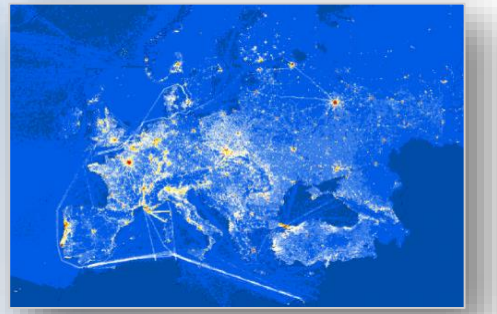
The role of satellite data in the Copernicus Atmosphere Monitoring Service

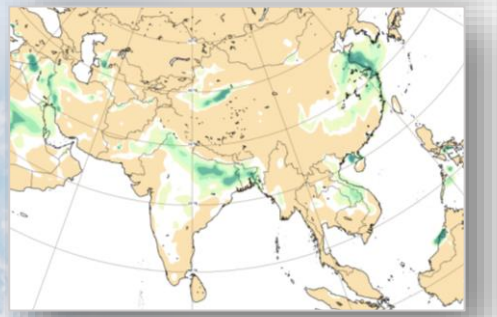
Mark Parrington (mark.parrington@ecmwf.int)

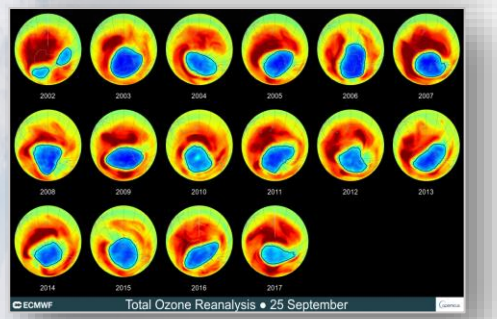
Acknowledgements: Vincent-Henri Peuch, Richard Engelen, Johannes Flemming, Antje Innes, Miha Razinger, many ECMWF colleagues & CAMS providers

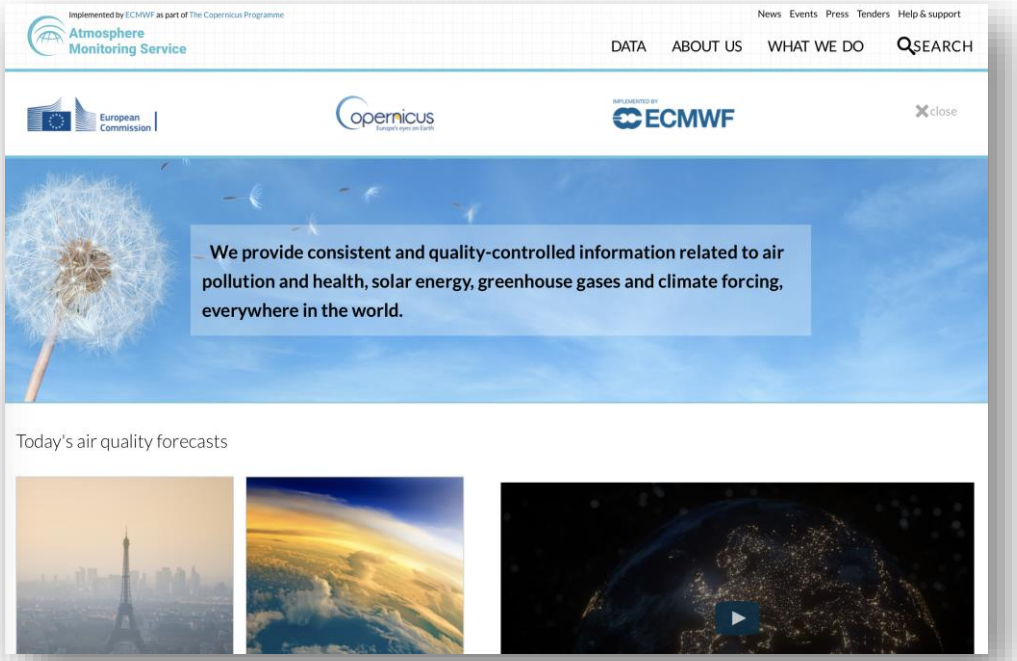
http://atmosphere.copernicus.eu

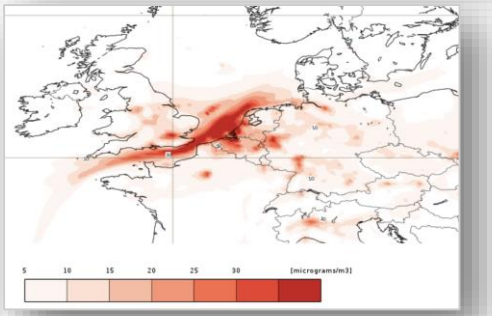
Atmosphere Monitoring

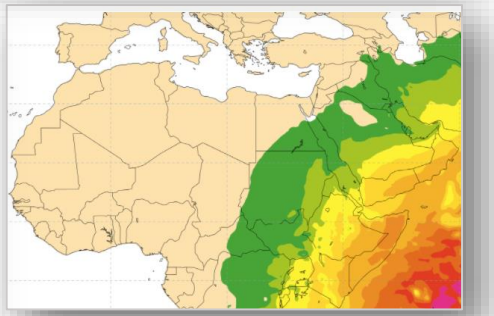












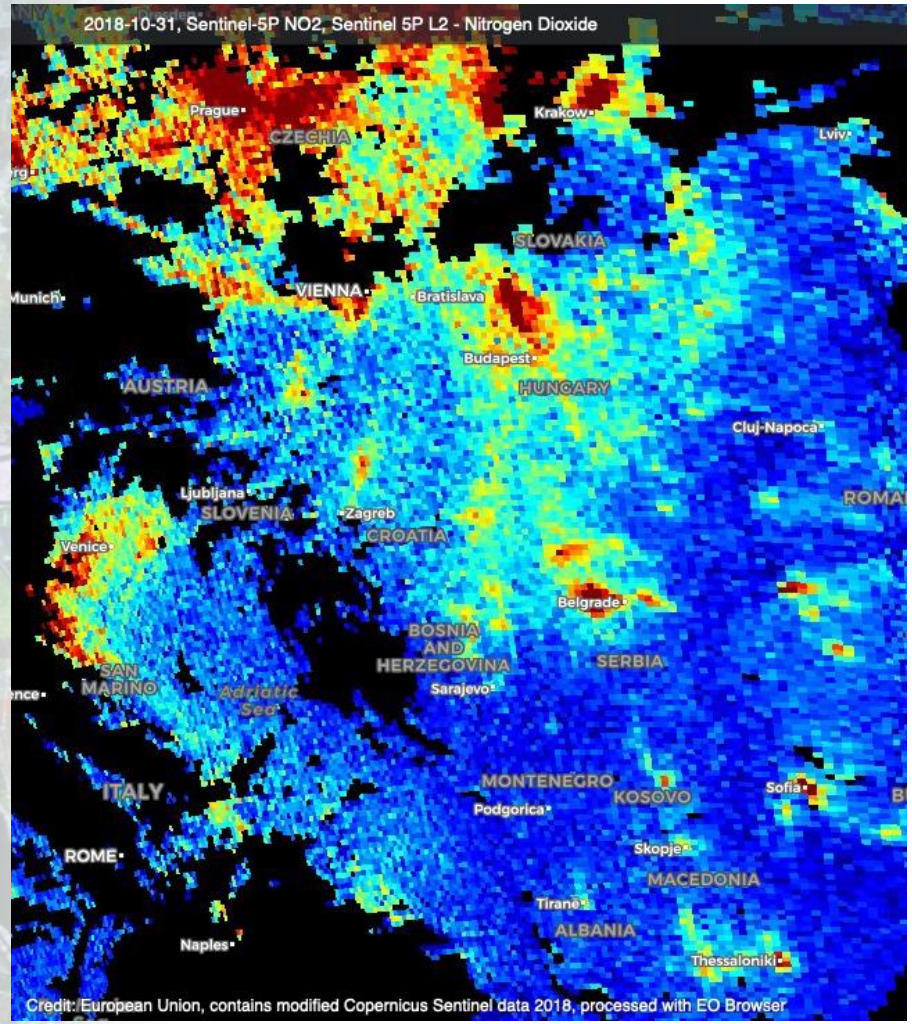
The CAMS portfolio includes Earth Observation based information products about:

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

This is delivered by a large European consortium (196 entities through 75 contracts).

ECMWF Copernicus Europe's eyes on Earth European Commission

Why is CAMS needed?



Example: NO_2 tropospheric column from Copernicus Sentinel-5P (31/10/2018)

Observations are essential, but **direct use** is generally **limited**:

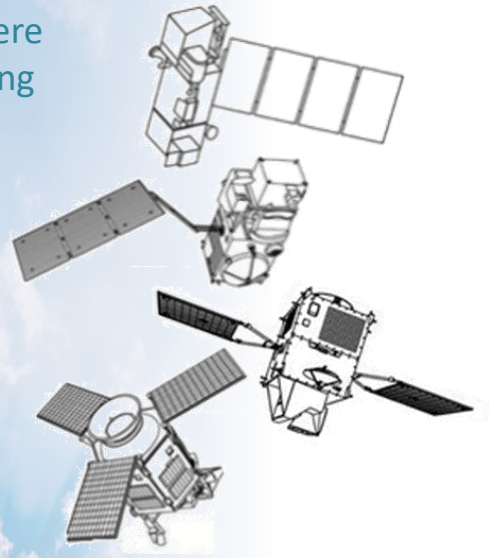
- gaps in space and time
- observed quantities may not be directly relevant (vertical column vs surface concentration)
- can be complex and numerous

What CAMS does:

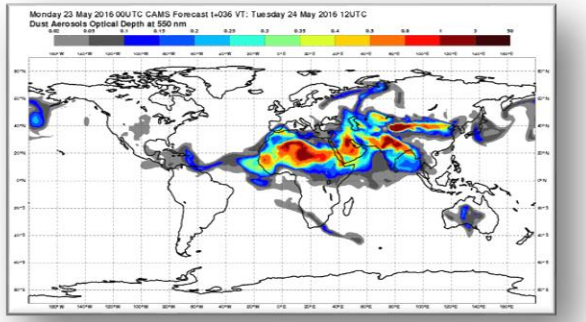
- blend observations (satellite and non satellite) with model to provide a consistent 3D state
- forecasts, a few days ahead
- reanalyses over past years or decades

