THE COPERNICUS ATMOSPHERE MONITORING SERVICE BEYOND 2020

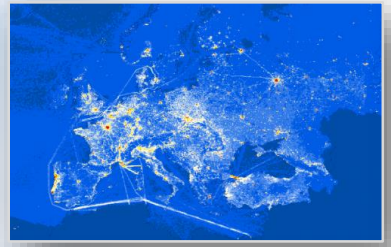
Atmosphere Monitoring

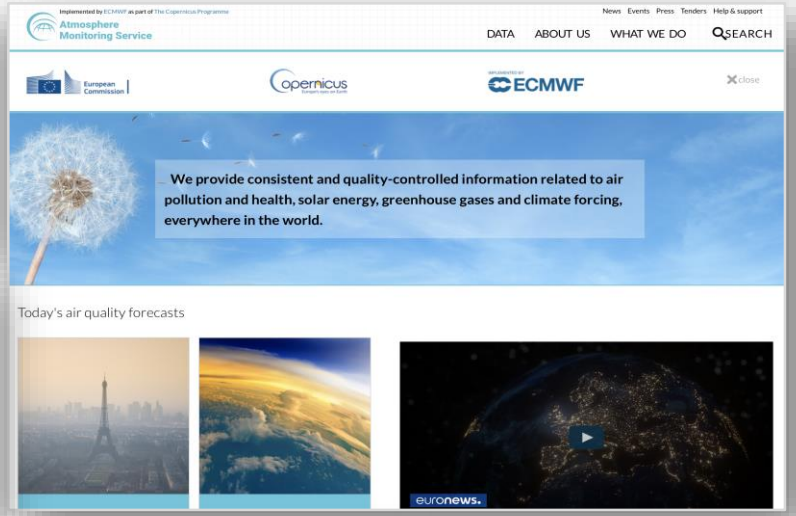
12 June 2020

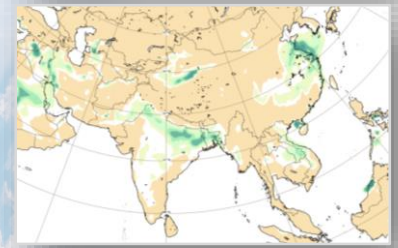
Presenters: V.-H. Peuch, J. Flemming, A. Inness, J. Barré (ECMWF) and L. Rouïl (Ineris, France)

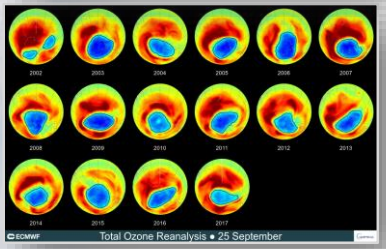
Copernicus Europe's eyes on Earth | European Commission | ECMWF

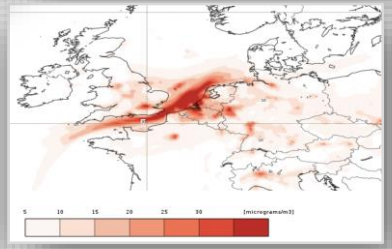
WHERE DO WE STAND?

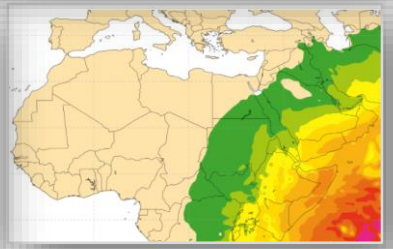












CAMS provides information products based on Earth Observation about:

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

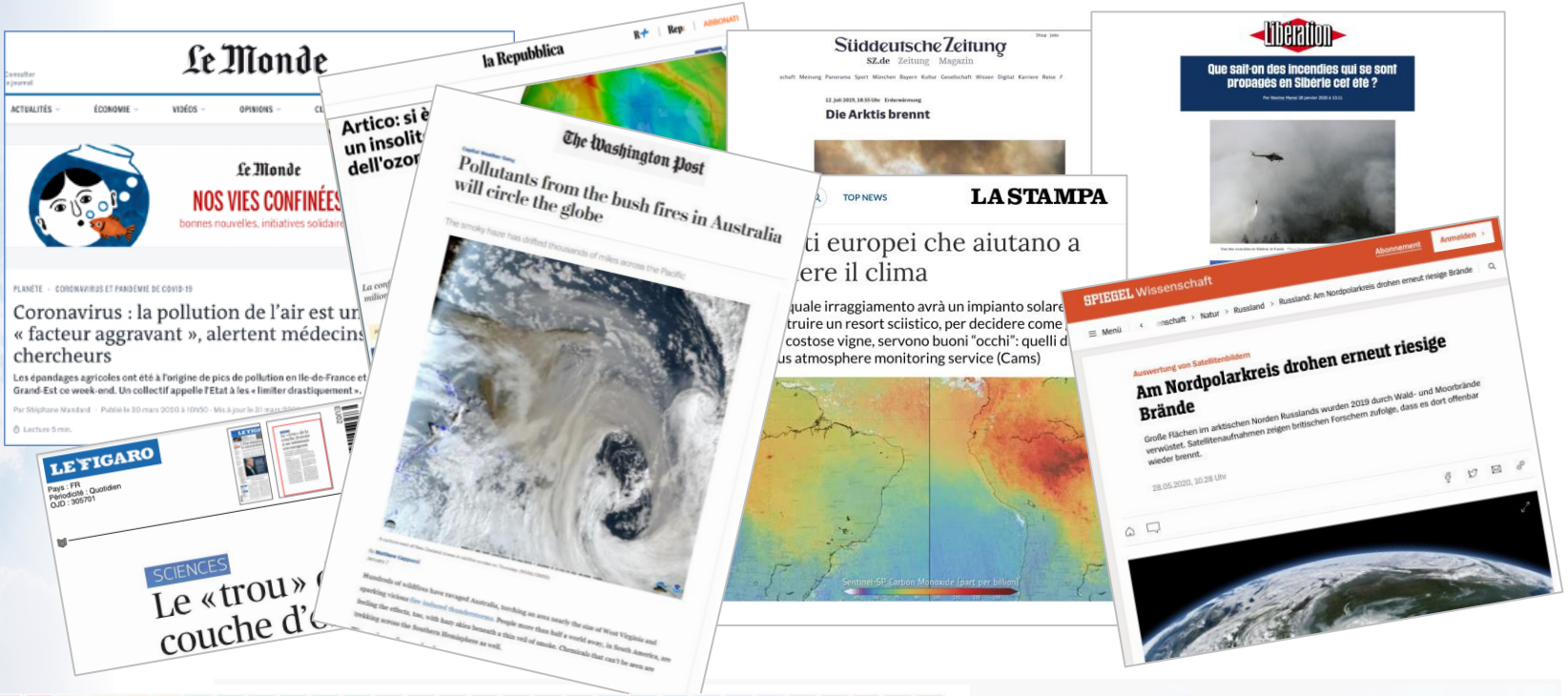
A TRULY EUROPEAN EFFORT

CAMS 4th General Assembly, Budapest, September 2019

- 196 different entities from 31 countries, 49% public / 51% private.
- Not a closed club: good mix of people/entities with long & short “history” with CAMS.
- 75 contracts.
- Private contractors & sub-: 74% SME.

A REFERENCE ON ITS TOPICAL AREAS

CAMS has become mainstream and authoritative in the topical areas covered. Example: coverage of ozone hole 2019 in 28 countries (NASA: 22; NOAA: 8).



Status Continuity+ Global Reanalyses Emissions National AQ

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HEALTHY USER UPTAKE STATISTICS

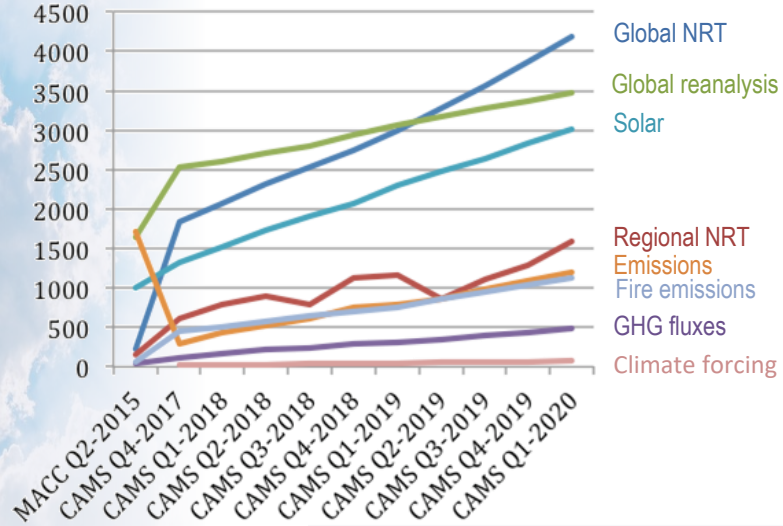
CAMS web analytics report 209k unique page views, 279k total page views and 75.5k unique visitors.

The Weather Channel

iOS

CAMS registered users

>15100 including 23% active in the quarter (Q1 2020)



Very large multiplier effect of global and European Air Quality

Windy: 750k unique users of CAMS layers in Q1 2020

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NATIONAL AND EU ENVIRONMENTAL POLICIES CONTEXT

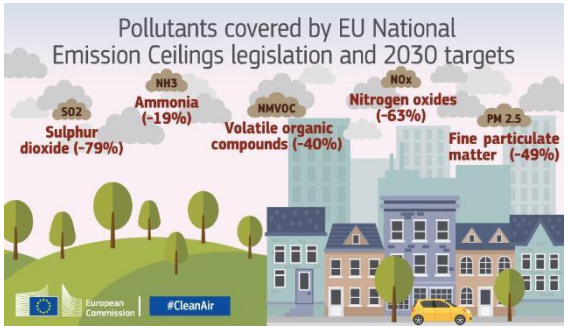
Atmosphere Monitoring

SUSTAINABLE DEVELOPMENT GOALS

MONTREAL PROTOCOL
caring for all life under the sun

PARIS2015
UN CLIMATE CHANGE CONFERENCE
COP21·CMP11

LRTAP
Long-range Transboundary Air Pollution



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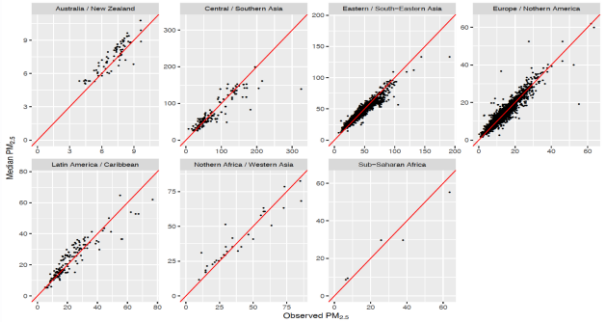
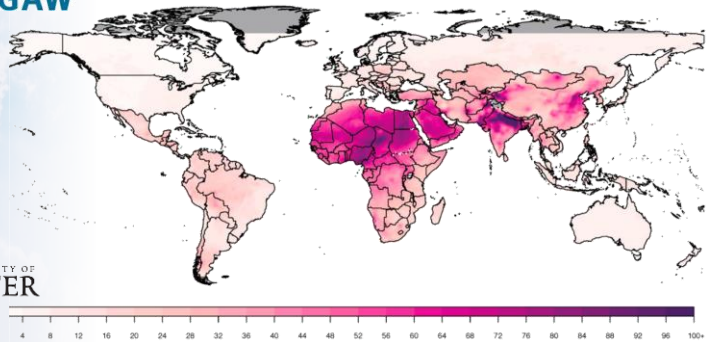
POLICIES: SUPPORT TO U.N. ORGANIZATIONS

