



Copernicus
Atmosphere Monitoring
Service

Implemented by



Assimilation of satellite data for air quality monitoring and forecasting

Angela Benedetti

With the contribution of Richard Engelen
(CAMS Deputy Head)

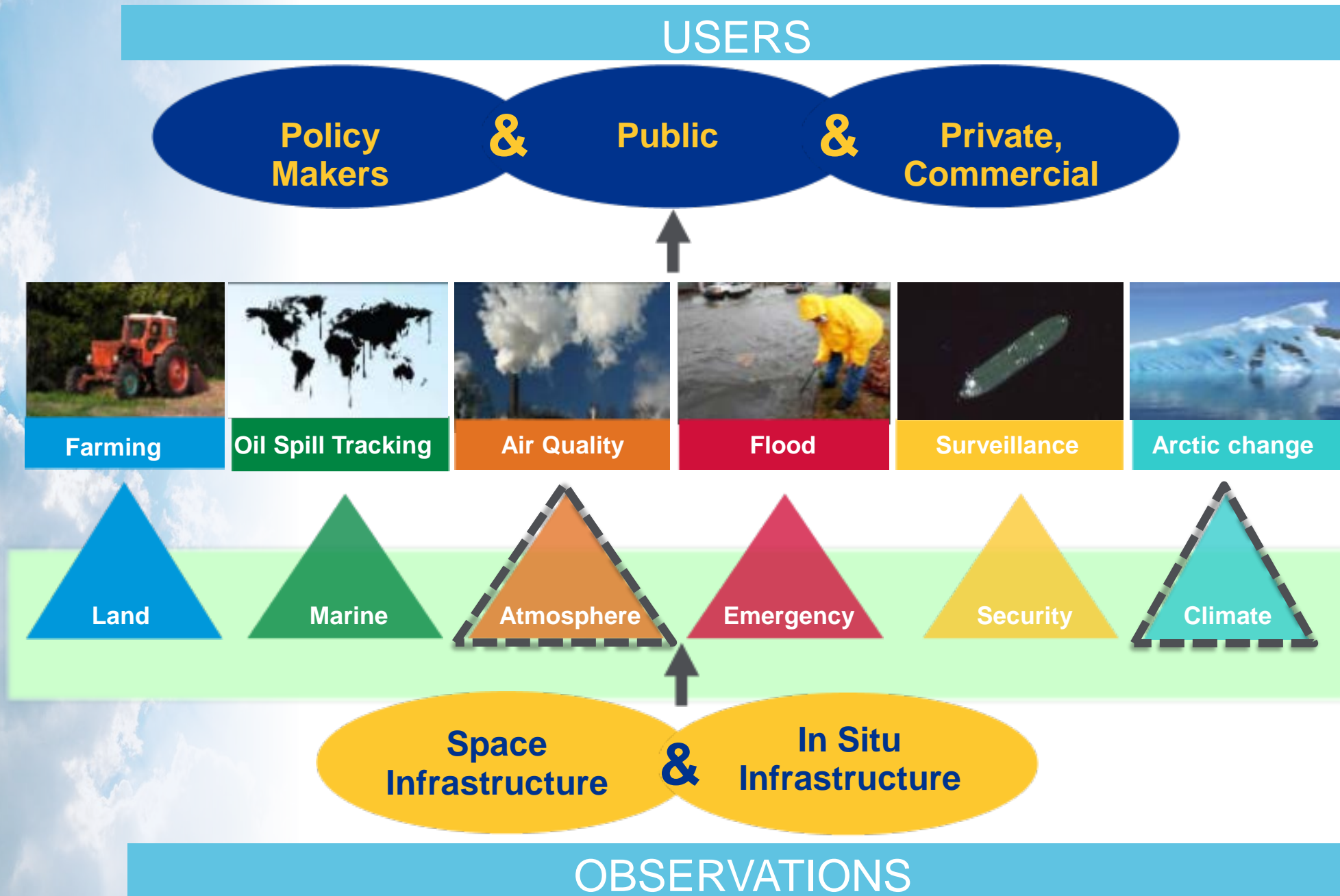


Different Needs

Examples of areas covered

Information Services

Sustainable observation capabilities



USERS

Policy Makers

&

Public

&

Private, Commercial



Farming



Oil Spill Tracking



Air Quality



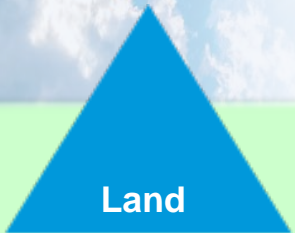
Flood



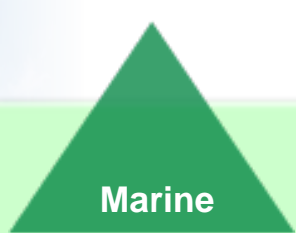
Surveillance



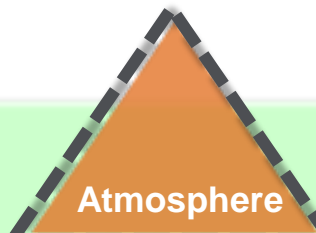
Arctic change



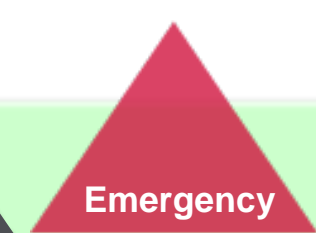
Land



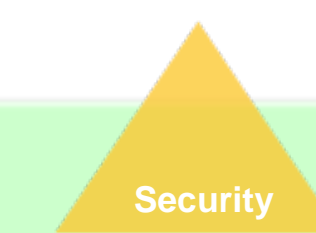
Marine



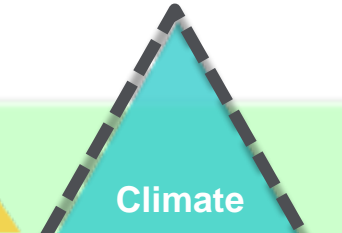
Atmosphere



Emergency



Security



Climate



Space Infrastructure

&

In Situ Infrastructure

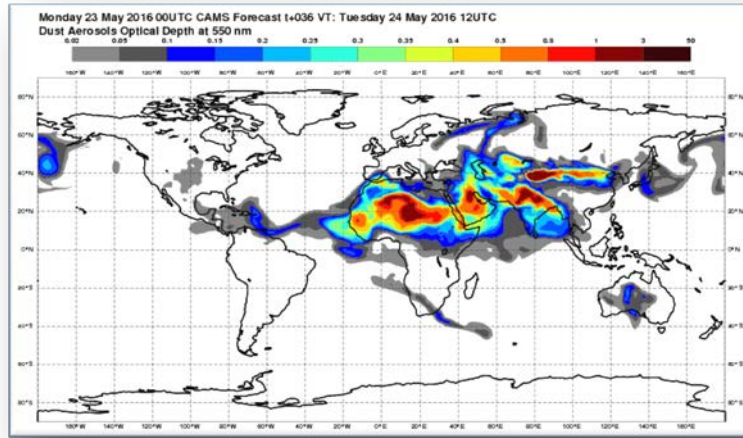
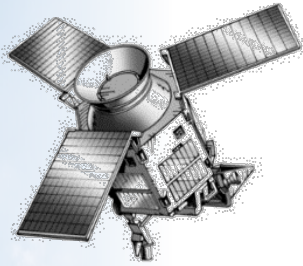
OBSERVATIONS



CAMS SERVICE CHAIN

Atmosphere
Monitoring

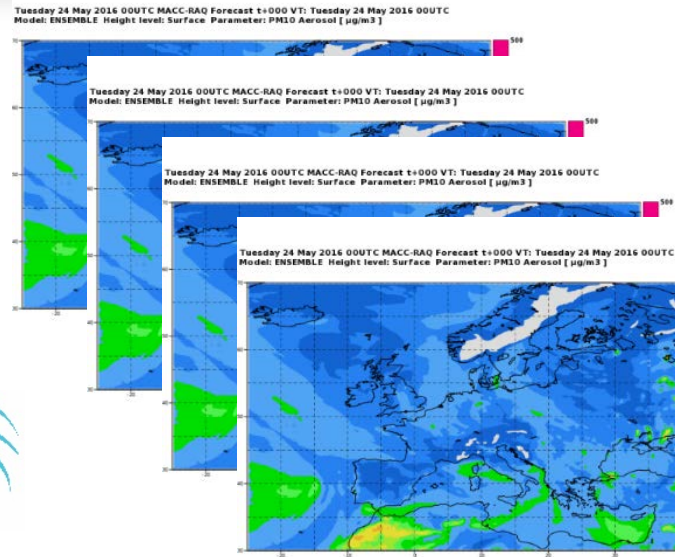
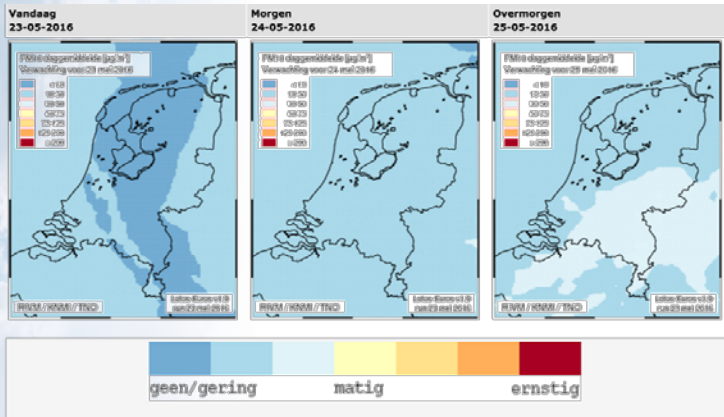
Space Agencies



