Research Networking Programmes

Science Meeting – Scientific Report

***Proposal Title*: Data Assimilation in Biogeochemical Cycles**

***Application Reference N°*: 5328**

1) Summary (up to one page)

The autumn school is part of the International Space Science Institute's (ISSI) Working Group on 'Carbon Cycle Data Assimilation: How to consistently assimilate multiple data streams'. The working group is lead by Dr. Marko Scholze and Prof. Martin Heimann, and both of them, with administrative support from the MPI for Biogeochemistry, co-organised the autumn school. The members of the working group participated in the autumn school as lecturers. The main goal of the autumn school was to provide a sound knowledge of the fundamental data assimilation methods in biogeochemical cycles and training in these methods linked to carbon cycle applications. A secondary goal was to foster collaborations among the participating young scientists. This autumn school is the first one focused on this specific topic since the pioneering summer school 'Inverse methods in global biogeochemical cycles' in 1999 (Kasibhatla, P., Heimann, M., Hartley, D., Rayner, P. J., Mahowald, N., and Prinn, R., 2000. Inverse Methods in Global Biogeochemical Cycles. Geophysical Monograph Series. Volume 114. American Geophysical Union, Washington D.C.). For a complete list of lecturers and programme of the school see annexes below.

The school took place at the ICTP, Trieste, Italy, from 20 to 27 September 2014 as a 6-day long intensive school with two 1.5 hours blocks of lectures in the morning and two 1.5 hours blocks of exercises in the afternoon. A total of 38 students participated in the school (we had a maximum number of 40 participants, there were two last minute cancellations), which were chosen from among 90 applications. The high number of applications (despite two concurrent training activities around the same topic: ICOS-NEON Greenhouse Gas Data training workshop and ESA Earth Observation Summer School – Earth System Monitoring and Modelling) demonstrates that there is a high demand for these kind of training activities in a rather specific area. The participants were a mixture of experienced PhD students and PostDocs, 21 male and 17 female, coming from Argentina, Australia, Finland, Germany, Greece, Italy, Japan, Netherlands, Norway, Poland, Russia, Singapore, South Korea, Sweden, Switzerland, Taiwan, UK and USA.

The benefits of the school participants were besides the scientific training:

- Meeting other young scientists from around the world working in a similar field.
- Exchanging advice and contacts regarding developing scientific careers.
- Seeking feedback on the participants' individual work.
- Developing international and interdisciplinary collaborations, leading to cutting-edge science.

The school supported the training of young scientists building the next generation's researcher in the growing field of model-data fusion in biogeochemical (carbon) cycle science. Participants had the opportunity to present their work during a poster session (the posters were visible during the full period of the school).

2) Description of the scientific content of and discussions at the event (up to four pages)

Data assimilation (DA) objectively combines information from observations with information contained in a model of the evolving system taking into account errors in both observations and model. DA has evolved from Numerical Weather Prediction (NWP) where it is now routinely used to improve weather forecasts by improving the models' initial conditions for the next forecast. DA is now evolving to play a key role in various other fields of Earth System Science to initialise model simulations or to estimate model process parameters. Data assimilation methods are also becoming an important tool to assess and prepare for future Earth Observation (EO) missions. It is only over the recent past (~ 10 years) that in biogeochemical cycle research substantial progress has been achieved in the availability of observations (including EO) as well as in the use of these observational data to constrain models, and here in particular on the development of data assimilation systems to optimally estimate model process parameters given these observations. Pioneering work comes from the field of carbon cycle science where several carbon cycle data assimilation systems capable of assimilating multiple observational data have been developed in the most recent past. These observations cover the whole range of characteristics of the carbon cycle: from very local (plant leaf level data) to large-scale (ground-based flask samples of background atmospheric CO_2 concentrations) in the spatial domain and instantaneous (eddy-covariance CO_2 fluxes) to multi-annual (ground-based carbon inventories) in the temporal domain.

