



Preview of Award 1131834 - Annual Project Report

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Cover

Federal Agency and Organization Element to Which Report is Submitted:	4900
Federal Grant or Other Identifying Number Assigned by Agency:	1131834
Project Title:	Reconstructing Glacial Nitrogen and Carbon Cycling Using Isotopes
PD/PI Name:	Andreas Schmittner-Boesch, Principal Investigator Alan C Mix, Co-Principal Investigator
Recipient Organization:	Oregon State University
Project/Grant Period:	09/01/2011 - 08/31/2015
Reporting Period:	09/01/2013 - 08/31/2014
Submitting Official (if other than PD\PI):	Andreas Schmittner-Boesch Principal Investigator
Submission Date:	08/06/2014
Signature of Submitting Official (signature shall be submitted in accordance with agency specific instructions)	Andreas Schmittner-Boesch

Accomplishments

* What are the major goals of the project?

Here we propose to use a three-dimensional model of both nitrogen and carbon isotopes ($\delta^{15}\text{N}$, $\delta^{13}\text{C}$ and $\Delta^{14}\text{C}$), incorporated in a global circulation and biogeochemical model, in order to better understand the glacial nitrogen cycle and its impact on atmospheric CO_2 . The cycling of oxygen, nitrogen and carbon depends strongly on the largescale ocean circulation. Reproducing the glacial circulation pattern will therefore be an important aspect of the project. Carbon isotopes will provide constraints on ocean circulation and the biological pump.

We will test three specific null-hypotheses:

H1: The bio-available nitrogen inventory of the ocean during the Last Glacial Maximum (LGM) was not larger than during the Late Holocene (LH).

H2: Changes in iron supply did not increase the efficiency of nitrate consumption by phytoplankton in polar oceans during glacial periods.

H3: Changes in the nitrogen cycle (H1 & H2) did not contribute significantly to glacial-interglacial variations of atmospheric CO₂ concentrations.

Specific goals were:

yr 1) Model improvement (Including the iron cycle), calibration; building LH databases of $\delta^{15}\text{N}$, $\delta^{13}\text{C}$ and $\Delta^{14}\text{C}$ measurements.

yr 2) LGM simulations and databases

yr 3) Analysis, hypotheses tests

*** What was accomplished under these goals (you must provide information for at least one of the 4 categories below)?**

Major Activities: This year our work was focussed on:

- LGM simulations and their analysis using the UVic model version developed during the last year, which includes both nitrogen and carbon isotopes. Efforts to merge this version with the iron model are still in progress
- Analysis of PMIP3/CMIP5 simulations of the ocean's overturning circulation
- Implementation of carbon isotopes in the land carbon model components of the UVic model
- Simulations of the effect of North Atlantic freshwater perturbations on ocean circulation and carbon isotopes
- Data synthesis of carbon isotopes for the LGM
- Starting a new collaboration with Mattias Green (Bangor University, UK) to consider changes in tidal mixing for LGM simulations
- Organization of two workshops for (future) teachers on the science of climate change and ocean acidification (July 30-31, 2013, Corvallis; Aug. 11-12, 2014, Corvallis)
- Organization of a science workshop (Dec. 4-6, 2013, Corvallis)
- Initiation of two international efforts (OC3 and iPODS) for data synthesis and model data comparison in order to improve understanding of deglacial ocean circulation and carbon cycling
- Organization of OC3/iPODS workshop (Sep. 30-Oct. 3, 2014, Bern, Switzerland)

Specific Objectives:

- The UVic model was set up and tested to run with the observed, time varying atmospheric radiocarbon from ~28ka BP to 21ka BP, which is important for comparison with the observations.
- LGM simulations with $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ have been performed.
- Data synthesis of LGM $\delta^{13}\text{C}$ has been completed through collaboration with C. Peterson and L. Lisiecki
- Data synthesis of LGM $\Delta^{14}\text{C}$ has been initiated through the iPODS project and collaboration with L. Skinner and A. Burke

Significant Results:

- Somes et al. (in prep) shows that considering Non-Redfield stoichiometry (preferential P remineralization and larger N/P of diazotrophs compared to other phytoplankton) is important and impacts estimated (simulated) glacial-interglacial N-inventory changes.
- Muglia and Schmittner (in prep) show that the LGM simulations of the

Atlantic Meridional Overturning Circulation (AMOC) from the PMIP3 models are all stronger than present and inconsistent with reconstructions based on sediment data.

