CoCO2

Prototype system for a Copernicus CO_2 service

1st Overview of sensitivity studies performed in CoCO2

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With inputs from Maarten Krol, Bart van Stratum, Marko Scholze

Co-ordinated by ECMWF

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CoCO2: Prototype system for a Copernicus CO_2 service

Coordination and Support Action (CSA)
H2020-IBA-SPACE-CHE2-2019 Copernicus evolution – Research activities in support of a European operational monitoring support capacity for fossil CO2 emissions

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Table of Contents

1 Executive Summary

Sensitivity studies, including Observing Systems Simulation Experiments, are important tools for a successful design of the prototype CO2MVS capacity and especially for the foreseen (pre-)operational service in the Copernicus programme. The CoCO2 project includes many sensitivity studies distributed over most WPs to assess the impact of various choices (observation networks, modelling, data assimilation) on the produced results. To keep a clear focus on the outcome of the various results, this document summarises the performed studies and outcomes. This first version presents the activities for 2021, while future versions will add the activities for 2022 and 2023, respectively.

2 Introduction

2.1 Background

To support EU countries in assessing their progress for reaching their targets agreed in the Paris Agreement, the European Commission has clearly stated that a way to monitor anthropogenic CO_2 emissions is needed. Such a capacity would deliver consistent and reliable information to support policy- and decision-making processes.

To maintain Europe's independence in this domain, it is imperative that the EU establishes an observation-based operational anthropogenic CO_2 emissions Monitoring and Verification Support (CO2MVS) capacity as part of its Copernicus programme.

The CoCO2 Coordination and Support Action is intended as a continuation of the CO_2 Human Emissions (CHE) project, led by ECMWF. In the Work Programme, ECMWF is identified as the predefined beneficiary tasked to further develop the prototype system for the foreseen CO2MVS capacity together with partners principally based on the CHE consortium. In addition, ECMWF will continue some of the work initiated in the VERIFY project as well.

The main objective of CoCO2 is to perform R&D activities identified as a need in the CHE project and strongly recommended by the European Commission's CO_2 monitoring Task Force. The activities shall sustain the development of a European capacity for monitoring anthropogenic CO_2 emissions. The activities will address all components of the system, such as atmospheric transport models, re-analysis, data assimilation techniques, bottom-up estimation, in-situ networks and ancillary measurements needed to address the attribution of CO_2 emissions. The aim is to have prototype systems at the required spatial scales ready by the end of the project as input for the foreseen Copernicus CO_2 service element.

Putting together the building blocks of the CO2MVS requires extensive testing of all the components as well as the integrated end result. CoCO2 is therefore using various forms of sensitivity studies to test and illustrate the impact of specific configurations on the estimated emissions. In the Work programme text, specific reference was made to the use of Observation System Simulation Experiments (OSSEs). OSSEs in the context of satellite systems are defined as follows: *An OSSE uses computer models to test different designs of new satellite systems before their instruments are actually built or deployed, and to compare the performance of the new satellites against current observing platforms. The results can help to guide the design of new instruments and to determine if a new satellite platform will be cost-effective*. OSSEs can be computationally expensive and only address part of the overall system. CoCO2 therefore uses a variety of sensitivity study set-ups that not only address the requirements for the observation component of the CO2MVS, but also the requirements for some of the other components. This document provides an overview of the preparation for and results from the various sensitivity studies in CoCO2.

2.2 Scope of this deliverable

2.2.1 Objectives of this deliverables

During the review of the original CoCO2 proposal, reviewers commented that the continued prioritisation of the sensitivity studies and the Observing Systems Simulation Experiments will be important to the achievement of the objectives. The proposal includes many sensitivity studies distributed over most WPs to assess the impact of various options (observation networks, modelling, data assimilation) on the produced results. These are indeed very important for a successful design of the prototype and especially the foreseen (pre-)operational service in the Copernicus programme. To keep a clear focus on the outcome of the various results, this document summarises the performed studies and outcomes. It will be updated at the end of each year resulting in three Deliverables. The current version, D9.9, is the first version of the document.

