D5.9 Progress report on service elements for an integrated CHE monitoring infrastructure

Gianpaolo Balsamo
CHE-WP-leaders*

che-project.eu

Co-ordinated by ECMWF

D5.9 Progress report on service elements for an integrated CHE monitoring infrastructure

Dissemination Level: Confidential

Author(s): Gianpaolo Balsamo (ECMWF), Wouter Peters, Maarten Krol (WAGENINGEN), Corinne Le Quéré (UEA), Dominik Brunner (EMPA), Hugo Denier van der Gon (TNO), Greet Maenhout (JRC), Marko Scholze (LUND), Frédéric Chevallier (LSCE), Julia Marshall (MPI-BGC), Anna Agustì-Panareda, Richard Engelen, Daniel Thiemert (ECMWF).

Date: 14/12/2020
Version: 1.0
Contractual Delivery Date: 31/12/2020
Work Package/ Task: WP5
Document Owner: ECMWF
Contributors: Organisations listed above
Status: Final

CHE: CO2 Human Emissions Project

Coordination and Support Action (CSA)

H2020-EO-3-2017 Preparation for a European capacity to monitor CO2 anthropogenic emissions

Project Coordinator: Dr Gianpaolo Balsamo (ECMWF)

Project Start Date: 01/10/2017

Project Duration: 39 months

Published by the CHE Consortium

Contact:
ECMWF, Shinfield Park, Reading, RG2 9AX,
gianpaolo.balsamo@ecmwf.int

The CHE project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 776186.

Table of Contents

1 Executive Summary 6
2 Introduction 6
2.1 Background 6
2.2 Scope of this deliverable 7
2.2.1 Objectives 7
2.2.2 Work performed in this deliverable 7
2.2.3 Deviations and counter measures 9
3 Integration of the components of the CHE prototype 10
3.1 Earth Observations, Modelling, Data Assimilation, Uncertainty 10
3.1.1 Earth Observations 10
3.1.2 Modelling 10
3.1.3 Data Assimilation 11
3.1.4 Uncertainty characterisation 11
3.2 Prototype Implementation Strategy 12
3.3 Considerations on Scales, Species, Streams 13
4 Recommendation for a pre-operational CHE prototype 14
4.1 Implementation priorities to support the 2021 Global Stock Take 14
4.2 Proposed configurations 14
5 Research priorities 15
5.1 Action to maximise use of EO data 15
6 Service priorities 16
6.1 Linking the building blocks 16
6.2 Next phase of development: from CHE to CoCO2 16
6.3 Linking with Stakeholders 17
6.4 Roadmap to operational deployment 17
7 Conclusions 19
8 Acknowledgements 19
9 References 20

Figures

Figure 1 Building blocks of the CHE prototype with associated tasks and links to scientific Work Packages. 10
Figure 2 Temporal and spatial scales of CO_2 monitoring from plumes to global CO2 growth rate. 12
Figure 3: Schematic of the anthropogenic CO2 emissions Monitoring and Verification Support capacity (CO2MVS) as developed in the CHE project and adopted by the CO2 Monitoring Task Force. The foreseen service provision elements are depicted by the coloured boxes, while the required continuous development of the operational services is depicted by the white boxes. 16
Figure 4: Mapping the CHE project deliverables into the CoCO2 Work Breakdown Structure 16
Figure 5: High-level schematic of the envisaged interaction between the Copernicus CO2MVS capacity and countries as part of the UNFCCC reporting process. 17

Tables

Table 2: Regional Modelling Systems participating to the CO2 prototype phase (from the H2020 CoCO2 project) 8
Table 1: Building block elements and recommendations/priorities 15

1 Executive Summary

The CO2 Human Emissions (CHE) project has been tasked by the European Commission to prepare the development of a European capacity to monitor anthropogenic CO2 emissions. The monitoring of fossil fuel CO2 emissions has to come with a reported and sufficiently low uncertainty in order to be useful for policymakers. In this context, the main approaches to estimate fossil fuel emissions, apart from bottom-up inventories, are based on inverse transport modelling either on its own or within a coupled carbon cycle fossil fuel data assimilation system. Both approaches make use of atmospheric CO2 and other, co-emitted tracers (e.g., CO and NOx). While inverse transport modelling relies on the availability of prior fossil fuel CO2 emission estimates and uncertainties as well as prior biogenic fluxes and uncertainties, the coupled carbon cycle fossil fuel data assimilation system can be employed completely independent from fossil fuel CO2 emission estimates because of the included process knowledge.

The key requirements within the CHE project stem from research done in the Science-layer Work-packages (WP1-4) and connecting the specific requirements of the CHE Monitoring and Verification System prototype that are detailed in the CHE Service-layer Work-package WP5. These are detailed in the deliverables D5.2, D5.4, D5.6, D.5.8, respectively covering the Earth observations, the modelling components, the data assimilation methodology and the uncertainty characterisation. The current report is focusing on the prototype implementation roadmap, requirements and priorities in consideration of the calendar of milestones described within the Paris Agreement and in the European Commission CO2 Task Force reports (CO2 blue, red, green reports, https://www.copernicus.eu/en/news/news/new-co2-green-report-2019-published).

2 Introduction

2.1 Background

- The CHE prototype to monitoring CO2 emissions is built within the context of the transparency/verification framework of the Paris Agreement, where atmospheric measurements of CO2 are used to evaluate consistency and spatial/temporal disaggregation of country emission reports by UNFCCC (with reference to the CO2 Task Force reports).
- It will be a multi-scale and multi-stream system to monitor different sectors and scales and to provide information to different users (REF: prototype report introducing all building blocks of the CO2 monitoring system).
- The modelling of processes affecting CO2 in the atmosphere and the provision of ancillary and prior information are crucial to fill the gaps and link observations to emissions using adequate data assimilation techniques.

2.2 Scope of this deliverable

2.2.1 Objectives

In this report we aim at linking the reports on the building block deliverables D5.2 D5.4 D5.6 D5.8 with focus on the scales of relevance for the CO2 Monitoring and Verification support capacity.

