CO2MVS RESEARCH ON SUPPLEMENTARY OBSERVATIONS

D1.4 First version of uncertainty ranges in flux space derived by an ensemble of emission model runs

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1 Executive Summary

The present document is not a deliverable report but a short document that accompanies a dataset of fossil fuel emissions, which is of type OTHER.

The data set is an ensemble of 2018 fossil fuel emission fields derived with the Fossil Fuel Data Assimilation System (FFDAS, Rayner et al., 2010) in 0.1° x 0.1° spatial and daily temporal resolution. FFDAS was ran in an ensemble variational data assimilation mode. Following Fisher (2003) and Rayner et al. (2010), a 100 member ensemble of variational data assimilation experiments was performed, where each member is based on a realisation of the probability density functions of the prior control vector and the observations. Temporal emission profiles were taken from the data set that was derived in CORSO T1.2 and documented by M. Guevara in CORSO M1.

The Deliverable 1.4 provides a data set that is not only relevant on its own, but also as a prior for atmospheric transport inversions. Within CORSO it will be employed to populate the prior error covariance matrix (so-called B matrix) for inversion experiments with the Integrated Forecasting System (IFS). The deliverable is provided earlier than planned (Month 19 rather than 24), so the IFS team has more time to use the data within CORSO.

Potential next steps are

- to derive a similar data set in the Carbon Cycle Fossil Fuel Data Assimilation System that also uses atmospheric observations not used in the IFS inversion system
- to improve the fossil fuel emission model within FFDAS

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2 Introduction

The present document is not a deliverable report but a short document that accompanies a dataset of fossil fuel emissions, which is of type OTHER.

2.1 Background

To enable the European Union (EU) to move towards a low-carbon economy and implement its commitments under the Paris Agreement, a binding target was set to cut emissions in the EU by at least 40% below 1990 levels by 2030. European Commission (EC) President von der Leyen committed to deepen this target to at least 55% reduction by 2030. This was further consolidated with the release of the Commission's European Green Deal on the 11th of December 2019, setting the targets for the European environment, economy, and society to reach zero net emissions of greenhouse gases in 2050, outlining all needed technological and societal transformations that are aiming at combining prosperity and sustainability. To support EU countries in achieving the targets, the EU and EC recognised the need for an objective way to monitor anthropogenic CO_2 emissions and their evolution over time.

Such a monitoring capacity will deliver consistent and reliable information to support informed policy- and decision-making processes, both at national and European level. To maintain independence in this domain, it is seen as critical that the EU establishes an observation-based operational anthropogenic CO_2 emissions Monitoring and Verification Support (MVS) (CO2MVS) capacity as part of its Copernicus Earth Observation programme.

The CORSO research and innovation project within the Horizon Europe programme will build on and complement the work of previous projects such as CHE (the CO2 Human Emissions), and CoCO2 (Copernicus CO2 service) projects, both led by ECMWF. These projects have already started the ramping-up of the CO2MVS prototype systems, so they can be implemented within the Copernicus Atmosphere Monitoring Service (CAMS) with the aim to be operational by 2026. The CORSO project will further support establishing the new CO2MVS addressing specific research & development questions.

The main objectives of CORSO are to deliver further research activities and outcomes with a focus on the use of supplementary observations, i.e., of co-emitted species (nitrogen oxides, NO_x, and carbon monoxide, CO) as well as the use of auxiliary observations to better separate fossil fuel emissions from the other sources and sinks of atmospheric CO_2. CORSO will deliver improved estimates of emission factors/ratios and their uncertainties as well as the capabilities at global and local scale to optimally use observations of co-emitted species in data assimilation systems to better estimate anthropogenic CO_2 emissions. CORSO will also provide clear recommendations to CAMS, ICOS, and WMO about the potential added-value of high-temporal resolution $^{14}CO_2$ and Atmospheric Potential Oxygen (APO) observations as tracers for anthropogenic emissions in both global and regional scale inversions and develop coupled land-atmosphere data assimilation in the global CO2MVS system constraining carbon cycle variables with satellite observations of soil moisture, LAI, SIF, and Biomass. Finally, CORSO will provide specific recommendations for the topics above for the operational implementation of the CO2MVS within the Copernicus programme.

