Assimilation of satellite data for air quality monitoring and forecasting

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With the contribution of Richard Engelen
(CAMS Deputy Head)

Copernicus
Atmosphere Monitoring
Service
Implemented by

ECMWF

Copernicus
Europe's eyes on Earth

European
Commission

USERS

Policy Makers & Public & Private, Commercial

Different Needs

Farming

Oil Spill Tracking

Air Quality

Flood

Surveillance

Arctic change

Examples of areas covered

Land, Marine, Atmosphere, Emergency, Security, Climate

Information Services

Space Infrastructure & In Situ Infrastructure

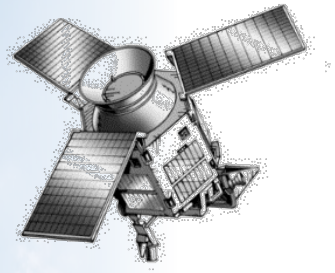
Sustainable observation capabilities

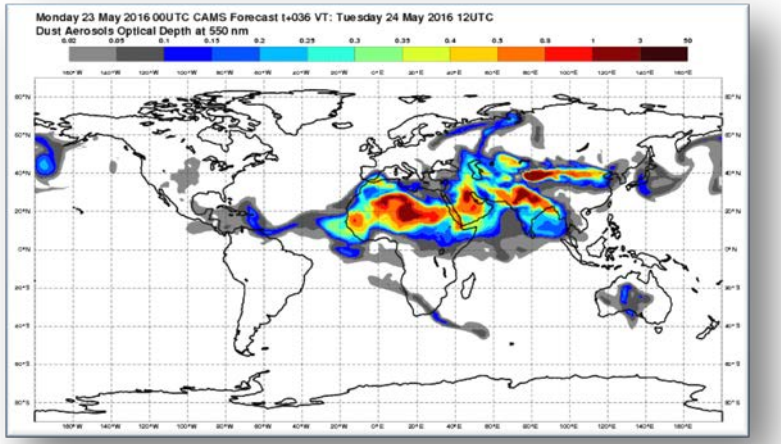
OBSERVATIONS

CAMS SERVICE CHAIN

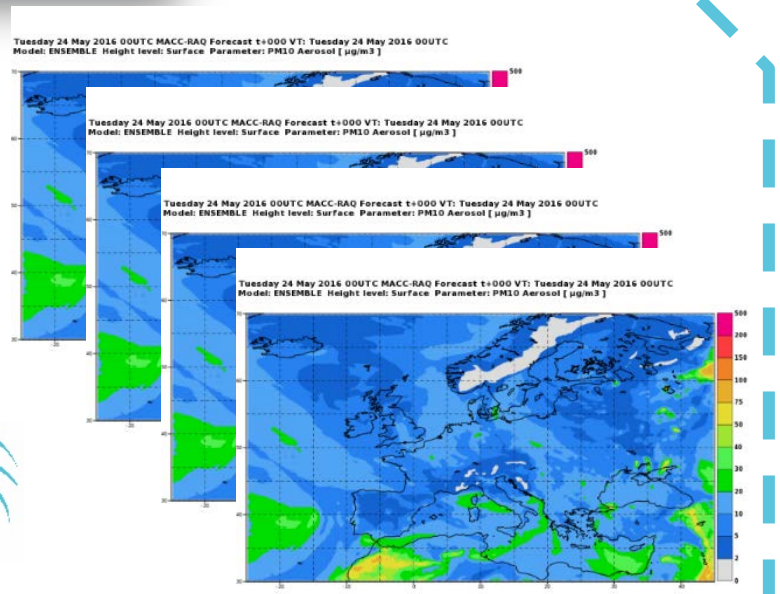
Atmosphere Monitoring

Space Agencies

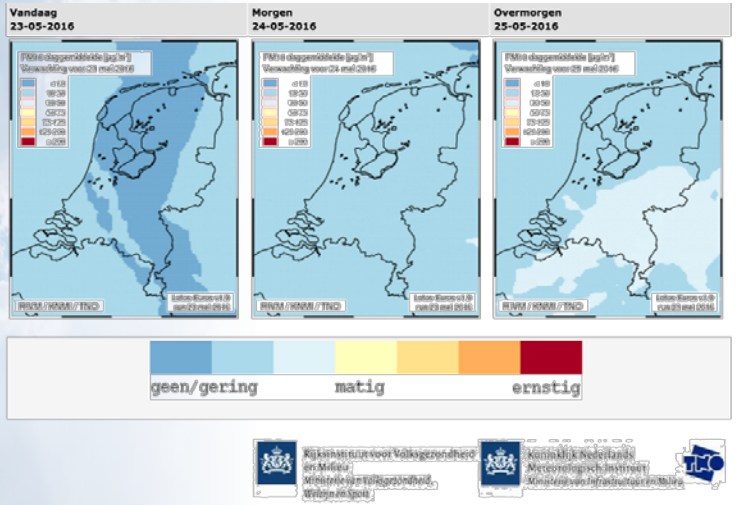




In-situ observations



National scale



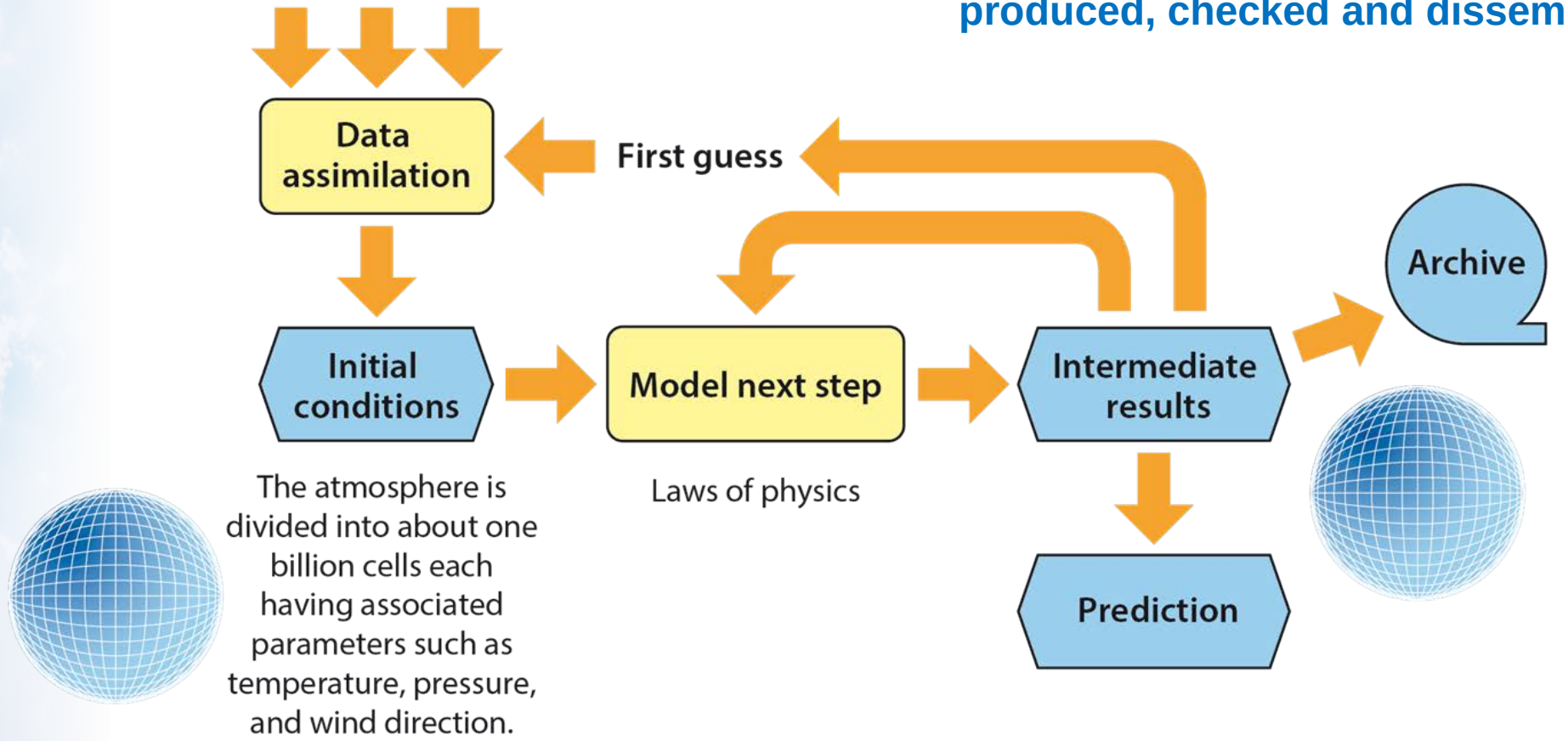
Atmosphere Monitoring

Global production

Approximately 20 million observations

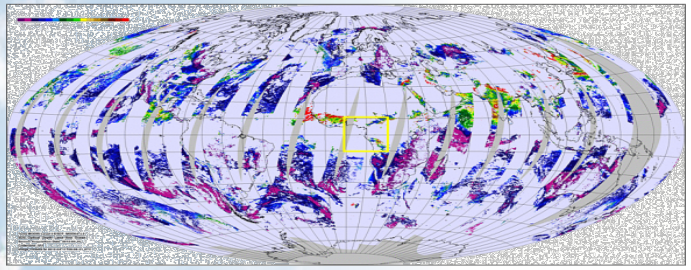
Every 12 hours, observations are acquired, pre-processed, quality controlled, and assimilated.

