CoCO2
Prototype system for a Copernicus CO_2 service

Summary report of the WP5 activities for the first year of the project

M. Scholze & WP5 team

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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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1 Executive Summary

This document reports on progress to date within WP5 'Connecting scales and uncertainties' of the CoCO2: Prototype system for a Copernicus CO_2 service project. The aim of WP5 is essentially to evaluate and benchmark improvements in the quantification of fossil fuel CO_2 emission estimates focussing on enhanced uncertainty estimates as well as across relevant scales. To this end, this work package involves performing observing system simulation experiments (OSSEs) and quantitative network design (QND) experiments, setting up benchmarking systems around natural terrestrial CO_2 flux and atmospheric transport modelling, developing multi-scale inversion framework, assessing uncertainty correlations and biases in the satellite observations as well as performing inverse model intercomparisons. All tasks within this WP have considerably progressed according to their work description in the Grant Agreement and no deviations from this work description have been identified. In Task 5.1, the ensemble data assimilation system has been extended to integrate both 3D atmospheric composition state and emission perturbations in the posterior ensemble. Task 5.2 has developed and consolidated a strategy for assessing and quantifying errors in biogenic CO_2 fluxes based on eddy-covariance flux measurements. Task 5.3 has implemented a set of atmospheric tracer transport models into the Community Inversion Framework (CIF), which has been developed in the VERIFY project, while Task 5.4 has so far made available CO2M data including systematic and random retrieval uncertainty with and without the use of a multi-angular polarimeter to account for aerosols. In task 5.5, the impact of various design options for the CO2M MVS have been assessed with respect to posterior emission uncertainties. These options include among others the availability of co-located NO_2 observation with varying degrees of random uncertainties. Finally, Task 5.6 has started distributing an intercomparison protocol for CH_4 inversions among the inverse modelling community as well as tested the impact of transport model uncertainties on atmospheric CO_2 inversions.

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 CO2 emissions Monitoring and Verification Support (MVS) capacity as part of its Copernicus programme.

The CoCO2 Coordination and Support Action is intended as a continuation of the CO2 Human Emissions (CHE) project, led by ECMWF.

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 with the aim 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.

The objective of WP5 is to improve the representation of uncertainties in inversions, which are important not only for the uncertainty of the generated flux estimates, but also to determine the weight that different elements of information that are used should receive.

The following aspects of connecting scales and uncertainties will receive specific attention:

- The uncertainty of boundary conditions, and how to combine information from separate inversions addressing different but complementary spatio-temporal scales (Task 5.1, see Section 3.1).
- The quantification of uncertainty arising from sampling biases (Task 5.4, see Section 3.4) and atmospheric transport models (Task 5.3, see Section 3.3).
- The impact of several design options (assimilation window, prior specification, online vs offline simulations) on posterior estimates and their uncertainty (Task 5.5, see Section 3.5).
- Best practice on evaluating/benchmarking atmospheric transport models (Task 5.6, see Section 3.6) and terrestrial ecosystem models for providing prior error covariances (Task 5.2, see Section 3.2).

2.2 Scope of this deliverable

2.2.1 Objectives of this deliverables

The objective of this deliverable is to provide a summary of the work progress made in WP5 within the first twelve month of the project (01/21-12/21).

2.2.2 Work performed in this deliverable

After consultation with the partners involved with tasks T5.1–T5.6, a summary of the progress within WP5 has been compiled.

2.2.3 Deviations and counter measures

Not applicable.

3 Progress on tasks within WP5

3.1 Develop mechanisms to transfer information from global to local scales and vice versa

A cornerstone of the multi-scale global inversion prototype is the use of ensembles for the exchange of statistical information between global and local inversion systems. This task focuses on two main activities, both of which rely on posterior ensembles generated by the Integrated Forecasting System (IFS) as well as 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.

Work for the first 12 months has focused on extending the existing Ensemble of Data Assimilation (EDA) framework available at ECMWF to integrate both 3D atmospheric composition state and emissions perturbations in the posterior ensemble. As a preliminary step, ECWMF has tested an EDA experiment in which only the model physics, the surface sea temperature and the observation were perturbed (i.e. no perturbation was applied to the surface emissions). The experiment was run for one week (from 01/08/2019 to 07/08/2019). Figure 1 shows the spread of the posterior 50-member ensemble for CO_2 concentrations at 500hPa after 5 days since the initialisation. This posterior ensemble is then used to construct a flow-dependent covariance matrix. The potential impact from using flow-dependent information is highlighted in Figure 2. Here we show a comparison of the horizontal correlation length scales (in km) for CO_2 concentration at 500 hPa (model level 95) obtained from the flow-dependent background covariance matrix used in the EDA experiment (left) against an estimate based on the static covariance matrix currently in used in CAMS. It is clear from Figure 2 that the use of flow-dependent information leads to very different correlation patterns than those prescribed by the climatological background covariance matrix. Eventually, a hybrid system combining together both ensemble and static information will be put in place for CO_2 at ECMWF, similarly to what is already done operationally for the NWP system.

Another critical aspect of using a flow-dependent wavelet-B matrix is the ability to model spatially heterogeneous covariance structures for the emission prior errors, a feature often not available in current state-of-the-art global inversion systems.