In-situ observations



National scale





Atmosphere
Monitoring

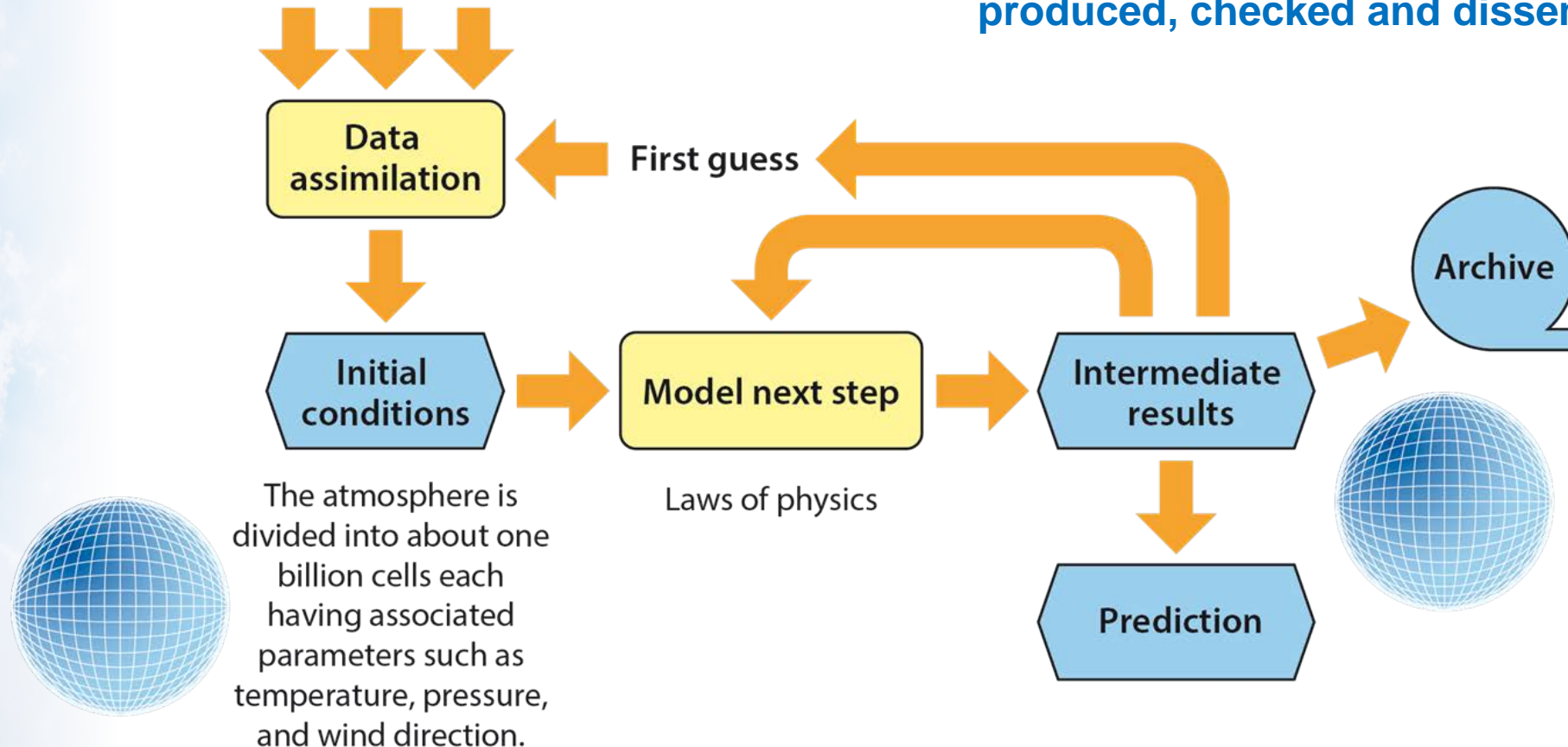
Global production



Approximately 20 million observations

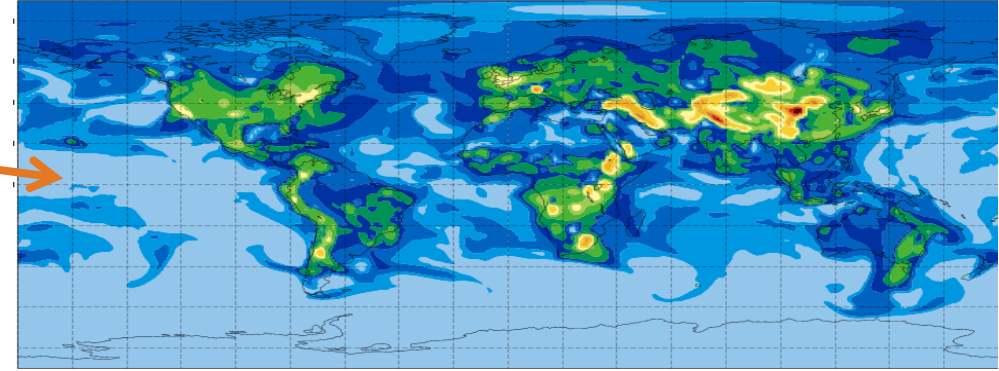
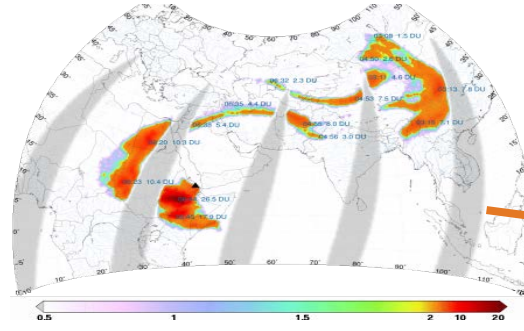
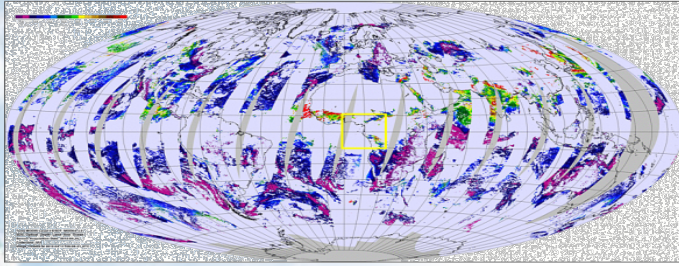
Every 12 hours, observations are acquired, pre-processed, quality controlled, and assimilated.

