

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 ₂ O
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 CH₄ inversions using new satellite retrievals (contribution to MACC-II and MACC-III project)**
- 2. Improve European CH₄ and N₂O 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 CH₄ inversions using new satellite retrievals (contribution to MACC-II and MACC-III project)

The MACC CH₄ 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 CH₄ 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 CH₄ inversion reanalysis has been used as reference for evaluation of improved XCH₄ products developed with the ESA-GHG cci - second phase project (Climate Research Data Package 2 (CRDP2)) [Chevalier *et al.*, 2015].

Furthermore, the MACC CH₄ inversion reanalysis contributed to the Global Carbon Project CH₄ [Kirschke *et al.*, *Nature Geoscience*, 2013].

Half-yearly MACC-II/MACC-III 'delayed-mode' CH₄ 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 CH₄ retrievals from GOSAT (RemoteC PROXY v2.0 XCH₄ product from SRON) have been used, while the previous CH₄ inversions were based on SCIAMACHY (IMAPv5.5), which became dysfunctional beginning 2012.

The performance of the 'delayed-mode' CH₄ 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 XCH₄ satellite products from SCIAMACHY and GOSAT, including additional XCH₄ 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 CH₄ 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 CH₄/yr [Alexe *et al.*, 2015].

Improve European CH₄ and N₂O inversions using in-situ observations

European CH₄ and N₂O inversions have been performed using the improved, harmonized European CH₄ in-situ measurements, generated in the InGOS ("Integrated non-CO₂ greenhouse gas Observing Systems") project (<http://www.ingos-infrastructure.eu/>) for the period 2007-2011. Overall the first InGOS CH₄ and N₂O 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 N₂O inversions contributed to the international TransCom-N₂O model comparison (N₂O forward and inverse model simulations) [Thompson *et al.*, 2014a; 2014b].

A detailed model validation has been performed using ²²²Rn simulations (based on a novel ²²²Rn 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 initiative 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 CH₄ 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 CH₄ and N₂O 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 CH₄ 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 CH₄ 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 CH₄ 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 ²²²Radon simulations based on the new ²²²Radon 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. Velasco, Assessing 5 years of GOSAT Proxy XCH₄ data and associated uncertainties, *Atmos. Meas. Tech. Discuss.*, 8, 5937–5972, 2015.
- Thompson, R. L., P. K. Patra, K. Ishijima, E. Saikawa, M. Corazza, U. Karstens, C. Wilson, P. Bergamaschi, E. Dlugokencky, C. Sweeney, R. G. Prinn, R. F. Weiss, S. O'Doherty, P. J. Fraser, L. P. Steele, P. B. Krummel, M. Saunois, M. Chipperfield and P. Bousquet, TransCom N₂O model inter-comparison – Part 1: Assessing the influence of transport and surface fluxes on tropospheric N₂O variability, *Atmos. Chem. Phys.*, 14, 4349–4368, 2014.
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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 CH₄ and N₂O emissions based on inverse modelling using in-situ and satellite measurements' (2015-2017).

