SPECIAL PROJECT PROGRESS REPORT

All the following mandatory information needs to be provided. The length should *reflect the complexity and duration* of the project.

Reporting year	2020 (01 July 2019 - 30 June 2020)
Project Title:	Improve European and global CH_4 and N_2O flux inversions
Computer Project Account:	spjrc4dv
Principal Investigator(s):	Dr. Peter Bergamaschi
Affiliation:	European Commission Joint Research Centre (EC-JRC) Directorate for Energy, Transport and Climate Air and Climate Unit TP 124 I-21027 Ispra (Va) Italy
Name of ECMWF scientist(s) collaborating to the project (if applicable)	Dr. Anna Agusti-Panareda (in the framework of the Copernicus / CAMS project)
Start date of the project:	01 January 2018
Expected end date:	31 December 2020

Computer resources allocated/used for the current year and the previous one

(if applicable)

Please answer for all project resources

		Previous year		Current year	
		Allocated	Used	Allocated	Used
High Performance Computing Facility	(units)	400000	353841	400000	9210 (14 June 2020)
Data storage capacity	(Gbytes)	800		1200	

Summary of project objectives (10 lines max)

1. Improve estimates of global CH4 emissions using new satellite retrievals

2. Improve estimates of European CH4 and N2O emissions using in-situ observations

3. Develop coupled global / regional inversion system with high spatial resolution

Summary of problems encountered (10 lines max)

no major problems

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Summary of plans for the continuation of the project (10 lines max)

The global CH_4 flux inversions will be further extended (until 2019) in order to further analyse trends in global and regional CH_4 emissions.

A 3rd series of VERIFY inversions will be performed in the second half of 2019 using updated a priori emission inventories and extended observational data sets.

The coupled FLEXPART-COSMO / TM5 4DVAR inverse modelling system ("FLEXVAR") will be further developed. Specific issues for the further development are the implementation and testing of several new approaches to estimate the model representation errors, the implementation of a new interface to use different a priori emission inventories, use of alternative approaches to prescribe the baselines / boundary conditions, and estimates of the a posteriori uncertainties.

List of publications/reports from the project with complete references

Bergamaschi, P., U. Karstens, A. J. Manning, M. Saunois, A. Tsuruta, A. Berchet, A. T. Vermeulen, T. Arnold, G. Janssens-Maenhout, S. Hammer, I. Levin, M. Schmidt, M. Ramonet, M. Lopez, J. Lavric, T. Aalto, H. Chen, D. G. Feist, C. Gerbig, L. Haszpra, O. Hermansen, G. Manca, J. Moncrieff, F. Meinhardt, J. Necki, M. Galkowski, amp, apos, S. Doherty, N. Paramonova, H. A. Scheeren, M. Steinbacher, and E. Dlugokencky, Inverse modelling of European CH_4 emissions during 2006–2012 using different inverse models and reassessed atmospheric observations, *Atmos. Chem. Phys.*, 18(2), 901-920, doi: 10.5194/acp-18-901-2018, 2018.

Bergamaschi, P., A. Segers, G. Manca, and D. Brunner, High-resolution inverse modelling of CH_4 emissions around monitoring station Ispra, Italy - first results, poster presented at 3rd ICOS Science Conference, Prague, 11-13 September 2018.

Bergamaschi, P., D. Brunner, R. Thompson, P. Bousquet, Top-down estimates of European CH_4 emissions during 2005-2016 using two different inverse models, oral presentation at 8th International Symposium on Non-CO_2 Greenhouse Gases, June 12-14, 2019, Amsterdam, The Netherlands, 2019.

Koffi, E.N. and Bergamaschi, P., Evaluation of Copernicus Atmosphere Monitoring Service methane products, EUR 29349 EN, Publications Office of the European Union, Luxembourg, 2018, ISBN 978-92-79-93409-4, doi:10.2760/906932, JRC112816, 2018.