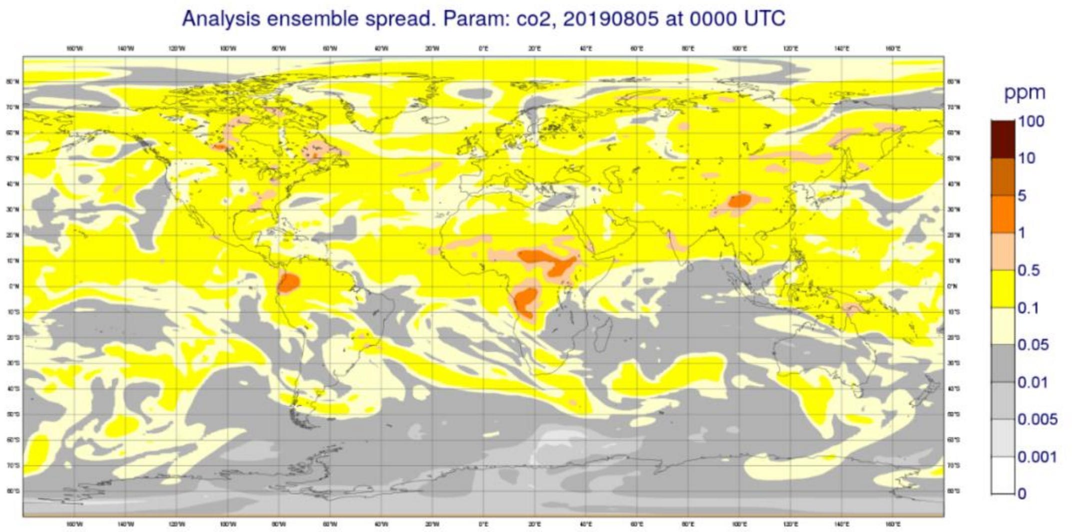

Figure 1: Spread of the posterior 50-member ensemble for CO_2 concentration at 500 hPa at 00 UTC on August 5th 2019. The results are obtained from an EDA experiment to test the development of an ensemble-based data assimilation system for CO_2.

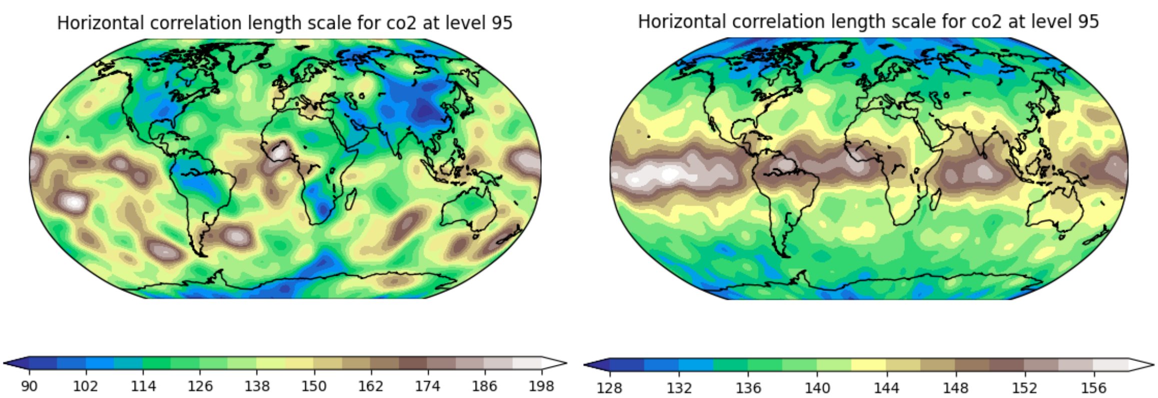

Figure 2: Horizontal correlation length scale (in km) for CO_2 concentration at 500 hPa (model level 95) based on: flow-dependent background covariance matrix used in the EDA experiment (left) and the static covariance matrix currently in use at ECMWF (right). Note that the values in the legend do not match.

In parallel, theoretical and technical investigations have been carried out to provide a flexible ensemble framework to ingest regional posterior emission products into the global IFS inversion prototype. Figure 3 provides a schematic of the approach which would consist in using ensemble statistics from perturbed inversions to infer their associated averaging kernel operators and retrieval errors for assimilation in the global IFS prototype as observations.

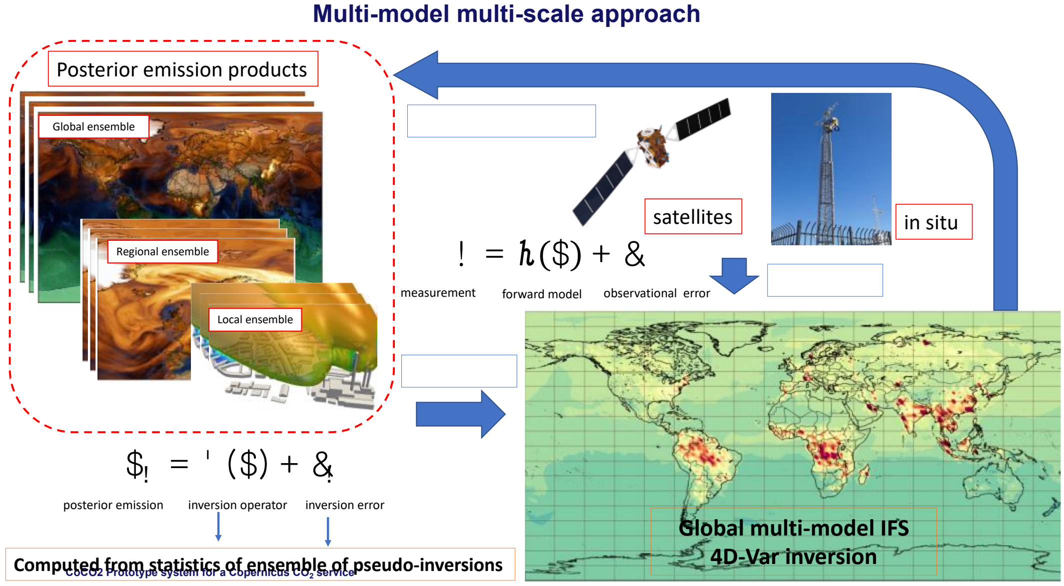

Figure 3: Schematic view of the assimilation of external (global, regional, local) inversion products into the global IFS prototype along with standard observations.

3.2 Assessing and quantifying errors of biogenic CO2 fluxes

In the first year we developed and consolidated a strategy for assessing and quantifying errors of biogenic CO_2 fluxes. Jointly with WP3 we conducted two discussions and a mini-workshop dedicated to this topic. The mini-workshop was assessing the state-of-the-art of model evaluation strategies by different modelling groups in CoCO2 and also included external international speakers and participants (Christian Seiler, Stephen Sitch, Gab Abramowitz, Tristan Quaife, see CoCO2 workshop on land surface model benchmarking - CoCO2 - ECMWF Confluence Wiki for the meeting notes). The overall conclusion from this discussion is that a multi-faceted and diversified evaluation approach across scales would be most desirable:

1. at local at flux-tower stations,
2. using case studies at country scale with good inventories,
3. large scale evaluation by comparison with atmospheric CO_2 concentrations using multiple atmospheric transport models,
4. global gridded multi-variable and multi-diagnostic ILAMB or AMBER style.

