Atmosphere Monitoring

Atmospheric composition observations: overview, recent developments and gap analysis in the context of environmental prediction

Antje Inness (ECMWF)

Thanks to the ECMWF CAMS team

Copernicus Europe's eyes on Earth

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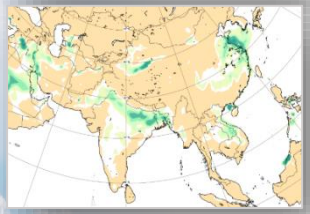
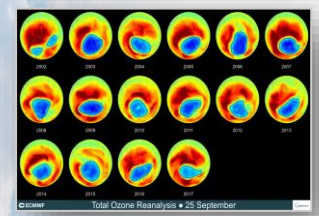
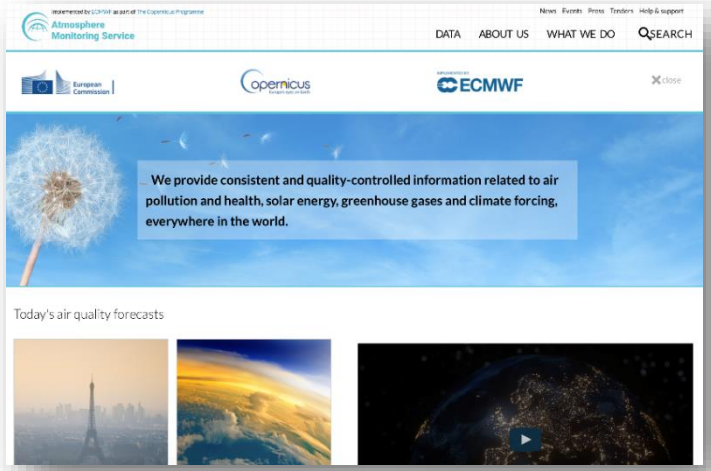
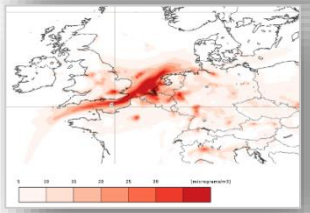
What the Copernicus Atmosphere Monitoring Service has to offer

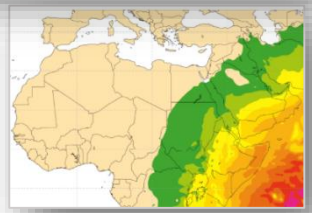
Atmosphere Monitoring











The CAMS portfolio includes Earth Observation based information products about:

- 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.
- reanalysis of atmospheric compositon

Quarterly validation reports of global and regional outputs.

This is done by assimilating **satellite retrievals of atmospheric composition** into the IFS (in addition to meteorological observations)

https://atmosphere.copernicus.eu

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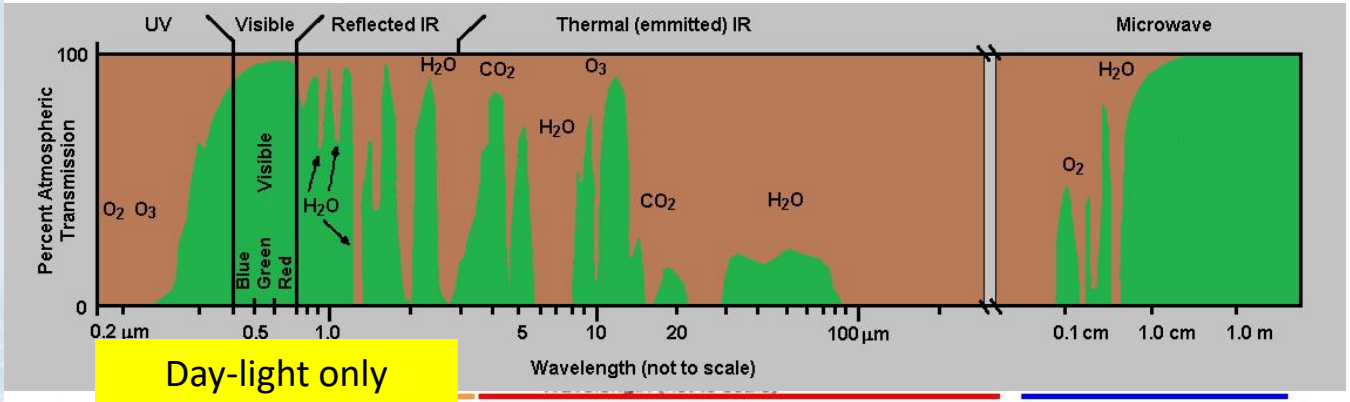
Spectral signature of trace gases

NIR, SWIR



Day-light only

O_3
H_2O
NO_2
SO_2
H_2CO, $C_2H_2O_2$
IO
BrO

CO_2
CH_4
CO

SCIAMACHY, GOSAT, OCO *at nadir* TROPOMI

AOD MODIS

GOME, GOME-2, SCIAMACHY, OMI *at nadir* TROPOMI
SCIAMACHY, OSIRIS *at limb*

H_2O
CO_2
CH_4
N_2O
O_3
CO
HNO_3
NH_3
CFC11, CFC12, …
CH_3OH, HCOOH, C_2H_2, C_2H_6,…
+ isotopologues

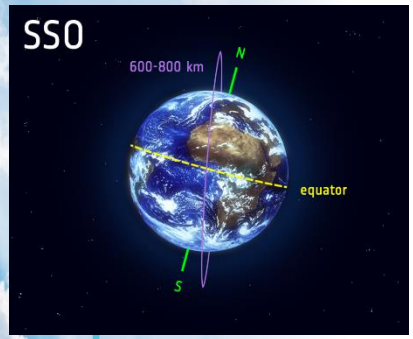
TES, AIRS, IASI, MOPITT *at nadir*
MIPAS, ACE *at limb*

O_2
H_2O, OH, HO_2
HNO_3
HCl, BrO, ClO, HOCl
O3
CO
HCN, CH_3CN

DMR, MLS *at limb*

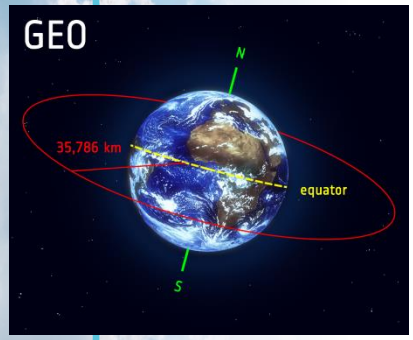
Credit: M. Van Roozendael

Satellite orbits



Polar Orbit:

- Low earth orbit (LEO, 600-800 km)
- **Sun-synchronous orbit:** overpass over given latitude always at the same local time, providing similar illumination
- Global measurements possible, but fixed overpass time & no observation of diurnal cycle
- Global coverage in a few days (in some cases better)