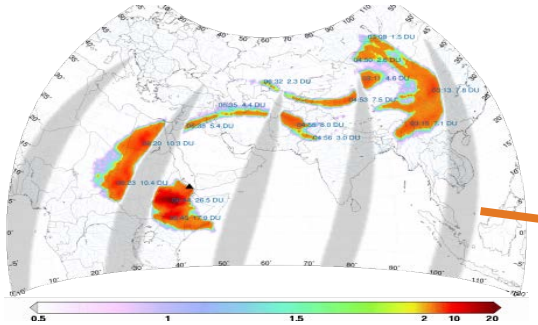
Every 12 hours a global 5-day forecast is produced, checked and disseminated.

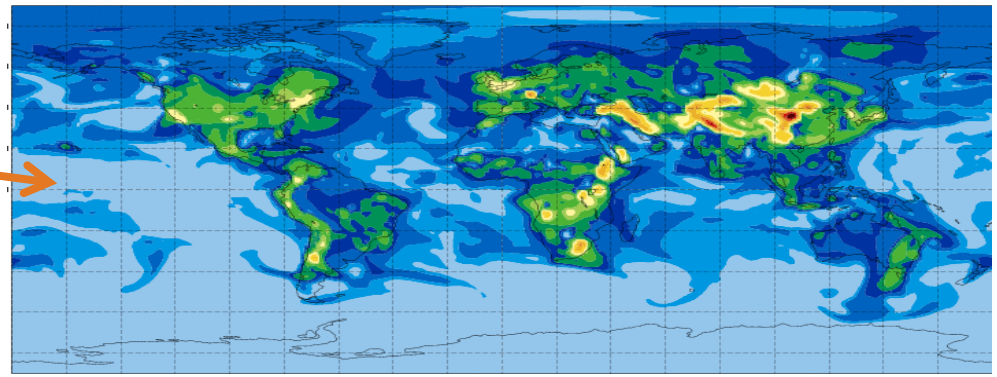


FROM EARTH OBSERVATIONS TO AIR QUALITY PRODUCTS

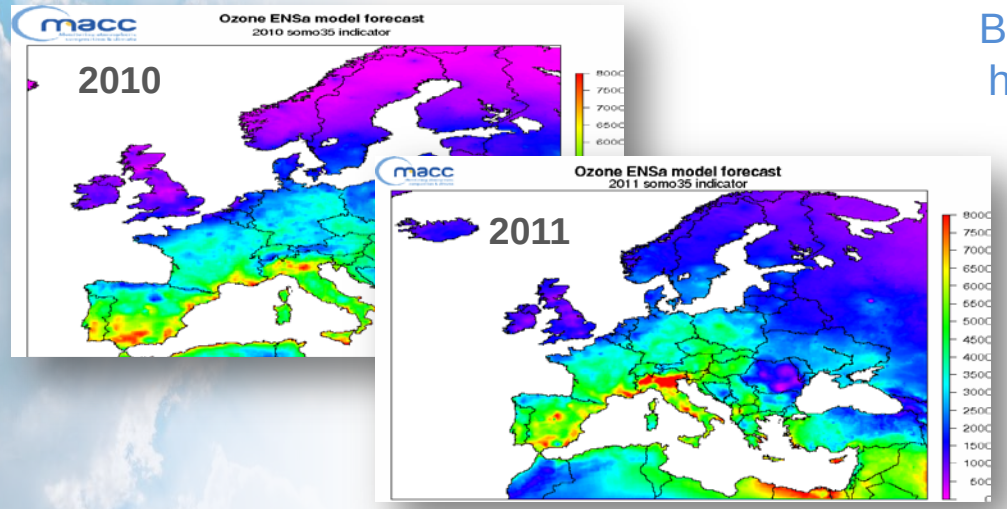
Over 70 EO instruments are assimilated in the global system



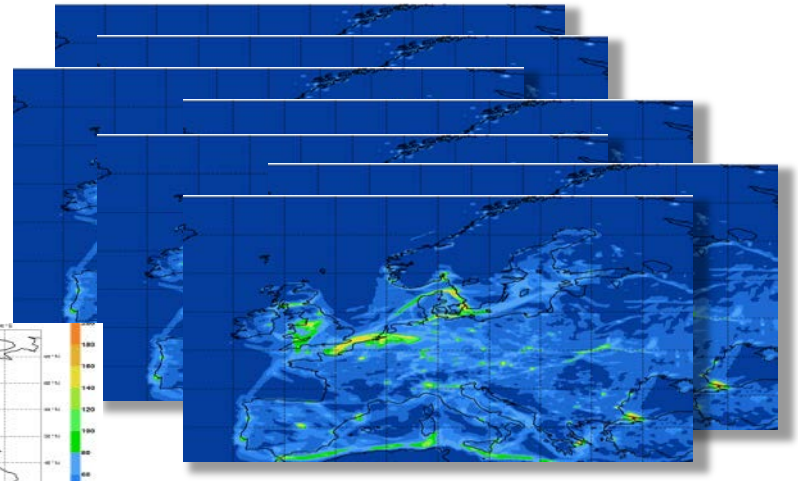


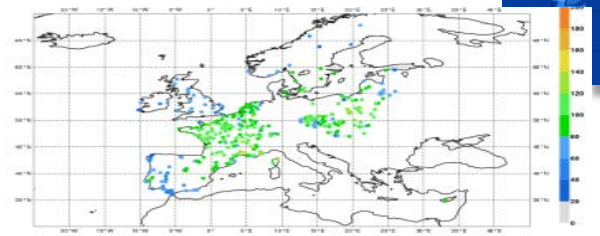


Boundary conditions feed an ensemble of high-resolution European AQ systems (in order to assess uncertainties)



More data are assimilated (in particular in situ) and used for extensive validation





Policy-relevant (here health indicator for ozone) products are delivered. They are “maps with no gaps”, which observations alone don’t provide and are essential to assess impacts.

Atmosphere Monitoring

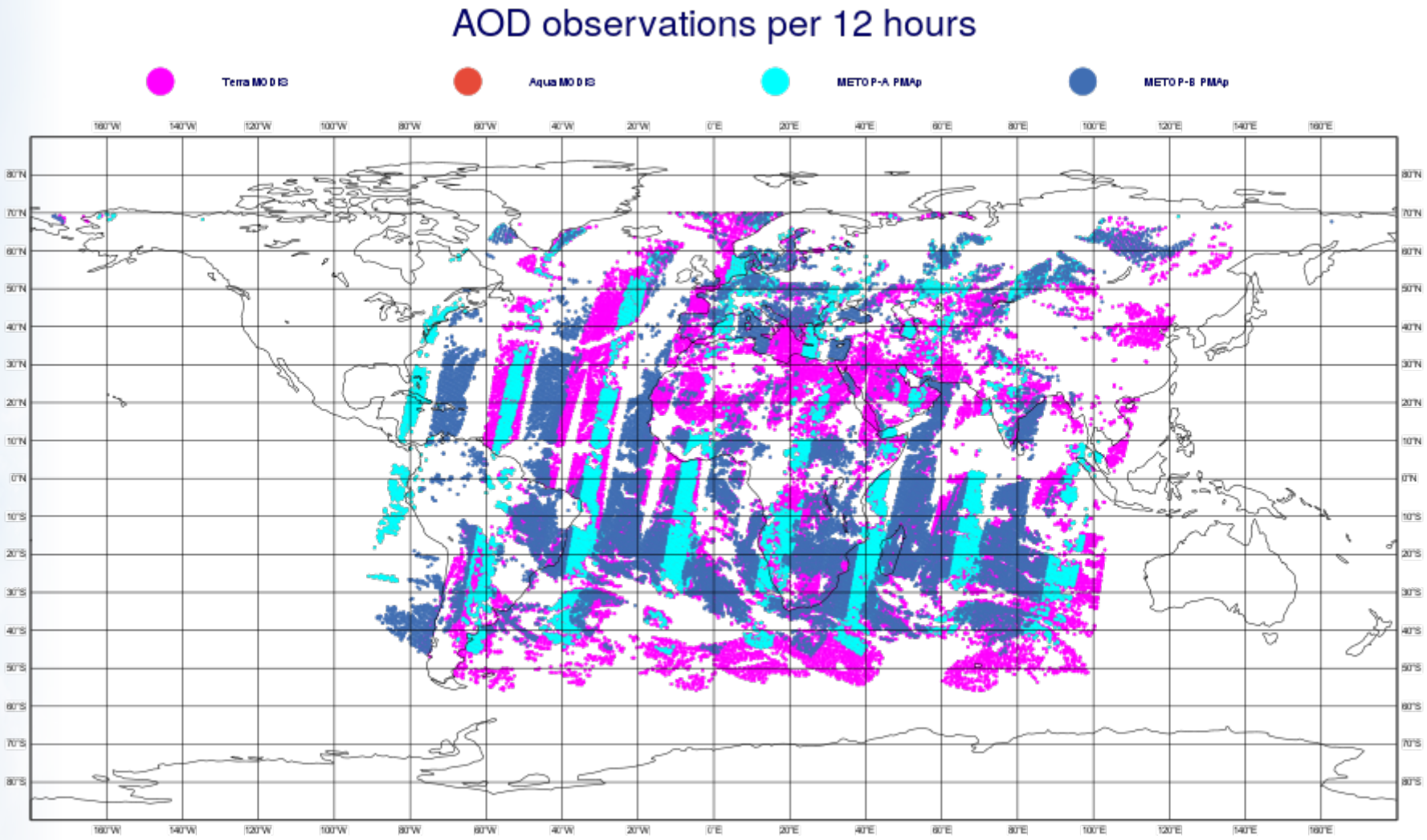
Current satellite data usage (global system)