The topics covered in the lectures during the school included biogeochemical cycles in the Earth System, modelling of dynamical systems with a focus on terrestrial and oceanic systems, data assimilation methods and their application in biogeochemical modelling, and satellite remotes sensing of greenhouse gases and vegetation activity. The tutorials took the content of the lectures further and demonstrated applications of the fundamental data assimilation methodologies using a simplified model of the carbon cycle. Additionally, the tutorials covered aspects of network design, atmospheric inversion and diagnosing the results of inversions as well as parameter identifiability.

3) Assessment of the results and impact of the event on the future directions of the field (up to two pages)

Overall the autumn school has been very successful both in terms of its primary objective to teach data assimilation methodologies and their applications in biogeochemical cycles and its secondary objective to create a network of young scientists in the field of data assimilation in biogeochemical cycles and foster collaborations among participants. All the school material including the lectures, tutorials, participants posters and additional background material is available through a school specific website: https://oc.bgcjena.mpg.de/public.php?service=files&t=e8cce0929ee0371bb8ed5ba66e57f289&path=%2F

Participants had to fill in a questionnaire during the last day of the school to provide feedback on various aspects of the school. The questions and a summary of the results are given below.

1. Overall how do you rate this autumn school? (rate on a scale of 1 to 10, 10 is perfect)

   8.3, generally participants enjoyed the school and learned a lot about relevant methods for their own work

2. Do you think this autumn school met its goals (teaching the fundamental concepts in data assimilation in biogeochemical cycles)? (rate on a scale of 1 to 10, 10 is perfect)

   8.1

3. Do you think this autumn school is important for your scientific future work? (rate on a scale of 1 to 10, 10 is perfect)

   8.3

4. Do you think this autumn school is important for your scientific future career? (rate on a scale of 1 to 10, 10 is perfect)

   8.3

5. Did you have enough chance to interact with your participating colleagues? (rate on a scale of 1 to 10, 10 is perfect)

   9.1

6. Did you have enough chance to interact with the lecturers? (rate on a scale of 1 to 10, 10 is perfect)

   8.5

7. How did you like the location (Trieste) and the venue (ICTP)? (rate on a scale of 1 to 10, 10 is perfect)

   9.1 for both

8. What was the best part of the autumn school?

   Poster session and exercises (especially Anna's and, quite surprisingly, the pen & paper) followed by the lectures in general and Peter's and Andreas' lecture in particular (although all other lectures were mentioned at least once), other highlights were the schedule (1.5 hrs blocks with the breaks) and meeting other participants

9. What improvements to the autumn school would you suggest?

   Most common comment refers to the consistency between lectures, exercises and notation/programming language. Other comments varied: some participants would like to have less but more in-depth exercises others would rather have more exercises to bridge the gap between theory and actual coding; some participants would like to spend less time on basics and show more applications while others would rather see more on fundamentals of DA. Further suggestions on small group exercises; more pen & paper work; some lectures not well organized; no virtual lectures; longer school or reduced programme; real lecture room for lectures; have all participants in one guesthouse

10. Do you anticipate any follow-up directly from this autumn school?

    Quite a few seem to be able to take the exercise code and use the examples for their own work

4) Annexes 4a) and 4b): Programme of the meeting and full list of speakers and participants

Annex 4a: Programme of the meeting

Autumn School *"Data Assimilation in Biogeochemical Cycles"* at ICTP, Trieste, Italy, Sep 22-27, 2014

