Atmosphere Monitoring

# Atmospheric Composition Reanalysis

Antje Inness & Angela Benedetti (ECMWF)

Thanks to the ECMWF CAMS and the UV VIS teams

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# What the Copernicus Atmosphere Monitoring Service has to offer

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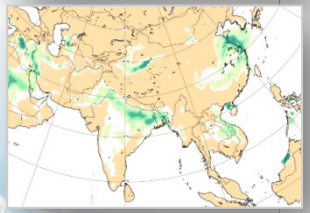

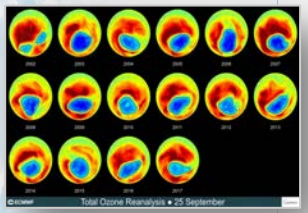


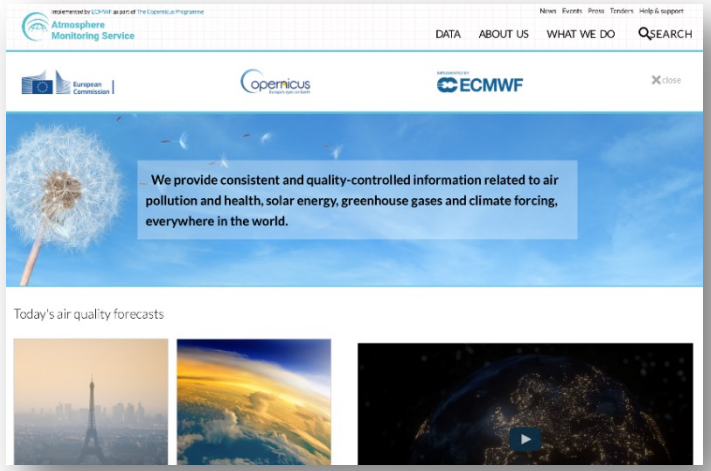


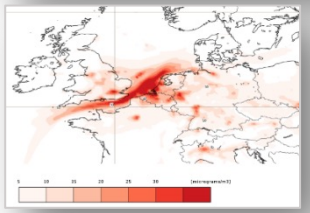

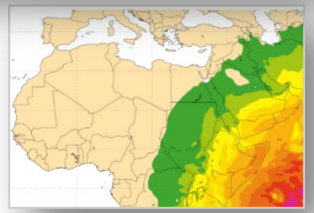

The CAMS portfolio includes Earth Observation based information products about:

- 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 atmospheric composition data into ECMWF's IFS (in addition to meteorological observations)

**https://atmosphere.copernicus.eu**

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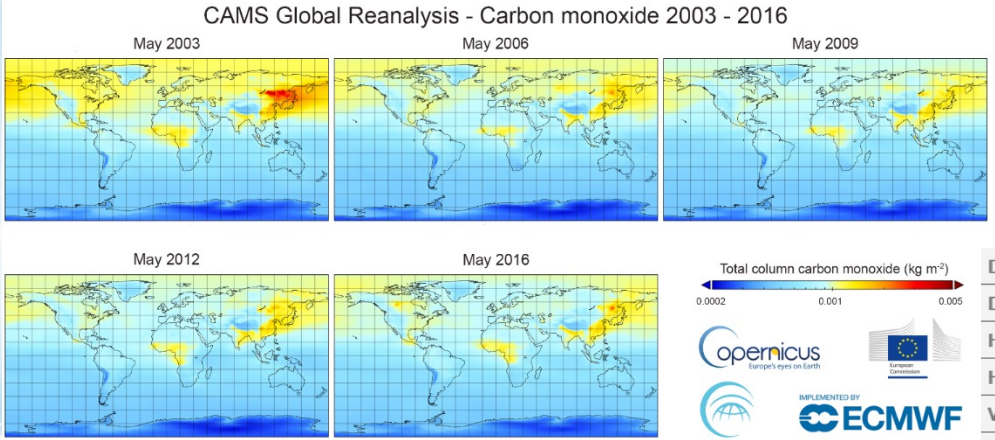
# CAMS global reanalysis 2003 – June 2021 (updated every 6 months)




**Reanalysis**
Using a combination of observations and computer models to recreate historical climate conditions.

| DATA DESCRIPTION | |
|---|---|
| Data type | Gridded |
| Horizontal coverage | Global |
| Horizontal resolution | 0.75°x0.75° |
| Vertical coverage | Surface, total column, model levels and pressure levels. |
| Vertical resolution | 60 model levels. Pressure levels: 1000, 950, 925, 900, 850, |
| Temporal coverage | 2003 to 2020 |
| Temporal resolution | 3-hourly |
| File format | GRIB (optional conversion to netCDF) |
| Versions | Only one version |
| Update frequency | Twice a year with 4-6 month delay |

**CAMS global reanalysis (CAMSRA, eac4)**

- 2003 –June 2021, with new years being added
- Aerosols, chemical pollutants, $CO_2$ & $CH_4$
- 80 km spatial resolution, 60 model levels
- Inness et al. (2019): https://doi.org/10.5194/acp-19-3515-2019
- Wagner et al. (2021): https://doi.org/10.1525/elementa.2020.00171
- atmosphere.copernicus.eu/eqa-reports-global-services
- Freely available from ADS https://atmosphere.copernicus.eu/data

