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	2017 (01 July 2016 - 30 June 2017)
Project Title:	Improve estimates of global and regional CH4 and N2O emissions based on inverse modelling using in-situ and satellite measurements
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 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)	400000	400000	400000	153244 (28/06/2016)
Data storage capacity	(Gbytes)	400		400	

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 #4 (CRDP#4) of the GHG-CCI project (http://www.esa-ghg-cci.org/) of ESA's Climate Change Initiative (CCI) (i.e. using updated GOSAT XCH_4 products and extending the inversion period until end 2015). Figure 1 displays the XCH_4 retrievals and the corresponding XCH_4 assimilated in TM5-4DVAR, showing overall good consistency regarding their spatial XCH_4 patterns. The use of these four products in the TM5-4DVAR inverse modelling system results in qualitatively similar spatial distributions of the posteriori CH_4 fluxes (average 2010-2015) (Figure 2). There are however quantitative differences in the derived regional fluxes which need to be further analyzed. An important issue remains also the bias correction, which is still required for the simultaneous assimilation of the satellite retrievals and the NOAA surface observations (see Figure 1). Our analysis suggests that the calculated bias correction reflects a combination of model errors (especially the vertical CH_4 gradient in the stratosphere at mid to high latitudes) and remaining systematic errors in the XCH_4 retrievals (for more details see ESA Climate Assessment report version 4 [*Chevallier et al*., 2017]).

The global 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; 2017].

Additional global CH_4 flux inversions have been performed at higher horizontal resolution ($3^o\times2^o$ instead of $6^o\times4^o$) and testing different wetland CH_4 emission inventories.

The JRC TM5-4DVAR CH_4 flux inversions have been used also for validation of the Copernicus Atmosphere Monitoring Service (CAMS) CH_4 products, showing overall similar performance of the CAMS v11r1_ra inversions (provided by TNO) and the JRC TM5-4DVAR CH_4 flux inversions at NOAA background surface stations (Figure 3). However, the comparison identified significant biases of the CAMS delayed-mode assimilation (gg5m).

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

The European CH_4 inversions have been updated and further analysed in a recent paper [Bergamaschi et al., 2017]. The analysis highlights the potential significant contribution of natural sources, such as peatlands, wetlands, and wet soils, estimated at 4.3 (2.3-8.2) Tg CH_4 yr^{-1} for EU-28 from the "Wetland and Wetland CH_4 Inter-comparison of Models Project" (WETCHIMP) ensemble of 7 different wetland inventories [Melton et al., 2013; Wania et al., 2013], corresponding to 22% (11%-41%) of anthropogenic CH_4 emissions reported to UNFCCC.
Furthermore, the analysis included a quantitative estimate of potential biases in the derived CH_4 emissions, based on the comparison of simulated and measured enhancements of CH_4 compared to the background, integrated over the entire boundary layer and over the lower troposphere. This analysis suggests that derived emissions may have regional bias on the order of up to 30% (based on aircraft profile sites in France, Hungary, and Poland). The mean bias over the larger European domain is probably smaller (but more aircraft measurements would be needed to confirm this).

Improve TM5-4DVAR inverse modelling system

The TM5-4DVAR observation interface has been updated for the satellite observations (from the ESA GHG cci CRDP#4 products).
Due to a lack of manpower, the new methods to estimate the uncertainties of the flux inversions could not be further developed during the current reporting period.
The implementation of the 'Roedenbeck scheme' to calculate baseline concentrations in order to couple TM5-4DVAR with regional high-resolution models has been further developed (in order to allow coupling with regional models with non-regular latitude / longitude grids).

List of publications/reports from the project with complete references

Bergamaschi, P., Karstens, U., Manning, A. J., Saunois, M., Tsuruta, A., Berchet, A., Vermeulen, A. T., Arnold, T., Janssens-Maenhout, G., Hammer, S., Levin, I., Schmidt , M., Ramonet, M., Lopez, M., Lavric, J., Aalto, T., Chen, H., Feist, D. G., Gerbig, C., Haszpra, L., Hermansen, O., Manca, G., Moncrieff, J., Meinhardt, F., Necki, J., Galkowski, M., O'Doherty, S., Paramonova, N., Scheeren, H. A., Steinbacher, M., and Dlugokencky, E.: Inverse modelling of European CH_4 emissions during 2006–2012 using different inverse models and reassessed atmospheric observations, Atmos. Chem. Phys. Discuss., https://doi.org/10.5194/acp-2017-273, in review, 2017.

