Estimating emissions of methane and carbon dioxide sources using analytical Bayesian inversion system based on WRF-GHG tagged tracer simulations

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INTRODUCTION

A good example of the complications that we need to face when studying the **Global Carbon Budget** is the fact that during the last fifty years, **uncertainties** in the estimates of fossil-fuel related carbon emissions have **increased**. Reason: significant differences in energy inventories and errors in bottom-up reporting.

Bayesian inverse modelling techniques can be used alternative means of providing the constraints on the emissions of the greenhouse compounds (such as CH_4 and CO_2). Because of high demands on accuracy and density of atmospheric observations on the regional scales, the ability of inverse models to reduce uncertainty on regional scales has been limited so far.

CoMet (Carbon Dioxide and Methane Mission) aircraft campaign (Fig. 1), executed in May – June 2018 has provided ground-based and airborne observations over a coal mining region (USCB, Upper Silesian Coal Basin) at precision levels necessary for well-constrained **regional inversions over a challenging source area with multiple strong point sources influencing the measured signals.**

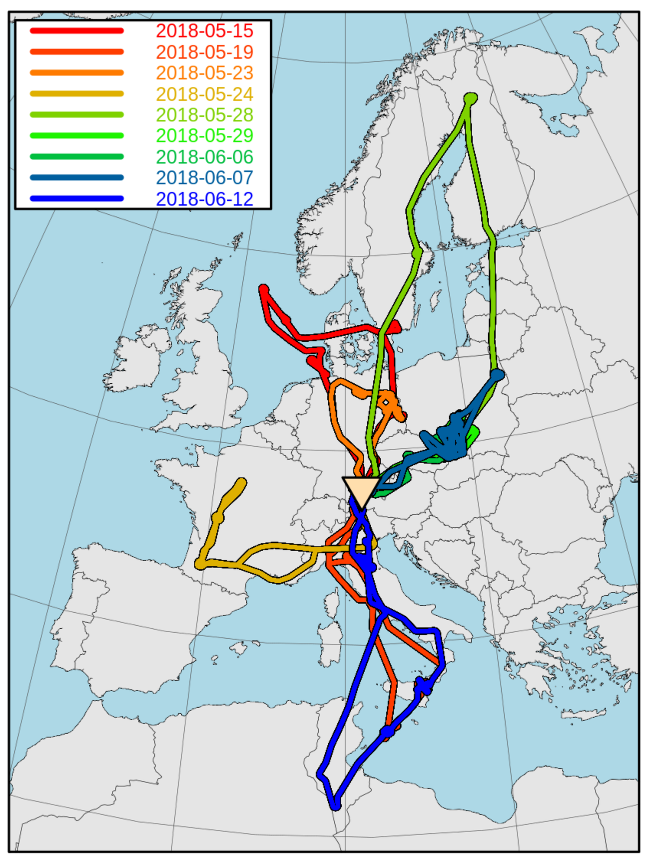

Fig. 1. Overview of the CoMet HALO flights.

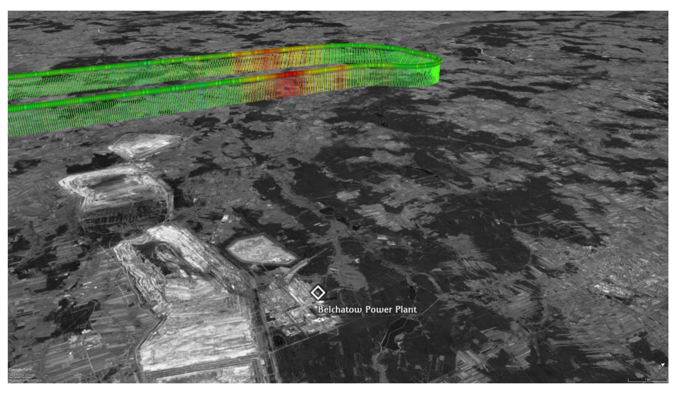

Fig. 2. Measurements taken downwind of the coal power plant.

MEASUREMENTS

- Aboard HALO (Fig. 3A): Jena Instrument for Greenhouse Gas Observations (JIG)
- Aboard FDLR (Fig. 3B): Picarro G1301m instrument
- Both instruments calibrated against WMO scales with bias within WMO compatibility goals (0.1 ppm for CO_2 and 0.2 ppb for CH_4).

