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 CH₄ and N₂O emissions based on inverse modelling using in-situ and satellite measurements

Computer Project Account: spjr4dv

Principal Investigator(s): Dr. Peter Bergamaschi

Affiliation: European Commission Joint Research Centre (EC-JRC) Institute for Environment and Sustainability (IES) 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 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

<table>
<thead>
<tr>
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<th>Previous year</th>
<th>Current year</th>
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<tbody>
<tr>
<td></td>
<td>Allocated</td>
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<td>High Performance Computing Facility</td>
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<td>580000</td>
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₁ original allocation
₂ request for additional resources 14/09/2015
₃ request for additional resources 30/10/2015

This template is available at: http://www.ecmwf.int/en/computing/access-computing-facilities/forms
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) 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 CH₄ emissions using new satellite retrievals

Global CH₄ flux inversions have been performed using four different GOSAT XCH₄ 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 CH₄ fluxes for the period 2010-2014. Overall, the four inversions show qualitatively very similar spatial distributions of the posteriori CH₄ fluxes, consistent with the analysis of previous XCH₄ 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' XCH₄ 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 CH₄ flux inversions have been used in a recent analysis of the global CH₄ budget within the international Global Carbon Project CH₄ initiative [Saunois et al., 2016].

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

Within the FP7 project InGOS ("Integrated non-CO₂ greenhouse gas Observing Systems" (http://www.ingos-infrastructure.eu/) European CH₄ and N₂O inversions have been completed for the period 2006-2012, using the new harmonized CH₄ and N₂O 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 CH₄, and 4 models for N₂O). For CH₄, the model comparison largely confirms the previous finding of higher total European CH₄ emissions compared to the total anthropogenic CH₄ 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 CH₄ emissions with maximum in summer, while anthropogenic CH₄ 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 N₂O, for which uncertainties of bottom-up inventories are very large - typically on the order of 100% for the total N₂O emissions per country (mainly due to N₂O emissions from agricultural soils) - the inversions demonstrate that atmospheric measurements and inverse modelling can significantly reduce the uncertainties. Furthermore, ²²²Rn 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


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$_2$O 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: CH₄ 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.