Another key result was that we lack specific knowledge which aspects of biogenic flux variability are most important to get right for the CO2MVS and how these can be encoded in metrics (e.g. amplitudes of seasonal or diurnal cycles) that can be assessed against independent data. This issue has now been taken up by Thomas Kaminski (iLab) together with Marko Scholze (ULUND), and Martin Jung (MPI-BGC) to design tailored OSSE experiments for better answering this questions.

To foster the planned systematic evaluation tool of biogenic CO_2 flux simulations by different models against globally distributed flux tower sites we have collected model forcing requirements, discussed some issues, and evaluated different implementation options. Following recommendations by modeling experts in CoCO2 we approached Gab Abramowitz

(Sydney, Australia) who is the PI of modelevaluation.org and Plumber-2 that focusses on land surface model benchmarking with flux tower data. Fortunately, Gab was very open for collaboration such that the decision was made to adapt the existing modelevaluation.org infrastructure to our CoCO2 needs rather than developing a similar system from scratch. We have then gathered the key people and stakeholders and started a discussion and exchange: Dario Papale from ICOS Ecosystem thematic centre, Alex Vermeulen and Ute Karstens from the ICOS Carbon Portal, Gab Abramowitz, and Jacob Nelson and Martin Jung from MPI-BGC. We identified that the main aspect that needs adaptation is related to data requirements:

1. in CoCO2 we need to additionally provide remote sensing products as model inputs,
2. the underlying flux tower measurements should flow automatically to the modelevaluation.org system to avoid working with a separate and partly modified copy of the data.

The latter aspect is particularly relevant for being able to run new evaluation experiments as new and updated flux tower data accumulate. Dario Papale and Gab Abramowitz have been in intensive exchange to facilitate this.

Activities at MPI-BGC concentrated on preparing the required data and tools. Remotely sensed inputs from MODIS (vegetation indices, land surface temperatures, reflectances) at flux tower sites have been acquired. Automated procedures for quality control and gap-filling have been developed and implemented. A related manuscript is in preparation and is foreseen to be submitted before the end of 2021. The accompanying processed site-level remote sensing products will be disseminated publicly through the ICOS Carbon Portal. We have further improved the gap-filling of in-situ measured precipitation, which is needed as model input, and which has been problematic in the past. The new developed technique based on machine learning essentially predicts the distribution of rainfall for a gap and is able to reproduce the stochastic nature of rainfall. Because the standard quality control of flux tower data was found to be insufficient for model benchmarking, a new and complementary approach to flux tower QC was developed and implemented. It is based on multiple indications of inconsistency among measured variables, and is automated, objective and traceable. A related manuscript is in preparation.

3.3 Assess and investigate model/inversion uncertainties employing a common inversion framework

Accurately assessing uncertainties originating from the use of different transport model and configurations need 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), developed in the H2020 project VERIFY. The first year of work in CoCO2 consisted in carrying out developments from the project VERIFY, in particular integrating additional models in the system. 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; the main contributor(s) to the integration is added between brackets; some models are integrated alongside their adjoint, hence allowing the computation of variational inversions, while models with no adjoint can only be used with ensemble methods; most models are so-called “offline” models as they simply use meteorological fields as inputs, while “online” models compute the meteorological fields at the same time as the transport:

- CHIMERE (CEA): regional, offline Eulerian transport model, including adjoint,
- LMDZ (CEA): global, offline Eulerian transport model, including adjoint,
- FLEXPART (NILU and EMPA): global and regional offline Lagrangian transport model, hence auto-adjoint; for this model, the integration work required to adapt the code to be compatible with both version of FLEXPART used by NILU and EMPA; the two versions are slightly different, are driven by different meteorological datasets and differ in their output formats; the CIF integration is now compatible with both versions,

- TM5 (VUA): global, Eulerian transport, including adjoint,
- WRF-Chem: regional, online Eulerian transport, with no adjoint.

Milestone MS11 due at month 12 mentioned six models integrated in the CIF. At present, five models are integrated, but the integration of the FLEXPART model with two different configurations required additional work. Besides, the integration of additional models (STILT and LOTOS-EUROS) is planned to start by the end of 2021 or in early 2022.

In parallel to the technical work of integrating new models, a scientific article describing and documenting the CIF was published in the journal Geoscientific Model Development in August 2021: Berchet et al.

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 WP and decide of a relevant inversion window consistent with other inversion carried out in other tasks.

3.4 Account for correlated uncertainty and samples biases in satellite data

The objective of this task is to investigate the use of the planned CO2M satellite constellation for monitoring CO_2 with a focus on measurement uncertainty and how to optimally account for them in regional scale inverse modelling. To this end, synthetic satellite data are used in three inverse modelling systems to assess the observational constraint on national scale CO_2 emissions, depending on how data uncertainty is represented. This will also address the question of how uneven sampling coverage influences the estimates, depending, among others, on the method used to aggregate collections of single column satellite retrievals into super-observations.

To more accurately define the experiments to be carried out in this task and formulate an experimental protocol to be used by the groups contributing to it, knowledge of the synthetic CO2M satellite data that will become availability within the COCO2 project is critical. Because of limitations of the dataset that was initially foreseen in the COCO2 program, which turned out not to make critical retrieval variables available such as retrieval uncertainty, we explored opportunities to obtain additional data. As an important outcome, SRON Netherlands Institute for Space Research, made data from their CO2M end-to-end simulator available to COCO2. This information includes systematic and random retrieval uncertainty with and without the use of the multi-angular spectropolarimeter (MAP) onboard CO2M. Averaging kernel information is not yet available, but will be for an updated dataset which will be available for the WP5.4 simulations.