2.2.2 Work performed in this deliverable

The work performed in this deliverable benefits from three dedicated integration modelling and mapping workshops, that took place in 2019-2020 additively to the Annual CHE General Assembly, and that permitted more in-depth discussions.

WP5-workshop: Integration, ECMWF Reading 25-26 September 2019

An integration dedicated workshop at ECMWF involving the WP-leaders and contributors within WP5 has identified the key elements in each of the development areas. This meeting has enabled drafting the deliverables D5.1, D5.3, D5.5, D5.7 that were due at the end of 2019 (precursors of the final reports D5.2, D5.4, D5.6, D5.8 linked to this document) and that clarified the expectations of the MVS for a Near-Real-Time component (with monitoring purpose to match the satellite observations) and a Behind-Real-Time component (with a more consolidated reanalysis purpose).

WP2-WP5-workshop: Modelling, EMPA (Online) 19-20 May 2020

A modelling dedicated workshop at EMPA involving the WP2 and WP5 has analysed the challenges involved in each of the scales from local plumes to regional, continental and global emissions, investigating the role of resolution in the horizontal and vertical dimension.

The workshop included sessions on "Model priors", "Transport models and nature runs", "Results from non-CHE projects and model simulations", with focus on how to (i) Evaluate the prior fluxes and transport (with model/data intercomparisons); (ii) Refine the recommendations related to prior/transport requirements for the CHE prototype, and (iii) Link the work done in CHE/VERIFY projects with CoCO2.

CHE-AFOLU-workshop: Mapping, ECMWF (Online) 25-26 November 2020

A mapping dedicated workshop organised by ECMWF (online) responded to the CO2 Task Force recommendation to clarify the different definitions and methods used in the AFOLU sector. This clarifies the roadmap for GHG monitoring and the CO2 MVS needs of a consistent input. The objectives to get a European consolidated view on the needs (for UNFCCC/Paris Agreement, EU carbon neutrality targets) with respect to the AFOLU sector, which then can be translated into technical requirements for the CO2 MVS capacity. This workshop allows to define the agenda for a wider AFOLU workshop in 2021 with international outreach.

2.2.2.1 Global MVS capacity

The CHE prototype for the global MVS capacity aims at providing global integrated CO2 emissions and concentrations at a resolution sufficiently high to enable the representation of large emissions and their evolution into the atmosphere. The availability of reliable CO2 concentrations and their transport will permit to provide lateral boundary conditions for regional-scale and local scale inversions. Moreover, the availability of ensemble-based CO2 realisations will enable offline modelling and assimilation efforts to refine emissions detection capabilities.

The ECMWF Integrated Forecasting System that supports the Copernicus Atmosphere Monitoring Service CAMS is currently running globally at 9km (HRES configuration, a single realisation) and 18 km (ENS and EDA configurations, with 51 members). The new High

Performance Computing infrastructure will permit to explore a combination of the ENS/EDA/HRES at around 9 km foreseen in 2023, moreover new initiatives supported by the European "Destination Earth" Programme will further explore impact of horizontal and vertical resolution and more sophisticated biogeochemistry, thanks to advanced supercomputing infrastructure and software innovations aiming at building a digital twin of planet Earth.

The global MVS will provide a robust, reliable, timely system to support the Global Stocktake (GST) and the Regional MVS capacity, well nested in a development plan that benefits from synergies with the other Copernicus services.

2.2.2.2 Regional MVS capacity

Regional scale inversions can step-up further the spatial resolution and include more accurate prior information (inventories available only at local scale). The verified quality of the emissions prior can be considered for a global multi-source prior update and for benchmarking the global MVS capacity on observationally dense areas.

The regional systems foreseen to participate in the next phase (from the CoCO2 project) are listed below. The global system will provide timely near real-time and retrospective boundary condition to enable regional applications in the 1-to-5 km resolution and exploratory sub-kilometres systems for local scales.

Table 1: Regional Modelling Systems participating to the CO2 prototype phase (from the H2020 CoCO2 project)

Model	Institute/ Consortium	Domain	Archived resolution			Meteorology Boundary Conditions
			horizontal	**vertical**	**temporal**	
IFS	ECMWF	Global	9 km	137 levels	hourly	N/A - Boundary condition provider
TM5+OpenIFS	WU	Global	25 km	60 levels	hourly	ECMWF operational/reanalysis
TM5	WU/SRON	Global	3 x 2 degrees	60 levels	hourly	ECMWF operational/reanalysis
		Zoom	1 x 1 degree	60 levels	hourly	
LMDZ	CEA	Global	3.75 x 1.9 deg^2	39 layers	30 min.	ECMWF operational/reanalysis
GEOS-Chem	University of Edinburgh	Global	2 x 2.5 degrees	47 levels	hourly	GEOS-FP/MERRA-2
		Zoom	0.25x0.3125			
CCFFDAS	Lund University, iLab	Global	0.1 degree		weekly	ECMWF operational/reanalysis
		Local	2 km		hourly	ECMWF/WRF

CHIMERE	CEA	Regional	1-2 km	20 layers	hourly	ECMWF operational/reanalysis
COSMO-GHG	EMPA	Europe	5 km	60 levels	hourly	ECMWF operational/reanalysis
		Regional	1 km	60 levels	hourly	
LOTOS-EUROS	TNO	Europe	5 km	20 levels	hourly	ECMWF operational/reanalysis
		Regional	1 km	20 levels	hourly	COSMO or WRF
ICON-ART	DWD/MPI-M/KIT-IMK	Europe	6.5 km	60 levels	hourly	global ICON and ECMWF
		Regional	2.5 km	65 levels	30 min.	regional ICON and ECMWF
MICRO-HH	WU	Local	1 - 100 m			Global or regional model

The provision of boundary conditions from global to regional modelling applications benefits from multi decadal experience within the weather and environmental modelling (both from the National Meteo-Hydrological Services and Consortia and the CAMS Regional Air Quality Forecasting Systems). The regional system capabilities are well demonstrated in the CHE D2.4 report.