Species	Instruments
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**, GOES, SEVIRI, VIIRS

Assimilated
Monitored
Planned

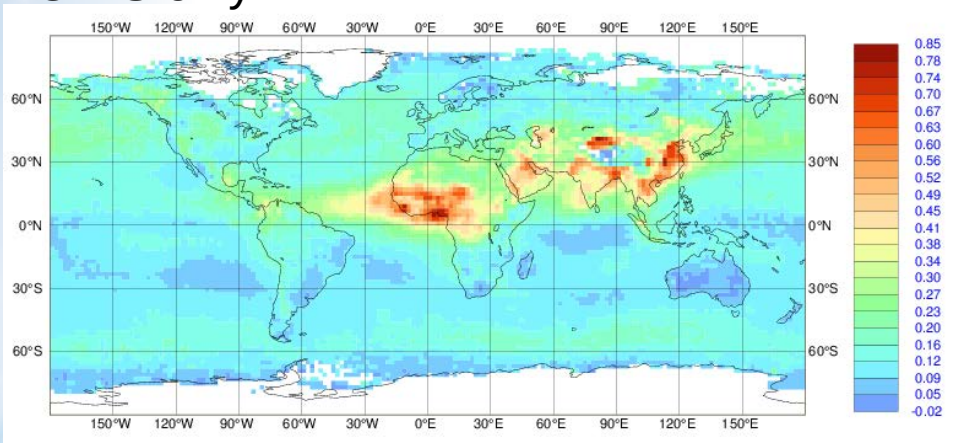
Atmosphere Monitoring

Example: AOD observations over 12 hours

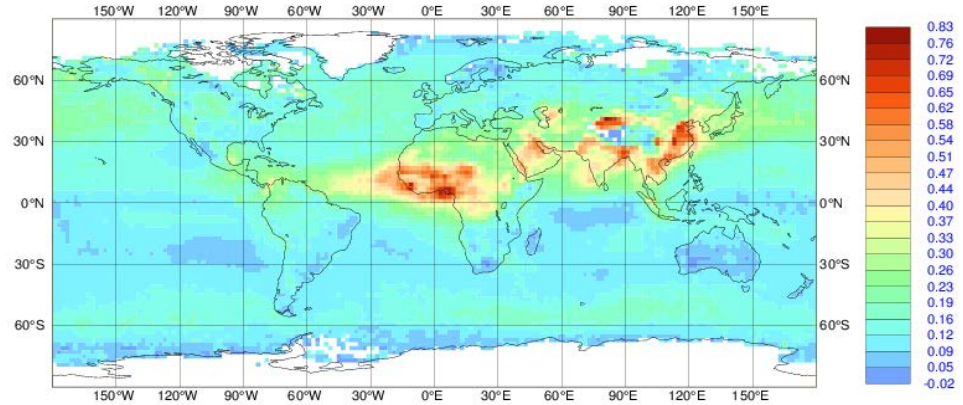


Excursus: The importance of redundancy

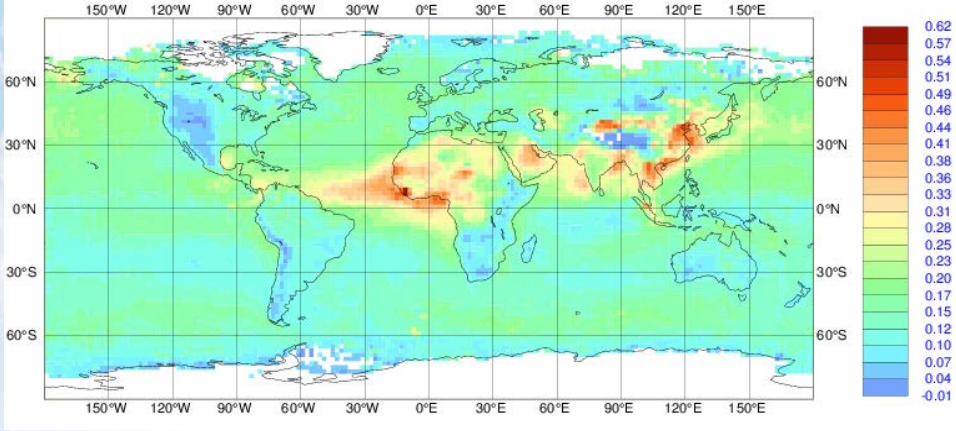
MODIS only



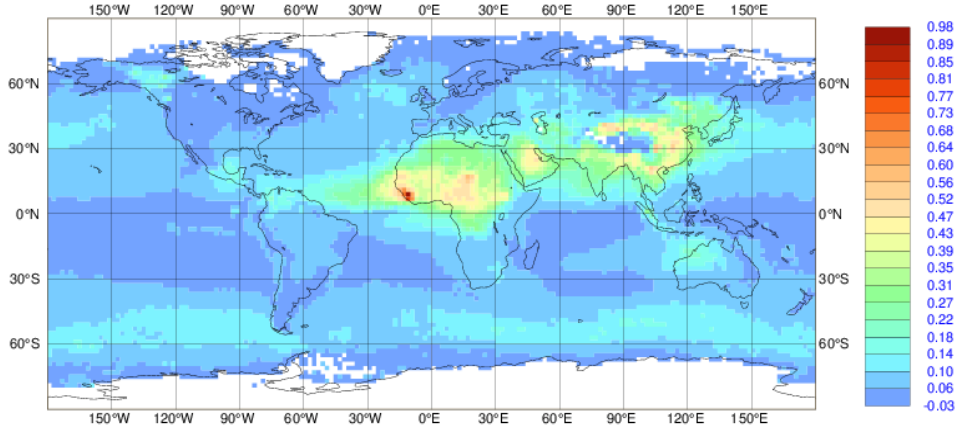
MODIS and PMAp



PMAp only



No AOD



- Very similar mean model state for MODIS only and MODIS + PMAp
- Effect of higher PMAp-B observations apparent for PMAp only
- PMAp only better than no AOD observations

CAMS PORTFOLIO

AIR QUALITY AND ATMOSPHERIC COMPOSITION

European air quality analyses, forecasts and assessments in support of reporting and policy making, pollen forecasts, global transport of constituents/pollutants...

CLIMATE FORCING

Distributions of aerosol components and their radiative impacts, other radiative forcings...

OZONE LAYER AND UV

Monitoring and forecasting of the ozone layer / hole, UV index, UV radiation (crops, ecosystems)...

SOLAR RADIATION

Estimates of solar irradiance at surface, improved potential yield assessments for solar plants...