- Muglia and Schmittner (in prep.) indentify that important causes for the simulated increased LGM AMOC in the PMIP3 models are (1) increased wind stress over the North Atlantic due to the Laurentide Ice sheet and (2) changes in atmospheric moisture transport
- So far all UVic model LGM simulations of $\delta^{13}\text{C}$ are inconsistent (too high) with the observed LGM $\delta^{13}\text{C}$; working hypotheses concerning the reason for this discrepancy are (1) the physical circulation is incorrect (2) the LGM deep ocean $\delta^{13}\text{C}$ distribution was influenced by transient effects e.g. ice sheet growth prior to the LGM

Key outcomes or
Other achievements:

Schmittner and Lund (2014) show that carbon isotope data from ocean sediments and ice cores and model simulations

- support a large and prolonged reduction of the AMOC during the early deglacial Heinrich Stadial 1 (19-15 ka BP),
- indicate that the early deglacial increase in atmospheric CO_2 and the decrease in its $\delta^{13}\text{C}$ value may be explained by the effect of the AMOC changes on the efficiency of the biological pump,
- Southern Ocean wind forcing is not sufficient nor required to explain the early deglacial CO_2 rise.

Preliminary results by Somes et al. (in prep.) indicates that

- the ocean's N inventory during the LGM might have been significantly larger (9%) than today, implying that hypothesis H1 is false
- the changes in sediment $\delta^{15}\text{N}$ between the LGM and the modern are consistent with the modeled changes if different surface iron distributions are considered. This consistency is decreased if iron changes are not considered, which indicates that hypothesis H2 is false.

Preliminary results from the collaboration with Dr. Green

- show a large increase (~50%) in deep ocean overturning due to increased tidal energy dissipation in the LGM deep ocean,
- indicate that this effect should be considered in future PMIP LGM simulations,
- if included in PMIP simulations would excacerbate the discrepancy with reconstructions (see results from Muglia et al. in prep described above).

* What opportunities for training and professional development has the project provided?

Graduate student Juan Muglia has finished the coursework required for his PhD. In addition to courses required for the Physical Oceanography program he has also taken courses on biogeochemical cycles and a seminar on carbon isotopes, which will equip him with useful background knowledge for his project.

Graduate student Christophere Owens from OSU's math departement is currently working as a summer internship on implementing a parameterization of the effect of mesoscale eddies on horizontal diffusion in the ocean model. One of the goals is to assess the effects of this parameterization on simulations of oxygen and denitrification.

Undergraduate student Catherine Wielgasz, who participates in CEOAS' Research Experience for

Undergraduates (REU) program, is currently working as a summer internship on synthesizing published and unpublished carbon isotope data from Mix's lab and comparing them to model output from Schmittner's carbon isotope enabled UVic model.

*** How have the results been disseminated to communities of interest?**

Through publications and presentations at scientific meetings (see below). The results concerning tidal energy dissipation in the LGM ocean have been presented in a physical oceanography session at the Ocean Sciences Meeting, thus exposing a community that is usually focussed on the modern ocean to paleoceanography. One workshop for future science teachers (OSU SED531-514 students) on climate change and ocean acidification included discussions of paleoclimate and its role in understanding anthropogenic effects. Schmittner teaches an undergraduate course on climate change (ATS320 "The Changing Climate") for science and non-science teachers, which includes lectures on paleoclimate and visits of OSUs sediment core and ice core labs. Schmittner gave a public presentation on 03-28-2014 on "Recent Developments in Climate Science" at the 5th Annual Passive House Northwest Conference in Portland, Oregon, which included paleoclimate.