2.2.2.3 Hotspots MVS capacity

Hotspots or point scale inversions will permit the follow up of emissions at local scale where observations availability enables following plumes. Point scale simulations will benefit from global and regional scales for the provision of boundary conditions and prior information. In return, the local scale knowledge can support the error characterisation for both the regional and global scale MVS that will be using CO2 emissions inventories prior. The Large-Eddy-Simulations LES report D2.8 contains detail information of the work undertaken to simulate CO_2 plumes

2.2.3 Deviations and counter measures

The COVID-19 pandemic required flexibility, adapting to online and remote working. The countermeasures taken within the CHE project have allowed to fulfil the calendar of workshops and meetings using dedicated online facilities.

3 Integration of the components of the CHE prototype

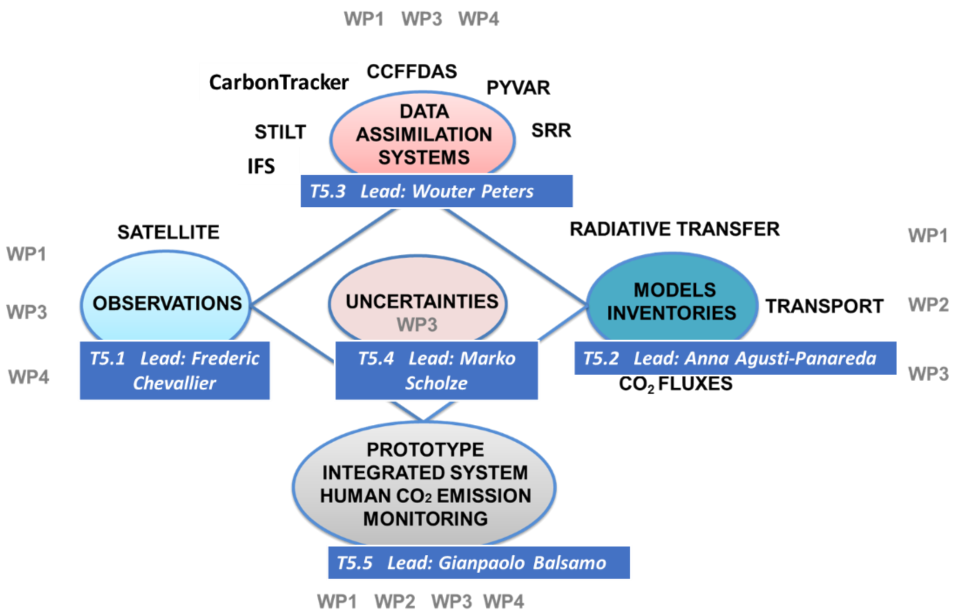

Figure 1 Building blocks of the CHE prototype with associated tasks and links to scientific Work Packages.

3.1 Earth Observations, Modelling, Data Assimilation, Uncertainty

3.1.1 Earth Observations

CO2 observations of fluxes and concentrations with other types of Earth observation such as radiocarbon, NO2, oxygen, solar-induced fluorescence and carbonyl sulphide are reviewed in D5.2, clustered in satellite CO2 and non-CO2, ground-based remote sensing, in-situ and flask-sampling observations. The relevant information from the Copernicus CO2 Monitoring Mission Requirements Document and from the three reports of the Copernicus Expert group and of the CO" Task Force are included. Research needs for the identification of the role of each relevant Earth observation type in the Copernicus CO2 support capacity system have been identified, for data streams currently available. The synthetic satellite data, instead are aiming at supporting studies for CO2M satellite constellation and are detailed in D2.5. From experience gained within CHE & CAMS the NO2 and SIF satellite-based data are identified as global-coverage EO information with currently more direct usability for data assimilation purposes. In-situ observing capability is paramount to Evaluation & Quality Control of the CO2MVS.

3.1.2 Modelling

The modelling and prior components subdivided in atmospheric transport from both resolved transport (advection schemes) and unresolved sub-grid processes (convection and turbulence), biogenic fluxes and anthropogenic emissions are reviewed in D5.4. The high-resolution regional nature runs nested in the European runs (described in D2.4), themselves nested in the global Tier-1 runs performed with the ECMWF/CHE-CAMS system (described in D2.2). These simulations are produced using two separate models, COSMO-GHG and LOTOS-EUROS. COSMO-GHG is used for both the meteorology and tagged tracers of multiple anthropogenic and biogenic sources. The meteorological outputs drive the offline model LOTOS-EUROS, which computes reactive trace gases and aerosols on top of the tagged tracers. A comparison of the different transport models and prior datasets is included in D5.4 to assess the different capabilities of the models and priors used to perform the CHE library of simulations. The Tier-2 global nature runs constitute a step improvement with respect to the Tier-1 runs and demonstrate the incremental improvement cycle that will support the CO2MVS capacity.

3.1.3 Data Assimilation

The data assimilation methodologies for CO2 distinguished in online 4D-Var, offline 4D-Var, online EnKF, offline EnKF, offline analytical and hybrid ensemble Var varieties are reviewed in D5.6. The differences between direct flux estimation (transport inversion) and the inclusion of models for fossil fuel emissions (FFDAS) and biospheric fluxes (CCFDAS) are discussed with their implications on the control vector configuration, the error covariances statistics along with examples of existing inversion systems. A configuration for global and regional inversions is presented. This includes a multi scale and multi species data assimilation system that targets anthropogenic CO_2 emissions capable of ingesting multiple streams of observations, including satellite observations. A hybrid 4D-VAR ensemble approach, implemented in an online transport model, and operated within the Numerical Weather Prediction environment, constitutes a fundamental building block that needs to be further extended as a DA system capable of using multiple tracers, and adaptable to short & long windows, optimizing both the atmospheric state as well as surface fluxes.