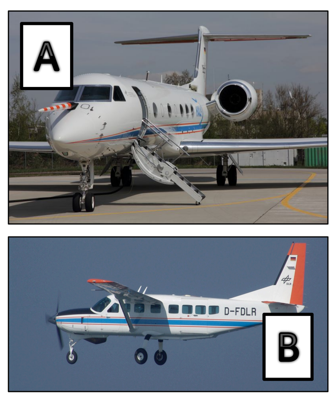

Figure 3. Airborne platforms.
A: HALO, airborne research platform, operated by DLR (Deutsches Zentrum fur Luft- und Raumfahrt), on which in-situ CO_2/CH_4 continuous online measurement instrument JIG (HALO) was installed.
B: Cessna airborne platform, DLR, equipped with in situ CRDS analyser (Picarro).

Transport model: WRF-GHG (WRF-Chem v 3.9.1.1.)

- Regional simulation, 2 km x 2 km domain over USCB, nested in 10 km x 10 km parent domain over Europe, 60 vertical layers up to approx. 21 km
- Initial + boundary conditions: ECMWF IFS + CAMS GHG product
- Net Ecosystem Exchange and Respiration fluxes from VPRM model (online)
- Individual tracers: 9 for CO_2, over 120 for CH_4 (individual coal-mine shafts)
- High-frequency output (1 minute) used for comparisons
- Installed on Mistral Cluster of DKRZ (Deutsches Klimatrechnenzentrum)

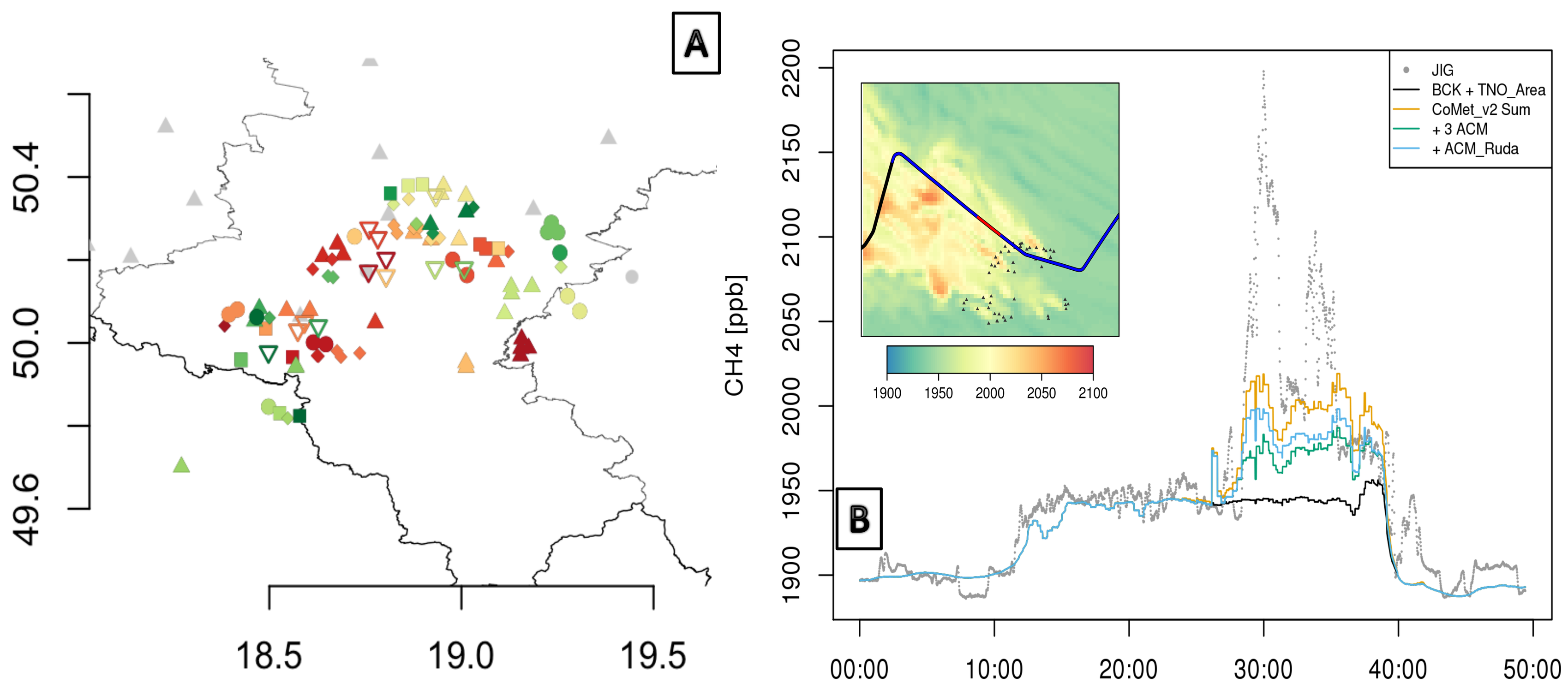

Figure 4. *WRF-GHG simulations over the study area.* ***A:*** *CH_4 emission sources over Silesia. Each point represents an individual source, with an assigned tagged tracer in the simulation.* ***B:*** *An example of comparison between model and observations. Full modelled signal (yellow) and an example of signal partitioning in green and blue. Green – background + 3 coal mines. Blue – background + 4 coal mines. Smaller panel on the left shows spatial distribution of the partitioned signal at the moment of measurement, with flight path overlaid.*