Figures

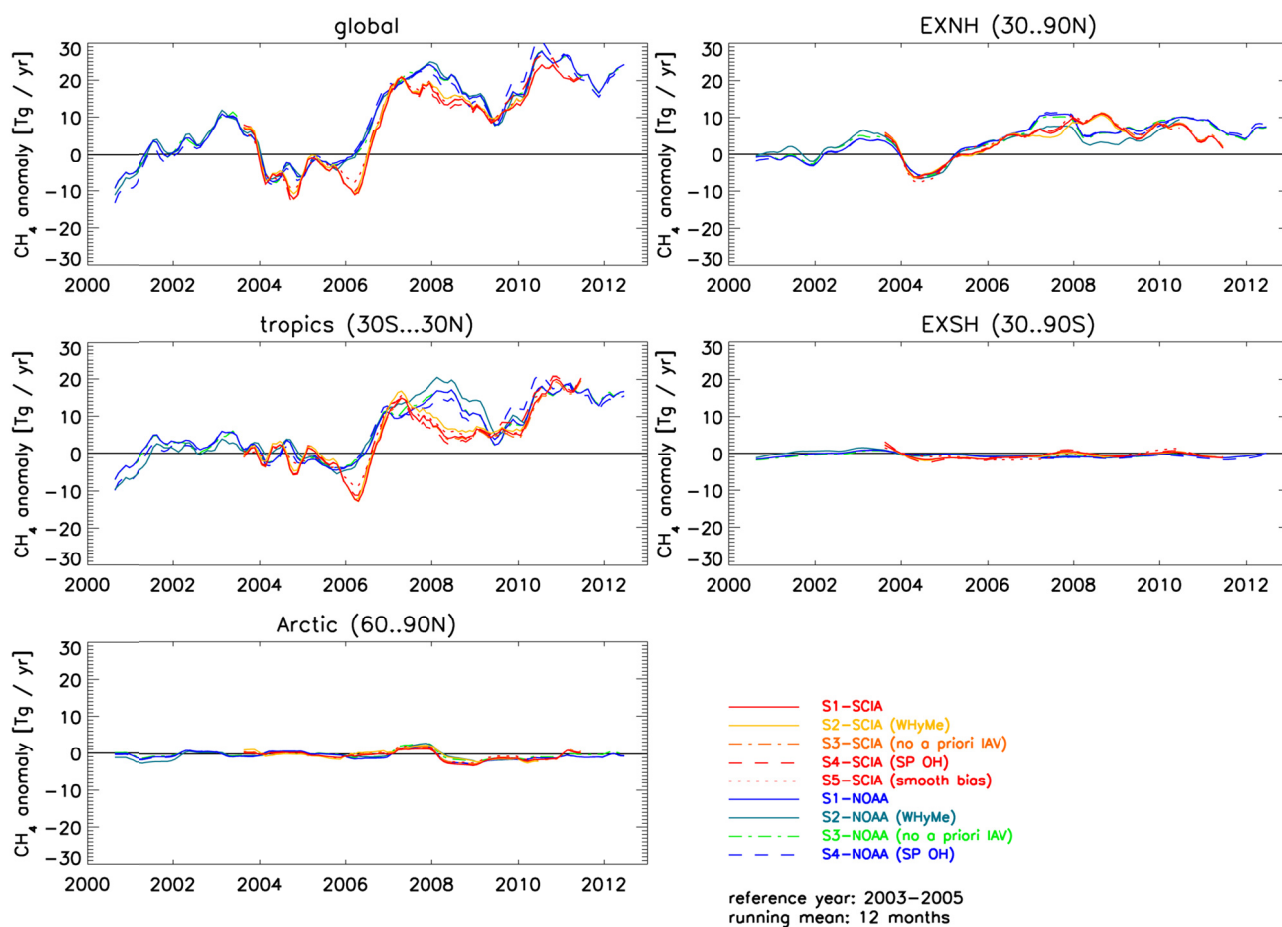


Figure 1: Extension of reanalysis of global CH₄ emissions until end 2012: CH₄ Inter-annual variation of total CH₄ emissions derived from the different inversions. The variations are shown relative to the average emissions during the reference period 2003-2005 (12-month running mean values). For the detailed analysis of the reanalysis until 2010 see [Bergamaschi *et al.*, 2013a].