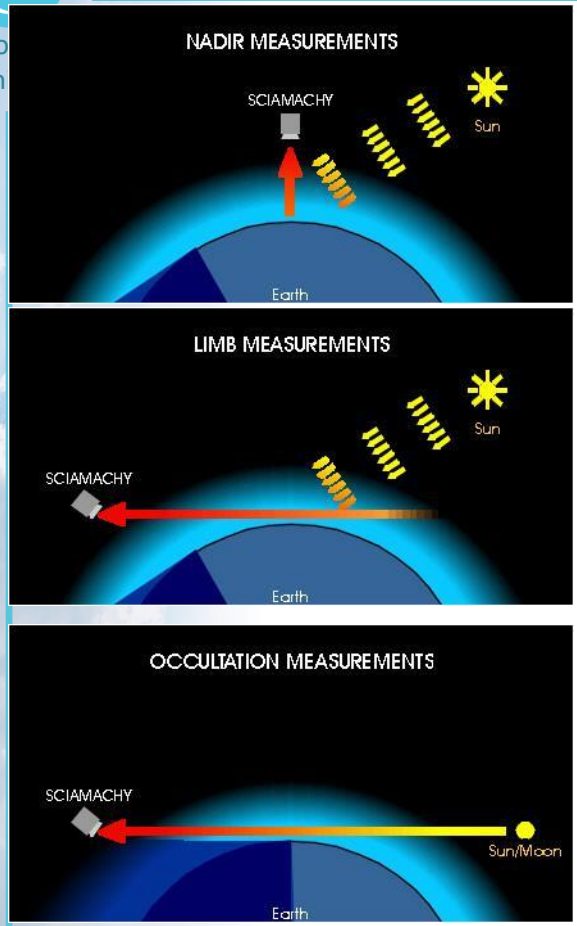


Geostationary Orbit:

- 36000 km flight altitude, equatorial orbit
- Fixed position relative to the Earth,
- Limited area from low to middle latitudes,
- No global measurements possible
- Observations of diurnal cycle
- AC constellation planned (S4, TEMPO, GEMS – already launched)

www.esa.int

Measurement geometries



Nadir measurements (e.g. TROPOMI, IASI):

- Observe atmospheric volume directly under the instrument.
- High horizontal resolution, low vertical resolution.
- Total columns, partial columns, limited sensitivity to PBL

Limb measurements (e.g. MLS):

- Look at the edge of the atmosphere and perform scans at different tangent altitudes over a larger range in horizontal direction.
- Low horizontal resolution, but higher vertical resolution.
- Ideal for stratospheric composition.
- No info about lower atmosphere.

Occultation measurements (e.g. ACE-FTS):

- Use limb geometry but point directly at sun/ moon/ stars. Atmospheric densities are obtained by comparing measurements of the transmitted solar or lunar radiation with the unattenuated source.
- Limited geographical coverage (one sunrise/ sunset per orbit)
- Self calibrating

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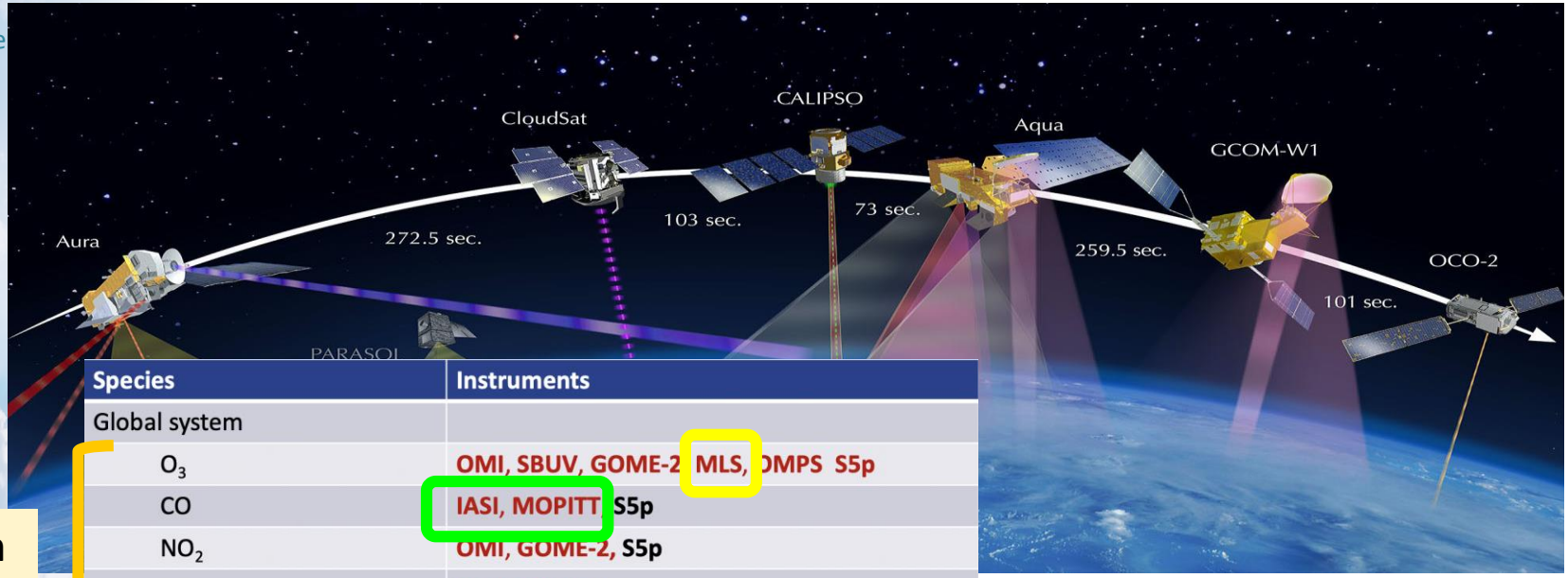
Earth observation satellites



All from LEOs

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 volcanic	OMI, GOME-2, S5p
Aerosol	MODIS, PMAp, VIIRS, S3
CO_2	GOSAT, OCO-2
CH_4	GOSAT, IASI, S5p
GFAS fire emissions	MODIS, GOES-E/W*, SEVIRI*, S3, VIIRS, HIMAWARI-8*, GOES-R*