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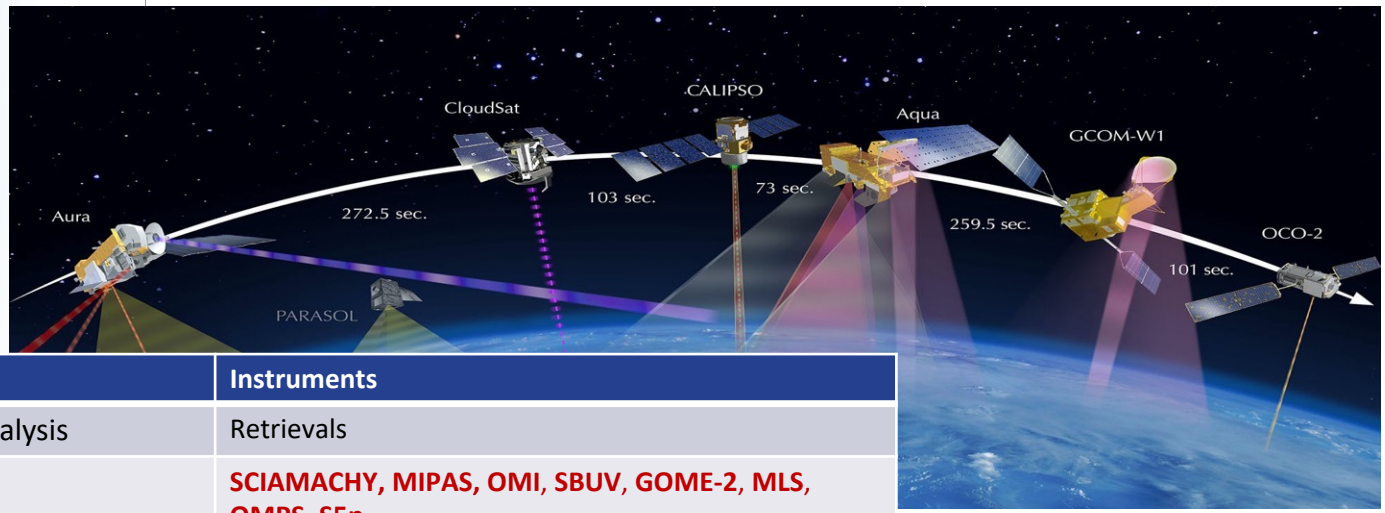
# AC Observations used in CAMSRA