2.2.2 Work performed in this deliverable

As per the Description of the Action, the work performed included interaction with WP leads to summarise the relevant activities within each Work Package during the first year of the project.

2.2.3 Deviations and counter measures

No deviations were encountered.

3 Related work in 2021

3.1 WP2 - Prior and ancillary information

The work in WP2 does not include specific sensitivity studies but supports studies in other work packages. The global and regional emission data sets are important inputs for the various nature runs, that are setting baselines for the planned sensitivity studies. The Mosaic data set, which is under development, will allow testing the impact of more detailed regional emission data sets compared to the globally consistent but coarser global data set.

3.2 WP3 - Global Modelling and data assimilation

The work in WP3 is primarily focused on further development of the global modelling and data assimilation system with a clear emphasis on ECMWF's IFS system, which already at the core of the global CAMS services. However, various tests and sensitivity studies will be carried out, also including other global systems. Examples are the sensitivity of the length of the data assimilation window on the emission estimates or the sensitivity of the modelling of atmospheric CO_2 to specific choices/assumptions in the land surface modelling. In addition, the work package will provide nature runs based on the improved global system that can be used in sensitivity studies in other work packages. Most of the foreseen work is in progress or planned for the next two years, but an overview of activities so far for the work package in general can be found in D3.1.

3.3 WP4 - Local and regional modelling and data assimilation

The future CO2M satellites will be able to identify the plumes of strong point sources and clusters of sources (e.g., cities, industrial complexes) with a horizontal resolution of 2 km x 2 km. In order to use this information in atmospheric inversion systems, the underlying atmospheric transport models should be able to resolve the plumes and reproduce their basic properties. Currently, large uncertainties exist regarding the ability of atmospheric transport models to describe individual observed plumes. Moreover, simulation results are sensitive to different model settings such as resolution, boundary layer and advection schemes, and to the representation of the source, such as its temporal variability and injection height in the case of stack emissions. Moreover, models that run on regional scale, are also sensitive to meteorological forcing.

In order to test the current high-resolution transport models, WP4 has defined several test cases that are relevant for emission verification. These cases are meant as benchmark cases that are simulated by an ensemble of high-resolution models (10 m – 1 km). The simulations will not only include CO_2, but also co-emitted species like NO_2 and CO, simulated with full or simplified linear chemistry. Cases will be presented for which suitable validation data (satellite, ground-based, (aircraft) campaigns) is available.

Deliverable D4.1 has documented the planned case studies, the participating modelling systems, and available observational datasets to evaluate the simulations. This document will then guide the experimentation with the various modelling systems; first results for the Jänschwalde powerplant are currently being gathered.

3.4 WP5 - Connecting scales and uncertainties

A cornerstone of the multi-scale CO2MVS prototype is the use of ensembles for the exchange of statistical information between global and local inversion systems. WP5 has focused on two main activities, both of which rely on posterior ensembles generated by the global Integrated Forecasting System (IFS) at ECMWF as well as the regional systems:

1. Use of the global IFS posterior ensemble as set of boundary conditions for the regional inverse models, in order to quantify the impact of uncertainties in those boundary conditions on the regional top-down estimates.
2. Combination of the global IFS posterior ensemble with posterior ensembles from regional emission products to assimilate the latter as observations in the global inversion prototype.

During 2021, work has focused on extending the existing Ensemble of Data Assimilation (EDA) framework of the IFS to integrate perturbations of both the 3-dimensional atmospheric composition state and the emissions in the posterior ensemble. The extended EDA framework can be used to create flow-dependent errors for use in the global inversion system as well as in the regional and local systems. It also allows to perform Observation System Simulation Experiments later in the project. A description of the work carried out so far is presented in D5.7.

