SPECIAL PROJECT PROGRESS REPORT

Progress Reports should be 2 to 10 pages in length, depending on importance of the project. All the following mandatory information needs to be provided.

Reporting year

2016 (01 July 2015 - 30 June 2016)

Project Title:

Improve estimates of global and regional CH_4 and N_2O emissions based on inverse modelling using in-situ and satellite measurements

Computer Project Account:

spjrc4dv

Principal Investigator(s):

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Name of ECMWF scientist(s) collaborating to the project
(if applicable)

Dr. Anna Agusti-Panareda (in the framework of the MACC-III project)

Start date of the project:

01 January 2015

Expected end date:

31 December 2017

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)	580000 (400000[1] +80000[2] +100000[3])	540000	400000	78288 (30/06/2016)
Data storage capacity	(Gbytes)	580 (400[2] +80[1] +100[2])		400	

[1]original allocation
[2] request for additional resources 14/09/2015
[3] request for additional resources 30/10/2015

Summary of project objectives
(10 lines max)

(1) Improve estimates of global CH_4 emissions using new satellite retrievals

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

(3) Improve TM5-4DVAR inverse modelling system

Summary of problems encountered (if any)
(20 lines max)

no major problems

Summary of results of the current year (from July of previous year to June of current year)
This section should comprise 1 to 8 pages and can be replaced by a short summary plus an existing scientific report on the project

Improve estimates of global CH_4 emissions using new satellite retrievals

Global CH_4 flux inversions have been performed using four different GOSAT XCH_4 products from the Climate Research Data Package #3 (CRDP#3) of the GHG-CCI project (http://www.esa-ghg-cci.org/) of ESA's Climate Change Initiative (CCI). Figure 1 shows the global maps of derived CH_4 fluxes for the period 2010-2014. Overall, the four inversions show qualitatively very similar spatial distributions of the posteriori CH_4 fluxes, consistent with the analysis of previous XCH_4 products described by *Alexe et al.* [2015]. Pronounced patterns in the inversions increments are the considerable emission increase over the South-Central United States, decrease over the Congo basin, but increase over tropical East Africa, and reductions over large parts of Southeast Asia compared to the prior emissions. These patterns are clearly visible in the inversions of all four GOSAT product, but especially the decrease over the Congo basin is much less pronounced in the inversions of the two 'full physics' XCH_4 products (RemoteC_FP v2.3.7 and OCFP v1.0), most likely largely related to the much lower number of retrievals close to the equator for these two products (for more details see ESA Climate Assessment report version 3 [*Chevallier et al*., 2016]).
The extended re-analysis performed within the MACC-II/MACC-III project and additional GOSAT CH_4 flux inversions have been used in a recent analysis of the global CH_4 budget within the international Global Carbon Project CH_4 initiative [*Saunois et al.,* 2016].

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

Within the FP7 project InGOS ("Integrated non-CO_2 greenhouse gas Observing Systems" (http://www.ingos-infrastructure.eu/) European CH_4 and N_2O inversions have been completed for the period 2006-2012, using the new harmonized CH_4 and N_2O InGOS dataset ('2014 InGOS data release'). The TM5-4DVAR inversions have been compared with the other models used in InGOS (total of 7 models used of CH_4, and 4 models for N_2O). For CH_4, the model comparison largely confirms the previous finding of higher total European CH_4 emissions compared to the total anthropogenic CH_4 emissions reported to UNFCCC ('bottom-up', based on statistical data and emissions factors) [*Bergamaschi et al.,* 2015]. A potential explanation for the discrepancy between the 'bottom-up' and 'top-down' estimates could be the contribution of natural sources, such as peatlands, wetlands, and wet soils, which might have been underestimated in previous analyses. The hypothesis of significant natural emissions is supported by the finding that the inversions yield significant seasonal cycles of derived CH_4 emissions with maximum in summer, while anthropogenic CH_4 emissions are assumed to have much lower seasonal variability. Furthermore we investigated potential biases of the flux inversions by comparing model simulations with regular aircraft profiles at 4 European sites and the 'Infrastructure for Measurement of the European Carbon Cycle (IMECC)' aircraft campaign.
For N_2O, for which uncertainties of bottom-up inventories are very large - typically on the order of 100% for the total N_2O emissions per country (mainly due to N_2O emissions from agricultural soils) - the inversions demonstrate that atmospheric measurements and inverse modelling can significantly reduce the uncertainties.
Furthermore, ^{222}Rn simulations have been performed for a detailed evaluation of the simulations of the boundary layer dynamics in TM5 [*Koffi et al.,* 2016].

Improve TM5-4DVAR inverse modelling system

The new modular TM5-pyshell version has been further developed including further updates of the interface for the satellite observations (from the ESA GHG cci CRDP#3 products).
Furthermore, two new methods to estimate the uncertainties of the flux inversions have been implemented: (1) an Ensemble (Monte Carlo) method and (2) a method using the finite differences of the gradient of the cost in order to approximate the Hessian matrix. The advantage of the new methods is that they can be used also for the non-linear version of the TM5-4DVAR system, in

contrast to the Conjugate Gradient / Lanczos algorithm. The different approaches are currently compared in more detail.