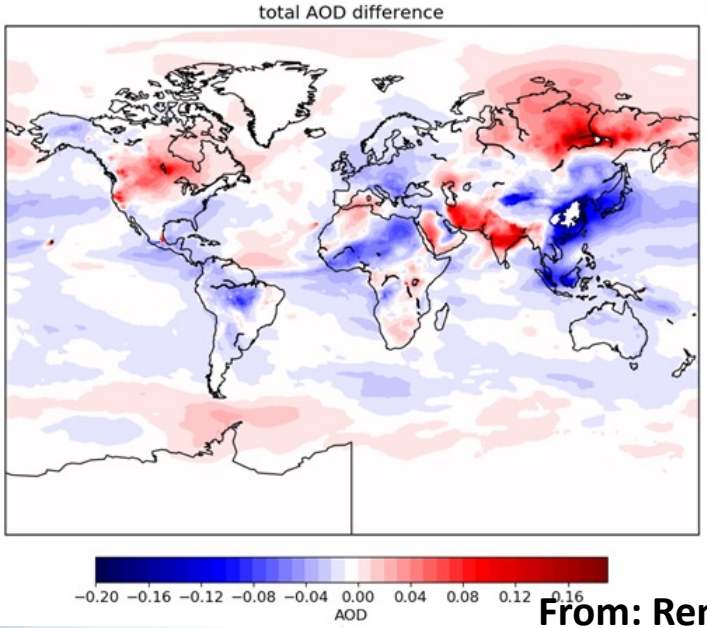


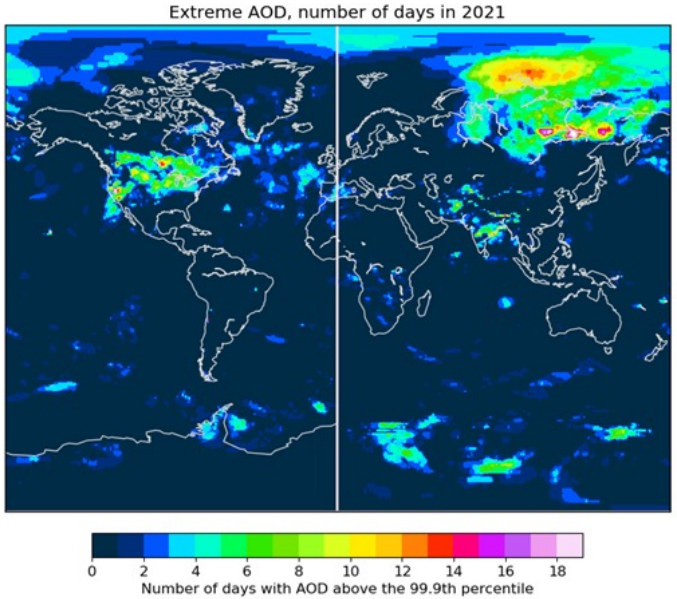

| Species | Instruments |
|---|---|
| CAMS Global reanalysis | Retrievals |
| $O_3$ | **SCIAMACHY, MIPAS, OMI, SBUV, GOME-2, MLS, OMPS, S5p** |
| CO | **MOPITT** |
| $NO_2$ | **SCIAMACHY, OMI , GOME-2** |
| Aerosol | **AATSR, MODIS** |
| $CO_2$ | **GOSAT, IASI** |
| $CH_4$ | **GOSAT, IASI** |
| | |
| GFAS fire emissions | **MODIS** |

- Offline/ reprocessed data used in first part
- NRT data used towards the end (~ 2017 onwards)

# Aerosol anomalies and extremes in 2021

Aerosol Optical Depth anomalies calculated against the 2003-2020 annual means from the CAMS reanalysis




Number of days in 2021 with extremely high AOD (extreme being defined as above the local 2003–2020 99.9$^{th}$ percentile).

The exceptional fires over parts of Siberia, U.S. and Canada, as well as their downstream plumes over the Arctic ocean and Eastern U.S. are clearly visible.

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**From: Remy et al, Aerosols to appear in BAMS State of Climate in 2021**

# Study of CO trends

## CO burdens

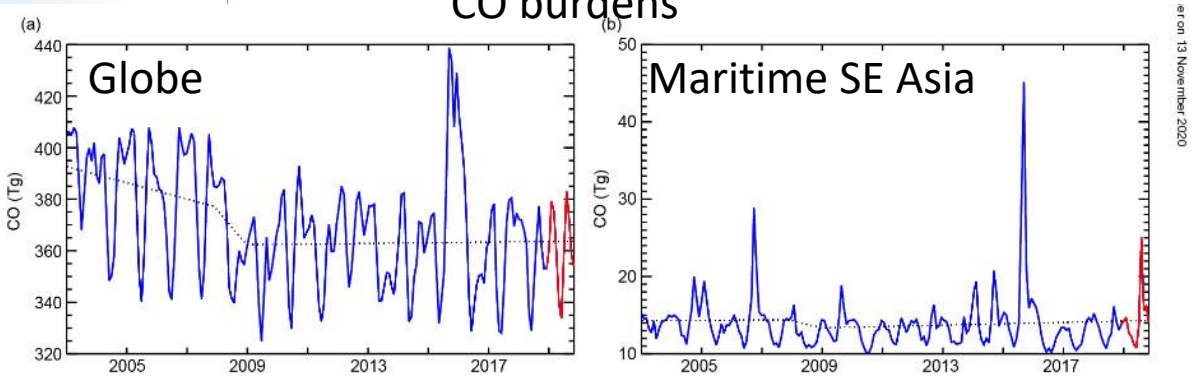


Fig. 2.60. Time series of monthly CO burdens (Tg) for (a) the whole globe and (b) over Maritime Southeast Asia from the CAMS reanalysis for 2003–19 (2019 is shown in red) and a piecewise linear trend (dotted line) for the periods 2003–07, 2008, and 2009–19.

## Comparison of xCO with TCCON at Parkfalls

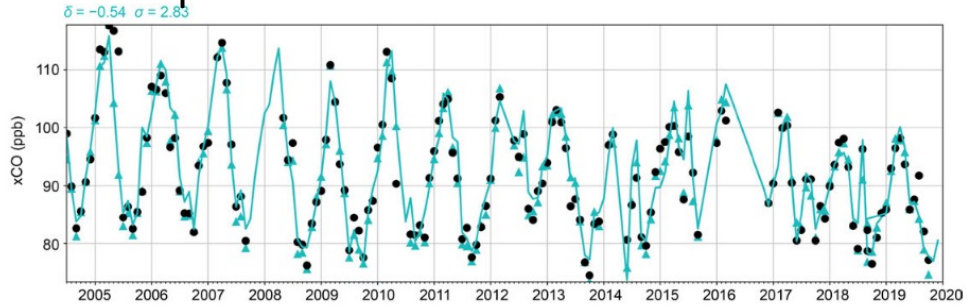


Fig. 2.62. Column-averaged CO (xCO, in ppb) at the Park Falls TCCON station. Monthly mean observations are shown by the black dots, and corresponding monthly mean xCO columns calculated using the TCCON-averaging kernels are shown by the blue triangles. The continuous blue line is the monthly xCO from the CAMS reanalysis.

