Monitoring wildfires and smoke in the Copernicus Atmosphere Monitoring Service

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Earth Observation for wildfire monitoring workshop, 25-27 May 2021

Acknowledgements:
Francesca Di Giuseppe, Claudia Vitolo, Sebastien Garrigues, Vincent-Henri Peuch, Melanie Ades, Anna Agusti-Panareda, Jerome Barre, Richard Engelen, Johannes Flemming, Antje Innes, Zak Kipling, Freja Vamborg (ECMWF)
CAMS development teams

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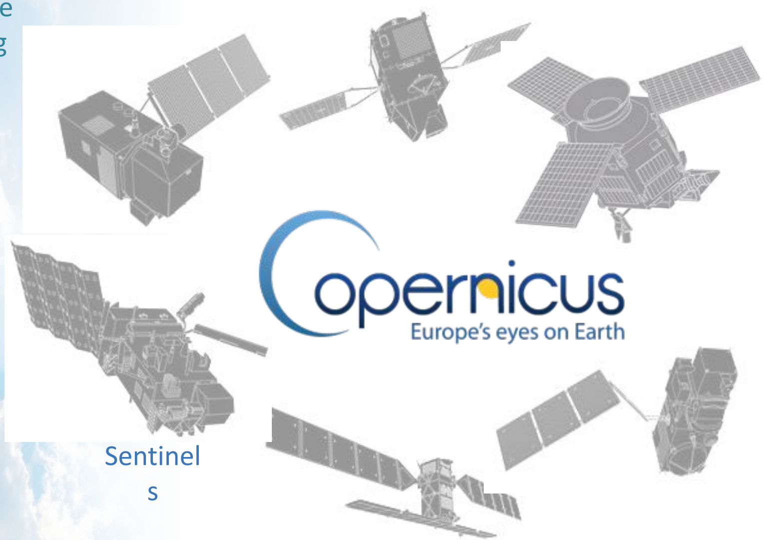

Sentinels

Observations feeding into value-added Services

- 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 all citizens.

User-driven with free and unrestricted data access

Service is implemented by ECMWF

ECWMF is contributing to the Service

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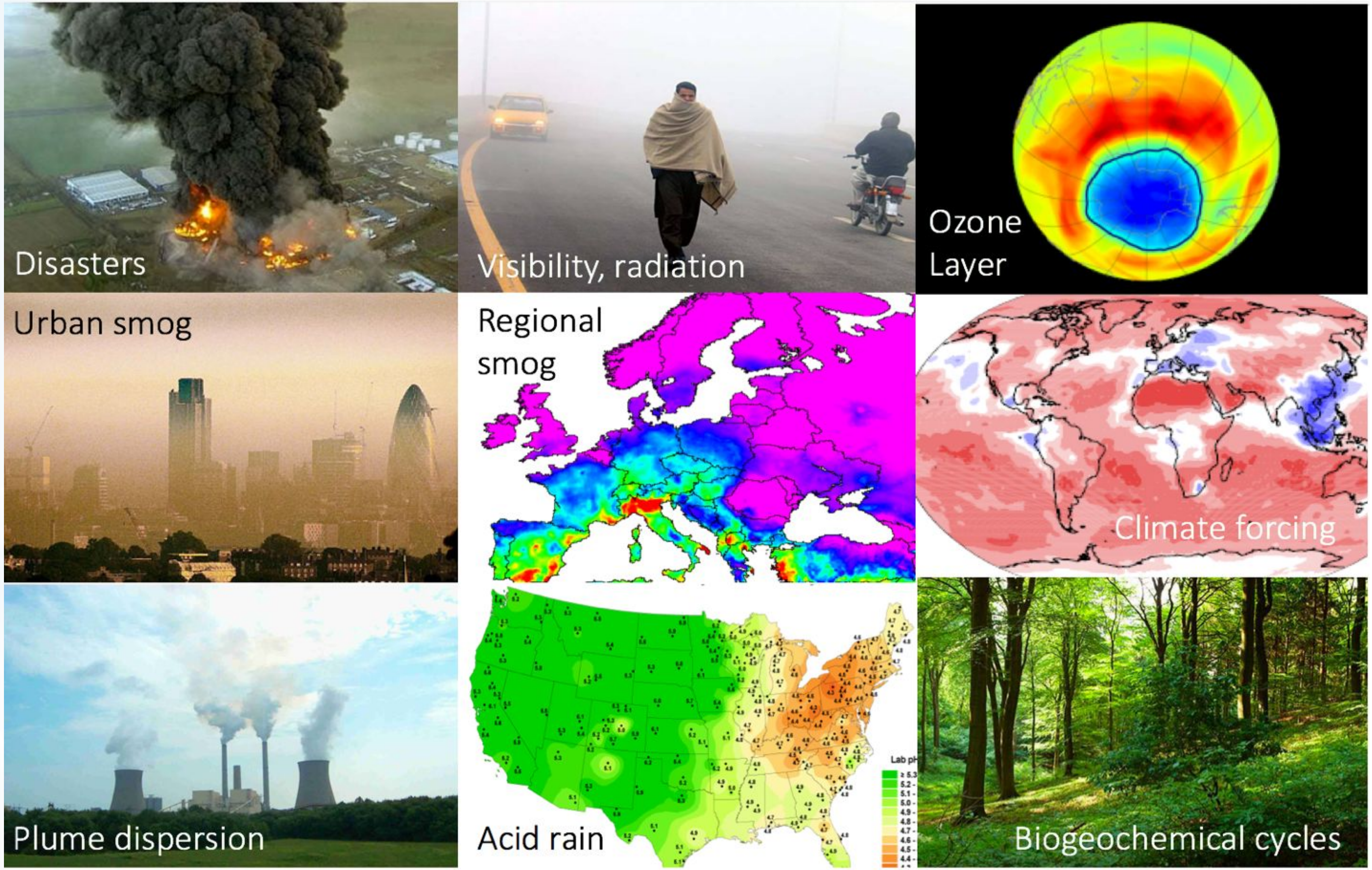
Atmosphere Monitoring

WHY MONITORING ATMOSPHERIC COMPOSITION?



Local < 100km

Regional 100-1000km

Global > 1000km

from D. Jacob (Harvard)

CAMS: COPERNICUS ATMOSPHERE MONITORING SERVICE

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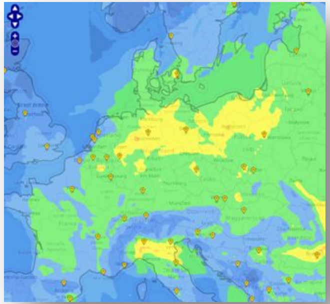
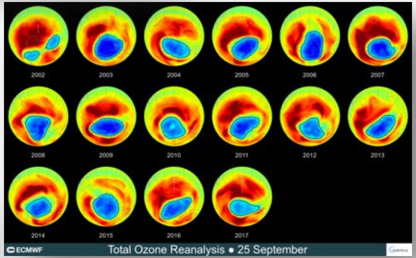
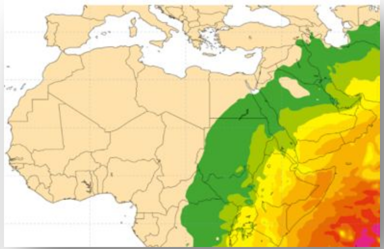