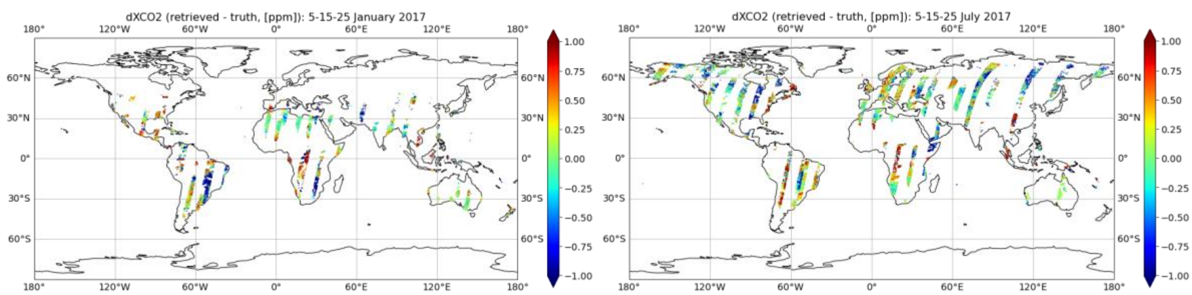

Figure 4: Examples of XCO2 retrieval uncertainty estimates for CO2M from the SRON end-to-end simulator for January (left) and July (right) in the configuration using MAP.

Examples of the available end-to-end simulator data are shown in Figure 4. As can be seen, the total retrieval error (retrieved minus truth) is within the retrieval uncertainty requirement for the mission (0.7 ppm). However, the errors show important systematic variations and are far from randomly distributed. This has potentially important implications for the performance of regional inversions using CO2M data, which we plan to further investigate and quantify.

The next step is to organize a meeting with the WP5.4 participants to discuss the available data and the experiments to be carried out in this task, which is planned for early 2022.

3.5 QND and data assimilation sensitivity studies to assess impact of design options on posterior uncertainty representation

This task assesses the impact of various design options for the MVS and has built in some flexibility to respond to questions from the CO2M task force.

iLab and ULund operated two versions of the Carbon Cycle Fossil Fuel Data Assimilation System (CCFFDAS) that were developed in the ESA CCFFDAS study (https://ccffdas.inversion-lab.com/). The global CCFFDAS version (Kaminski et al., 2021) provided a contribution to the CO2M task force report entitled “Recommendation on Constellation Size of 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 the other sector. For example, extending the constellation from one to four satellites reduces the posterior uncertainty of fossil fuel emissions from China’s other sector from ~180 MtC/yr to 124 MtC/yr, i.e. by roughly 30%. The added value of an extra satellite varies depending on the country and the local conditions (e.g. cloud cover) during the study week. For three out of the five countries the third satellites brings the largest added value in terms of reduction in posterior uncertainty.

iLab and ULund also operated a local CCFFDAS version for a 200 × 200 km^2 domain around Berlin in the 2 x 2 km^2 spatial resolution of CO2M. As the global system it contains models of sectoral fossil CO_2 emissions, natural fluxes, and atmospheric transport. In addition, it has the unknown inflow form the four lateral boundaries as an additional component of its control vector. It has the capability of exploring complementary observations of the NO_2 column and thus also includes scaling factors for the NO_2/CO_2 emission ratio as additional components of the control vector. The 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. We explored the sensitivity to the random uncertainty in NO_2 observations by analysing five cases:

1. prior, i.e. neither XCO_2 nor NO_2 observations,
2. no NO_2 observations,
3. NO_2 observations with a random uncertainty of 0.5 x 10^{15} molec/cm2, an average value based on assessments of the TROPOMI instrument by Lorente et al. (2019),
4. NO_2 observations with a random uncertainty of 1.5 x 10^{15} molec/cm^2, the upper limed specified in the CO2M MRD,
5. 0.25 x 10^{15} molec/cm^2, i.e. half the value estimated by Lorente et al. (2019). The assumed systematic error was 0.3 x 10^{15} molec/cm^2 in all cases.

Simulations of systematic errors in XCO_2 assumed the availability of a MAP instrument. The setup used 20% prior uncertainty for prior fossil fuel emission (per power plant, at city level: 52.8% per pixel for other sector), each parameter of the natural flux model, and ~1ppm for the inflow into each lateral boundary grid cell. As an exemplary result, Figure 5 shows the posterior uncertainty in emissions from the other sector at the pixel scale on average of the domain (right set of bars) and for various levels of aggregation: Berlin district (6th to 8th set of bars), smaller cities in domain (3rd to 5th set of bars), the city of Berlin (2rd set of bars), the entire domain (left set of bars). In case (3) the combination of NO_2 with XCO_2 achieves a reduction of the prior uncertainty for the entire city by 50%, which underlines the usefulness of the atmospheric observations. Case (4) shows that NO_2 observations are still useful, even if the random error was three times as high as estimated by Lorente et al. (2009). Case (5) shows that the reduction in the NO_2 random error (to a level just below that of systematic error) yields a small benefit compared to case (3) with an extra uncertainty reduction of ~10% at city scale. At the pixel scale of 2 km x 2 km the effect of the satellite observations is only small on average (right set of bars), at isolated pixels with high emissions (within the city) it can however yield uncertainty reductions of up to 35% (Figure 6). Figure 6 also shows the higher uncertainty reduction for grid cells with larger emissions (within the city or along the motorways, e.g. the one to the Southwest). Not surprisingly, NO_2 observations have also a large effect on larger power plants (not shown).