CAMS INFORMATION FLOW

Atmosphere Monitoring

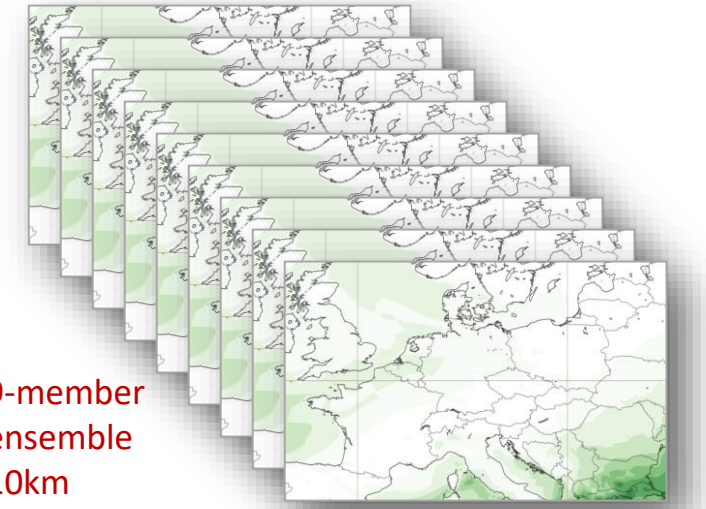


Earth Observation from satellite (>75 instruments) and in-situ (regulatory and research)

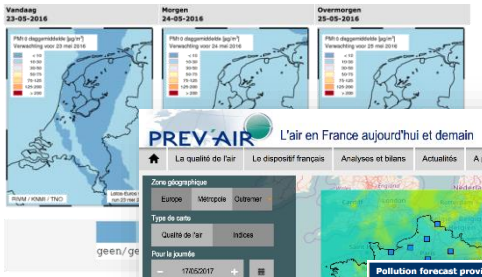


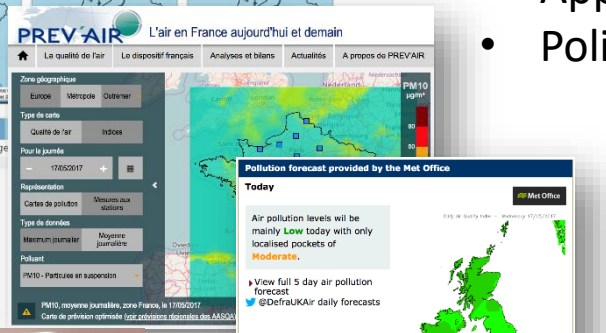
IFS 40km (oper) / 80km (rean) Globe

CAMS main operational data assimilation and modelling systems



9-member ensemble 10km Europe





CAMS users
- Applications
- Policy products

The Weather Channel

iOS

CNN

euronews.

ECMWF Copernicus Europe's eyes on Earth European Commission

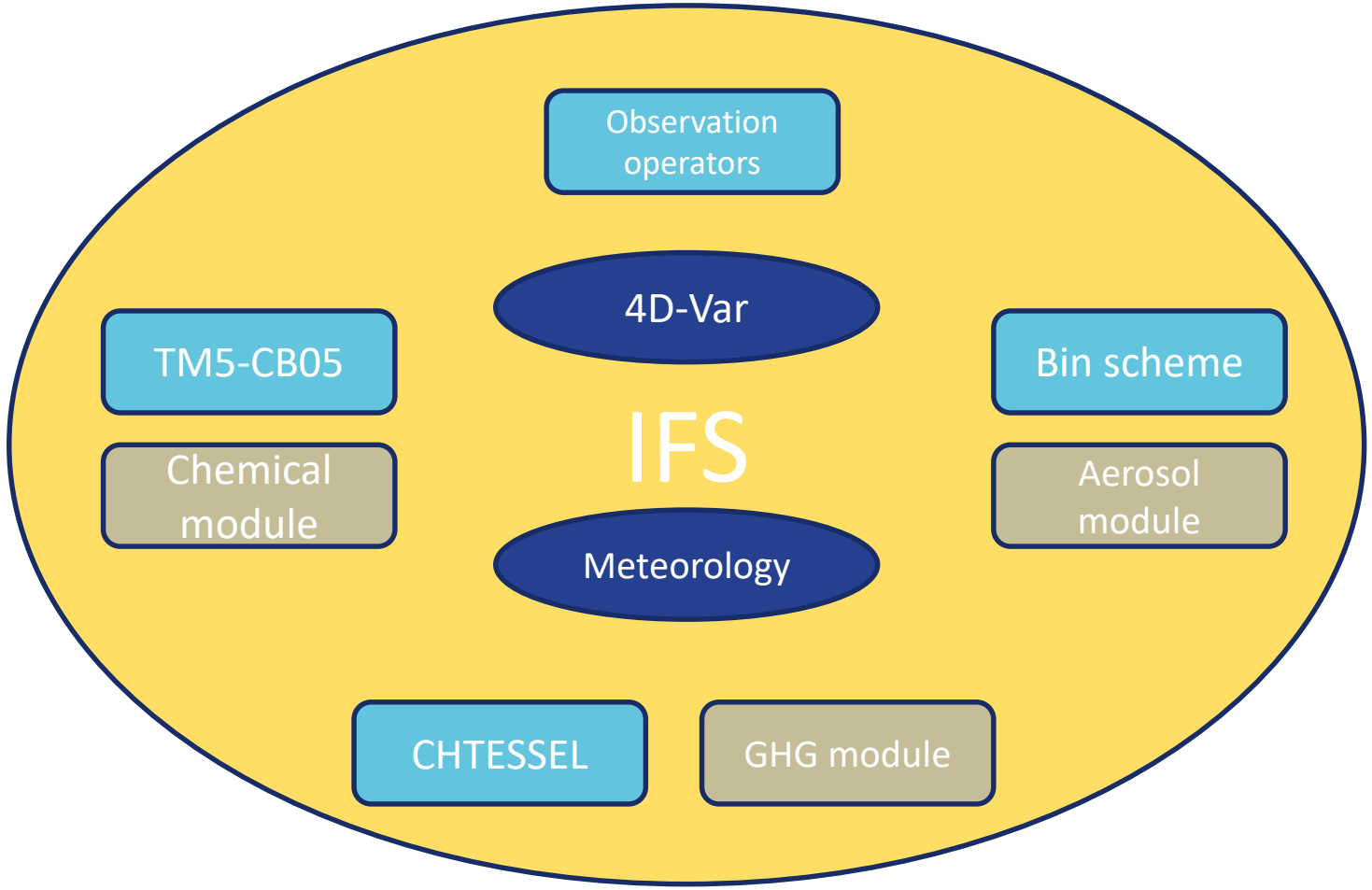
Atmosphere Monitoring

Atmospheric composition in the ECMWF IFS model

The CAMS global production system is the ECMWF Integrated Forecast System (IFS).

IFS is the full NWP forecasting and data assimilation system of ECMWF.

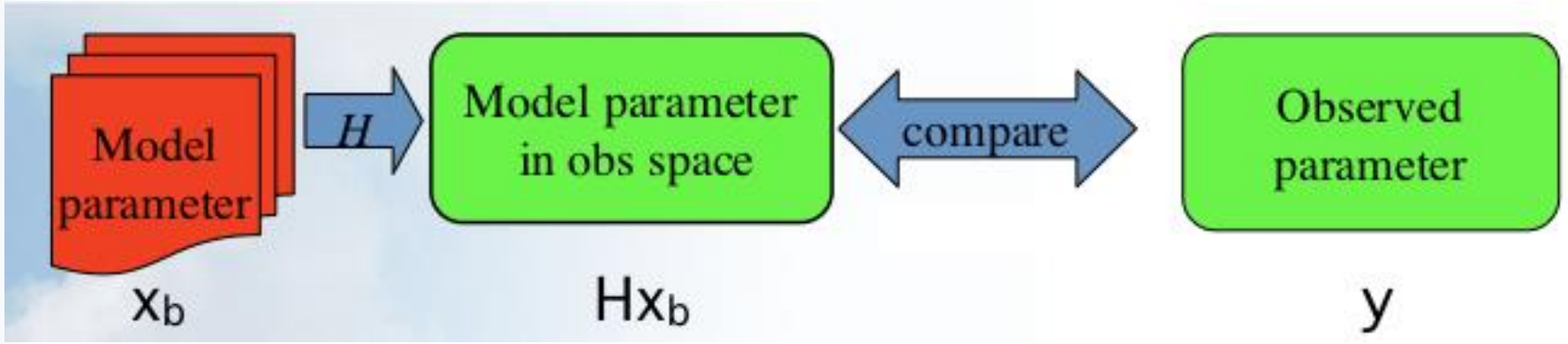
In CAMS, assimilated data includes all meteorological observations as well as atmospheric composition.



ECMWF Copernicus Europe's eyes on Earth European Commission

Atmosphere Monitoring

Observation operator



- To assimilate any data we need a means of directly comparing the model parameter with an observed quantity.
- The observation operator (H) converts a model parameter for comparison against an observation in observation space (i.e., taking into account location, time of day, etc.).
- Simplest form is interpolation from model grid to observation location (e.g., in situ measurements).
  - For satellite observations it also includes complex transformations based on the physics of the measurement.

Near-real-time satellite data usage

Species	Instruments
Global system	
O_3	**OMI, SBUV-2, GOME-2, MLS, TROPOMI, OMPS,** IASI
CO	**IASI, MOPITT, TROPOMI**
NO_2	**OMI, GOME-2, TROPOMI**
SO_2	**OMI, GOME-2, TROPOMI,** IASI
Aerosol	**MODIS, PMAp,** VIIRS, SLSTR, SEVIRI
CO_2	**GOSAT, OCO-2**
CH_4	**GOSAT, IASI, TROPOMI**
GFAS: Fire Radiative Power **Assimilated** **Monitored** Future	**MODIS**, GOES-E/W*, **SEVIRI*,** SLSTR, **VIIRS**, HIMAWARI-8*

*Geostationary platform

A wide-range of atmospheric composition satellite observations are assimilated in the IFS to produce daily analyses.

Control runs (with no data assimilated) and forecasts (initialised from analyses) are also produced in CAMS.

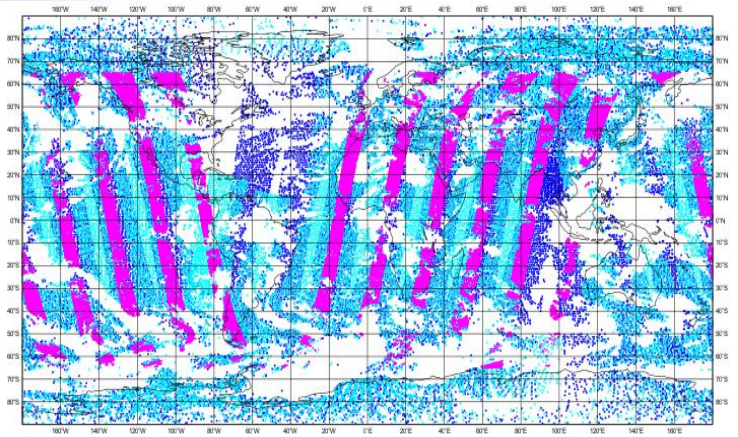
CAMS data used for field campaign planning and evaluating special events.

