The CO_2 service element

Atmosphere Monitoring

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Atmosphere Monitoring

Outline

- Introduction
- Evolvement of ideas
- Overall concept
- What does already exist
- Working together

Commission ambition

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The 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories acknowledged the complementary capability offered by the monitoring of greenhouse gas emissions through in situ and satellite observations.

"You should explore ways in which we can make the most of our assets to deliver on climate objectives, including the use of Copernicus to monitor CO_2 emissions."

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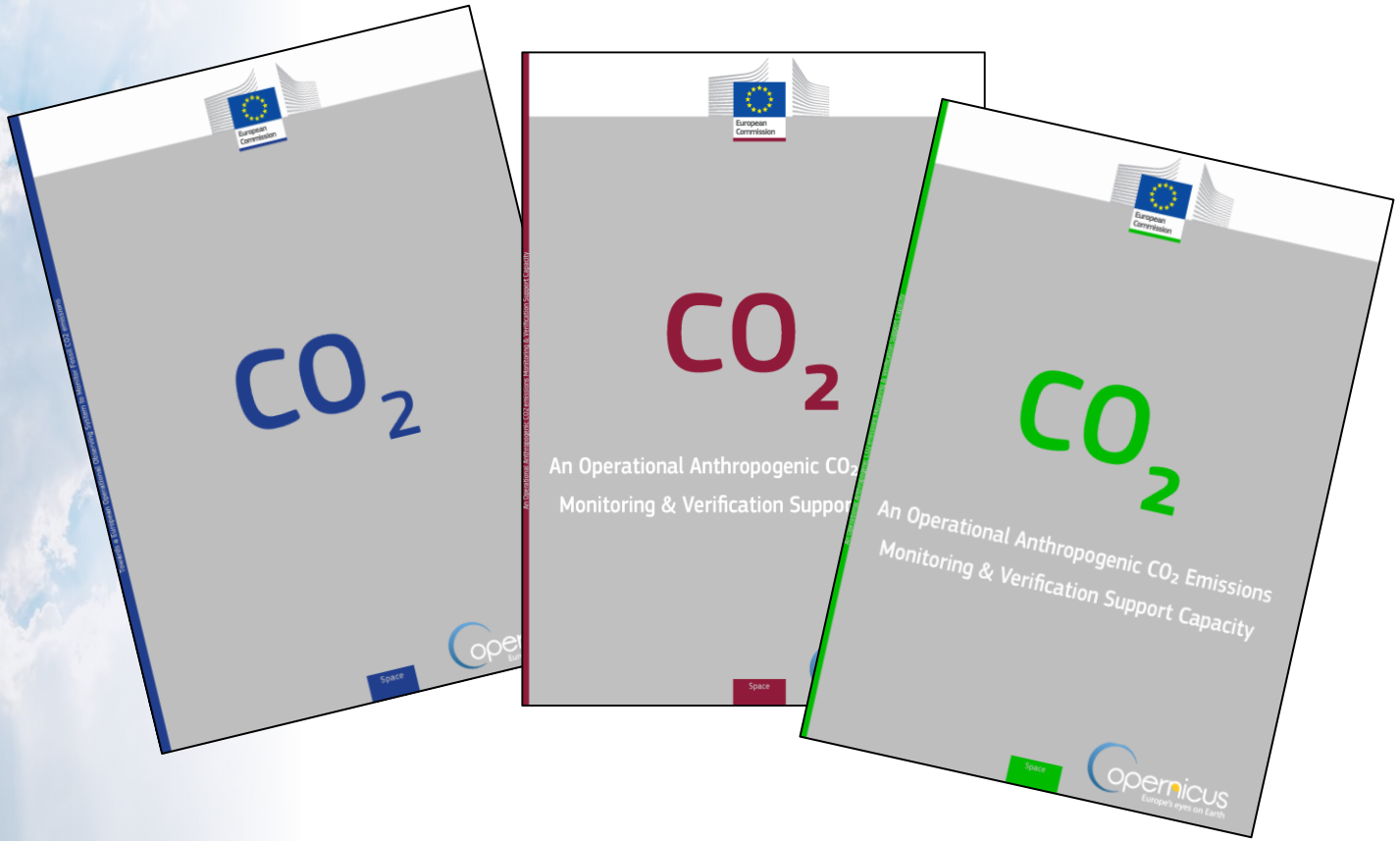
Anthropogenic CO_2 emission monitoring

Recommendations by the European Commission CO_2 Monitoring Task Force for an Anthropogenic CO_2 Emissions Monitoring & Verification Support (MVS) capacity



1. Detection of emitting hot spots such as megacities or power plants,
2. Monitoring the hot spot emissions to assess emission reductions of the activities,
3. Assessing emission changes against local reduction targets to monitor impacts of the NDCs,
4. Assessing the national emissions and changes in 5-year time steps to estimate the global stock take.

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Proposed Copernicus MVS capacity

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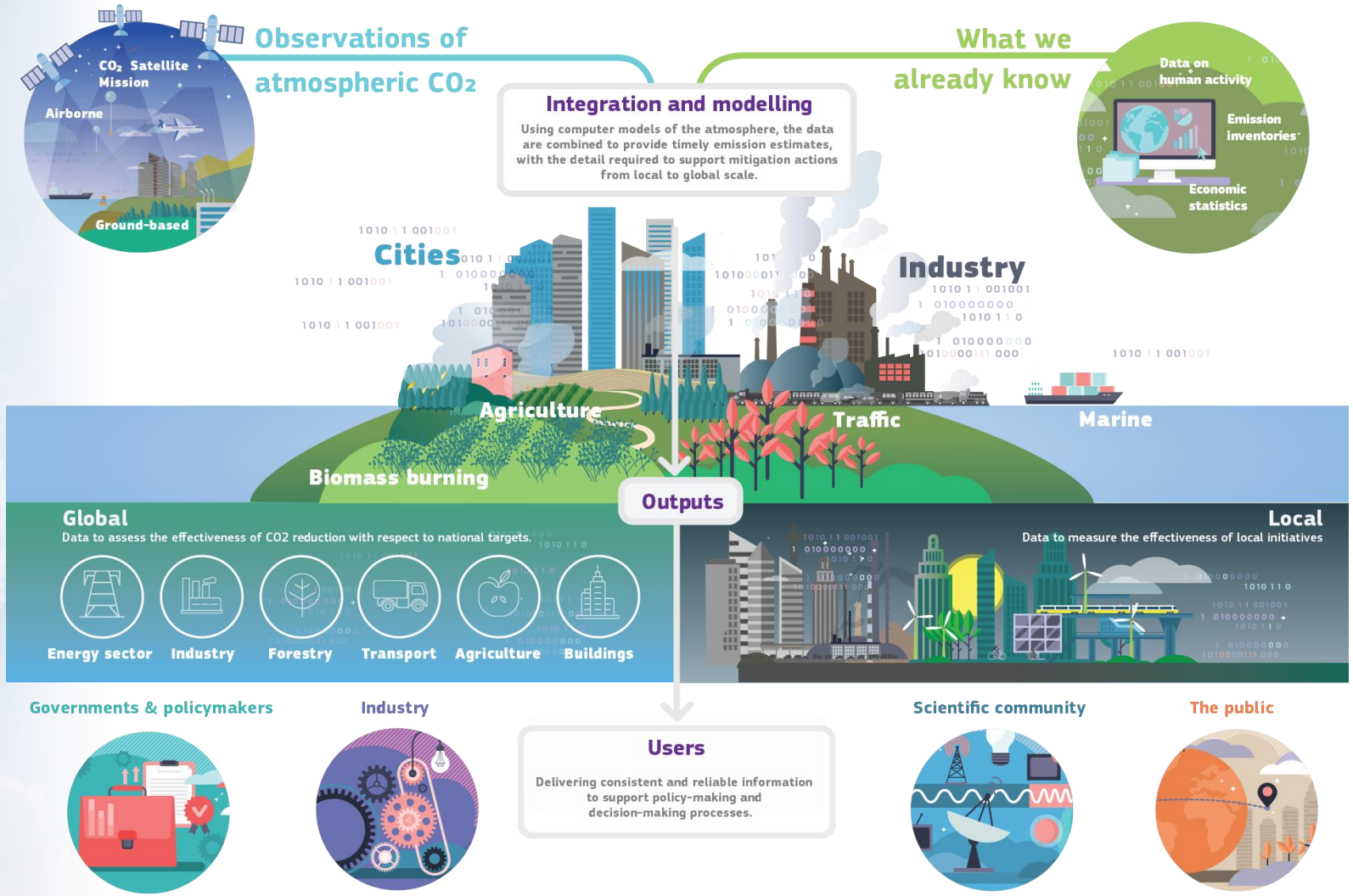

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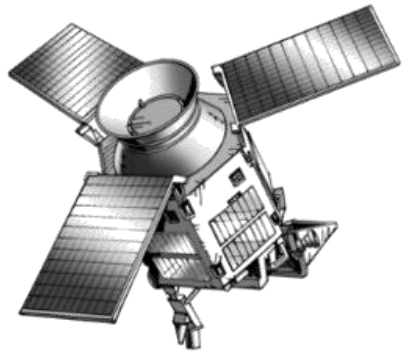
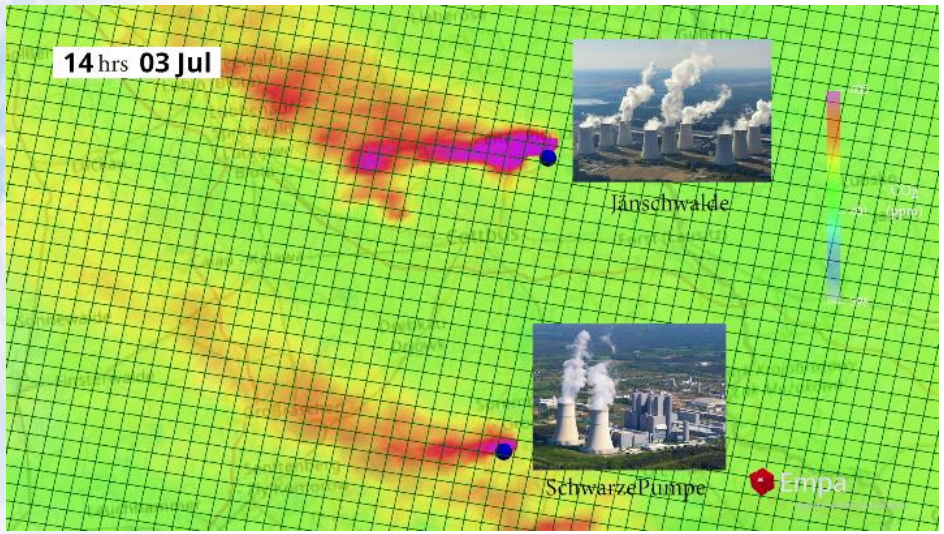
CO_2 Monitoring Mission

Mission requirements for XCO_2 & NO_2:

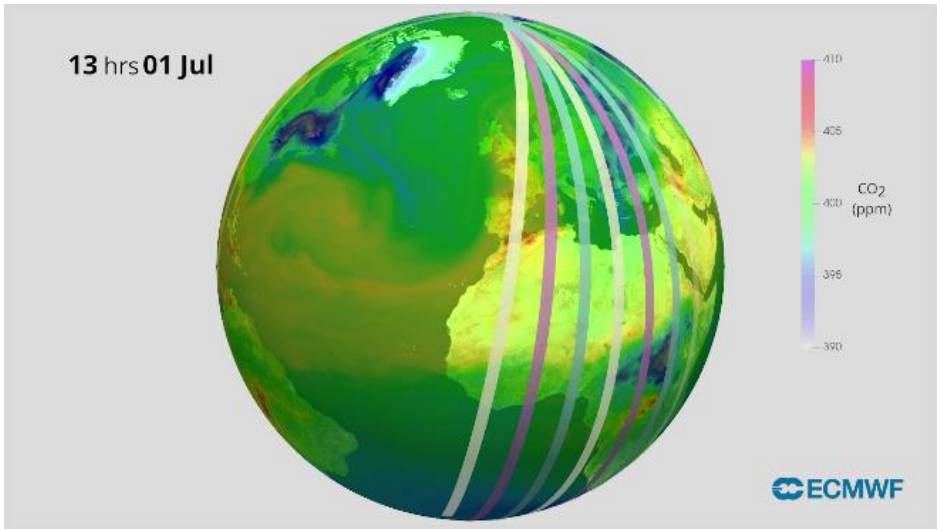
- Spatial resolution **4 km²**
- XCO_2 precision: **0.7 ppm (veg. scene, 50° SZA)**
- NO_2 precision: **$1.5 \cdot 10^{15}$ molec/cm²**
- Imaging swath **> 250 km**
- Viewing modes: **nadir (land) & sun-glint (water)**