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

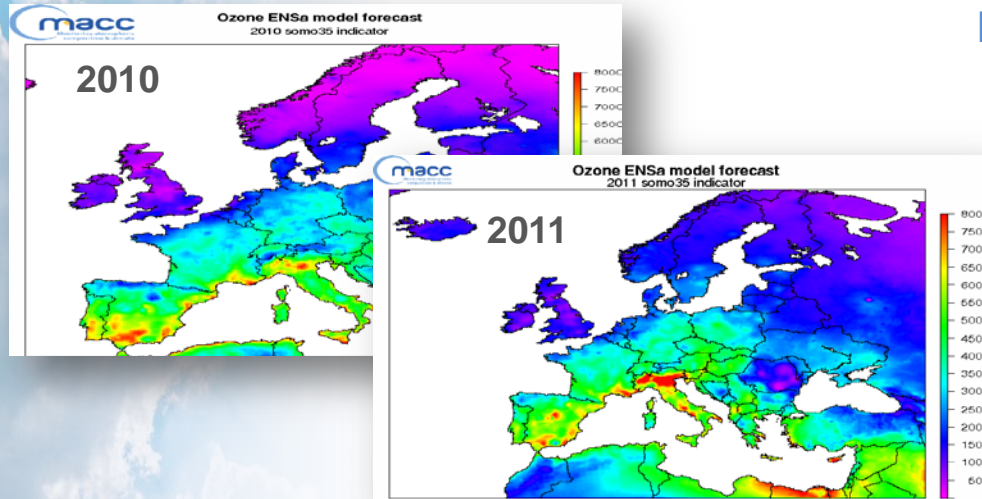


FROM EARTH OBSERVATIONS TO AIR QUALITY PRODUCTS

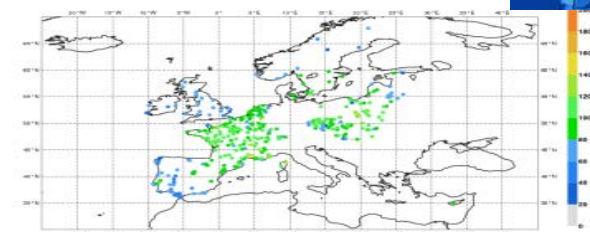
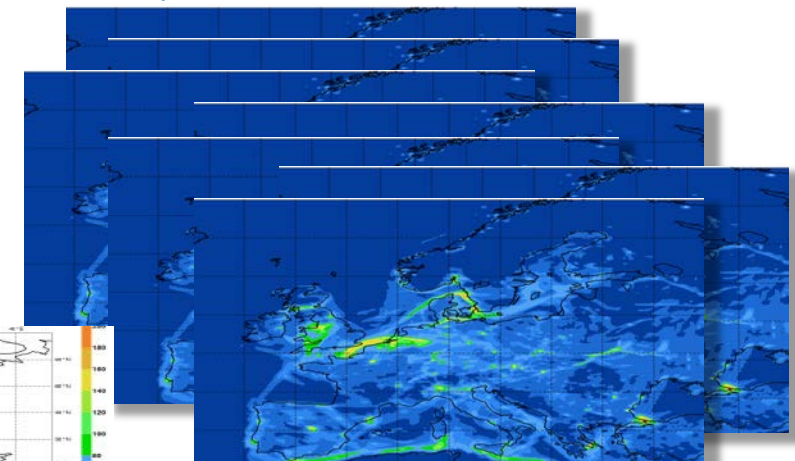
Over 70 EO instruments are assimilated in the global system



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.



Current satellite data usage (global system)

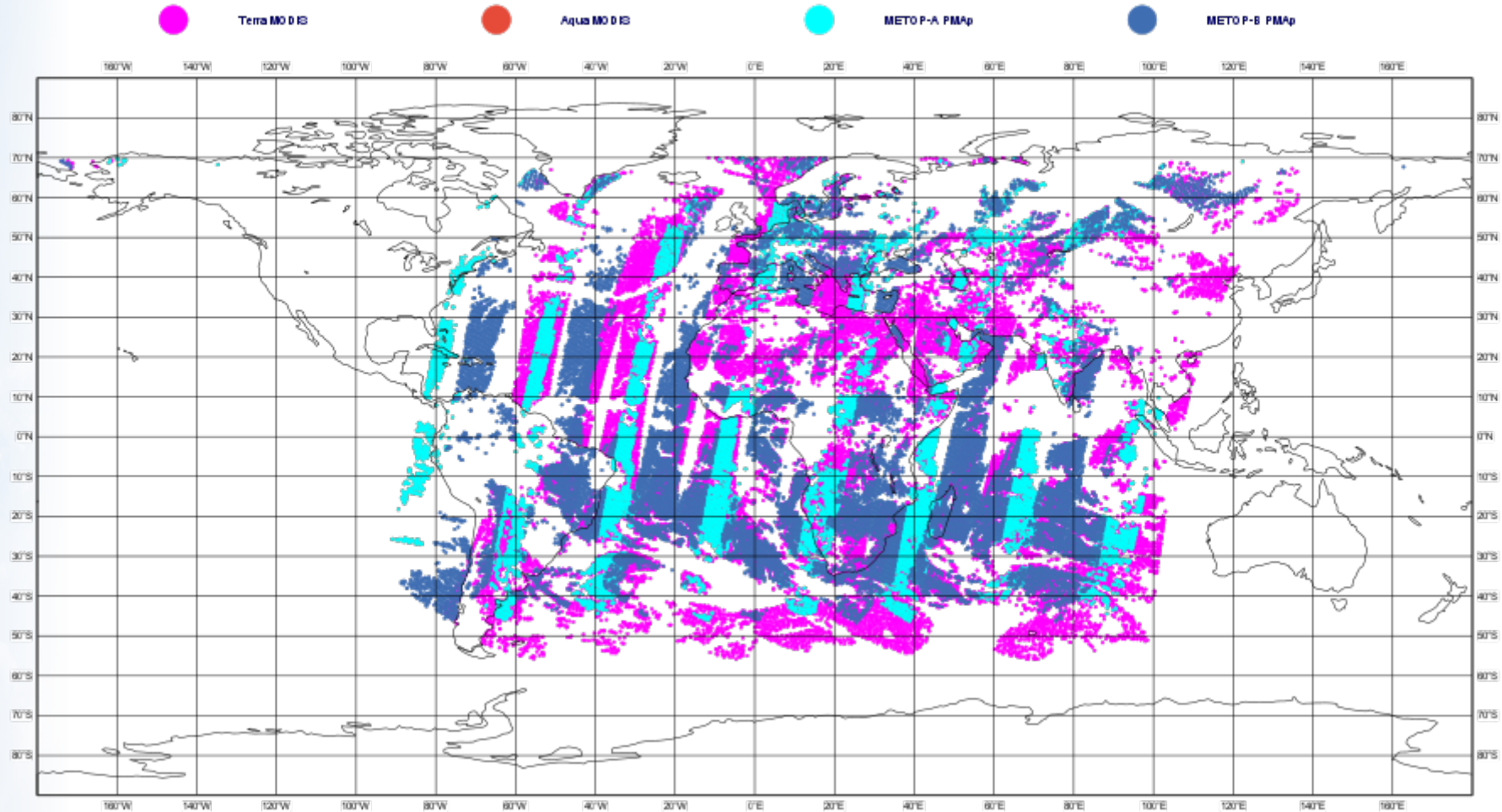
Species	Instruments
O ₃	OMI, SBUV, GOME-2, MLS, OMPS, S5p
CO	IASI, MOPITT, S5p
NO ₂	OMI, GOME-2, S5p
SO ₂	OMI, GOME-2, S5p
Aerosol	MODIS, PMAp, VIIRS, S3
CO ₂	GOSAT, OCO-2
CH ₄	GOSAT, IASI, S5p
GFAS fire emissions	MODIS, GOES, SEVIRI, VIIRS