European Air Quality

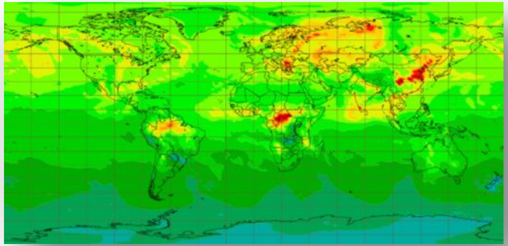


Ozone layer



Solar radiation and UV index

Emissions and surface fluxes



Global analyses, forecasts and reanalyses

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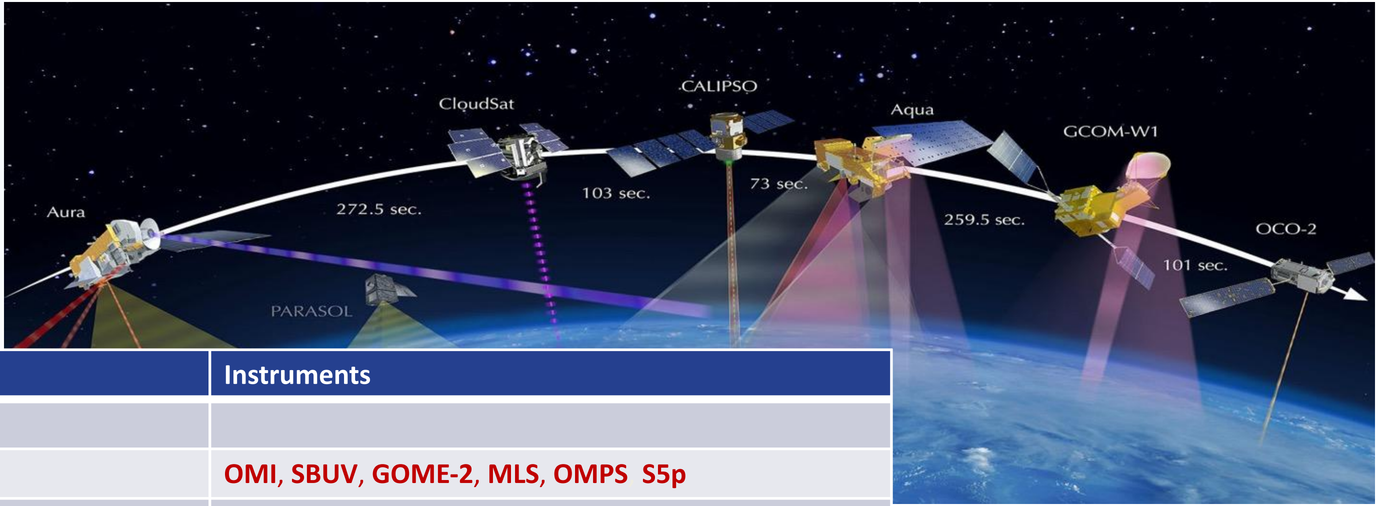
Earth Observation satellites



Species	Instruments
Global system	
O_3	**OMI, SBUV, GOME-2, MLS, OMPS S5p**
CO	**IASI, MOPITT, S5p**
NO_2	**OMI, GOME-2, S5p**
SO_2	**OMI, GOME-2, S5p**
Aerosol	**MODIS, PMAp,** VIIRS, S3
CO_2	**GOSAT, OCO-2**
CH_4	**GOSAT, IASI, S5p**
GFAS fire emissions	**MODIS, SEVIRI*, VIIRS**, Sentinel-3, GOES-E/W*, HIMAWARI-8*

Assimilated **Monitored** Under development *Geostationary platform

CAMS uses Earth Observation data from many satellites for atmospheric composition and weather.

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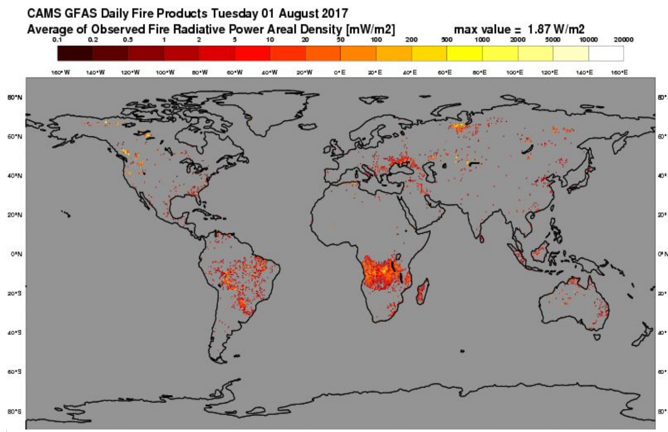
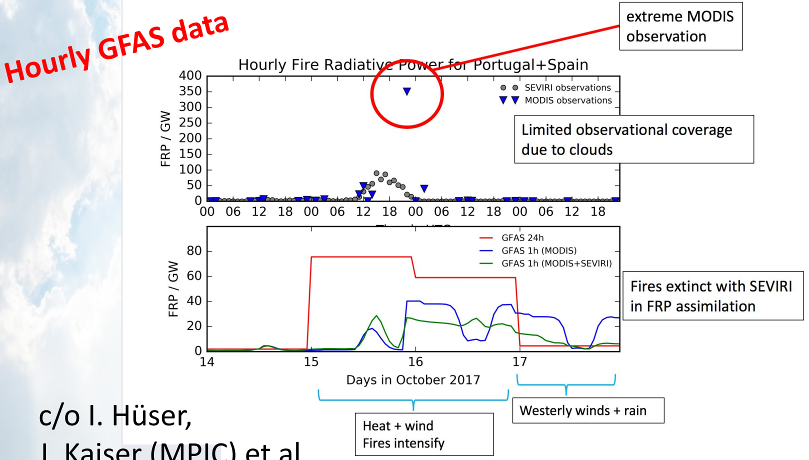
ESTIMATING GLOBAL WILDFIRE EMISSIONS IN CAMS



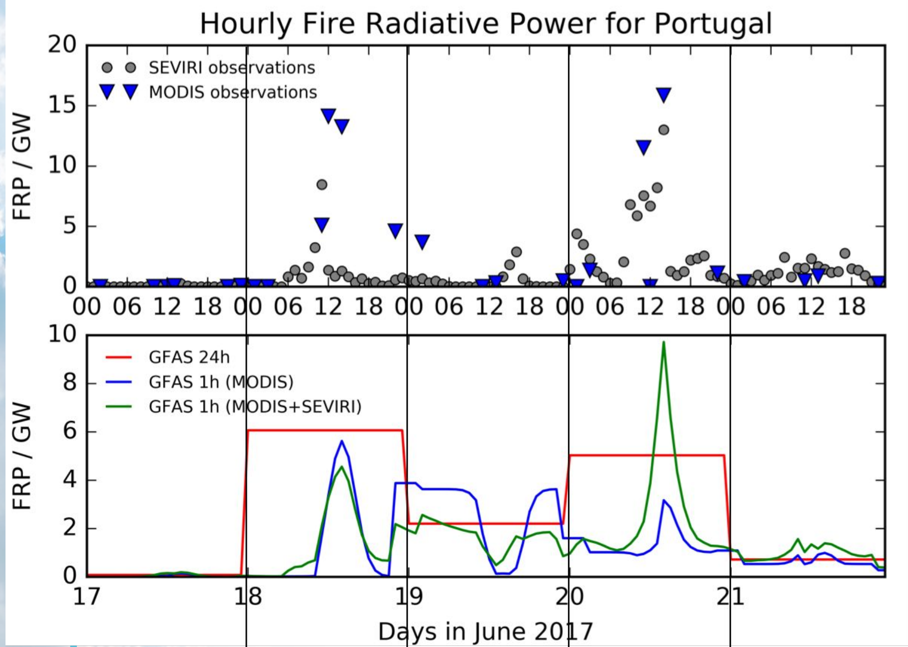


c/o I. Hüser,
J. Kaiser (MPIC) et al.