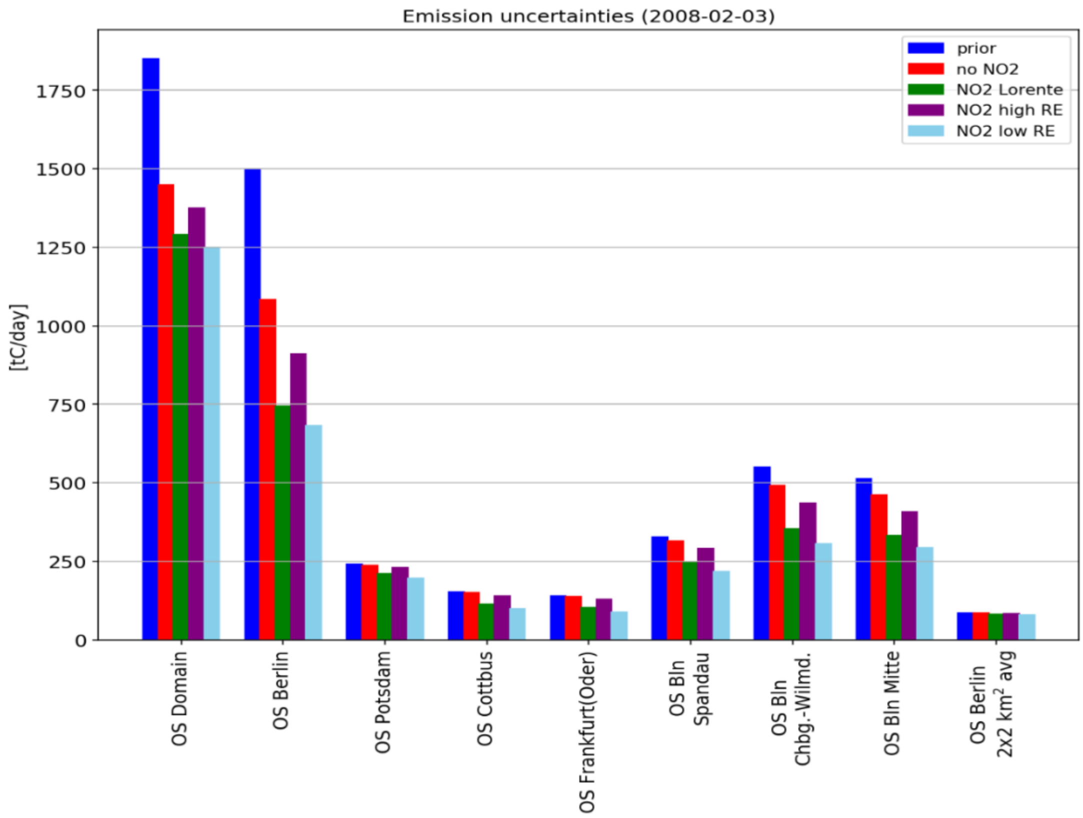

Figure 5: Posterior uncertainty in emissions from the other sector at the pixel scale on average of the domain (right set of bars) and for various levels of aggregation: Berlin district (6th to 8th set of bars), smallers citis in domain (3rd to 5th set of bars), the city of Berlin (2nd set of bars), then entire domain (left set of bars).

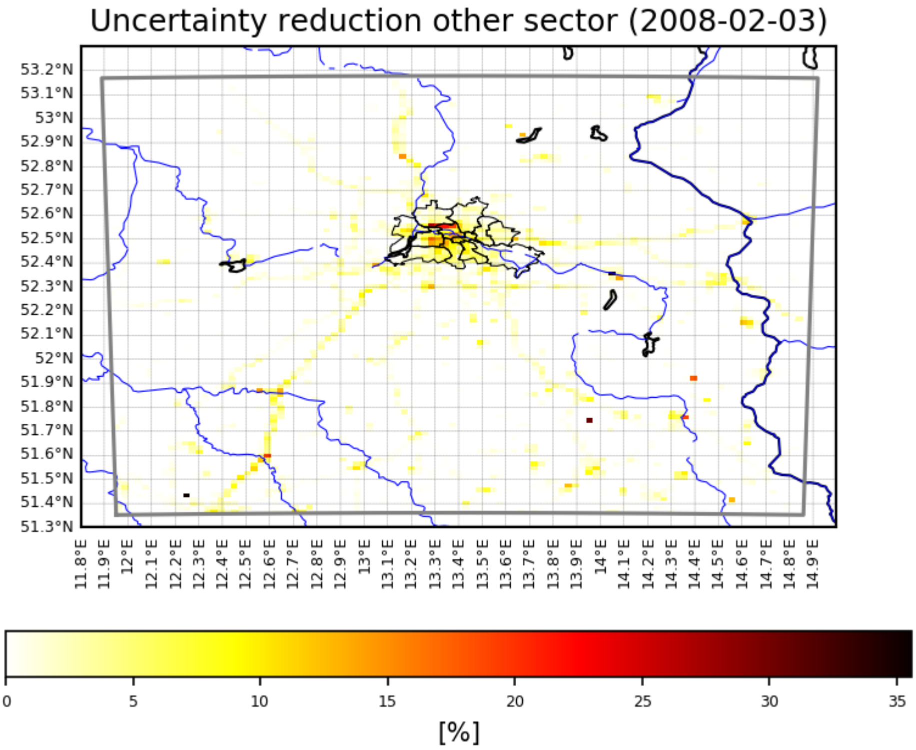

Figure 6: Uncertainty reduction for the other sector at the pixel level.

The CEA team has updated their "Western Europe analytical inversion system co-assimilating XCO_2, CO_2 and $^{14}CO_2$ data" (developed in CHE)" so that it can use a variable XCO_2 random error (instead of a homogenous one as before). This system, with a zoomed configuration of the CHIMERE transport model at 2 km resolution on Northern France, Western Germany, Belgium and a part of the Netherlands, performs inversions of CO_2 and $^{14}CO_2$ fluxes (from fossil-fuels and biofuels sources, nuclear power plants, ecosystem net primary production and heterotrophic respiration) at regional to plant scale. The system is ready to be used for new assessments, in particular to further explore the complementarity of space-borne observations and in situ networks. It will take advantage of the large ensemble of simulations for 14 days in 2015, while only 1 day was exploited in CHE. This system plans to support the analysis in WP4-5 with tests including the simulation of the CO2M observations used in WP4/5 and some surface networks used in T4.4.