Assimilated
Monitored
Planned



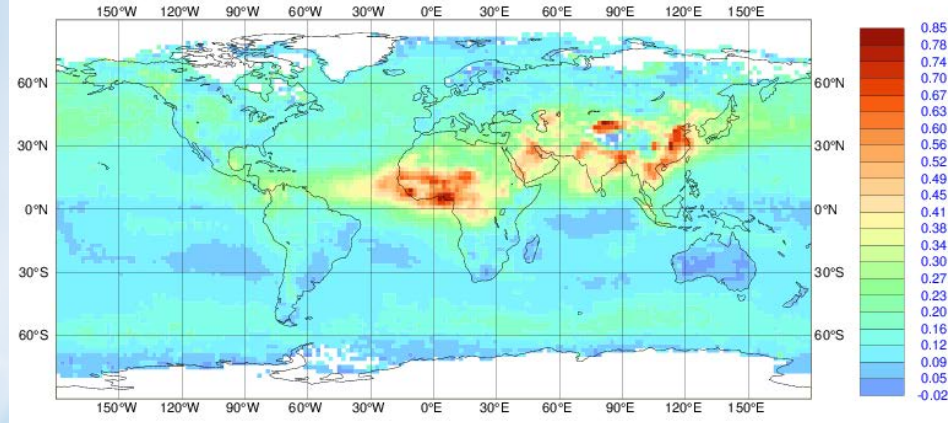
Example: AOD observations over 12 hours

AOD observations per 12 hours

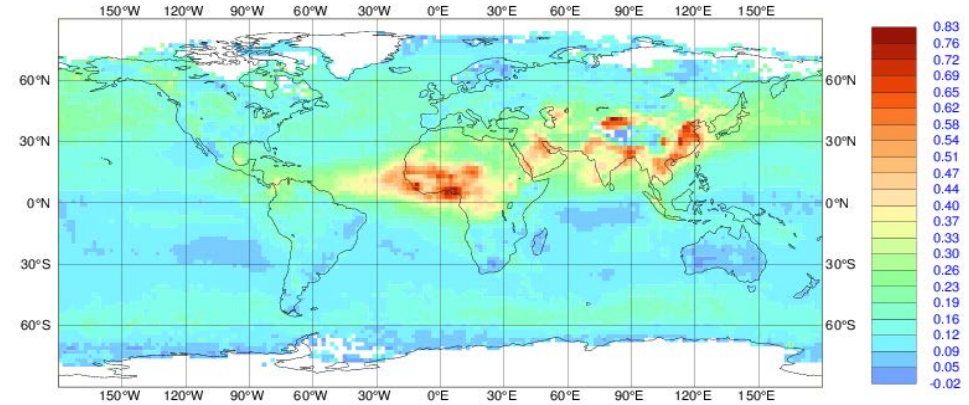


Excursus: The importance of redundancy

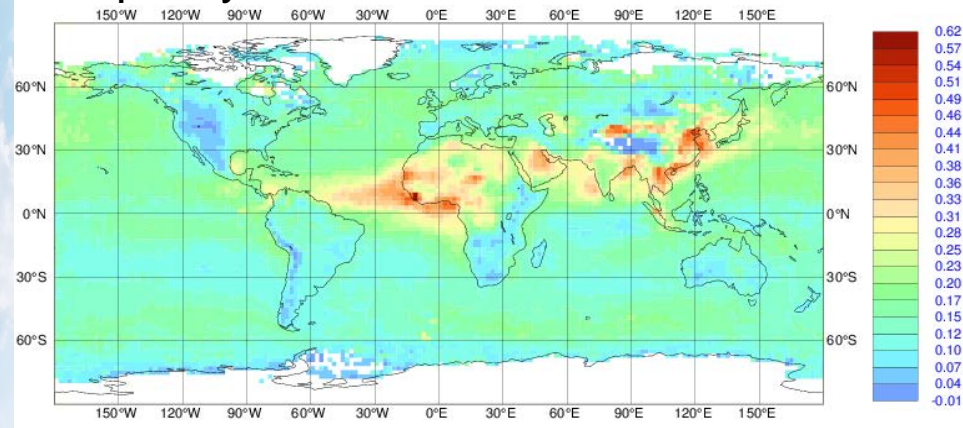
MODIS only



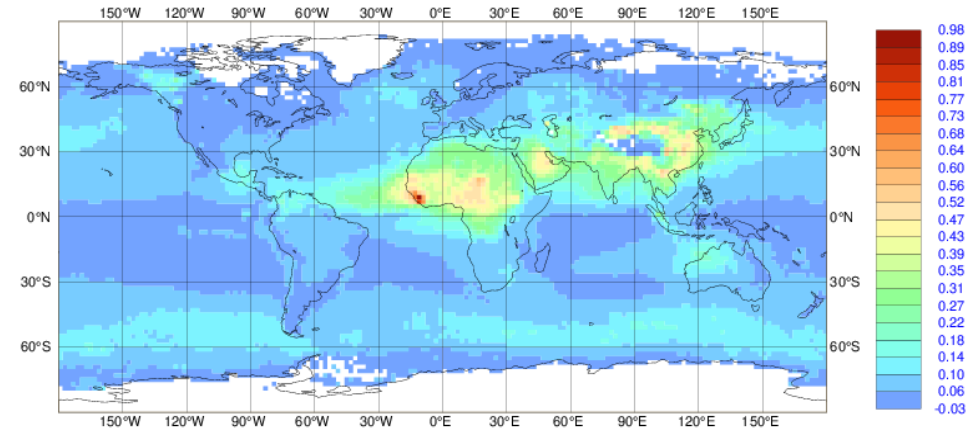
MODIS and PMAp



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 CO₂, CH₄ and N₂O...



Accessing the Products

<https://atmosphere.copernicus.eu/>

Search
Reset

PRODUCT FAMILY

- Global forecasts
- Global reanalyses
- Global analyses
- Regional analyses
- Regional forecasts
- Climate forcings
- Anthropogenic emissions
- Solar radiation
- Greenhouse gas fluxes
- Fire emissions
- Policy support

PARAMETER FAMILY

- Aerosol
- Greenhouse gas
- Reactive gas
- Radiation
- Fire

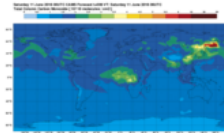
PARAMETER

- Sulfates concentration
- Organic carbon concentration
- Black carbon concentration
- Sea-salt concentration
- Dust concentration
- PM10

CURRENT FILTERS:

Product family: Global forecasts

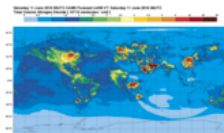
Total results: 5



Global forecasts of chemical species - carbon monoxide

This service provides chemical species observations

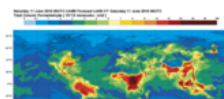
Parameter: Carbon monoxide



Global forecasts of chemical species - dioxide

This service provides chemical species observations

Parameter: Nitrogen dioxide

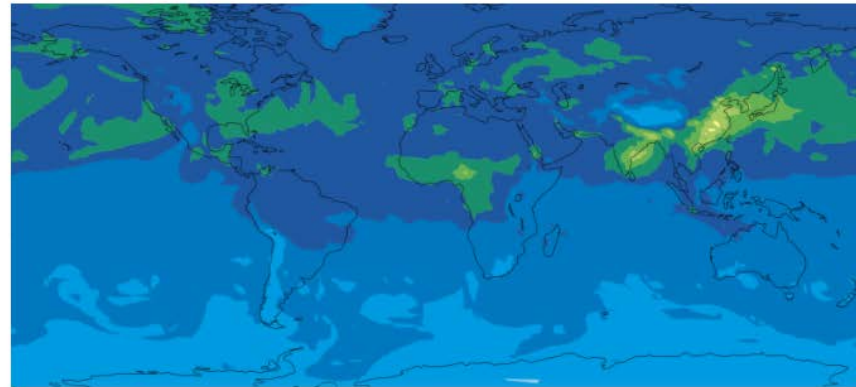


Global forecasts of assimilated chemical species - formaldehyde

More details

Global forecasts of chemical species - carbon monoxide

[Back to index](#)



This service provides daily forecasts up to 5 days of chemical species

Theme: Air quality and atmospheric composition

Product family: Global forecasts

Parameter: Carbon monoxide

Geographical area: (-180, 180, -90, 90)

Time coverage:

Metadata: XML



Data download



Verification results



Validation reports



Plots



Documentation

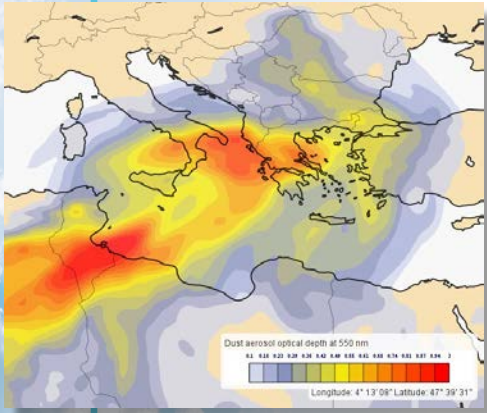


Contact us

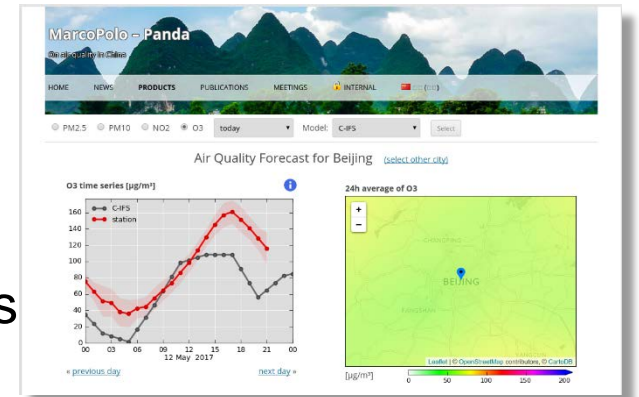




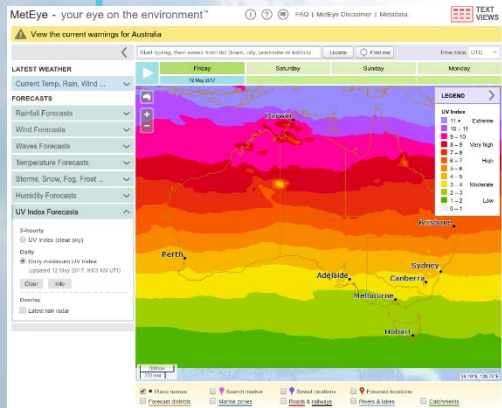
Use of global services



- 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)