Providing downscaled & calibrated $PM_{2.5}$ global data for the Global Burden of Disease

WMO GAW





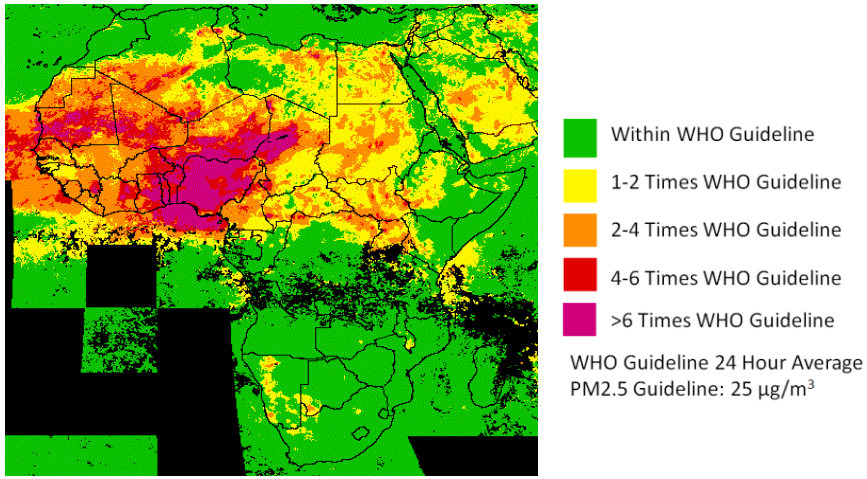
UNIVERSITY OF EXETER

UN environment

STi Sonoma Technology

Google

Estimating ground-level $PM_{2.5}$ at 1 km resolution using satellite (MAIAC OAD algorithm) and model (CAMS) data in Google Earth Engine.



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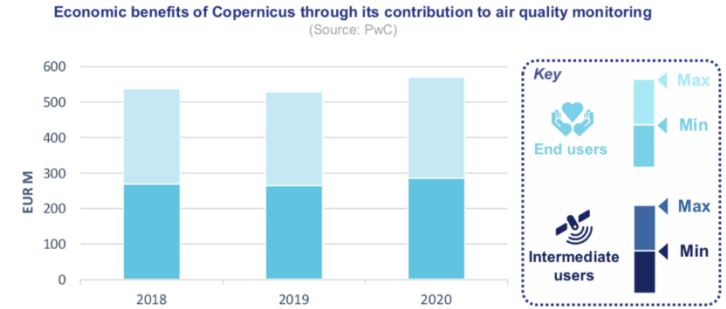
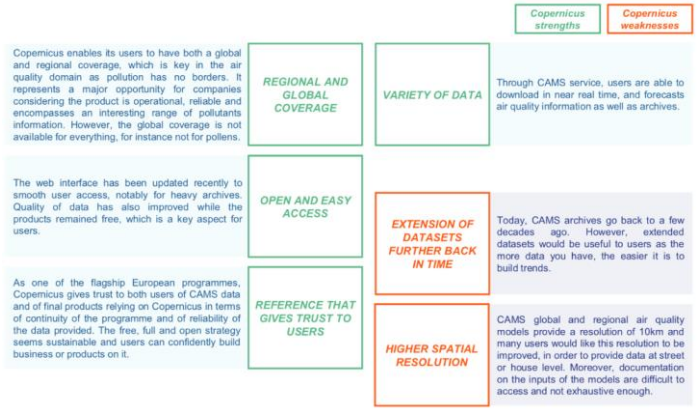
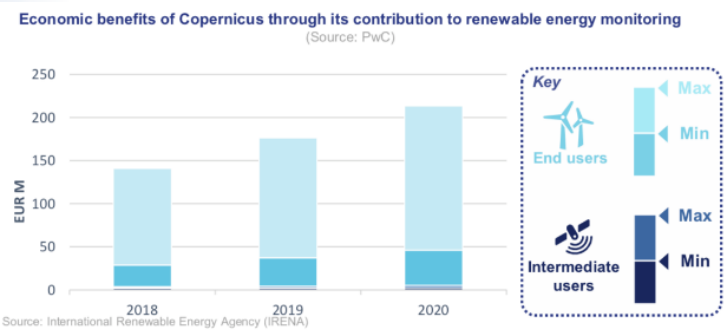
BUSINESS: COPERNICUS MARKET REPORTS

Air Quality & health





Solar photovoltaic energy



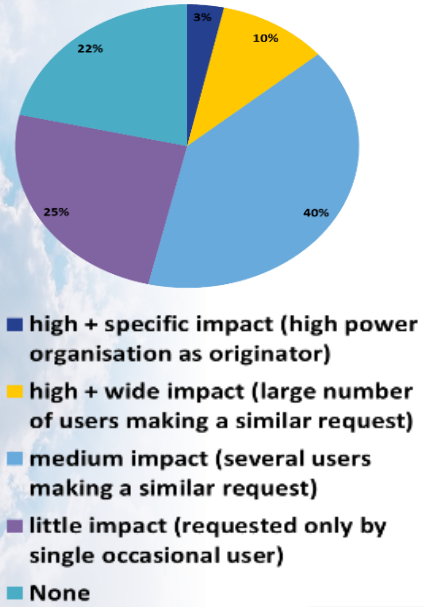
Two main weaknesses identified in the most recent report (#2) to be addressed with:

- extension of global and regional reanalyses further back in time
- higher resolution of global and regional products

HOW DO WE KNOW WHAT USERS EXPECT?

A specific aspect of the CAMS contract about user interactions (lead: DLR, Germany) is to collect and analyse expressed user requirements and categorise them in terms of impact.

Impact analysis



Same/Similar requirement	Number repeated
PROVIDE HIGHER SPATIAL RESOLUTION AIR QUALITY DATA	14
Provide sub-setting interfaces for download	14
More detailed information on current state of CAMS / roadmap	8
Accompany atmospheric composition with meteorological data	8
Provide products in netCDF format	8
EXTEND HISTORIC LENGTH OF GLOBAL CAMS REANALYSES	7
Provide regions, cities source apportionment	7
PROVIDE UNCERTAINTIES WITH THE DATA	6
Provide a forum facility for users to exchange	5
User survey / online questionnaire	5
Provide interim reanalysis earlier in the year	5
PROVIDE DEPOSITION PRODUCTS	5
Provide daily AQ forecasts earlier in the morning	4
PROVIDE LONGER MULTI-ANNUAL REGIONAL AIR QUALITY DATASETS	4

PROPOSAL 2.0

Done

External limitations

PROGRAMME-LEVEL USER REQUIREMENT


EUROPEAN COMMISSION

Brussels, 25.10.2019
SWD(2019) 394 final

COMMISSION STAFF WORKING DOCUMENT

Expression of User Needs for the Copernicus Programme

The detailed requirements collection work performed by CAMS, together with other sources and specific interviews and surveys fed into the Commission Staff Working Document about the "Expression of User Needs for the Copernicus Programme" (25/10/2019)

Some key words from the document:

- up to seasonal forecasts of pollutants and pollens at fine scale;
- source [apportionment] information;
- support information and early warning of citizens;
- long time series in the past;
- deep understanding of the ozone layer;
- inventories and hourly updated emissions at pan-EU scale;
- support monitoring of SDGs, especially 11 (air pollution and health) and 13 (greenhouse gases);
- deposition fluxes of nitrogen oxides, ammonia and ammonium salts, sulphur oxides, particulate matter & ozone.