The FMI team has performed a series of experiments using TROPOMI CH_4 observations with their CarbonTracker Europe-CH4 inversion system. The experiments differ in the retrieval product assimilated. One is based on the operational algorithm and one on the Weighting Function Modified Differential Optical Absorption Spectroscopy (WFM-DOAS or simply WFMD). Figure 7 contrasts the respective inversion results for northern high-latitude wetland CH_4 fluxes with results of an inversion using observations from the surface network. While the fluxes inferred from the inversion using TROPOMI data show lower fluxes than the prior in summer, fluxes from the inversion using the surface network show an increase with respect to the prior. The fluxes inferred from WFMD are closest to the prior, such that those using operational data show the lowest fluxes. The spatial distribution of European anthropogenic fluxes are also investigated. Figure 8 shows the spatial anomaly (estimates - regional mean) of prior and posterior fluxes and reveals an anthropogenic emission enhancement in central Europe, especially in cities. The inversion based the surface network shows the strongest emission enhancement in western Europe, which weakens when satellite data are assimilated. Nevertheless, no significant changes in the location of hot spots from the prior are found by the inversions.

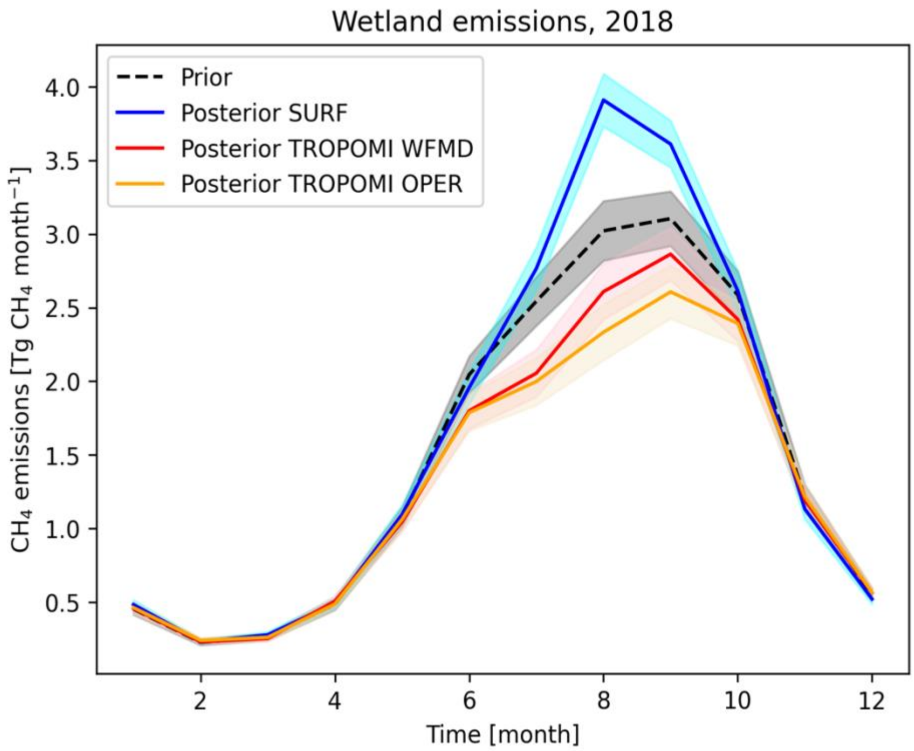

Figure 7: Northern High Latitude wetland CH_4 fluxes inferred by inversions with CTE-CH4 system against XCH_4 retrieved from TROPOMI (orange and red lines) and against observations provided by the surface network (blue line) and prior (dashed).

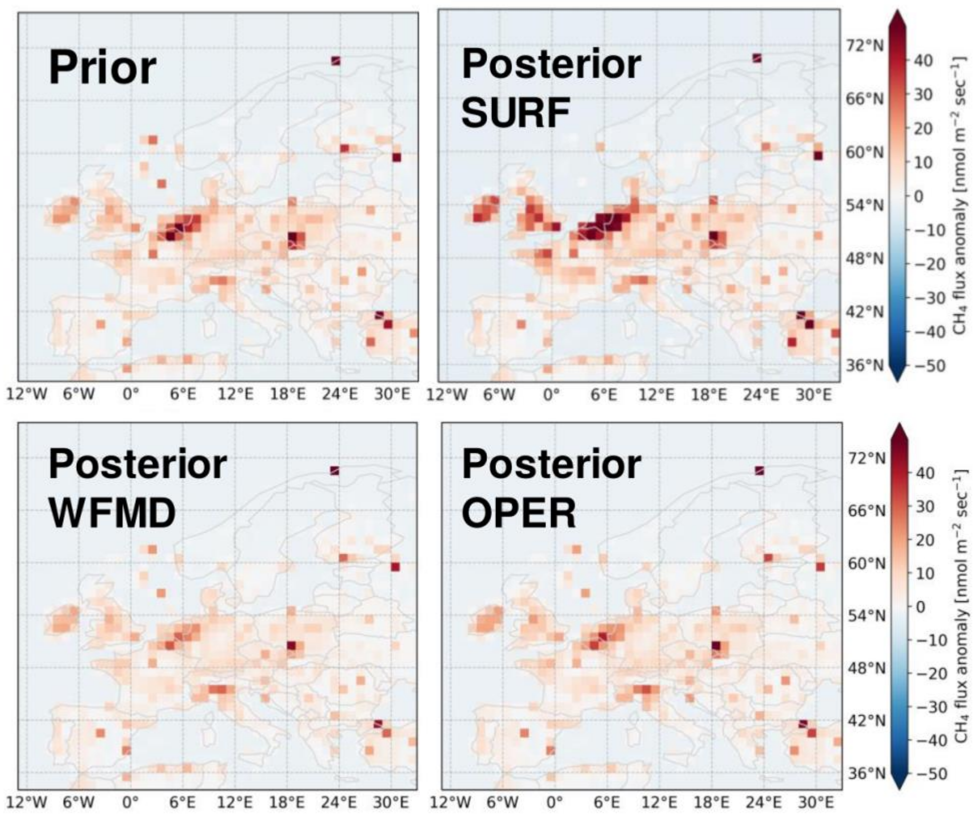

Figure 8: Spatial anomaly (estimates – regional mean) of prior and posterior anthropogenic fluxes over Europe, averaged over 2018.

The DLR team has set up their Jena-CarboScope (STILT) system to perform assessments of changes in the in-situ network (i.e. type and coverage of observations) and the inclusion of $^{14}CO_2$ observations.