Bruhwiler, L. M., S. Basu, P. Bergamaschi, P. Bousquet, E. Dlugokencky, S. Houweling, M. Ishizawa, H. S. Kim, R. Locatelli, S. Maksyutov, S. Montzka, S. Pandey, P. K. Patra, G. Petron, M. Saunois, C. Sweeney, S. Schwietzke, P. Tans and E. C. Weatherhead, U.S. CH_4 emissions from oil and gas production: Have recent large increases been detected?, J. Geophys. Res. Atmos., 122, 4070–4083, doi:10.1002/2016JD026157, 2017.

Chevallier, F., P. Bergamaschi, D. Brunner, L. Feng, S. Houweling, T. Kaminski, W. Knorr, J. Marshall, P. I. Palmer, S. Pandey, M. Reuter, M. Scholze, and M. Voßbeck, Climate Assessment Report for the GHG-CCI project of ESA's Climate Change Initiative, pp. 96, version 4, 28 March 2017, 2017.

Houweling, S., P. Bergamaschi, F. Chevallier, M. Heimann, T. Kaminski, M. Krol, A. M. Michalak, and P. Patra, Global inverse modeling of CH_4 sources and sinks: an overview of methods, Atmos Chem Phys, 17(1), 235-256, doi: 10.5194/acp-17-235-2017, 2017.

Koffi, E. N., P. Bergamaschi, U. Karstens, M. Krol, A. Segers, M. Schmidt, I. Levin, A. T. Vermeulen, R. E. Fisher, V. Kazan, H. Klein Baltink, D. Lowry, G. Manca, H. A. J. Meijer, J. Moncrieff, S. Pal, M. Ramonet, H. A. Scheeren and A. G. Williams, Evaluation of the boundary layer dynamics of the TM5 model over Europe, Geosci Model Dev, 9, 3137-3160, doi: 10.5194/gmd-9-3137-2016, 2016.

Saunois, M., P. Bousquet, B. Poulter, A. Peregon, P. Ciais, J. G. Canadell, E. J. Dlugokencky, G. Etiope, D. Bastviken, S. Houweling, G. Janssens-Maenhout, F. N. Tubiello, S. Castaldi, R. B. Jackson, M. Alexe, V. K. Arora, D. J. Beerling, P. Bergamaschi, D. R. Blake, G. Brailsford, V. Brovkin, L. Bruhwiler, C. Crevoisier, P. Crill, K. Covey, C. Curry, C. Frankenberg, N. Gedney, L. Höglund-Isaksson, M. Ishizawa, A. Ito, F. Joos, H.-S. Kim, T. Kleinen, P. Krummel, J.-F. Lamarque, R. Langenfelds, R. Locatelli, T. Machida, S. Maksyutov, K. C. McDonald, J. Marshall, J. R. Melton, I. Morino, V. Naik, S. O'Doherty, F.-J. W. Parmentier, P. K. Patra, C. Peng, S. Peng, G. P. Peters, I. Pison, C. Prigent, R. Prinn, M. Ramonet, W. J. Riley, M. Saito, M. Santini, R. Schroeder, I. J. Simpson, R. Spahni, P. Steele, A. Takizawa, B. F. Thornton, H. Tian, Y. Tohjima, N. Viovy, A. Voulgarakis, M. van Weele, G. R. van der Werf, R. Weiss, C. Wiedinmyer, D. J. Wilton, A. Wiltshire, D. Worthy, D. Wunch, X. Xu, Y. Yoshida, B. Zhang, Z. Zhang and Q. Zhu, The global methane budget 2000-2012, Earth System Science Data, 8(2), 697-751, doi: 10.5194/essd-8-697-2016, 2016.

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., Bruhwiler, L., Crevoisier, C., Crill, P., Covey, K., 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., Melton, J. R., Morino, I., Naik, V., O'Doherty, S., Parmentier, F.-J. W., Patra, P. K., Peng, C., Peng, S., Peters, G. P., Pison, I., Prinn, R., Ramonet, M., Riley, W. J., Saito, M., Santini, M., Schroeder, R., Simpson, I. J., Spahni, R., Takizawa, A., Thornton, B. F., Tian, H., Tohjima, Y., Viovy, N., Voulgarakis, A., Weiss, R., Wilton, D. J., Wiltshire, A., Worthy, D., Wunch, D., Xu, X., Yoshida, Y., Zhang, B., Zhang, Z., and Zhu, Q.: Variability and quasi-decadal changes in the methane budget over the period 2000–2012, Atmos. Chem. Phys. Discuss., https://doi.org/10.5194/acp-2017-296, in review, 2017.

