Summary of the Final Report of Research Results

1) Title of the proposed research

Modeling of the CO_2 and CH_4 fluxes using advanced mathematical techniques

2) Principal Investigator (PI) and Co-Investigators (Co-Is)

PI:

Prof. Emil Pelikán

Co-I:

Dr. Ing. Marek Brabec

Dr. Mgr. Pavel Jurus

Prof. Milan Palus

Dr. Martin Vejmelka

Dr. Pavel Krc

Dr. Ing. Petr Musilek

3) PI's affiliation

Institute of Computer Science, Academy of Sciences of the Czech Republic

4) Summary of the Final Report of Research Results

The main part of utilizing GOSAT data was aimed towards regional-scale modelling of CO2 concentrations and CO2 fluxes. Most of the activities in the field of anthropogenic emissions typically addresses reporting and creation of annual inventories. We tried to complement this approach by evaluating the role of regional-scale models as the tools that connect in high spatial and temporal resolution atmospheric concentrations and surface fluxes.

We have set up a testing domain in Northern Alberta, Canada, which has only a few dominant sources of GHG emissions but nevertheless it contains important industrial area of Athabasca oil sands where monitoring, continuous evaluation of GHG inventory, and modelling of the impact of potential future changes is advisable. The modelling system consists of the numerical weather model, chemical transport model (although atmospheric chemistry is not of the real concern in case of CO2, CTM model is used here mainly for its dispersion part), and model of both biogenic and anthropogenic fluxes.

The results showed fairly good agreement of biogenic surface fluxes and also acceptable agreement of the CO2 concentrations during the daytime. Nighttime peaks in concentrations which are not correctly captured by a model can be attributed to incorrectly modelled turbulent mixing and we have introduced the method of statistical postprocessing of the model to amend this behaviour.

After the verification of the modelling system for CO_2 fluxes and concentration on regional scale versus in-situ flux tower measurements we proceeded with the verification of modelling system versus GOSAT observations. We have compared the two types of quantities related to CO_2 concentrations provided by GOSAT project. The first variable is the total column of CO_2, a vertical sum of CO_2 at the point of measurement. The second is the column-averaged molar fraction of CO_2 (XCO_2), computed as the total column of CO_2 divided by the total column of dry air. Dry air columns are based on the operational analysis data provided by the Japan Meteorological Agency (JMA).

In order to compare the GOSAT observations with the simulation results, CO_2 total columns are calculated from the model output by summing over all vertical levels. The dry air columns are computed in similar fashion. The XCO_2 is a simple ratio of those two quantities. The dry air columns assumed in GOSAT data are not available directly, but can be derived simply as the ratio of CO_2 column and XCO_2, provided by GOSAT.

The comparisons of model versus GOSAT observations shows in general high correlation of the model and observations. To get unbiased model results for both CO_2 and dry air columns we had to add a compensation for the fact that the model has limited vertical height up to 100 hPa meaning that about top 10% of the atmosphere mass is not represented by the model. After this correction, the value of mean percentage error changed from -10.4% to -0.482% for the CO_2 columns, and from -10.9% to -0.17% for the dry air columns. However, even after the correction, the XCO_2 values show much higher variance for observed values by GOSAT compared to modelled values.

We hypothesize that the difference between model and GOSAT data is caused by the fact that the XCO_2 in the model is computed by dividing a modeled CO_2 column by a modeled dry air column which are highly correlated (because CO_2 is well mixed in higher layers of the atmosphere), as are errors in CO_2 and dry air quantities. Most of the error in both CO_2 and dry air quantities is not due to the incorrect concentration of CO_2, as that is almost constant, especially in higher layers of the model. Rather, an incorrect distribution of air mass is likely to contribute significantly to the errors. It affects both the CO_2 column and the dry air column proportionally. As a result, division of the two quantities leads to a reduction in the overall variance. The results obtained by the WRF-VPRM in this study comply with a study of XCO_2 distribution by Olsen and Randerson (2004).

