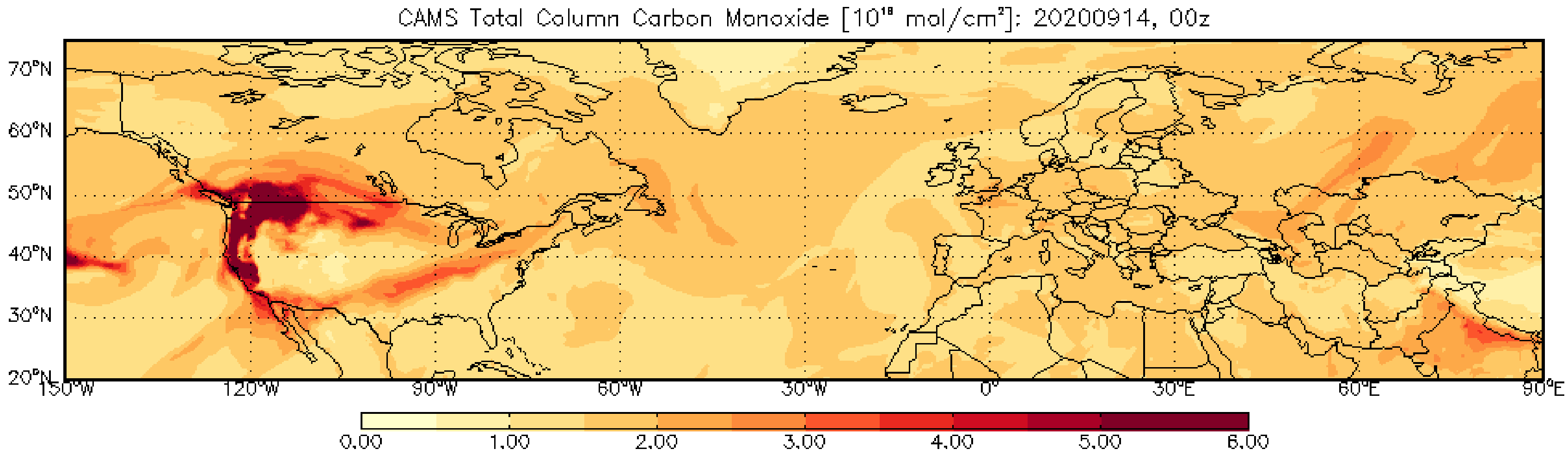
ECMWF Copernicus Europe's eyes on Earth European Commission