Flemming et al. (2020), BAMS State of Climate 2019

TCCON data from: https://tccondata.org/

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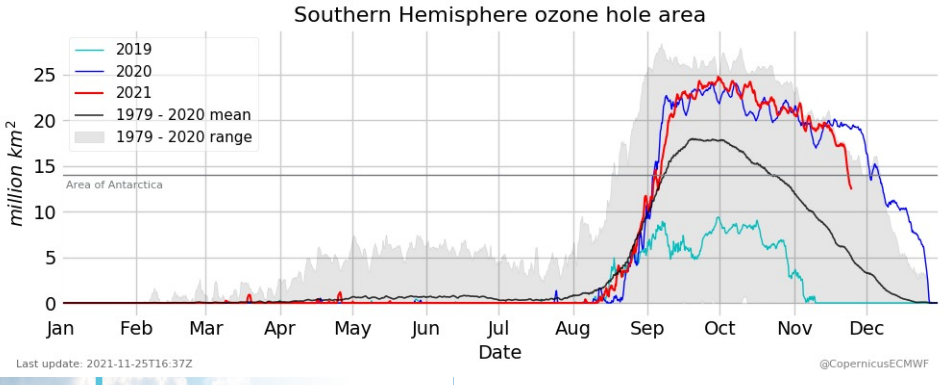
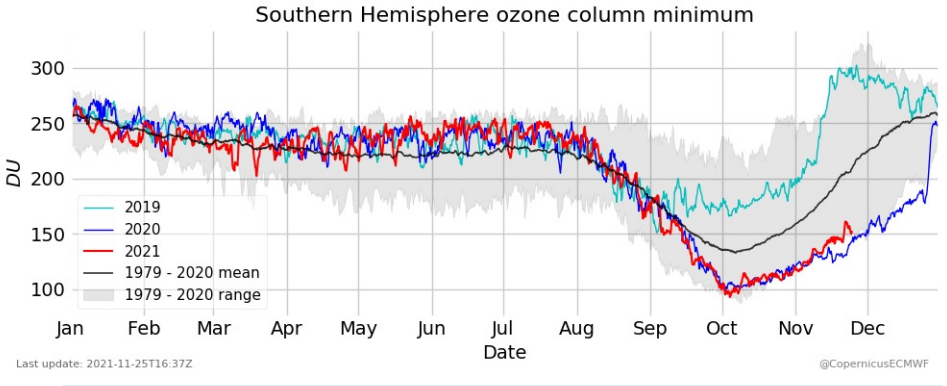
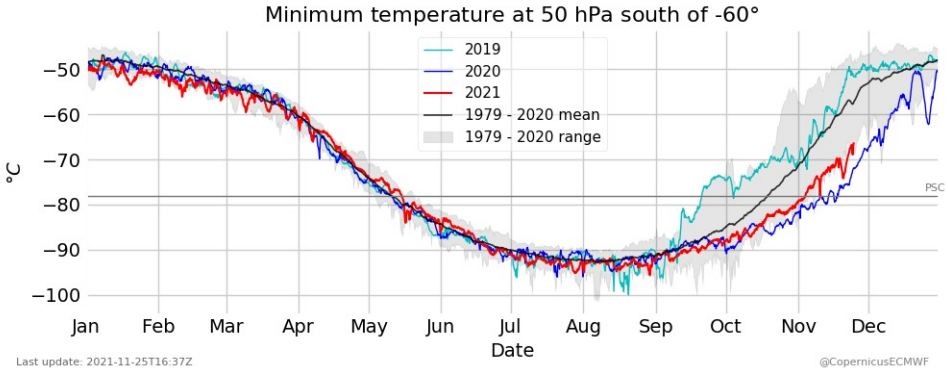
# Antarctic ozone hole 2019, 2020 & 2021

## In addition to long-term recovery there is a lot of interannual variability




- 2019, 2020 & 2021 all had exceptional Antarctic ozone holes
- 2019 small and short-lived because of unusual stratospheric warming
- 2020 & 2021 deep, big & long-lived due to very cold stratosphere and stable polar vortex

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(1979-2002 from ERA5; 2003-2020 from CAMSRA; 2021 CAMS NRT)

# Points to consider for future reanalyses

- Improvements to reanalysis possible from advances in
  - composition modelling
  - data assimilation methodology (e.g. emission inversion, background errors)
  - data selection, quality control and bias correction
  - improved meteorology
  - improved emission inventories
  - improved, reprocessed data sets
  - new observations (i.e. lidar profiles, radiances)

