SPECIAL PROJECT FINAL REPORT

All the following mandatory information needs to be provided.

Project Title:	Global and regional inverse modelling of atmospheric CH_4 and N_2O
Computer Project Account:	spjrc4dv
Start Year - End Year :	2012 - 2014
Principal Investigator(s)	Dr. Peter Bergamaschi
Affiliation/Address:	European Commission Joint Research Centre (EC-JRC) Institute for Environment and Sustainability (IES) Air and Climate Unit TP 123 I-21027 Ispra (Va) Italy
Other Researchers (Name/Affiliation):	Dr. Mihai Alexe, EC-JRC IES Dr. Ernest Koffi, EC-JRC IES Dr. Arjo Segers, TNO Utrecht, Netherlands

The following should cover the entire project duration.

Summary of project objectives

(10 lines max)

1. Improve global CH_4 inversions using new satellite retrievals (contribution to MACC-II and MACC-III project)

2. Improve European CH_4 and N_2O inversions using in-situ observations

3. Further development of TM5-4DVAR system

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.)

- Application procedure straight-forward
- Reporting template could be improved (embedded tables for reporting are not convenient for sections exceeding 1 page)

Summary of results

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

Improve global CH_4 inversions using new satellite retrievals (contribution to MACC-II and MACC-III project)

The MACC CH_4 inversion reanalysis over the period 2003-2010 [*Bergamaschi et al., 2013a*] has been further extended until end of 2012 (with inversions using SCIAMACHY data extended only until 2011 (due to the end of operation of ENVISAT)). As for 2007-2010, also for 2011-2012 higher global CH_4 emissions are derived compared to 2003-2005. Most of the inferred emission increase was located in the tropics and mid-latitudes of the northern hemisphere, while no significant trend was derived for Arctic latitudes (Figure 1).

The extended MACC CH_4 inversion reanalysis has been used as reference for evaluation of improved XCH_4 products developed with the ESA-GHG cci - second phase project (Climate Research Data Package 2 (CRDP2)) [Chevalier et al., 2015].

Furthermore, the MACC CH_4 inversion reanalysis contributed to the Global Carbon Project CH_4 [*Kirschke et al., Nature Geoscience, 2013*].

Half-yearly MACC-II/MACC-III 'delayed-mode' CH_4 inversions have been delivered to ECMWF and published on the MACC website:

http://www.copernicus-atmosphere.eu/d/services/gac/delayed/ch4_flux_inversions/

Since 01/2012 CH_4 retrievals from GOSAT (RemoteC PROXY v2.0 XCH_4 product from SRON) have been used, while the previous CH_4 inversions were based on SCIAMACHY (IMAPv5.5), which became dysfunctional beginning 2012.

The performance of the 'delayed-mode' CH_4 inversions has been further documented in specific MACC technical reports [*Bergamaschi et al., 2013b; Bergamaschi and Alexe, 2014*].

In order to investigate the impact of the changing data streams on the inversions, a detailed comparison study has been performed using the different XCH_4 satellite products from SCIAMACHY and GOSAT, including additional XCH_4 products developed within the ESA GHG climate change initiative project [*Alexe et al., 2015*]. This study shows the significant improvement of GOSAT retrievals compared to SCIAMACHY, with significantly lower bias and noise of the GOSAT retrievals (RMS reduced by more than factor 3). The most important result is that the different retrieval products yield qualitatively consistent regional CH_4 emission patterns, particularly over the United States and Tropical Africa (Figure 2). The derived regional fluxes (2010-2011 average) for the TRANSCOM regions agree within ~10-15 Tg CH_4/yr [*Alexe et al., 2015*].

Improve European CH_4 and N_2O inversions using in-situ observations

European CH_4 and N_2O inversions have been performed using the improved, harmonized European CH_4 in-situ measurements, generated in the InGOS ("Integrated non-CO_2 greenhouse gas Observing Systems") project (http://www.ingos-infrastructure.eu/) for the period 2007-2011. Overall the first InGOS CH_4 and N_2O inversions showed good consistency with an earlier analysis performed for the

years 2006 and 2007 [*Bergamaschi et al., 2015*]. These inversions are currently further updated within the InGOS project (which will run until end 2015).

The global N_2O inversions contributed to the international TransCom-N_2O model comparison (N_2O forward and inverse model simulations) [*Thompson et al., 2014a; 2014b*].

A detailed model validation has been performed using ^{222}Rn simulations (based on a novel ^{222}Rn soil emission inventory, parameterized by soil type, porosity, moisture and water table [*Karstens et al., 2014a*]. Furthermore boundary layer height dynamics in TM5 have been compared with the NOAA Integrated Global Radiosonde Archive (IGRA) and LIDAR measurements [*Karstens et al., 2014b*].