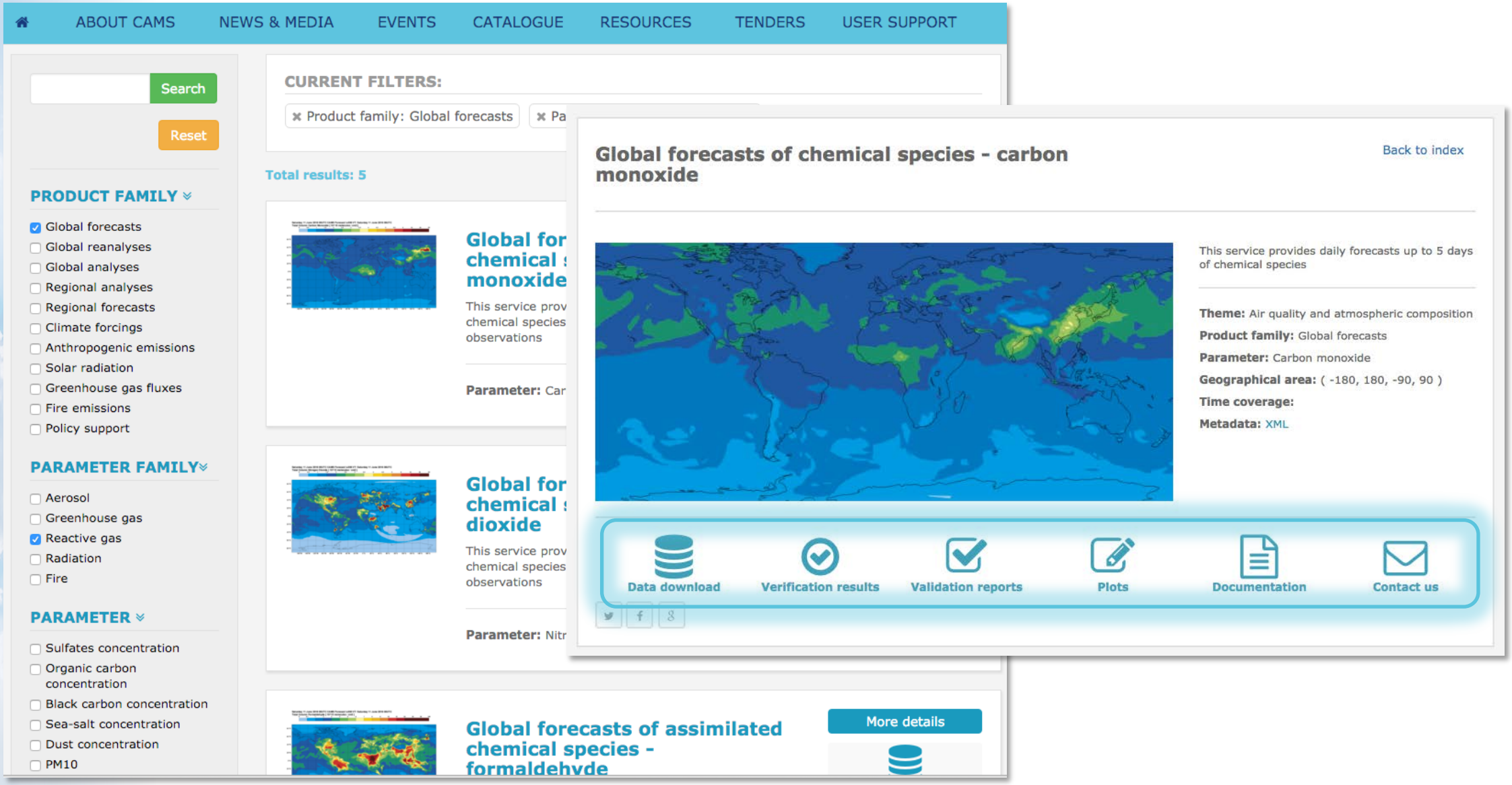
EMISSIONS AND SURFACE FLUXES

Estimates of human emissions globally and in Europe (high-resolution), emissions by wildfires, surface fluxes of CO_2, CH_4 and N_2O...

Accessing the Products

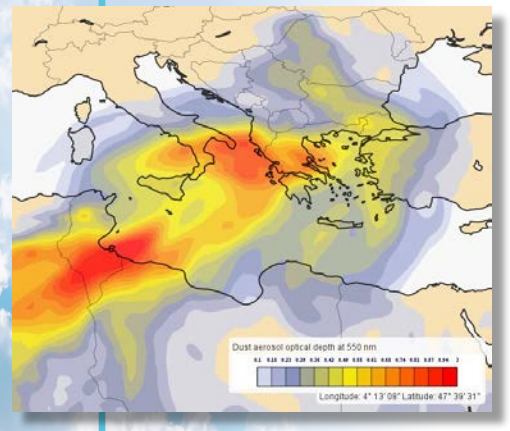
Atmosphere Monitoring

https://atmosphere.copernicus.eu/

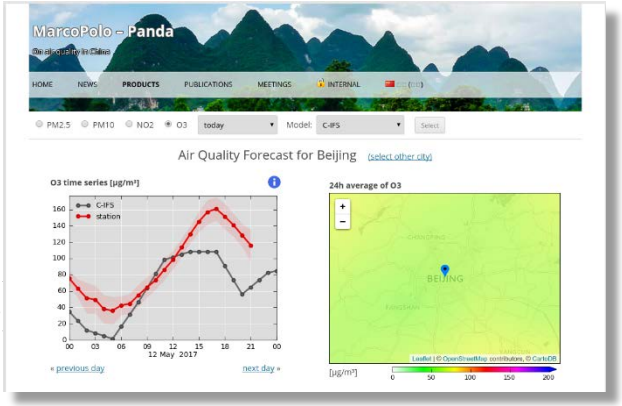


Use of global services

Atmosphere Monitoring

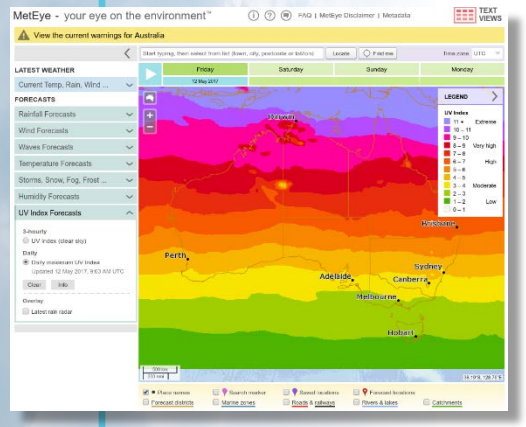


- Boundary conditions (CAMS, PANDA, HTAP,…)



- Pollution and long-range transport on global scale (e.g., large wildfires, volcanic eruptions, dust storms

- Input for downscaling applications (e.g., smartphone apps)



- Input for national forecasting services (e.g., dust, UV)

- WMO warning advisory centres

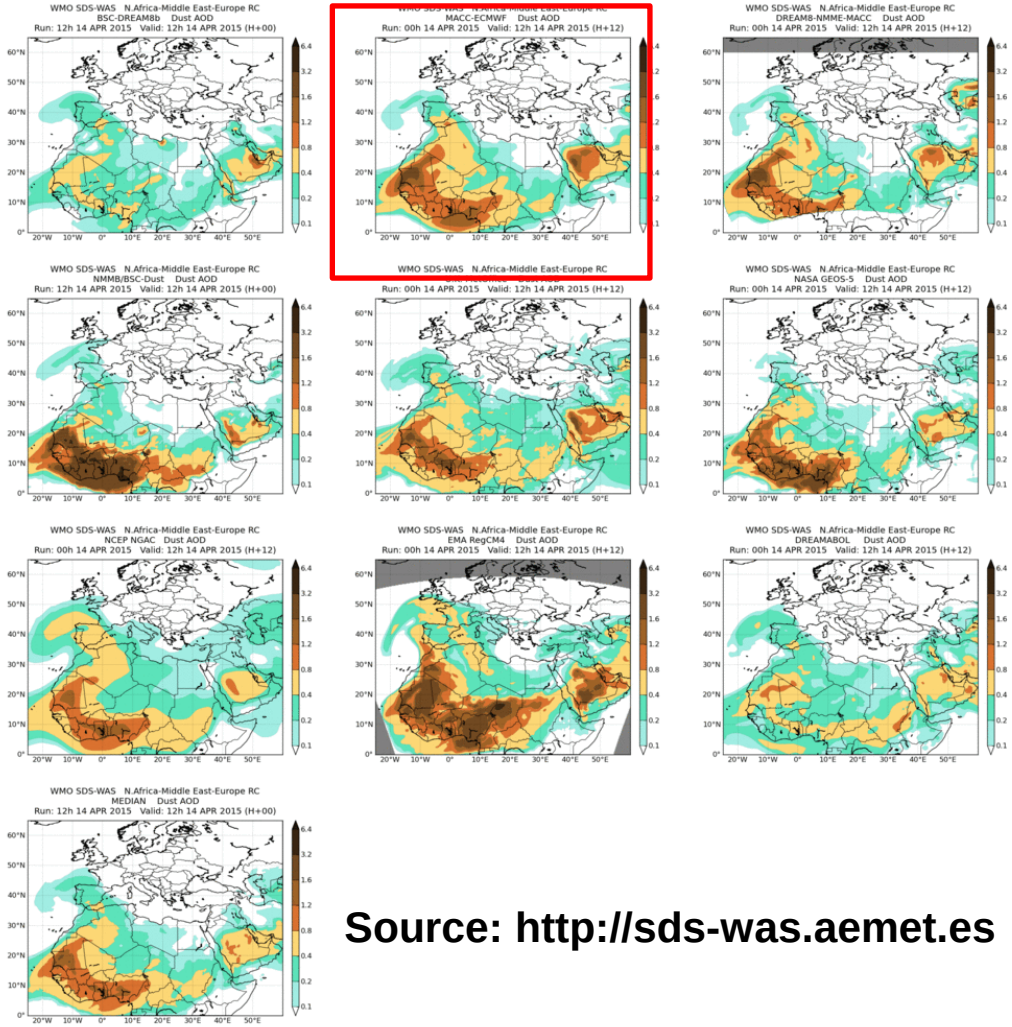
- Scientific community (field campaigns, scientific studies, ...