# Impact of model improvements - AOD

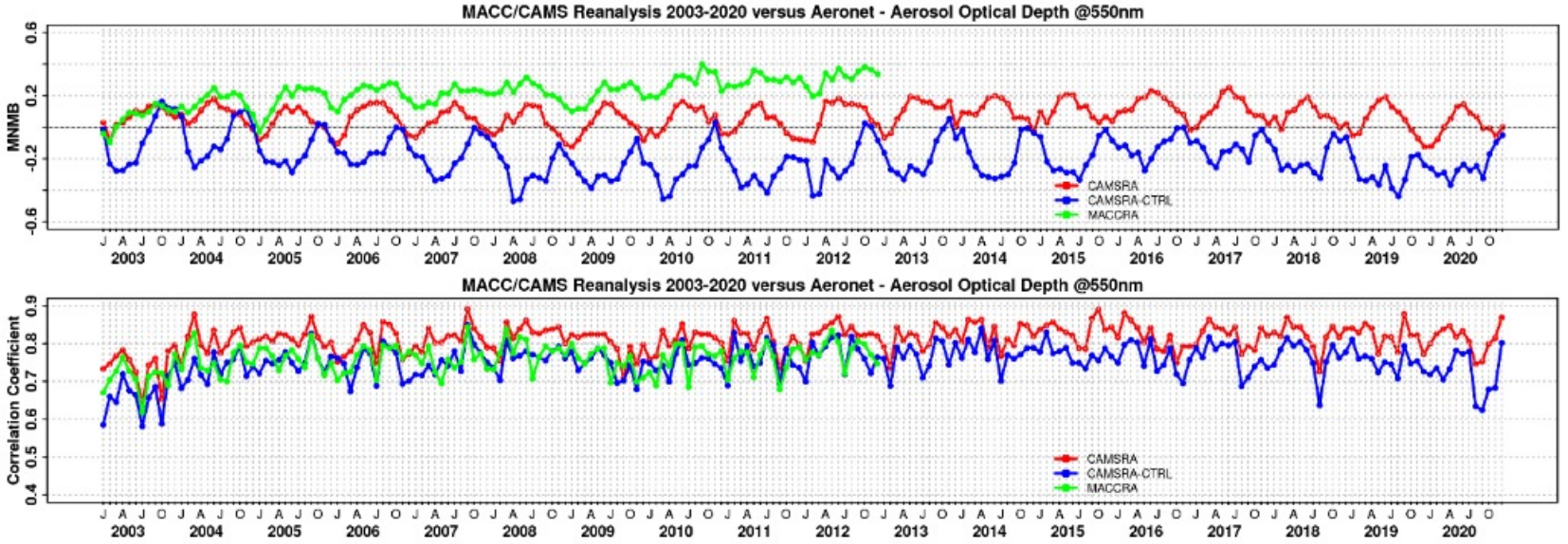
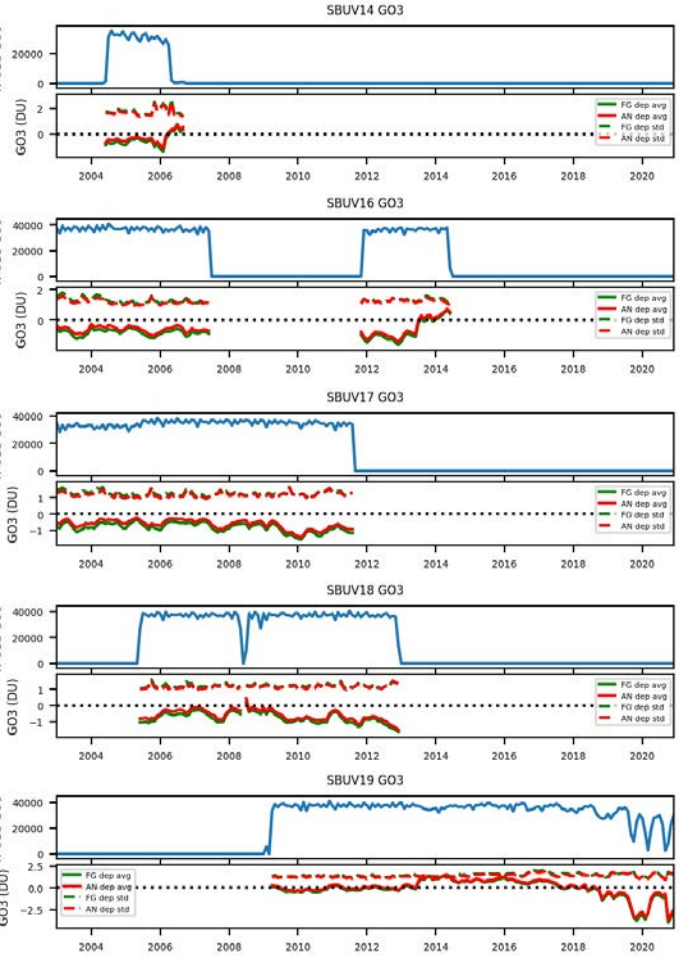


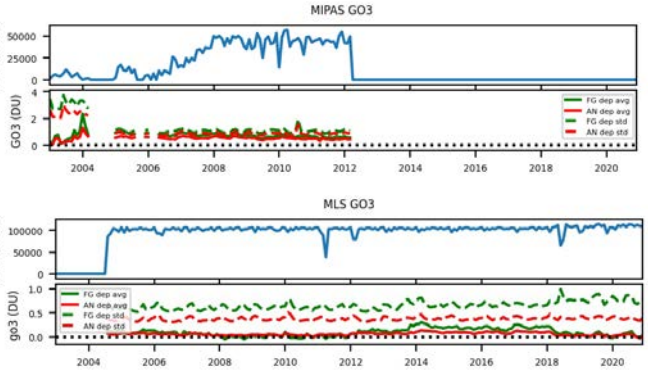

Figure S.1: a) Aerosol optical depth at 550nm in IFS 00Z model simulations for 2003–2020 against daily matching Aeronet Version3 level 1.5; (top) b) Modified normalized mean bias (MNMB); CAMS reanalysis (red) and control run (blue); MACC reanalysis (green); (bottom) Corresponding correlation coefficient.