*** What do you plan to do during the next reporting period to accomplish the goals?**

1. Merge the iron cycle model with the carbon and nitrogen isotope model. Perform LGM simulations with this model considering changes in aeolian (dust) and benthic (sea level) iron fluxes.
2. Further explore simulations of deep ocean LGM circulations and $\delta^{13}\text{C}$ distributions with the goal to produce an improved match with observed $\delta^{13}\text{C}$.
3. Test hypothesis H3.
4. Publish peer-reviewed version paper on early deglacial AMOC, CO_2 and $\delta^{13}\text{C}$ changes (Schmittner and Lund, 2014).
5. Finish writing, submit and publish the analysis of the LGM nitrogen cycle (Somes et al. in prep).
6. Write, submit, and publish the analysis of PMIP3 model's LGM AMOC (Muglia and Schmittner, in prep).
7. Finish analysis, write, submit, and publish paper on effect of tidal mixing changes on LGM deep overturning circulation.
8. Combine 1. and 2. to write comprehensive paper on LGM circulation, carbon, nitrogen, and iron cycles.

Products

Books

Book Chapters

Conference Papers and Presentations

Muglia, J., and Schmittner, A. (2013). *Atlantic Circulation During the Last Glacial Maximum Simulated by PMIP3 Climate Models*. PMIP Ocean Workshop 2013. Corvallis, Oregon, USA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Somes, C. J. (2011). *Changes in the nitrogen cycle in the modern and glacial ocean*. 43th International Liège Colloquium on Ocean Dynamics Tracers of physical and biogeochemical processes, past changes and ongoing anthropogenic impacts. Liège, Belgium. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Somes, C. J. (2011). *Changes in the nitrogen cycle in the modern and glacial ocean*. XVIII International Union for Quaternary Research Congress. Bern, Switzerland. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Somes, C., Oschlies, A., and Schmittner, A. (2012). *Constraining rates of N_2 fixation and denitrification in the*

ocean using NO₃:PO₄ ratios. Ocean Sciences Meeting. Salt Lake City, USA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Somes, C., Schmittner, A., and Oschlies, A. (2012). *Isotopic constraints on the global oceanic nitrogen inventory in the modern and glacial oceans*. International Conference on Earth System Modelling. Hamburg, Germany. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Somes, C., Schmittner, A., and Oschlies, A. (2013). *Isotopic constraints on the global oceanic nitrogen inventory in the modern and glacial oceans*. 11th International Conference on Paleoceanography. Barcelona-Sitges, Catalonia-Spain. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Somes, C., Oschlies, A., and Schmittner, A. (2012). *Isotopic constraints on the pre-industrial fixed nitrogen budget*. American Geophysical Union Fall Meeting. San Francisco, California, USA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Breeden, M., and Schmittner, A. (2012). *Last Glacial Maximum Ocean Circulation Simulated by PMIP3 Climate Models*. American Geophysical Union Fall Meeting. San Francisco, California, USA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Schmittner, A., Egbert, G., and Green, M. (2014). *Modeling Tidal Mixing, Past, Present, and Future*. Ocean Sciences Meeting. Honolulu, Hawaii, USA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Muglia, J., and Schmittner, A. (2013). *Ocean Circulation During the Last Glacial Maximum Simulated by PMIP3 Climate Models*. Key Uncertainties in the Global Carbon Cycle: Perspectives across terrestrial and ocean ecosystems. Boulder, Colorado, USA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Somes, C. J., A. Schmittner, and A. Oschlies (2014). *Using Nitrogen Isotope Records to Constrain Changes to the Global Oceanic Fixed Nitrogen Budget during the Last Glacial Maximum in an Earth System Climate Model*. American Geophysical Union Fall Meeting. San Francisco, California, USA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Somes, C. J. (2011). *Using nitrogen isotopes and xsP to constrain the fixed-N budget in the past and present ocean*. 2nd NICOPP Meeting: Sedimentary $\delta^{15}\text{N}$ - data synthesis, analysis and modeling. Halifax, Canada. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Inventions

Journals

A. Schmittner, N. Gruber, A. C. Mix, R. M. Key, A. Tagliabue, and T. K. Westberry (2013). Biology and air–sea gas exchange controls on the distribution of carbon isotope ratios ($\delta^{13}\text{C}$) in the ocean. *Biogeosciences*. 10 5793. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.5194/bg-10-5793-2013