Further development of TM5-4DVAR system

The TM5-4DVAR observations interface has been upgraded for various GOSAT retrievals products (from ESA GHG climate change intiative project [*Alexe et al., 2015*]).

The new TM5-4DVAR pyshell version (with enhanced modularity) has been further developed, implementing important features of the JRC TM5-4DVAR version used so far ('T38'), including support of m1qn3, semi-lognormal probability density function for a priori, continuous surface observations, treatment of model representation errors.

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.

Bergamaschi, P. and Alexe, M. Report on the quality of the inverted CH_4 fluxes (second report), MACC-II Deliverable D_43.3, Tech. rep., available at: https://www.gmes-atmosphere.eu/documents/maccii/deliverables/ghg/, Joint Research Center, European Commission, 2014.

Bergamaschi, P., S. Houweling, A. Segers, M. Krol, C. Frankenberg, R. A. Scheepmaker, E. Dlugokencky, S. Wofsy, E. Kort, C. Sweeney, T. Schuck, C. Brenninkmeijer, H. Chen, V. Beck and C. Gerbig, Atmospheric CH_4 in the first decade of the 21st century: Inverse modeling analysis using SCIAMACHY satellite retrievals and NOAA surface measurements, J. Geophys. Res., doi:10.1002/jgrd.50480, 2013a.

Bergamaschi, P., Segers, A., Scheepmaker, R., Frankenberg, C., Hasekamp, O., Dlugokencky, E., Sweeney, C., Ramonet, M., Tarniewicz, J., Kort, E., and Wofsy, S.: Report on the quality of

the inverted CH_4 fluxes, MACC-II Deliverable D_43.3, Tech. rep., available at: https://www.gmes-atmosphere.eu/documents/maccii/deliverables/ghg/, Joint Research Center, European Commission, 2013b.

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, 2015. http://www.esa-ghg-cci.org/?q=node/95

Houweling, S., M. Krol, P. Bergamaschi, C. Frankenberg, E. J. Dlugokencky, I. Morino, J. Notholt, V. Sherlock, D. Wunch, V. Beck, C. Gerbig, H. Chen, E. A. Kort, T. Röckmann and I. Aben, A multi-year methane inversion using SCIAMACHY, accounting for systematic errors using TCCON measurements, Atmos. Chem. Phys., 14, 3991–4012, 2014.

Karstens, U., P. Bergamaschi, I. Levin, E. Koffi, M. Saunois, R. Locatelli, I. Heard, A.J. Manning, A.T. Vermeulen, M. Schmidt, R. Fisher, J. Hatakka, H.A.J. Meijer, J. Moncrieff, and C. Schlosser, Comparison of ^{222}Radon simulations based on the new ^{222}Radon inventory with observations, InGOS Deliverable D15.4, report, 2014a.

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Kirschke, S., P. Bousquet, P. Ciais, M. Saunois, J. G. Canadell, E. J. Dlugokencky, P. Bergamaschi, D. Bergmann, D. R. Blake, L. Bruhwiler, P. Cameron-Smith, S. Castaldi, F. Chevallier, L. Feng, A. Fraser, M. Heimann, E. L. Hodson, S. Houweling, B. Josse, P. J. Fraser, P. B. Krummel, J.-F. Lamarque, R. L. Langenfelds, C. Le Quéré, V. Naik, S. O'Doherty, P. I. Palmer, I. Pison, D. Plummer, B. Poulter, R. J. Prinn, M. Rigby, B. Ringeval, M. Santini, M. Schmidt, D. T. Shindell, I. J. Simpson, R. Spahni, L. P. Steele, S. A. Strode, K. Sudo, S. Szopa, G. R. van der Werf, A. Voulgarakis, M. van Weele, R. F. Weiss, J. E. Williams and G. Zeng, Three decades of global methane sources and sinks, Nature Geoscience, 6, 813–823, 2013.

Parker, R. J., H. Boesch, K. Byckling, A. J. Webb, P. P. I., L. Feng, P. Bergamaschi, F. Chevallier, J. Notholt, N. Deutscher, T. Warneke, F. Hase, R. Sussmann, S. Kawakami, R. Kivi, D. W. T. Griffith and V. Velazco, Assessing 5 years of GOSAT Proxy XCH_4 data and associated uncertainties, Atmos. Meas. Tech. Discuss., 8, 5937–5972, 2015.

