CO2MVS RESEARCH ON SUPPLEMENTARY OBSERVATIONS

D2.3 Software library for data-driven emission quantification of hot spots

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1 Executive Summary

This work has been done as part of WP2, which focuses on the use of co-emitted species to better estimate anthropogenic emissions in the future CO2MVS capacity. This report contributes to the objectives of WP2 by providing access to the software library for data-driven emission quantification (ddeq), which is used in WP2 for estimating CO and NO_x emissions of hot spots. *ddeq* is an open-source Python library that was developed in the CoCO2 and CORSO project.

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2 Introduction

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 European Commission (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 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 it 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 as well as the use of auxiliary observations to better separate fossil fuel emissions from the other sources 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 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 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 WP-2

The work presented in this report is part of WP2 of CORSO, which deals with “Use of co-emitted species (correlations, improved emission ratios, uncertainties) in data assimilation systems". The aim of WP2 is to improve the use of observations of co-emitted species (NO_2, CO) to better estimate anthropogenic CO_2 emissions in the future CO2MVS capacity. This is based on the recognition that anthropogenic CO_2 emissions cannot completely be constrained with CO_2 concentration observations alone, and the detectability of the anthropogenic signal of co-emitted species is often much better than that of CO_2. For the emission estimation development at local scale, this WP focuses on the development of methods to increase the accuracy of annual CO_2 emission estimates of hot spots, industrial and urban areas by integrating satellite observations of co-emitted species (NO_2 and CO) in data assimilation

systems. Since CO_2 satellite observations are temporally sparse (even with the future CO2M constellation), temporal sampling biases are a significant source of uncertainty in annual CO_2 emission estimates of hot spots. Co-emitted species such as CO and NO_2 are and will be available at sub-diurnal temporal coverage from current and future LEO and GEO satellites. They can therefore be used to improve the constraint on the temporal variability of CO_2 emissions and hence for reducing the uncertainty in annual estimates. The local and regional studies will focus on three regions: Europe, Africa, and Southeast Asia.

2.2.1 Objectives of this deliverables

The objectives of this deliverable are to provide a software library for data-driven emission quantification of hot spots. The title of this deliverable is "Software library for data-driven emission quantification of hot spots". The deliverable contains this report, which provides the following references to the open-source Python library data-driven emission quantification (ddeq): peer-reviewed publication, code repository and documentation.

2.2.2 Work performed in this deliverable

This deliverable was accomplished through the publication of the ddeq library and the collection of the relevant references.

2.3 Project partners involved with this deliverable

Partners	
EIDGENOSSISCHE MATERIALPRUFUNGS- UND FORSCHUNGSANSTALT	EMPA

3 The *ddeq* Python library

This document describes the Python software for data-driven emission quantification (*ddeq*). The ddeq library was originally developed in the SMARTCARB project for detecting and quantifying CO_2 and NO_x emissions in synthetic CO_2 and NO_2 images of the CO2M mission (Kuhlmann et al. 2019, 2020, 2021). *ddeq* has been used in the CoCO2 project for benchmarking the different methods using synthetic CO2M observations (Santaren et al., 2023) and TROPOMI NO_2 observations (Hakkarainen et al., 2023). In the CORSO project, the library was expanded as part of WP-2 for quantifying NO_x and CO emissions from TROPOMI observations (Meier et al. 2024).

ddeq is an open source library, whose latest release is available on the Python Package Index (PyPI; https://pypi.org/project/ddeq/). The issue tracker and the development version of the library are available on the project's website: https://gitlab.com/empa503/remote-sensing/ddeq. The documentation of the library is available on "Read the Docs" (https://ddeq.readthedocs.io/).

The library was published in Geoscientific Model Development (DOI: https://doi.org/10.5194/gmd-17-4773-2024):

Abstract

Atmospheric emissions from anthropogenic hotspots, i.e., cities, power plants and industrial facilities, can be determined from remote sensing images obtained from airborne and space-based imaging spectrometers. In this paper, we present a Python library for data-driven emission quantification (ddeq) that implements various computationally light methods such as the Gaussian plume inversion, cross-sectional flux method, integrated mass enhancement method and divergence method. The library provides a shared interface for data input and output and tools for pre- and post-processing of data. The shared interface makes it possible to easily compare and benchmark the different methods. The paper describes the theoretical basis of the different emission quantification methods and their implementation in the ddeq library. The application of the methods is demonstrated using Jupyter notebooks included in the library, for example, for NO_2 images from the Sentinel-5P/TROPOMI satellite and for synthetic CO_2 and NO_2 images from the Copernicus CO_2 Monitoring (CO2M) satellite constellation. The library can be easily extended for new datasets and methods, providing a powerful community tool for users and developers interested in emission monitoring using remote sensing images.

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