- Global Fire Assimilation System (**GFAS**); see http://apps.ecmwf.int/datasets/data/cams-gfas/
- 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

GFAS hourly fire emissions

Portugal fires 17-22 June 2017: diurnal cycle (including LEO+GEO obs) improves temporal profile of fire emissions



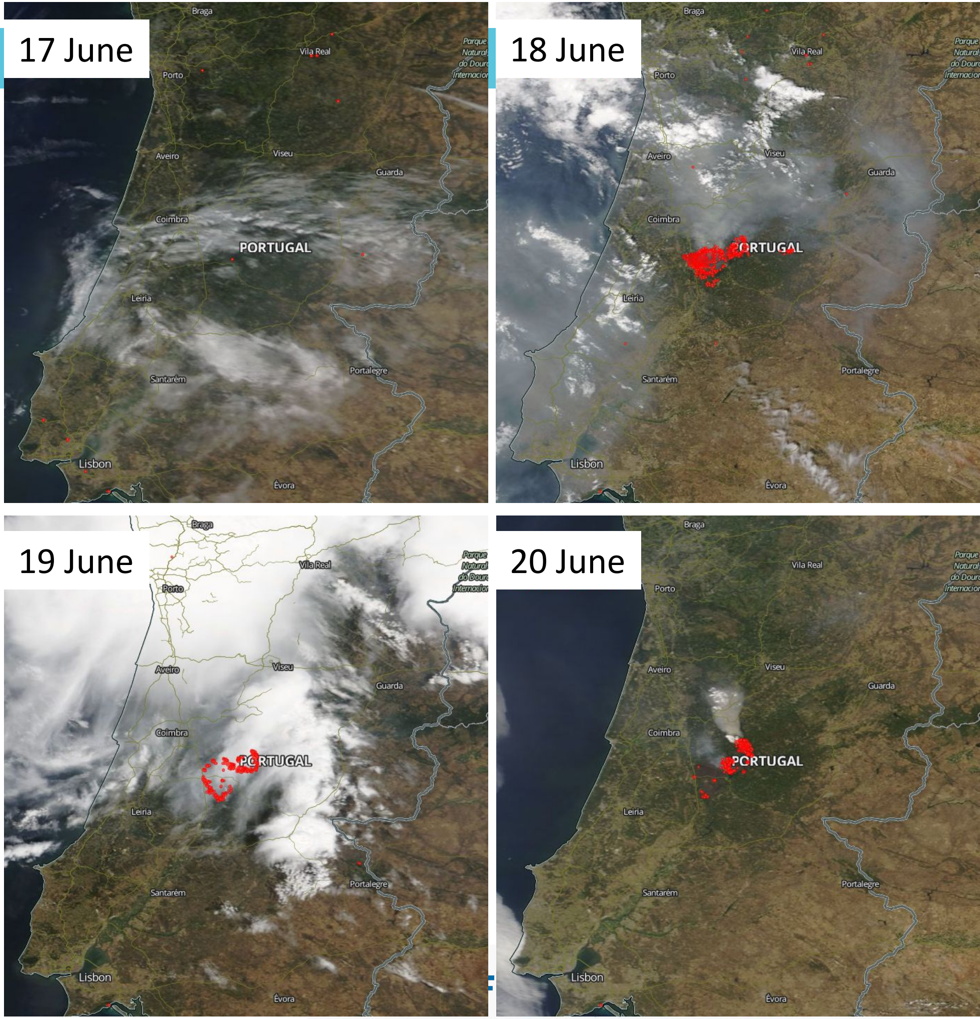
- Fire start reported in afternoon but no observations
- Portugal always at the edge of night-time MODIS swaths

- Fires raging
- First detected at 11 UTC

- Fires burning through the night
- Clouds limit daytime observations

- Fires flare up again

- Distinguishing fires
- extinct at 22/23-06



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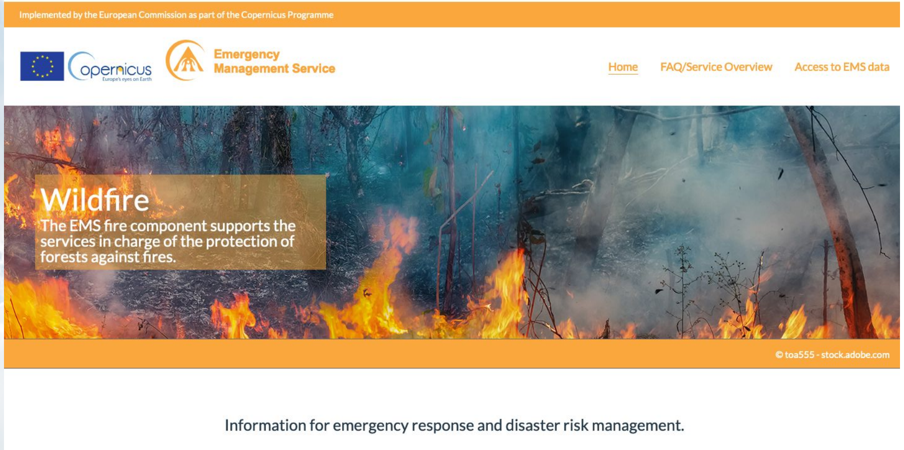
Linking Copernicus Services: From fire monitoring to fire forecasts

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 service is implemented by the EU Joint Research Centre

Flood and fire danger forecasts are provided by ECMWF.

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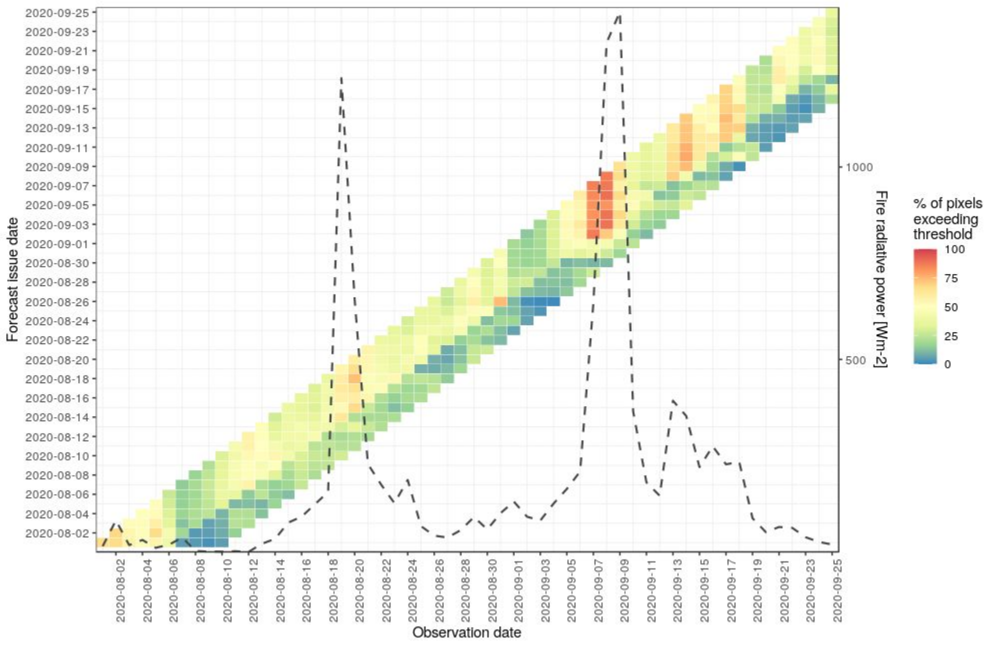
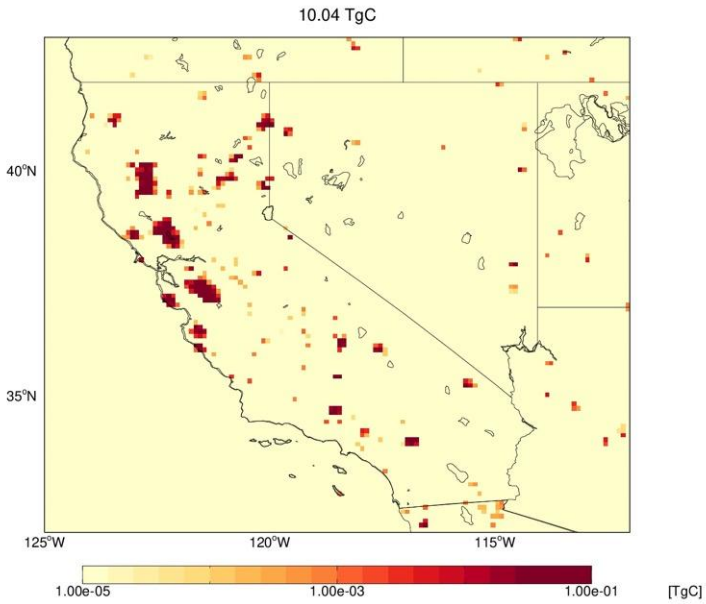
California fires in August-September 2020