Composition data additional to thousands of assimilated meteorological data.

Assimilated reactive gases in CAMS real-time system

Atmosphere Monitoring

CO

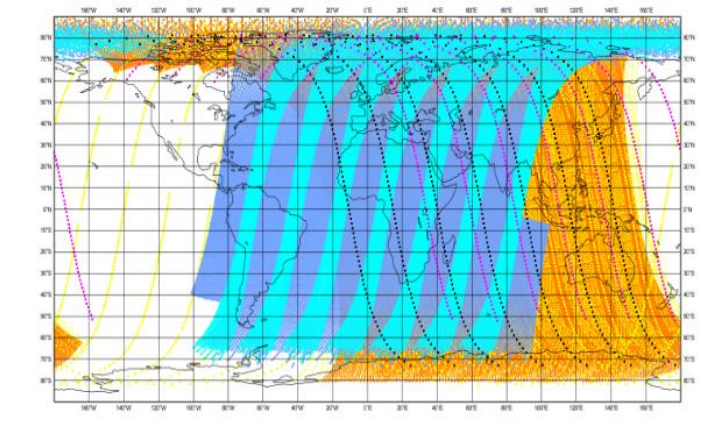


IASI Metop-A

IASI Metop-B

MOPITT TERRA

O3



GOME-2 Metop-A

GOME-2 Metop-B

OMI, MLS AURA

SBUV/2 NOAA-19

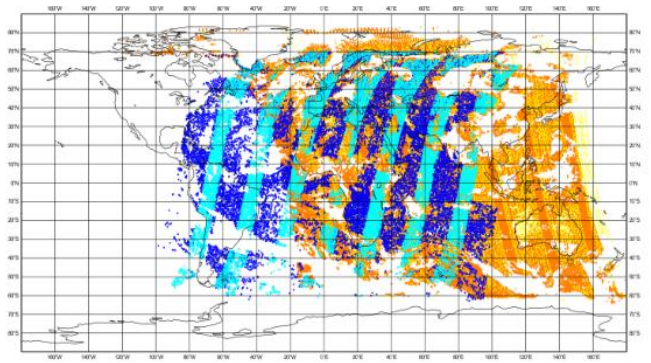
OMPS SNPP

TROPOMI S5P

assimilated

monitored

Tropospheric NO2



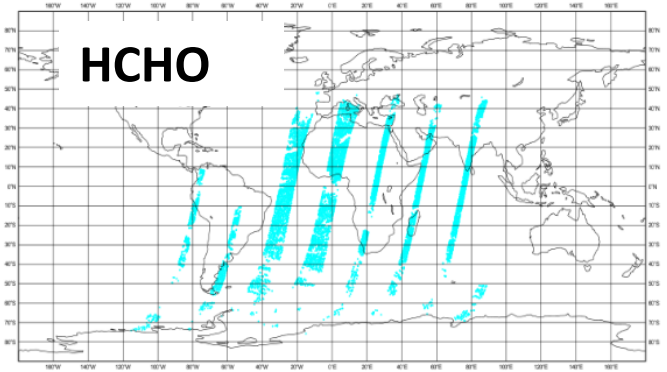
OMI AURA

TROPOMI S5P

GOME-2 Metop-A

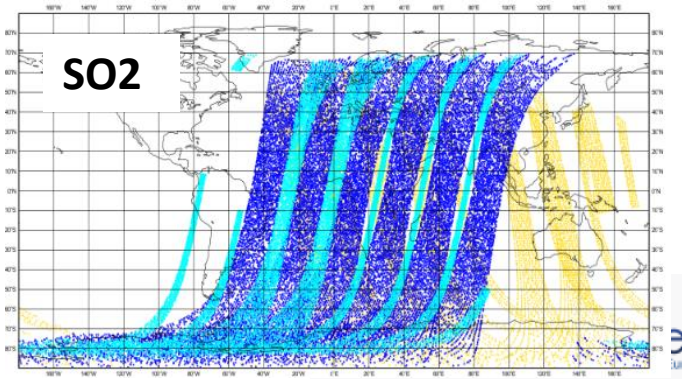
GOME-2 Metop-B

HCHO



GOME-2 Metop-A

SO2



OMI AURA

GOME-2 Metop-A

GOME-2 Metop-B

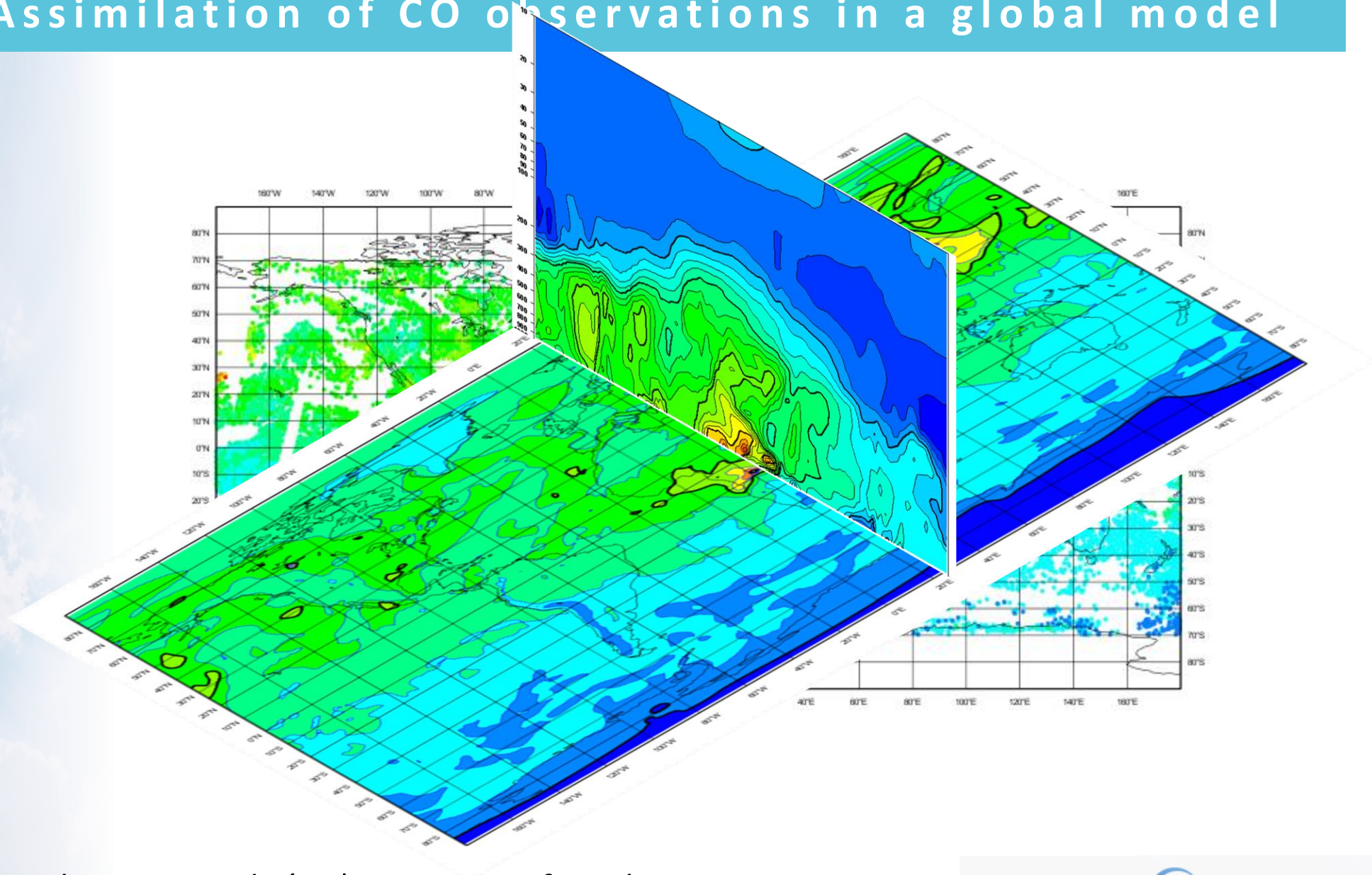
https://atmosphere.copernicus.eu/satellite-observations

Copernicus Europe's eyes on Earth

European Commission

Atmosphere Monitoring

Assimilation of CO observations in a global model

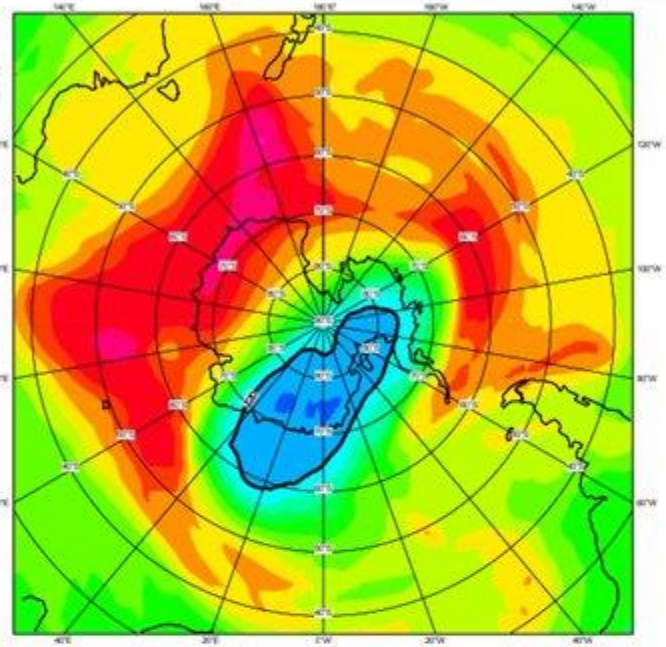


Carbon monoxide (CO) is a tracer of combustion sources

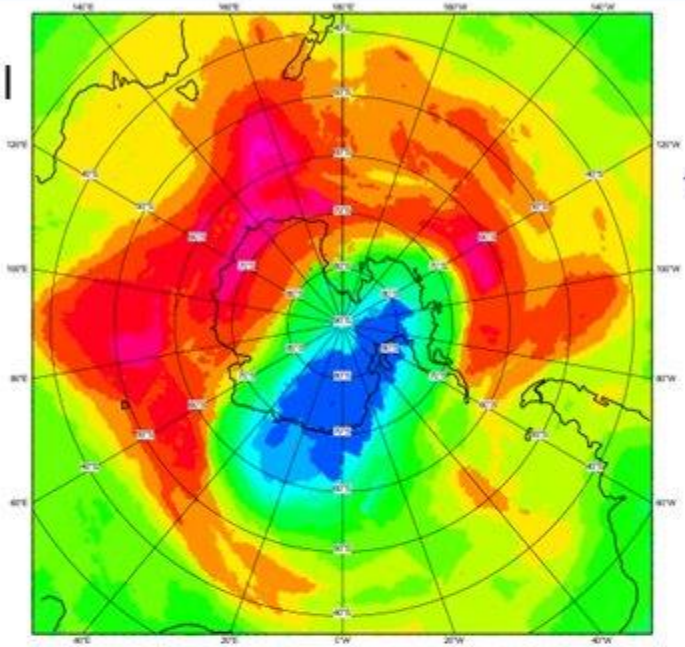
ECMWF Copernicus Europe's eyes on Earth European Commission