Lund, D. C., Tessin, A. C., Hoffman, J. L., and Schmittner, A. (2014). Southwest Atlantic watermass evolution during the last deglaciation. *Paleoceanography*. . Status = UNDER_REVIEW; Acknowledgment of Federal Support = No ; Peer Reviewed = No

Muglia, J. Schmittner, A. (2014). Last Glacial Maximum Ocean Circulation in Paleoclimate Model Intercomparison Project 3 Simulations. *Climate of the Past Discussions*. . Status = OTHER; Acknowledgment of Federal Support = No ; Peer Reviewed = No

Schmittner, A. Lund, D. C. (2014). Carbon Isotopes Support Atlantic Meridional Overturning Circulation Decline as a Trigger for Early Deglacial CO₂ rise. *Climate of the Past Discussions*. 10 2857. Status = UNDER_REVIEW;

Acknowledgment of Federal Support = Yes ; Peer Reviewed = No ; DOI: 10.5194/cpd-10-2857-2014

Somes, C. J. Schmittner, A. Oschlies, A. (2014). Isotope Constraints on the Oceanic Nitrogen Cycle during the Last Glacial Maximum. *Nature Geoscience*. . Status = OTHER; Acknowledgment of Federal Support = No ; Peer Reviewed = No

Somes, C. J., Oschlies, A., and Schmittner, A (2013). Isotopic constraints on the pre-industrial oceanic nitrogen budget. *Biogeosciences*. 10 5889. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.5194/bg-10-5889-2013

Licenses

Other Products

Databases.

Modern water column carbon isotope dataset. <http://cdiac.ornl.gov/oceans/Schmittner13bg.html>

Models.

Model of Ocean Biogeochemistry and Isotopes (MOBI). <http://www.biogeosciences.net/10/5793/2013/bg-10-5793-2013-supplement.zip>

<http://people.oregonstate.edu/~schmita2/Models/MOBI/index.html>

Other Publications

Patents

Technologies or Techniques

Thesis/Dissertations

Websites

Ocean Circulation and Carbon Cycling (OC3)

<http://people.oregonstate.edu/~schmita2/Projects/OC3/index.html>

International project aimed at synthesizing carbon isotope data from ocean sediments in order to improve understanding of deglacial changes in ocean circulation and carbon cycling.

Reconstructing Glacial Nitrogen and Carbon Cycling Using Isotopes

<http://people.oregonstate.edu/~schmita2/Projects/LGM/>

Project website.

Participants/Organizations

What individuals have worked on the project?

Name	Most Senior Project Role	Nearest Person Month Worked
Schmittner-Boesch, Andreas	PD/PI	3

Name	Most Senior Project Role	Nearest Person Month Worked
Mix, Alan	Co PD/PI	1

Full details of individuals who have worked on the project:
Andreas Schmittner-BoeschEmail: aschmittner@coas.oregonstate.edu**Most Senior Project Role:** PD/PI**Nearest Person Month Worked:** 3

Contribution to the Project: Project lead. Supervision of graduate student. Implementation of carbon isotopes in land carbon model component. Simulations of AMOC perturbation and LGM experiments. Writing papers. Organization of international projects OC3 and iPODS.

Funding Support: NA**International Collaboration:** No**International Travel:** Yes, Belgium - 0 years, 0 months, 5 days**Alan C Mix**Email: mix@coas.oregonstate.edu**Most Senior Project Role:** Co PD/PI**Nearest Person Month Worked:** 1

Contribution to the Project: Data synthesis. Student advising.

Funding Support: no**International Collaboration:** No**International Travel:** No

What other organizations have been involved as partners?

Name	Type of Partner Organization	Location
McGill University	Academic Institution	Montreal, Canada
University of Kiel	Academic Institution	Kiel, Germany

Full details of organizations that have been involved as partners:
McGill University**Organization Type:** Academic Institution**Organization Location:** Montreal, Canada**Partner's Contribution to the Project:**

Collaborative Research

More Detail on Partner and Contribution: Eric Galbraith is a collaborator on the nitrogen cycle model.

University of Kiel

Organization Type: Academic Institution

Organization Location: Kiel, Germany

Partner's Contribution to the Project:

Collaborative Research

More Detail on Partner and Contribution: Chris Somes continued to work on the nitrogen isotope model. Levin Nickelson works on including the iron cycle. Andreas Oschlies supervises both.