Analytical inversion system

- Inverse modelling system
  - Analytical inversion system

$$\hat{x} = x_a + (K^T S_e^{-1} K + S_a^{-1}) \cdot K^T \cdot S_e^{-1} \cdot (y - K \cdot x_a)$$

  - State space: 9 (for CO_2) or 116 (CH_4) scaling factors representing simulated tagged tracers and background
  - Assuming prior emission uncertainty of 10%

RESULTS – CO_2

- Case study from June 7th, 2018, assimilating JIG data from HALO (Fig. 2)
- Flying downwind of a strong point source (Bełchatów power plant)
- Model-data mismatch: 3 ppm
- Transport error: 10 ppm, decaying exponentially with tau = 10 seconds
- Prior emissions assumed uncorrelated, 10% uncertainty

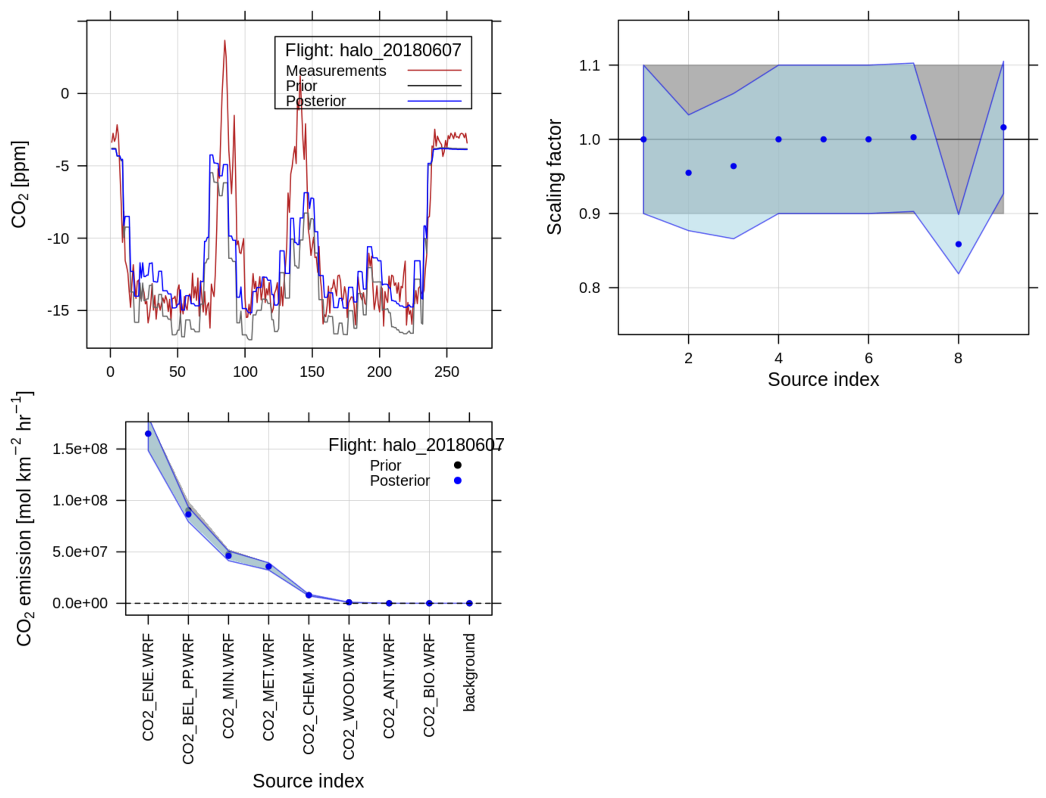

Figure 5. Results of the CO_2 inversion using measurements downwind of the Bełchatów power plant. Top - left: in situ observations against a-priori and a-posteriori model concentrations. Top-right: a priori and a posteriori (blue) scaling factors for 9 source groups. Bottom-left: results of the inversion in the flux space with uncertainties. Results ordered by respective annual emissions, except biogenic and background (far right). Colours: red – measurements, black - a-priori, blue - a-posteriori.