Ceci n'est pas une CO2M



CO_2 measured at 2x2 km² grid (credit: EMPA)



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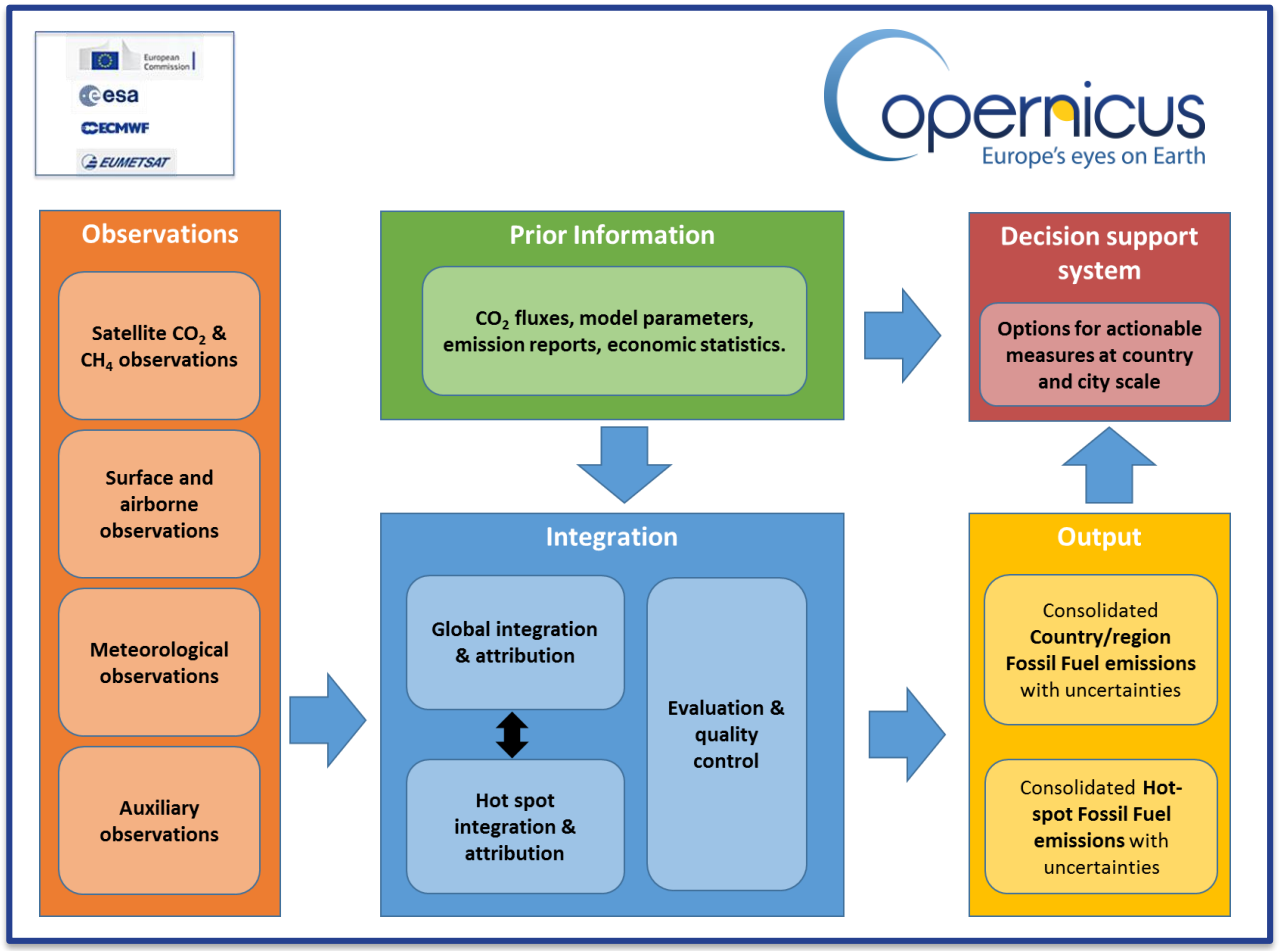
Developing a new CAMS service element

Atmosphere Monitoring

Atmosphere Monitoring Service
atmosphere.copernicus.eu

Climate Change Service
climate.copernicus.eu



Synergies with existing Copernicus services shall be exploited.

Especially the CAMS existing infrastructure and the plans for estimating emissions of CO and NO_2 fits very well with the planned CO_2 MVS.

Also linking with other services and national activities.

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Roadmap

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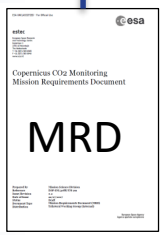
CO_2 Monitoring Task Force

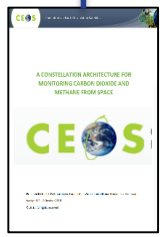
2015 | 2018 | 2020 | 2022 | 2024 | 2026 | 2028

1st global stocktake

Launch of the CO_2 Sentinel constellation

2nd global stocktake





Prototyping activities including relevant CO_2 satellite missions from international space agencies

Copernicus service in full operations using CO_2 Sentinels and international virtual constellation

R&D Support Actions

CO_2 Human Emissions

VERIFY

CoCO2 Prototype system for a Copernicus CO_2 service

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Current Research & Development

CO_2 Human Emissions

Period: 2017 – 2020
Coordinator: ECMWF (22 partners)
Aim: Explore the development of a European system to monitor human activity related carbon dioxide (CO_2) emissions across the world.

VERIFY

Period: 2018 – 2021
Coordinator: LSCE (40 partners)
Aim: Develop a system to estimate greenhouse gas emissions in Europe to support countries' emission reporting to the UNFCCC Secretariat. The emissions are estimated based on land, ocean and atmospheric observations and cover CO_2, CH_4 and N_2O.

CoCO2
Prototype system for a Copernicus CO_2 service

Period: 2021 – 2023
Coordinator: ECMWF (25 partners)
Aim: Further develop and integrate all components of the recommended MVS capacity and co-design an information product portfolio together with the European Commission and EU member states.

Overall concept

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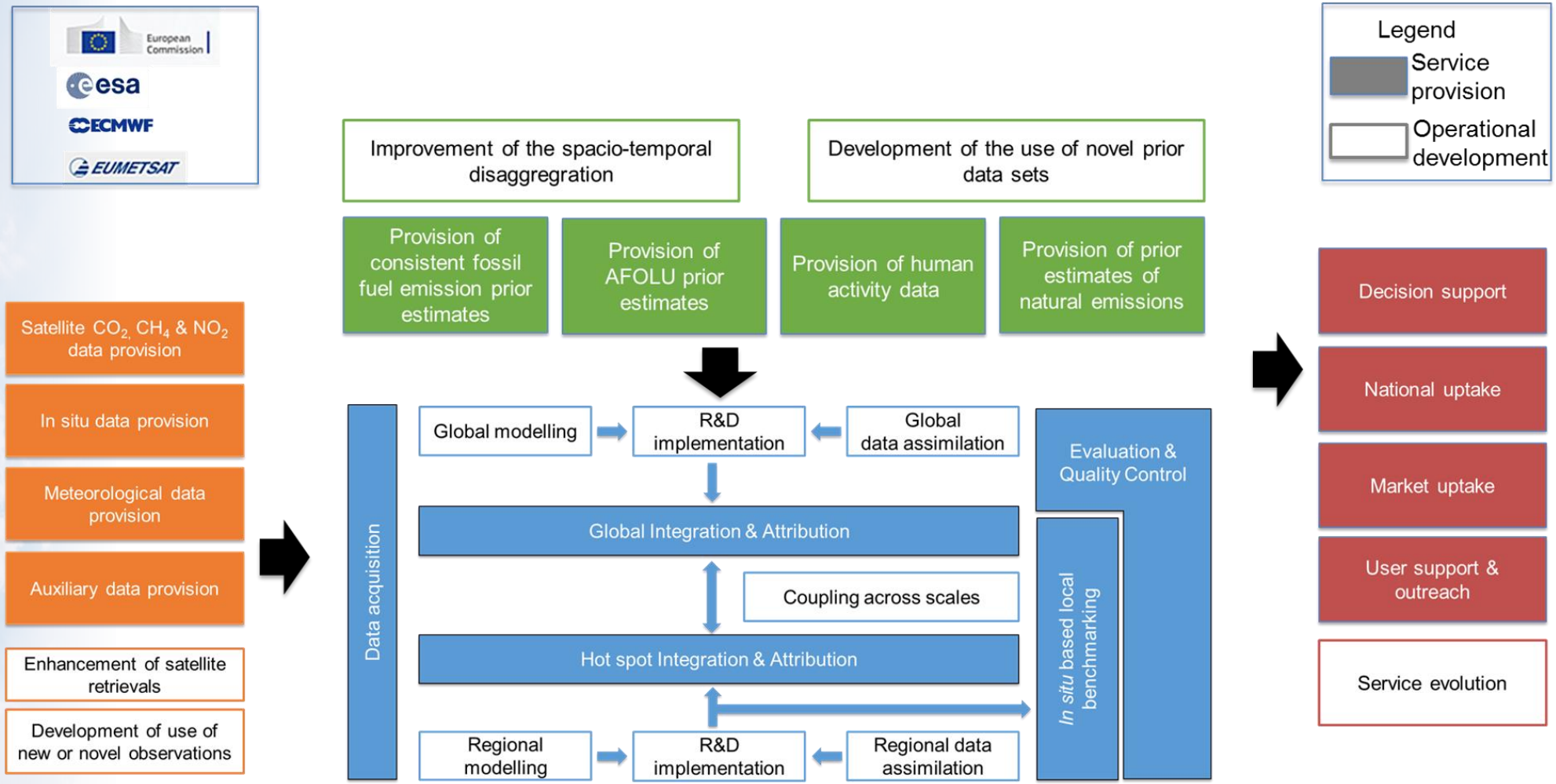

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Observations - satellite

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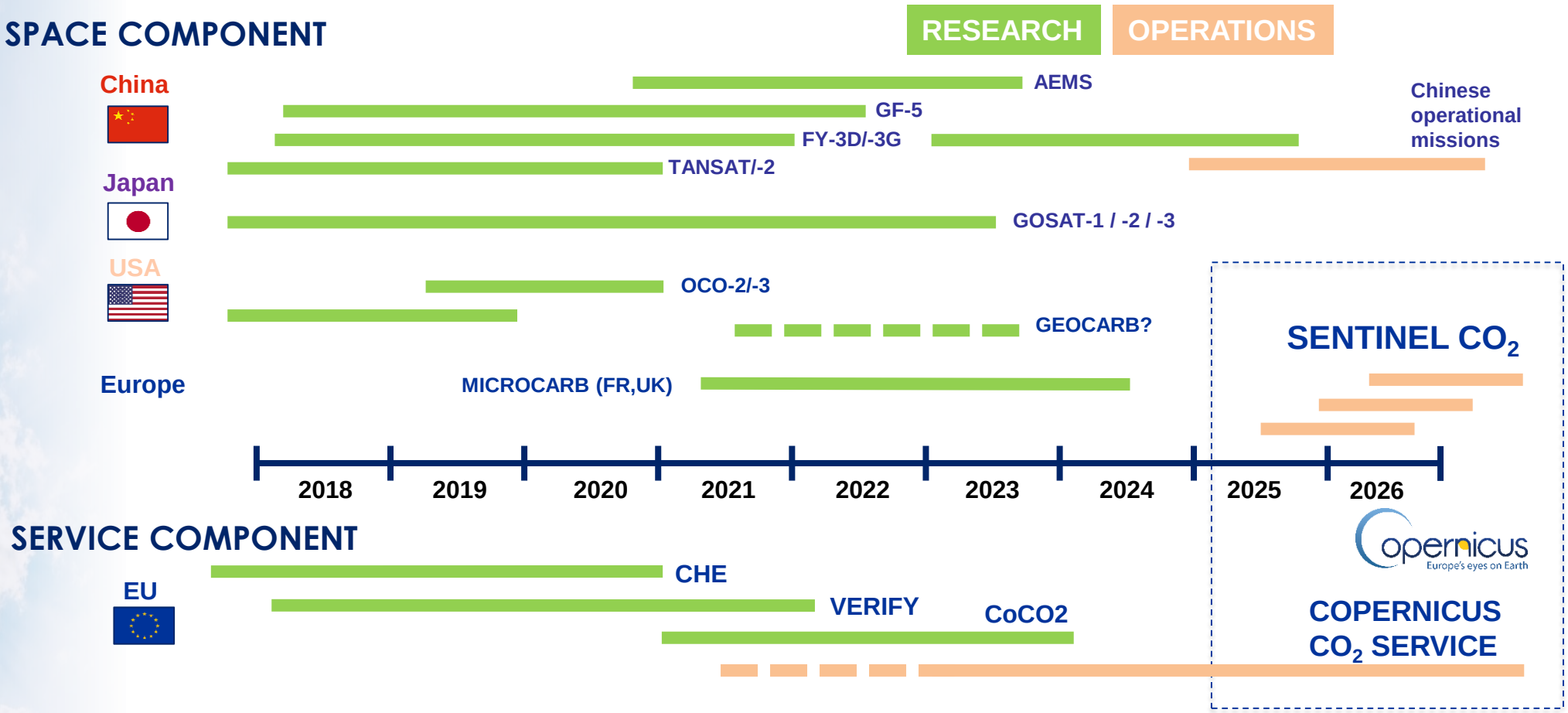

Under CEOS coordination a global observing system is being realized. The Sentinel CO_2 mission will be the major game changer.