Summary of plans for the continuation of the project

(10 lines max)

Further sensitivity experiments of global CH_4 flux inversions. 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. Evaluate performance of various TM5-4DVAR sensitivity inversions against regular European aircraft profiles and other independent observations.

First tests of prototype system of coupled TM5-4DVAR / FLEXPART system for high resolution regional inversions.

Figures

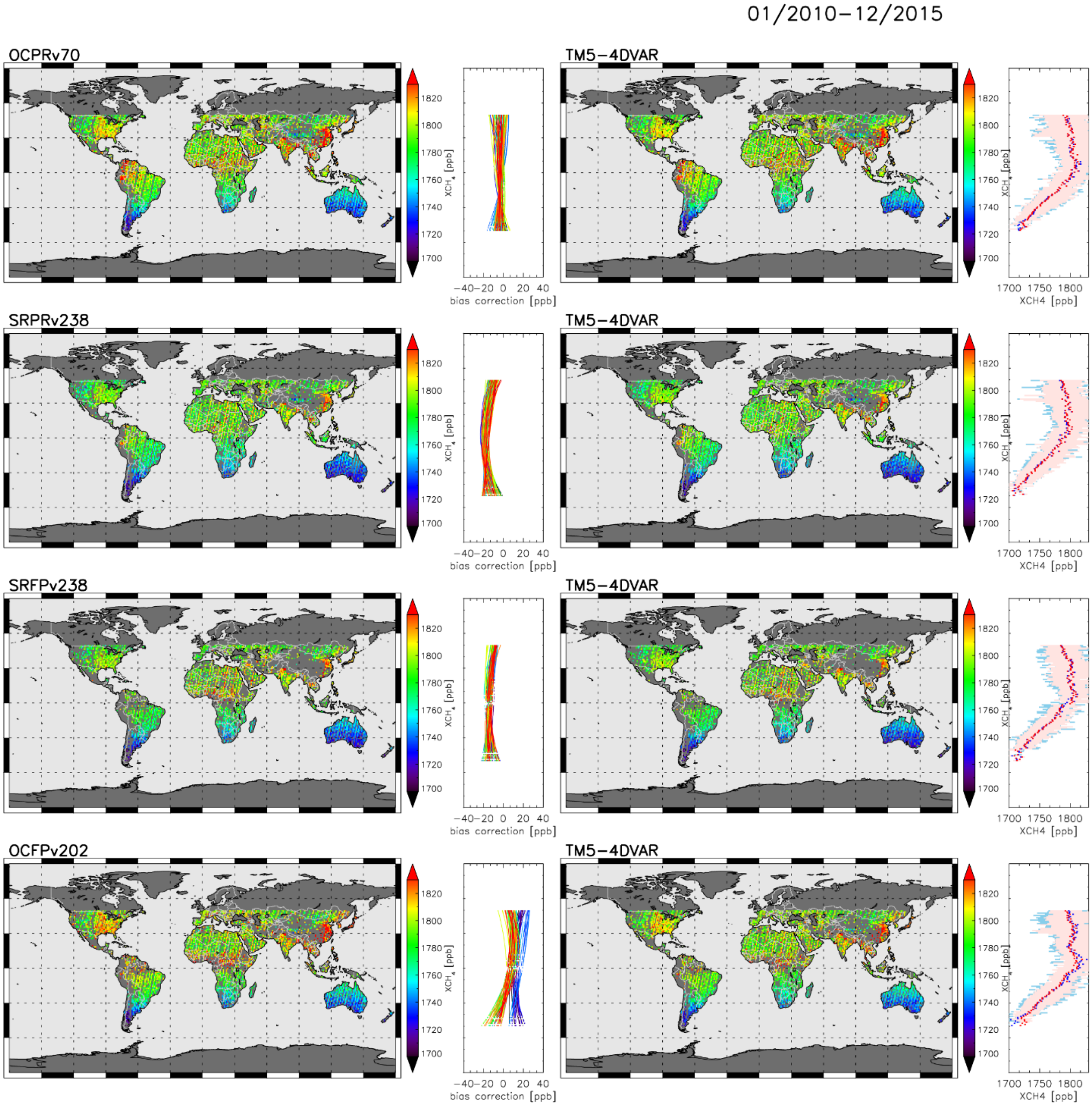

Figure 1: Column averaged CH_4 dry air mole fractions (XCH_4). Left: XCH_4 retrievals (composite average 2010-2015) including bias correction calculated by TM5-4DVAR. The bias correction (as function of latitude and month) in shown in the small panels (second column; bias corrections for individual months shown in different colors (from dark violet (01/2010) to red (12/2015))). Right: Assimilated XCH_4. The longitudinal averages of XCH_4 retrievals (after bias correction; blue) and assimilated XCH_4 (red) are shown in the small panels on the right side (4th column). The light blue area shows the range of XCH_4 retrievals accross all longitudes (for the 2010-2015 average) and the light red area the corresponding range for the assimilated XCH_4. The four rows show the retrievals and corresponding model simulations for the 4 GOSAT products analyzed.