3.1.4 Uncertainty characterisation

The components in the sub-sections above are all characterised by uncertainties in space and time that need to be realistically represented and that are detailed in D5.8. The posterior uncertainty is evaluated in Observing System Simulated Experiments - OSSEs and in the Quantitative Network Design - QND studies, within the CHIMERE and CCFFDAS systems, respectively. The CCFFDAS allowed to assess a number of design aspects of the upcoming Monitoring and Verification Support capacity as part of the Copernicus CO2 Monitoring mission (CO2M). The assessment was based on the Quantitative Network Design technique and quantified the mission's performance in terms of the posterior uncertainty in the total CO2 emissions classified into two sectors, one for electricity generation and the other for all other emissions denoted as the “other” sector. Analysis of two different observing networks, ground based in situ observations and satellite based total column observations, in a range of configurations is detailed in D3.6.

3.2 Prototype Implementation Strategy

When considering the requirements for data assimilation methodology within the context of a CO_2 monitoring service, a particular consideration for its building blocks, as detailed above, should be the multiscale aspect of the problem. Multiscale in this context refers to (a) the spatial domain and (b) the temporal domain represented in a prototype system, but also (c) the required products for users.

For the spatial domain (a) a large challenge is formed by the inherently local nature of anthropogenic emissions as they emanate from stacks, cars, and buildings (point sources, <100 m scale), while the resulting CO_2 in the atmosphere travels over hundreds of kilometres while interacting strongly with natural ecosystems (from 1 to 100 km), weather systems (from 10 to 1000 km) and eventually across the full hemisphere (10,000+ km) and the rest of the globe. Not one modelling system can capture all these scales, and strengths of global scale models will need to be combined with other modelling approaches (Lagrangian, Gaussian plume, Large-eddy simulations...).

In the temporal domain (b), we need to recognize that signals of anthropogenic emissions are strongest and easiest to detect close to their source but get strongly diluted at the typical boundary layer mixing time scale of 15-30 minutes. A system that would just target such scales in data assimilation would however not see the integral of emissions over larger areas and thus requires observations nearly everywhere, and all the time, which is not feasible even with new (satellite) instruments and techniques. The integral of CO_2 emissions and uptake is moreover a very useful constraint to quantify changes in biospheric uptake and release over ecosystem/country scales, which is needed to understand the annual carbon balance. A system that can combine scales from minutes up to weeks/months would thus represent the best of both worlds.

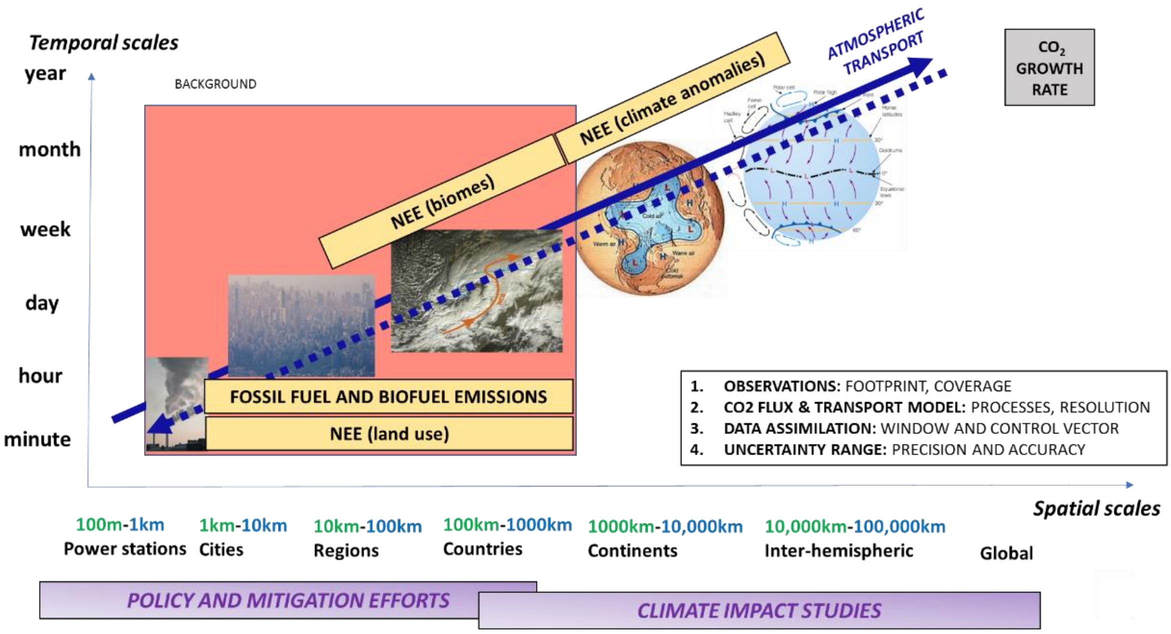

Figure 2 Temporal and spatial scales of CO_2 monitoring from plumes to global CO2 growth rate.

Finally, user requirements (c) suggest there to be a need for both a short-medium range real-time forecast of CO_2 uptake + release and resulting 4D mole fractions, as well as a less frequent but much longer consistent and more accurate yearly and/or multiyear reanalysis to monitor changes in anthropogenic and natural emissions and uptake and contribute to the

Global Stocktake Exercises. The NWP community has grown strong over the past decades from consistently applying the forecast-analysis cycle, which allows incremental improvements to the modelling components, adjustments in the treatment of large and diverse observational data streams, and objective skill-scores as feedback to the observational and numerical development community. From a carbon cycle perspective, much value gets added to the forecast-analysis cycle through reanalyses such as ERA5, as they inform on slow changes over time which are detectable

only when the same modelling components and same observational data selection and treatment are applied over large temporal windows.