- 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.

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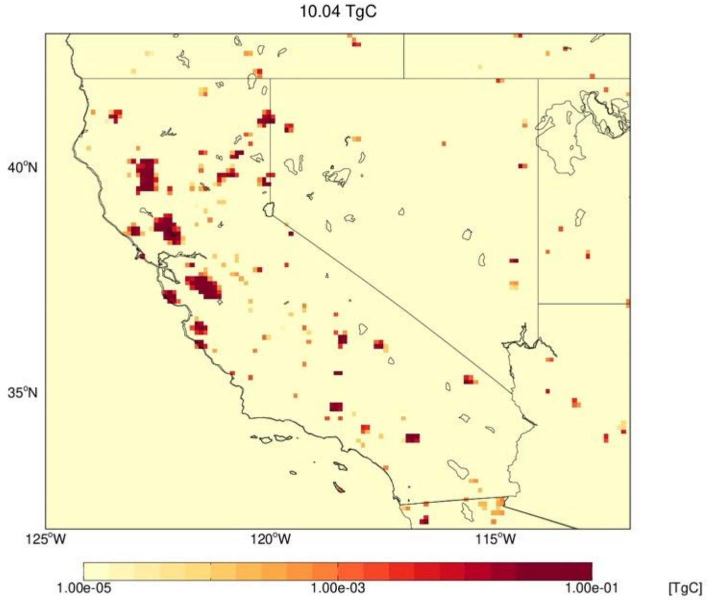
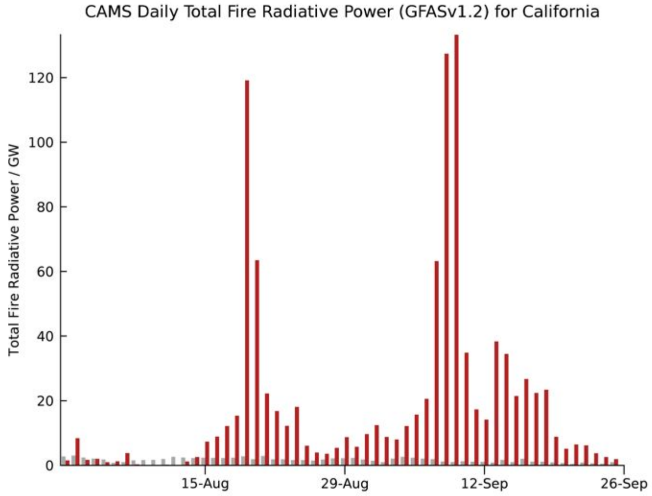
CAMS in action: California fires in August-September 2020





- 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.

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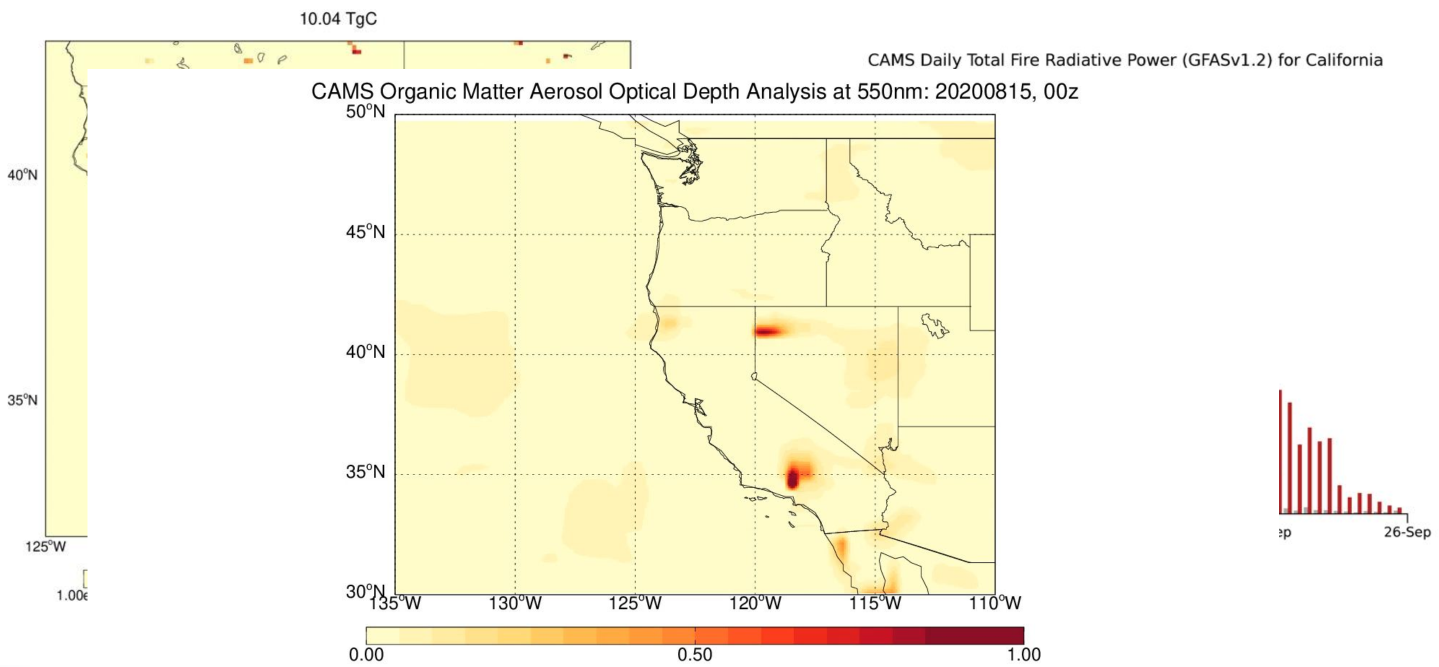
CAMS in action: California fires in August-September 2020