Atmosphere Monitoring

Enhanced Continuity of CAMS existing products

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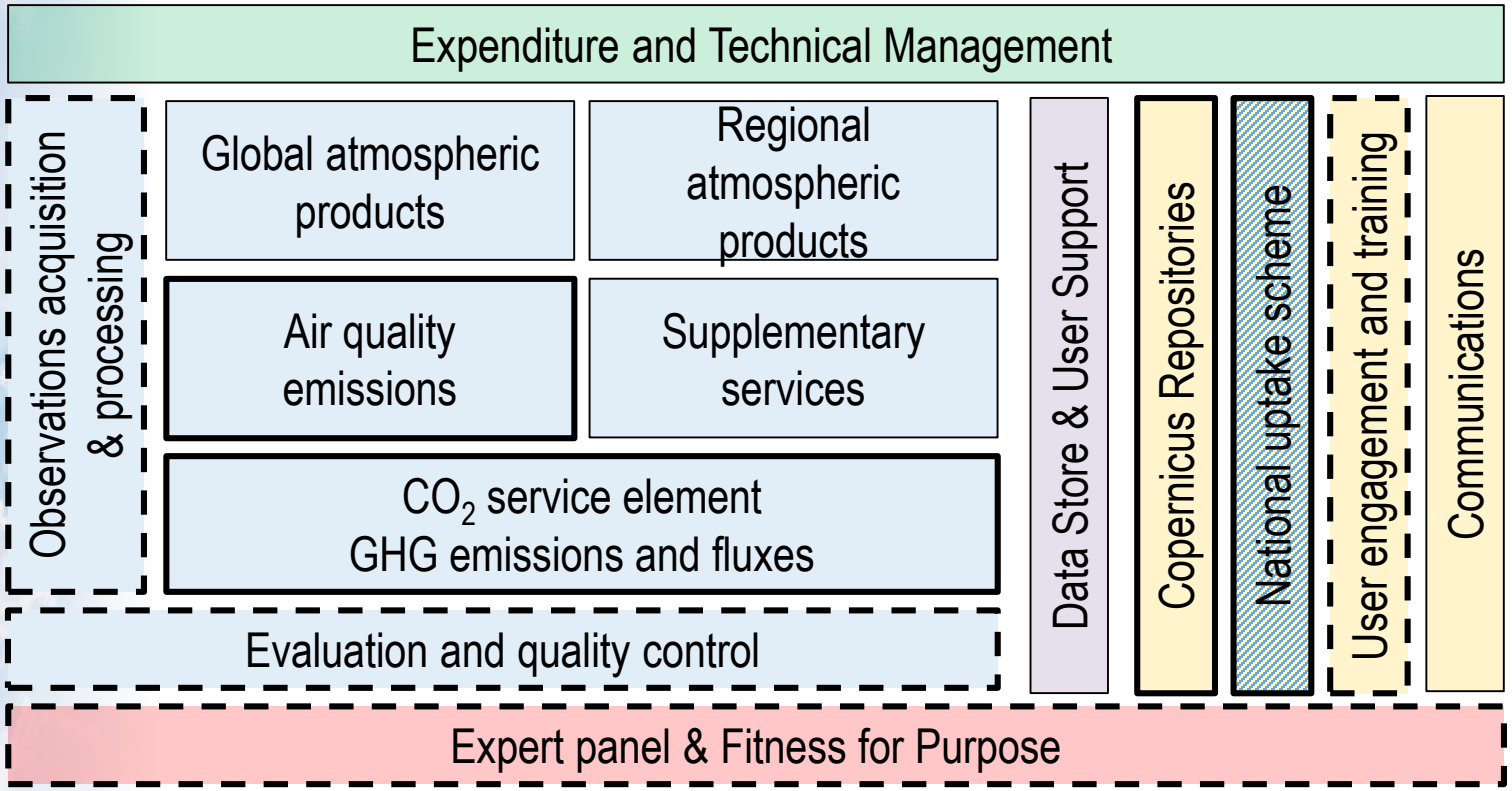
CAMS 2.0 ARCHITECTURE

Atmosphere Monitoring



Management
Production
Data Store
User facing
Advice & Evaluation

Degree of change

Evolution
Major
New

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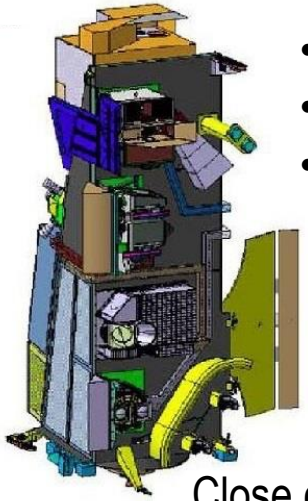
CHANGES IN THE OBSERVING SYSTEM

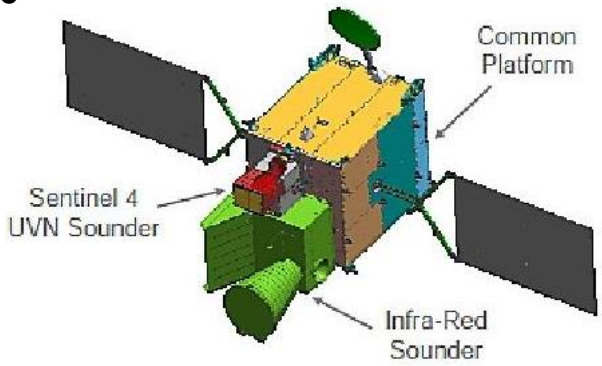
Observations acquisition & processing

MetOp-SG-A



- Sentinel-5
- IASI-NG
- 3MI

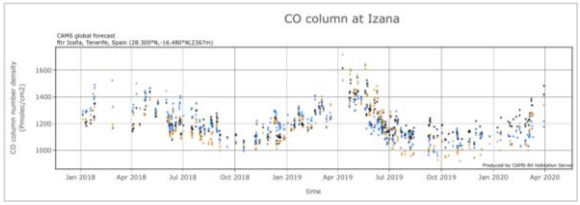
MTG-S



- Sentinel-4
- IRS

Close collaboration with EUMETSAT esa

Continue the work with in-situ networks and relevant research infrastructures.



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EVOLUTION PARADIGM FOR THE MAIN SYSTEMS

Atmosphere Monitoring

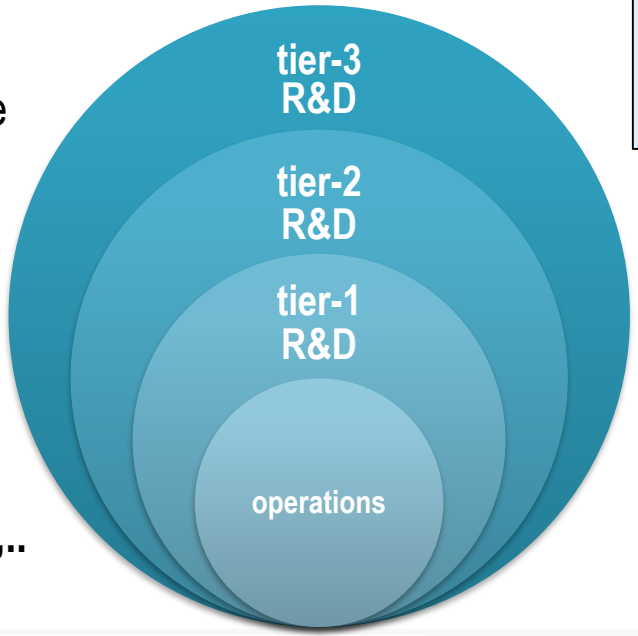
Global atmospheric products	Regional atmospheric products
	Supplementary services

Longer term R&D
Under Horizon Europe

12-18 months R&D
CAMS development contracts

Next cycle developments
ECMWF and regional production

Respond to rapid obs changes,..
ECMWF and regional production



Track record of responding as part of these evolution to user requirements, as synthesized by the CAMS user interaction contract (resolution, timeliness...)

HIGHLIGHTS OF PROPOSED EVOLUTIONS

- Global GHG developments and GHG surface fluxes organised together with the CO_2 Service element
- Regional production, attach tier-2 R&D activities but remove verification aspects to join common Evaluation and Quality Control function
- Strong enhancement of emissions inventory work to provide a priori information for observations-based emissions products, pollutants and CO_2

"New" elements

- Major evolutions in the global system (Johannes Flemming)
- Improved global and regional reanalyses (Antje Inness)
- Satellite observation-based emissions of pollutants (Jérôme Barré)
- National Air Quality collaboration scheme (Laurence Rouïl, Ineris, France)
- CO_2 Service Element (Richard Engelen and Anna Agusti-Panareda)

Atmosphere Monitoring

New Service element
Major enhancements of global operational products

Johannes Flemming (ECMWF)

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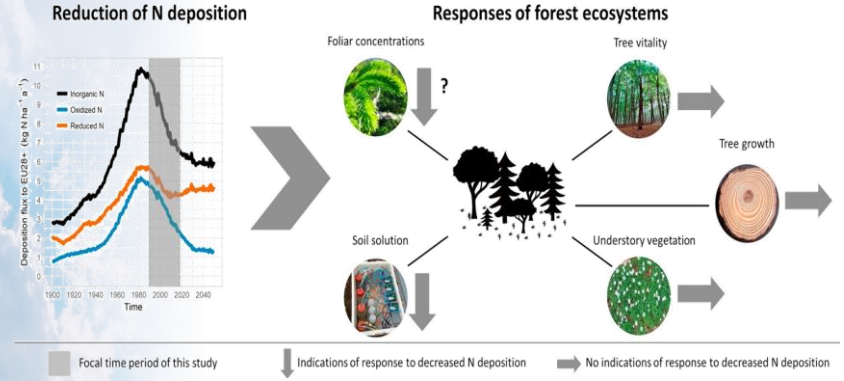
SOME IMPACTS ON ECOSYSTEMS AND AGRICULTURE

Deposition fluxes (acidification, eutrophication, soiling of plants and solar panels…) are a major user requirement and have been an active area of development in the last years.

Example 1: European forest response to N deposition

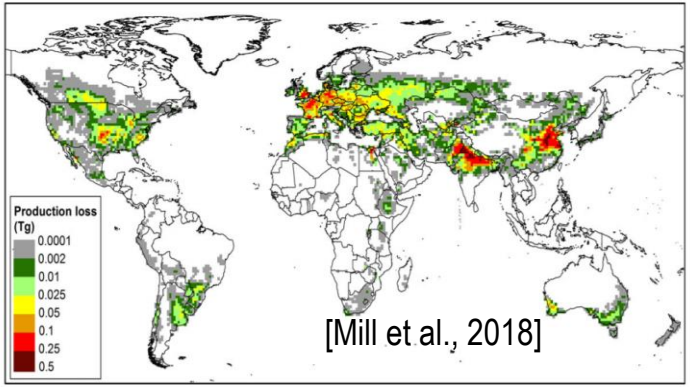


Consequences of increasing N deposition in ecosystems:

- biodiversity loss;
- soil acidification and water quality degradation;
- growth reduction.

[Schmitz et al., 2018]

Example 2: loss in wheat production because of O_3



[Mill et al., 2018]

Production loss for wheat modelled considering stomatal uptake of ozone and soil moisture:

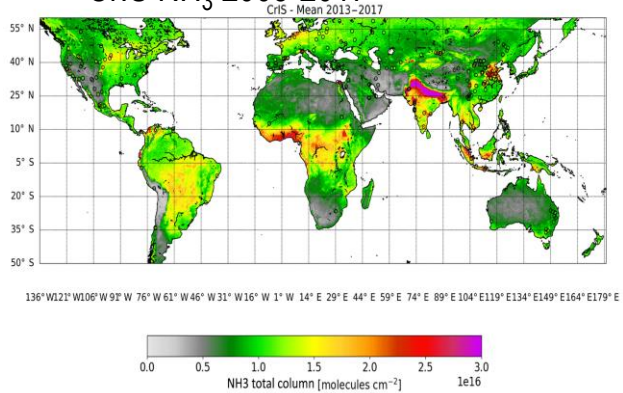
- 9.9 % (NH) and 6.2 (SH) loss of yield (2010-2012);
- lower loss and different spatial patterns than yield loss calculated by AOT40 and M7 (concentration based).