Assimilated **Monitored** Future /Testing

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

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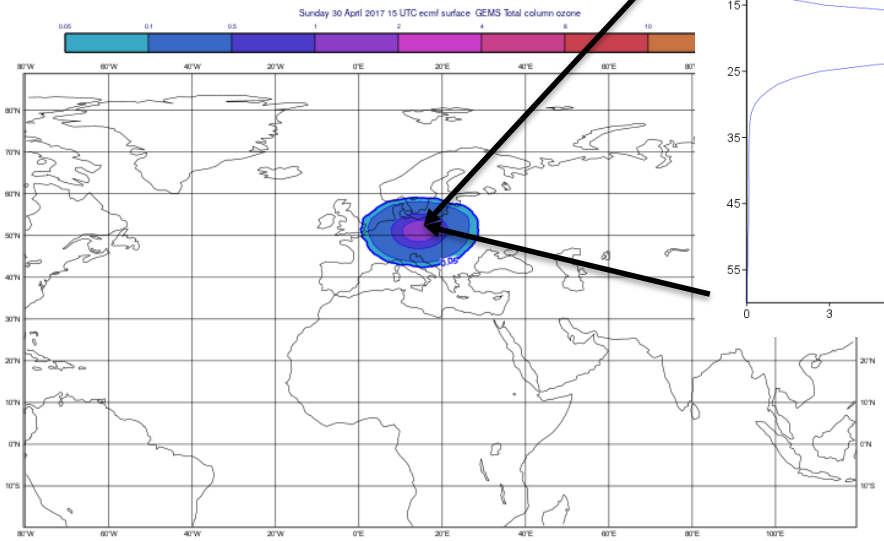
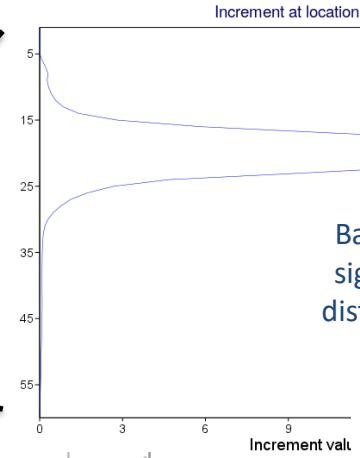
Example of limited information content

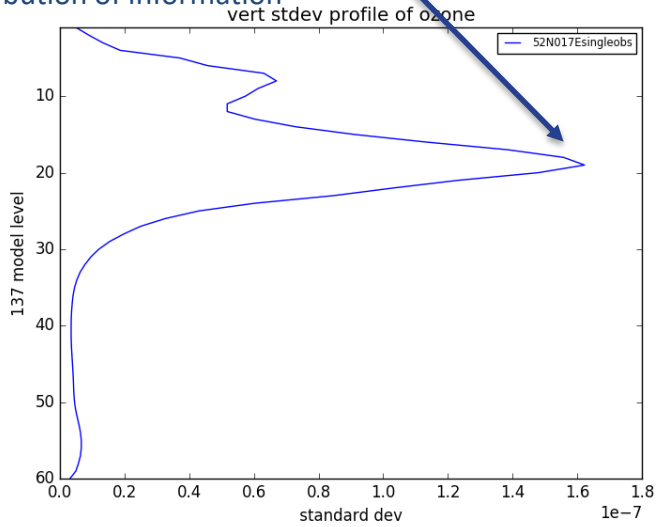
Assimilation of TCO3 data





Vertical profile of the increment at the observation location

Background matrix has a significant impact on the distribution of information



Increment created by a single ozone observation of 375 DU, 10 DU higher than background

Standard deviation from the background matrix at the observation location

Formulation of the B-matrix is very important for AC

An extreme example: Ozone 7 October 2004

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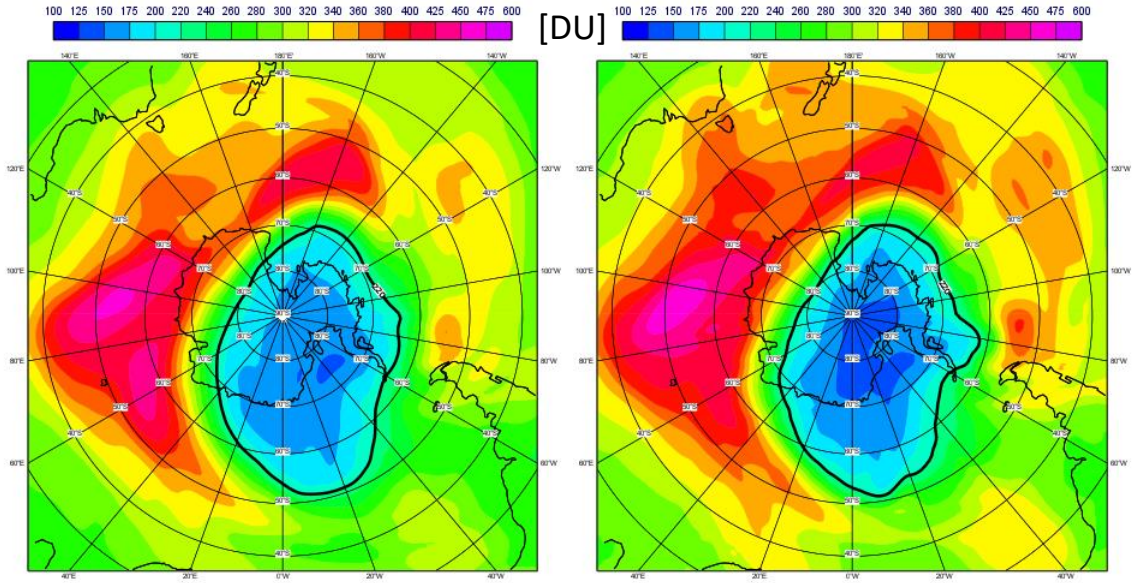
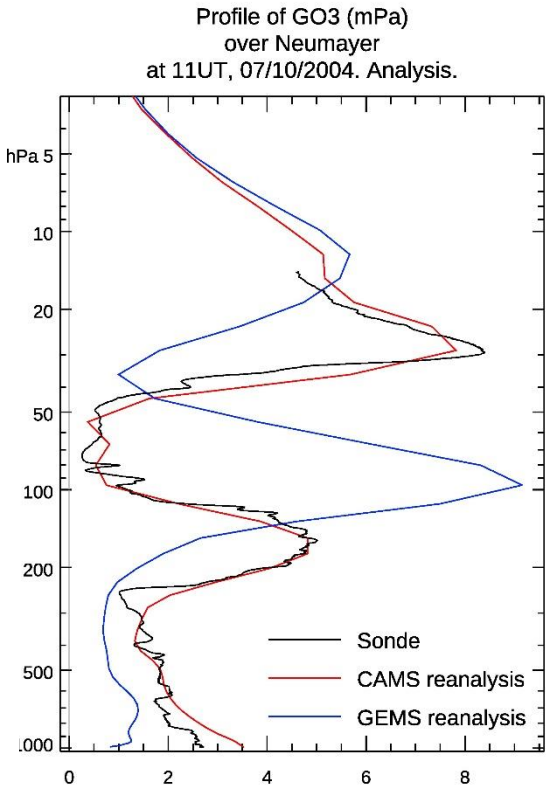
GEMS reanalysis

CAMS reanalysis





Sonde launched by AWI

- Similar TCO3 analysis from (old) GEMS reanalysis and CAMS reanalysis
- Huge differences between corresponding O3 profiles
- No profile data (MIPAS, MLS) were assimilated in GEMSRA in Oct 2004 and model had a large O3 bias leading to very bad vertical O3 analysis profiles
- Shows importance of using limb sounding data for O3 analysis

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Benefit of combining observations in DA system