Total column O3 on 20191020 from CAMS, TROPOMI, OMI & GOME-2AB

CAMS



TROPOMI

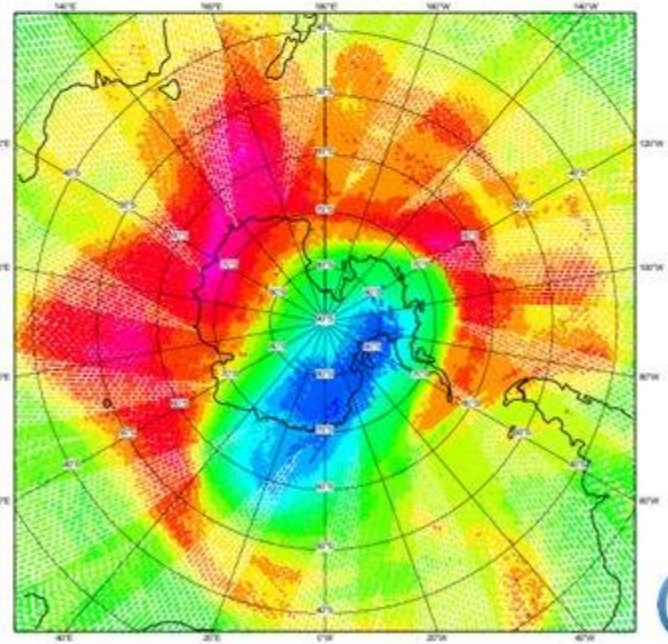


150 175 200 220 240 260 280 300 320 340 360 380 400 425 450 475 600

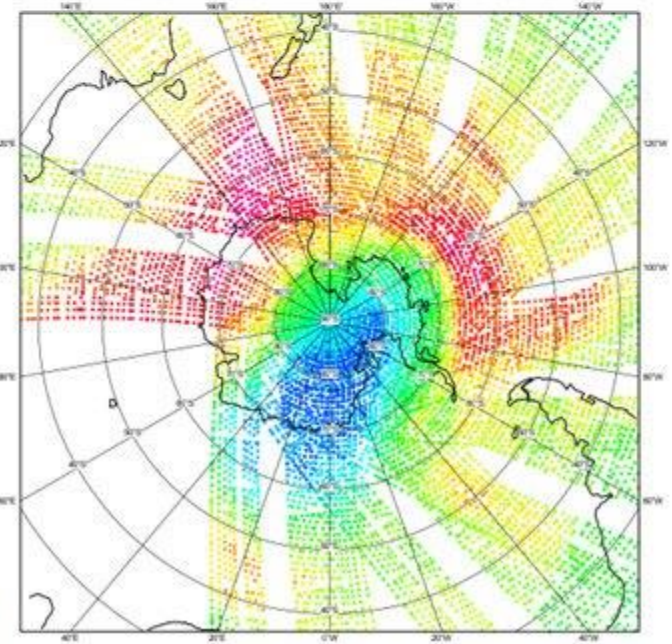
Dobson Units

Shown are all total column satellite data available for the CAMS ozone analysis (some at are not assimilated, e.g. at low solar elevations)

GOME-2AB



OMI



European Commission

Copernicus Europe's eyes on Earth

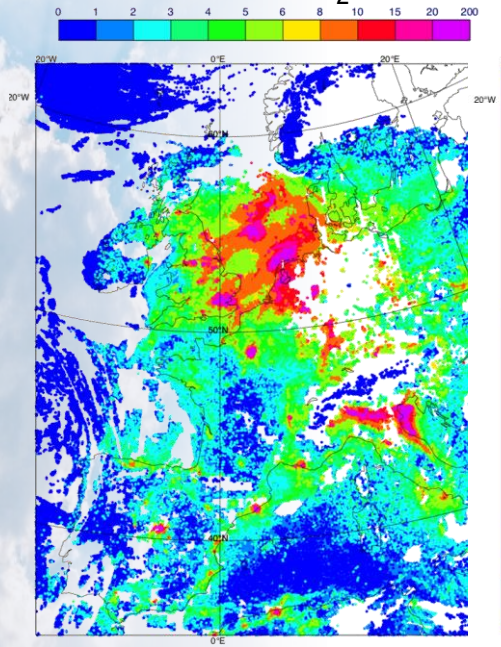
IMPLEMENTED BY ECMWF

OBSERVATIONS: UPTAKE OF SENTINEL-5P

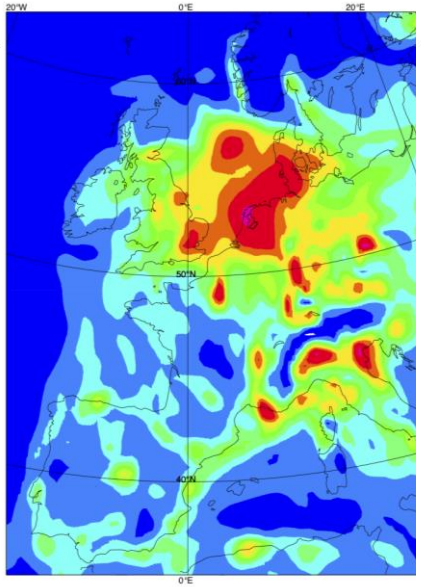
Atmosphere Monitoring

Operational monitoring of all products (online) and active assimilation of ozone since 12/2018. Providing detailed input to ESA and contractors in charge of L2 processing for solving issues. CAMS system is ready.

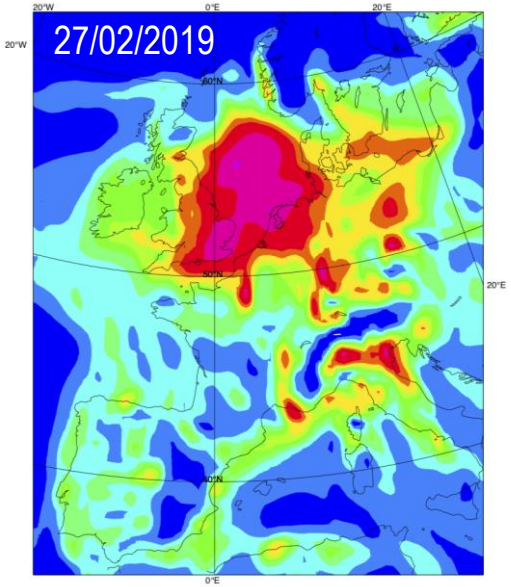
S-5P observation NO_2 column



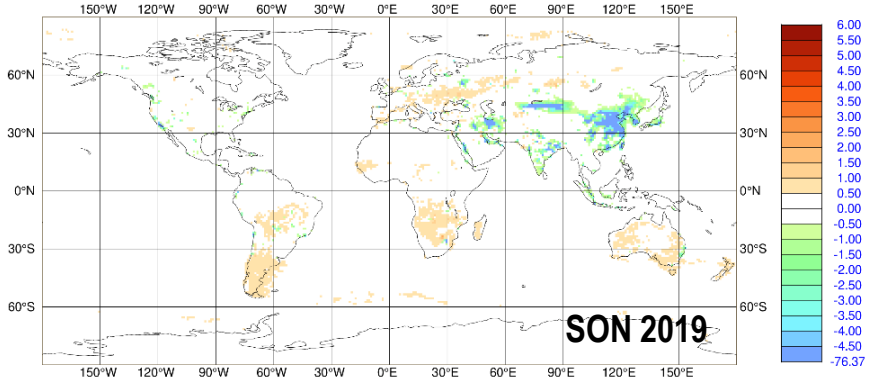
Assimilation (test) GOME2-A,B+OMI+S-5P



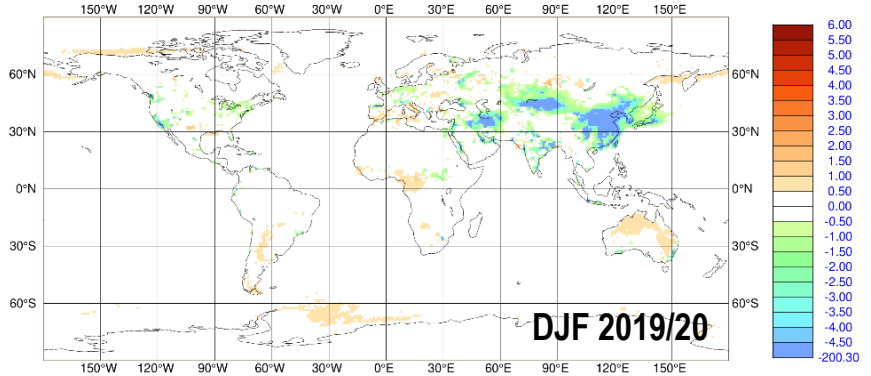
Assimilation (oper) GOME2-A,B+OMI



S-5P NO_2 seasonal mean departures



10^{15} molec/cm^2

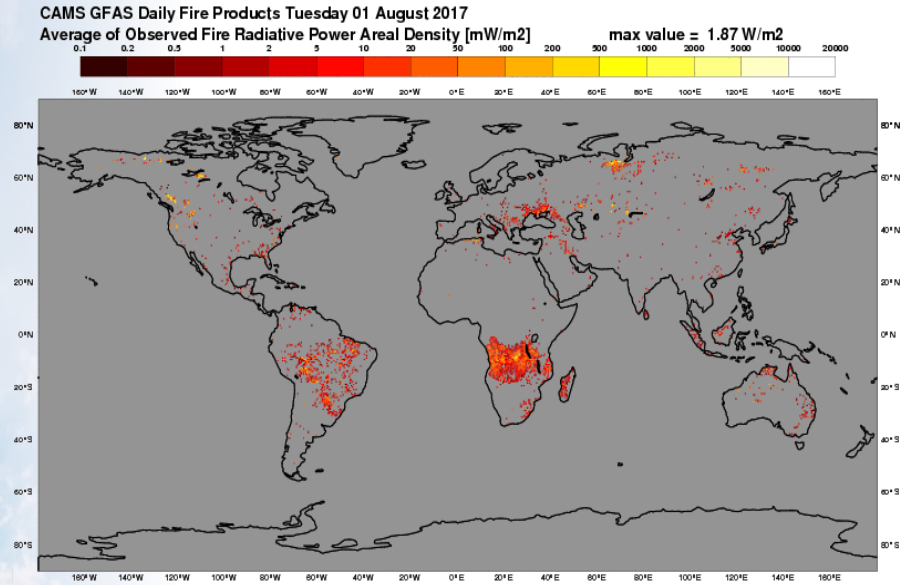


At present NO_2 analysis is degraded when data are assimilated. Issue identified with handling the effects of thin clouds. Waiting for PDGS upgrade this summer.