This implementation strategy will therefore describe the components needed to address the challenges under (a), (b), and (c), through the use of multiple modelling components in two separate configurations:

An operational forecast-analysis system for atmospheric CO_2 and its sources and sinks from anthropogenic, biospheric, and oceanic sources, its main aim to serve as early-warning for unexpected changes in the emission landscape (monitoring and verification), and to improve the numerical and observational infrastructure in the traditional NWP approach. We will refer to this as the

NWGP (Numerical Weather and Greenhouse gas Prediction system)

A reanalysis system for the same CO_2 sources and sinks that allows consistent interpretation of diverse datasets in a consistent modeling framework, allowing verification and attribution of anthropogenic CO_2 sources and improved understanding of natural sources and sinks. We will refer to this as the

NWGR (Numerical Weather and Greenhouse gas Reanalysis system)

3.3 Considerations on Scales, Species, Streams

The CHE prototype will encompass multiple scales, species and streams in order to support the global, regional and local information. The approaches consist of:

- **Multi-scale** approach to monitor emission from point sources (power stations or industrial facilities), cities and countries using different model domains from global, regional to local and model resolutions (e.g. from 25km to 100m).
- **Multi-species** approach to detect and attribute the observed atmospheric signal to specific sources/sinks (e.g. natural and anthropogenic emissions with sectorial distribution).
- **Multi-stream** approach to support different applications and users with a near-real time stream focusing on shorter synoptic timescales designed to provide early warnings and giving feedback to data producers, and a re-analysis stream that uses consolidated quality-controlled data, products and models with their associated uncertainties to estimate trends.

4 Recommendation for a pre-operational CHE prototype

4.1 Implementation priorities to support the 2021 Global Stock Take

This set of recommendations focuses on the follow-on project to CHE that will aim at being taken up in the CoCO2 H2020.

- A "step-wise" approach to the MVS prototype will be followed according to the priority defined in D5.2 D5.4 D5.6 D5.8 to achieve a prototype by 2023.
- Three scales Global, Regional, Hotspots will have different setups and observation/modelling possibilities. Global scale will serve the regional/local scale boundary conditions. Regional/local will serve as important benchmarks for the Global CHE prototype.
- The modelling resolutions of the first CHE prototype will focus on a highest resolution of 9km globally with support from an ENS system to characterise uncertainties.
- An NRT/early-warning system (for satellite monitoring, and attribution studies) with all available NRT observations (L2 and/or radiances) supported by a multi-scale data assimilation approach will aim at consistency of scales above,
- A delay-mode reanalysis (with focus on the Global Stock Take) with best quality observations ancillary/inventories will be developed by 2023 applied to 2021.
- The Benchmarking with observations that are not used in the assimilation steps.
- Cross-comparison between systems is a way forward to gain insights on the prototype.

4.2 Proposed configurations

The proposed configurations to cover the domain and stream are reported below:

Operational System	Domain	Stream	Recommendations
IFS / Global Models	Global	NRT (Near Real Time, as in the NWGP Predictions mode) + BRT (Behind Real Time, as in NWGR Reanalysis mode)	Resolution + Accuracy + Timeliness to provide Satellite Monitoring Capabilities relevant for CO2M & Modelling Boundary Conditions for the Regional/Local efforts. Inclusion of activity data and process knowledge.
LAM type	Regional	BRT	Linkage to global enabling European high quality inventories & insitu coverage for EQC efforts
LES types	Local	BRT	Linked to regional/global for identified hotspots and to characterise model uncertainty and improve transport modelling.

5 Research priorities

5.1 Action to maximise use of EO data

This set of recommendations focuses on a wider set of actions to maximise the use of available satellite and in-situ observations, EO-driven prior, EO-driven model development, HPC-capacities that can support an evidence based CO2 Monitoring and Verification prototype and can prepare for the CO2M satellite observation operational uptake.

Table 2: Building block elements and recommendations/priorities

Building block	Element	Recommendations	Estimated Efforts	Priorities
Observations	CO2 +non-CO2, satellite +non-satellite	Guided by QND/OSSEs	See D5.2	Prior CO2M, NO_2 + SIF (for global human +natural CO_2), COS(partially informative). APO (experimental), Radiocarbon (experimental)
Modelling	Natural + Anthropogenic CO2 emissions, transport,	Guided by benchmarking activities	See D5.4	Improved transport model, Emission injection profile, co-emission groups, native 1km grid inventory
Data Assimilation	Methodology for minimisation, Bias handling	Guided by CCDAS/FFDAS + prototype + existing inversions	See D5.6	Focus on 4D-Var flux inversion & covariant emissions. Prepared of Ensemble DA & long-window.
Uncertainty	Methodology for posterior error representation, Intercomparions	Guided by verification and uncertainty calibration	See D5.8	Ensemble representation & Error propagation

6 Service priorities

6.1 Linking the building blocks

The structure of the CO2MVS service is outlined in **Figure** 3.