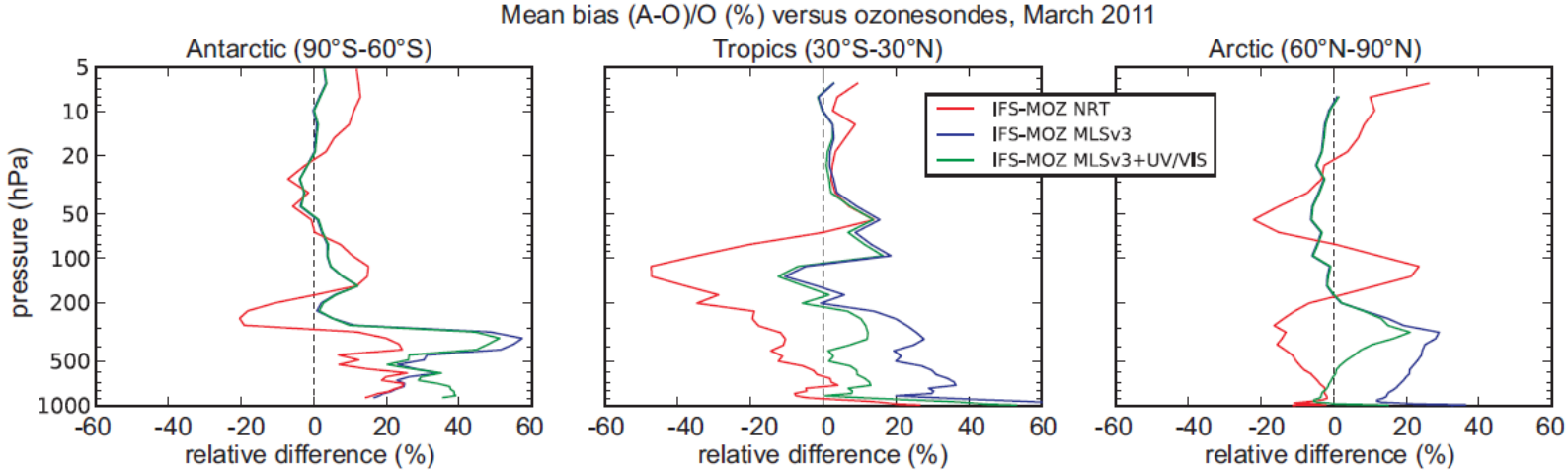
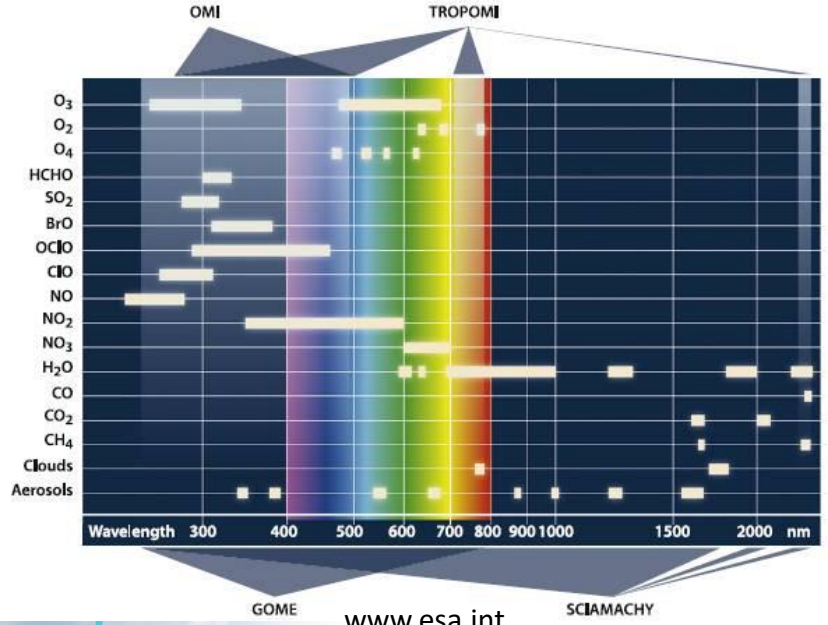


Figure 12. Mean biases, in %, of three ozone analyses by IFS-MOZART using O_3 sonde profiles as reference, for March 2011. Results are shown for the Antarctic (left), tropics (centre) and Arctic (right) latitude bands using the IFS-MOZART NRT analyses (red lines), the offline experiment assimilating only MLS v3 (blue lines) and another offline experiment assimilating MLS v3 and the UV–Vis observations (green lines). See text for details.

Lefever et al. (2015, doi:10.5194/acp-15-2269-2015)

- Improved quality of ozone analysis if MLS and UV-VIS obs are assimilated together
- Tropospheric ozone is improved compared to MLS-only assimilation and stratospheric O3 analysis is not degraded

Introducing a new instrument: TROPOMI



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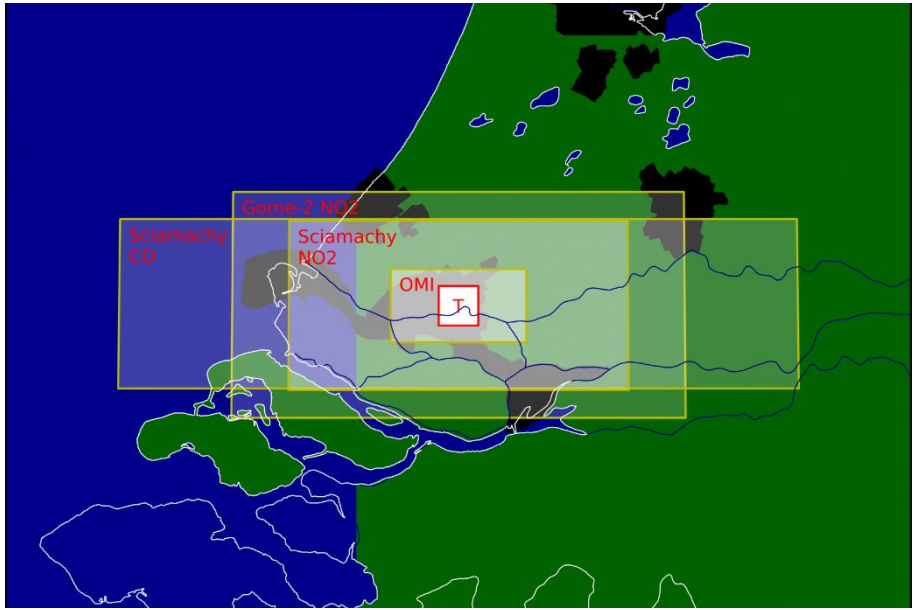

http://www.tropomi.eu

- TROPOMI has ultraviolet and visible (270–500 nm), near-infrared (675–775 nm) and shortwave infrared (2305–2385 nm) spectral bands.
- Retrievals of O3, NO2, SO2, HCHO, CH4 & CO ….