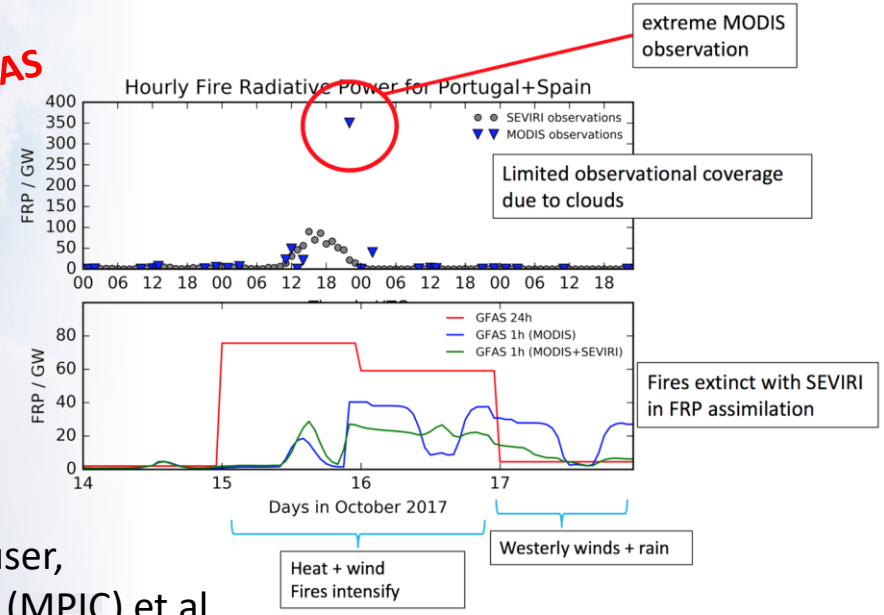
ECMWF Copernicus Europe's eyes on Earth European Commission

Estimating global wildfire emissions

Atmosphere Monitoring



Upcoming hourly GFAS



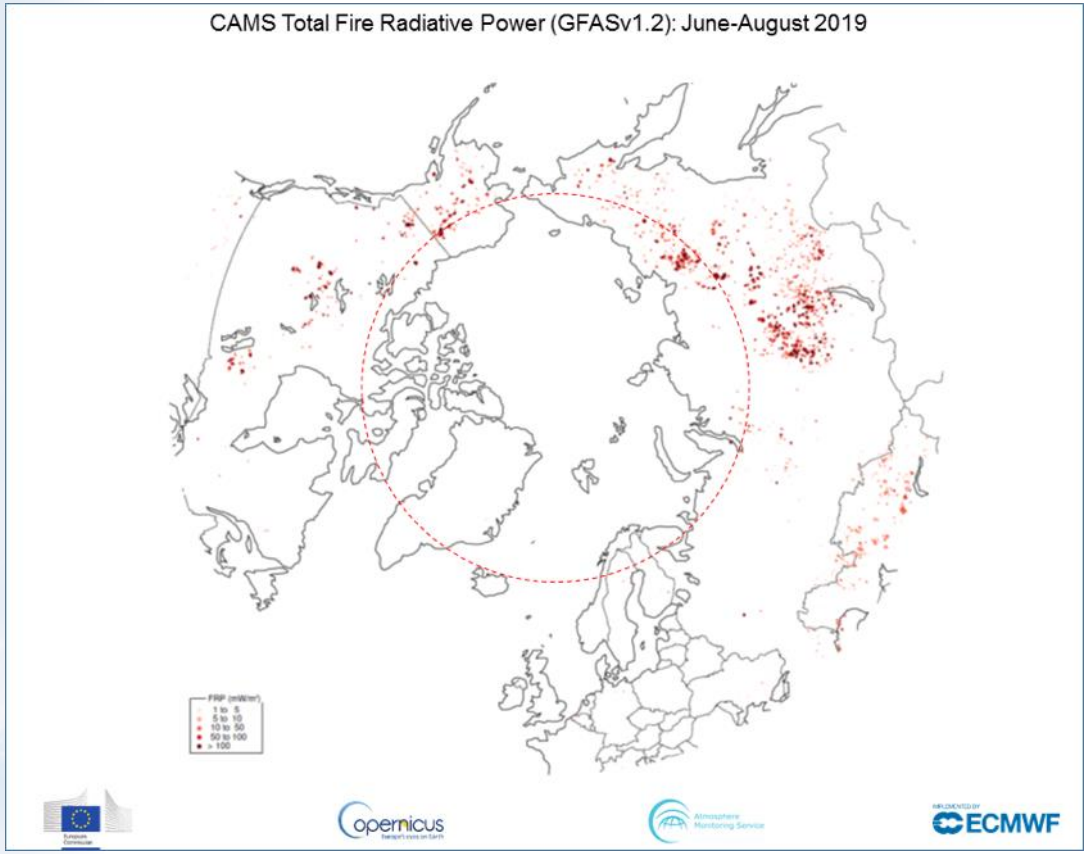
c/o I. Hüser,
J. Kaiser (MPIC) et al.

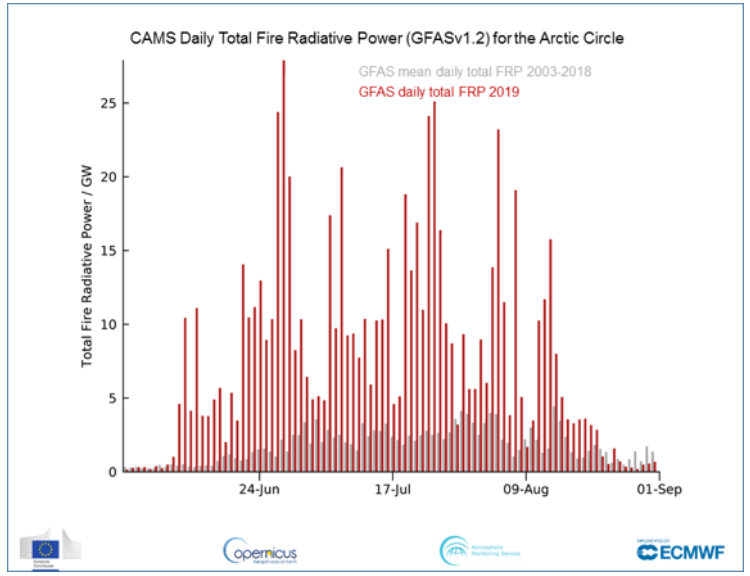
- Global Fire Assimilation System (**GFAS**); see http://apps.ecmwf.int/datasets/data/cams-gfas/
- Uses satellite observations of Fire Radiative Power (FRP)
  - Currently Aqua and Terra MODIS FRP observations
  - FRP from VIIRS, Sentinel-3 and geostationary satellites will be included
- Daily global coverage at ~10km resolution
  - 1-day behind NRT (diurnal cycle/hourly output available since this year)
- Emissions of aerosols and gases are estimated using factors dependent on vegetation type.
- Injection heights calculated with Plume Rise Model and IS4FIRES.

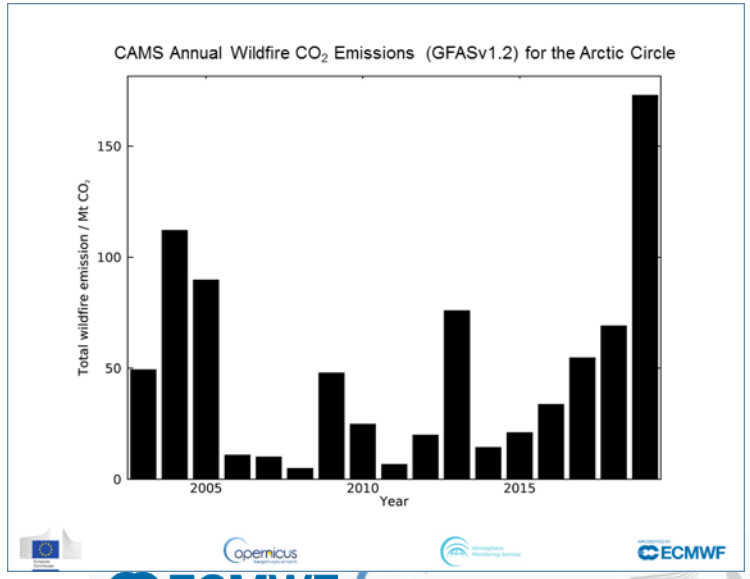
Copernicus Europe's eyes on Earth
European Commission