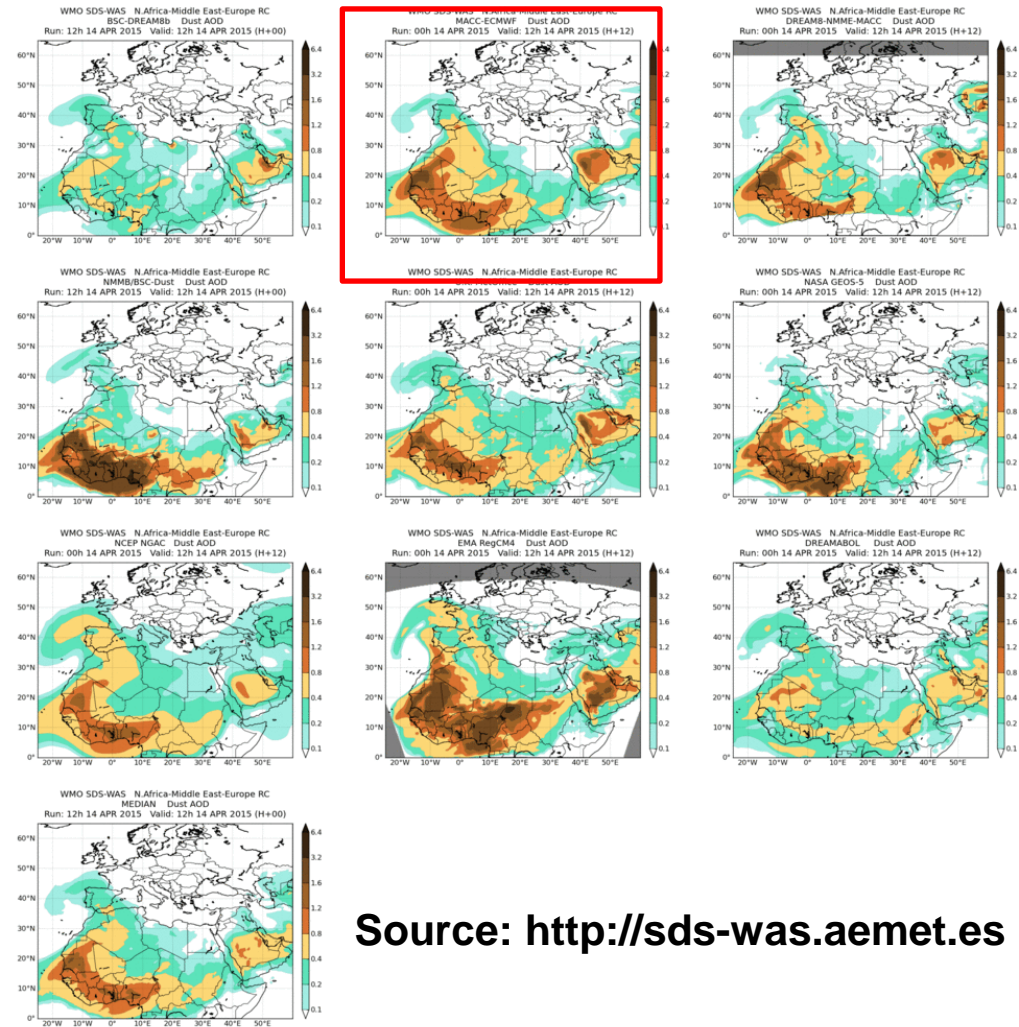


- WMO warning advisory centres

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

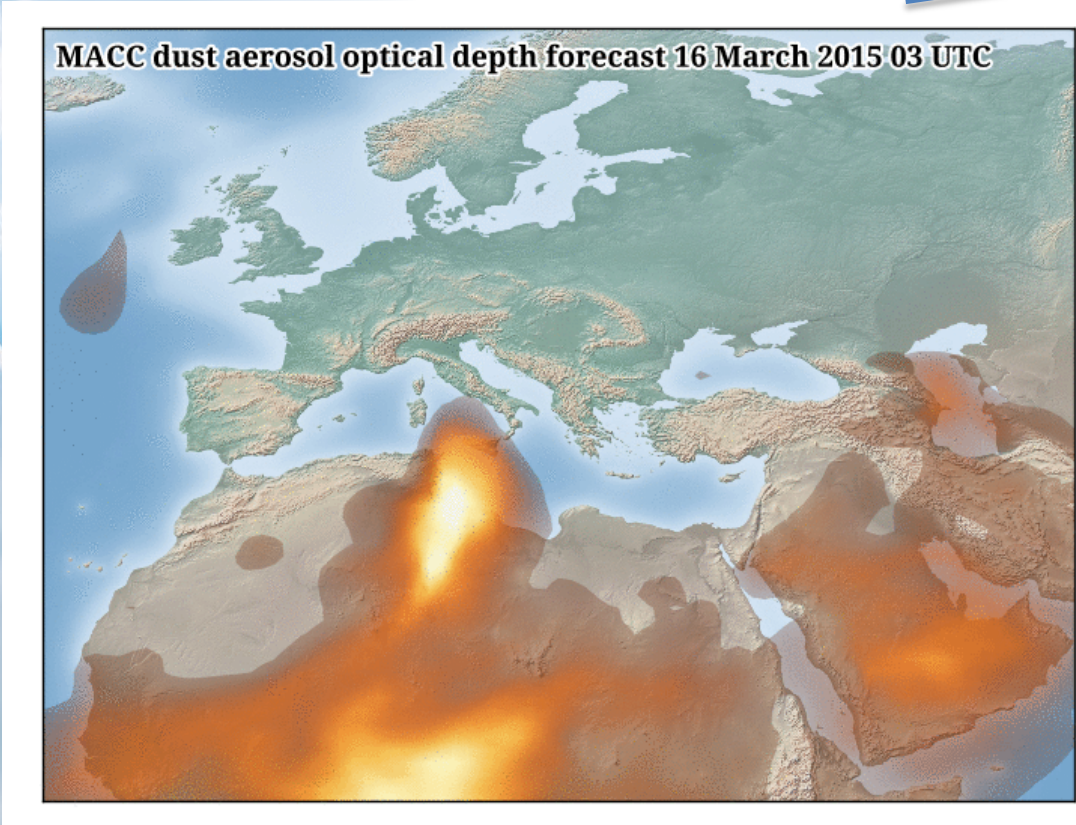
CAMS AEROSOL FORECASTS

- 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.

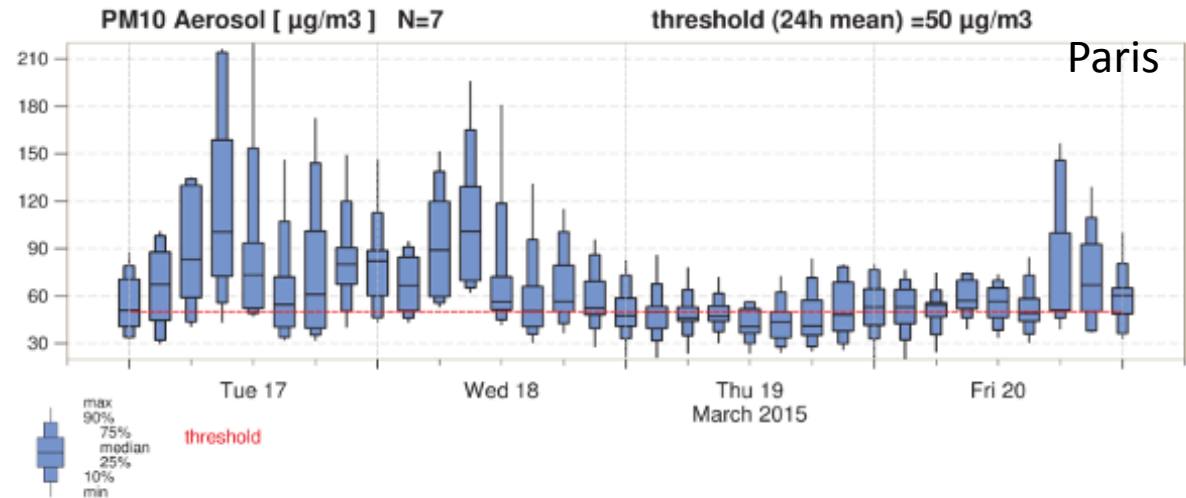
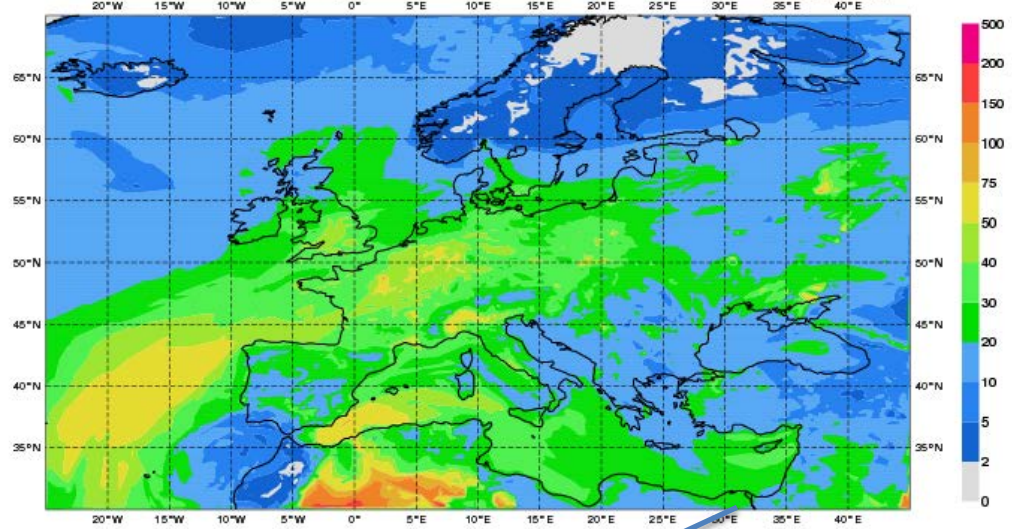


