SPECIAL PROJECT FINAL REPORT

All the following mandatory information needs to be provided.

Project Title:	Extend and improve CH_4 flux inversions at global and European scale
Computer Project Account:	spjrc4dv
Start Year - End Year :	2021 - 2021
Principal Investigator(s)	Dr. Ernest Koffi (EC-JRC[1], ECMWF[2])
Affiliation/Address:	[1]European Commission Joint Research Centre (EC-JRC) Directorate for Energy, Transport and Climate Air and Climate Unit TP 124 I-21027 Ispra (Va) Italy [2]now at: ECMWF, Bonn, Germany
Other Researchers (Name/Affiliation):	Dr. Peter Bergamaschi, EC-JRC, Ispra, Italy (retired) Dr. Arjo Segers, TNO, Utrecht, Netherlands Prof. Dr. Dominik Brunner, Empa, Dübendorf, Switzerland

The following should cover the entire project duration.

Summary of project objectives

(10 lines max)

- Extend and improve estimates of global CH_4 emissions
- Further develop, test and apply coupled FLEXPART-COSMO / TM5 4DVAR inverse modelling system ("FLEXVAR") with high spatial resolution.

Summary of problems encountered

(If you encountered any problems of a more technical nature, please describe them here.)

no major problems

Experience with the Special Project framework

(Please let us know about your experience with administrative aspects like the application procedure, progress reporting etc.)

Overall, the administrative procedures are straight-forward.
The excellent technical support by the ECMWF user support team is highly appreciated.

Summary of results

(This section should comprise up to 10 pages, reflecting the complexity and duration of the project, and can be replaced by a short summary plus an existing scientific report on the project.)

Due to changes in the JRC internal work plan, the work performed within this special project focussed on the second project objective ("Further develop, test and apply coupled FLEXPART-COSMO / TM5 4DVAR inverse modelling system ("FLEXVAR") with high spatial resolution"), performed by P. Bergamaschi and A. Segers.

Major further developments of the FLEXVAR system included:

- a new approach to estimate / parameterize the model representation error based on meteorological data (from COSMO-7 model) at the monitoring stations has been implemented and tested. This new approach results in generally somewhat better statistical performance of the station data (posteriori model simulations vs. observations) compared to the parameterization of the model representation error based on the difference between prior model simulations and observations.

- a new approach to describe the boundary conditions ("baseline") for the limited domain model FLEXPART has been implemented, based on the "particle dumps" of the FLEXPART trajectories (particle positions at termination of the back trajectories) and 3D CH_4 concentration fields from global TM5-4DVAR inversions (with European zoom). In general, the baselines calculated with the new approach ("particle position baselines") are rather similar to those calculated with the scheme of Rödenbeck et al. [2009] (https://doi.org/10.5194/acp-9-5331-2009; "Rödenbeck baselines"). However, sometimes the "particle position baselines" are somewhat higher than the "Rödenbeck baselines", resulting in slightly lower derived emissions in the inversions.

- The conjugate gradient / Lanczos algorithm has been implemented to estimate the posteriori uncertainties, including aggregated uncertainties, e.g., for total emissions from countries (taking into account the estimated posterior covariance). In general, the inversions based on the conjugate gradient algorithm yield rather similar posterior emissions as the inversions using the m1qn3 algorithm.

- The emission interface has been extended to allow the use of various further emission inventories (e.g., EDGARv6.0 or TNO-VERIFYv3.0) as prior emission estimates.

The FLEXVAR system has been thoroughly tested, including detailed analyses of the sensitivity of the FLEXVAR inversions to the model parameterizations (model representation error, baselines) and different settings of the prior error covariance parameters (horizontal correlation length, temporal correlation scale, and assumed uncertainties of emissions per grid cell and month). Furthermore, the sensitivity of the FLEXVAR inversions to the main input data (i.e., prior emission inventories and observational data) has been investigated.
The FLEXVAR system, the various sensitivity experiments, and the application for the inverse modelling of European CH_4 emissions 2018 has been described in detail in a new publication [Bergamaschi et al., 2022]. The analysis showed that derived total emissions per country depend only weakly on the applied prior emission inventory (for 3 different emission inventories) for regions / countries which are well constrained by the observations. Furthermore, the sensitivity experiments showed that additional observational constraints can have a significant impact in the surroundings of the additional observation sites (Fig. 1). At the same time, the additional observational constraints result in a significant reduction of calculated posterior uncertainties.
Finally, the FLEXVAR inversions have been compared with the FLEXPART extended Kalman filter system and with TM5-4DVAR inversions at $1^o \times 1^o$ resolution over Europe, showing overall good consistency. For further details see [Bergamaschi et al., 2022].