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Observations - satellite

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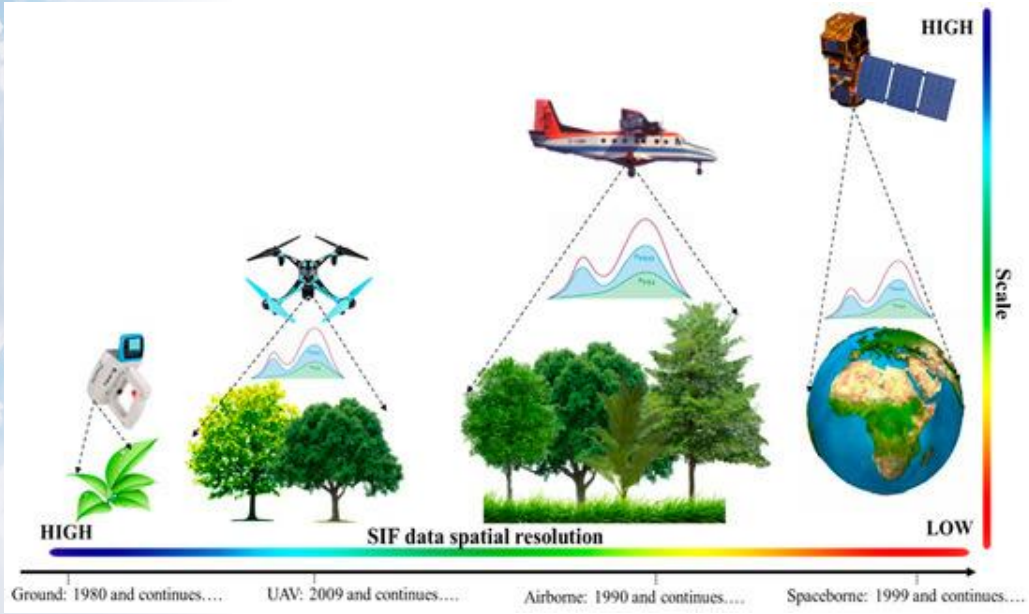
Meteorological data provision

Auxiliary data provision

Both meteorological satellite data and satellite data constraining other parts of the Earth system (e.g., land biosphere) are important element of the CO2MVS.



From: Bandopadhyay et al., 2020.

ECMWF Integrated Forecasting System (IFS) provides a perfect framework for including these data streams in a consistent way.

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Observations – in situ

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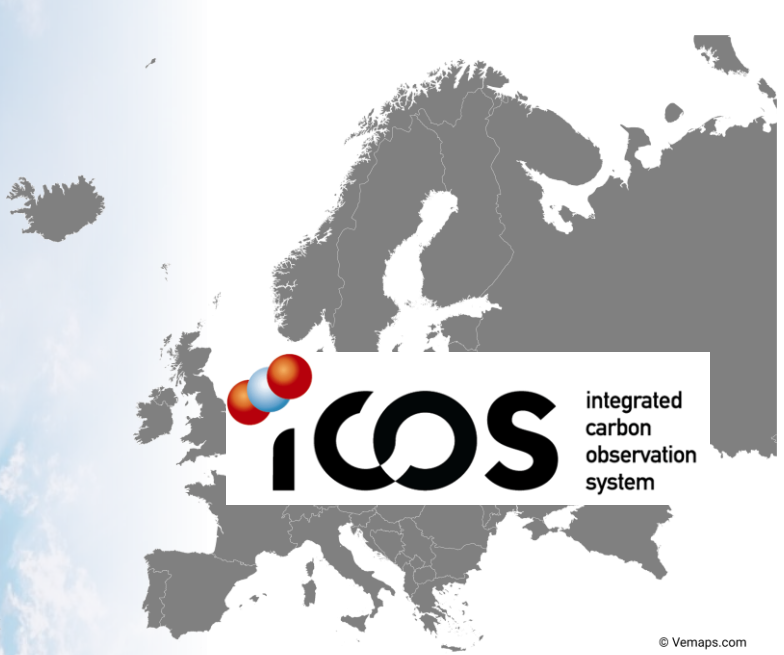
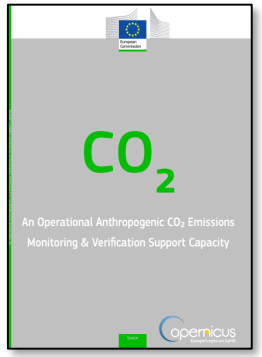


© Vemaps.com

The in situ observation component (atmosphere, land and ocean) is critical for the success of the CO_2 service. Close collaboration with international frameworks to exploit ways to strengthen this part of the service.

An operational service has specific requirements in terms of timeliness and automatic quality control. This was documented by CO_2 Task Force Green Report



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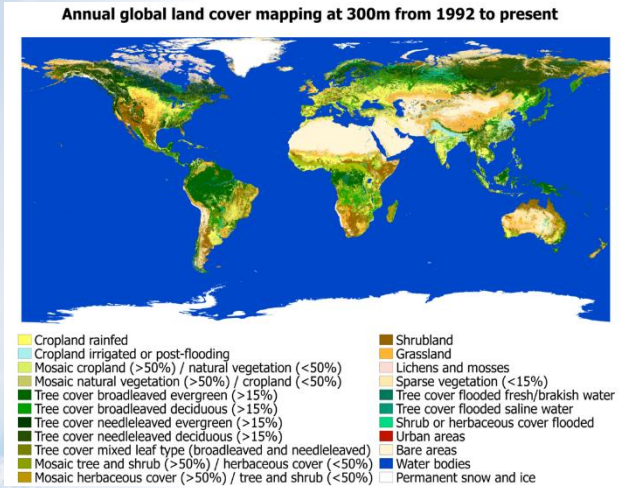
Prior information on emissions

Atmosphere Monitor

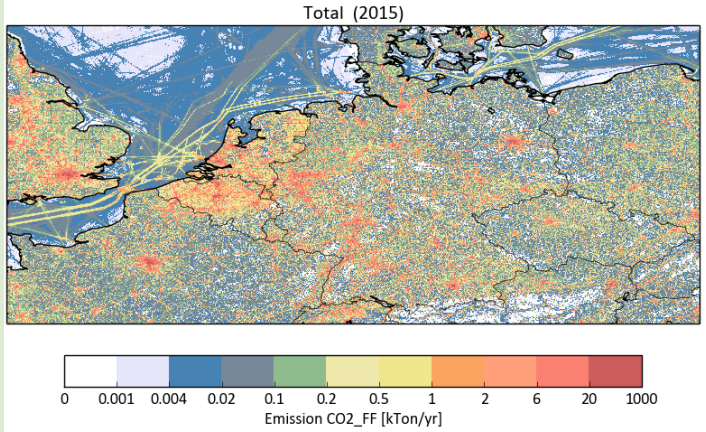
In Near Real Time (NRT)



C3S Annual 300m land cover map (1992-present)

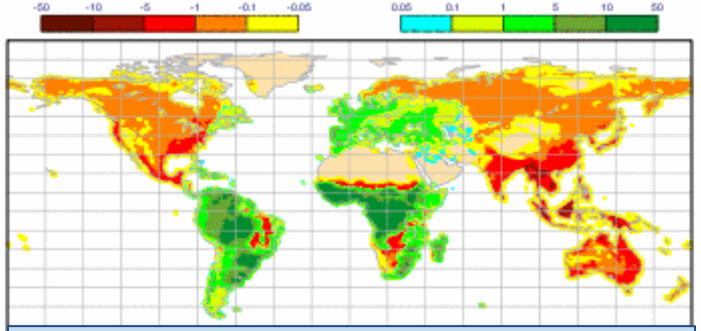
CGLS 100m Land Cover maps for 2015

>1 year behind real time



CHE - individual maps by sector at 1×1 km^2 resolution (TNO)

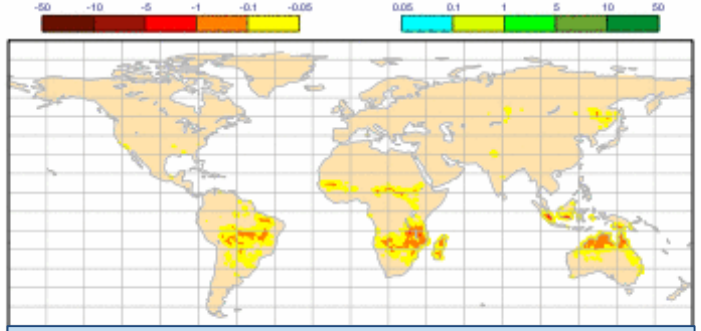
Net Ecosystem Exchange



From model (CTESSEL) forecast:
Temporal resolution: ~15 min

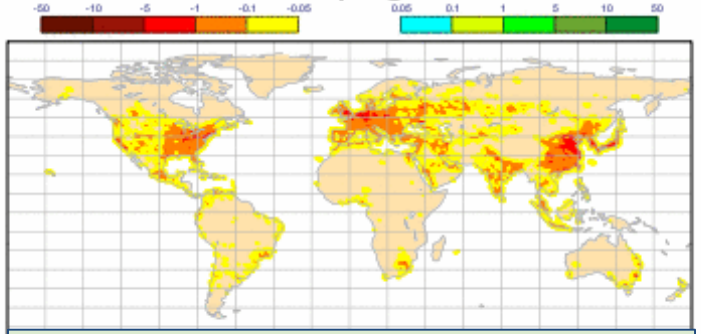
Fires

2012-10-28 12:00:00



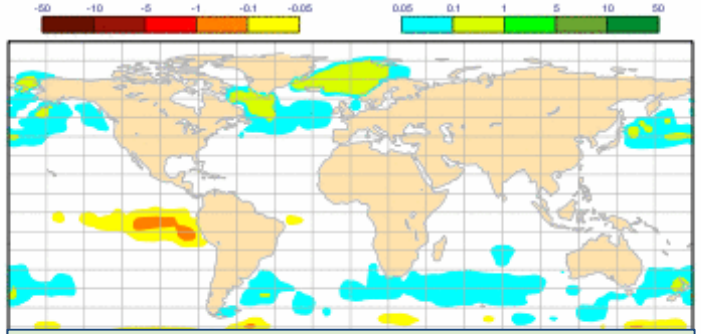
From CAMS GFAS :
Temporal resolution: hourly

Anthropogenic



From emission inventory (EDGAR):
Temporal resolution: monthly

Ocean



From SOCAT Carboscope, CMEMS
Temporal resolution: daily, monthly

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Prior information on emissions