Monitoring Arctic wildfires during summer 2019

Atmosphere Monitoring





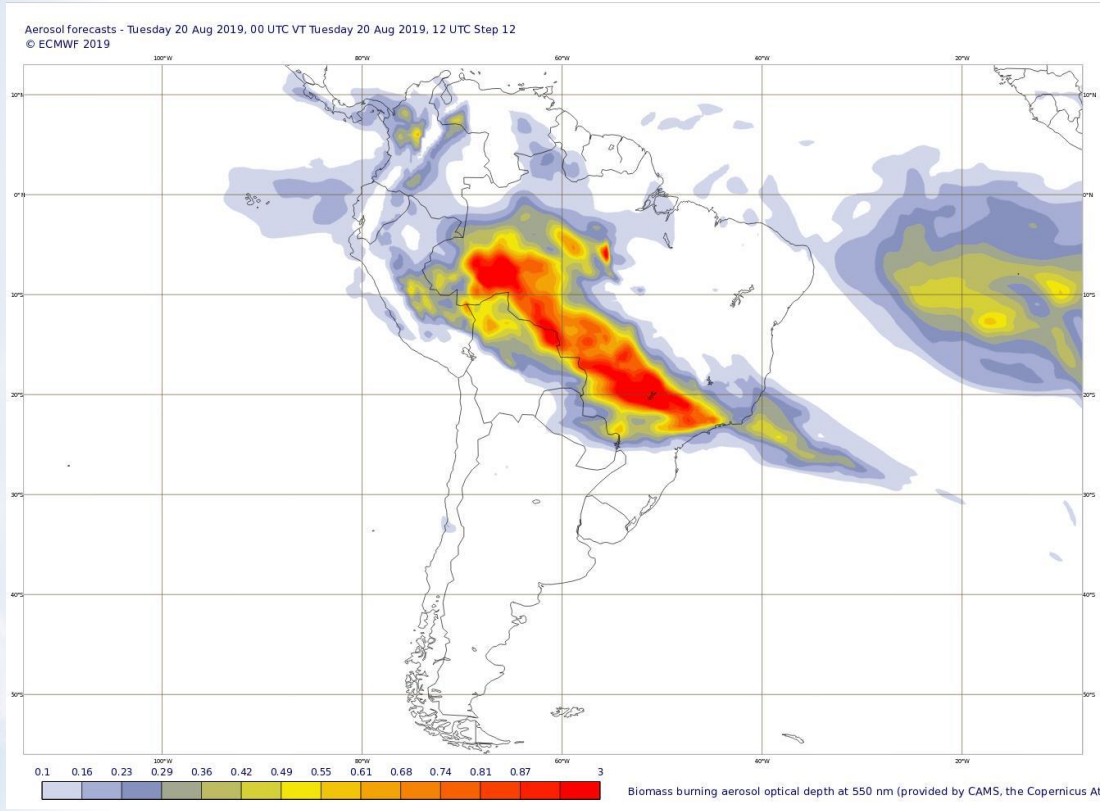


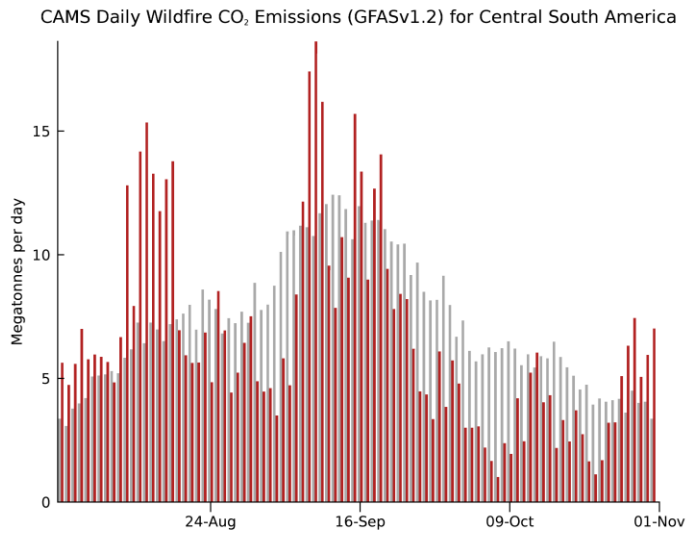
- Daily total wildfire emissions were well above the 2003-2018 average throughout the summer north of the Arctic Circle
- Many wildfires concentrated in the Sakha Republic, Russia with other fire activity in Alaska, Yukon Territory and Greenland
- Total estimated equivalent CO2 of ~170 megatonnes

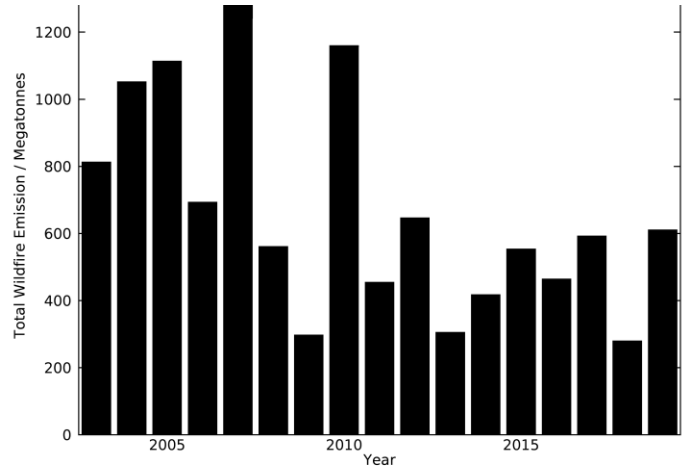
ECMWF opernicus Europe's eyes on Earth European Commission

Monitoring Amazon fires in August 2019

Atmosphere Monitoring





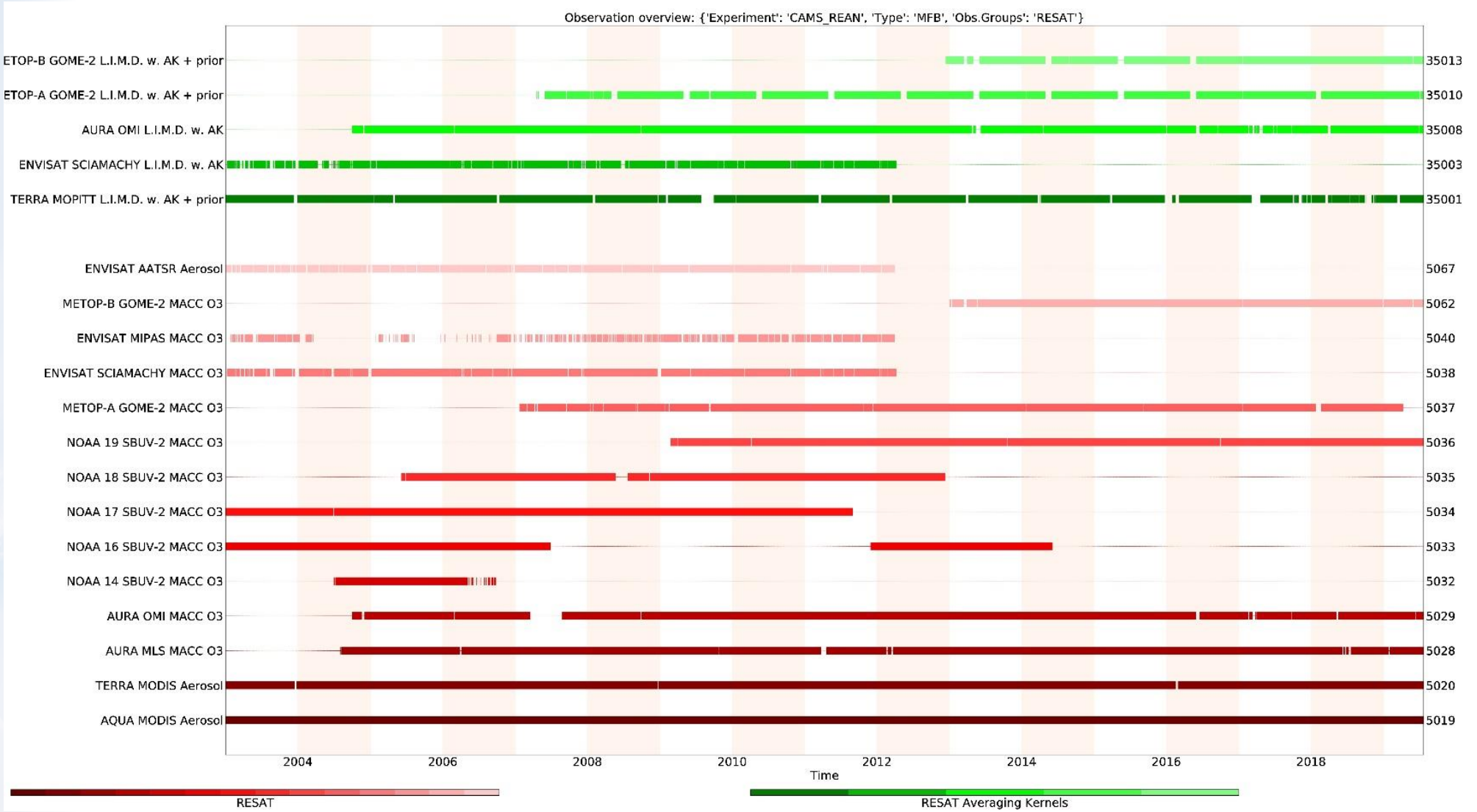


- Above average daily fire activity during first 2 weeks of August across the main states of the Brazilian Amazon (also in Bolivia and Paraguay) with smoke predicted by CAMS across much of southern Brazil
- Below average (2003-2018) daily activity through September and October shows annual total is not particularly high compared to previous years in GFAS dataset.