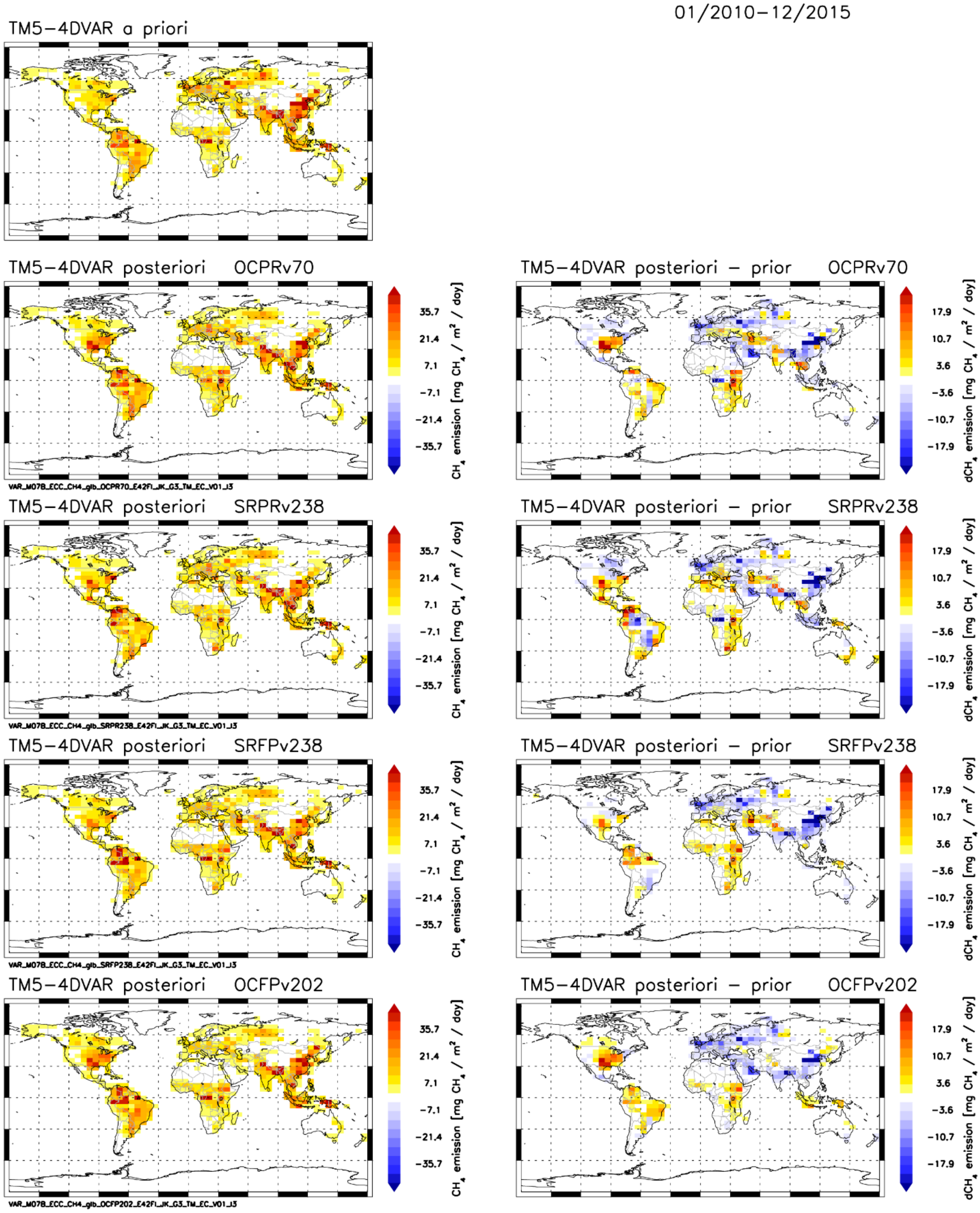

Figure 2: CH_4 emissions (average 2010-2015). Upper left map shows the applied prior emissions, and the subsequent rows the posteriori emissions (left) and the inversion increments (difference between posterior and prior emissions; right) for the inversions of four GOSAT products from the Climate Research Data Package #4 (CRDP#4) of the ESA GHG cci project - second phase.