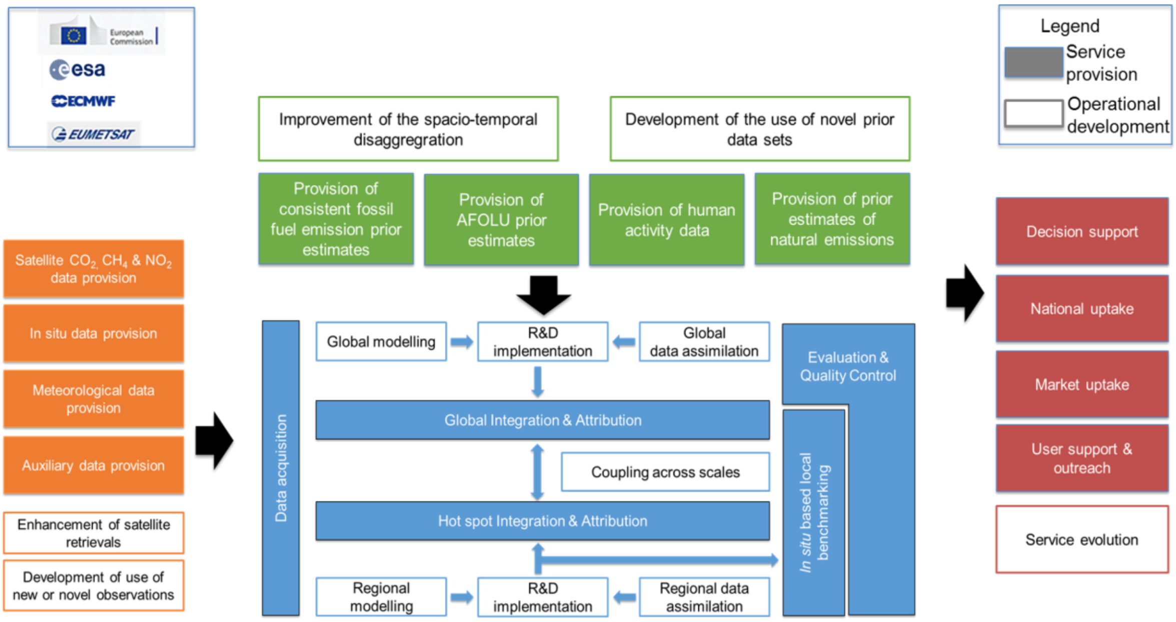

Figure 3: Schematic of the anthropogenic CO2 emissions Monitoring and Verification Support capacity (CO2MVS) as developed in the CHE project and adopted by the CO2 Monitoring Task Force. The foreseen service provision elements are depicted by the coloured boxes, while the required continuous development of the operational services is depicted by the white boxes.

6.2 Next phase of development: from CHE to CoCO2

The achievements within CHE are linked to the follow-on CoCO2 project

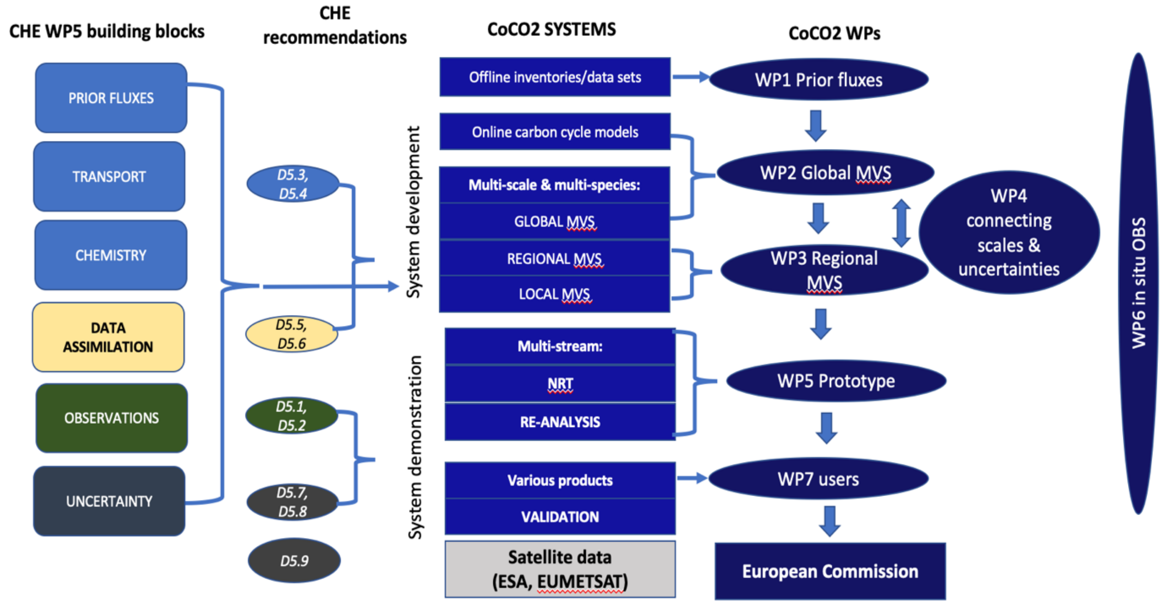

Figure 4: Mapping the CHE project deliverables into the CoCO2 Work Breakdown Structure

6.3 Linking with Stakeholders

For the CO2MVS, being designed as a support capacity, it is vital to link with the stakeholders.

As a new Copernicus element, it will be imperative to ensure a fit-for-purpose service. In this context, early interaction with national emission inventory agencies, responsible for the official reporting to the UNFCCC, will be key.

Copernicus is designed to support national activities, in this case by providing observation-based added-value information that can help the official reporting process. For countries where ambitions exist to build up national observation-based emission estimation capabilities, the interaction can be even stronger.

The CO2MVS can for instance provide boundary conditions, share expertise, support observation network design studies, and generally work with the relevant agencies to advance the science and technical implementation (see also Figure 5). In return, the CO2MVS will benefit from for instance the increased observation infrastructure in those countries as well as from their local expertise.