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Thompson, R. L., K. Ishijima, E. Saikawa, M. Corazza, U. Karstens, P. K. Patra, P. Bergamaschi, F. Chevallier, E. Dlugokencky, R. G. Prinn, R. F. Weiss, S. O'Doherty, P. J. Fraser, L. P. Steele, P. B. Krummel, A. Vermeulen, Y. Tohjima, A. Jordan, L. Haszpra, M. Steinbacher, S. van der Laan, T. Aalto, F. Meinhardt, M. E. Popa, J. Moncrieff and P. Bousquet, TransCom N2O model inter-comparison Part II: Atmospheric inversion estimates of N_2O emissions, Atmos. Chem. Phys., 14, 6177–6194, 2014.

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.)

Major activities of this special project are continued in the new special project 'Improve estimates of global and regional CH_4 and N_2O emissions based on inverse modelling using in-situ and satellite measurements' (2015-2017).

Figures

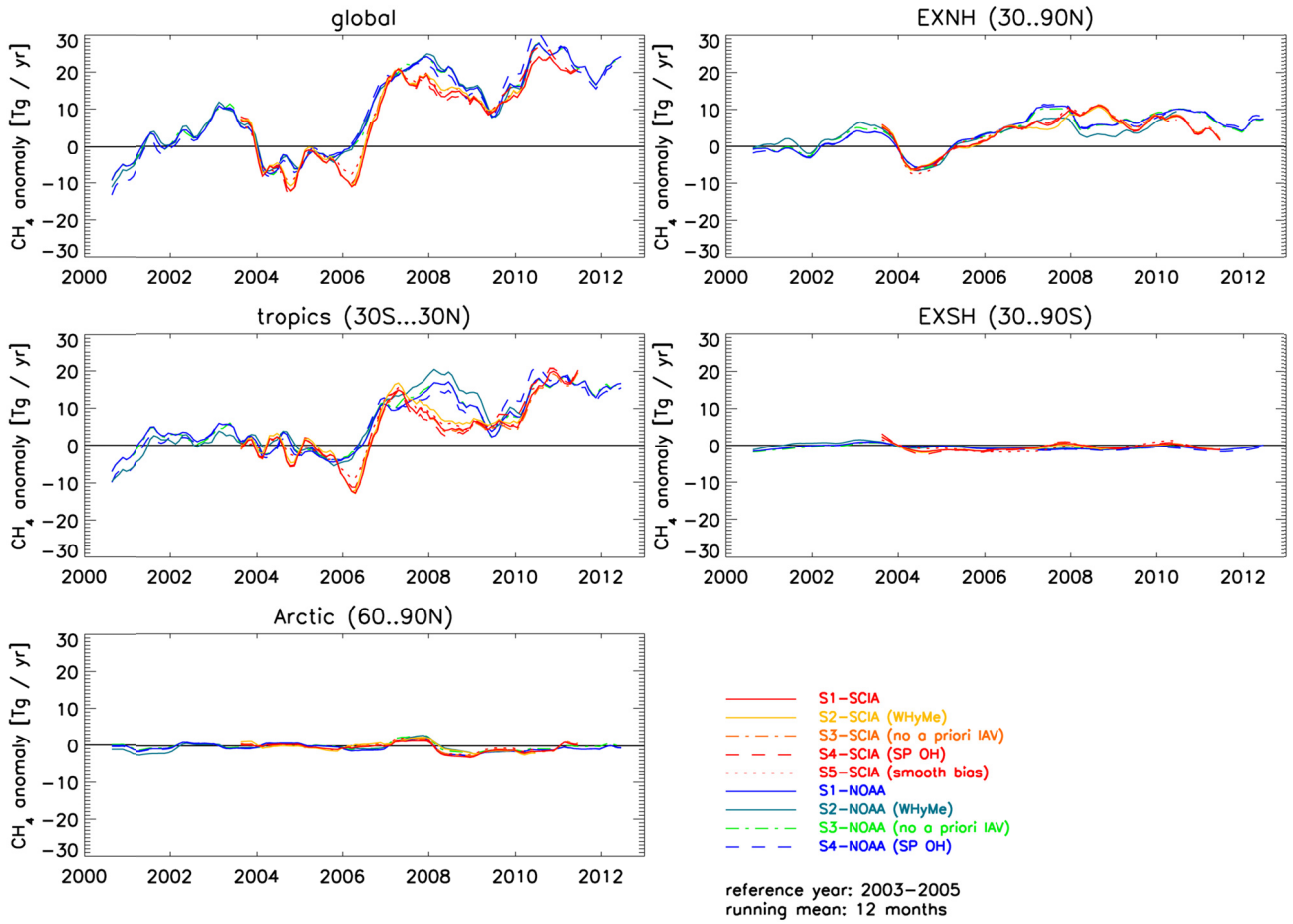

Figure 1: Extension of reanalysis of global CH_4 emissions until end 2012: CH_4 Inter-annual variation of total CH_4 emissions derived from the different inversions. The variations are shown relative to the average emissions during the reference period 2003-2005 (12-month running mean values). For the detailed analysis of the reanalysis until 2010 see [*Bergamaschi et al., 2013a*].