Have other collaborators or contacts been involved? No

Impacts

What is the impact on the development of the principal discipline(s) of the project?

The results have advanced knowledge of

- the LGM nitrogen cycle (we estimate large increase in fluxes (50%) but only a rather modest increase (10%) in the inventory),
- methods to reconstruct past changes in the ocean's nitrogen cycle using isotope enabled modeling and sediment data,
- driving forces for LGM ocean circulation (quantified effects of tides, wind stress, and atmospheric water vapor transport),
- methods to reconstruct past changes in ocean circulation using carbon isotope enabled modeling and sediment data,
- quantifying early deglacial AMOC changes and their impacts on global carbon cycling.

What is the impact on other disciplines?

The development and application of the nitrogen isotope model has already had an impact on ecological research that uses nitrogen isotope measurements in marine organisms. Chris Somes has been invited and attended several meetings of ecologists.

It also has an impact on modern marine geochemists who try to understand cycling of other isotopes such as $\delta^{114}\text{Cd}$, which is supposed to have similar fractionation effects during photosynthesis as $\delta^{15}\text{N}$, but no effects during nitrogen fixation or denitrification. We have shared model output with John Seth from the University of South Carolina who measures $\delta^{114}\text{Cd}$ in the GEOTRACES program.

What is the impact on the development of human resources?

One graduate student (Juan Muglia) has been trained in oceanography. One African American graduate student (Christopher Owens) and two female undergraduate students (Melissa Breeden and Catherine Wielgasz) have been (or are currently) involved in the research as summer internships. Melissa Breeden, who was an intern in 2012, is now a graduate student of atmospheric sciences at the University of Wisconsin - Madison. Thus, the project has already had a positive impact on attracting underrepresented groups and developing their skills in the Earth sciences.

Last years workshop for future math and science teachers (OSU graduate students of science education) has provided exposure to young people and future teachers to the science of climate change, ocean acidification, and paleoclimate.

What is the impact on physical resources that form infrastructure?

Nothing to report.

What is the impact on institutional resources that form infrastructure?

Two international collaborative projects have been initiated.

1. OC3 (Ocean Circulation and Carbon Cycling) is an effort funded by PAGES (Past Global Changes) with the goal to synthesize published and unpublished carbon isotope ($\delta^{13}\text{C}$) data with a focus on the last deglaciation. <http://pages-igbp.org/workinggroups/oc3/intro>
2. iPODS (Investigating Past Ocean DynamicS) is an effort funded by INQUA (International Quaternary Association) with the goal to synthesize radiocarbon, oxygen isotope, and perhaps other (e.g. ϵNd) data for the last deglaciation. <http://www.inqua.org/PALCOMM/pcProjects.html>

What is the impact on information resources that form infrastructure?

This project has improved a global model of climate and ocean biogeochemistry that is widely used in the community. The University of Victoria (UVic) Earth System Climate Model (<http://climate.uvic.ca/model/>) has been improved in various physical and biogeochemical aspects. Some of the physical aspects we have improved are atmospheric water vapor transport (Muglia and Schmittner, in prep) and the parameterization of deep ocean (tidal) mixing (collaboration with M. Green). The combined nitrogen and carbon model code has been submitted to the UVic group and will most likely enter the next official version of the UVic model. Thus it will become available for the large user community of that model.

What is the impact on technology transfer?

Nothing to report.

What is the impact on society beyond science and technology?

Schmittner is actively engaged in various outreach activities such as the teacher workshops mentioned above, public presentations, letters to the editor, and participation in the Climate Change National Forum blog (<http://climatechangenationalforum.org/>) all of which are intended to advance climate literacy of the general public.

Changes/Problems

Changes in approach and reason for change

Nothing to report.

Actual or Anticipated problems or delays and actions or plans to resolve them

Nothing to report.

Changes that have a significant impact on expenditures

Nothing to report.

Significant changes in use or care of human subjects

Nothing to report.

Significant changes in use or care of vertebrate animals

Nothing to report.

Significant changes in use or care of biohazards

Nothing to report.