Source: <http://sds-was.aemet.es>

INTERESTING CASES: Saharan Dust affecting Europe



Tuesday 17 March 2015 00UTC MACC-RAQ Forecast D+3 VT: Friday 20 March 2015
Model: Ensemble Median (N=7) Height level: Surface Parameter: PM10 Aerosol Daily Maximum [$\mu\text{g}/\text{m}^3$]



INTERESTING CASES: Asian Dust

VIIRS True Color Image – May 3 2017



Date 20170501 - Time 00

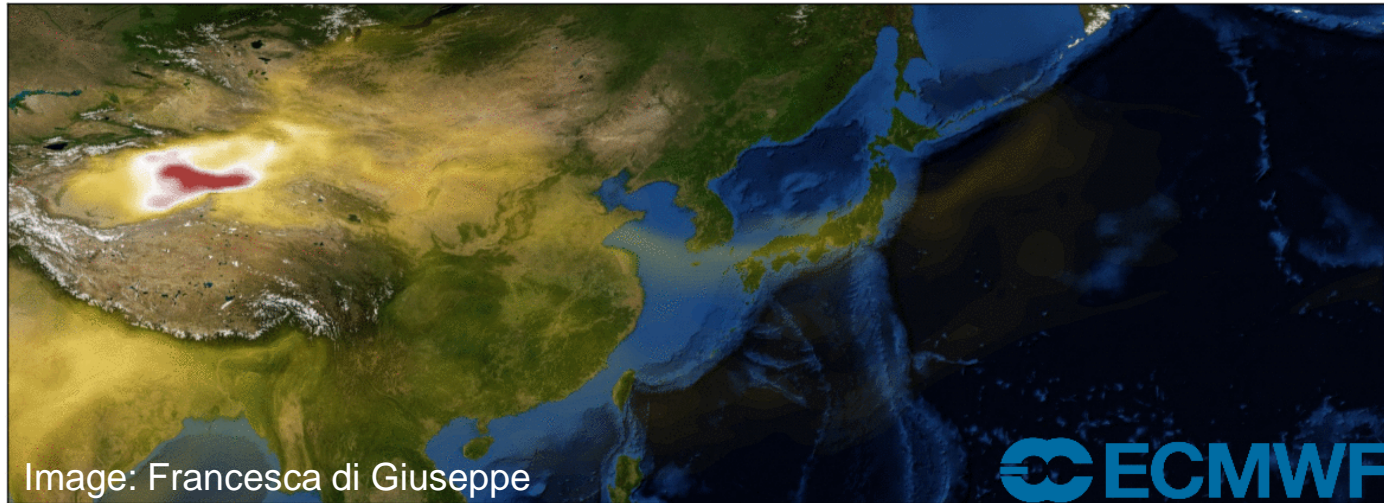


Image: Francesca di Giuseppe

NEWS

[f](#) [t](#) [G+](#) [in](#) [e](#) [r](#)

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

By Reuters May 4, 2017 | 10:26am



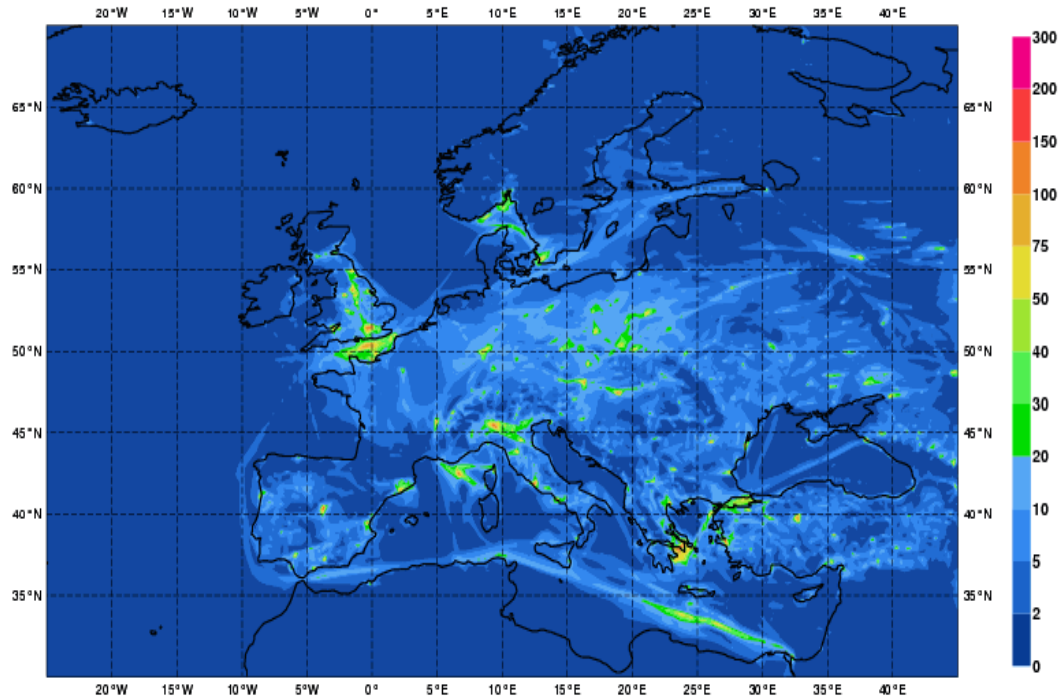
Beijing during a dust storm that enveloped a large swathe of northern China.
Reuters

Source: NY Post

European Air Quality

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

Wednesday 22 May 2013 00UTC



ÖSTERREICH-WETTER
Nach Auflösung von Restwolken und Hochnebelfeldern scheint verbreitet die Sonne. Neben einigen Quellwolken über den Bergen ziehen später auch im Nordosten über den Wolken durch. Schauer sind aber nur vereinzelt dabei. Teils lebhaftes Nordwestwind und 21 bis 28 Grad.

POLLENBELASTUNG
Gepölz hoch
Roggen hoch
Beflüß hoch

BIOWETTER
Der häufige Sommerchein und die angenehmen Temperaturen sorgen für gute Laune. Beschwerden treten kaum auf.

UNWETTER-WARNUNGEN

REISE-WETTER
Chiang Mai sonnig
Doha sonnig
Hongkong heiter
London heiter
Lima bewölkt
New York bewölkt
Paris bewölkt
Rio de Janeiro bewölkt
Sankt Petersburg bewölkt
Shanghai bewölkt
Tokyo bewölkt
Wien bewölkt

SONNE | MOND
Beobachtet Wien Vollmond 22.7
5:06 22:28 20:51 0:28

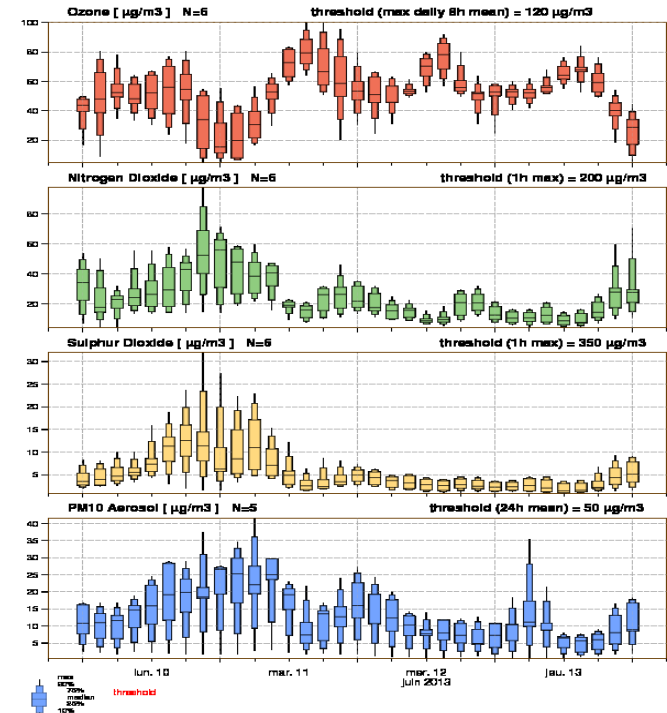
LUFTQUALITÄTSINDEX
Schadstoffbelastung: 12.07
Quelle: MACC
Innsbruck mittel
Graz mittel
Linz mittel
Wien mittel

MOND-TIPP Der Muskelatmbau geht derzeit am besten.