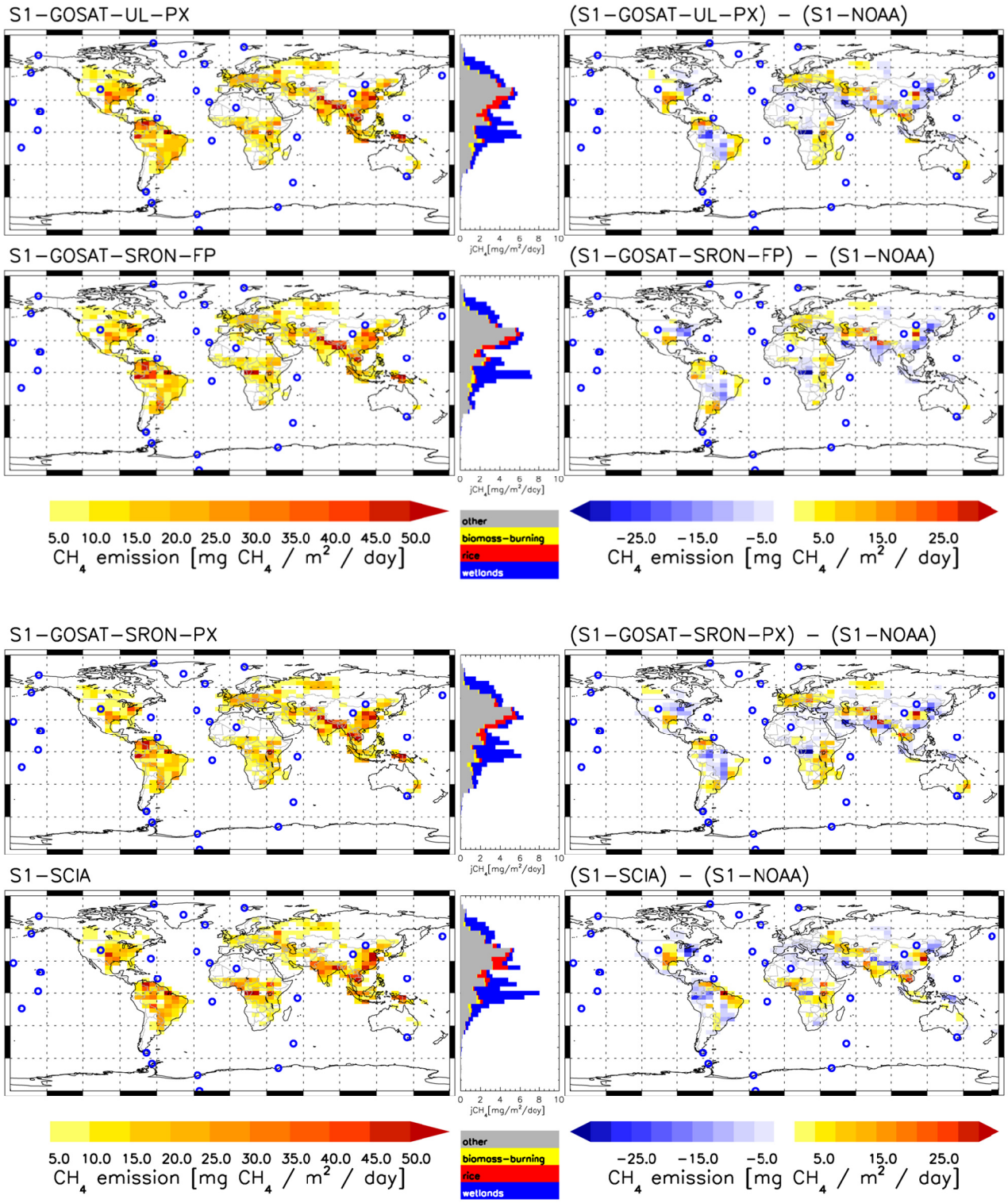

Figure 2: Comparison of derived global CH_4 emissions using 3 different GOSAT XCH_4 retrievals (GOSAT-UL-PX: OCPR v4.0; GOSAT-SRON-FP: RemoTeC FP v2.1; GOSAT-SRON-PX: RemoteC PROXY v2.0) and using SCIAMACHY retrievals (IMAPv55) [*Alexe et al., 2015*]; the figure shows 2010-2011 average emissions (left) and difference compared to a reference inversion using only NOAA surface observations (right).