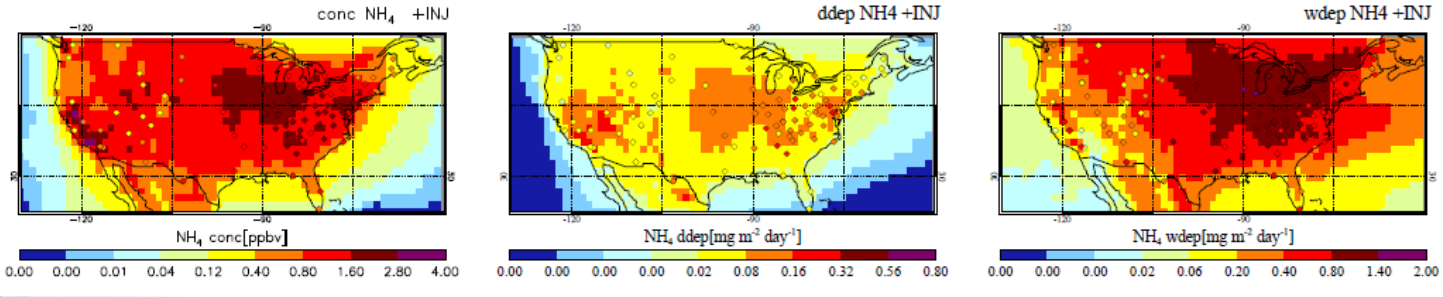
DEVELOPMENT FOR DEPOSITION PRODUCTS

Progress to operational status is possible thanks to:

- advances in modelling in with the CAMS global system:
  - Nitrates and Ammonium in aerosol scheme
  - Improvements in dry deposition simulation
  - Updated anthropogenic and natural emissions
- availability of good quality NO_2 (S5P, S4, S5) and NH_3 (CrIS, IASI) satellite retrievals

CrIS NH_3 2003-2017



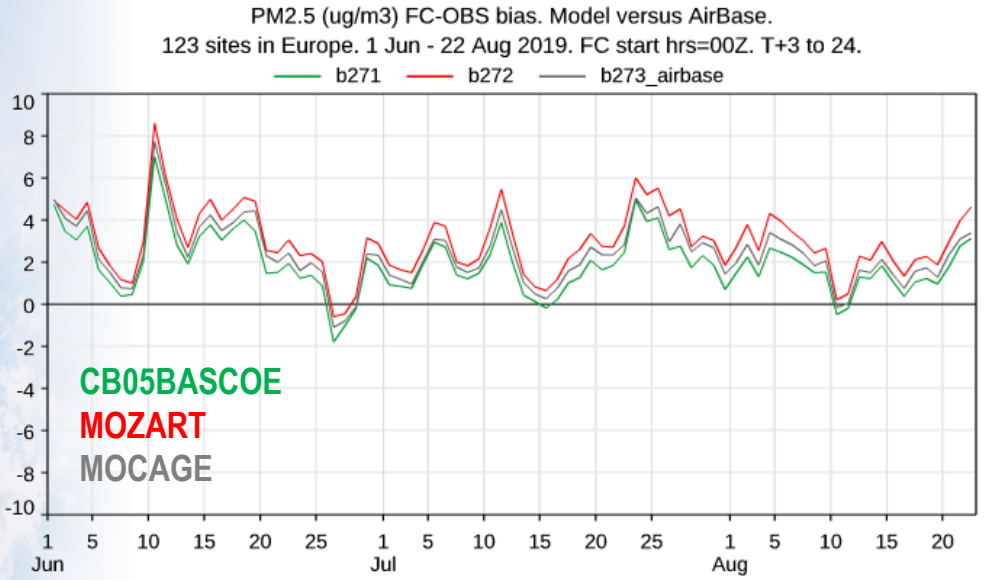


Work is also in the context of MMF-TAD

WMO GAW

Evaluation of CAMS NH_4 annual mean concentration, dry and wet deposition over Eastern US

HOW TO QUANTIFY UNCERTAINTY?



Impact of using different precursor chemistry on PM2.5 forecasts over Europe.

Providing **uncertainty information with global forecasts** is a major challenge.

The same approach as for regional products cannot be pursued because there aren't enough advanced global models in Europe to build a meaningful multi-model ensemble.

Uncertainty estimation can however be based on variants of IFS and of its main inputs, which result from a number of developments contracts.

Example: different approaches to tropospheric chemistry lead to an ensemble of inorganic aerosol and PM2.5.

QUANTIFYING UNCERTAINTY OF EMISSIONS

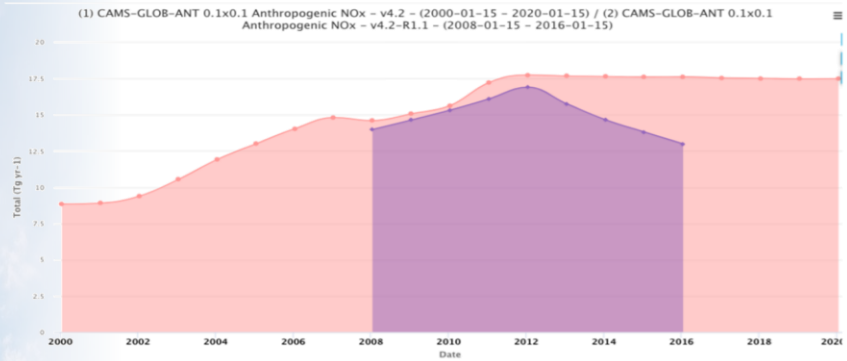
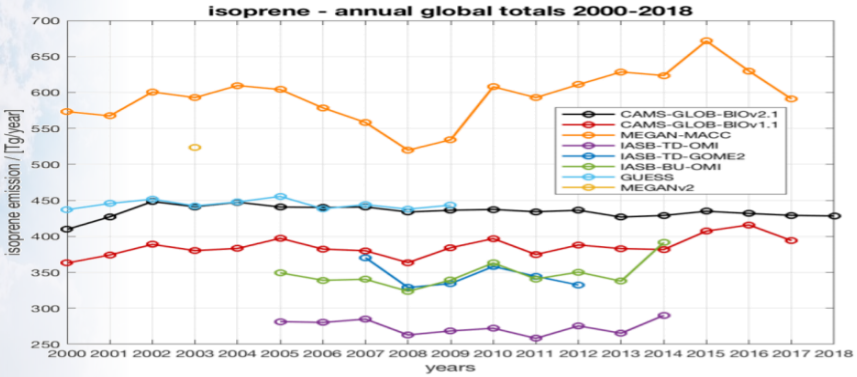


Figure : NOx emissions in China from the standard version 4.2 compared to the v4.2_R1.1 version.



Emissions of pollutants are a major contribution to uncertainty on atmospheric concentrations at the global scale.

Developing emissions scenarios will be a key evolution of contracted work on emissions inventories.

In addition, we will make use of IFS ensemble prediction system and EDA.

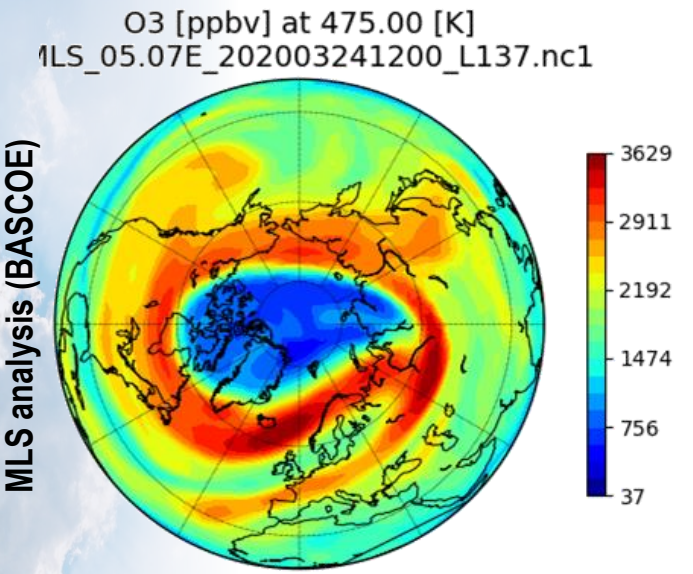
There are clear synergies between this work and the developments for observations-based emissions of pollutants (next talk) and of CO_2.

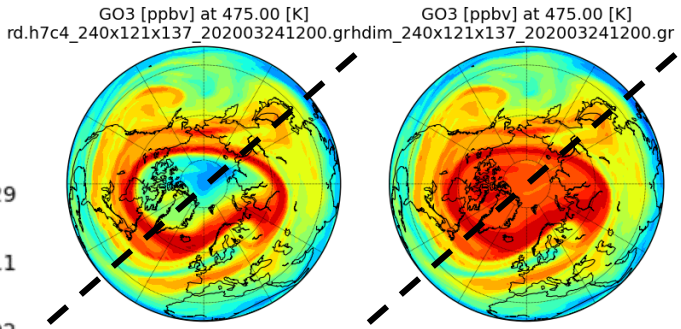
DETAILED STRATOSPHERIC CHEMISTRY REPRESENTATION

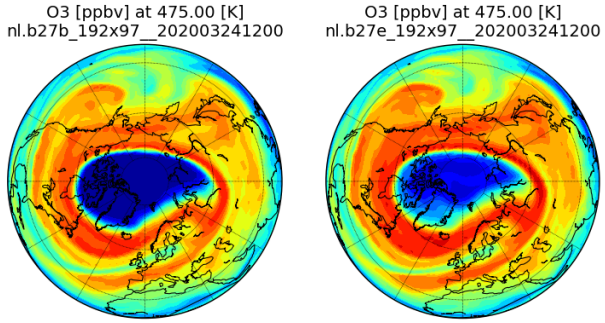
IFS Linear schemes

IFS-CARIOLLE **IFS-HLO**

MLS analysis (BASCOE)







IFS detailed schemes

IFS-CB05/BASCOE **IFS-MOCAGE**

Detailed representation of stratospheric composition is a repeated user requirements.

Developments have been essentially completed and the next step is transferring to operations.

Opportunity to assimilate certain satellite observations, which are not used today.

Users: academia (ozone hole, climate…) and NWP.