Koffi, E. N., Bergamaschi, P., Alkama, R., and Cescatti, A., An observation-constrained assessment of the climate sensitivity and future trajectories of wetland methane emissions, *Science Advances* 10 Apr 2020: Vol. 6, no. 15, eaay4444, DOI: 10.1126/sciadv.aay4444, 2020.

Parker, R. J., A. Webb, H. Boesch, P. Somkuti, R. Barrio Guillo, A. Di Noia, N. Kalaitzi, J. Anand, P. Bergamaschi, F. Chevallier, L. Feng, N. M. Deutscher, D. G. Feist, D. W. T. Griffith, F. Hase, R. Kivi, I. Morino, J. Notholt, Y. S. Oh, H. Ohyama, C. Petri, D. F. Pollard, C. Roehl, M. K. Sha, K. Shiomi, K. Strong, R. Sussmann, Y. Té, V. A. Velazco, T. Warneke, P. O. Wennberg, and D. Wunch, A Decade of GOSAT Proxy Satellite CH_4 Observations, submitted to *Earth Syst. Sci. Data,* 2020.

Saunois, M., Stavert, A. R., Poulter, B., Bousquet, P., Canadell, J. G., Jackson, R. B., Raymond, P. A., Dlugokencky, E. J., Houweling, S., Patra, P. K., Ciais, P., Arora, V. K., Bastviken, D., Bergamaschi, P., Blake, D. R., Brailsford, G., Bruhwiler, L., Carlson, K. M., Carrol, M., Castaldi, S., Chandra, N., Crevoisier, C., Crill, P. M., Covey, K., Curry, C. L., Etiope, G., Frankenberg, C., Gedney, N., Hegglin, M. I., Höglund-Isaksson, L., Hugelius, G., Ishizawa, M., Ito, A., Janssens-Maenhout, G., Jensen, K. M., Joos, F., Kleinen, T., Krummel, P. B., Langenfelds, R. L., Laruelle, G. G., Liu, L., Machida, T., Maksyutov, S., McDonald, K. C., McNorton, J., Miller, P. A., Melton, J. R., Morino, I., Müller, J., Murgia-Flores, F., Naik, V., Niwa, Y., Noce, S., O'Doherty, S., Parker, R. J., Peng, C., Peng, S., Peters, G. P., Prigent, C., Prinn, R., Ramonet, M., Regnier, P., Riley, W. J., Rosentreter, J. A., Segers, A., Simpson, I. J., Shi, H., Smith, S. J., Steele, L. P., Thornton, B. F., Tian, H., Tohjima, Y., Tubiello, F. N., Tsuruta, A., Viovy, N., Voulgarakis, A., Weber, T. S., van Weele, M., van der Werf, G. R., Weiss, R. F., Worthy, D., Wunch, D., Yin, Y., Yoshida, Y., Zhang, W., Zhang, Z., Zhao, Y., Zheng, B., Zhu, Q., Zhu, Q., and Zhuang, Q.: The Global Methane Budget 2000–2017, *Earth Syst. Sci. Data Discuss.*, https://doi.org/10.5194/essd-2019-128, accepted for publication in *Earth Syst. Sci. Data,* 2020.

Summary of results

If submitted **during the first project year**, please summarise the results achieved during the period from the project start to June of the current year. A few paragraphs might be sufficient. If submitted **during the second project year**, this summary should be more detailed and cover the period from the project start. The length, at most 8 pages, should reflect the complexity of the project. Alternatively, it could be replaced by a short summary plus an existing scientific report on the project attached to this document. If submitted **during the third project year**, please summarise the results achieved during the period from July of the previous year to June of the current year. A few paragraphs might be sufficient.

Improve estimates of global CH_4 emissions using new satellite retrievals

The series of global CH_4 flux inversions (provided for the period 2000-2017 in the previous reporting period) has been used in a detailed analysis of the global CH_4 budget [Saunois et al., 2020] in the framework of the Global Carbon Project CH_4 (GCP-CH_4). In the current reporting period this inversion series has been further extended until end of 2018 (Figure 1). As in the previous inversion series, the inversions for 2018 show the significant differences in the derived spatial emission patterns between the inversions using only surface observations (from NOAA Earth System Research Laboratory (ESRL) global cooperative air sampling network (INV1)), and inversions which assimilate both surface observations and satellite retrievals of column-average dry-air mole fractions (XCH_4) from GOSAT (using the GOSAT OCPRv7.2 product) (INV2). These differences are due to the different observational constraints: While the surface observations from remote background stations provide information on emissions mainly on larger continental scales, the GOSAT satellite retrievals provide additional constraints on regional scales.