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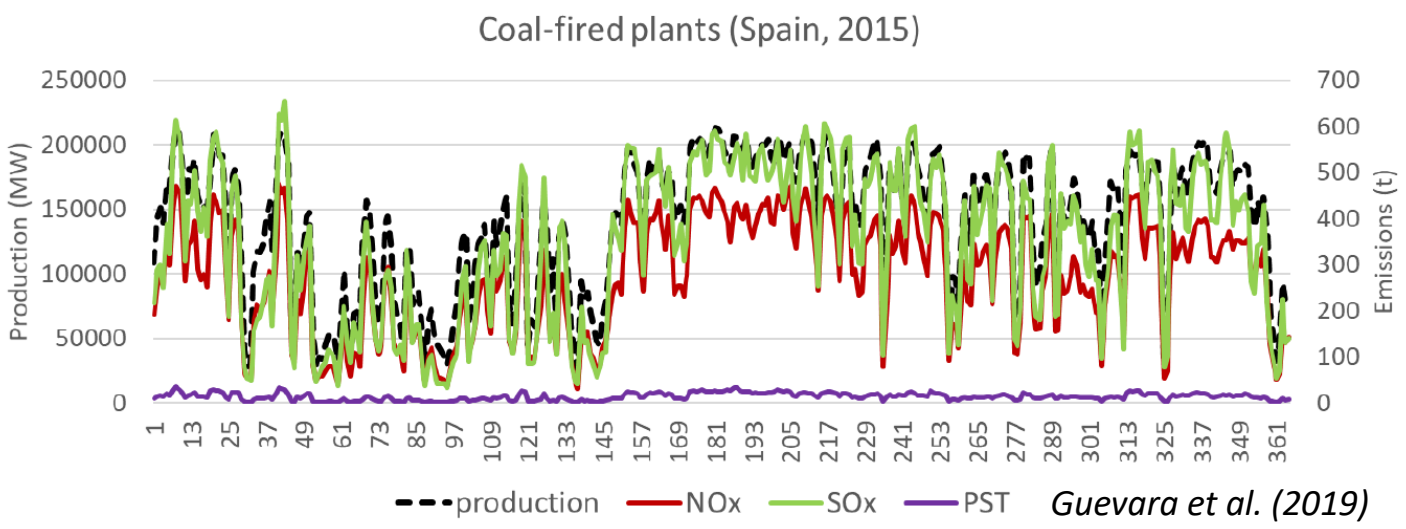
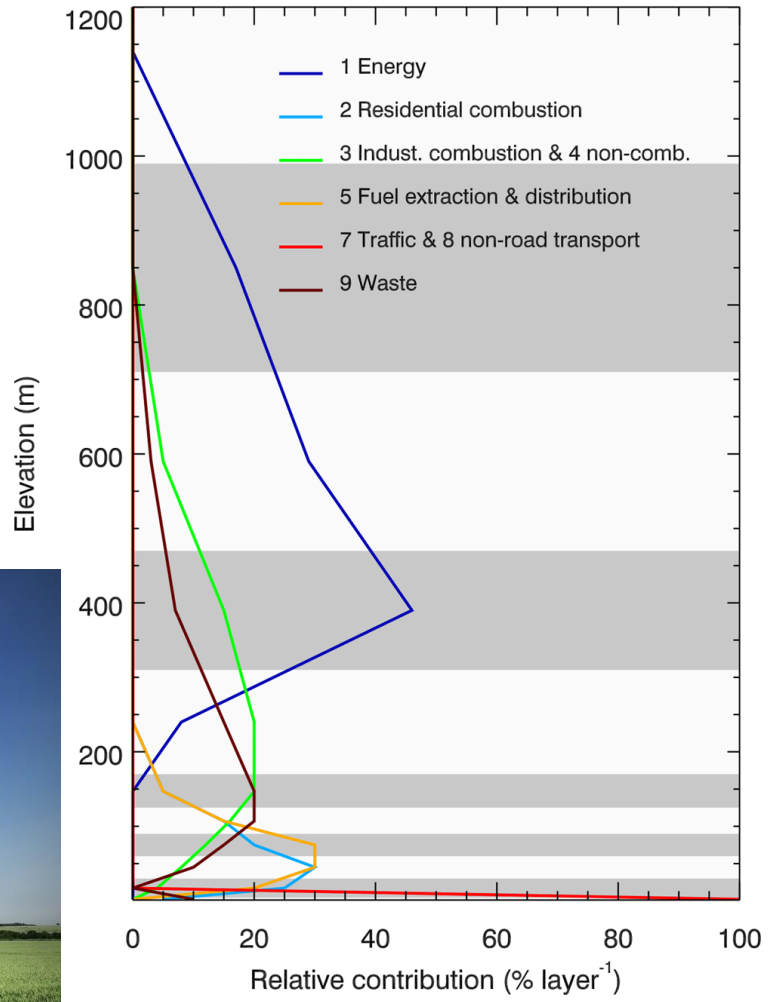
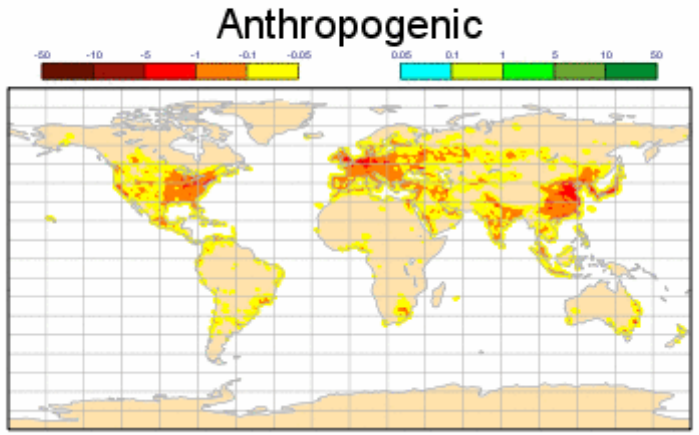
TEMPORAL/VERTICAL PROFILE OF EMISSIONS



Guevara et al. (2019)

Brunner et al. 2019





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Global system

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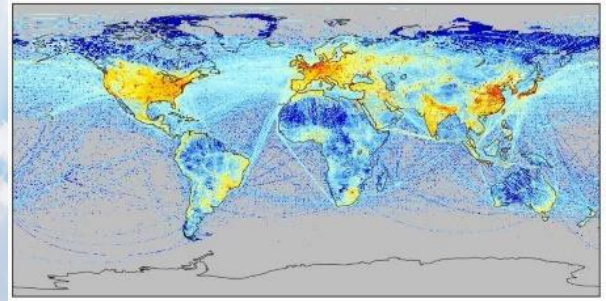
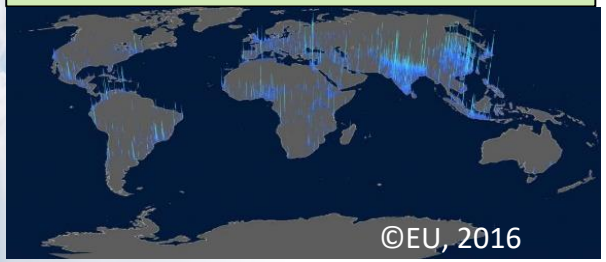
INPUT DATASETS

EMISSION INVENTORIES WITH TEMPORAL/VERTICAL PROFILES & UNCERTAINTIES (JRC EDGAR,TNO/BSC, CAMS81)

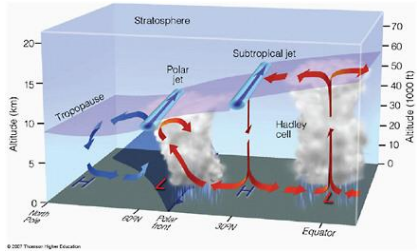


VEGETATION & URBAN MAPS (ESA-CCI, JRC GHSL) OCEAN FLUXES (CMEMS)

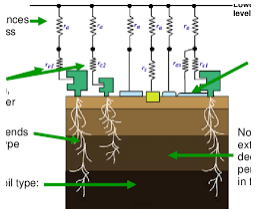


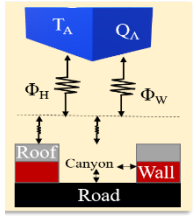
IFS FORECAST MODEL & DATA ASSIMILATION

IFS ATMOSPHERIC TRANSPORT

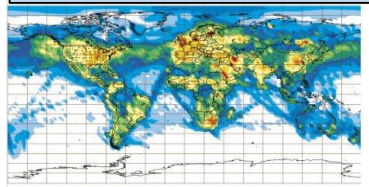


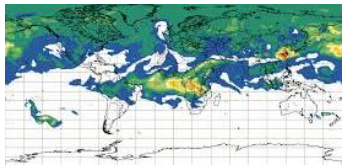
URBAN & VEGETATION MODEL, LAND SURFACE DATA ASSIMILATION



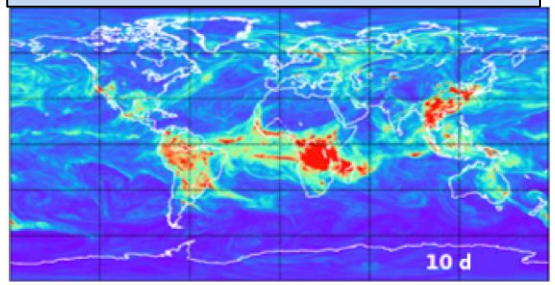


CAMS REACTIVE SPECIES (NOx, CO, CH4)

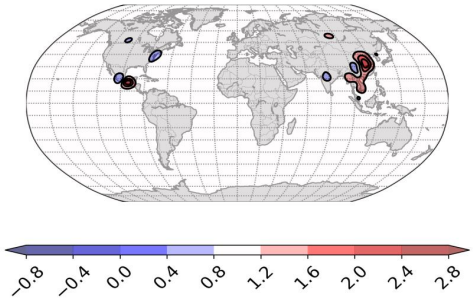




ENSEMBLE APPROACH (uncertainty propagation)



4DVAR ATMOSPHERIC ANALYSIS & INVERSION CAPABILITY



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Local systems

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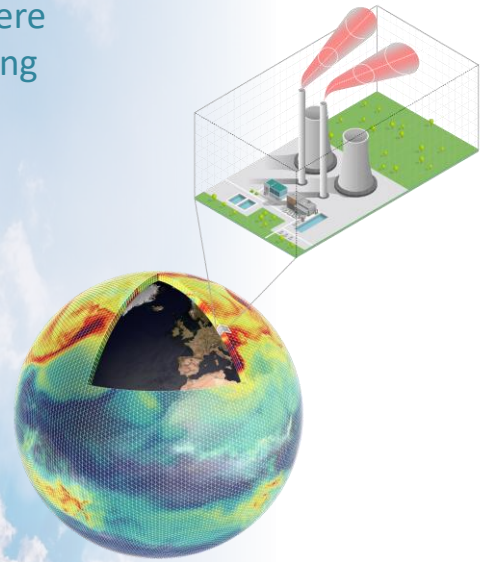
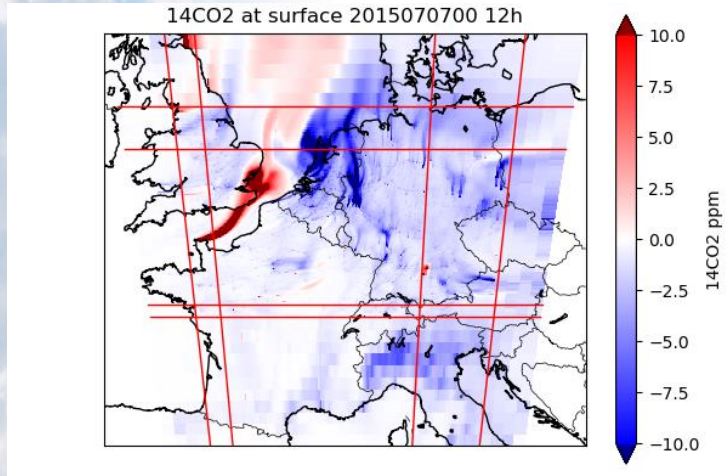
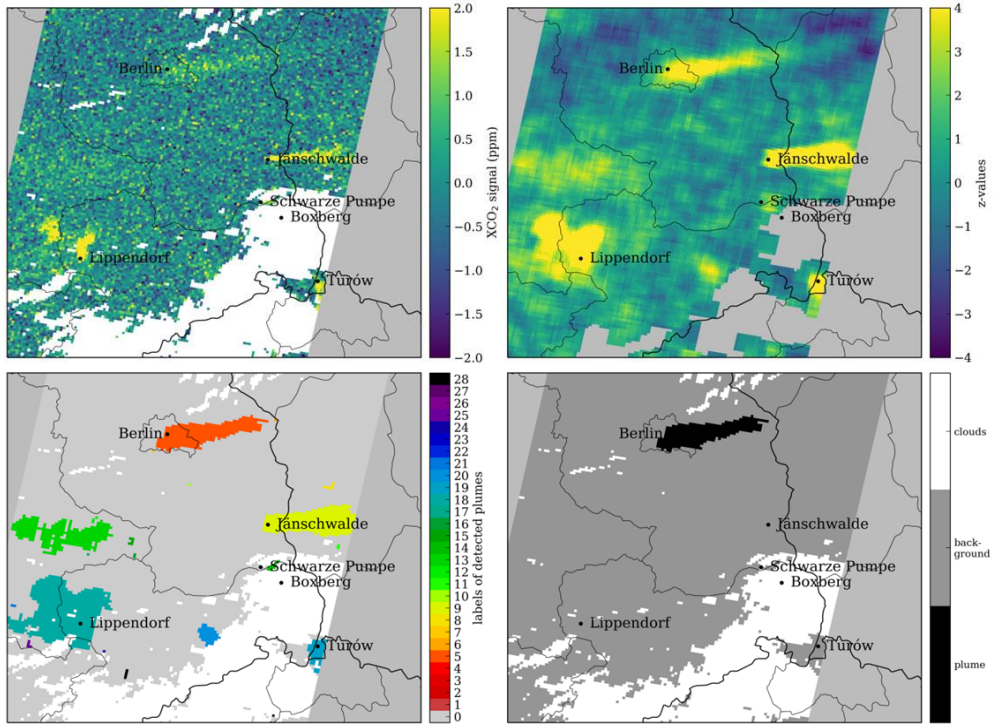


- High resolution model (~1km to 100m) over emission hotspot
- Potential for analytical solution of inversion
- Additional use of local observations (in situ & aircraft, isotopes)
- High resolution local emission inventories, where available



CHE - surface $^{14}CO_2$ from CHIMERE simulations (LSCE)



SMARTCARB – identification of individual plumes (EMPA)

Examples:
Paris (CO2-Megaparis),
Indianapolis (INFLUX),
LA (Megacities)
London (Boon),
Berlin (Pillai), etc.