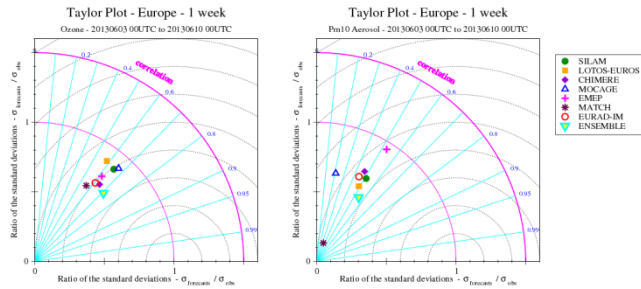
> 450 "power users"
downloading daily air
quality information



MACC RAQ EPSGRAM
London(51.5° N, 0.13° W)
Forecast lund 10 Jun 2013 00 UTC



NRT / on-line
evaluation



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

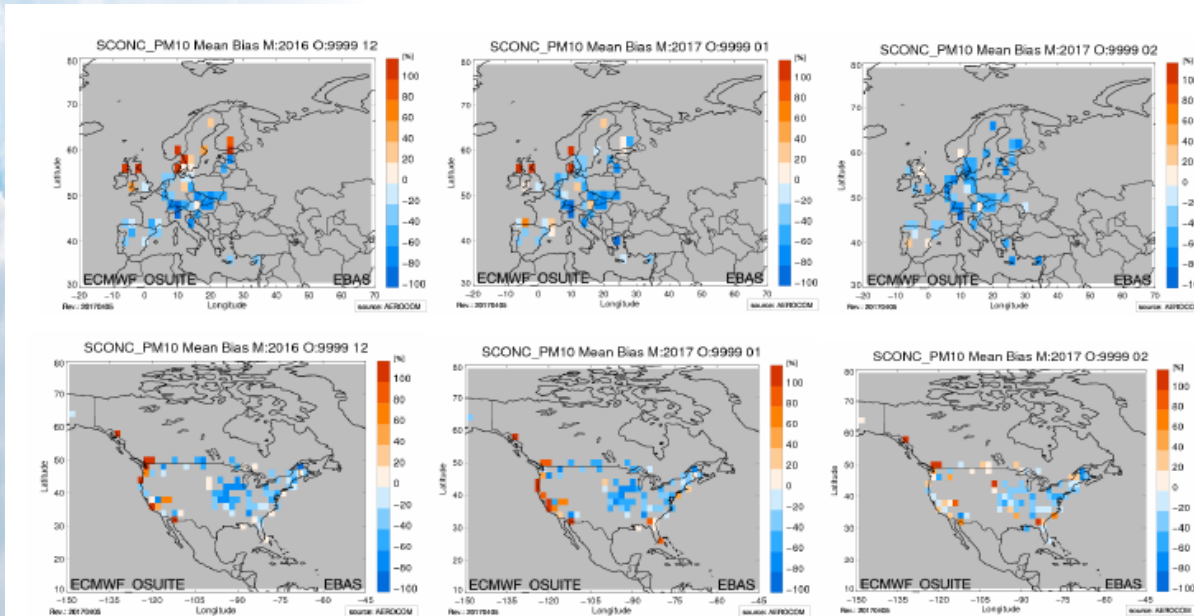
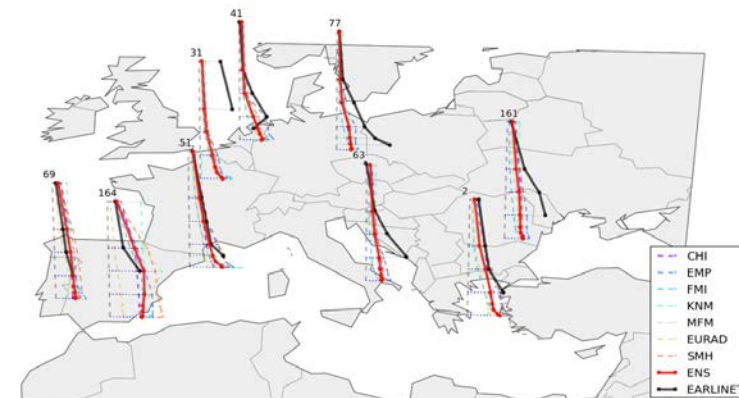
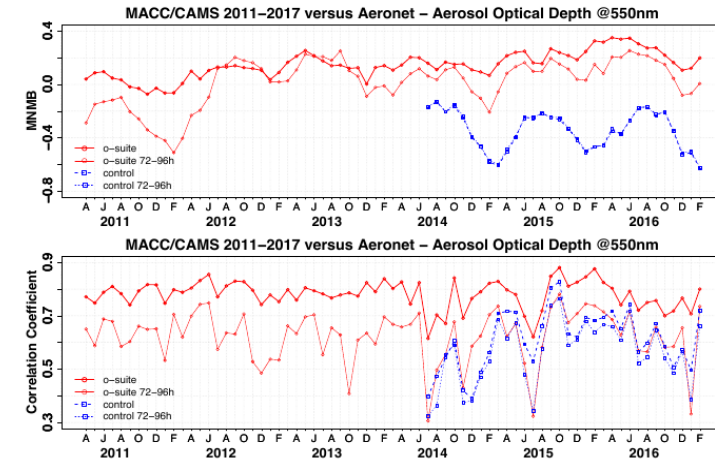


Figure 3.5.5: Bias [%] map of December/January/February mean PM 10 concentrations at EMEP (Europe) and IMPROVE sites (North America); simulated o-suite versus climatological average (2000-2009).



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

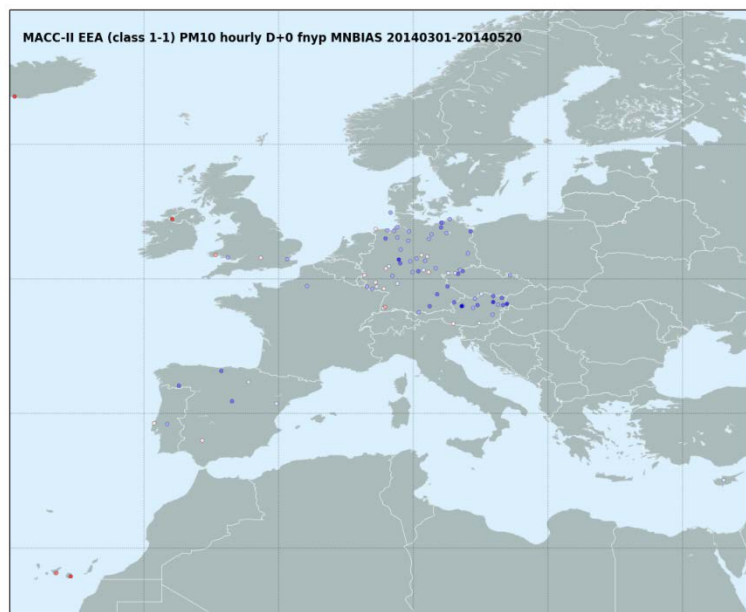
More on PM Verification (global model)

Credits: Miha Razinger

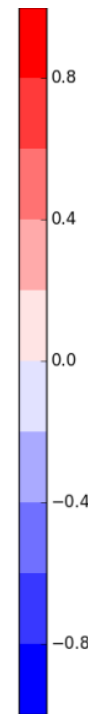
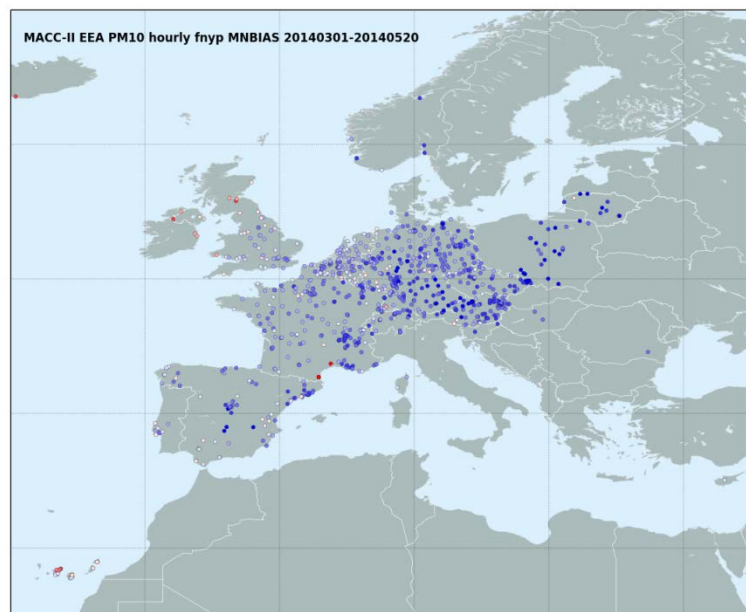
- Many users ask for PM from the global model
- How good/bad is a global aerosol model for air quality applications?
- Quality of verifying data is also not perfect
- Example from the MACC model verified using European Environment Agency observations

