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Collaborative Research: An Interdisciplinary Investigation of Groundwater-Carbon Coupling in Large Peat Basins and its Relation to Climate Change

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Signature of Submitting Official (signature shall be submitted in accordance with agency specific instructions)	Andrew S Reeve

Accomplishments

*** What are the major goals of the project?**

This project focused on the interaction between biogenic gas and hydrology within the Red Lake Peatlands of northern Minnesota. Interest in peatlands is driven by their role in carbon cycling, particularly their influence on 'greenhouse

gasses'.

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

Major Activities: Over the past year work has focused on data analysis:

* Modified python scripts to plot and analyze large (tens of millions of measurements) amounts of hydrologic and meteorologic data.

* Developing a one-dimensional visco-elastic model of peat deformation that incorporates gas content and water table position. This Kelvin-Voigt model couples ten vertically stacked peat block using dashpot and spring elements to simulate the viscous and elastic response of peat to surface loading and changing water content.

* Development of a peat accumulation model coupled to groundwater hydrology is ongoing. This modeling effort interfaces a cellular automata model of peat accumulations with a traditional finite volume groundwater flow model.

* Incorporated finding from this project in public presentations (bog nature walks), including secondary school groups, at the Orono Bog Boardwalk.

Specific Objectives: The objectives for this project over the past year included:

* Analyzing the GPS and hydrologic data and moving toward a more quantitative assessment of these data.

* Constructing a one-dimensional model of peat deformation and using this model to evaluate the linkage between peatland surface motion and water content in the peat column.

* Constructing a coupled peat accumulation and groundwater hydrology model and using this model to assess peatland carbon sequestration rates.

Significant Results: A local GPS network documented significant changes in surface elevations throughout 2009 with the greatest vertical displacements associated with rapid changes in peat water table position and unloading due to melting of the winter snow pack. Up to 25.3 cm of vertical movement through the year was measured using GPS antennas mounted to small (10 cm diameter) trees. These changes were coherent with changes in water table elevation and also with abnormal pore-pressure changes measured by nests of instrumented piezometers. A Kelvin-Voigt deformation model reproduced these changes when the gas content was adjusted to 10\% of peat volume and Young's modulus was varied between 5 and 100 KPa as the peat profile shifted from tension to compression. In contrast, the model predicted little peat deformation when the gas content was 3\% or lower. These model simulations are consistent with previous estimates of gas volume in northern peatlands and suggest an upper limit of gas storage controlled by the elastic moduli of the peat fabric. Venting gas from these models changes the buoyancy of the peat and results in a rapid drop in peat surface. Similarly, surface loading and unloading associated with a changing snowpack produces significant (centimeter to decimeter) changes in surface elevation over daily to weekly time periods.

The vertical hydraulic gradients measured at the bog site in 2009 were generally

downward, with the largest and smallest hydraulic head differences measured in April and September. Upward hydraulic gradients were measured in the upper portion (50 to 150 cm depths) of the BOGS peat column in June and July, in the deepest wells, near the peat and mineral soil interface throughout 2009 and in the lower half of the peat column during October and November (although the vertical gradient is very small). Small downward hydraulic gradients at the FEN0 site are measured in the spring 2009, decreasing and shifting to upward hydraulic gradients in the summer and early fall, before returning to downward gradients in the late fall.

Several anomalous changes in hydraulic head were recorded through 2009. Some changes can be attributed to external factor such as the 5 cm increasing in hydraulic head following a 15 mm (water equivalent) snowfall event recorded in Waskish, MN. However, several anomalous events show rapid changes which appear to be internally driven, and may be related to movement of biogentic gas through or out of the peat column. In addition to these isolated events, cm-scale oscillations in hydraulic head were recorded near the interface between the peat and the mineral soil. These oscillations are coincident with air temperature and dissipate during the fall and winter when air temperature is lower. No clear mechanism has been identified for these unusual oscillations.

Detailed information on this work is described by Reeve et al (In Press in Journal of Geophysical Research-Biogeosciences).

Key outcomes or Other achievements:

In addition to the results described in the previous section, two-dimensional (cross section) peat accumulation and groundwater flow models have been created and linked together to assess the feedback between hydrology and the accumulation of carbon-rich organic matter. Work on the model is ongoing, but preliminary results produce mounded peat deposits that mimic an idealized peatland.

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

Claire Westervelt is pursuing an M.S. and is working on coupling a peat accumulation model to a finite volume groundwater flow model. She has received instruction in hydrogeology, GIS analysis, and computer programming and model construction using the python scripting language.

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

Research results are distributed to the general public through an annual hydrology focused nature walk at the Orono Bog
Boardwalk. During these walks information developed through this and other projects are presented to the public while touring a peatland in central Maine. Tours for secondary school students at this site also incorporate facets of this research project when appropriate.

Graduate students participating in this project have been encouraged to present their work at regional and national scientific
conferences (Geological Society of America, Scipy). In addition to conference presentations and associated abstracts, results of this work have been disseminated through publication of a technical paper.

Data analysis using the python scripting language, a tool used throughout this project, has been made available to the general public through a class website where notes covering aspects of data analysis and mathematical methods underlying computer modeling in the earth sciences can be downloaded or reviewed. These notes have been used by local high school students (Bangor High School and Old Town High School) for either in class exercises (where lectures where provided by Reeve) or for an independent study by a high school student who developed a one

dimensional heat transport model to evaluate groundwater flow data.