Participants list

first name	name	institution	email
John Walter	Acevedo Valencia	Meteorology Institute of Freie Universität Berlin, Germany	acevedo@zedat.fu-berlin.de
Gianna	Battaglia	University of Bern, Switzerland	battaglia@climate.unibe.ch
Dmitry	Belikov	National Institute of Polar Research, Tokyo, Japan, and Tomsk State University, Tomsk, Russian Federation	dmitry.belikov@nies.go.jp
Sven	Boese	Max Planck Institute for Biogeochemistry, Jena, Germany	sboese@bgc-jena.mpg.de
Felix	Carrasco	CIMA, Ciudad Universataria, Buenos Aires, Argentina	felix.carrasco@cima.fcen.uba.ar
Mohamadou Abdoulaye	Diallo	University of Virginia, Dept. of Environmental Sciences, Charlottesville, VA, USA	mad4hj@virginia.edu
Yassir Art	Eddebbar	Scripps Institution of Oceanography, UC San Diego, La Jolla CA, USA	yeddebbar@ucsd.edu
Michal	Galkowski	AGH University of Science and Technology, Krakow, Poland	Michal.Galkowski@agh.edu.pl
Wei	He	University of Groningen, Groningen, The Netherlands	hubuhewei@163.com
Andrea	Hurtado de Mendoza Rosales	University of Leicester, Leicester, United Kingdom	ah325@le.ac.uk
Sofia	Kalaroni	HCMR - Hellenic Centre for Marine Research, Anavyssos Attiki, Greece	skalaroni@hcmr.gr
Jin-Woong	Kim	Yonsei University, Seoul, South Korea	adcaelum@yonsei.ac.kr
Shubham	Krishna	GEOMAR - Helmholtz Centre for Ocean Research, Kiel, Germany	skrishna@geomar.de
Hsiang-He	Lee	Singapore-MIT Alliance for Research and Technology (SMART), Singapore	hsiang-he@smart.mit.edu
Robert Todd	Letscher	University of California, Earth System Science, Irvine, CA, USA	robert.letscher@uci.edu
Yu	Liu	Institute of Biogeochemistry and Pollutant Dynamics, ETH, Zuerich, Switzerland	yu.liu@usys.ethz.ch
Mark	Lunt	School of Chemistry, University of Bristol	mark.lunt@bristol.ac.uk
Sabine	Mathesius	GEOMAR, Kiel, Germany	smathesius@geomar.de
Andrew Douglas	McRobert	Department of Physical Geography and Ecosystem Science, Lund University, Sweden	andrew.mcrobert@nateko.lu.se
Anne Lien	Morée	Geophysical Institute, University of Bergen, Norway	anne.moree@gfi.uib.no
Alexander John	Norton	School of Earth Sciences, University of Melbourne, Australia	nortona@student.unimelb.edu.au
Patricia Yoshino	Oikawa	Department of Environmental Science Policy and Management, Berkeley, USA	pattyoikawa@berkeley.edu
Brian	Oney	Center for Climate Systems Modeling, ETH Zuerich, Switzerland	Brian.Oney@empa.ch
Sudhanshu	Pandey	Netherlands Institute for Space Research (SRON), Groningen / Utrecht, The Netherlands	S.Pandey@sron.nl
Rasmus	Raecke	Institute of Environmental Physics, University of Heidelberg, Germany	rasmus.raecke@gmx.de
Nina Marie	Raoult	College of Engineering, Mathematics and Physical Sciences, University of Exeter, United Kingdom	nr278@exeter.ac.uk
Friedemann	Reum	Max Planck Institute for Biogeochemistry, Jena, Germany	freum@bgc-jena.mpg.de
Katherine Michelle	Saad	California Institute of Technology, Pasadena, CA, USA	katsaad@caltech.edu
Vibe	Schourup-Kristensen	Alfred Wegener Institute, Bremerhaven, Germany	vibe.schourup-kristensen@awi.de
Benjamin David	Stocker	Imperial College London, Ascot, United Kingdom	b.stocker@imperial.ac.uk
Jouni Ilari	Susiluoto	Finnish Meteorological Institute, Helsinki, Finland	jouni.susiluoto@fmi.fi
Ritu	Taneja	School of Earth Sciences, University of Melbourne, Australia	ritutanejawithlearningcurve@gmail.com
Anna	Teruzzi	National Institute of Oceanography and Experimental Geophysics (OGS), Trieste, Italy	ateruzzi@ogs.trieste.it
Aki	Tsuruta	Finnish Meteorological Institute, Helsinki, Finland	Aki.Tsuruta@fmi.fi
Thijs Thomas	Van Leeuwen	VU University Amsterdam, The Netherlands	ttvanleeuwen@gmail.com
Shreeya	Verma	Max Planck Institute for Biogeochemistry, Jena, Germany	sverma@bgc-jena.mpg.de
Luca	Visinelli	Euro-Mediterranean Center on Climate Change (CMCC), Bologna, Italy	luca.visinelli@gmail.com
Stephanie M.	Wuerth	Dept. of Earth and Planetary Science, University of Berkeley, CA, USA	swuerth@berkeley.edu