CAMS in action: California fires in August-September 2020

CAMS Daily Total Fire Radiative Power (GFASv1.2) for California



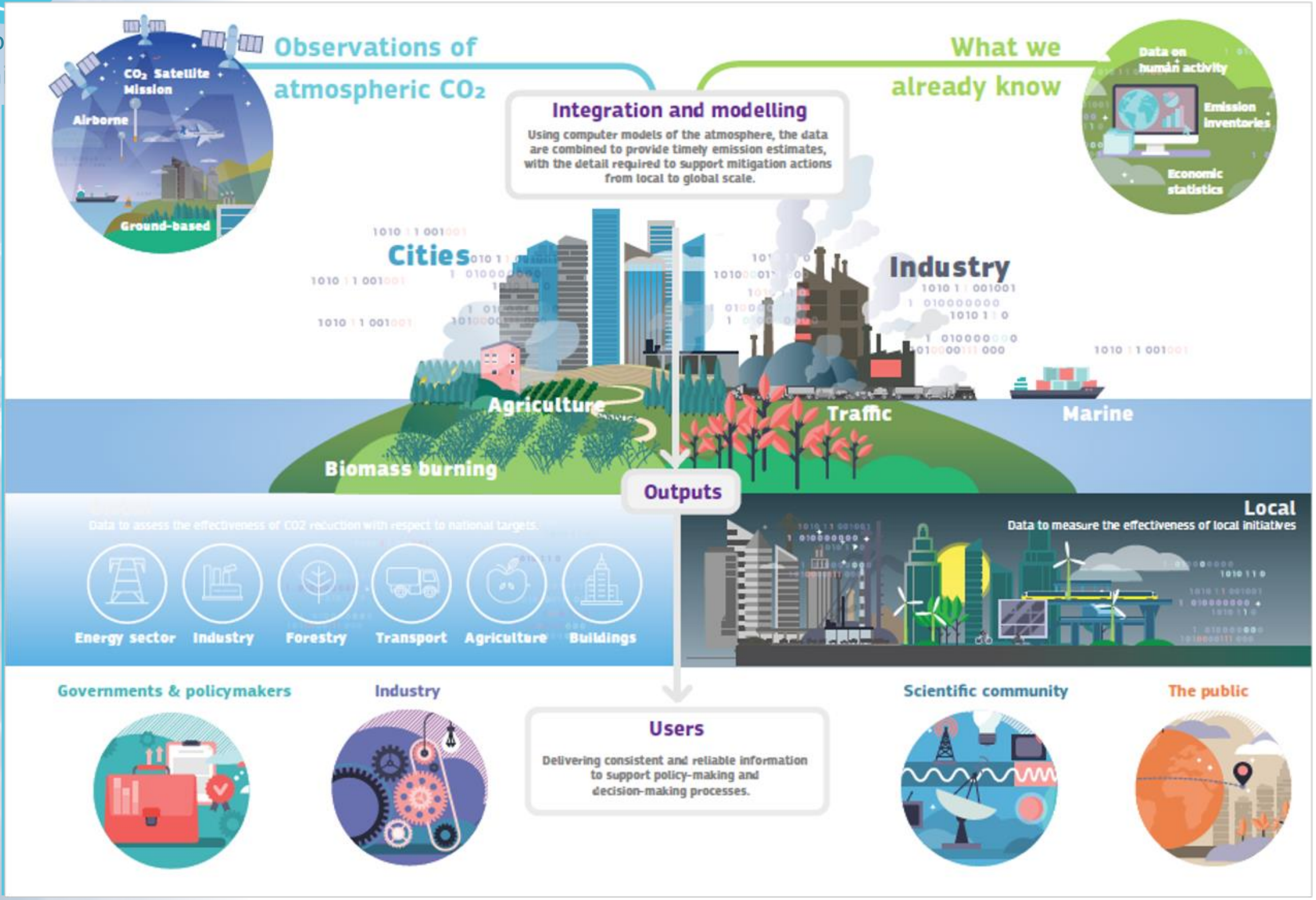
- CAMS global analyses and forecasts of aerosol optical depth and total column carbon monoxide used to monitor local and long-range smoke transport.

Atmosphere Monitoring

Overview

- Brief introduction to emissions
- Examples of emissions inventories & surface fluxes
- Estimating wildfire emissions
- Example case studies on wildfire emissions
  - Arctic
  - California
  - Merging information from the Copernicus services
- Building a CO_2 monitoring service - improving emission estimation

CO_2 monitoring service – operational emission estimation



Combining near-real-time satellite and in situ observations to better quantify CO_2 emission sources – will also be applied to key atmospheric pollutants: NO_2, CO, VOCs.

Operational development:

- Adjoint of model transport and chemistry.
- Long enough window to assimilate observations (12 hours to days/weeks).

Europe's eyes on Earth

IMPLEMENTED BY ECMWF

Atmosphere Monitoring

Summary

- Knowledge of emissions is essentiel to accurately modelling and forecasting atmospheric composition.
  - Several different methods for estimating emissions from anthropogenic and natural sources.
  - Observations are playing an ever-growing role in improving estimation and timeliness for operational monitoring.
- Wildfires are a significant source of pollution to the atmosphere.
  - Heterogeneous in space and time make observations essential.
  - Copernicus services provide a huge amount of complimentary information on underlying conditions and wider impacts on atmospheric composition.