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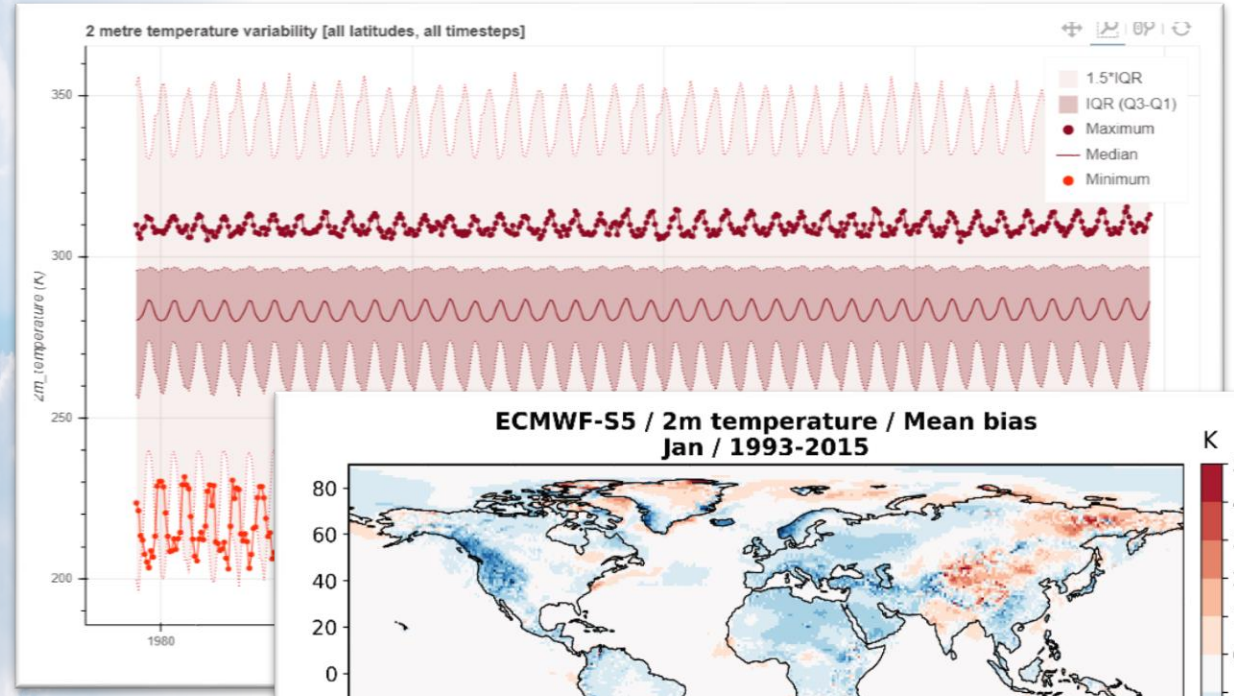
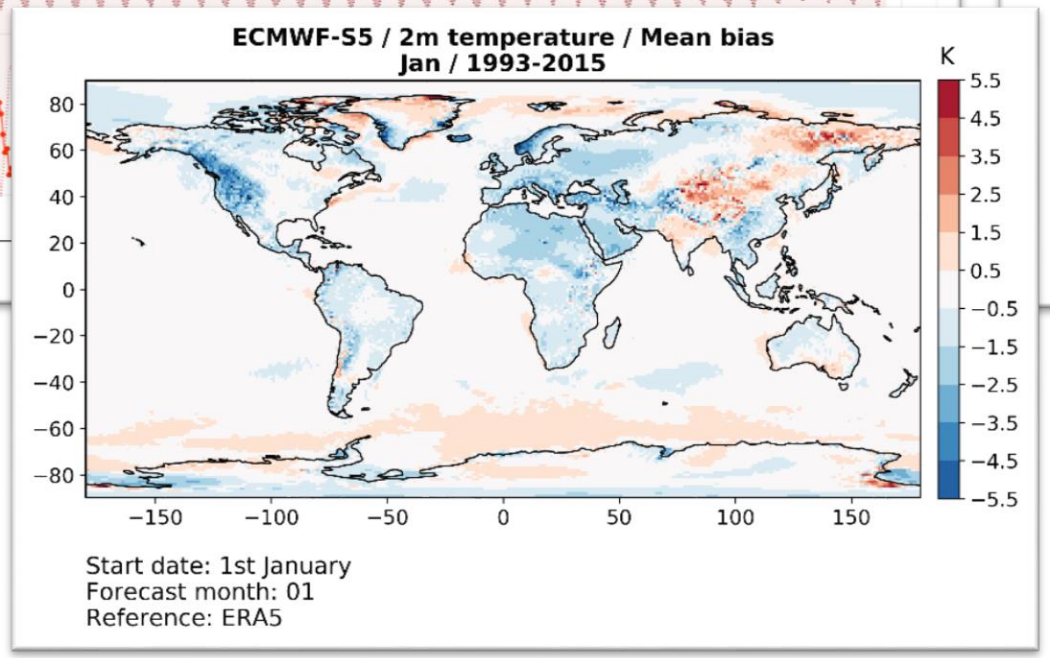
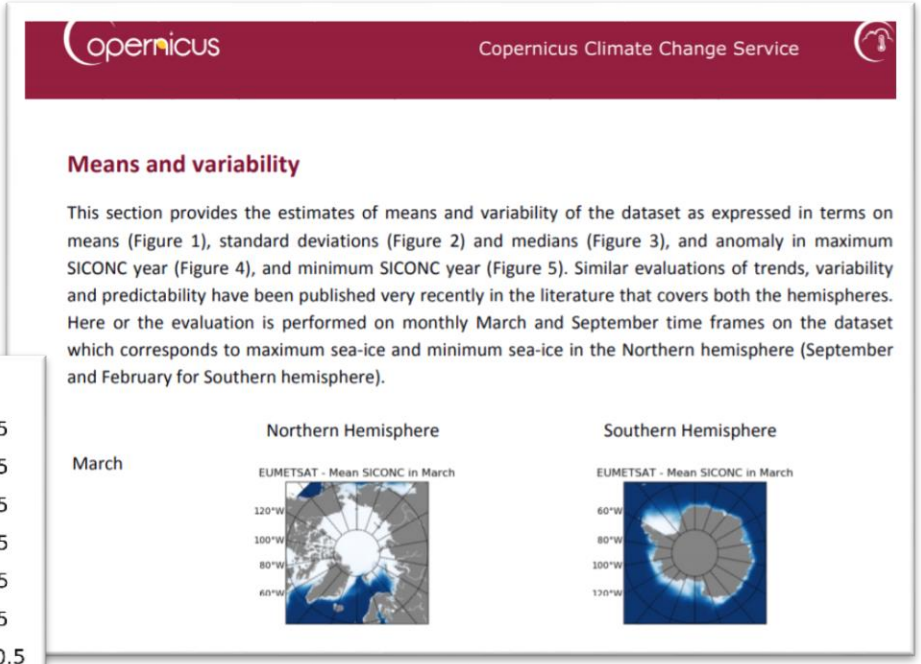
Evaluation and Quality Control (EQC)

Following current practice and further evolution in C3S and CAMS

- Documentation, Data Checker, Scientific Assessments, and much more…







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Evaluation & Quality Control (EQC)

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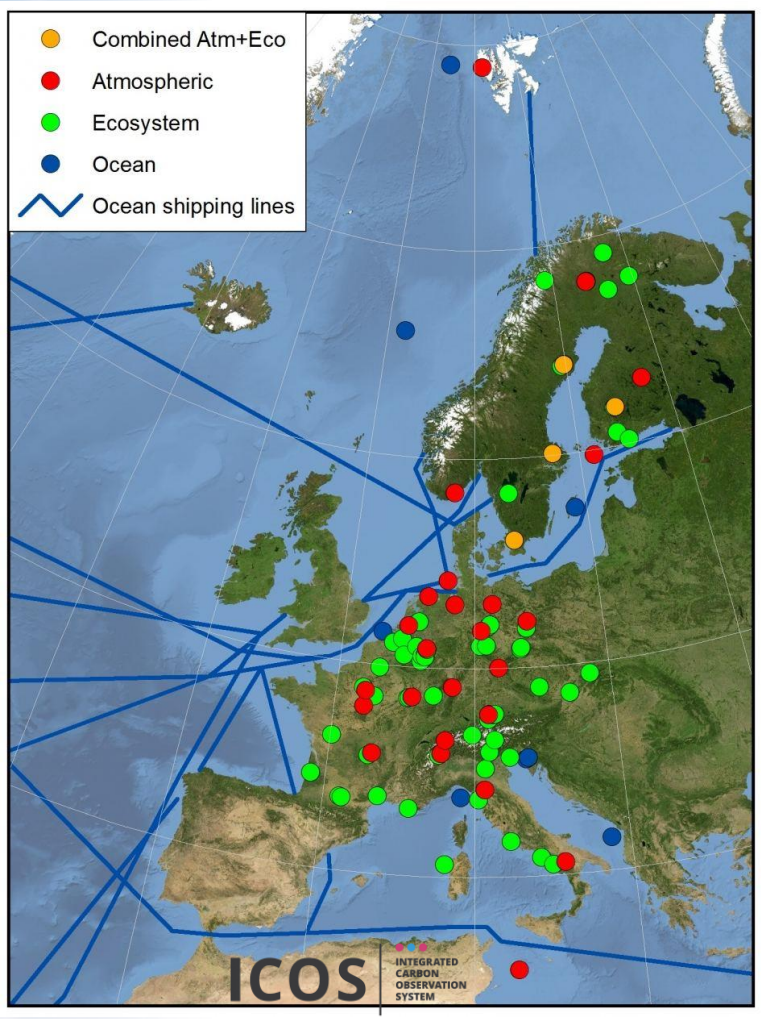
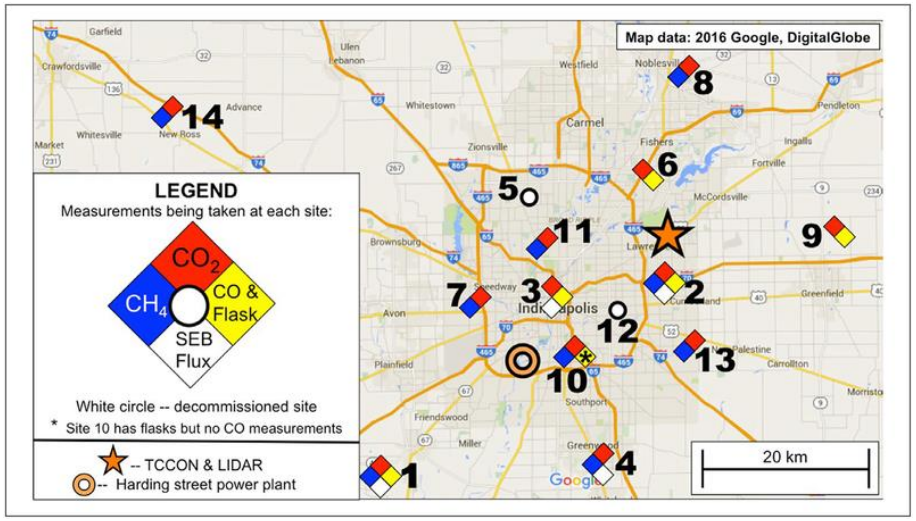
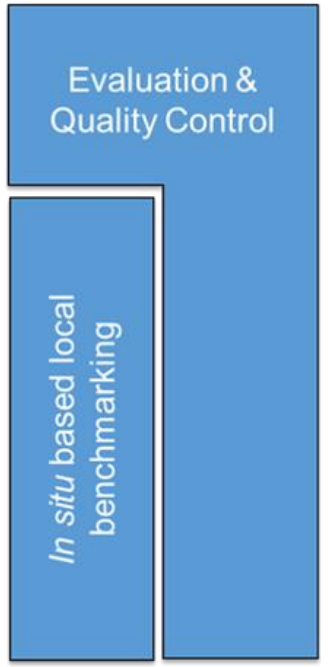


A planned element of the EQC is to establish local or regional in-situ-based inversion systems in Europe to benchmark the satellite-based estimates.