RESULTS – CH_4

- Case study from June 7th, 2018, assimilating in situ data from FDLR Cessna.
- Flying through USCB
- Model-data mismatch: 30 ppb
- Transport error: 30 ppb, decaying exponentially with tau = 30 seconds

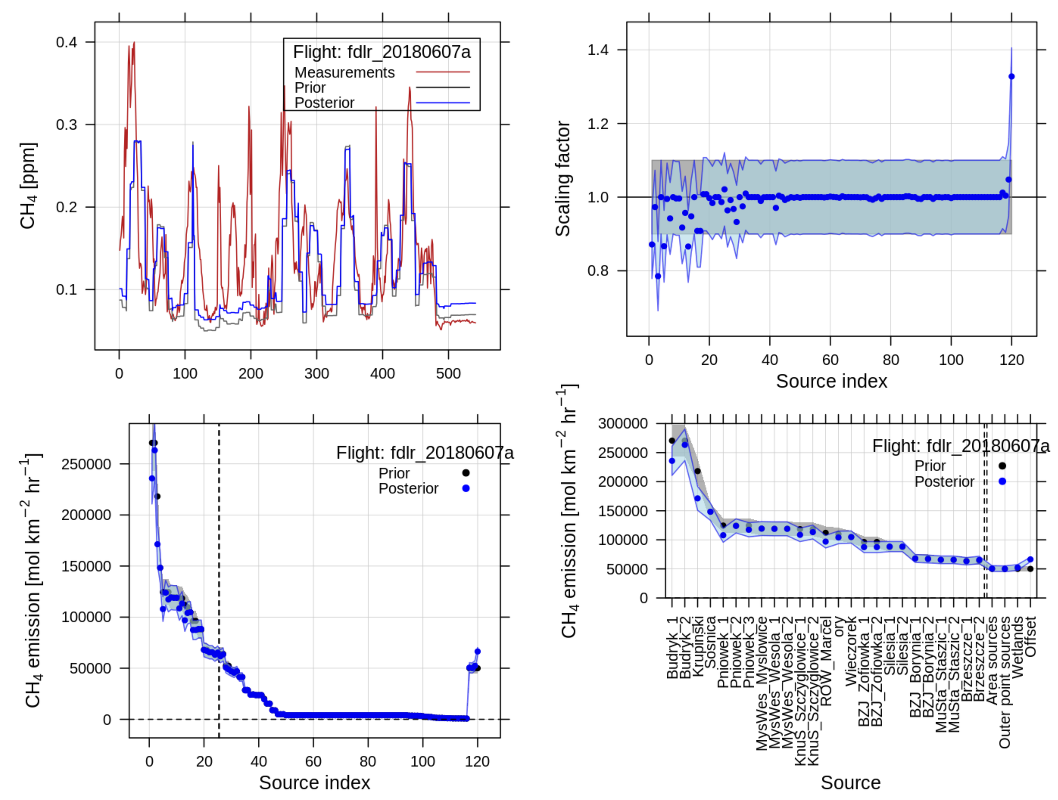

Figure 6. Results of the CH_4 inversion using measurements downwind of the Bełchatów power plant. Top - left: in situ observations against a-priori and a-posteriori model concentrations. Top-right: a priori and a posteriori (blue) scaling factors for available emission sources. Bottom-left: prior and posterior emissions with uncertainties. Results ordered by respective annual emissions, except biogenic and background tracers (far right). Bottom-right: same as before, with 25 strongest sources plotted. Colours: red – measurements, black - a-priori, blue - a-posteriori.

DISCUSSION

Presented framework allows to constrain uncertain emissions from point anthropogenic sources (or clusters of sources) based on available high-resolution in situ data.

In presented case of CO_2 (Fig. 5) the system correctly attributed the signal to the studied source. The predicted a-posteriori emissions for the power plant were lower by 18.3%, albeit the sensitivity to transport errors are high. It should be noted that the biogenic flux was optimized to be 12.3% lower, pointing to an overestimation of the NEE predicted by VPRM module in WRF-GHG.

For the presented CH_4 case (Fig. 6), the system predicts overall reduction in emissions (by 4.6%), but is unable to represent the full variability for specific cases. For example, a posteriori emissions Krupiński coal mine are reduced by 21.5%, whereas the newest bottom-up estimates show 75% reduction due to closing down of the mine in that time.

Results also suggest that in case of nearby sources, transport simulations at resolutions higher than 2 km may be required in such a complicated emission cluster.

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