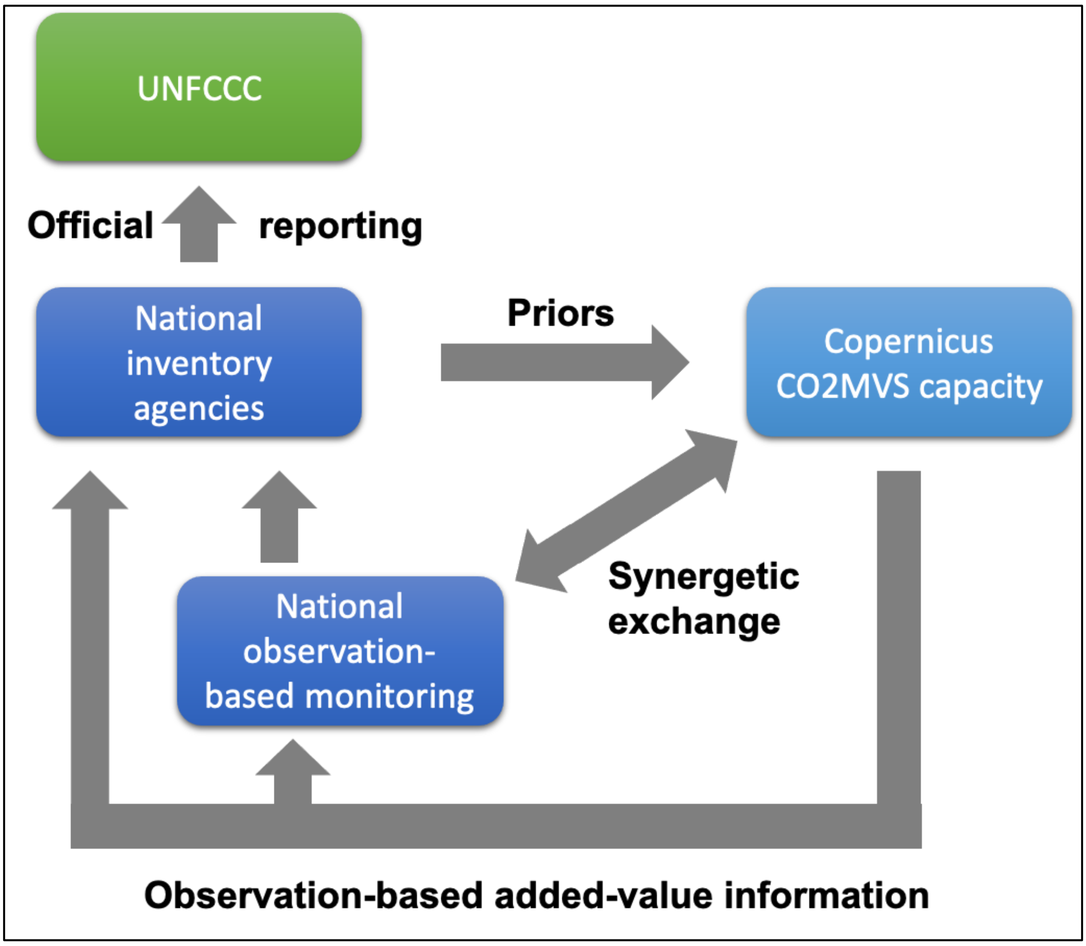

Figure 5: High-level schematic of the envisaged interaction between the Copernicus CO2MVS capacity and countries as part of the UNFCCC reporting process.

6.4 Roadmap to operational deployment

The development of the Copernicus CO2MVS is a very ambitious project that includes major developments within a very tight timeline. In addition, the requirements are only defined at a very high level and details will have to be added during the development phase in collaboration with the end user communities. Also, while the European Commission and the national inventory agencies are considered as key users of the service, other user communities (e.g., cities, companies, finance) need to be accommodated as well, each with their own specific requirements. Indeed, a key task of the CoCO2 project is to liaise with these diverse user communities and define together a fit-for-purpose service.

As stated in the second CO2 Monitoring Task Force report (Pinty et al., 2017), detection of changes of the order of 0.1-0.5 Mton CO_2 fossil fuel emissions per year for a small country and a coverage of the entire land area of all the world's countries would be needed in order to contribute significantly to the estimates provided by the current self-reporting methodologies based on inventories. This is very challenging. However, a key contribution from the foreseen CO2MVS would be to provide a consistent estimate of emissions around the world, which can be used to detect anomalies that need further investigation. Also, contributions from other sectors, most notably the AFOLU sector, have larger uncertainties that can be reduced by the foreseen CO2MVS, and discussions with experts are on-going to better define the requirements for these other sectors and the potential of the CO2MVS to deliver the relevant information.

Ultimately the expectations for the observation-based CO2MVS are to add further granularity and accuracy in time and space to current bottom-up inventories or top-down inversions that characterise the current CO2 estimates with a much better timeliness than is currently possible, with the aim to reliably inform whether CO2 anthropogenic emissions are increasing, stabilising or reducing at country-scale or even smaller scales (e.g., for hotspots emissions).

While a full product portfolio will have to be defined during the CoCO2 project in collaboration with the Commission's CO2 Monitoring Task Force, the current view is to provide global data products at sufficiently high resolution to capture the variability of atmospheric CO2 concentrations at similar spatial scales as the expected satellite observations from the CO2M mission, and to enable the assimilation of observations at these scales (2 x 2 km^2), both in routine monitoring mode and reanalysis mode. The routine monitoring mode targets the provision of timely feedback to the space agencies regarding the quality of the data and the support of downstream applications that fall outside the Global Stocktake process.

A good example of this is for instance the significant reduction in emissions during the COVID-19 crisis, for which timely information was needed that was not readably available. The reanalysis mode would reprocess the available data to provide the most accurate estimates of global emissions, their uncertainties, and their trends. This could be done every five years in support of the Global Stocktake or more often to support for instance the biennial transparency reports that form part of the Paris Agreement. Again, this will need to be further defined in the coming years in collaboration with the relevant stakeholders and user communities.

For ECMWF specifically, this means that to meet the CO2MVS requirements for the global IFS-based system significant progress needs to be made in both the modelling and data assimilation aspects. For the land surface modelling, this means that current developments will be continued in the coming one to two years. This includes the implementation and testing of aspects not encompassed in CHE, but recognised to be of high priority, such as new land use maps, and an urban tile, the improvement of the seasonal representation of vegetation cover, the implementation and testing of the Farquhar model to improve the photosynthetic carbon uptake, and the implementation and testing of LAI, VOD and SIF observation operators.

For the required data assimilation developments, a detailed plan was developed over the course of the CHE project. The plan focuses on the implementation of the key aspects needed for estimating CO2 emissions as well as emissions from other pollutants, with the aim of having a working prototype available by the end of the CoCO2 project in 2023.

The period after CoCO2 will be used to test the prototype system with available satellite data sets in preparation for the launch of the CO2M mission. This phase will be critical to fine-tune the system and align with the development work for the IFS modelling (land surface, ocean, and numerical aspects). The application of the system and therefore the testing will not just focus on CO2 only, but also include CH4, NO2 and possibly other atmospheric pollutants in line with the developments needed for the foreseen extension of CAMS services and exploiting the IFS coupled data assimilation methodology.