Products

Books

Book Chapters

Conference Papers and Presentations
Westervelt, Claire D., A.S. Reeve, and P.H. Glaser (2013). *Cell-based simulation of peat accumulation in northern peatlands*. Geological Society of America Northeast Section. Bretton Woods, NH. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Reeve, A.S., P.H. Glaser, and D.O. Rosenberry (2013). *Coupling peatland surface movement to biogenic gas accumulation and hydrology using simple 1-D dynamic computer models*. Geological Society of America Northeast Section. Bretton Woods, NH. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Reeve, Andrew and Claire Westervelt (2013). *Peatland data analysis and simulation with Python*. Scientific Computing with Python. Austin, TX. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Inventions
Nothing to report.

Journals
Reeve, A.S., P.H. Glaser, and D.O. Rosenberry (2014). Seasonal changes in peatland surface elevation recorded at GPS stations in the Red Lake Peatlands, northern Minnesota, USA. *Journal of Geophysical Research - Biogeosciences*. InPress . Status = ACCEPTED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

Licenses
Nothing to report.

Other Products
Software or Netware.

Reeve assisted with the implementiation and testing of an enhancement to the FiPy finite volume model. This modification allowed the FiPy program to include anisotropic properties in computer simulations. This computer code is distributed by NIST as an open source tool to solve a range of partial differential equations.

Other Publications

Patents
Nothing to report.

Technologies or Techniques
Nothing to report.

Thesis/Dissertations

Websites
U.Maine Hydrogeology
http://hydro16.geology.um.maine.edu/class/index.html

Reeve continually develops a web site describing the application of the python scripting language to earth and environmental science problems. This web site is primarily maintained as a resource for Reeve's students, but it left available to the public. Much of the material developed for this site is the result of knowledge gleaned from working on

a range of research projects.

Participants/Organizations

What individuals have worked on the project?

Name	Most Senior Project Role	Nearest Person Month Worked
Reeve, Andrew	PD/PI	3
Bon, Christiaan	Graduate Student (research assistant)	2
Westervelt, Claire	Graduate Student (research assistant)	5

Full details of individuals who have worked on the project:

Andrew S Reeve
Email: asreeve@maine.edu
Most Senior Project Role: PD/PI
Nearest Person Month Worked: 3

Contribution to the Project: Supervised and mentored graduate students; developed computer scripts to analyze hydrologic, gps, and meteorologic data; assisted with development of cellular automata models for peat accumulation; developed 1-D model of peat deformation.

Funding Support: Supported by the University of Maine

International Collaboration: No
International Travel: No

Christiaan Bon
Email: Christiaan_Bon@umit.maine.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 2

Contribution to the Project: Analyzed hydraulic head data in an effort to identify anomalous data logger measurements possibly related to biogenic gas release.

Funding Support: Supported by the University of Maine and NSF EAR 1044979.

International Collaboration: No
International Travel: No

Claire Westervelt
Email: cdwestervelt@gmail.com
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 5

Contribution to the Project: Prepared cellular automata peat accumulation model and coupled this model to groundwater flow model.

Funding Support: Supported by the University of Maine

International Collaboration: No
International Travel: No

What other organizations have been involved as partners?
Nothing to report.

What other collaborators or contacts have been involved?

NO

Impacts

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

This work adds to the growing body of literature that indicates peatland surfaces experiences significant movement over the year. This work, along with previous work done by others, noted that this movement appears to be related to water table position within the peatland. The one-dimensional model developed to simulate vertical surface movement couples changing water table position with peat compression and expansion and demonstrates that buoyancy effects can explain the observations made in the Red Lake and other peatland systems. Results from this model provide an explanation for observed surface changes related to gas release.

What is the impact on other disciplines?

Educational materials on using the Python programming language for data analysis are distributed through Reeve's web site and currently accessible to the public.

What is the impact on the development of human resources?

Two graduate students were supported by this project. One student has taken the skills developed through this project and now works for state government regulatory agencies (Ohio EPA).

Application of the python computer language for data analysis has been an important tool used throughout this project. Educational materials related to using python for data analysis are available through a web site, through a class taught annually by Reeve, and through a short course offered during the Geological Society of America Northeast Section 2013 meeting. These resources have been used by local high school students and Reeve has presented material to high school students in a classroom setting and as an independent (project centered) study.

What is the impact on physical resources that form infrastructure?
Nothing to report.

What is the impact on institutional resources that form infrastructure?
Nothing to report.

What is the impact on information resources that form infrastructure?
Nothing to report.

What is the impact on technology transfer?
Nothing to report.

What is the impact on society beyond science and technology?

I lead an annual peatland hydrology nature walk at the Orono Bog Boardwalk and serve as a guide for secondary school children through this organization. Each year I typically lead about 10 groups of students on these nature walks,

explaining the geologic and hydrologic linkages to the peatland ecosystem.

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

Both the GPS data processing and development of the peat accumulation model were delayed due to Reeve's failure to recruit suitable graduate students early in the project, and the departure of a Ph.D. student in 2009. The GPS processing has been completed and a publication related to this work is in press. The peat accumulation modeling is underway but has proven more difficult to do than anticipated. Simulations of peat accumulation were taking 8 to 16 hours to complete and feedback between the hydrology and peat accumulation models were producing numerically unstable computer models. In an effort to address these issues, the model has been simplified and work on this model is ongoing.

Changes that have a significant impact on expenditures

Funding was being held to pay for page charges for a publication. The grant expired before being billed for these funds resulting in some funds being unspent on the project.

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.