The new inversions are used for the further validation of the Copernicus Atmosphere Monitoring Service (CAMS) CH_4 products (updating and extending the previous report [*Koffi and Bergamaschi*, 2018]). In addition, the NOAA-only inversions have been used to evaluate the latest release (v9.0) of the University of Leicester GOSAT Proxy XCH_4 dataset [Parker et al., 2020].

Furthermore, the global CH_4 flux inversions were used to derive an observation-driven estimate of the climate sensitivity of wetland methane emissions [Koffi et al., 2020], analyzing the response functions of CH_4 fluxes (derived in the inversion) to observed temperature and precipitation. The derived climate sensitivity has been used to estimate the increase of wetland CH_4 emissions by 2100 under different climate scenarios [Koffi et al., 2020], resulting in a projected increase by 50 to 80% under the RCP 8.5 ("business-as-usual") climate scenario.

Improve estimates of European CH_4 and N_2O emissions using in-situ observations

Within the H2020 project VERIFY ("Observation-based system for monitoring and verification of greenhouse gases"; http://verify.lsce.ipsl.fr/) updated CH_4 inversions with zoom over Europe have been performed, following the updated VERIFY modelling protocol 2019.

Figure 2 shows the derived European CH_4 emissions (average of 2005-2017) as provided for the VERIFY project. The results are currently analyzed in more detail, including a comprehensive comparison between different inverse models and various bottom-up inventories for natural and anthropogenic emissions (including both various scientific inventories and emission data reported to UNFCCC).

Furthermore, various sensitivity inversions have been performed, investing the impact of using different a priori emission inventories, different OH fields, different parameterizations of vertical transport, and different observational data sets.

The 3nd series of VERIFY inversions will be performed in the second half of 2020, using updated a priori emission inventories and extended observational data sets, and extending the inversions until end of 2018.

Develop coupled global / regional inversion system with high spatial resolution

The coupled FLEXPART-COSMO / TM5 4DVAR inverse modelling system ("FLEXVAR") has been further developed (main model development: Arjo Segers, TNO; FLEXPART simulations: Dominik Brunner, EMPA). The most important development was the significant speed-up of the previous prototype system (by a factor of about 16) and extension of the observation operation to allow the use of observational data sets from multiple stations.

Figure 3 shows first results using the updated FLEXVAR system and a comprehensive observational data set of 25 European atmospheric stations. Further tests of the updated system demonstrated that the inversion is performed in a technically correct way, as indicated by the achieved significant reduction in the gradient norm of the cost function and the significant improvement of the statistics of the simulated vs. observed station data (correlation, bias, RMS difference).

A major issue remains the more realistic description of the model representation error (which largely determines the weighting of the individual observation data). The further development of different approaches to estimate the model representation error has started and will be continued in the coming project period.