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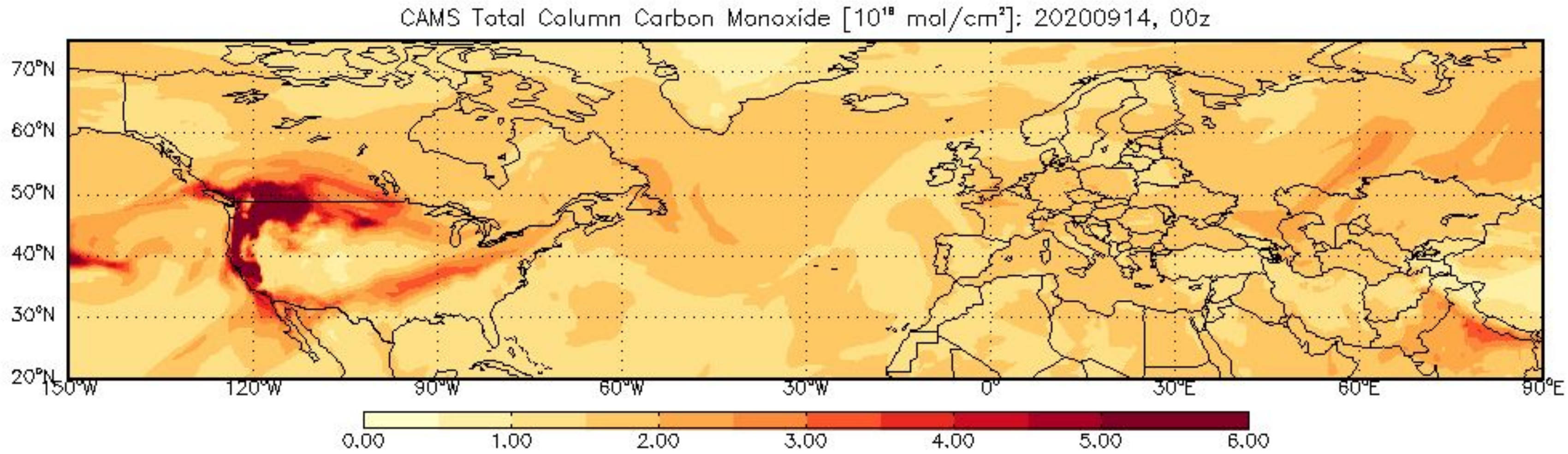
CAMS in action: California fires in August-September 2020

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.

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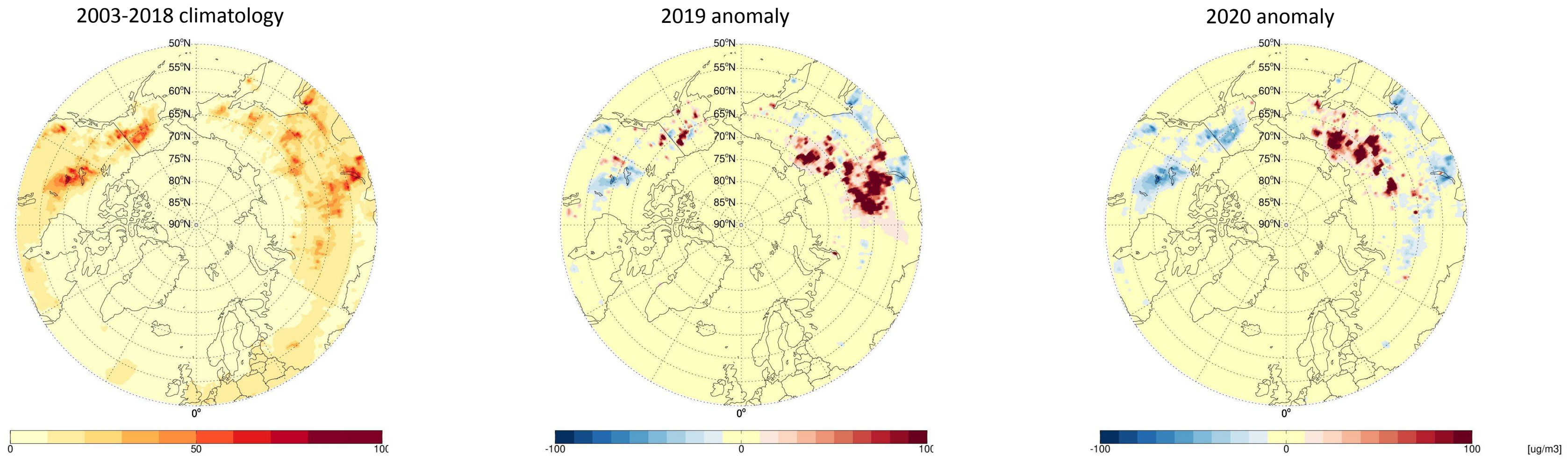
Air quality impacts of high latitude wildfires

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



- 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.

Atmosphere Monitoring

Future directions for fire monitoring in Copernicus and ECMWF

- CAMS and CEMS provide operational, near-real-time, independent information on global fire weather and emissions. All data are free and open access.
  - Future developments will bring elements of theses services closer together to provide end-to-end information on the role of fires in atmospheric composition.
  - Several case studies which show consistent agreement between forecasts and observed activity in different regions around the world.

- A diurnal cycle of fire emissions has been developed in GFAS to provide hourly emissions estimates based on FRP observations from Low Earth Orbit (MODIS, VIIRS, Sentinel-3) and Geostationary Orbit (SEVIRI, GOES-R/-S, Himawari-8).

- Modelling of the fire emissions, following the fire danger forecasts will improve atmospheric composition forecasts with more realistic changes to environmental changes over the duration of the forecast (currently fixed in CAMS air quality forecasts).

- Help and support available:
  - CAMS: copernicus-support@ecmwf.int
  - CEMS: jrc-effis@ec.europa.eu

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Data and tools to forecast wildfire danger - Copernicus Emergency Management Service (CEMS-Fire)

Claudia Vitolo

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European Centre for Medium-range Weather Forecasts

Fire danger forecasting team:
Francesca Di Giuseppe, Ruth Coughlan, Milana Vuckovic, Christopher Barnard, Martin Blick.

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The European Earth Observation Programme

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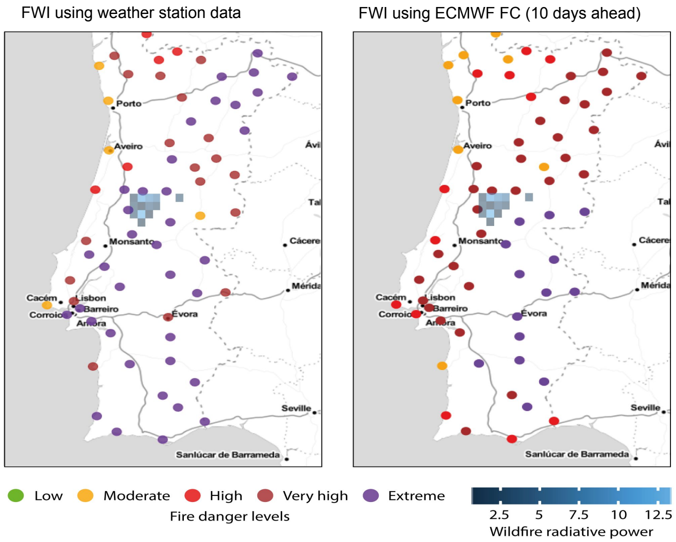
CEMS-Fire activities for proactive fire management practices

Monitoring and forecasting **fire weather**.

Monitoring fire weather can be done using weather station data, but the information is:

- Only available at discrete locations → CEMS provides homogeneous global coverage
- Only available for the current day → CEMS makes use of **ECMWF**'s IFS to forecast fire weather days/months in advanced

Fire weather:
weather conditions conducive of a dangerous fire, typically this includes high temperature, low humidity and strong winds, but other variables can play a role.