Model and data improvements compared to older MACC reanalysis

https://atmosphere.copernicus.eu/sites/default/files/2021-06/CAMS84_2018SC3_D5.1.1-2020_reanalysis_validation.pdf

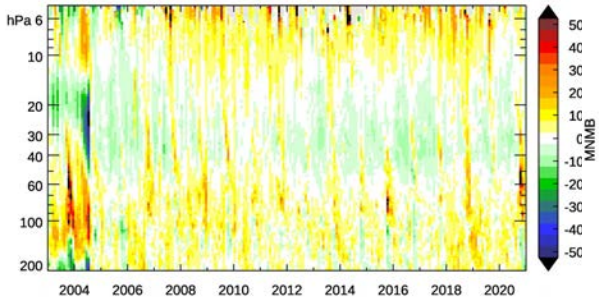
# Impact of changing observing system

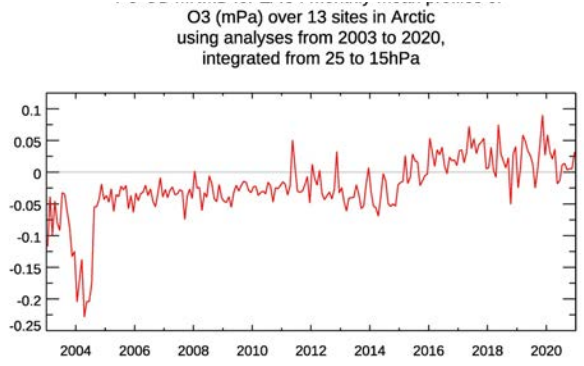


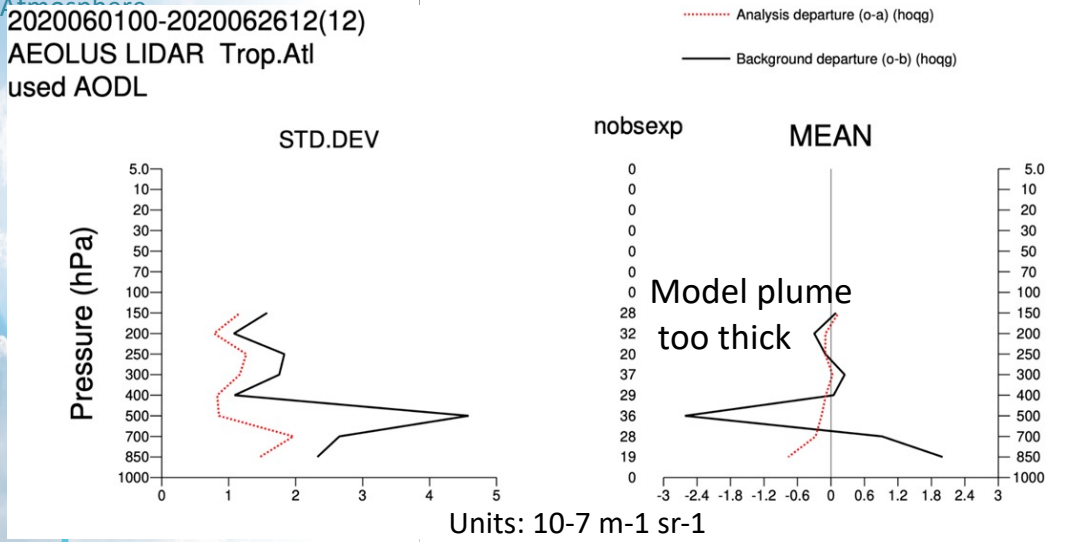

- Example stratospheric O3 (SBUV/2, MLS, MIPAS)
- Changing observing system can limit quality/ consistency of the reanalysis
- Would it be better to keep some data passive and for validation?

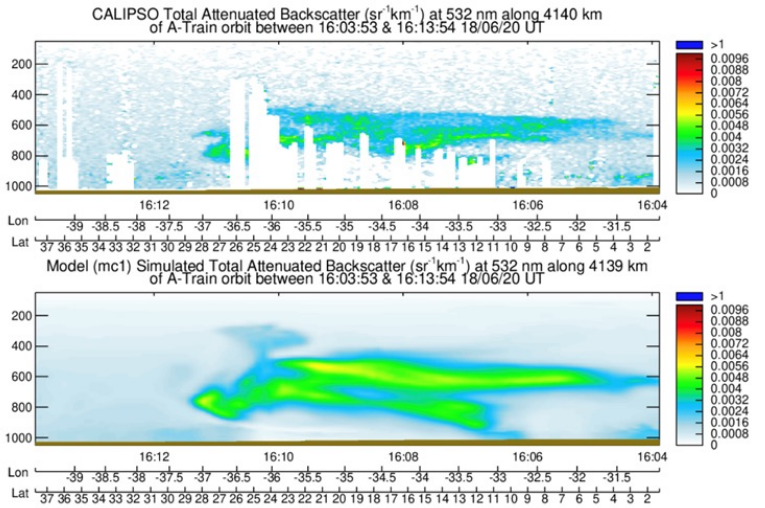
## Biases against ozone sondes



# New observations: lidar backscatter




- Aeolus particle backscatter assimilation changes aerosol load in the vertical profile bringing it more in line with CALIPSO data
- Comparison with AERONET shows AOD calculated by Aeolus+AOD assimilation shows a better fit to the AERONET values at the time of the event
- However, a positive bias is observed globally