Collaboration with ICOS and national networks to establish/expand the in-situ infrastructure in key areas.



Davis et al., 2017



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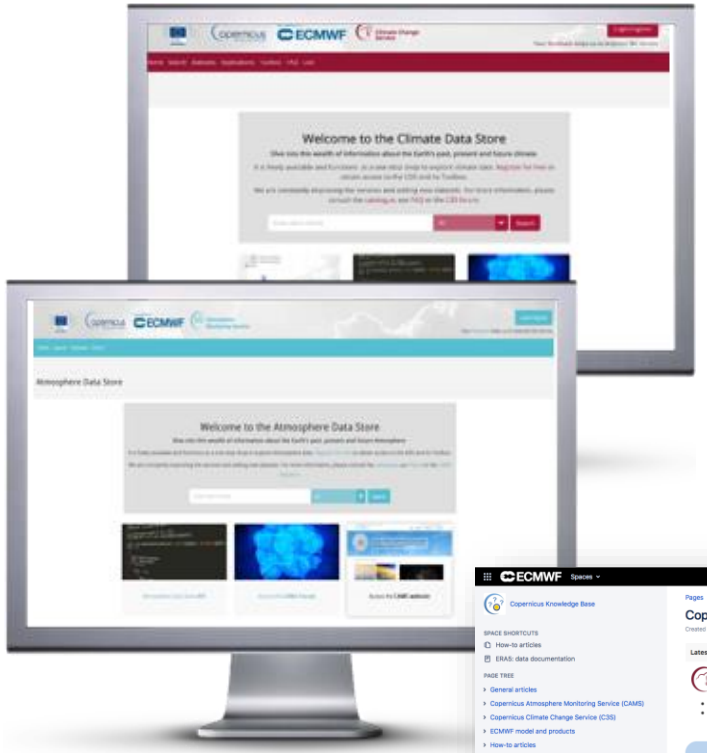
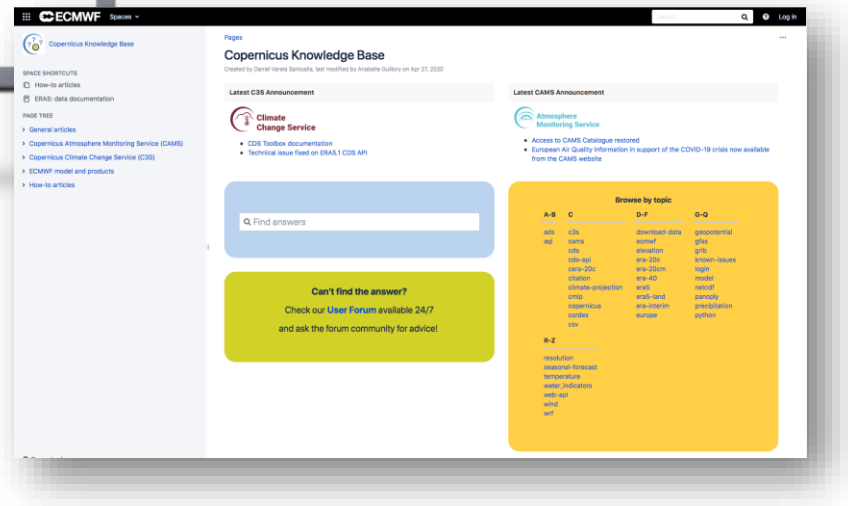
Data interface

- **Common Technical Infrastructure**
  - Cloud based data stores
  - Backend Computing and DHS facilities
  - ECMWF operational NWP know-how
  - ECMWF contribution to WEkEO
- **Service Desk**
  - Integrated in ECMWF User Services
  - Unified Copernicus Knowledge base
  - Common approach to the user journey
  - Will extend to user learning platforms



On-Premises Private Cloud
72+ nodes, 4000+ CPUs, 13TB RAM
3.9 PB usable (of which 380TB SSD)

Monitoring, Capacity building, reporting, backups, ...



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User interface – co-designed with users

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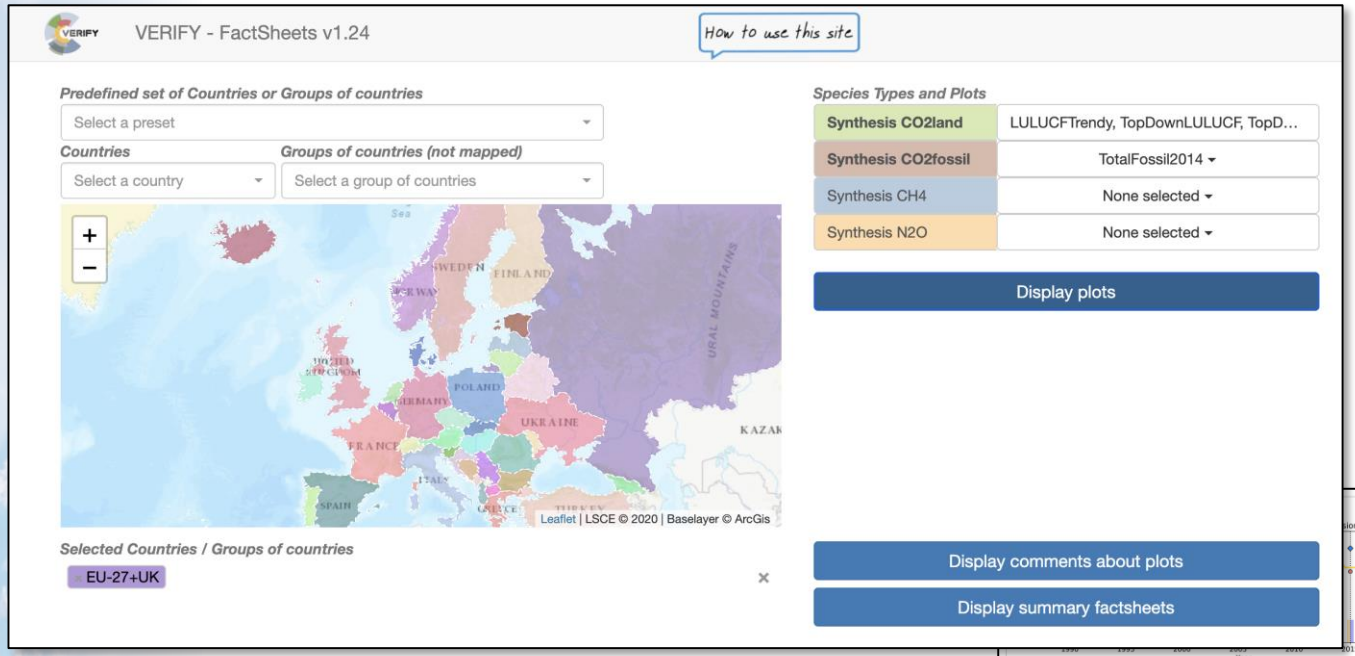

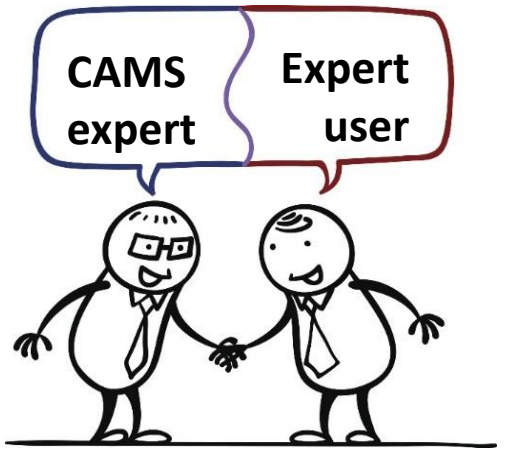

Policy relevant products/interfaces are being developed together with key user communities.
This ensures the services will be fit-for-purpose.

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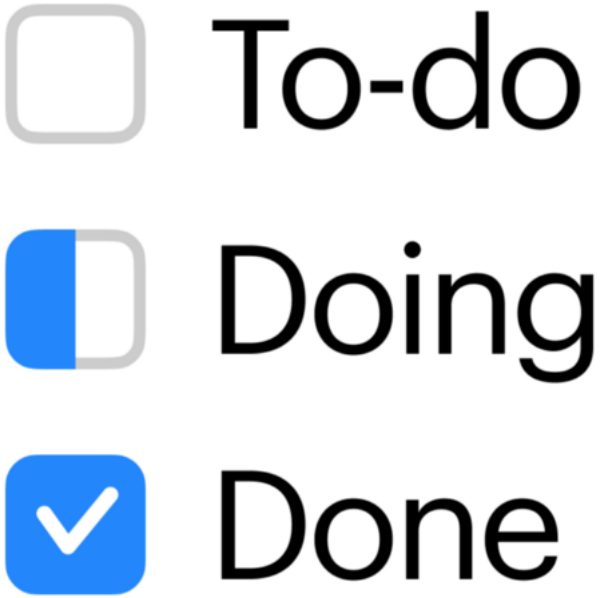
What is already in place



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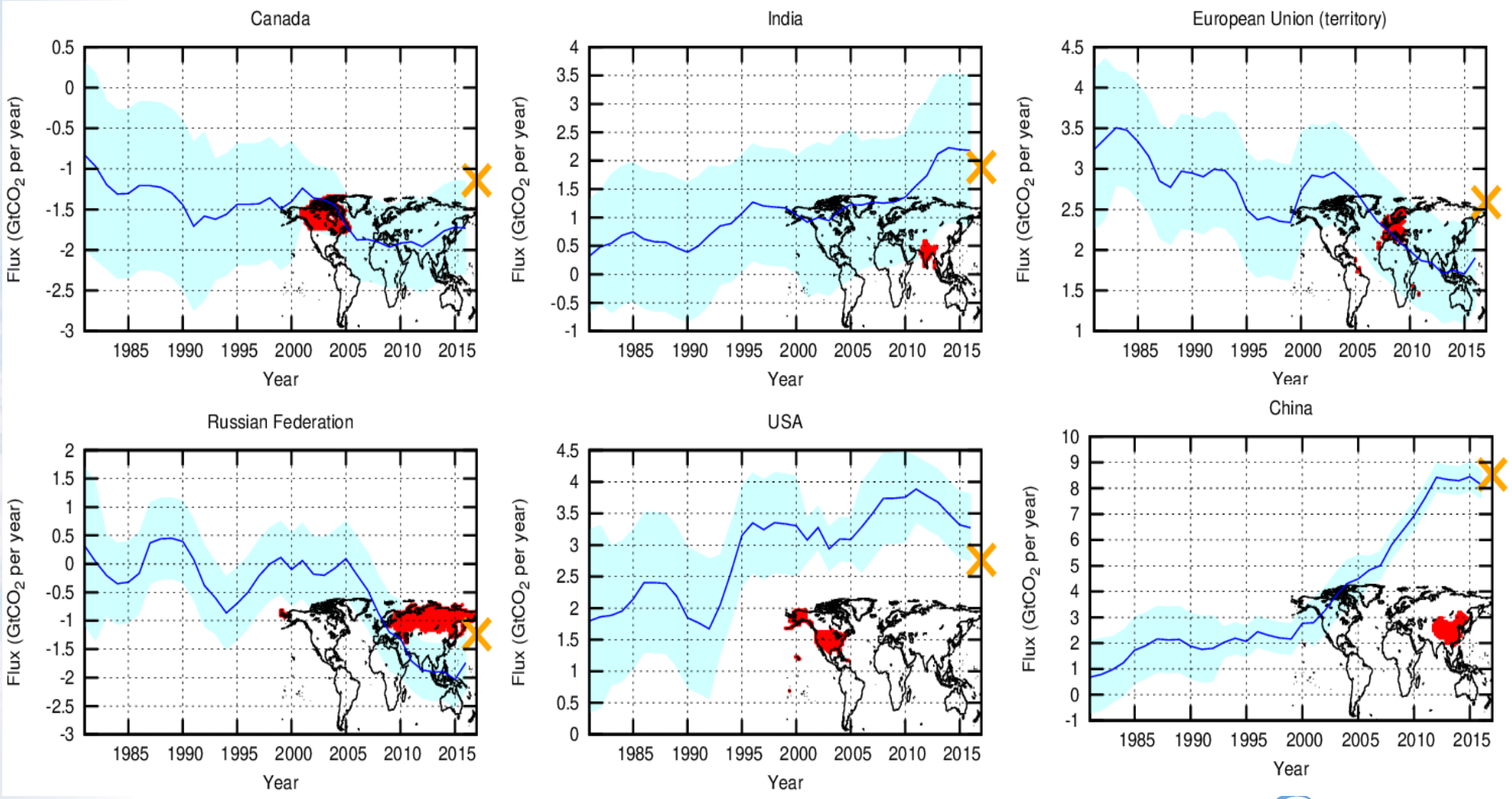
CAMS net fluxes of greenhouse gases