Lecturers:

first name	name	institution	email
Abhishek	Chatterjee (AC)	Carnegie Institution for Science, Stanford CA, USA	abhishek@ucar.edu
Frédéric	Chevalier (FC)	CEA-Orme des Merisiers, France	frederic.chevallier@lsce.ipsl.fr
Martin	Heimann (MH)	Max Planck Institute for Biogeochemistry, Jena, Germany *(organizing committee)*	martin.heimann@bgc-jena.mpg.de
Sander	Houwelling (SH)	Institute for Marine and Atmospheric research Utrecht (IMAU), Utrecht, The Netherlands	s.houweling@sron.nl
Thomas	Kaminski (TK)	FastOpt, Hamburg, Germany	Thomas.KaminskiInsert@FastOpt.com
Andreas	Oschlies (AO)	GEOMAR, Kiel, Germany	aoschlies@geomar.de
Peter	Rayner (PR)	University of Melbourne, Australia	prayner@unimelb.edu.au
Markus	Schartau (MSch)	GEOMAR, Kiel, Germany	mschartau@geomar.de
Marko	Scholze (MS)	Lund University, Sweden *(organizing committee)*	marko.scholze@nateko.lu.se
Ulrike	Schleier	Max Planck Institute for Biogeochemistry, Jena, Germany *(organizing committee)*	uschleier@bgc-jena.mpg.de

Annex 4b: Full list of speakers and participants

DA in BGC Autumn School Schedule

Time	Mo, 22.9	Tu, 23.9	We, 24.9	Thu, 25.9	Fr, 26.9	Sat, 27.9
9.00 – 10.30	Welcome **MH:** Overview of BGC cycles and why we care about them	**MS:** Basics: Data, uncertainty and their use in DA	**MS:** State of the art: Terrestrial carbon cycle models and uncertainties	**AO/MSch:** State of the art: Marine carbon cycle models and uncertainties	**SH:** Non CO2 GHG: - atm. lifetime - combining tracers - opt. transport	**TK/SH:** Satellites: - sensors - retrievals - GHGs & unc.
10.30 – 11.00	**Break**	**Break**	**Break**	**Break**	**Break**	**Break**
11.00 – 12.30	**AM/PJR:** Basics: Overview of data assimilation and probability theory	**PJR:** Basics: Forward modelling, dynamical systems	**PJR:** DA methods: direct sampling (MCMC) & Kalman filtering	**TK:** DA methods: adjoints and 4DVar	**FC:** Multiple data streams **TK:** Network design	**FC/AM:** Posterior diagnostics, performance evaluation & DA for model development
12.30 – 14.00	**Lunch**	**Lunch**	**Lunch**	**Lunch**	**Lunch**	**Lunch**
14.00 – 15.30	**MS/PJR:** Pen & Paper Exercise	**PJR/MS:** Practical introduction of toy model	Free afternoon	**PJR:** MCMC exercises	**TK:** Network design exercises	**FC:** Posterior diagnostics exercises
15.30 – 16.00	**Break**	**Break**		**Break**	**Break**	
16.00 – 17.30	Student intro & Posters	**MS/PJR:** Hands on model runs, forward sensitivities		**PJR:** EnKF exercises **TK:** 4D-VAR exercises	**AC:** Transport inversion exercises (part 1)	
18.00 – 19.00	**Dinner**	**Dinner**		**Dinner**	**Dinner**	
19.15 – 20.00	Poster session (part 1)	Poster session (part2)		**MSch:** Parameter exercises	**AC:** Transport (part 2)	