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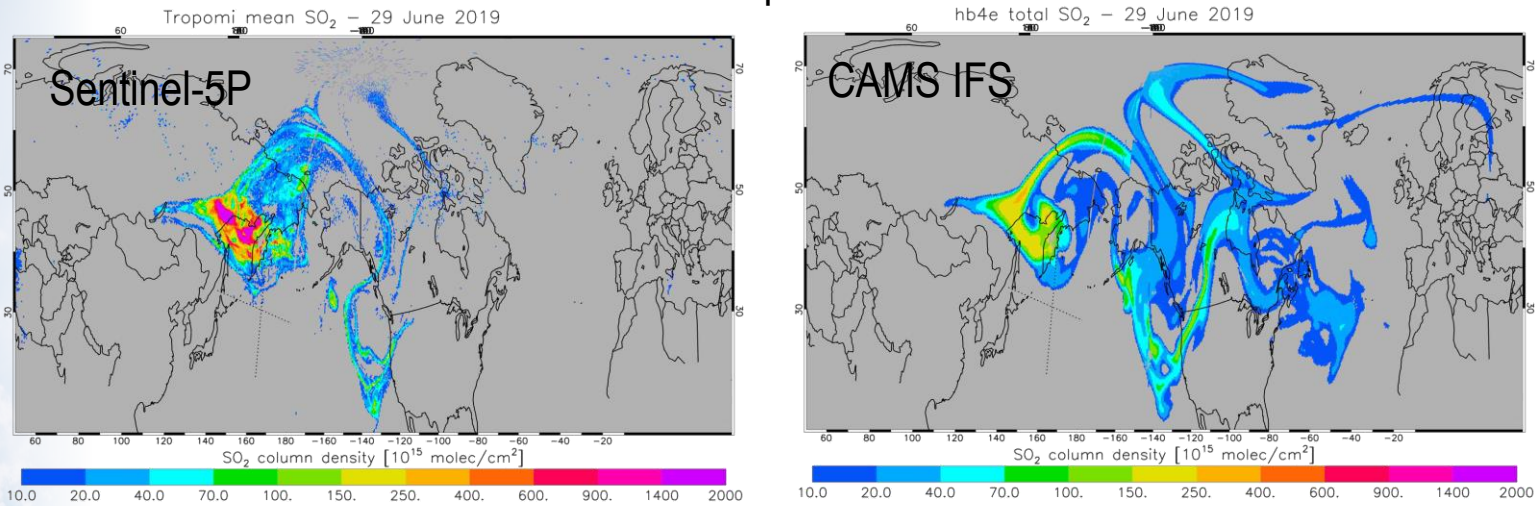
STRATOSPHERIC SO_2 AND SULPHATE

Raikoke eruption 2019



- Raikoke eruption (June 2019) doubled total global SO_2 burden within 3 days (1Tg)
- SO_2 plume observed by satellites instruments (TropOMI, OMI, GOME-2) assimilated in global CAMS model
- Conversion to stratospheric sulphate modelled with IFS-AER and IFS-GLOMAP
- "Pinatubo-strength" eruption (20 Tg SO_2) "statistically" due, could impair NWP and other EO applications

Atmosphere Monitoring

New Service element Longer and improved regional and global reanalyses

Antje Inness (ECMWF)

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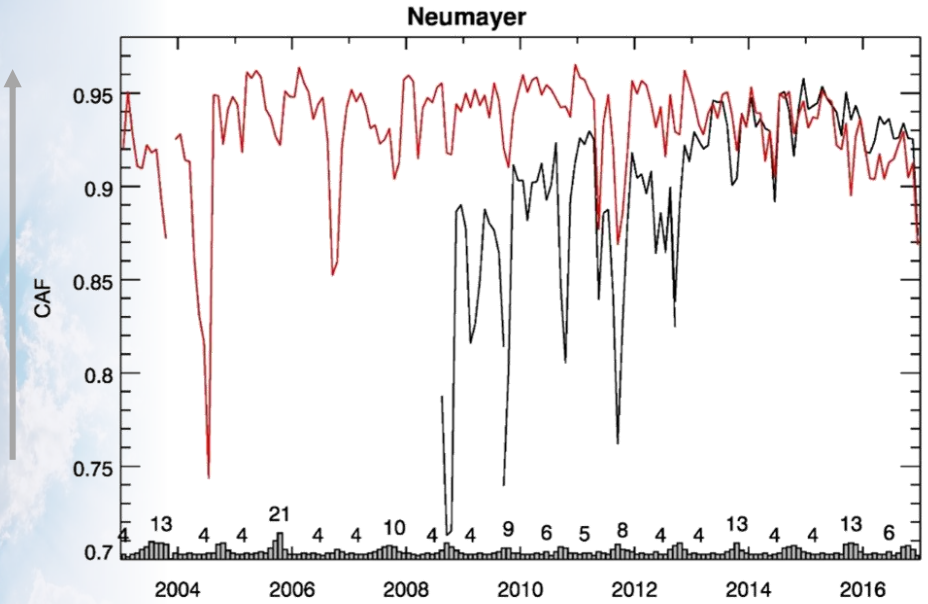
WHY ARE REANALYSES USEFUL?

Example: skill of ozone profiles in Antarctica



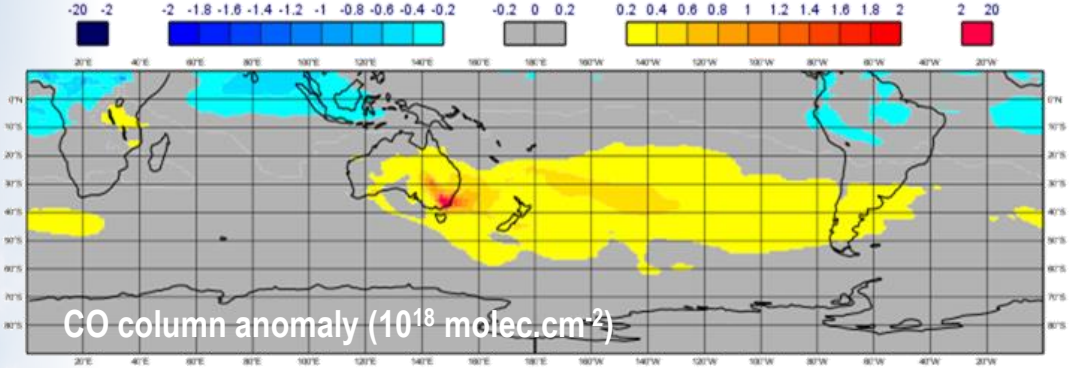
Daily analyses

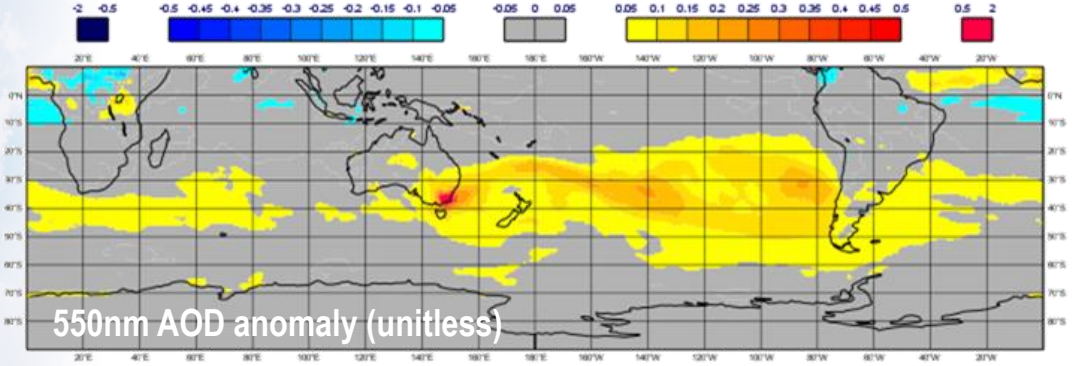
- Evolve with time, at least one system change per year
- Horizontal and vertical resolution can change
- Observation usage changes
- Cut-off time for producing the forecasts means that some data are missed
- Emission datasets might change

Reanalysis

- Consistent long term dataset produced with one model version
- Consistent emissions
- Consistent, reprocessed observations

ASSESS EXCEPTIONAL EVENTS



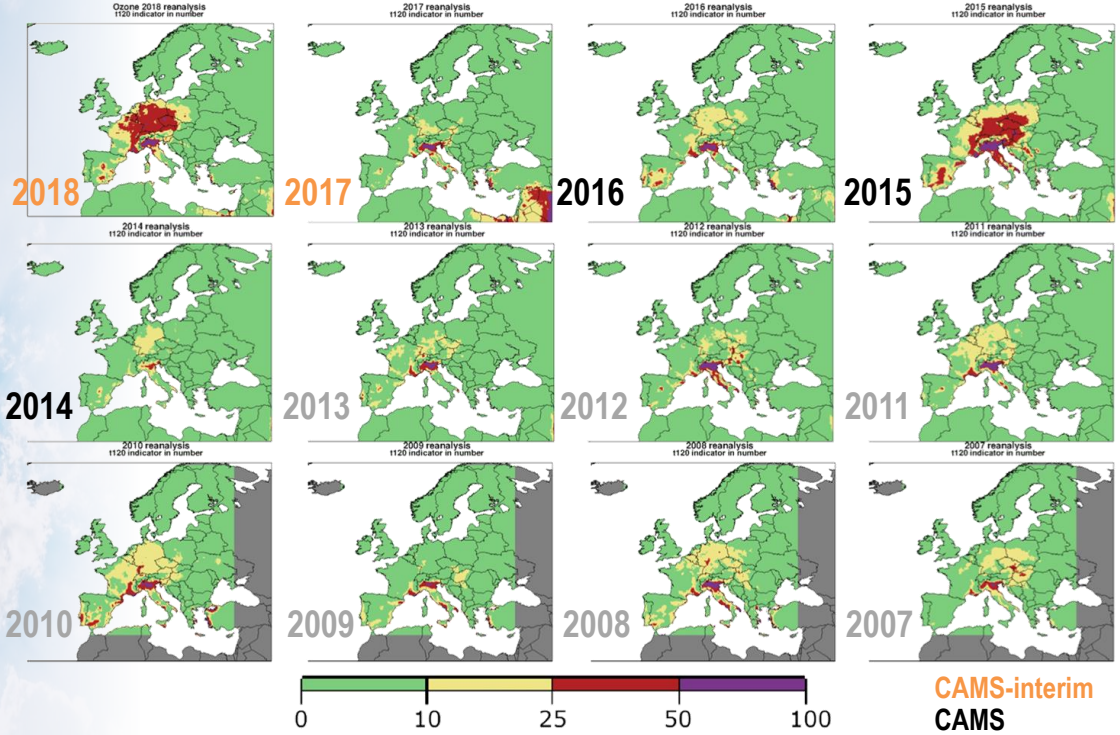


What was the impact of the January 2020 fires in South-Western Australia?

Anomalies calculated against the 2003-2019 January means from the CAMS reanalysis. Information is useful for e.g. BAMS State of Climate.