2.2 Scope of this deliverable

2.2.1 Objectives of this deliverables

Deliverable 1.4 provides a data set that combines information from a process model of the fossil fuel emissions with a number of data constraints.

Deliverable 1.4 is not only relevant on its own, but also as a prior for atmospheric transport inversions. Within CORSO it will be employed to populate the prior error covariance matrix (so-called B matrix) for inversion experiments with the Integrated Forecasting System (IFS).

2.2.2 Deviations and counter measures

The deliverable is provided earlier than planned (Month 21 rather than 24), so the IFS team has more time to use the data within CORSO.

3 FFDAS

The Fossil Fuel Data Assimilation System (FFDAS, Rayner et al., 2010) uses a variational approach to optimise parameters in a sectoral process model fossil fuel emissions against 2018 sectoral national emission totals derived from the World Energy balances data base provided by the International Energy Agency[1] and nighttime light intensities observed by satellites (Elvidge et al., 2021). Locations of and emissions from individual power plants for the year 2018 taken from a data base compiled within the Horizon 2020 project CoCO2[2] are used to derive prior information on the energy generation sector. These data sets were complemented by maps of population density (Sims et al., 2022) and roads[3] as well as meteorological data from ECMWF's ERA5 atmospheric reanalyses of the global climate (Hersbach et al., 2020).

The FFDAS version used explicitly resolves the sectors

- energy generation,
- residential combustion,
- and road transport.

All remaining fossil fuel emission are comprised in the system's "other sector". Temporal emission profiles were taken from the data set that was derived in CORSO T1.2 and documented by M. Guevara in CORSO M1.

FFDAS was ran in an ensemble variational data assimilation mode. Following Fisher (2003) and Rayner et al. (2010), a 100 member ensemble of variational data assimilation experiments was performed, where each member is based on a realisation of the probability density functions of the prior control vector and the observations.

The ensemble allows to compute various statistics, including the ensemble mean and the ensemble (co)variance. As an example, Figure 1 shows for each 0.1° x 0.1° grid cell the ratio of the posterior uncertainty in the 2018 annual fossil fuel emissions (quantified as standard deviation of the ensemble) relative the (ensemble) mean.

Work in Task 1.4 will continue and improvements of the data set are anticipated through

[1] see https://www.iea.org/data-and-statistics/data-product/world-energy-balances
[2] see Hugo Denier van der Gon and CoCO2 WP2 team; D2.1 Prior Emission data 2018 documentation report, available at https://coco2-project.eu/node/327
[3] taken from the Open Streetmap project

- refinement of the existing sectoral models
- finer sectoral differentiation, and
- validation against other emission data sets.

It is foreseen to publish the final data set in an open source repository.