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

Class 1 Joly-Peuch classification= background stations



All reporting stations



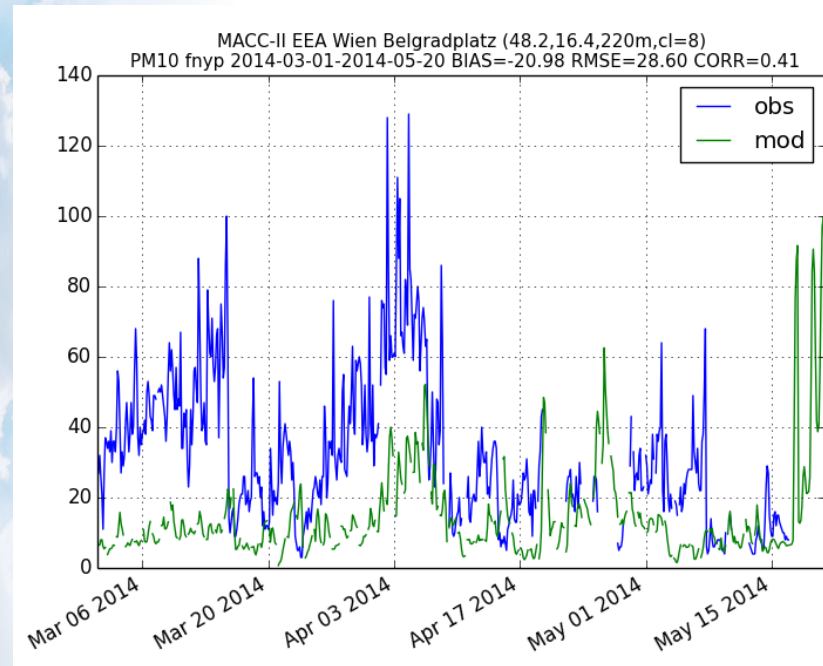
Period: 20140301-20140520

PM Verification (global model)

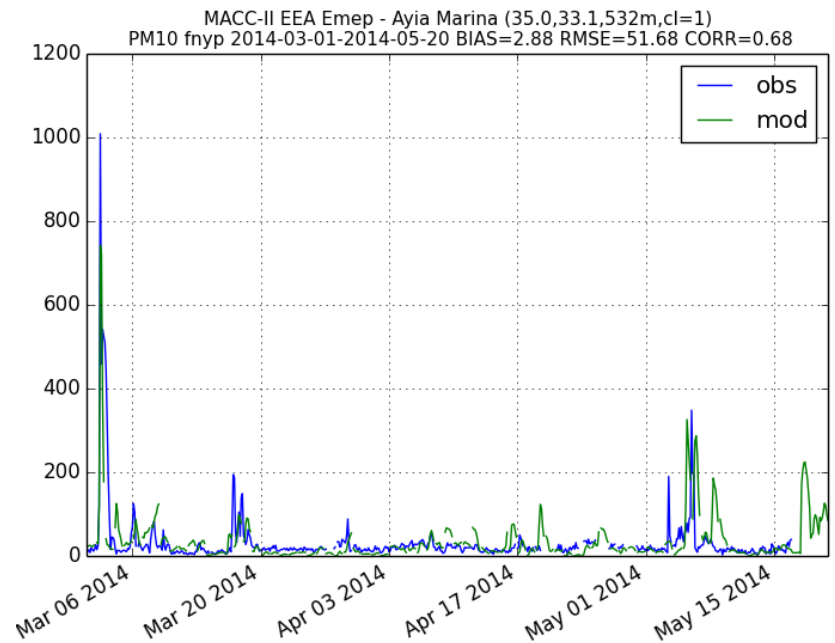
Credits: Miha Razinger

- 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



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

Coupled system

GEMS reanalysis: eac1, CY32R3

MACC reanalysis: rean, CY36R1

Inness et al. 2013, ACP

IFS

CAMS interim reanalysis: eac3, CY40R2, CY41R1

Flemming et al. 2017, ACP

CHEM &
AER

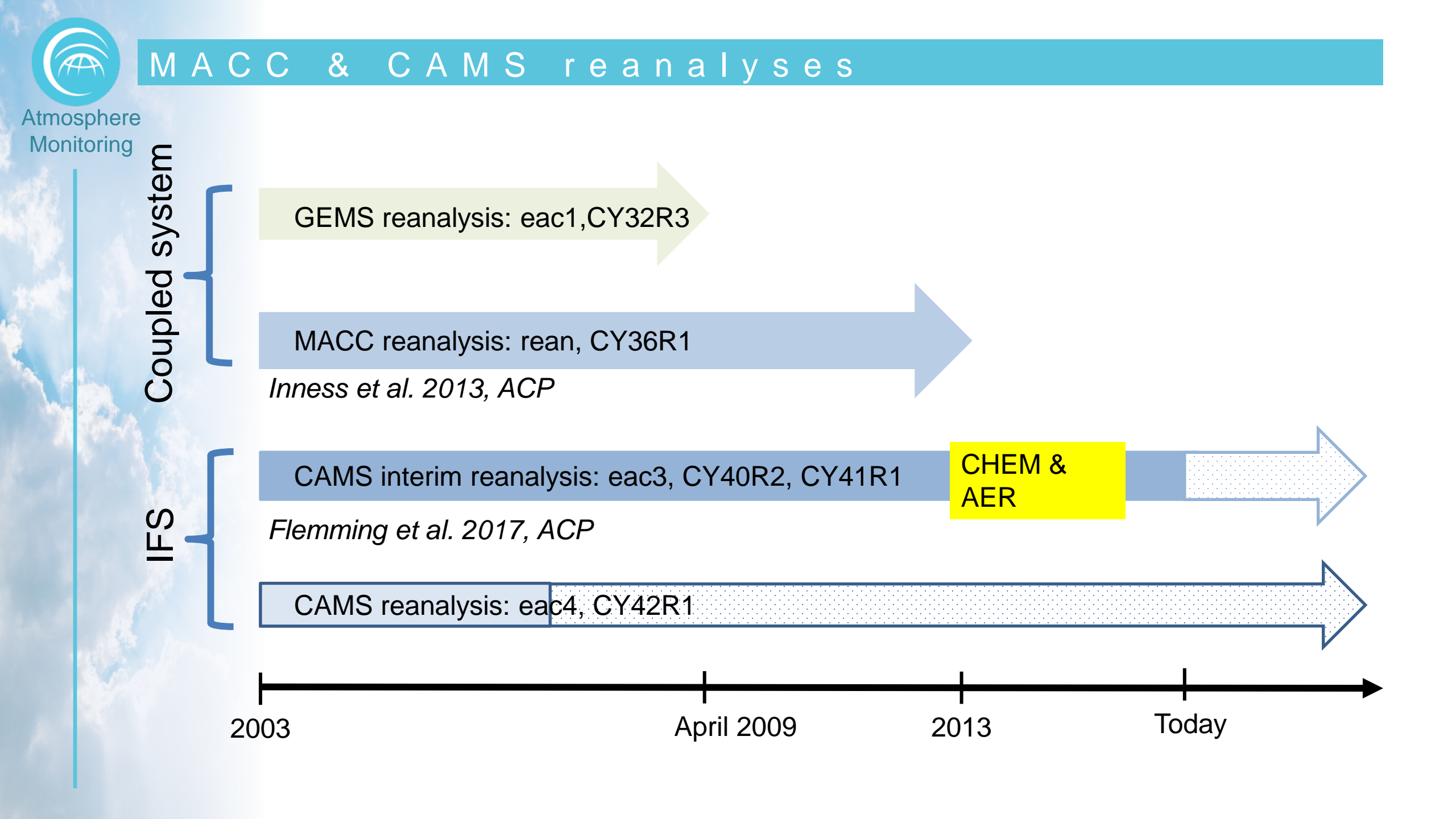
CAMS reanalysis: eac4, CY42R1

2003

April 2009

2013

Today





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