Reference paper: www.atmos-chem-phys.net/19/3515/2019/

ASSESS HEALTH IMPACTS



Ozone (number of days with 8-hour daily maximum over 120 mg.m^{-3})

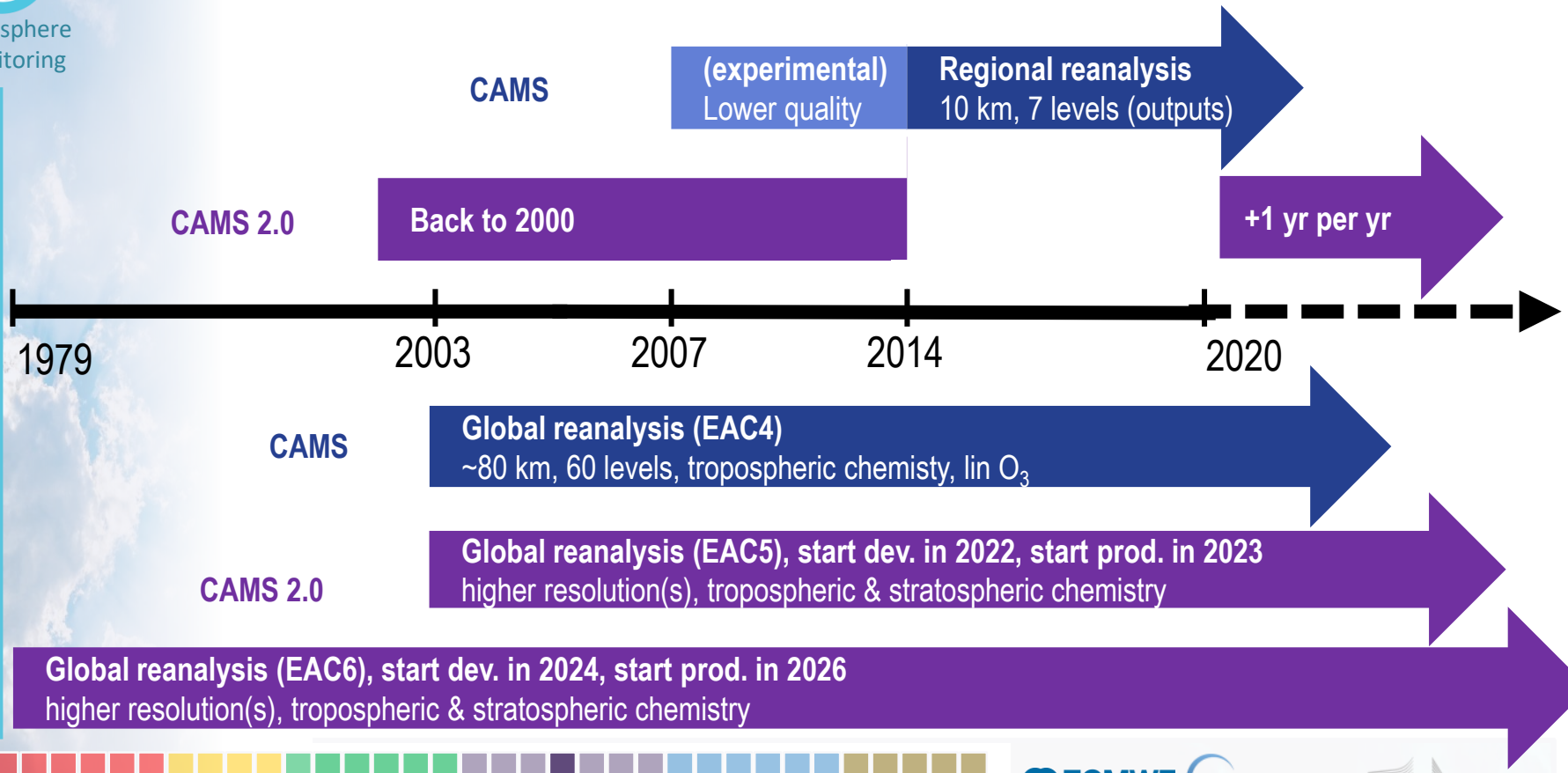
Regional reanalyses are required to bridge the gap with exposure scales and assess impacts.

Multi-year reanalyses are useful because:

- interannual variability is very large especially in Europe so one particular year may not be representative
- some impacts (health) result from long term or even childhood exposures

PLANS FOR CAMS REANALYSES

Atmosphere Monitoring



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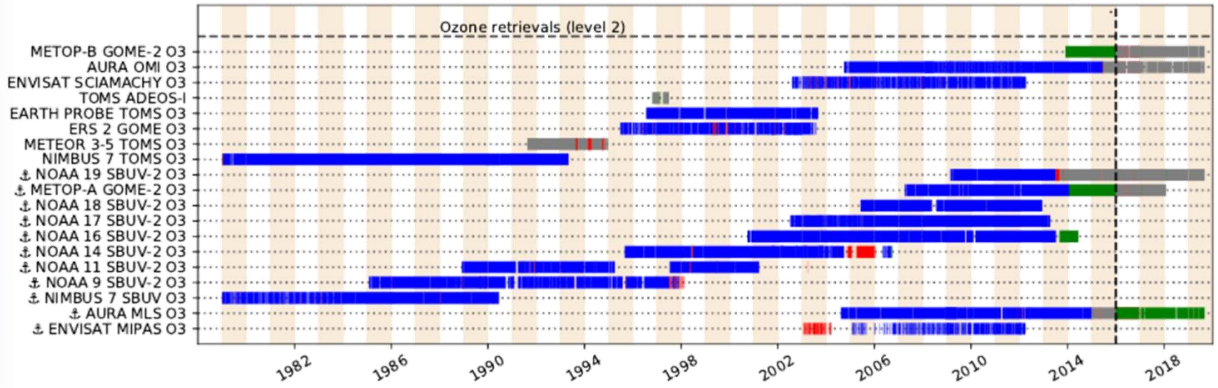
GLOBAL REANALYSIS: GOING BACK TO 1980S

Some challenges:

- availability of atmospheric composition datasets
- availability of emission data sets (anthropogenic, biogenic, biomass burning)
- …

Asset: collaboration with C3S (possibly joint efforts EAC6/ERA7)

O3 data assimilated in ERA5 (Hersbach et al., 2020, QJRMS)

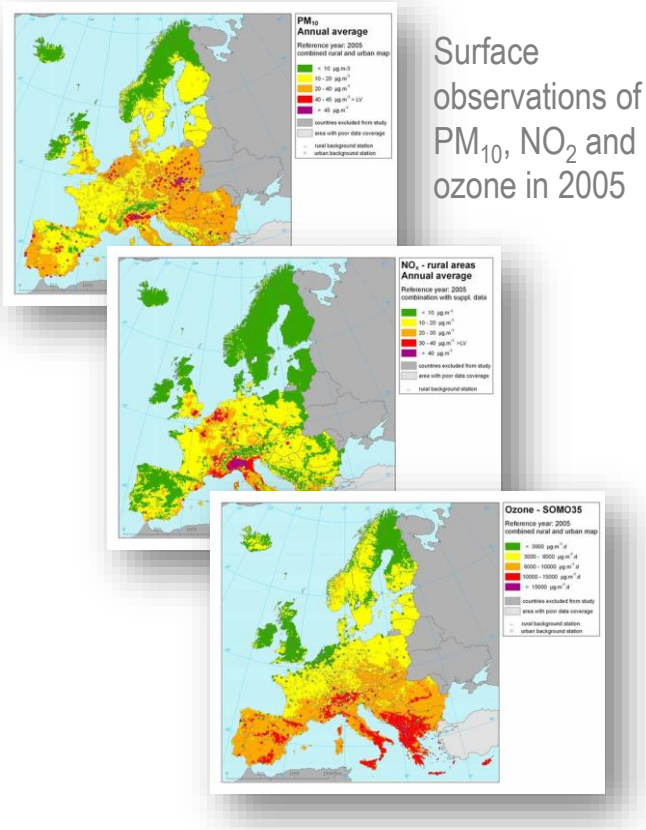


CANDIDATE SATELLITE DATASETS PRE-2003

Species	New data	Period	Comments
O_3	TOMS, SBUV, ERS GOME	1979-2002 1995-2003	Reasonably well covered, but vertically resolved data limited. CAMS brings detailed stratospheric chemistry and this would cover cover the whole ozone hole period.
AOD	AVHRR ATSR-2	1979- 1995-	Huge interest for aerosol reanalysis back to 1979 in particular for climate modelling.
SO_2	TOMS ERS GOME	1979- 1995-2003	Major interest due to volcanic eruptions (El Chichon 1982, Pinatubo 1991) and abatement of SO_2 emissions (desulphurisation of fuels).
NO_2	ERS GOME	1995-2003	Coarse resolution. Data quality? Emissions in control variable ready in time for EAC6 (would increase impact)?

REGIONAL REANALYSES

- Good coverage and availability of surface observations for SO_2, ozone, NO_2 and PM_{10} (not $PM_{2.5}$) back to 2000.
- The main challenges are:
  - emissions for the 2000s (but resources available from EMEP);
  - production (computing and human resources), as existing systems can be used with limited changes.
- 10km remains an appropriate resolution: global reanalyses will be at least x4 coarser in surface area.
- Assessment of cost vs value regarding the number of ensemble members for the period 2000 to 2013.
- Years >2022 will be run with all the systems (9, then 11) in order to be consistent with NRT production.