The period after 2023 will also be used to fully implement the global component of the CO2MVS in the operational infrastructure at ECMWF in terms of data acquisition, setting up and testing of operational suites, and data dissemination (e.g., ECMWF-MARS, Copernicus Atmosphere Data Store, DIAS, etc.). Running a pre-operational service, based on available observational input data, will allow further fine-tuning of all aspects of the global component of the CO2MVS in preparation of the launch of the CO2M mission. The intent is to run a global emission monitoring suite (NWGP mode) as close to real-time as possible as well as recurring reanalyses (NWGR mode) to be defined through more detailed user consultation.

The timeliness of the monitoring suite will especially depend on the availability of the input satellite data (e.g., current commitment from ESA and EUMETSAT for the CO2M mission is 24 hours after sensing), but also on more detailed user requirements. The exact schedule for the reanalyses will also have to be defined and tested based on user requirements and reprocessing capabilities by EUMETSAT. Furthermore, all service provision activities at ECMWF will have to be linked to and coordinated with the contracted service provision activities as well as with other relevant activities within CAMS (e.g. NO_2). All these aspects are a critical element of the ramp-up phase and will require significant time and resources. ECMWF has gained expertise with the implementation and operation of the current C3S and CAMS services, which will benefit the introduction of the CO2MVS in an operational environment. The track record of successfully converting science into operational services is key to engage European expertise implementing a CO_2 Copernicus service element.

7 Conclusions

This report serves the purpose of linking the CHE Service elements WP5 reports that take up the scientific work done in WP1-4 and outlining the CHE preoperational setup handed to further development in the CoCO2 project 2021-2023. The V2 of the report has been submitted coincidentally with the closure of CHE activities in December 2020 and in a preliminary V1 version in December 2019. The progress report serves as review material for the CHE Final Review meeting foreseen on the January 2021.

8 Acknowledgements

The report benefits from input and discussions within ECMWF and the authors wish to thank and acknowledge the CO2 Task Force.

9 References

CHE D5.2: F. Chevallier, 2020: Progress report on service elements for CO_2 Earth observation integration, https://www.che-project.eu/node/223

CHE D5.4, A. Agustì-Panareda and D. Brunner, 2020: Progress report on service elements for CO2 emission and transport models integration. https://www.che-project.eu/node/220

CHE D5.6: Wouter Peters and Maarten Krol, 2020: Progress report on service elements for data assimilation methodology. https://www.che-project.eu/node/224

CHE D5.8: M. Scholze et al. 2020: Progress report on service element requirements for uncertainty representation. https://www.che-project.eu/node/221

CHE D2.4: Jean-Matthieu Haussaire, Dominik Brunner, Arjo Segers, 2020: D2.4 Part I: Regional nature runs. https://www.che-project.eu/node/217

CHE D2.5: Johan Strandgren, 2020: Synthetic Satellite dataset. https://www.che-project.eu/node/218

CHE D2.8: Andrzej Klonecki and Pascal Prunet, 2020: LES simulations report. https://www.che-project.eu/node/222

CHE D3.6: Marko Scholze, Hans Chen, Thomas Kaminski, Michael Vossbeck, 2020: Inversion strategy based on joint QND assessments. https://www.che-project.eu/node/219

Pinty B., P. Ciais, D. Dee, H. Dolman, M. Dowell, R. Engelen, K. Holmlund, G. Janssens-Maenhout, Y. Meijer, P. Palmer, M. Scholze, H. Denier van der Gon, M. Heimann, O. Juvyns, A. Kentarchos and H. Zunker (2019) An Operational Anthropogenic CO2 Emissions Monitoring & Verification Support Capacity – Needs and high level requirements for in situ measurements, doi: 10.2760/182790, European Commission Joint Research Centre, EUR 29817 EN. ISBN 978-92-76-09004-5 doi: 10.2760/182790.

Pinty B., G. Janssens-Maenhout, M. Dowell, H. Zunker, T. Brunhes, P. Ciais, D. Dee, H. Denier van der Gon, H. Dolman, M. Drinkwater, R. Engelen, M. Heimann, K. Holmlund, R. Husband, A. Kentarchos, Y. Meijer, P. Palmer and M. Scholze (2017) An Operational Anthropogenic CO2 Emissions Monitoring & Verification Support capacity - Baseline Requirements, Model Components and Functional Architecture, doi: 10.2760/39384, European Commission Joint Research Centre, EUR 28736 EN. ISBN 978-92-79-72101-4, doi: 10.2760/08644.

Ciais, P., D. Crisp, H. Denier Van Der Gon, R. Engelen, M. Heimann, G. Janssens-Maenhout, P. Rayner and M. Scholze (2015) Towards a European Operational Observing System to Monitor Fossil CO2 emissions, European Commission – ISBN 978-92-79-53482-9; doi 10.2788/350433.

Document History

Version	Author(s)	Date	Changes
V0.1	Gianpaolo Balsamo (ECMWF)	21/11/2019	Pre-release for M27 CHE Interim Review
V0.2	Gianpaolo Balsamo (ECMWF)	08/11/2020	Release for M39 CHE Final Review
V1.0	Gianpaolo Balsamo and Anna Agusti-Panareda (ECMWF), Marko Sholze and Hans Chen (ULund), Thomas Kaminski (iLab)	27/11/2020	First round of updates from WP-leaders

Internal Review History

Internal Reviewers	Date	Comments
Daniel Thiemert (ECMWF)	15/12/2020	Approved with comments

Estimated Effort Contribution per Partner

Partner	Effort
ECMWF	20 %
JRC	10 %
WAGENINGEN	10 %
MPI-BGC	10 %
EMPA	10 %
LUND	10 %
TNO	10 %
LUND	10 %
LSCE	10 %
Total	**100 %**