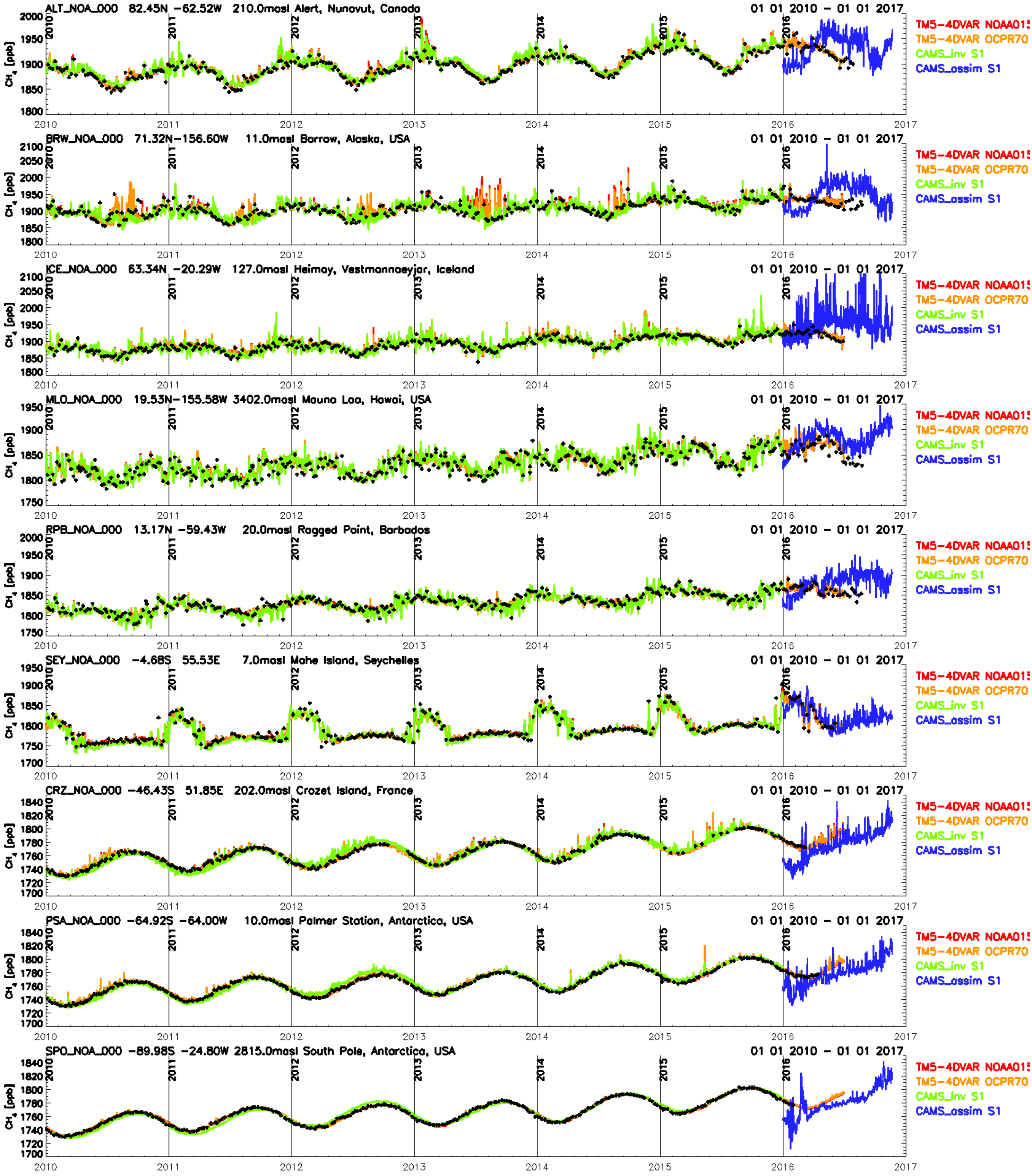

Figure 3: Comparisons of JRC TM5-4DVAR CH_4 inversions, CAMS CH_4 inversion (v11r1_ra provided by TNO), and CAMS CH_4 assimilation (delayed-mode experiment gg5m) with NOAA surface measurements.