CAMS AEROSOL FORECASTS

- Built on the ECMWF NWP system with additional prognostic aerosol variables (sea salt, desert dust, organic matter, black carbon, sulphates)

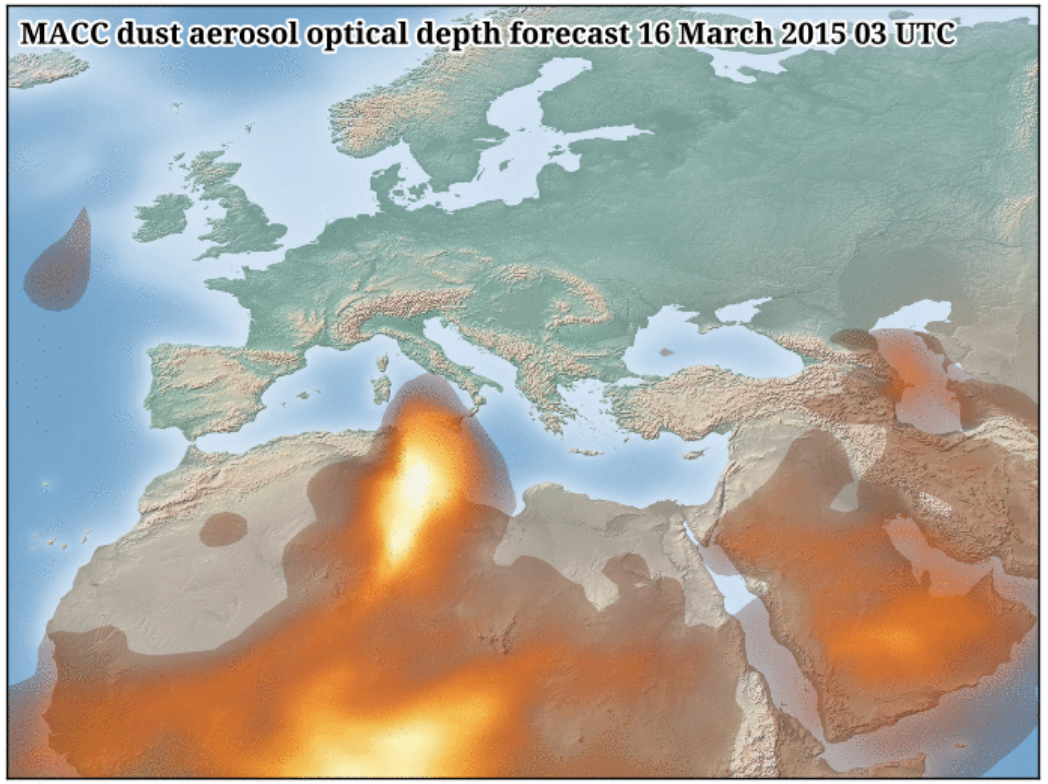
- Aerosol data used as input in the aerosol analysis:
  - NASA/MODIS Terra and Aqua Aerosol Optical Depth at 550 nm, MetOp PMAP 550 AOD
  - NASA/CALIOP CALIPSO Aerosol Backscatter, EARLINET Aerosol Backscatter (experimental)
  - AATSR, SEVIRI, VIIRS (experimental)
  - S3 (to come)
- Verification based on AERONET Aerosol Optical Depth (and now also Angstrom exponent and scattering coefficient - experimental)

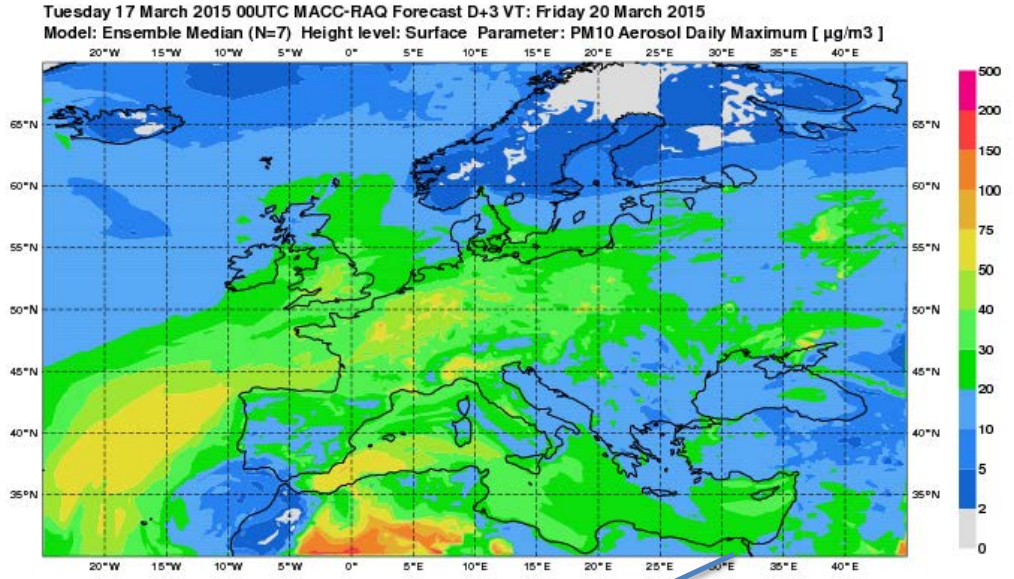
- Part of multi-model ensemble efforts such as the International Cooperative for Aerosol Prediction (ICAP) and the WMO Sand and Dust Storm Warning and Assessment System (SDS-WAS) North-African-Middle-East-Europe and Asian nodes.