Figures

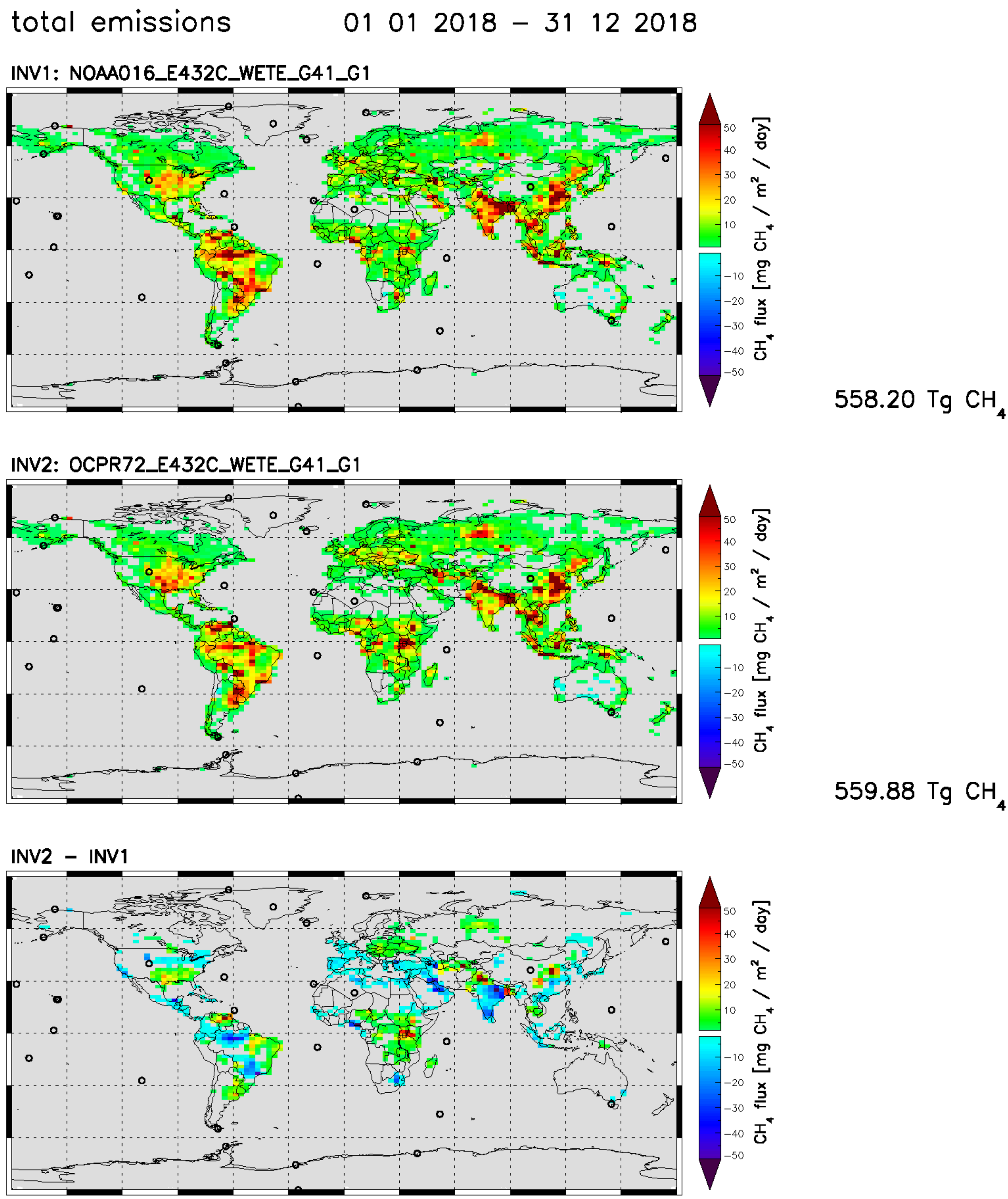

Figure 1: Derived (a posteriori) total CH_4 emissions 2018. Top: INV1 including only NOAA surface observations. Middle: inversion INV2 using both NOAA surface observations and XCH_4 satellite retrievals from GOSAT. Bottom: Difference between INV2 and INV1. The open circles show the locations of the NOAA discrete air sampling sites used in the inversion.