TNO is continuously providing advice to the modelling teams on use of the emissions data and their uncertainties. Furthermore they have set up their LOTOS-EUROS system to analyse the sensitivity of the inversion result on a priori uncertainty definition

3.6 Assessment of uncertainties in European inversion of CO_2 and CH_4

3.6.1 CO_2 inversions

We tested the impact of transport model uncertainties on atmospheric CO_2 inversions through a set of inversions that differ only by their atmospheric transport models. For that, we performed a series of LUMIA inversions using different transport model configurations:

- In its default configuration, LUMIA relies on the FLEXPART Lagrangian particle dispersion model to compute CO2 transport within Europe, with lateral boundary conditions (LBC) taken from a TM5-4DVAR simulation. The LBC is provided in the form of timeseries of “background” concentrations (i.e., far-field contributions), computed directly at the observation sites by the TM5 model, using the 2-step inversion scheme of Rödenbeck et al., 2009.
- In addition, LUMIA inversions were performed using the Lagrangian transport model STILT, as an alternative to FLEXPART, and using background concentrations from global (TM3-based) CarboScope inversions, as an alternative to TM5-4DVAR.

All simulations used the same VPRM NEE prior, optimized at a weekly resolution on a variable resolution grid (up to 0.25°, in the vicinity of the observation sites), and continuous observations from 44 tall-tower sites in Europe. Anthropogenic emissions from the EDGAR4.3/TNO product and climatological air-sea exchanges from Takahashi et al., 2009 were also used.

We first analyzed the impact of the transport model configurations on the prior fit to the observations. The bias between STILT and FLEXPART simulations is generally in a ±1.3 ppm range, except at Ispra (3.3 ppm, RMSD of 8.2 ppm) where it in exceeds the prescribed observational uncertainty. While there is no obvious systematic bias between the two models, there are regional and seasonal biases, illustrated in Figure 9. On the contrary, the impact of the boundary condition (TM5 vs TM3) can largely be described as a seasonal, domain-wide bias, close to zero in winter, but up to 0.9 ppm in summer (May to July).

In terms of optimized fluxes, the inversions using TM3 background concentrations lead to an annual NEE more negative by ~0.18 PgC/year compared to their TM5-based counterparts, and inversions using STILT instead of FLEXPART lead to an annual NEE more negative by ~0.15 PgC (Figure 10). However, the impact of the boundary condition is rather constant, both in time and space, whereas the impact of the regional transport model is largely concentrated in the period from June to August and shows distinct spatial patterns (Figure 9).

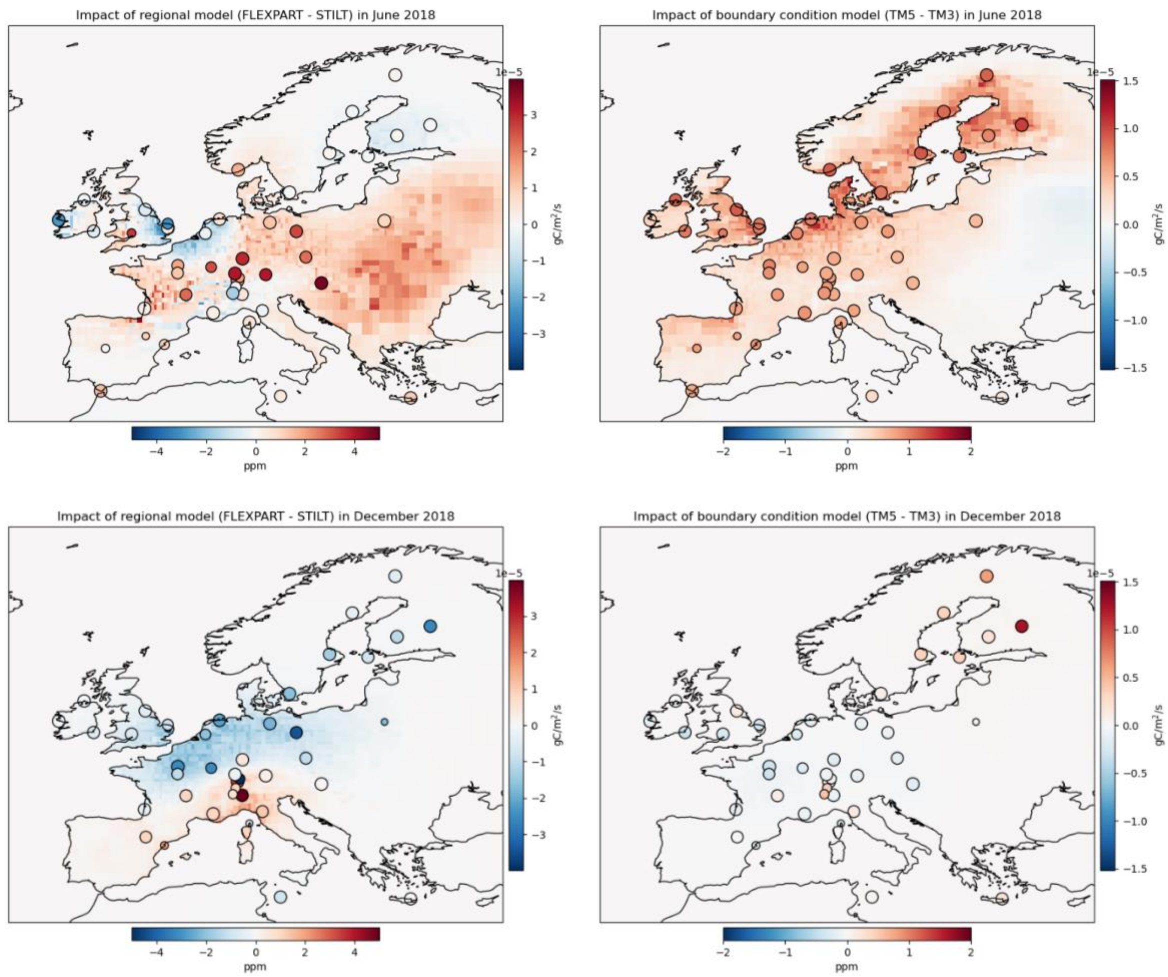

Figure 9: Impact of the regional transport model (left) and of the boundary conditions (right) on the modelled concentrations (dots, horizontal colour bars) and on the optimized fluxes (vertical colour bars), in June (upper row) and December (lower row). Note that the colour scales are different between the left-hand side plots and the right-hand sides ones. The size of the dots is proportional to the number of observations assimilated at each site.