List of publications/reports from the project with complete references

Alexe, M., P. Bergamaschi, A. Segers, R. Detmers, A. Butz, O. Hasekamp, S. Guerlet, R. Parker, H. Boesch, C. Frankenberg, R. A. Scheepmaker, E. Dlugokencky, C. Sweeney, S. C. Wofsy and E. A. Kort, Inverse modeling of CH_4 emissions for 2010–2011 using different satellite retrieval products from GOSAT and SCIAMACHY, Atmos. Chem. Phys., 15, 113-133, 2015.

Bergamaschi, P., M. Corazza, U. Karstens, M. Athanassiadou, R. L. Thompson, I. Pison, A. J. Manning, P. Bousquet, A. Segers, A. T. Vermeulen, G. Janssens-Maenhout, M. Schmidt, M. Ramonet, F. Meinhardt, T. Aalto, L. Haszpra, J. Moncrieff, M. E. Popa, D. Lowry, M. Steinbacher, A. Jordan, S. O'Doherty, S. Piacentino and E. Dlugokencky, Top-down estimates of European CH_4 and N_2O emissions based on four different inverse models, Atmos. Chem. Phys., 15, 715-736, 2015.

Chevallier, F., P. Bergamaschi, D.Brunner, S.Gonzi, S.Houweling, T.Kaminski, G.Kuhlmann, T.T. van Leeuwen, J.Marshall, P.I. Palmer, and M.Scholze, Climate Assessment Report for the GHG-CCI project of ESA's Climate Change Initiative, pp. 87, version 2, 22 April 2015, http://www.esa-ghg-cci.org/?q=webfm_send/256, 2015.

Chevallier, F., M. Alexe, P. Bergamaschi, D. Brunner, L. Feng, S. Houweling, T. Kaminski, W. Knorr, T. T. van Leeuwen, J. Marshall, P. I. Palmer, M. Scholze, A.-M. Sundström and M. Voßbeck, Climate Assessment Report for the GHG-CCI project of ESA's Climate Change Initiative, pp. 94, version 3, 3 May 2016, http://www.esa-ghg-cci.org/?q=webfm_send/318, 2016.

Koffi, E. N., Bergamaschi, P., Karstens, U., Krol, M., Segers, A., Schmidt, M., Levin, I., Vermeulen, A. T., Fisher, R. E., Kazan, V., Klein Baltink, H., Lowry, D., Manca, G., Meijer, H. A. J., Moncrieff, J., Pal, S., Ramonet, M., and Scheeren, H. A.: Evaluation of the boundary layer dynamics of the TM5 model, Geosci. Model Dev. Discuss., doi:10.5194/gmd-2016-48, in review, 2016.

Parker, R. J., Boesch, H., Byckling, K., Webb, A. J., Palmer, P. I., Feng, L., Bergamaschi, P., Chevallier, F., Notholt, J., Deutscher, N., Warneke, T., Hase, F., Sussmann, R., Kawakami, S., Kivi, R., Griffith, D. W. T., and Velazco, V.: Assessing 5 years of GOSAT Proxy XCH_4 data and associated uncertainties, Atmos. Meas. Tech., 8, 4785-4801, doi:10.5194/amt-8-4785-2015, 2015.

Saunois, M., Bousquet, P., Poulter, B., Peregon, A., Ciais, P., Canadell, J. G., Dlugokencky, E. J., Etiope, G., Bastviken, D., Houweling, S., Janssens-Maenhout, G., Tubiello, F. N., Castaldi, S., Jackson, R. B., Alexe, M., Arora, V. K., Beerling, D. J., Bergamaschi, P., Blake, D. R., Brailsford, G., Brovkin, V., Bruhwiler, L., Crevoisier, C., Crill, P., Curry, C., Frankenberg, C., Gedney, N., Höglund-Isaksson, L., Ishizawa, M., Ito, A., Joos, F., Kim, H.-S., Kleinen, T., Krummel, P., Lamarque, J.-F., Langenfelds, R., Locatelli, R., Machida, T., Maksyutov, S., McDonald, K. C., Marshall, J., Melton, J. R., Morino, I., O'Doherty, S., Parmentier, F.-J. W., Patra, P. K., Peng, C., Peng, S., Peters, G. P., Pison, I., Prigent, C., Prinn, R., Ramonet, M., Riley, W. J., Saito, M., Schroeder, R., Simpson, I. J., Spahni, R., Steele, P., Takizawa, A., Thornton, B. F., Tian, H., Tohjima, Y., Viovy, N., Voulgarakis, A., van Weele, M., van der Werf, G., Weiss, R., Wiedinmyer, C., Wilton, D. J., Wiltshire, A., Worthy, D., Wunch, D. B., Xu, X., Yoshida, Y., Zhang, B., Zhang, Z., and Zhu, Q.: The Global Methane Budget: 2000–2012, Earth Syst. Sci. Data Discuss., doi:10.5194/essd-2016-25, in review, 2016.