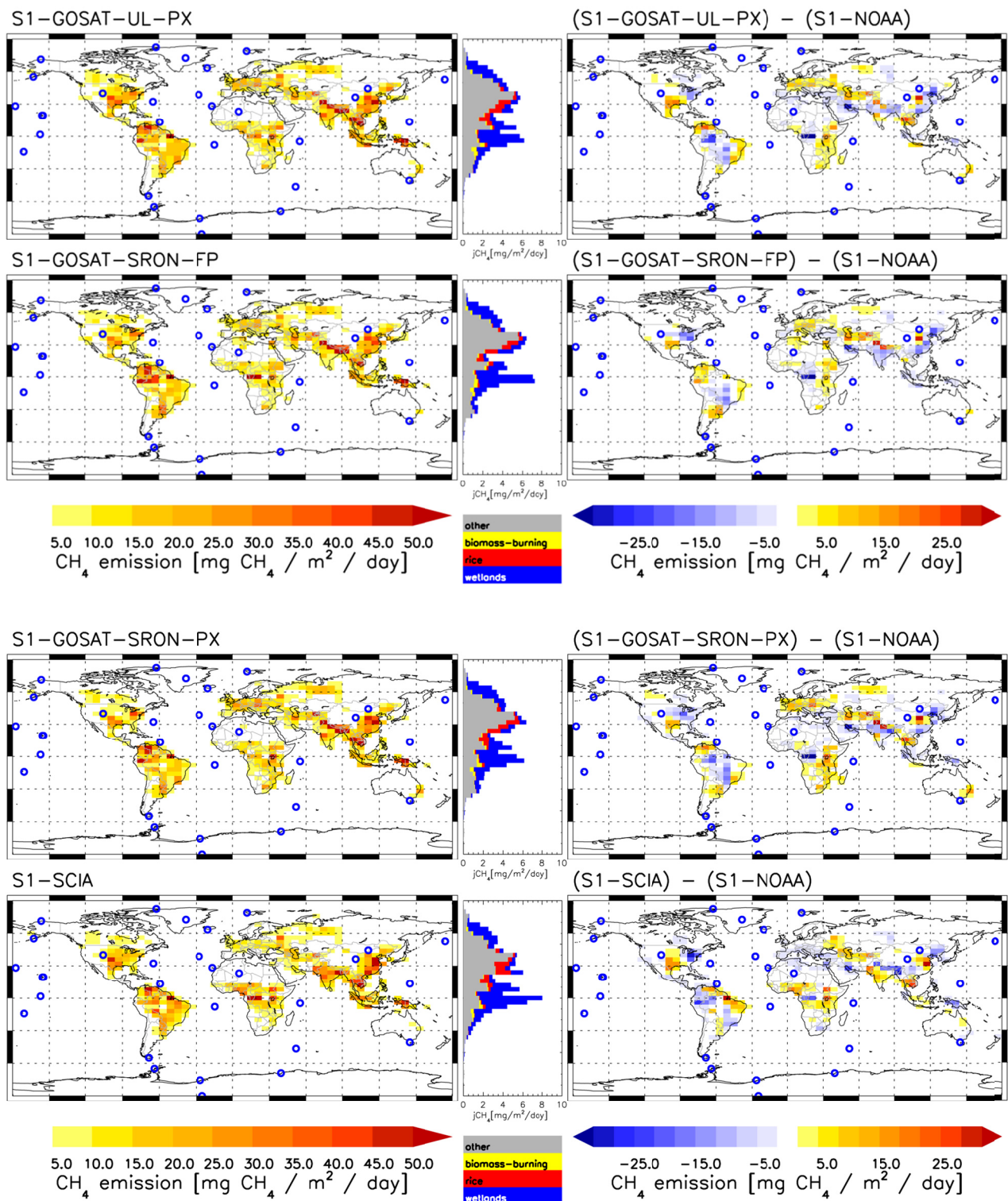


Figure 2: Comparison of derived global CH₄ emissions using 3 different GOSAT XCH₄ retrievals (GOSAT-UL-PX: OCPv4.0; GOSAT-SRON-FP: RemoTeC FP v2.1; GOSAT-SRON-PX: RemoteC PROXY v2.0) and using SCIAMACHY retrievals (IMAPv55) [Alexe et al., 2015]; the figure shows 2010-2011 average emissions (left) and difference compared to a reference inversion using only NOAA surface observations (right).