CEMS-Fire products are useful for:

- Early Warning Systems
- Decision makers
- Scientists/Researchers

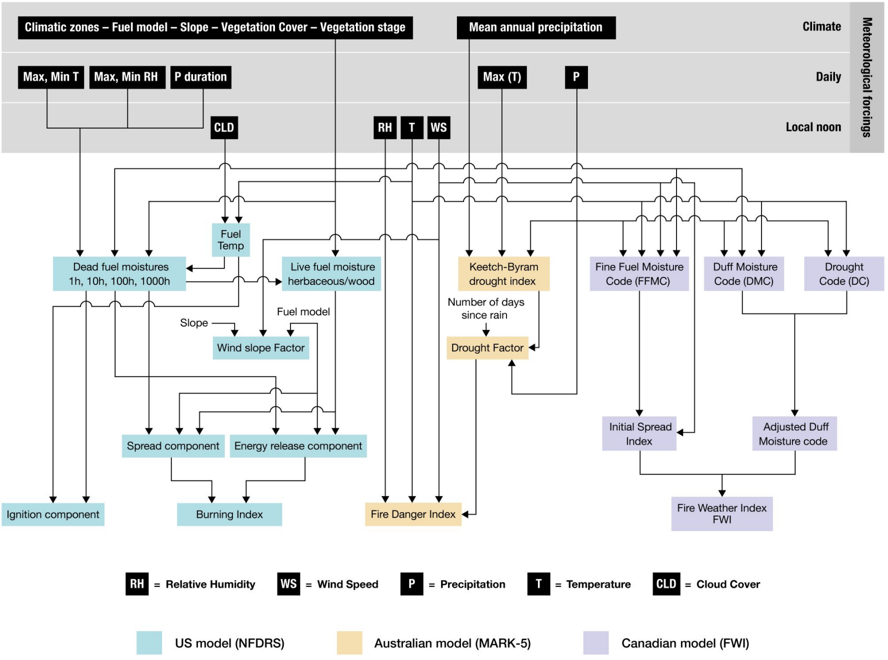
How do we measure danger related to fire weather?

Fire weather/danger => weather conditions conducive of a dangerous fire but conditional to an ignition to occur (only a potential danger!).

Three main systems:

- **Canadian Forest Fire Weather Index** (most widely used around the world)
- The U.S. Forest Service National Fire-Danger Rating System
- The Australian McArthur's Forest Fire Danger Meter

The **Global ECMWF Fire Forecasting (GEFF) system** implements the three systems.

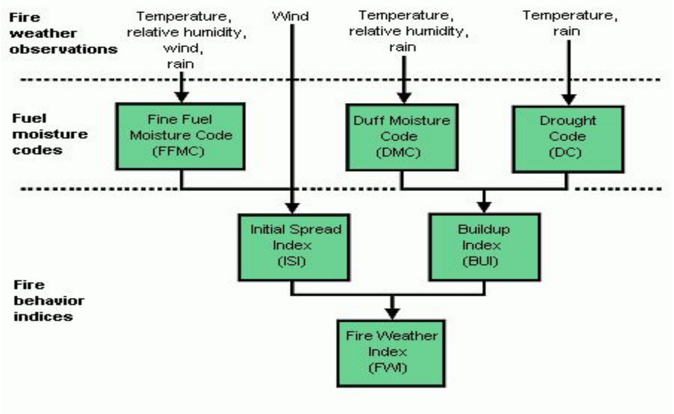


*Di Giuseppe, F., Vitolo, C., Krzeminski, B., Barnard, C., Maciel, P., and San-Miguel, J.: "**Fire Weather Index: the skill provided by the European Centre for Medium-Range Weather Forecasts ensemble prediction system**", Nat. Hazards Earth Syst. Sci., 20, 2365–2378, https://doi.org/10.5194/nhess-20-2365-2020, 2020.*

*Di Giuseppe, Francesca, et al. "**The potential predictability of fire danger provided by numerical weather prediction.**" Journal of Applied Meteorology and Climatology 55.11 (2016): 2469-2491.*

The Canadian Fire Weather Index System

- Three non interactive fuel layers
- Drying depends on long and short term temperature, humidity and precipitation conditions
- Wind mostly controls flammability
- Combinations of dryness and flammability produces a general index of fire danger called **Fire Weather Index (FWI):**
  - FWI is a numeric rating in the range [0, Inf[
  - FWI gives an indication of the consequences of a fire, if one was to start. The higher the FWI, the more dangerous the conditions.



https://cwfis.cfs.nrcan.gc.ca/background/examples/fwi

*Alexander, M.E.; De Groot, W.J. 1988. **Fire behavior in jack pine stands as related to the Canadian Forest Fire Weather Index System**. Canadian Forest Service, Northern Forestry Centre, Edmonton, AB. Poster with text.*

*Quintilio, D.; Fahnestock, G.R.; Dubé, D.E. 1977. **Fire behavior in upland jack pine: the Darwin Lake Project**. Canadian Forest Service, Northern Forestry Centre, Edmonton, AB. Information Report NOR-X-174.*

Global ECMWF Fire Forecasting (GEFF) system - data offering

Climatological data sets, ~40 years of daily reanalysis**

- ERA5, ~28 Km resolution, 5 days behind real-time, using IFS cycle 41r2 (2016), ~50GB/index
  Vitolo, C., Di Giuseppe, F., Barnard, C. et al. ERA5-based global meteorological wildfire danger maps. Sci Data 7, 216 (2020). https://doi.org/10.1038/s41597-020-0554-z
- ERA-Interim, ~80 Km resolution, 2 months behind real-time, using IFS cycle 31r2 (2006), ~7.5GB/index
  Vitolo, C., Di Giuseppe, F., Krzeminski, B. et al. A 1980–2018 global fire danger re-analysis dataset for the Canadian Fire Weather Indices. Sci Data 6, 190032 (2019). https://doi.org/10.1038/sdata.2019.32

Medium-range forecasts, issued daily for 12 local noon, using IFS cycle 47r2 (May 2021)

Di Giuseppe, F., Vitolo, C., Krzeminski, B., Barnard, C., Maciel, P., and San-Miguel, J.: Fire Weather Index: the skill provided by the European Centre for Medium-Range Weather Forecasts ensemble prediction system, Nat. Hazards Earth Syst. Sci., 20, 2365–2378, https://doi.org/10.5194/nhess-20-2365-2020, 2020.

- High resolution* ~9 Km (1 realisation, 10 days lead time, ~3.6 GB/day)
- ENS prediction* ~18 Km (51 ensemble members, 15 days lead time, ~20 GB/day).
- Statistical indicators*: anomaly, ranking, Extreme Forecast Index (EFI) and Shift Of Tail (SOT)
- Experimental products**:
  - Hourly FWI (up to 3 days)
  - Probability of ignition from lightning

Seasonal forecast, to be issued monthly, 6 months lead time (work in progress)**

- Test development using ECMWF seasonal forecast S5
- Validation in collaboration with NASA

ECMWF

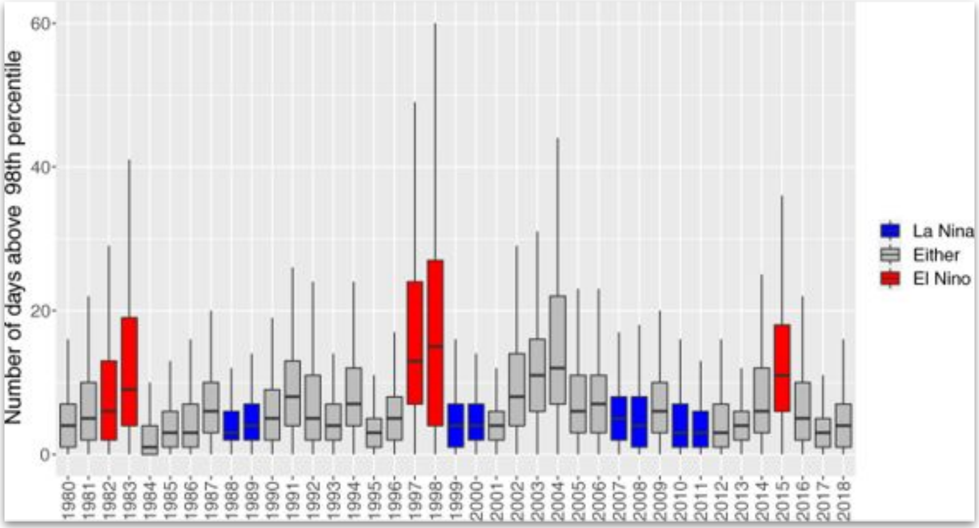
* EC-JRC products available under request from EFFIS/GWIS: https://effis.jrc.ec.europa.eu/apps/data.request.form/
Data also available in ECFS and from 2021 also in MARS (under JRC license)