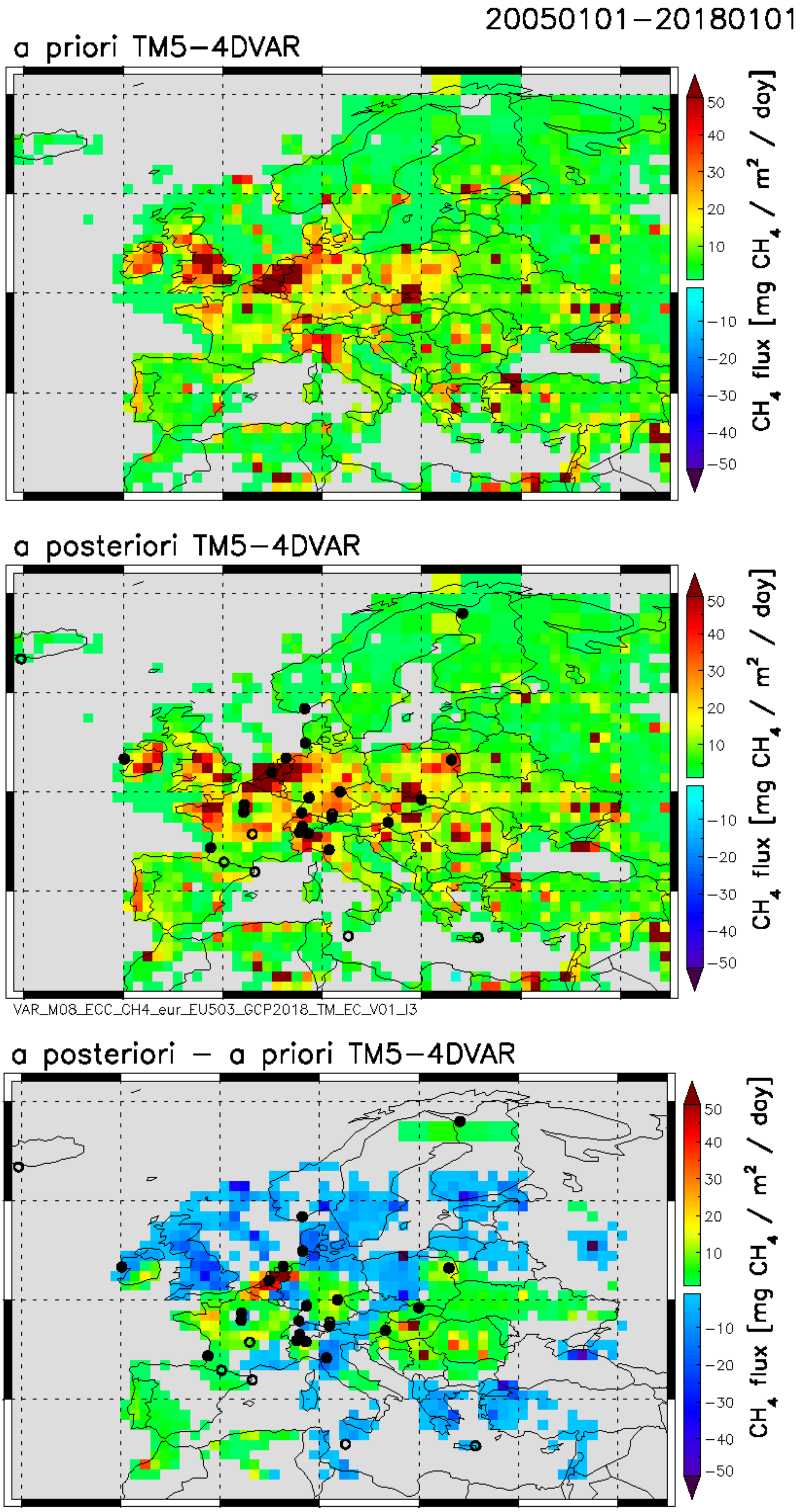

Figure 2: European CH_4 emissions (average 2005-2017). Top: a priori emissions. Middle: a posteriori emissions. Bottom: difference between a posteriori and a priori. Black circles show locations of measurement stations used in the inversion; filled circles: stations with quasi-continuous measurements; open circles: discrete air sampling sites.