In the case of GOSAT, the CO_2 columns are observed, but the dry air columns originate from the meteorological model. Errors in those two quantities can therefore be considered uncorrelated (although some hidden correlation is still possible due to the retrieval algorithms, which often use a number of model-derived atmospheric variables). The error in the distribution of air mass is thus amplified: the CO_2 column based on a real air mass distribution is divided by a dry air column based on a modeled air mass distribution. Division in this case causes further nonlinear propagation of errors and larger overall variance.

Apart from regional-scale CO_2 modelling, the GOSAT project data are directly or indirectly used in other activities. One of the uses is for the general spatial and spatio-temporal analysis methods – the testing and development of the methods as well as for educational purposes – the GOSAT data play part in promoting science among high-school and university students and in teaching basic approaches for scientific datasets processing, analysis and visualization. Analysis of GOSAT data was for example one of the university student projects during international student summer school "Schola ludus".

Another activity which is partly inspired by GOSAT project is the ongoing investigation and modelling of atmposphere/ocean CO_2 fluxes. Although the GOSAT data have not be utilized yet, we envision the verification using all available satellite data including the GOSAT in the next stages of the research.

5) List of publications relating to the proposed research

(In addition, if there are any publication plans, please also describe them as well.)

J. Rodway, P. Jurus, P. Musilek, Tracking Greenhouse Gases From Space: Dealing with Missing Data, 6th Annual University of Alberta Space Symposium, September 25-26, 2009.

P. Jurus, Possibilities for greenhouse gas fluxes modelling, Workshop on modelling of greenhouse gas fluxes in ecosystems, Prague, February 24, 2010.

P. Jurus, Relating ground- and satellite-based CO_2 observations, Earth Observation Sciences Day, Edmonton, March 4, 2010.

J. Rodway, K. Filimonenkov, Y. Li, P. Jurus, P. Musilek, Source Constitution of Carbon Dioxide in the Atmosphere: Analysis and Visualization, First Annual Graduate Research Symposium, Edmonton, June 17, 2010

P. Jurus, P. Musilek, Y. Li, J. Rodway, K. Filimonenkov, E. Pelikan, Towards regional-scale modelling of industrial CO_2 emissions, 12th Symposium of the International Commission on Atmospheric Chemistry and Global Pollution (CACGP), 11th Science Conference of the International Global Atmosphere Chemistry (IGAC) Project Halifax, Canada, July 11-16, 2010.

P. Jurus, M. Brabec, P. Krc, E. Pelikan, P. Musilek, Utilisation of micrometeorological variables in regional-scale CO2 modelling, Verification and validation in meteorology, climatology and air quality, Annual Workshop of the Czech Meteorological Society, Bozi Dar, September 22-24, 2010.

P. Jurus, P. Musilek, Y. Li, J. Rodway: "Regional-scale modeling of greenhouse gas fluxes," in „Restoration and Reclamation of Boreal Ecosystems. Attaining Sustainable Development." Cambridge University Press, 2012 - (Vitt, D.; Bhatti, J.), p. 23-55 ISBN 978-1-107-01571-5

P. Jurus, J. Resler, K. Eben, E. Pelikan: Towards satellite data assimilation using adjoint in an Eulerian regional-scale model, 3rd PI meeting of GOSAT Project, Edinburgh, UK, May 19-20, 2011

Vieira, V. M. N. C. S., Sahlée, E., Jurus, P., Clementi, E., Pettersson, H., & Mateus, M. (2015). Comparing solubility algorithms of greenhouse gases in Earth-System modelling. Biogeosciences Discussions, 12(18).

Vieira, V. M. N. C. S., Sahlée, E., Jurus, P., Clementi, E., Pettersson, H., & Mateus, M. (2015). Improving estimations of greenhouse gas transfer velocities by atmosphere–ocean couplers in Earth-System and regional models. Biogeosciences Discussions, 12(18).