Resolution: 3.5 km x 5.5 km UV/VIS
7 km x 5.5 km SWIR

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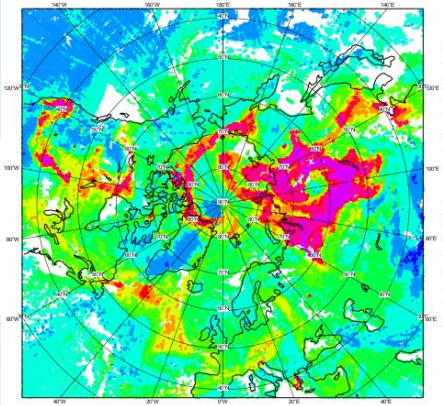
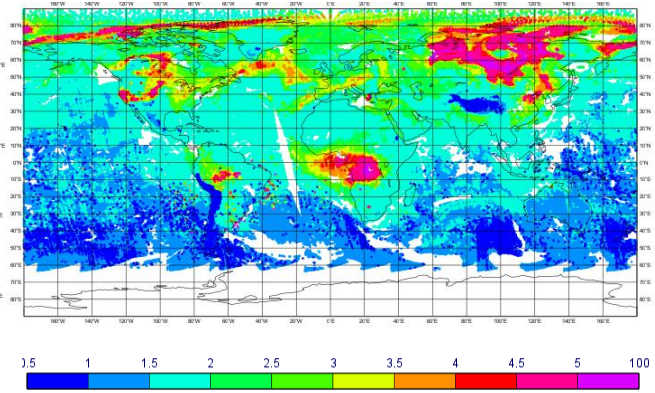
Transport of pollution from wildfires

Atmosphere Monitoring

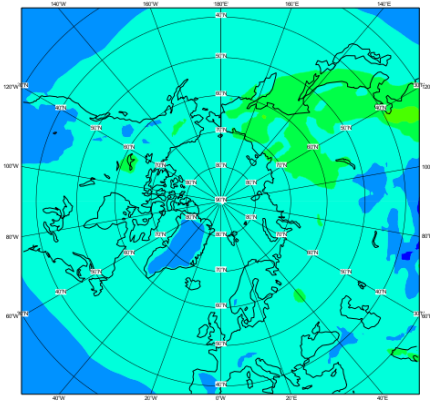
TCCO from TROPOMI 8 August 2021

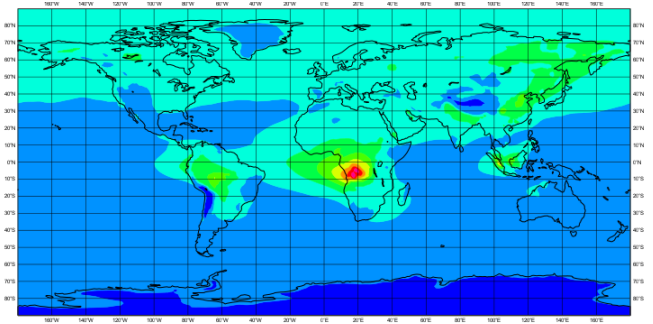




TCCO 10^{18} molec/cm^2

August TCCO climatology (2003-2019) from CAMS reanalysis





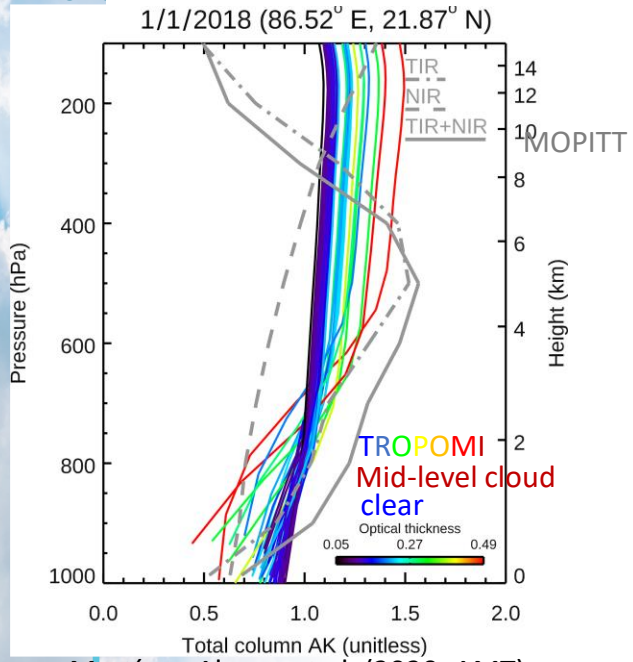
Carbon Monoxide is a

- tracer for incomplete combustion processes
- has a lifetime of several weeks
- can be used to track pollution from wild fires
- TROPOMI CO shows this clearly

CAMS reanalysis 2003-2020 data available from the Atmosphere Data Store (ADS): ads.atmosphere.copernicus.eu

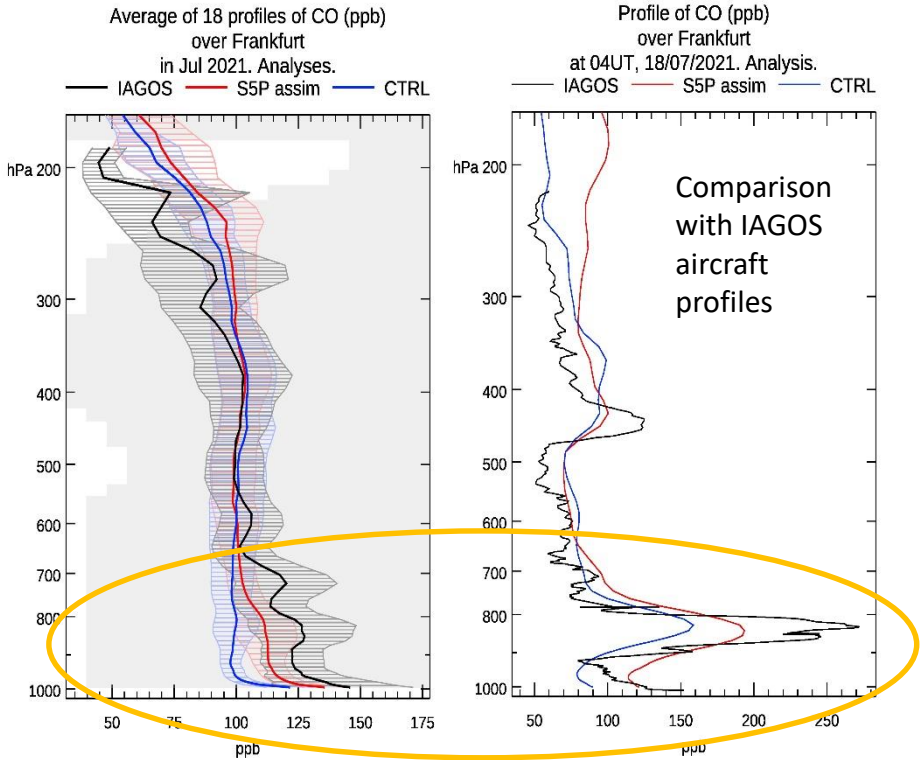
Examples of averaging kernels

TROPOMI & MOPITT AKs



Martínez-Alonso et al. (2020, AMT)