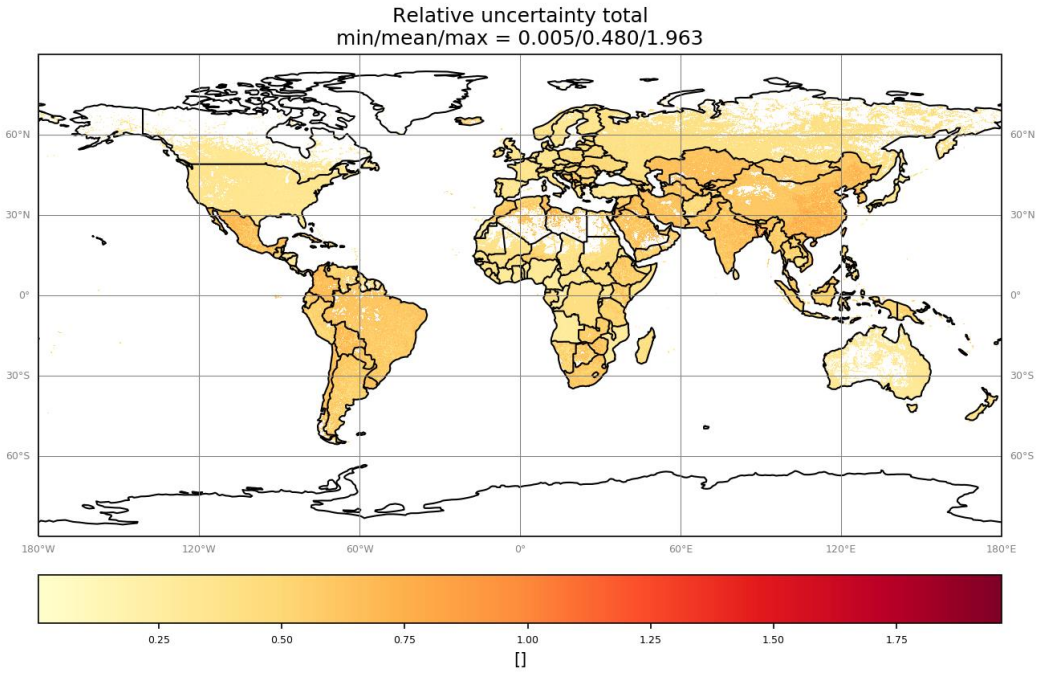

Figure 1: Ratio of the posterior uncertainty in the 2018 annual fossil fuel emissions (quantified as standard deviation of the ensemble) relative the (ensemble) mean.

4 Data Format

The data set contains a 100 member ensemble of fossil fuel emissions of the year 2018 in gC/m^2/day at 0.1° x 0.1° spatial and daily temporal resolution. It is provided in NetCDF4, in the file ffdas-ensemble-emissions_total_nens100_2018.nc with the following header:

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netcdf ffdas-ensemble-emissions_total_nens100_2018 {
dimensions:
    n_points = 1534739 ;
    time = 365 ;
    ensemble_size = 100 ;
variables:
    double lon(n_points) ;
        lon:long_name = "longitude" ;
        lon:units = "degrees_east" ;
        lon:comment = "coordinate of grid-cell centre" ;
    double lat(n_points) ;
        lat:long_name = "latitude" ;
        lat:units = "degrees_north" ;
        lat:comment = "coordinate of grid-cell centre" ;
    double time(time) ;
        time:long_name = "time" ;
        time:units = "days since 2018-01-01" ;
    float total_emission_ensemble(ensemble_size, time, n_points) ;
        total_emission_ensemble:_FillValue = 9.96921e+36f ;
        total_emission_ensemble:long_name = "total CO2 emissions" ;
        total_emission_ensemble:units = "gC/m2/d" ;
        total_emission_ensemble:missing_value = 9.96921e+36f ;

// global attributes:
        :title = "CO2 emissions from FFDAS ensemble runs" ;
        :institution = "The Inversion Lab, Hamburg, Germany" ;
        :geospatial_lon_min = -180. ;
        :geospation_lon_max = 180. ;
        :geospatial_lon_resolution = 0.1 ;
        :geospatial_lat_min = -90. ;
        :geospation_lat_max = 90. ;
        :geospatial_lat_resolution = 0.1 ;
        :time_coverage_start = "2018-01-01" ;
        :time_coverage_end = "2018-12-31" ;
        :time_coverage_resolution = "P1D" ;
        :date_created = "2024-07-22T22:52:25.167728" ;
}
```

5 References

Elvidge CD, Zhizhin M, Ghosh T, Hsu F-C, Taneja J. Annual Time Series of Global VIIRS Nighttime Lights Derived from Monthly Averages: 2012 to 2019. *Remote Sensing*. 2021; 13(5):922. https://doi.org/10.3390/rs13050922

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Document History

Version	Author(s)	Date	Changes
1	Thomas Kaminski and Michael Voßbeck	23 July 2024	Initial version
2	Thomas Kaminski	9 August 2024	Updates reflecting internal review
3	Thomas Kaminski	September 2024	Updates reflecting internal review by second reviewer

Internal Review History

Internal Reviewers	Date	Comments
Auke Visser and Nicolas Bousserez	9 August 2024	Minor requests for clarification and textual suggestions
Jean-Christophe Calvet	20 August 2024	Suggestion of minor changes