**Work by Will McLean funded by the ESA Aeolus Data Innovation and Science Cluster**

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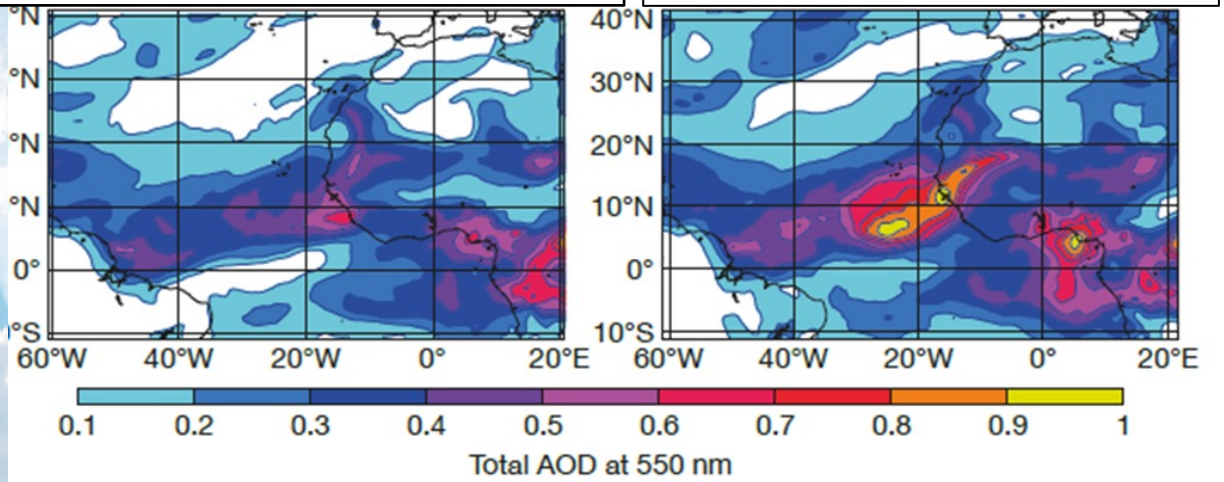
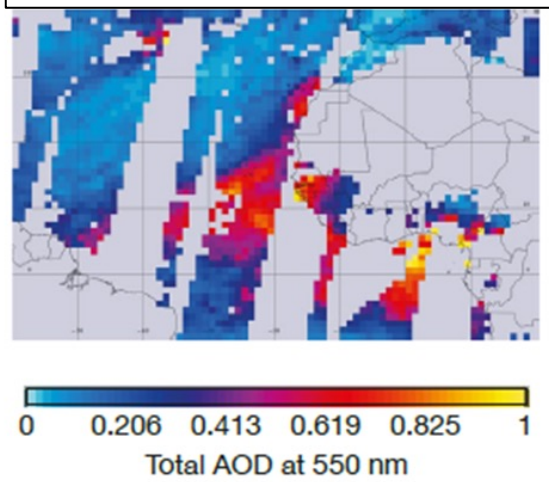
# "New" observations: visible reflectances

**Model without assimilated aerosol observations**

**Model with assimilated visible reflectances**

**MODIS Retrieved AODs (not assimilated)**




- Comparable performance of MODIS AOD and reflectance assimilation over **ocean** as verified against AERONET data
- Crucial role of the **bias correction** for reflectances
- Better performance of reflectance assimilation for Angstrom exponent
- More work is needed over land: the weak link is the **surface reflectance**

More information: https://www.ecmwf.int/en/about/media-centre/news/2020/progress-towards-using-visible-light-satellite-data-weather

**Work by Samuel Quesada Ruiz and Angela Bendetti funded by the ESA ARAS project**

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# Plans for a CAMS2.0 reanalysis

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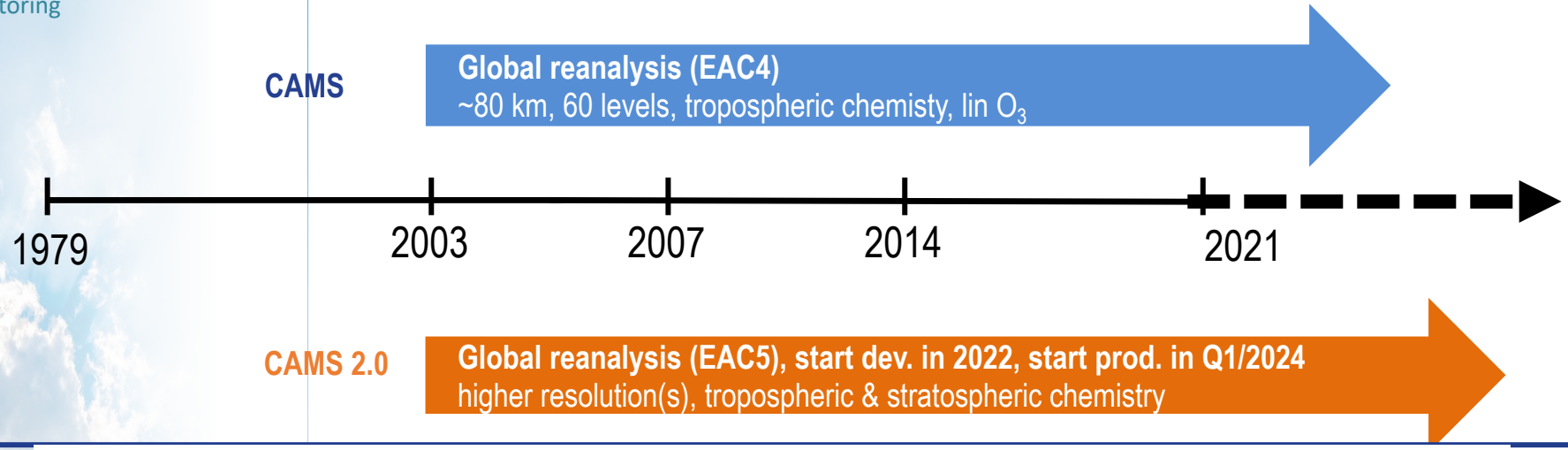