- TROPOMI has sensitivity to the CO column
- Clear TROPOMI data have some sensitivity to lower troposphere and PBL



Assimilation of TROPOMI CO can give additional information in lower troposphere in DA system that already assimilates MOPITT TIR and IASI CO retrievals

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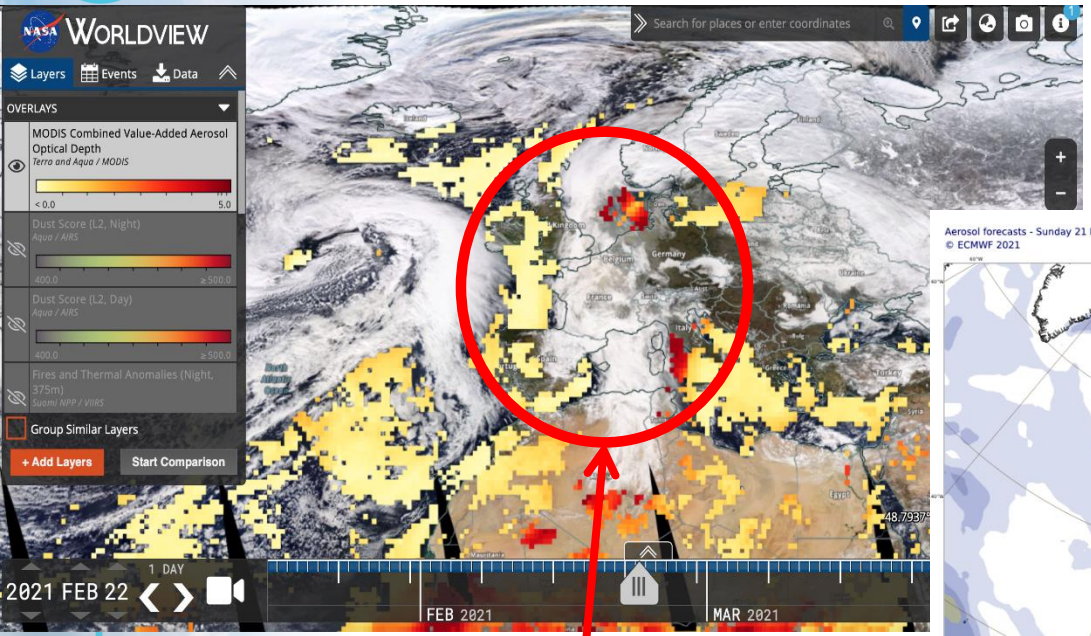
Aerosol analysis

- CAMS aerosol model has 14 aerosol bins:
  - 3 size bins each for sea-salt and desert dust
  - 2 bins (hydrophilic and hydrophobic) each for organic matter and black carbon
  - 1 bin for sulphate
  - 2 bins (fine and coarse) for nitrate
  - 1 bin for ammonium
- Assimilated observations are AOD at 550 nm from MODIS (Aqua and Terra) over land and ocean & PMAp (Metop-BC) over ocean
- Assimilation tests with VIIRS and SLSTR AOD
- Control variable is formulated in terms of the total aerosol mixing ratio.
- Analysis increments are repartitioned into the species according to their fractional contribution to the total aerosol mixing ratio.
- The repartitioning of the total aerosol mixing ratio increment into the different bins is difficult

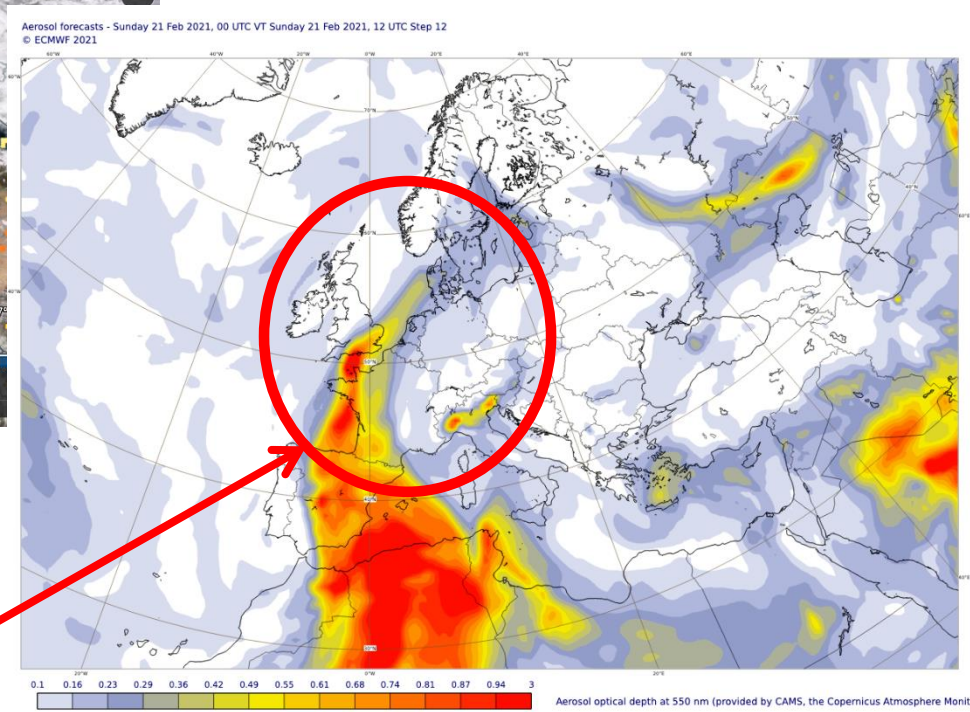
Dust test case February 2021

Credit: Melanie Ades



NASA Worldview – MODIS Aqua and Terra AOD 550nm observations for 20210222

CAMS Total AOD at 550nm 12hr forecast valid at 20210222 12hr



The CAMS forecast does a good job of forecasting the AOD plume from Africa over Northern Europe