ECMWF Copernicus Europe's eyes on Earth European Commission

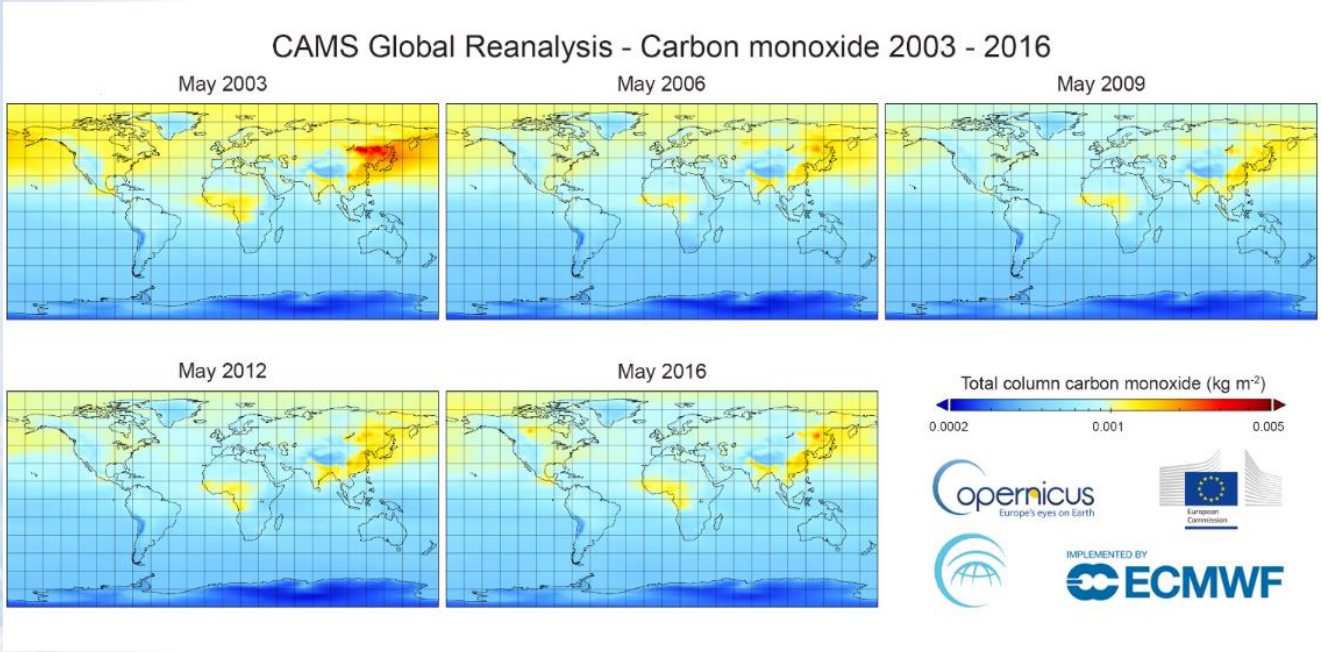
Atmosphere Monitoring

Assimilated satellite products in CAMS Reanalysis

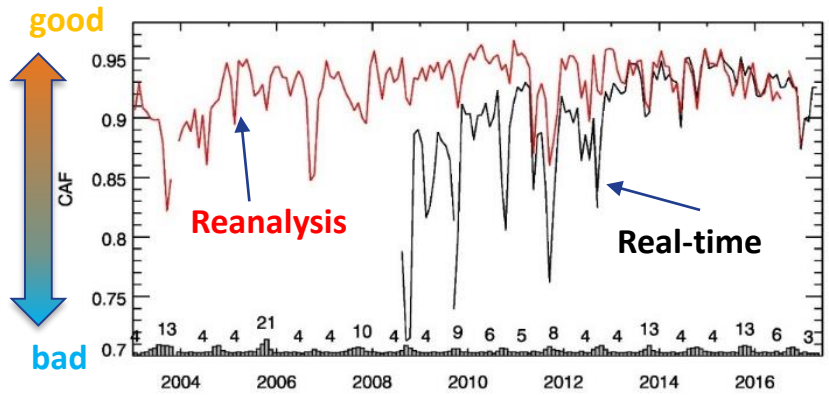


CAMS global reanalysis 2003 – 2018 (updated yearly)

Atmosphere Monitoring



O3 score at Neumayer station



CAMS global reanalysis

- 2003 – 2018, with new years being added
- Aerosols, 13 chemical pollutants, CO_2 & CH_4
- 80 km spatial resolution
- Inness et al. 2019, https://doi.org/10.5194/acp-19-3515-2019

ECMWF opernicus Europe's eyes on Earth European Commission

Atmosphere Monitoring

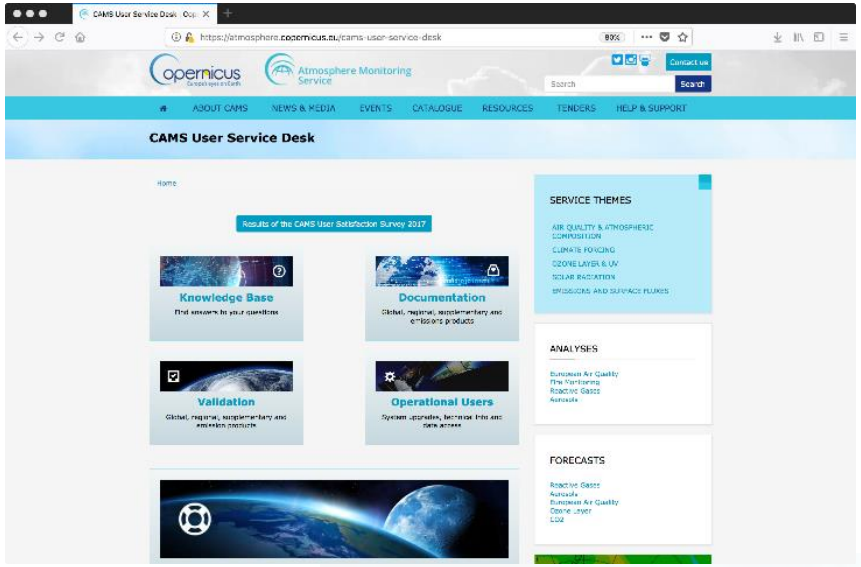
User support and contact details

web site: https://atmosphere.copernicus.eu

Twitter: @CopernicusECMWF

user support: copernicus-support@ecmwf.int

help desk: https://atmosphere.copernicus.eu/cams-user-service-desk/



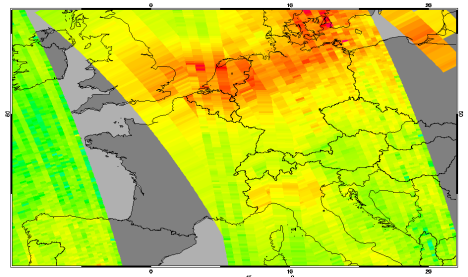
Copernicus Europe's eyes on Earth

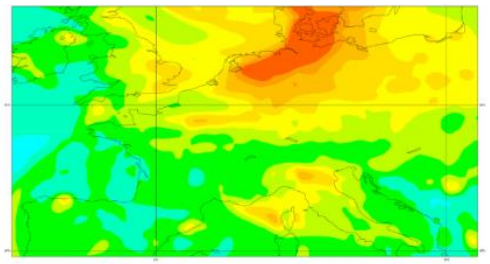
European Commission

Atmosphere Monitoring

Summary

- Timely, high quality, satellite observations are essential for monitoring atmospheric composition.
- Data flow takes into account caveats, uncertainties and relative sensitivity of each retrieved product used.
  - Observations are monitored in the system for some time before active assimilation.
- Value is added to observations, filling gaps based on detailed modelling of atmospheric physics and chemistry.
- Products are extensively and routinely validated against independent observations (satellite, ground-based, in situ).





Atmosphere Monitoring Service

atmosphere.copernicus.eu

User-driven service
Free, full and open data licence
Making observations more meaningful to you
Provide information about past, present and future

ECMWF Copernicus Europe's eyes on Earth European Commission

Atmosphere Monitoring

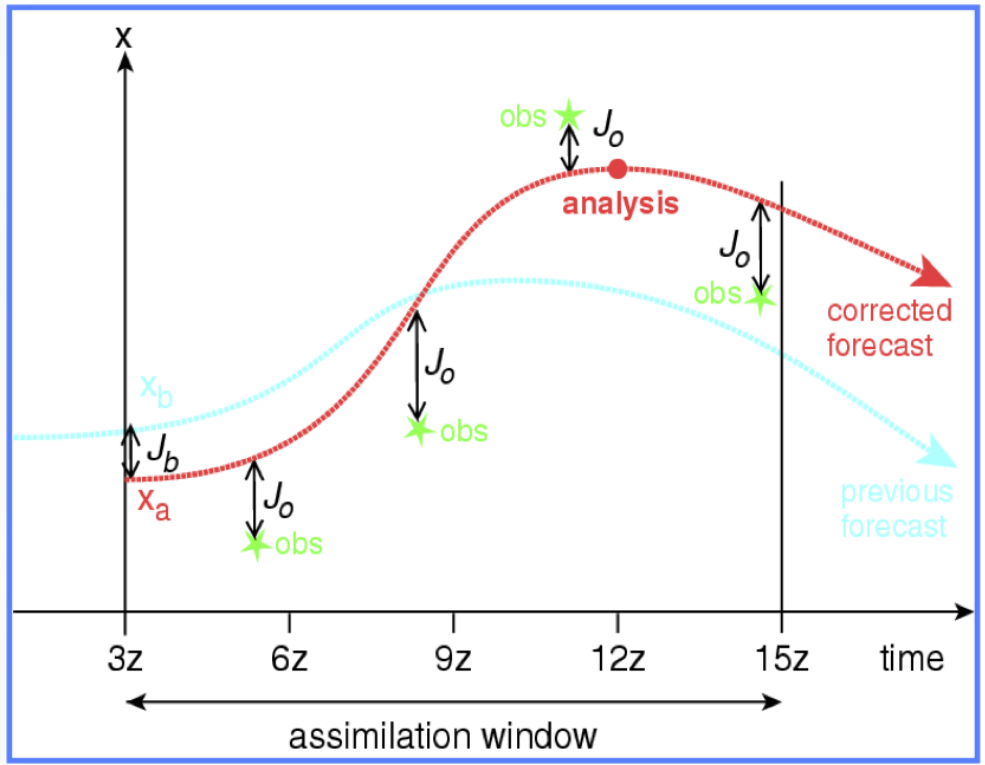
Extra slides

ECMWF Copernicus Europe's eyes on Earth European Commission

Atmosphere Monitoring

4D-VAR - method of combining observations with model

- We need efficient means of combining the information from ~20,000,000 observations with a global model at ~40 km horizontal resolution
- Data assimilation is the process of merging observations with a background model forecast in a statistically consistent manner
- We want to minimize a cost function (J) that evaluates the model background (J_b) and observations (J_o).



$$\mathbf{x}_a = \text{Arg min} J$$

$$J(\mathbf{x}) = (\mathbf{x}-\mathbf{x}_b)^{\mathrm{T}}\mathbf{B}^{-1}(\mathbf{x}-\mathbf{x}_b) + (\mathbf{y}-H[\mathbf{x}])^{\mathrm{T}}\mathbf{R}^{-1}(\mathbf{y}-H[\mathbf{x}])$$

$$= J_b(\mathbf{x}) + J_o(\mathbf{x})$$

forecast — observation — observation operator

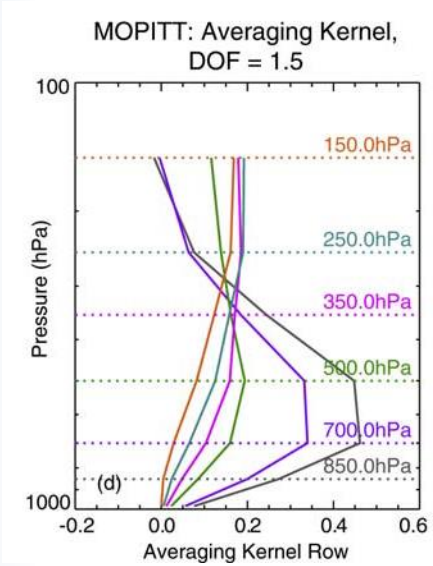
$$\mathbf{x}_a = \mathbf{x}_b + \mathbf{A}(\mathbf{y} - \mathbf{H}\mathbf{x}_b)$$