Surface observations of PM_{10}, NO_2 and ozone in 2005

Atmosphere Monitoring

New Service element Satellite observation-based emissions of pollutants

Jérôme Barré (ECMWF)

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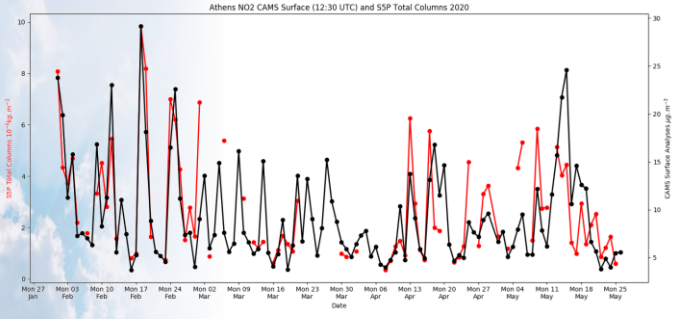
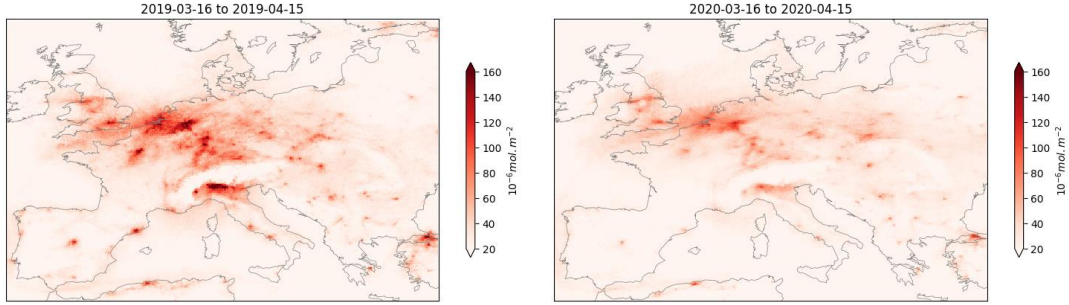
THE ADVENT OF AIR QUALITY MONITORING FROM SPACE

With the COVID-19 crisis, it has become clear that air quality monitoring from space is a reality and no longer a “technical push” from Earth Observation scientists and Space agencies.



Sentinel-5P/TROPOMI NO_2 column vs CAMS regional analyses of surface NO_2 (Athens) at overpass time.



Sentinel-5P/TROPOMI NO_2 column mid-March to mid-April 2019 vs 2020 (lockdown)

CAMS shows that the information provided on day-to-day variability is very similar to what is inferred from surface observation and it can be relied upon.

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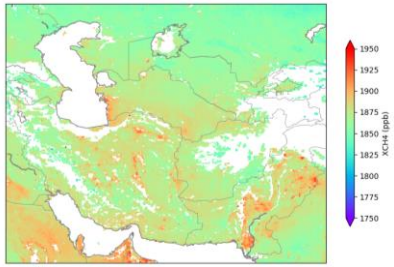
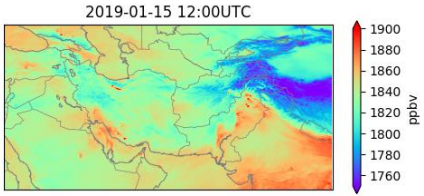
EXAMPLE OF THE CAMS CH_4 MONITORING SYSTEM

Satellite observations

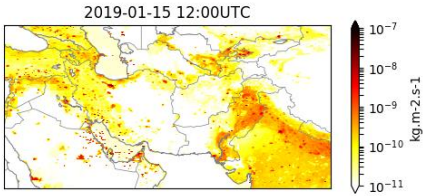


Automated comparison (classification, AI..)

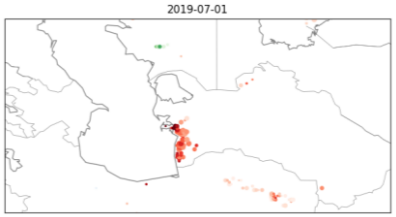
Model forecasts (simulated satellite observations)



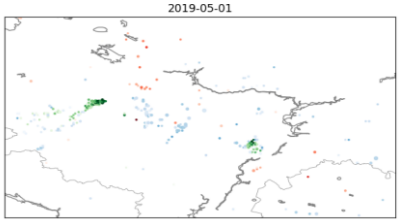
Emission inventory data



Monitoring of CH_4 emission anomalies for EC/DG ENER



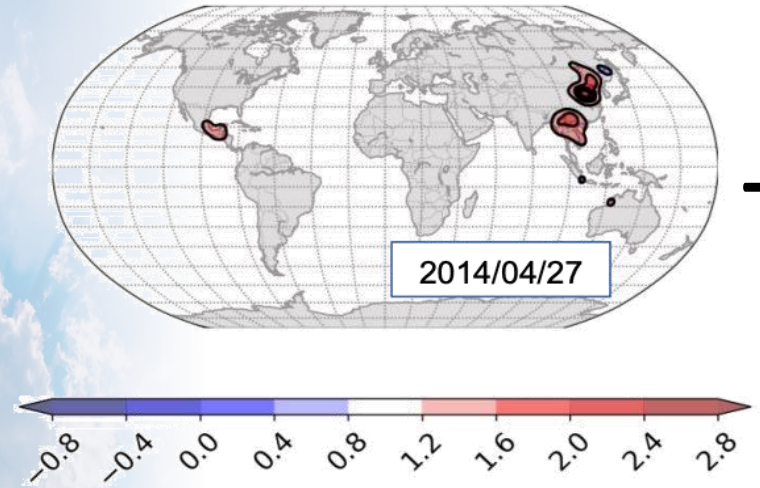
Observed emissions not in inventory



Emissions in inventory that are not observed

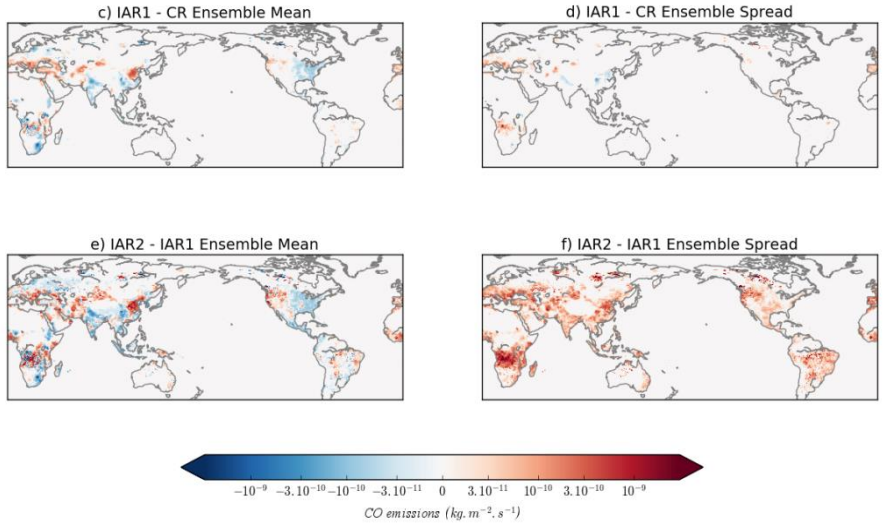
POLLUTANTS EMISSIONS ESTIMATION USING IFS

4D Var information: deterministic



+

Ensemble Information: statistical



The IFS framework offers the possibility to compare and use the two in combination for parameter estimation (here: emissions). Obvious synergies with the CO_2 Service Element, although the problems are different (lifetime of species, background vs fresh emissions, observations…).

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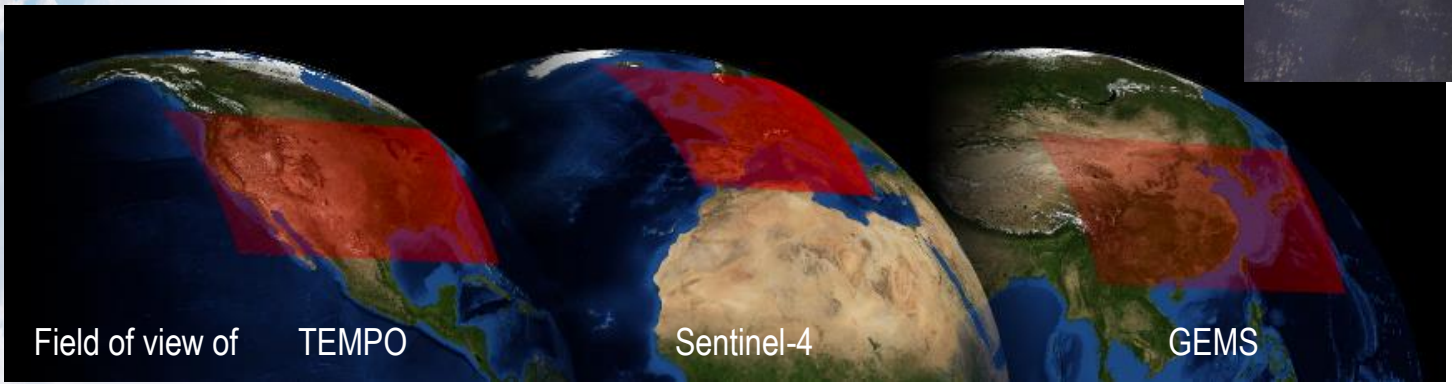
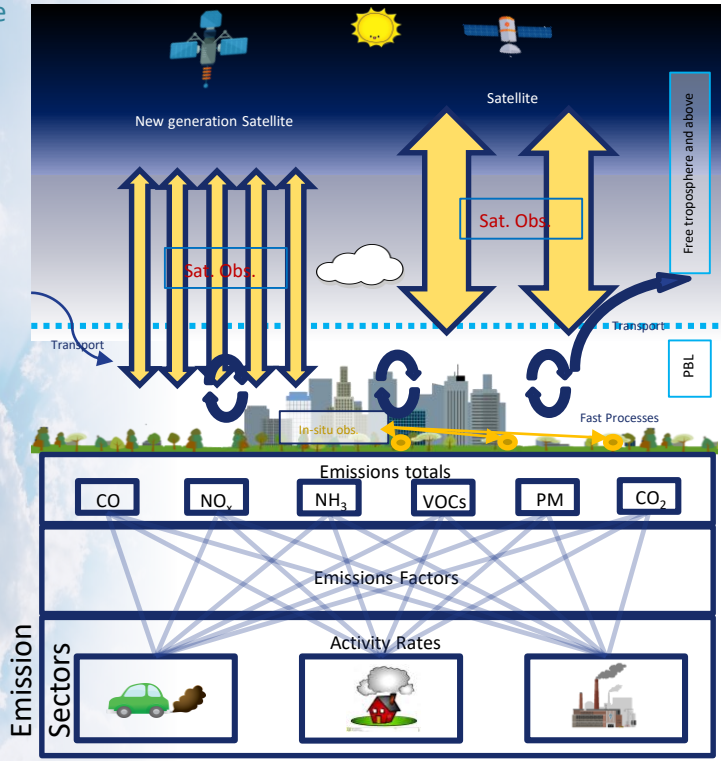
OPPORTUNITY: THE UPCOMING GLOBAL OBSERVING SYSTEM

- Low Earth Orbiting instruments: Sentinel-5p, Sentinel-5, IASI-NG, 3MI…
- The global geostationary constellation providing hourly revisit: Sentinel 4 + MTG/IRS, TEMPO (USA), GEMS (Korea)

This calls for a global integrated approach to benefit from all the possible synergies between instruments and species observed.