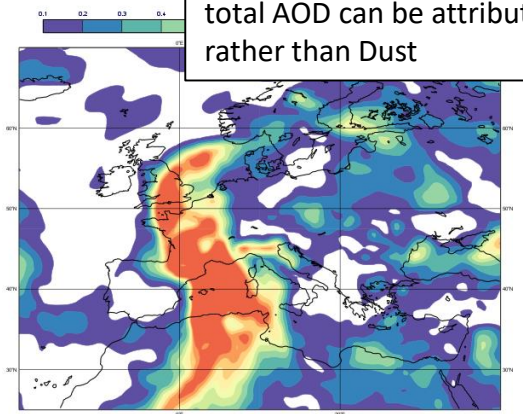
Dust test case February 2021

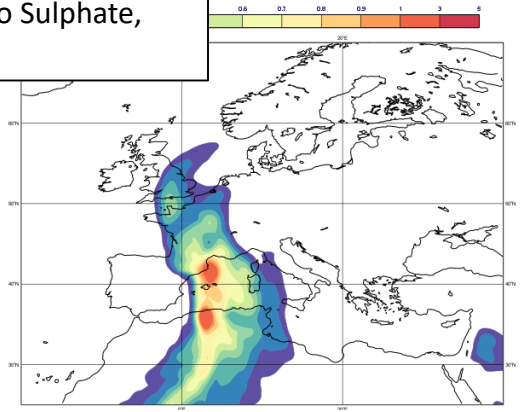
Credit: Melanie Ades

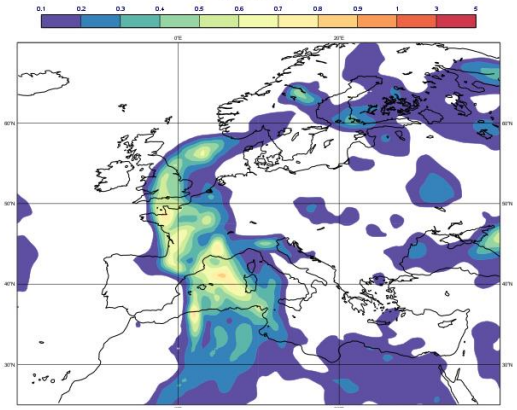
Closer examination shows that some of this total AOD can be attributed to Sulphate, rather than Dust

Dust

Sulphate



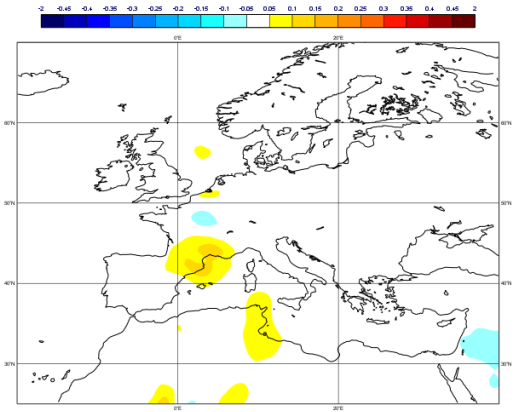


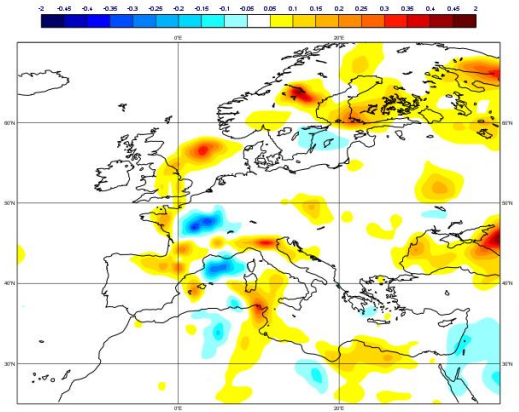


AOD at 550nm

Total AOD at 550nm: 20210222 03hr

Increments





AOD incr at 550nm

- AOD increments are attributed to the different species according to their proportion in the nonlinear forecast.
- If there is no dust in the forecast in a specific location then the increment will be given to whatever species are there – in this case Sulphate

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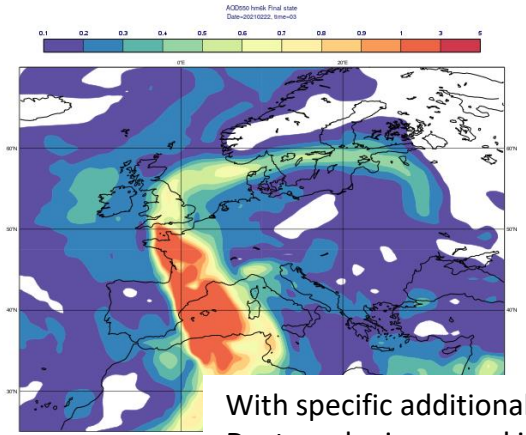
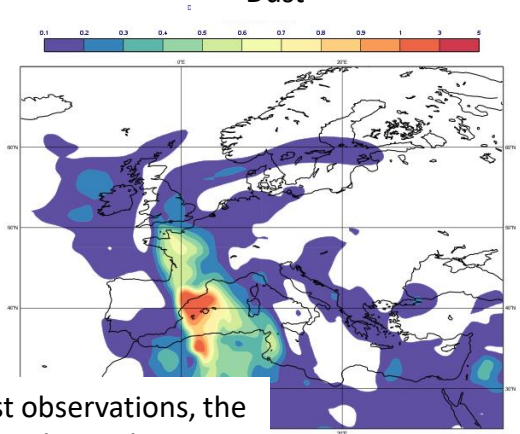
Dust test case February 2021

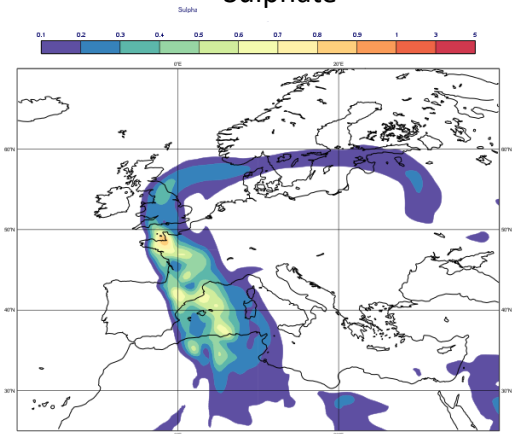
Credit: Melanie Ades

Dust

Sulphate

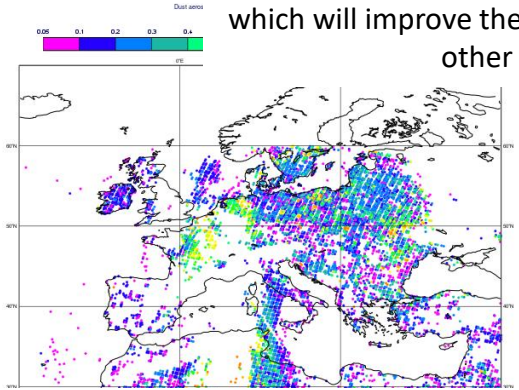


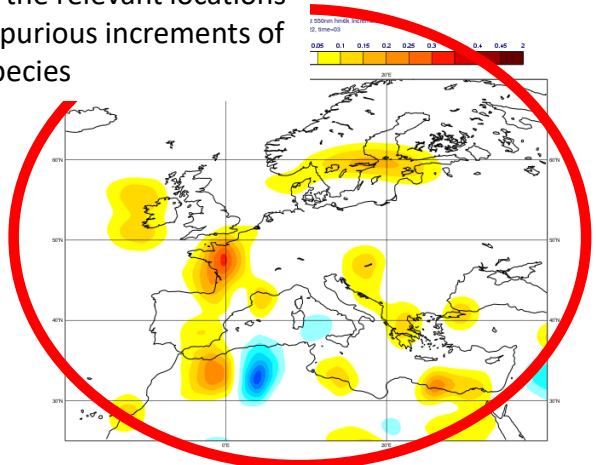


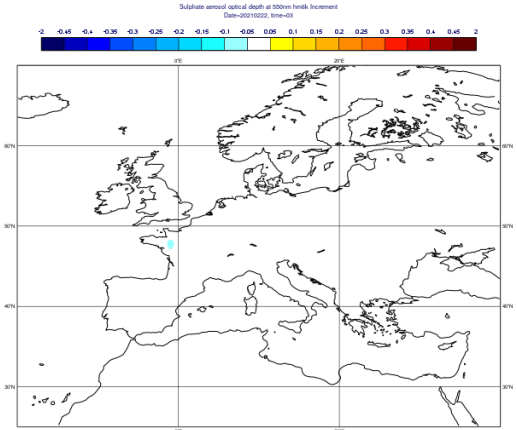


AOD at 550nm

With specific additional Dust observations, the Dust can be increased in the relevant locations which will improve the spurious increments of other species