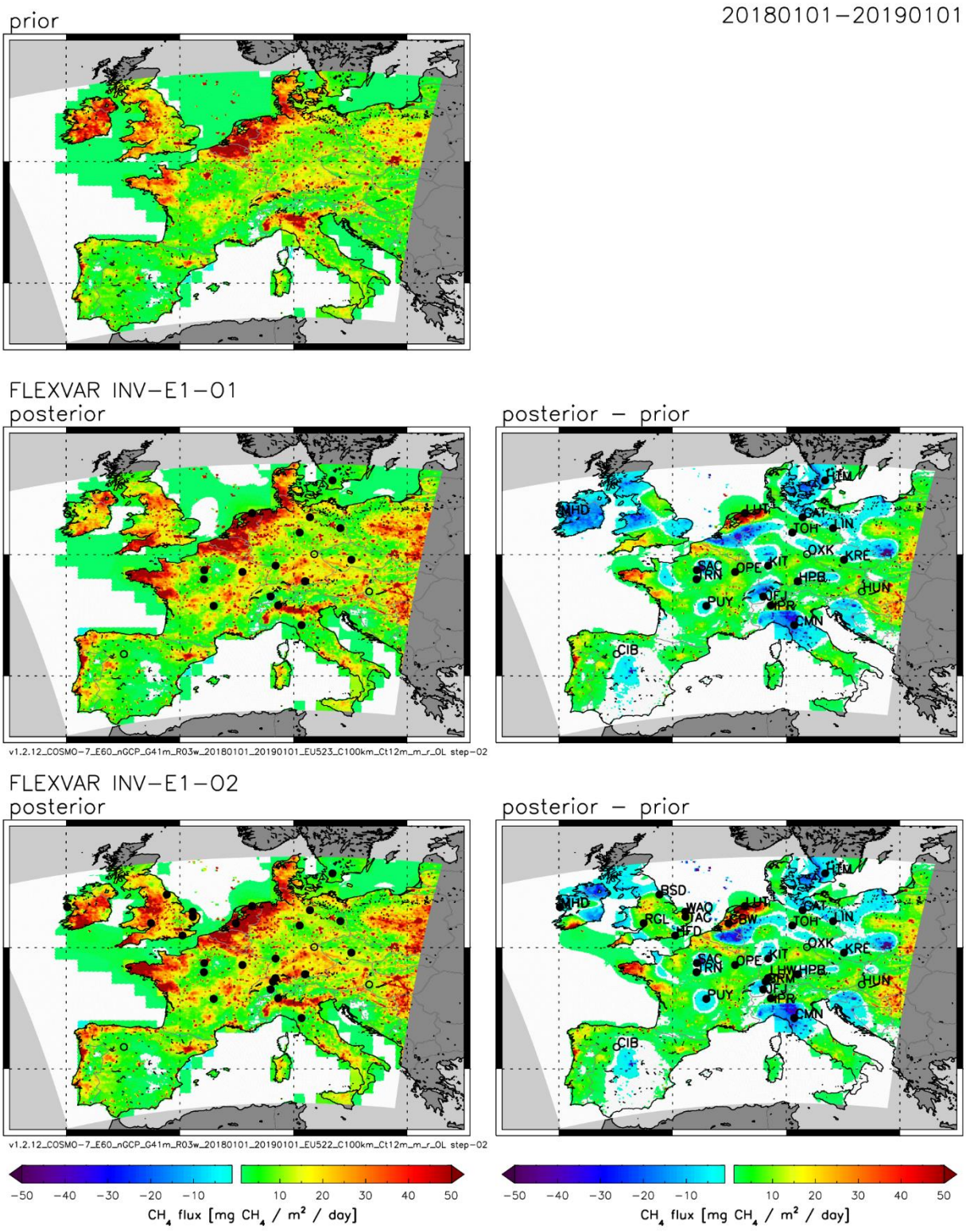

Figure 1: Sensitivity of FLEXVAR inversions to applied observation data sets (figure from [Bergamaschi et al., 2022]). FLEXVAR inversion INV-E1-O1 (middle row) uses the base observation data set O1 (15 ICOS stations with continuous measurements, complemented with 5 discrete air sampling sites from NOAA ESRL). Inversion INV-E1-O2 (lower row) uses 9 additional stations with continuous measurements, including 6 stations on the British Isles. Solid black circles show locations of stations with in situ data, open circles locations of stations with discrete air sampling. For further details see [Bergamaschi et al., 2022].

List of publications/reports from the project with complete references

Bergamaschi, P., Segers, A., Brunner, D., Haussaire, J.-M., Henne, S., Ramonet, M., Arnold, T., Biermann, T., Chen, H., Conil, S., Delmotte, M., Forster, G., Frumau, A., Kubistin, D., Lan, X., Leuenberger, M., Lindauer, M., Lopez, M., Manca, G., Müller-Williams, J., O'Doherty, S., Scheeren, B., Steinbacher, M., Trisolino, P., Vítková, G., and Yver Kwok, C.: High-resolution inverse modelling of European CH_4 emissions using novel FLEXPART-COSMO TM5 4DVAR inverse modelling system, Atmos. Chem. Phys. Discuss. [preprint], https://doi.org/10.5194/acp-2022-118, in review, 2022.

Future plans

(Please let us know of any imminent plans regarding a continuation of this research activity, in particular if they are linked to another/new Special Project.)

It is planned to continue the work on the inverse modelling under the new special project "Extend and improve CH_4 flux inversions at global and European scale based on ERA5 reanalyses" (2022-2024).