analysis — averaging kernel

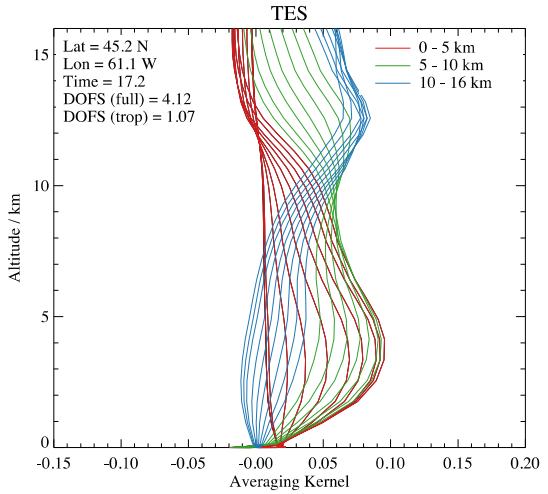
Atmosphere Monitoring

Vertical sensitivity of AC retrievals

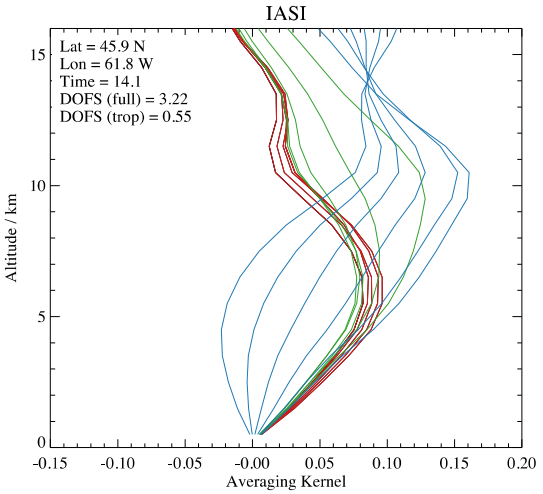
- Averaging kernels provide the information required to directly compare satellite retrievals with models/in situ observations.



MOPITT CO



TES O_3

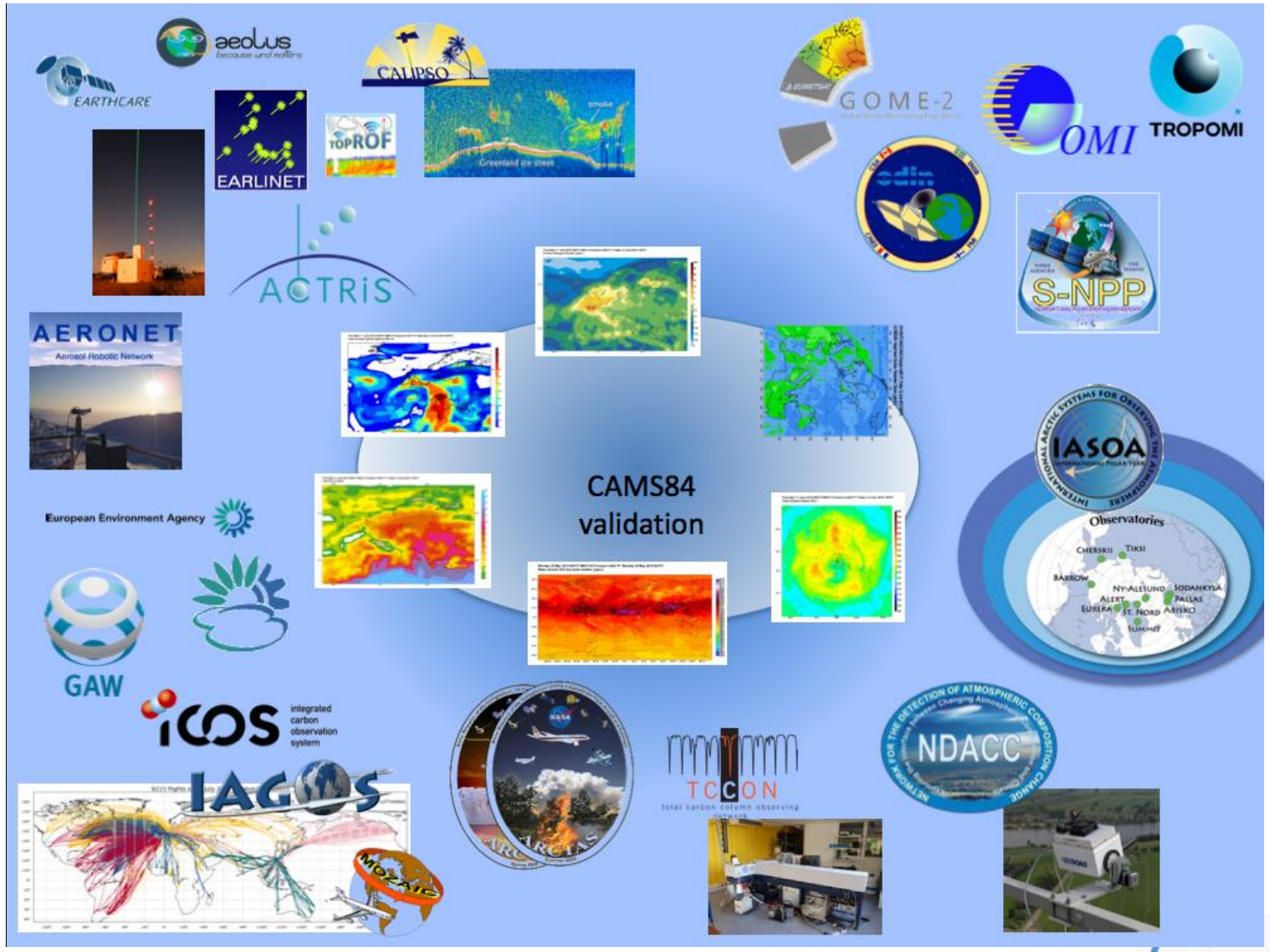


IASI O_3

- Data assimilation into NWP models redistributes atmospheric composition observations to provide vertical information

Atmosphere Monitoring

Independent observations for validation

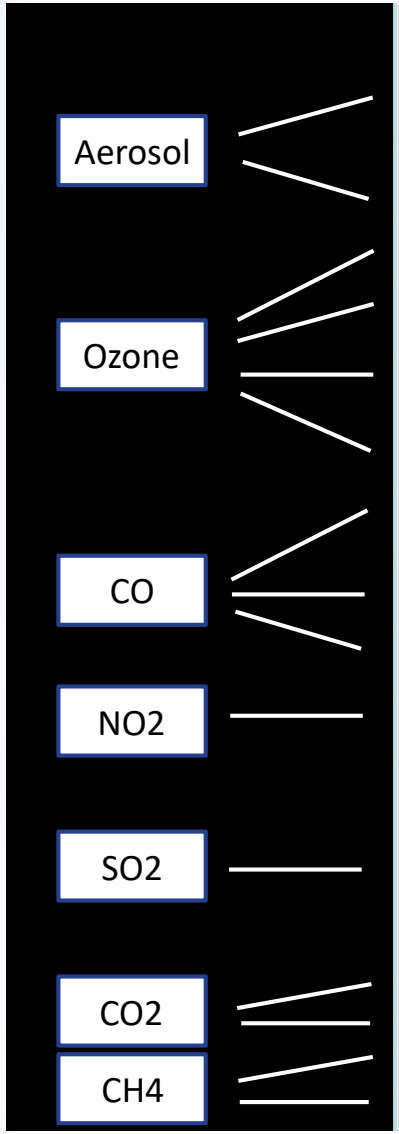


Copernicus Europe's eyes on Earth

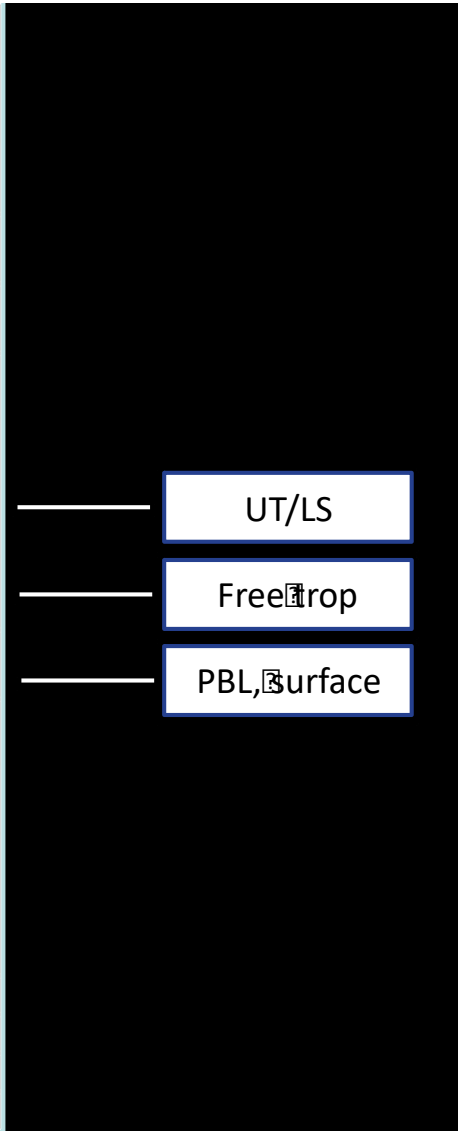
European Commission

Independent observations for validation

Atmosphere Monitoring



Species, vertical range	Assimilation	Validation
Aerosol, optical properties	MODIS Aqua/Terra AOD	AOD, Ångström: AERONET, GAW, Skynet, MISR, OMI, lidar, ceilometer
Aerosol mass (PM10, PM2.5)	MODIS Aqua/Terra	European AirBase stations
O_3, stratosphere	MLS, GOME-2A, GOME-2B, OMI, SBUV-2	Sonde, lidar, MWR, FTIR, OMPS, ACE-FTS, OSIRIS, BASCOE and MSR analyses
O_3, UT/LS	MLS	IAGOS, ozone sonde
O_3, free troposphere	Indirectly constrained by limb and nadir sounders	IAGOS, ozone sonde
O_3, PBL / surface	-	Surface ozone: WMO/GAW, NOAA/ESRL-GMD, AIRBASE
CO, UT/LS	IASI, MOPITT	IAGOS
CO, free troposphere	IASI, MOPITT	IAGOS, MOPITT, IASI, TCCON
CO, PBL / surface	IASI, MOPITT	Surface CO: WMO/GAW, NOAA/ESRL
NO_2, troposphere	OMI, partially constrained due to short lifetime	SCIAMACHY, GOME-2, MAX-DOAS
HCHO	-	GOME-2, MAX-DOAS
SO_2	GOME-2A, GOME-2B (Volcanic eruptions)	-
Stratosphere, other than O_3	-	NO_2 column only: SCIAMACHY, GOME-2
CO_2, surface, PBL		ICOS
CO_2, column		TCCON
CH_4, surface, PBL		ICOS
CH_4, column		TCCON



Copernicus Europe's eyes on Earth

European Commission