- Improvements to chemistry (+ stratospheric chemistry)
- Newer/ improved IFS version (better meteorology)
- Increased resolution
- Better, reprocessed observations
- Improved QC for assimilated data
- Continued use of reprocessed observations instead of switch to NRT data (?)
- No emission inversion yet

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# Summary

- CAMS provides atmospheric composition data at global and European regional scale
- CAMS data freely available from ADS: https://atmosphere.copernicus.eu/data
- CAMS reanalysis covers the years from 2003 onwards
- CAMSRA will be extended until CAMS2.0 reanalysis is in place (Fingers crossed for MOPITT, MODIS and MLS)
- CAMSRA can be used to look at trends and anomalies (e.g. CO, AOD, total O3)
- A new CAMS2.0 reanalysis (eac5) will be produced (start Q1/2024) still covering the period from 2003 onwards

# The Atmosphere Data Store (ADS)

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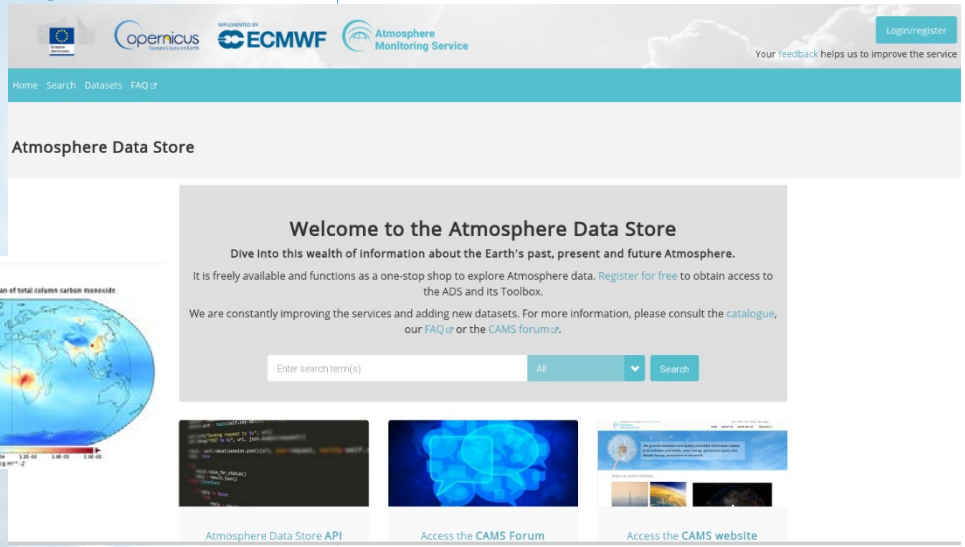
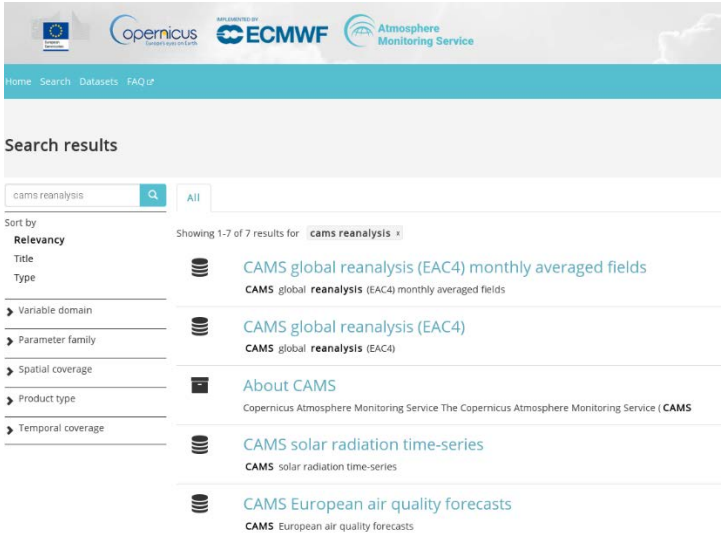
All CAMS data are freely available **https://atmosphere.copernicus.eu/data**







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