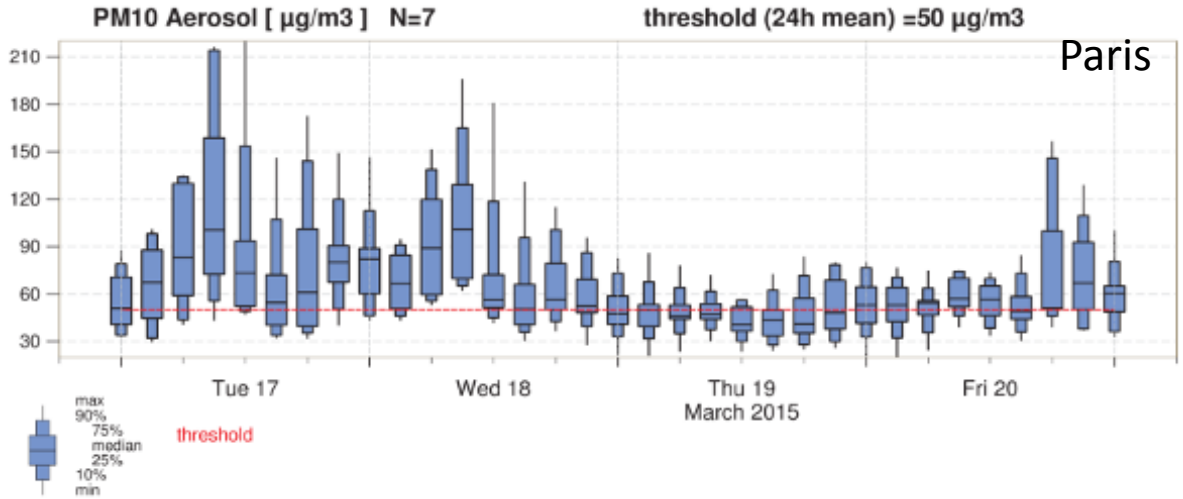


Source: http://sds-was.aemet.es

INTERESTING CASES: Saharan Dust affecting Europe

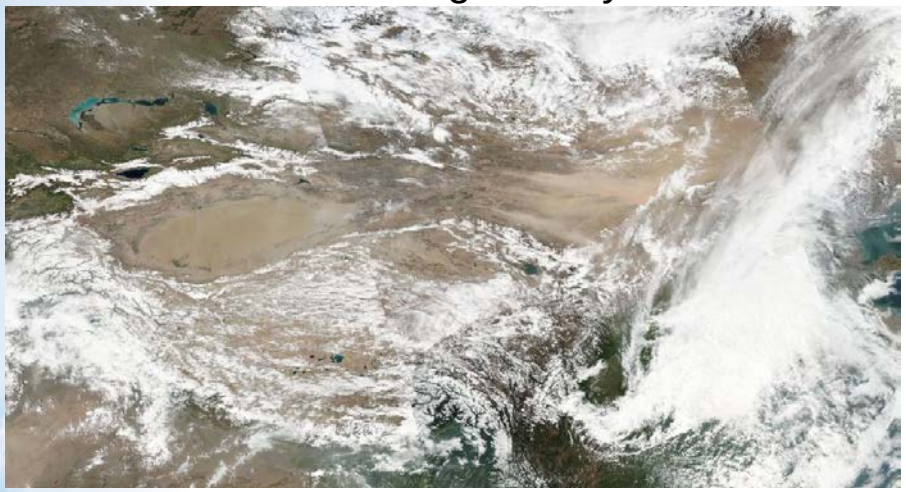




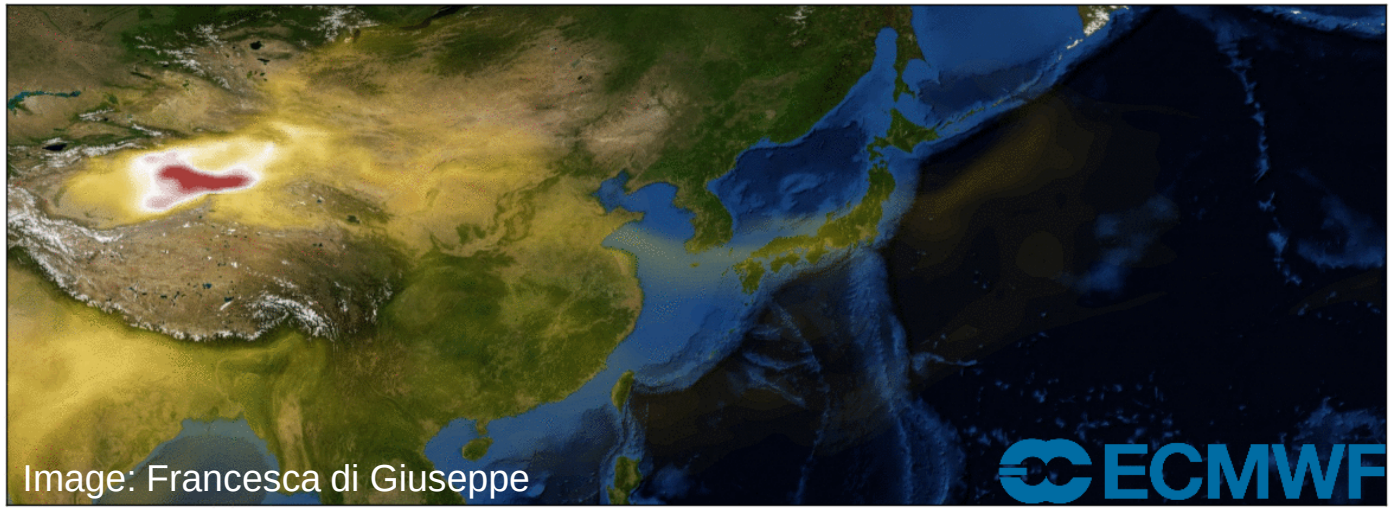


INTERESTING CASES: Asian Dust

VIIRS True Color Image – May 3 2017



Date 20170501 - Time 00



NEWS

Dust storm from the Gobi whips Beijing, sends Chinese running for cover

By Reuters

May 4, 2017 | 10:26am

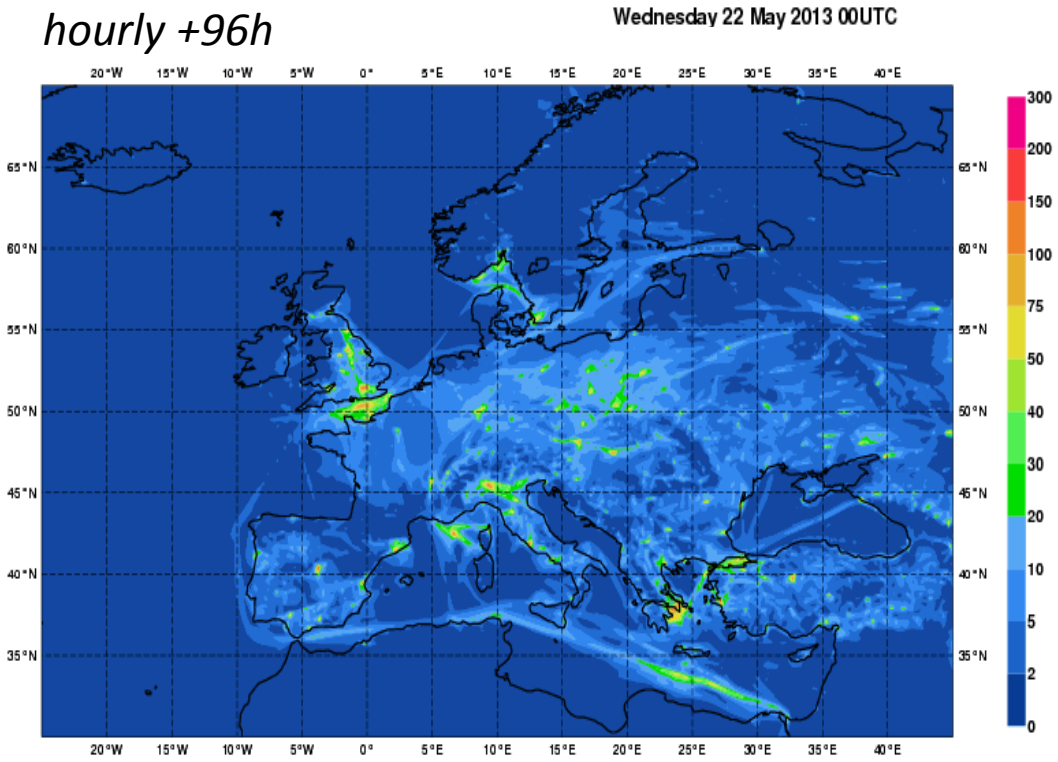
1 | 5

Beijing during a dust storm that enveloped a large swathe of northern China.
Reuters

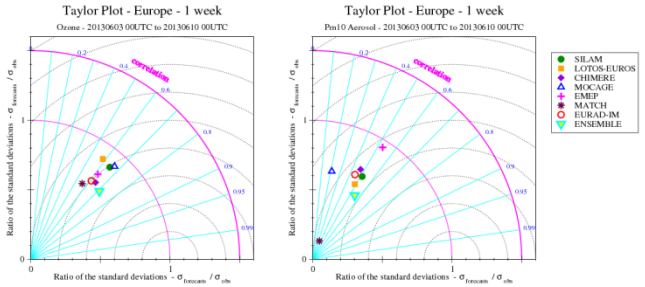
Source: NY Post

European Air Quality

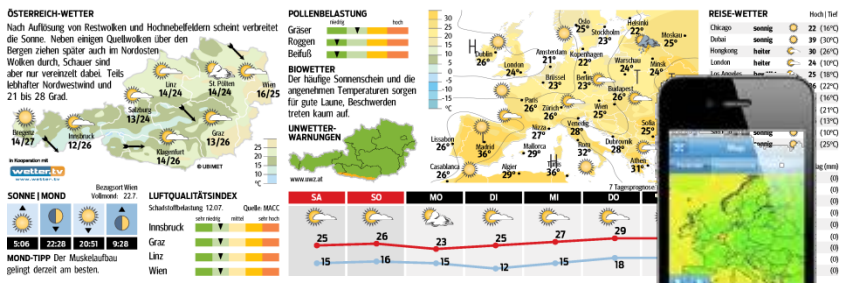
Europe-wide, ~15 km, hourly +96h



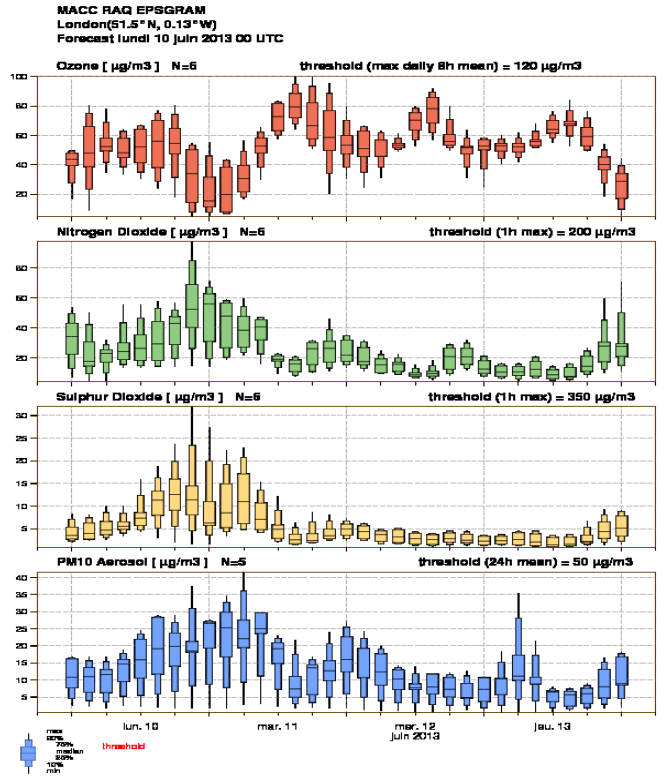
NRT / on-line evaluation



KURIER



> 450 "power users" downloading daily air quality information



Multi-model spread as a measure of forecast uncertainty

Verification

Credits: CAMS validation team

- Verification plots using independent observations are available online
- Detailed validation reports are prepared every 4 months
- Aerosol verification uses for example AERONET data for AOD and Angstrom coefficient and EMEP/IMPROVE data for PM10
- EARLINET lidar data are used for vertical extinction profiles