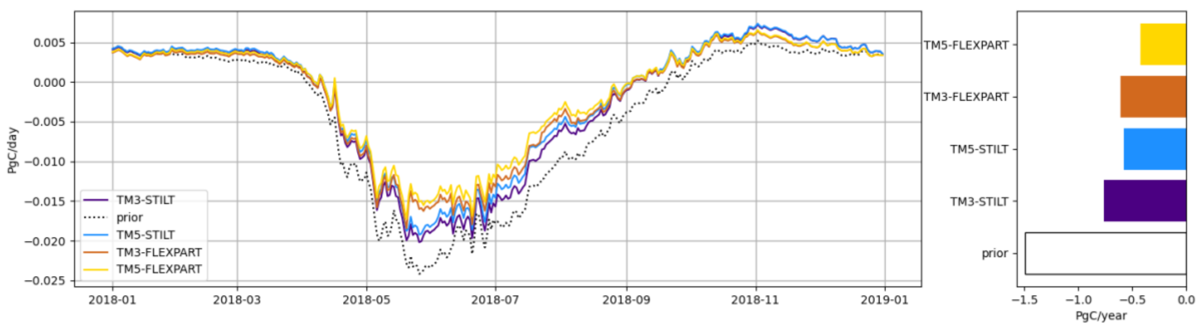

Figure 10: Daily (left) and annual (right) prior and posterior fluxes for the four inversions aggregated over Europe (the domain shown in Figure 9).

3.6.2 CH_4 inversions

The intercomparison of CH_4 inversion will be performed in two phases. In the first phase we focus on national CH_4 emissions using only in situ observations covering the period 2005-

2018 in the inversions. This is done in collaboration with the VERIFY project that provided all the necessary prior fluxes (monthly, 0.25 deg) up to 2018. For this first phase we assembled an observational database including core sites to be used in the inversions as well as additional sites either for inclusion in the inversion or as validation sites (Figure 11). The protocol specifies that from each participating inversion system output at monthly and 0.25 deg resolution for national total emissions and uncertainties per category as well as the mixing ratios for some selected core years is required. The protocol has been distributed to the partners participating in the intercomparison.

In the second phase the inversion period is extended to 2021 and the observational database is extended to also include satellite CH_4 observations in addition to the in-situ observations.

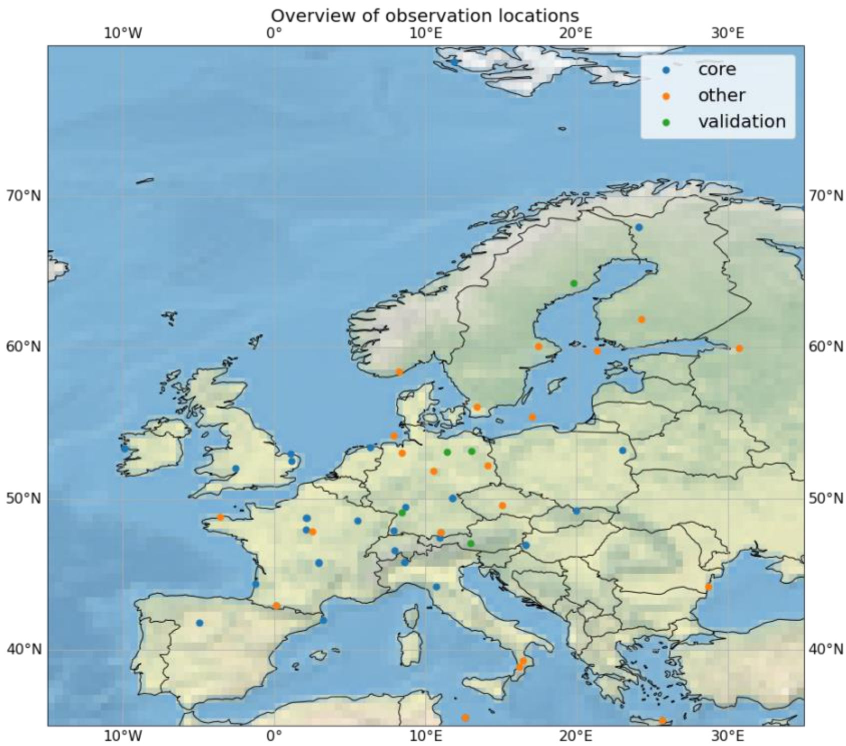

Figure 11: Map of CH_4 sites.

The protocol and input datasets have been finalized, and an announcement has been sent out to the international inverse modelling community to formally kick of the intercomparison and invite researcher to participate and contribute to the experiment. The deadline for submissions has been set at March, 1th 2022. A first opportunity to discuss the initial outcomes with the international community will be at the next TRANSCOM meeting, which will most likely take place in September 2022.

4 Conclusion

This document summarises the progress to date within the different tasks of WP5 “Connecting scales and uncertainties” of the CoCO2 project. All partners have made considerable progress towards the goals of WP5 within the first twelve months of the project (01/21-12/21) and no deviations from the planned milestones and deliverables have been encountered.

This deliverable will serve as a reference document reporting on progress within the first twelve months of the project in WP5 of the CoCO2 project.

5 References

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0.1	M. Scholze (ULUND)	02/11/2021	Initial draft
0.2	M. Scholze (ULUND) & WP5 team	04/12/2021	Complete version for internal review
1.0	M. Scholze (ULUND) & WP5 team	22/12/2021	Final version including revisions from internal review

Internal Review History

Internal Reviewers	Date	Comments
Dario Papale (CMCC)	10/12/2021	Approved with comments
Tamminen Johanna (FMI)	15/12/2021	Approved with comments

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Partner	Effort
ULUND	0.5
Total	**0.5**

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