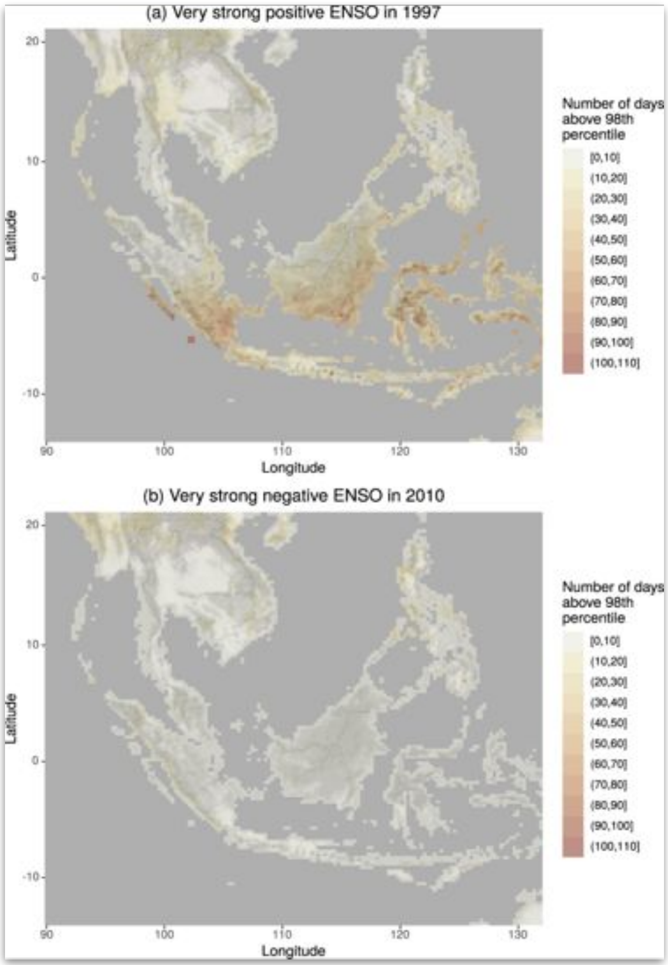
** Copernicus products available on the Climate Data Store: https://cds.climate.copernicus.eu/

Fire danger reanalysis

Used for:

- Fire regime changes
- Fire season modifications
- Identification of fire prone areas
- Climate teleconnection
- … and more

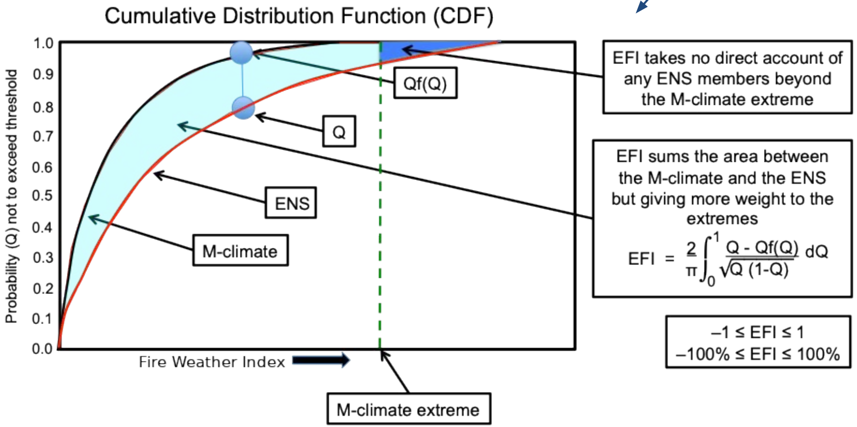


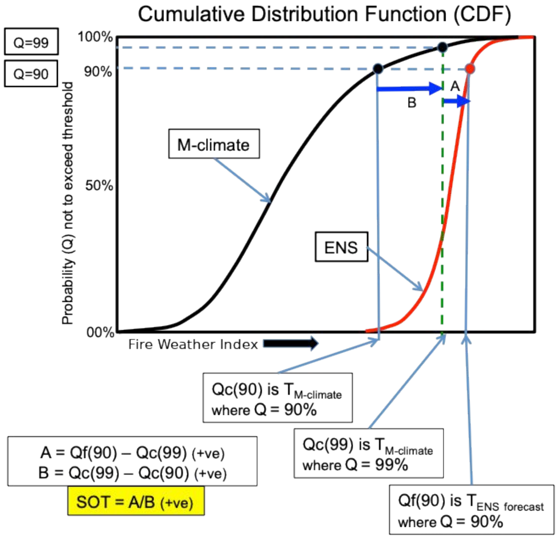


Vitolo, C., Di Giuseppe, F., Barnard, C. et al. **ERA5-based global meteorological wildfire danger maps.** Sci Data 7, 216 (2020). https://doi.org/10.1038/s41597-020-0554-z

Probabilistic products: anomaly, EFI and SOT

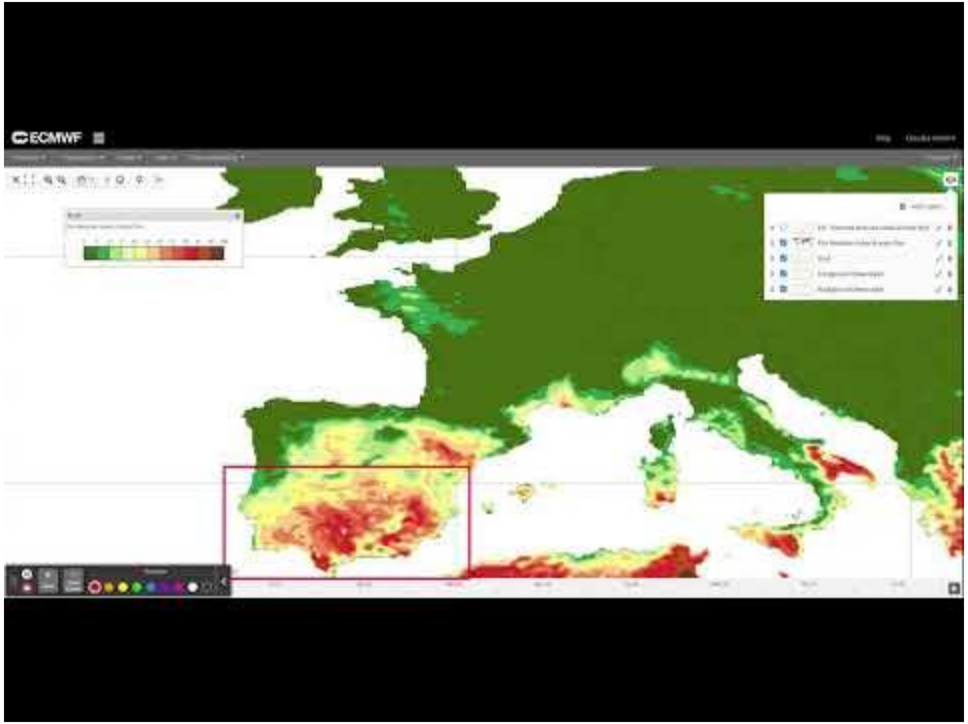
FWI is classified into 6 danger levels (from very low to extreme), however the thresholds that define these levels are often pre-defined, while different ecosystems would require a local calibration. When assessing extreme events, it is not advisable to rely on the raw FWI but refer to statistical indicators such as anomalies, Extreme Forecast Index (EFI) and the Shift Of Tail (SOT).