CAMS atmospheric CO_2 inversion products (surface in situ and OCO-2)



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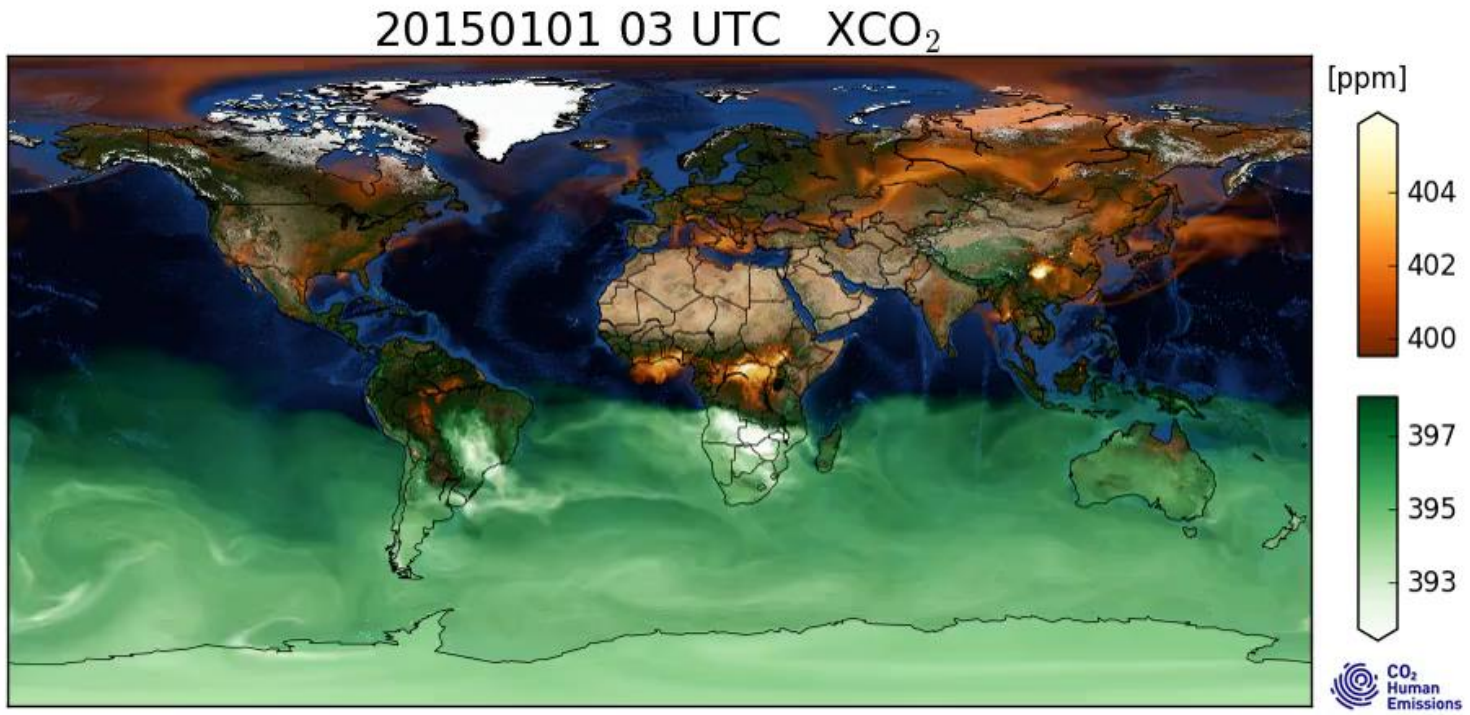
Global forecasts of atmospheric values



User requirements from:

- EUMETSAT (S-4/-5)
- MicroCarb
- flight campaigns
- boundary conditions

CO_2, CH_4, and linear CO at Tco1279 (~9km) L137 in ECMWF IFS

- CTESSEL NEE (+bias correction)
- EDGAR+CAMS81 anthropogenic emissions
- SOCAT Carbo-Scope, CMEMS ocean fluxes
- GFAS biomass burning
- IFS transport (Bermejo & Conde mass fixer)

Developments are aligned with ECMWF's Earth system modelling strategy (e.g., strengthen IFS land surface modelling).

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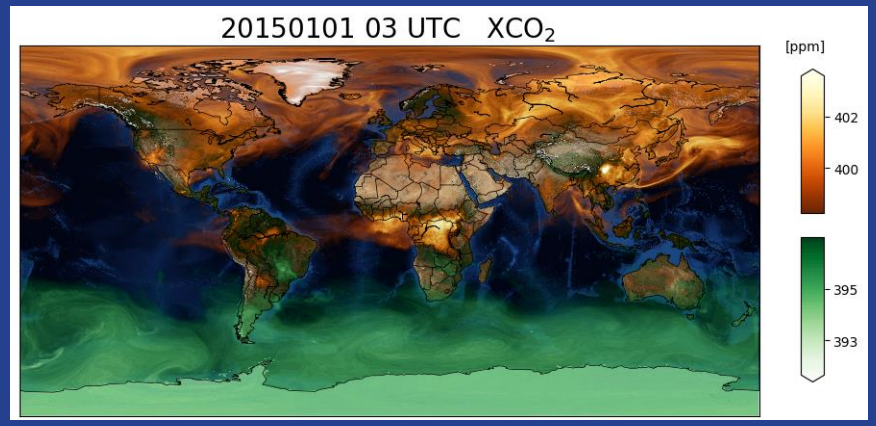
Extending IFS 4D-Var capabilities

Atmospheric GHG analysis in IFS

GOSAT XCO2

IASI CO_2

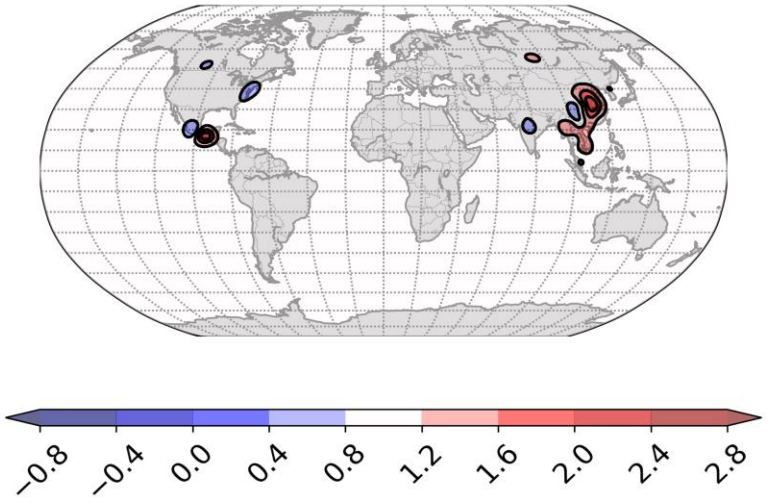
OCO-2 XCO2



ATMOSPHERIC ANALYSIS & RE-ANALYSIS (3D FIELDS OF CO_2, CH_4, etc)

Atmospheric inversion capability in IFS

Hybrid data assimilation system: optimal combination of 4D-Var adjoint-based and ensemble-based error covariance propagation (Bousserez et al., Tech Memo)



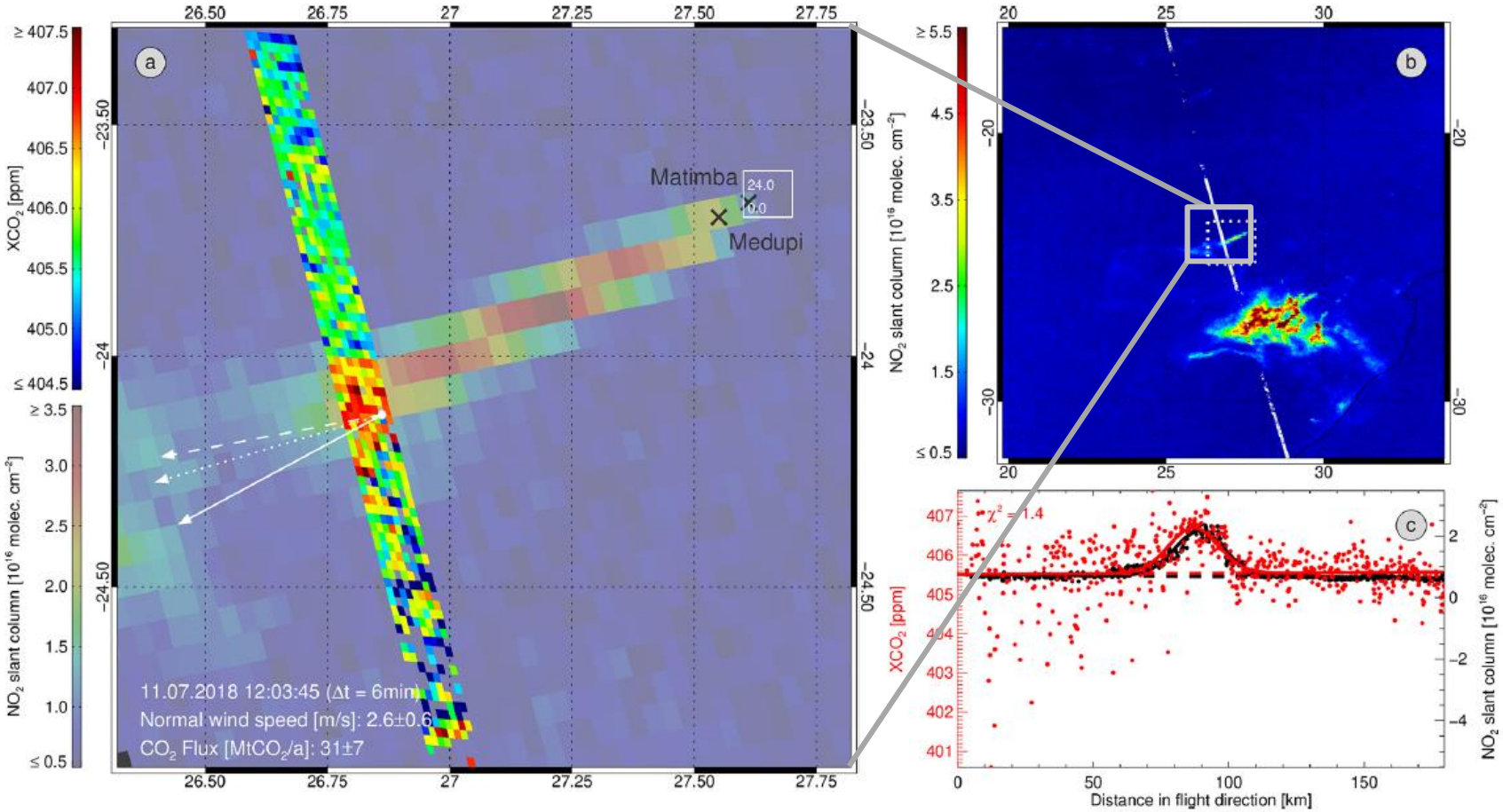
ANTHROPOGENIC EMISSIONS

Plume inversions

ESTIMATION OF CO_2 EMISSION HOTSPOTS (POWER PLANTS, CITIES) USING SATELLITE DATA:

- **NO_2 plume detection and cross-section CO_2 flux estimation**
  Reuter et al (2019)
- **Gaussian plume model**
  Bo Zheng et al. (VERIFY), Nassar et al. (2017)
- **High resolution Eulerian transport model**
  Zheng et al. (2019), Ye et al. (2020)
- **Lagrangian transport model**
  Wu et al. (2020)

Example: Power plant (South Africa)



Reuter et al. (2019)