AOD incr at 550nm

LMD IASI 10um obs 20210222 12hr

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Atmosphere Monitoring

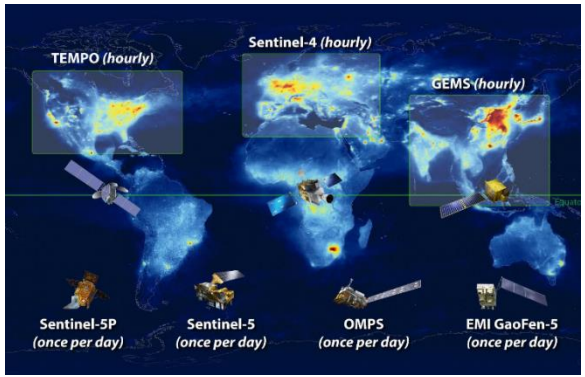
Gaps and limitations of AC observations

- Spatial resolution (horizontal and vertical); small scales not resolved
- Lack of vertically resolved AC observations (e.g. lower troposphere, UTLS)
- Lack of limb-sensor data for the continued monitoring of stratospheric composition (only ALTIUS to come)
- Revisit time (diurnal cycle); will improve with upcoming GEO missions
- Provision of data during night/ polar night
- Information about aerosol speciation in addition to AOD (e.g. dust, smoke…)
- Latency (NRT data needed within 3 hours)
- Availability of good quality validation data (regular, dense networks, close to NRT, common data formats, qc information)
- General data availability and accessibility. Easy access to data is important.
- Long-term consistent data sets & temporal continuity (also extending back in time & reprocessing for use in reanalyses)
- Past AC datasets: Difficult to go back further than early 2000s for species other than O3 or AOD

Atmosphere Monitoring

Future AC missions

- Future of **nadir missions** looks good:
  - Constellation of GEOS for AQ measurements: S4, GEMS (already launched), TEMPO; hourly obs during sun-lit hours, resol 2.5 km x 4.5 km
  - OMPS, VIIRS: JPSS-2, -3, -4 – afternoon overpass
  - S5 (on MSG-A) - morning overpass
  - IASI-NG (on MSG-A)
  - 3MI (on MSG-A)
  - CO2M (S7A&S7B) CO2, NO2 (2025/6?)
- Future of **limb missions** does not look good:
  - ALTIUS (2025)
  - OMPS-limb JPSS-2, -3, -4 (day-light only)
  - *CAIRT (1 of 4 candidates for ESA's 11th Earth Explorer mission. If selected, launch planned for 2031/32)*



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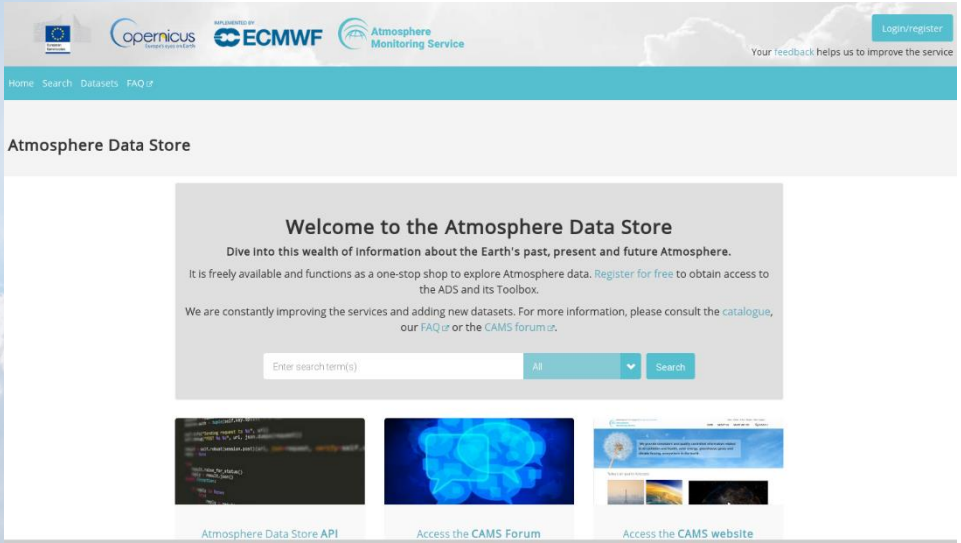
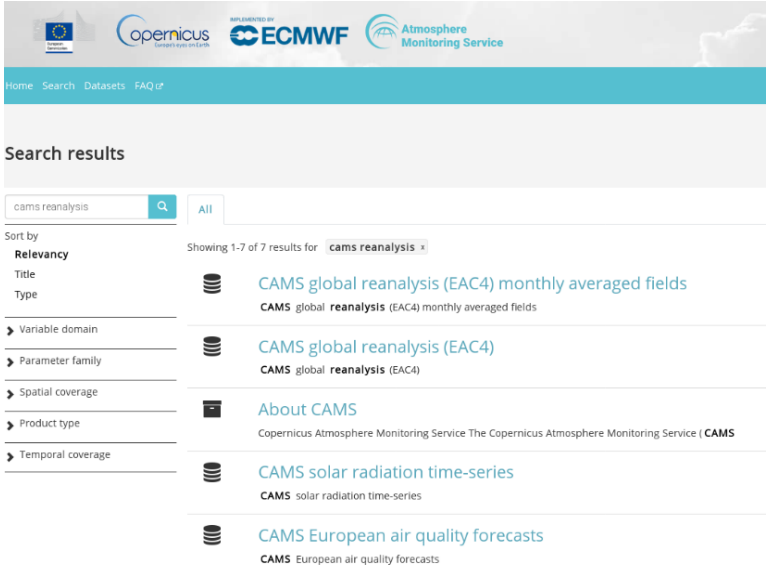
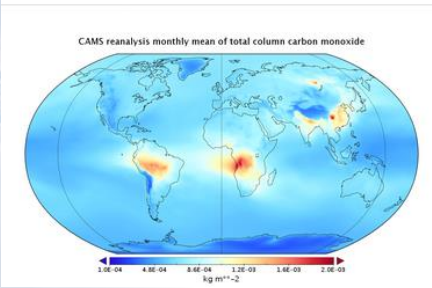
The Atmosphere Data Store (ADS)

Atmosphere Monitoring

All CAMS data are freely available







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