Summary of plans for the continuation of the project

(10 lines max)

Update (and extend) global CH_4 flux inversions using upcoming new release of GOSAT XCH_4 retrievals from the next Climate Research Data Package of the ESA-GHG cci project. Comprehensive validation of model results, including the stratosphere (using e.g. stratospheric air core data).

Further sensitivity tests for European CH_4 and N_2O flux inversions (including further tests of different parameterisations of convection and diffusion). Evaluate performance of various TM5-4DVAR sensitivity inversions against regular European aircraft profiles.

Continue development of Monte-Carlo / finite differences techniques for uncertainty estimates.

Figures

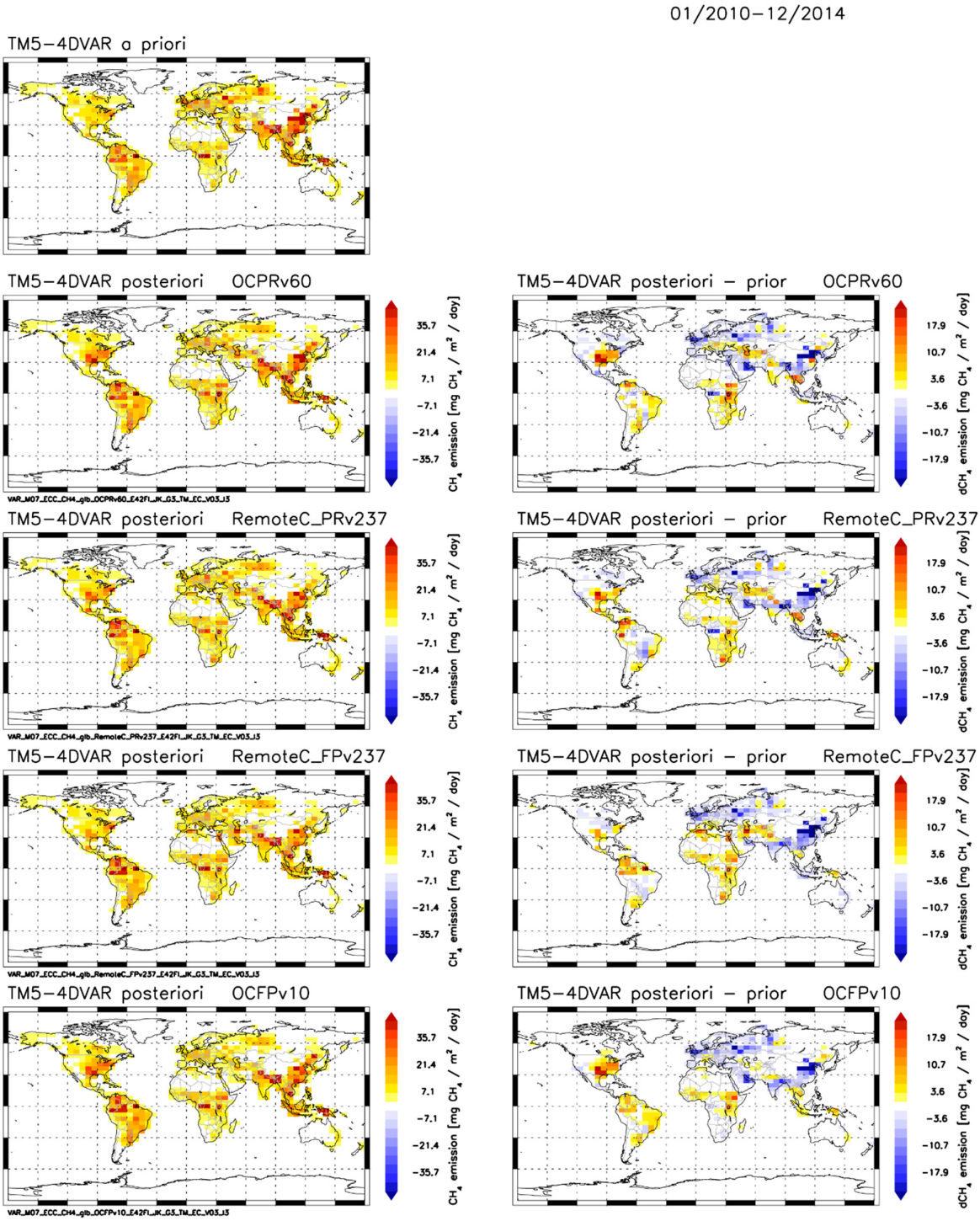

Figure 1: CH_4 emissions (average 2010-2014). Upper left map shows the applied prior emissions, and the subsequent rows the posteriori emissions (left) and the inversion increments (difference between posterior and prior emissions; right) for the inversions of four GOSAT products from the Climate Research Data Package #3 (CRDP#3) of the ESA GHG cci project - second phase.