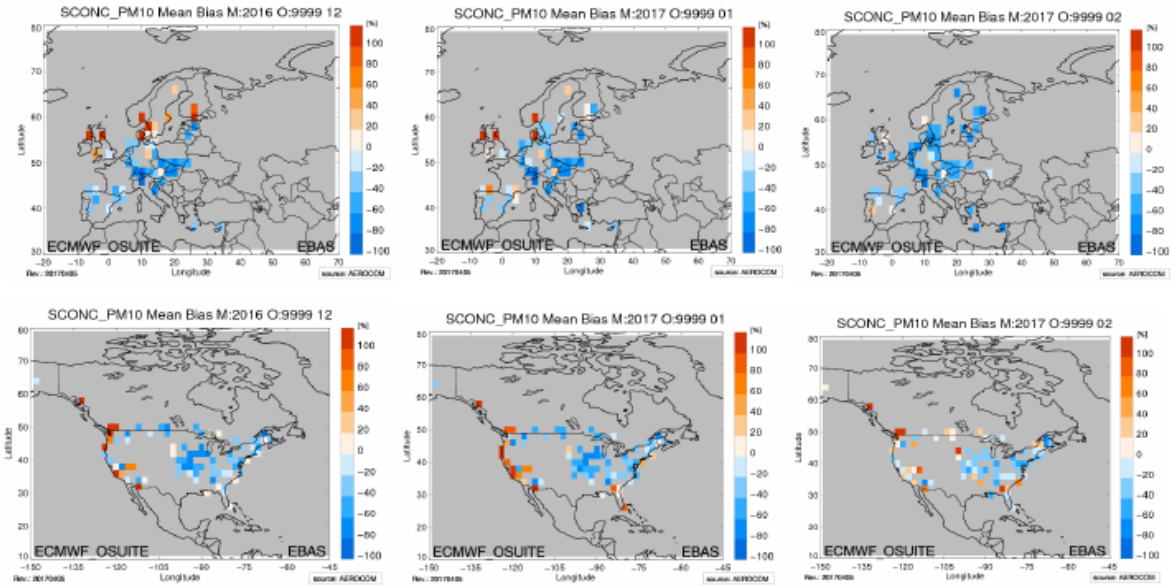
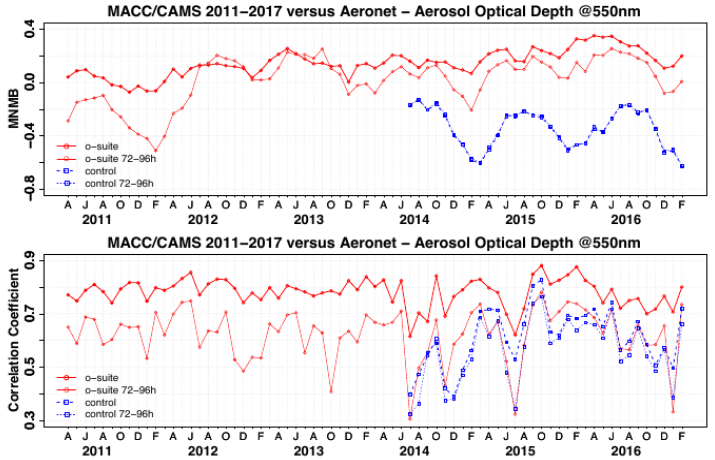
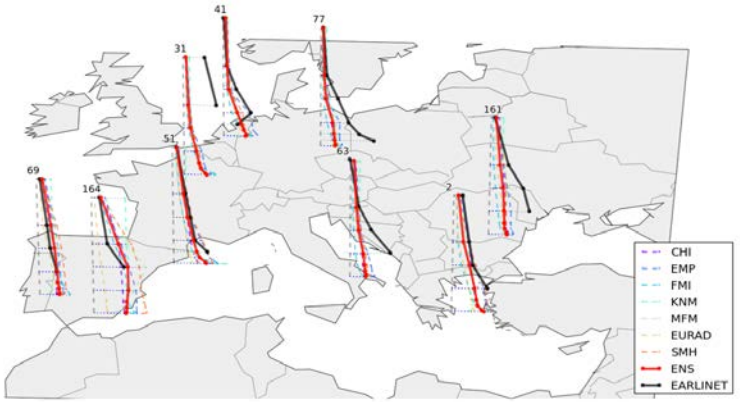


Figure 3.5.5: Bias [%] map of December/January/February mean PM 10 concentrations at EMEP (Europe) and IMPROVE sites (North America); simulated o-suite versus climatological average (2000-2009).





Quarterly validation reports can be downloaded at https://atmosphere.copernicus.eu/quarterly_validation_reports

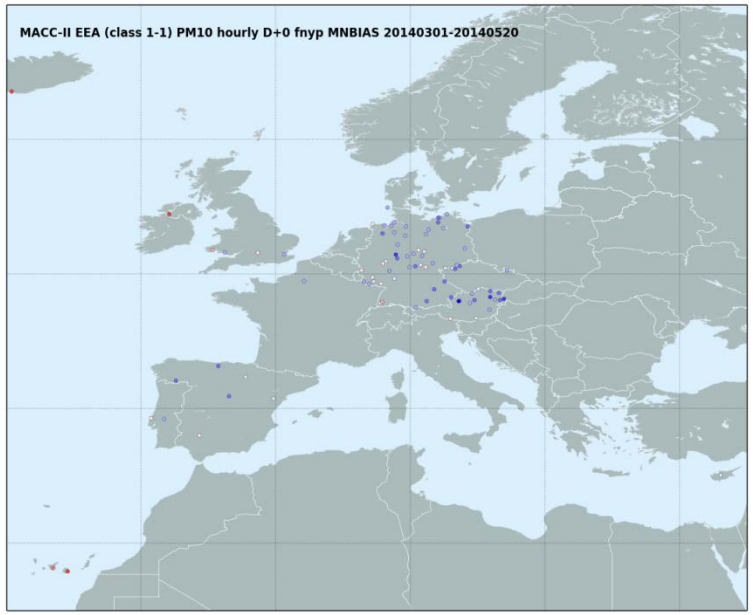
More on PM Verification (global model)

Credits: Miha Razinger

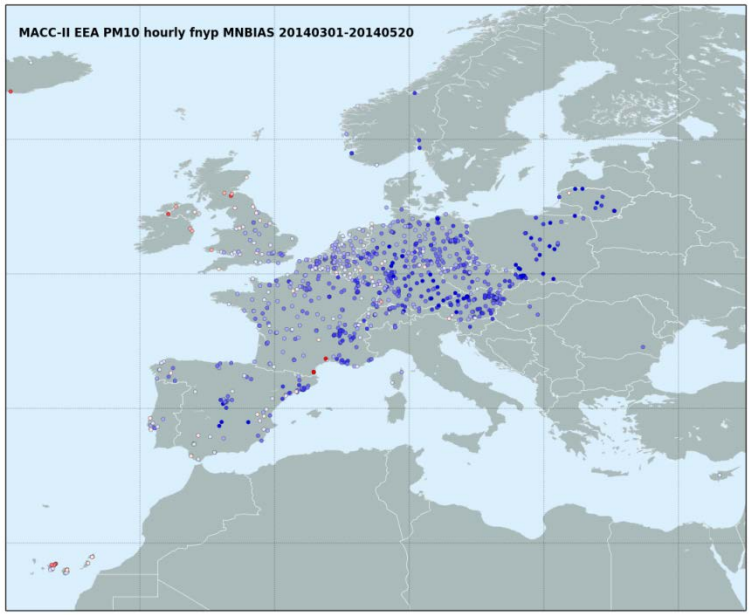
- Many users ask for PM from the global model
- How good/bad is a global aerosol model for air quality applications?
- Quality of verifying data is also not perfect
- Example from the MACC model verified using European Environment Agency observations

Normalized Mean Bias = $\frac{2}{N}\sum_{i=1}^{N}\left(\frac{P_i - O_i}{P_i + O_i}\right)$