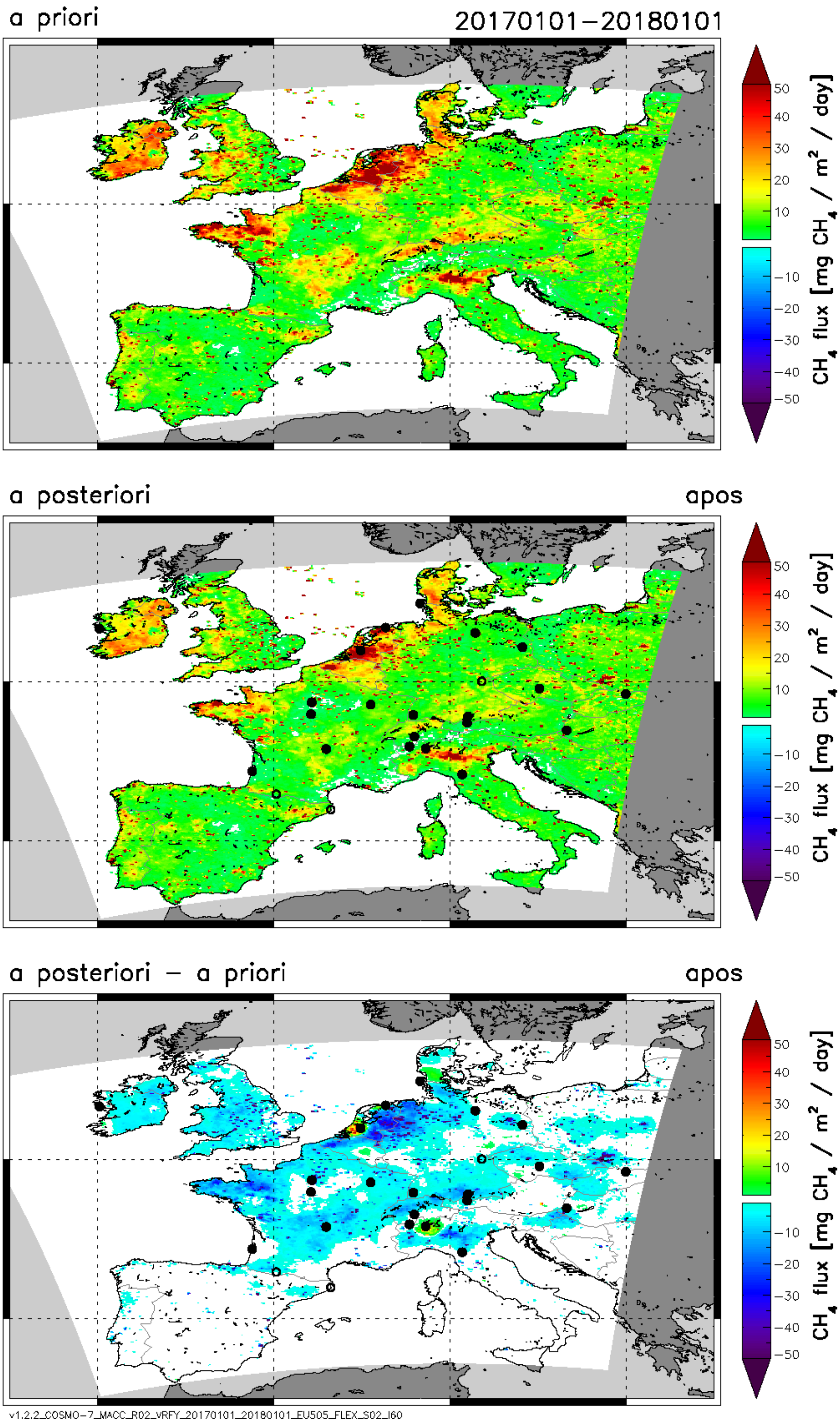

Figure 3: Inverse modelling of European CH_4 emissions with high-resolution FLEXVAR inverse modelling system. The FLEXVAR system uses FLEXPART-COSMO-7 backtrajectories at a resolution of about 7 km. Top: a priori emissions. Middle: a posteriori emissions. Bottom: difference between a posteriori and a priori. Black circles show locations of measurement stations used in the inversion; filled circles: stations with quasi-continuous measurements; open circles: discrete air sampling sites.