Member state interactions

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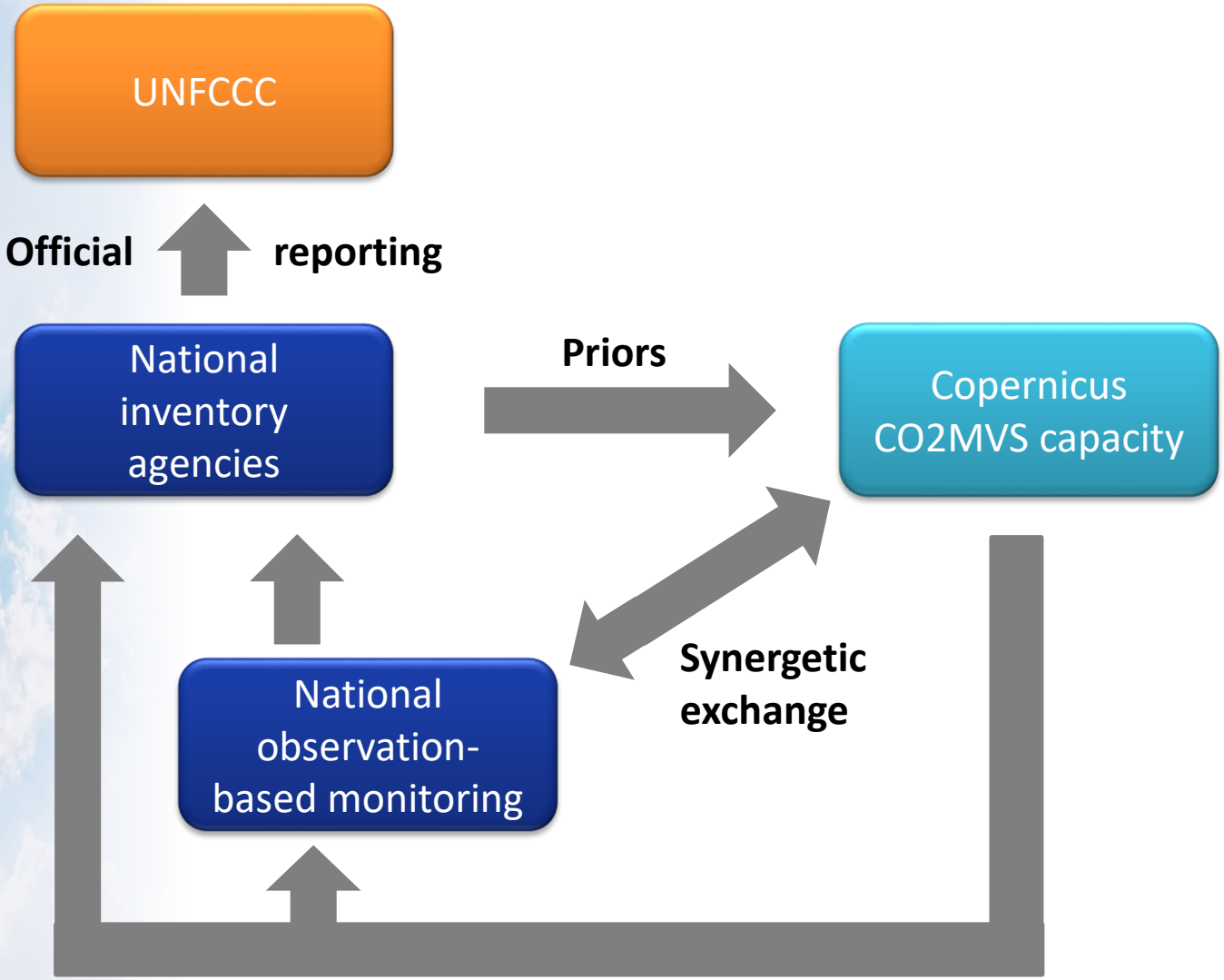

The 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories acknowledged the complementary capability offered by the monitoring of greenhouse gas emissions through in situ and satellite observations.

The Copernicus anthropogenic CO_2 emissions verification & support capacity aims to work with countries to help them strengthen their national activities and to fill gaps where needed.

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Co-design of portfolio

CoCO2 work package on user requirements

- Blueprint for a decision support system
- Engagement with user communities (policy, industry and others)
- Priority needs for national inventory-based reporting

CoCO2
Prototype system for a Copernicus CO_2 service

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atmosphere.copernicus.eu

Develop portfolio together with users:

- Fit-for-purpose
- Provide relevant services for a diverse range of user communities
- Avoid duplication and/or interference

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Support for activities at national scale

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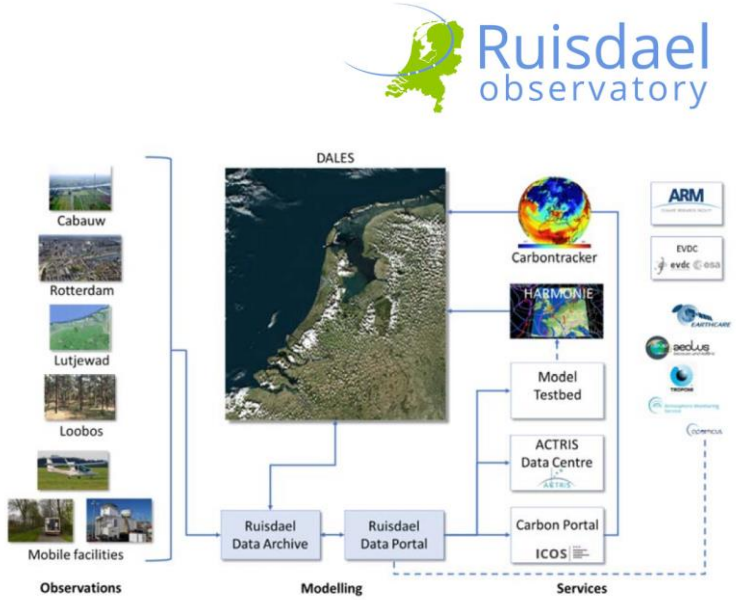

Bundesministerium für Verkehr und digitale Infrastruktur

DWD

Objectives of the BMVI and DWD ICOS:

- Provision of data and products for the future development of greenhouse gases in D / EU
- long-term verification of emission reductions
- scientific basis for policy makers for climate change

Various European countries already have or are developing national capabilities for the monitoring of greenhouse gas emissions.

The Copernicus CO_2 MVS capacity will align with these national efforts to provide support where useful, for instance provision of boundary conditions or the exchange of expertise.

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Distributed service (development)

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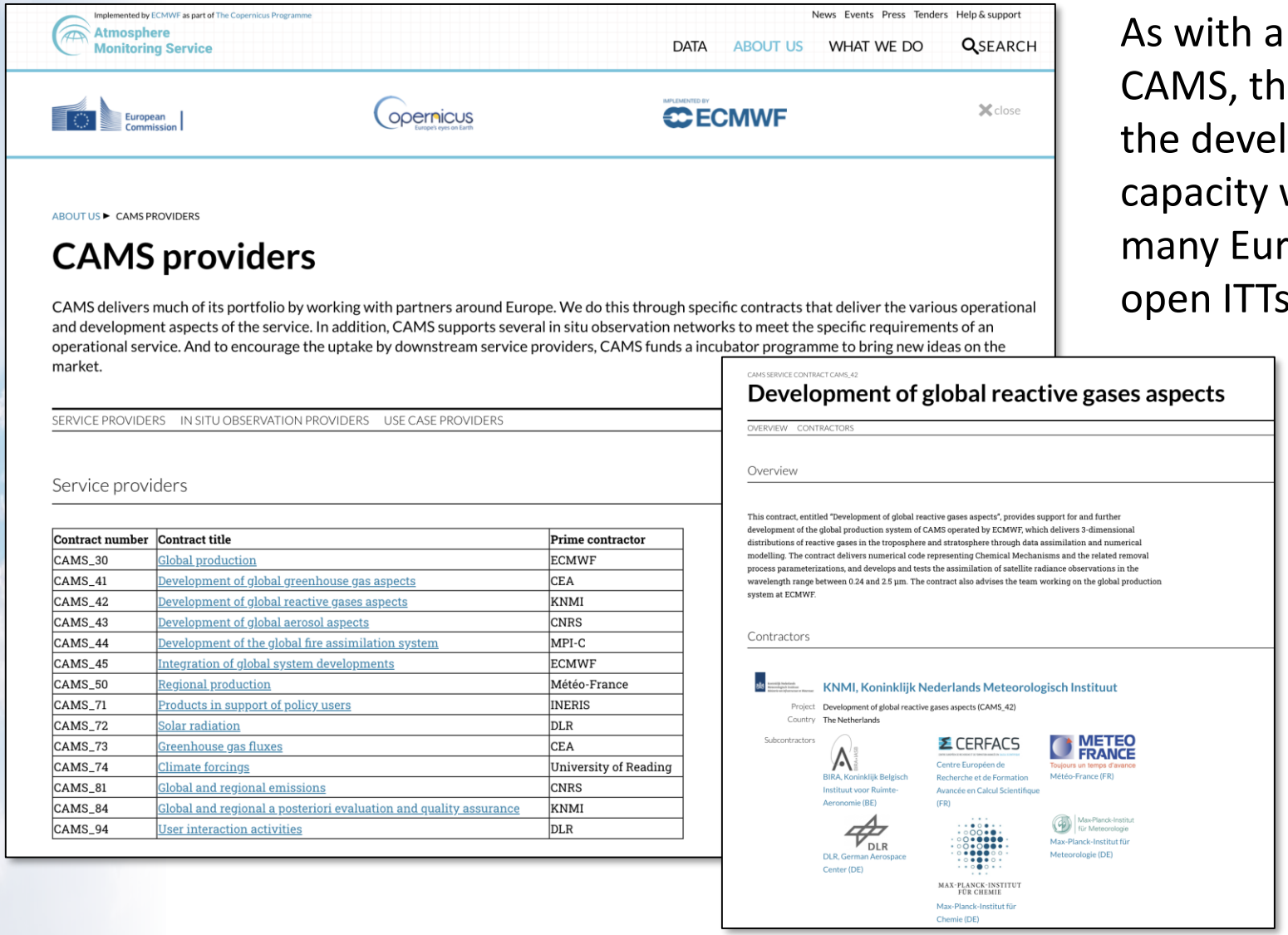

Implemented by ECMWF as part of The Copernicus Programme

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ABOUT US ► CAMS PROVIDERS

CAMS providers

CAMS delivers much of its portfolio by working with partners around Europe. We do this through specific contracts that deliver the various operational and development aspects of the service. In addition, CAMS supports several in situ observation networks to meet the specific requirements of an operational service. And to encourage the uptake by downstream service providers, CAMS funds a incubator programme to bring new ideas on the market.

SERVICE PROVIDERS IN SITU OBSERVATION PROVIDERS USE CASE PROVIDERS

Service providers

Contract number	Contract title	Prime contractor
CAMS_30	Global production	ECMWF
CAMS_41	Development of global greenhouse gas aspects	CEA
CAMS_42	Development of global reactive gases aspects	KNMI
CAMS_43	Development of global aerosol aspects	CNRS
CAMS_44	Development of the global fire assimilation system	MPI-C
CAMS_45	Integration of global system developments	ECMWF
CAMS_50	Regional production	Météo-France
CAMS_71	Products in support of policy users	INERIS
CAMS_72	Solar radiation	DLR
CAMS_73	Greenhouse gas fluxes	CEA
CAMS_74	Climate forcings	University of Reading
CAMS_81	Global and regional emissions	CNRS
CAMS_84	Global and regional a posteriori evaluation and quality assurance	KNMI
CAMS_94	User interaction activities	DLR

CAMS SERVICE CONTRACT CAMS_42

Development of global reactive gases aspects

OVERVIEW CONTRACTORS

Overview

This contract, entitled "Development of global reactive gases aspects", provides support for and further development of the global production system of CAMS operated by ECMWF, which delivers 3-dimensional distributions of reactive gases in the troposphere and stratosphere through data assimilation and numerical modelling. The contract delivers numerical code representing Chemical Mechanisms and the related removal process parameterizations, and develops and tests the assimilation of satellite radiance observations in the wavelength range between 0.24 and 2.5 µm. The contract also advises the team working on the global production system at ECMWF.

Contractors

KNMI, Koninklijk Nederlands Meteorologisch Instituut

Project: Development of global reactive gases aspects (CAMS_42)

Country: The Netherlands

Subcontractors

BIRA, Koninklijk Belgisch Instituut voor Ruimte-Aeronomie (BE)

CERFACS Centre Européen de Recherche et de Formation Avancée en Calcul Scientifique (FR)

METEO FRANCE Toujours un temps d'avance Météo-France (FR)

DLR, German Aerospace Center (DE)

Max-Planck-Institut für Chemie (DE)

Max-Planck-Institut für Meteorologie (DE)

As with all service elements in CAMS, the service provision and the development of the CO_2 MVS capacity will be distributed over many European actors through open ITTs.

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A true collaborative effort already

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CONCLUSIONS

- Plan is to embed the foreseen anthropogenic CO_2 emissions verification & support capacity in CAMS
- Aim of the CO2MVS capacity is to support the European Commission and EU member states with monitoring the anthropogenic impact on atmospheric CO_2 concentrations
- The exact product portfolio will be co-designed with member states and other user communities
- The service provision and its continual development will be distributed over European partners as is already the case for CAMS and C3S
- ECMWF can strengthen its Earth system modelling and data assimilation capabilities improving all services delivered by IFS for the benefit of ECMWF Member States