Class 1 Joly-Peuch classification= background stations



All reporting stations



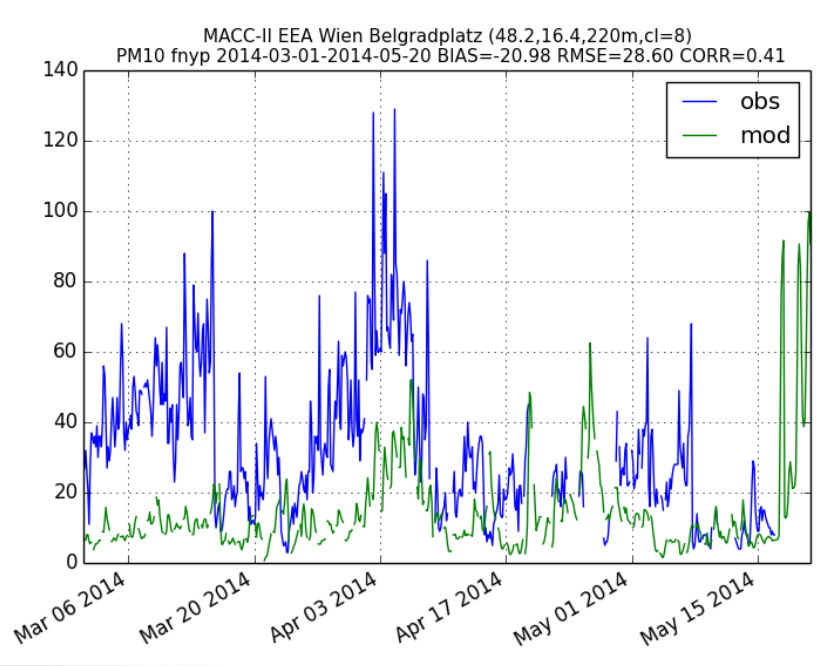
Period: 20140301-20140520

PM Verification (global model)

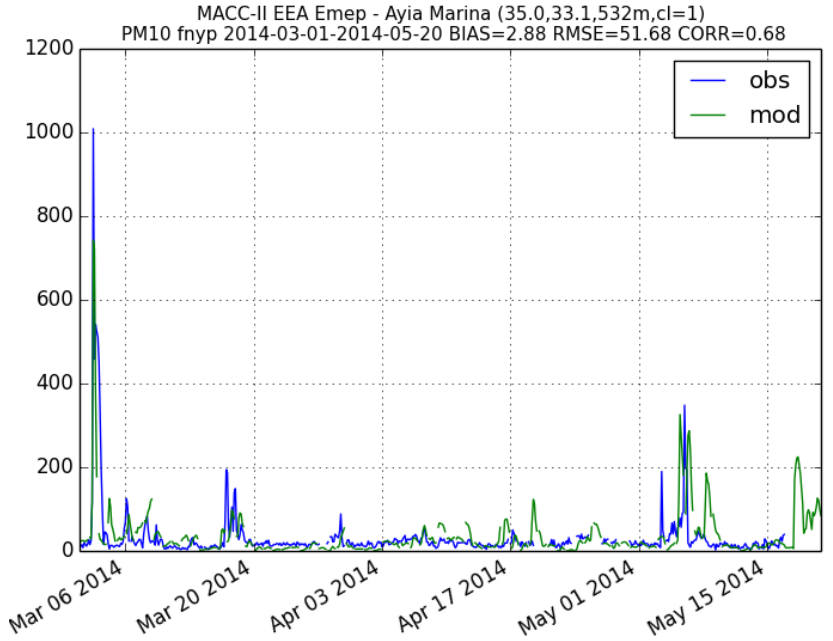
Credits: Miha Razinger

- Overall very large biases even in background stations
- General underestimation of anthropogenic component (missing emissions, low resolutions spatial resolution, etc) in urban areas
- Dust contribution is generally in good agreement with the observations

Urban station:
Vienna (48.2N,16.4E)



Dust station:
Aya Marina (35.0N,33.1E)



obs model

Atmosphere Monitoring

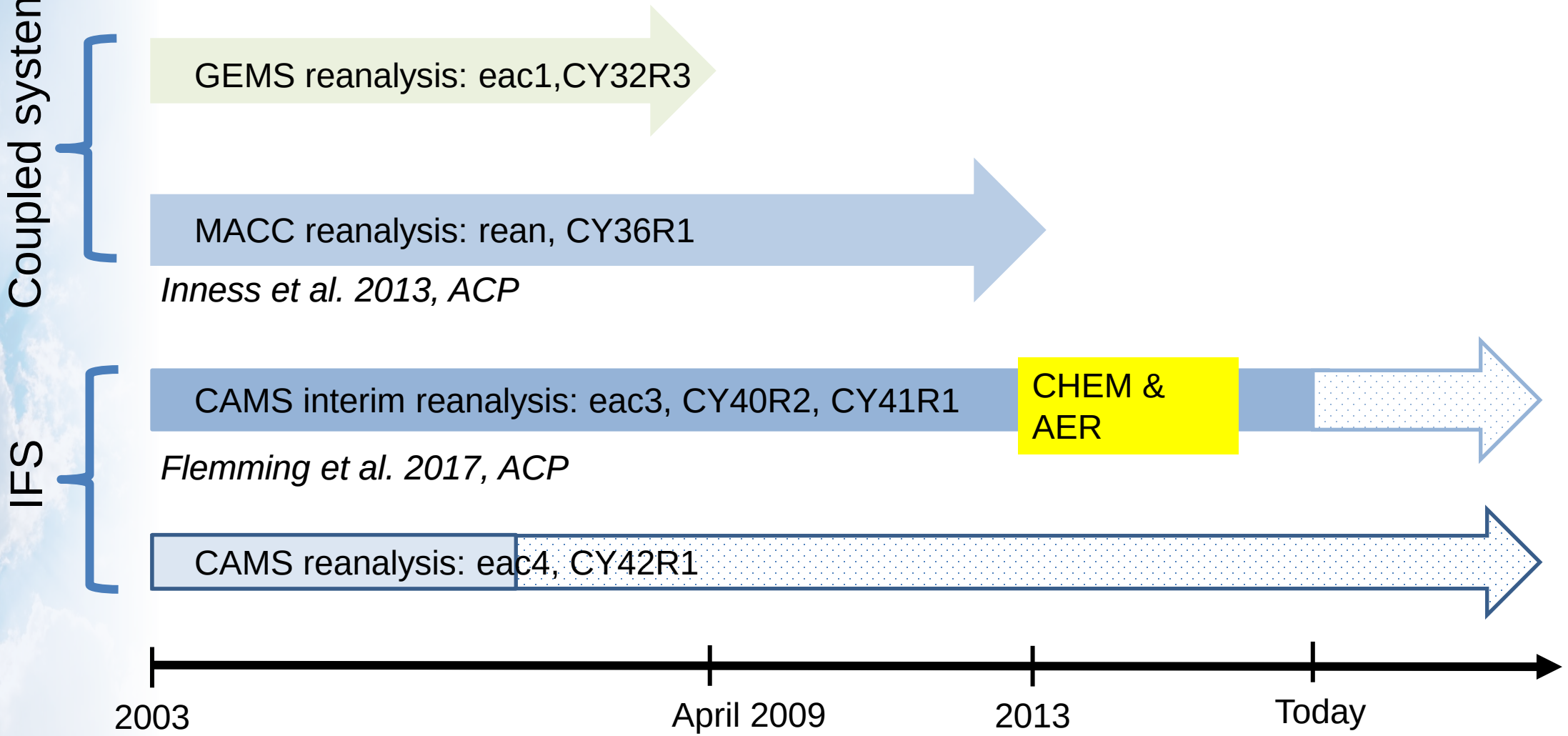
Reanalysis and real-time analyses

- Real-Time CAMS system (daily analysis and 5-day forecast):
  - Evolves with time: Usually 2 model updates per year
  - Horizontal and vertical resolution can change
  - Observation usage changes
  - Emission data sets might change (e.g. change from GFED to GFAS fire emissions)

- Reanalysis (retrospective):
  - Consistent long term dataset produced with one model version
  - Consistent emissions
  - Consistent, reprocessed data sets
  - Gridded continuous presentation of atmospheric composition combining model and satellite retrievals in an optimal way
  - Can be used for trend analysis

Atmosphere Monitoring

MACC & CAMS reanalyses



Atmosphere Monitoring

Summary

- Satellite data are extensively used in CAMS to produce global products related to air quality (i.e. Particulate Matter)
- Analyses and forecasts are available from the real-time system as well as reanalyses from 2003 onward
- The quality of the global products is assessed via comparison with independent data
- Specifically for PM10, the global model underestimates it at urban sites due to coarse resolution but has good skills in dust prediction
- Regional air quality models, which are also part of the CAMS production chain, provide higher resolution forecasts using boundary conditions from the global model
- Some regional models also have assimilation capabilities and use near surface and satellite data for air quality applications
- Extensive validation is also provided for regional models
- Regional model perform well for PM