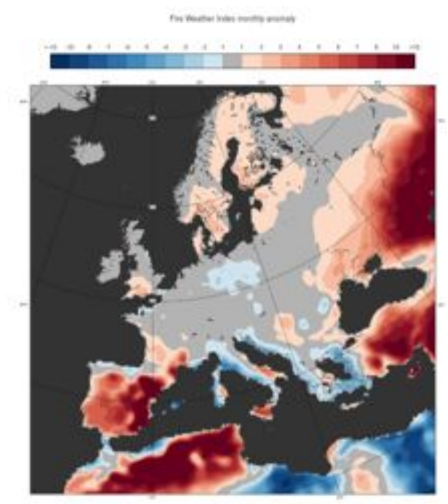
ECMWF

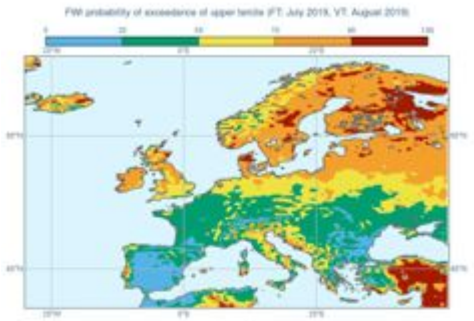
FWI vs EFI for identifying extreme events: an example



Seasonal forecast

- Forecast of monthly anomaly for the FWI are generated for up to 6 months ahead to provide an outlook of the likely fire danger conditions in the incoming period.
- The forecast is now produced in real time once a month.
- The anomalies are evaluated with respect to the climate defined in 1993-2016.

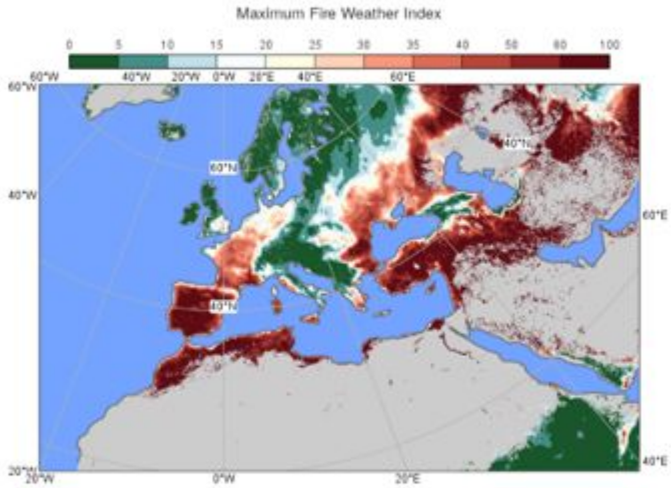


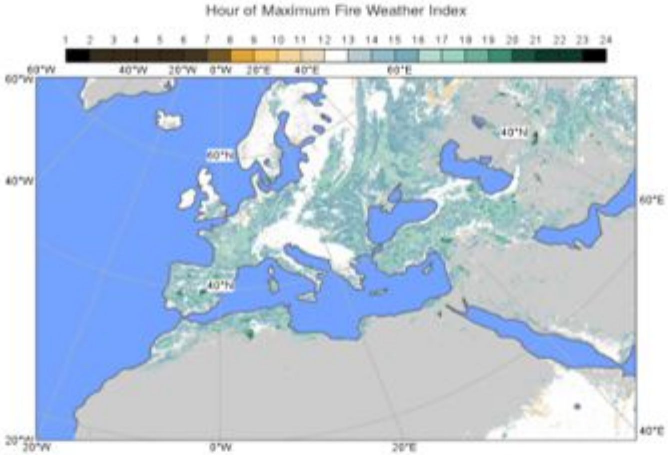


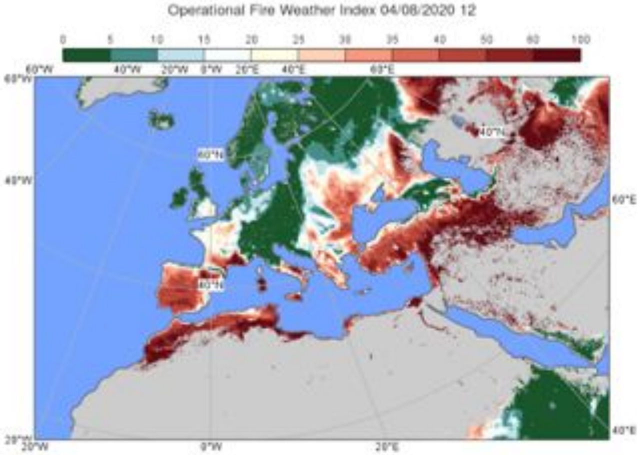
https://effis.jrc.ec.europa.eu/about-effis/technical-background/seasonal-forecast-explained

Experimental: Max hourly FWI for the day

- Maximum fire danger might not occur at 12 local time!
- 24 independent calculations are performed at different local time
- Forecast is re-initialised with the 12 local time forecast
- Maximum fire danger & time at which it occurs







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Experimental: Machine Learning model to predict ignition from lightning

- Dry lightning are more likely to ignite a fire than lightning associated with heavy precipitation
- The key predictors of natural ignitions are lightning, fuel availability and moisture content.

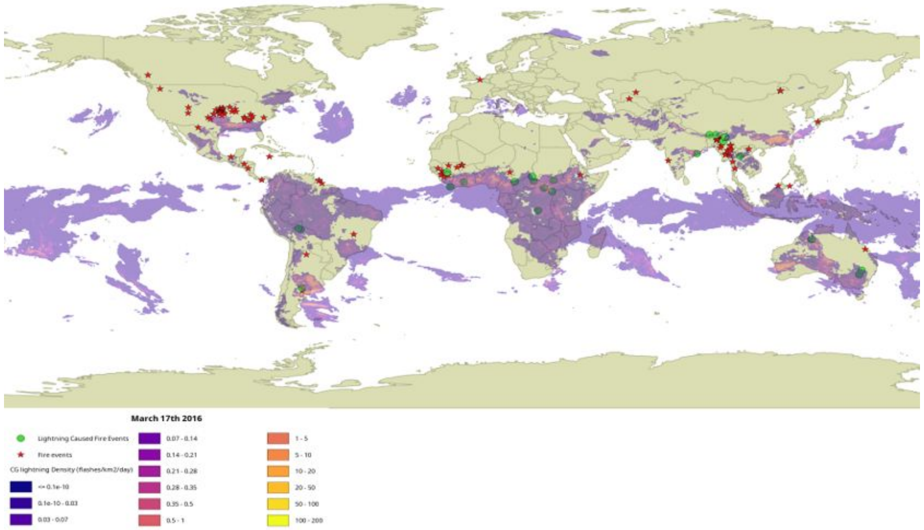

Photo by [Jonathan Bowers](#) on [Unsplash](#)

Coughlan, R, Di Giuseppe, F, Vitolo, C, Barnard, C, Lopez, P, Drusch, M. **Using machine learning to predict fire-ignition occurrences from lightning forecasts**. Meteorol Appl. 2021; 28:e1973. https://doi.org/10.1002/met.1973

Thank you!