Another activity in WP5, also documented in D5.7, is the extension of the VERIFY Community Inversion Framework (CIF) to the models used in CoCO2. Accurately assessing uncertainties originating from the use of different transport models and configurations needs to be carried out using a common system with all inversion steps identical, with the exception of the transport. The chosen system is the Community Inversion Framework (CIF). At the time of writing of the present report, the following models are fully integrated in the CIF and are usable for later assessment of transport uncertainties: CHIMERE, LMDZ, FLEXPART, TM5, and WRF-Chem. Discussions with partners to establish a clear inversion protocol, to use the CIF with different models and later deduce a quantification of transport uncertainties have started in autumn 2021. The purpose is to coordinate with other WPs and decide of a relevant inversion window consistent with other inversions carried out in other tasks.

WP5 also contains a specific task to assess the impact of various design options for the CO2MVS and has built in some flexibility to respond to questions from the CO_2 Task Force (T5.5). The global CCFFDAS provided a contribution to the CO_2 Task Force report entitled “Recommendation on Constellation Size of the CO2M Mission”. The contribution quantified the effect of adding satellites to the CO2M constellation for an exemplary week in June on sectoral fossil fuel emissions from five countries (Australia, Brazil, China, Germany, and Poland). It detailed that “each additional satellite in the constellation achieves a further reduction in posterior uncertainty of country-scale sectoral fossil fuel emissions. As the electricity generation sector is relatively well-constrained by prior information, at country scale the main impact of atmospheric XCO_2 and in situ CO_2 observations was on the posterior uncertainties of the fossil fuel emissions from other sectors. A local CCFFDAS system was employed to assess the constraint of simulated CO2M images of XCO_2 and of the NO_2 column

for an overpass on February 3, 2008, on fossil fuel emissions from power plants and all other sectors (called “the other sector”) at varying degrees of spatial aggregation over the 24 hours preceding the emission. It explored the sensitivity to the random uncertainty in NO_2 observations by analysing five cases. More details can be found in section 3.5 of D5.7. In addition, a series of experiments using TROPOMI CH_4 observations was performed with the CarbonTracker Europe-CH4 inversion system. The experiments differ in the retrieval product assimilated. One was based on the operational algorithm and one on the Weighting Function Modified Differential Optical Absorption Spectroscopy (WFM-DOAS or simply WFMD). An inversion based on the in-situ network was used as a benchmark. Results show that significant differences still exist when using different (satellite) observation products. More details in D5.7.

Finally, the impact of transport model uncertainties on atmospheric CO_2 inversions was tested through a set of inversions that differ only by their atmospheric transport models. Findings are described in Section 3.6.1 of D5.7.

3.5 WP7 - Observations

One specific task in this work package, Task 7.3 Identification of gaps in the currently available in-situ observations and ancillary data, will address in-situ observational needs with a design study for a future comprehensive in-situ network. This will link directly with Task 5.5, which aims to perform quantitative network design studies addressing the in-situ network (i.e., type and coverage of observations) and the inclusion of radiocarbon observations. The task has not been active yet, because it needs the results from Task 7.1 (Definition of requirements for in situ observations) and Task 7.2 (Identification of data providers) to confront the data needs documented in Task 7.1 with the currently available data streams documented in Task 7.2. It is expected that a mismatch will be apparent, which may take the form of insufficient measurement coverage, or limited timeliness and/or quality control of the required measurements for use in an operational context. Entirely missing data streams, representing scales and variables that are currently not observed, may also be identified. Thus, the outcome of this task will not only be the documentation of the gaps themselves but will also lead to recommendations for how to cost-effectively close these gaps for the in-situ network and radiocarbon measurements.

4 Conclusion

This deliverable provides an overview of the sensitivity studies, and their preparation, carried out across the various work packages in CoCO2. It emphasizes the importance of these sensitivity studies for the design of the CO2MVS and makes it easier to find the relevant Deliverables that describe the various studies in more detail. In this first version, activities performed during 2021 are described. Future versions will add the activities that will take place during 2022 and 2023, respectively.

Document History

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1.0	Richard Engelen (ECMWF)	10/01/2022	Final version

Internal Review History

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