DEVELOPMENT TARGETS



- Target species (direct): NO_2, CO, NH_3, CH_4, SO_2 (large sources only)
- Target species (indirect): $PM_{2.5}$/PM_{10} (AOD and aerosol size information) and NMVOCs (HCHO, glyoxal, vegetation parameters…).
- global, ~10km, hourly.
- Sectorial inversion.
- Requirements on emissions prior information (link to activities on uncertainty).
- Same building blocks as for the CO_2 service IFS system: co-emission with NO_2.
- Links and support to policies on AQ and GHG emissions, working with the Member States and national efforts.

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IMPLEMENTATION PRINCIPLES

- Development in IFS supported by dedicated external developments contract
- Specific IFS version (9km) with simplified chemistry for production, separate from main forecast stream
- Dedicated work on emissions priors (synergies with CO_2)
- Extensive EQC contract, including comparison with benchmark regional systems to ensure quality of CAMS operational products (and feeding into developments)
- Tentative timeline:
  - 2021-2022: prototyping with S-5P, IASI and GEMS
  - 2023: release of experimental emissions products ; preparation/tests with S-4, IRS, S-5
  - 2024: start ramping up of operational pollutants emissions products

Atmosphere Monitoring

New Service element National Air Quality collaboration scheme

Laurence Rouïl (Ineris, FR)

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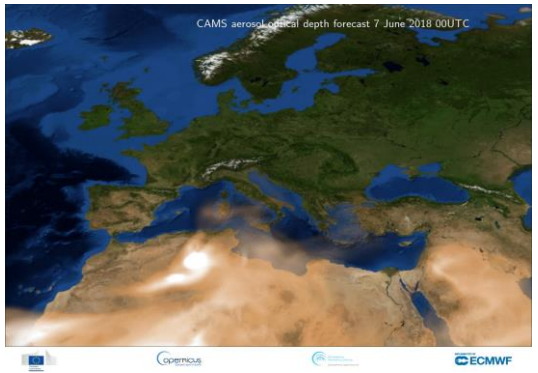
WHAT ARE MS RESPONSIBILITIES & WHAT CAMS PROVIDES?

EU Member States are responsible for the implementation of the Air Quality Directives:

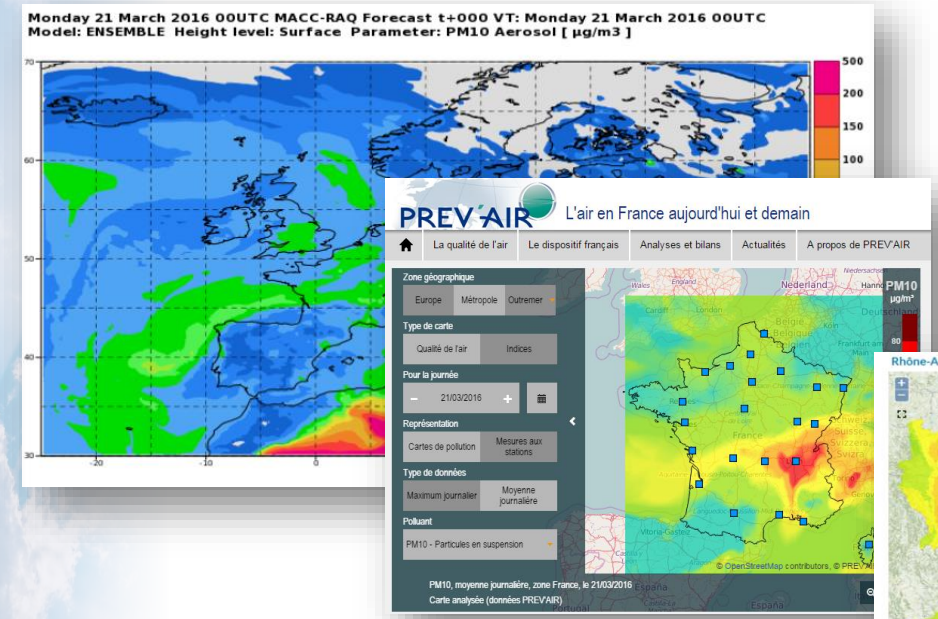
- air quality monitoring strategy (measurement and modelling);
- air quality objectives (limit and target values);
- analysis of main drivers of air pollution episodes, including transboundary and natural contributions;
- information to the general public;
- conception and implementation of short-term and long-term action plans to comply with AQ objectives.

CAMS provides relevant Europe-wide information products:

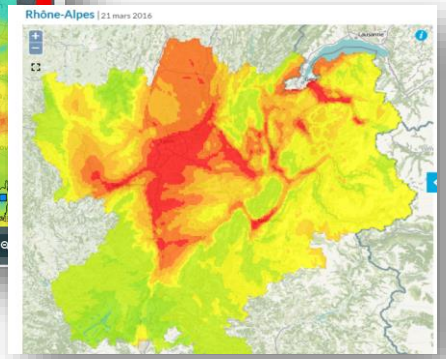
- air quality forecasts and (re)analyses;
- natural contributions: dust, sea salts, forest fires;
- European-scale emission inventories;
- policy tools co-designed with MS to meet their needs.



EXAMPLE: CAMS DATA FEEDING INTO MS' WORKFLOWS

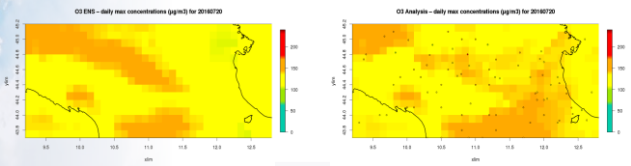


Objective: generalise operational integrated modelling chains to monitor and forecast air quality in a fully consistent way from the global scale to the city scale.



Please note colour scales are different.

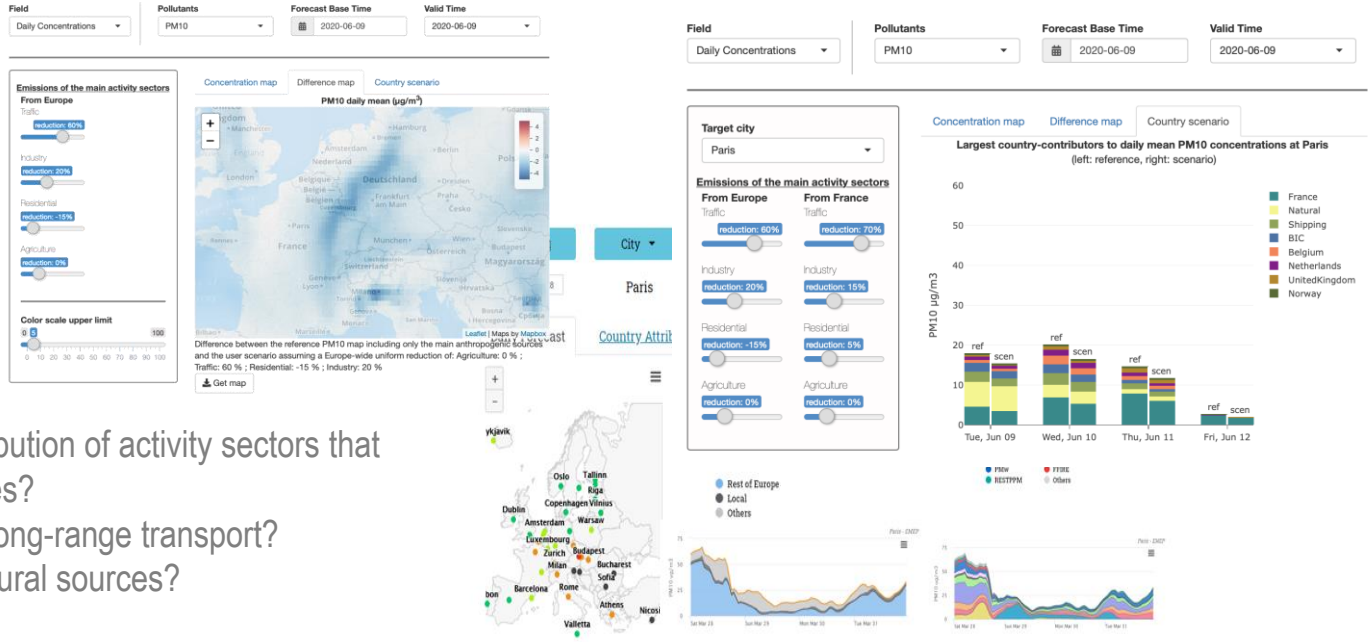
CAMS regional



CAMS regional + local observations

EXAMPLE: MAKING FULL USE OF CAMS ADVANCED TOOLS

Atmosphere Monitoring



- weight/contribution of activity sectors that drive episodes?
- influence of long-range transport?
- impact of natural sources?
- …

Objective: set-up of decision making protocols based on integrated information from CAMS tools, fully adapted to national context.

Status Continuity+ Global Reanalyses Emissions National AQ

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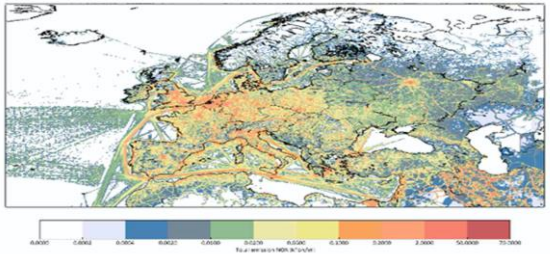
EXAMPLE: CAMS LEVERAGING FROM WORK AT MS LEVEL

Objective: provide to CAMS users seamless higher resolution products that correspond to official MS Air Quality information, avoiding "Frankenstein maps" (where borders show and undermine quality of information).

Meet #1 outstanding user requirement (consistent higher-resolution maps and forecasts)

Objective: improve the quality of CAMS products by scrutinising CAMS emissions (inventories and observations-based) with national and local emissions datasets and expertise.



IMPLEMENTATION PRINCIPLES

- Contract between CAMS and each of the EU and Copernicus Member States for the entire duration of the period (possibly split but just for administrative reasons).
- Contractor will be ministry or agency in charge of the air quality portfolio; can be delegated to another public or private entity and organized with subcontractors as needed.
- Detailed work plan to be defined together with each country in order to adapt to the current situation and to define realistic objectives.
- Consolidation of a two-ways flow both in terms of data and of information.
- Annual event bringing all MS together (can be virtual) in order to assess collective progress and define next high-level targets.
- Subject to funding decision: order of €100k per MS per year and 2 to 3 dedicated staff at ECMWF with scientific & technical expertise on CAMS air quality modelling and emissions to interact with the ~30 contracts.

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