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Derived Quantities: A Coupled Dynamic/Thermodynamic Ice Sheet Model

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Organization: University of Maine

Derived Quantities: A Coupled Dynamic/Thermodynamic Ice Sheet Model

Project Participants

Senior Personnel

Name: Fastook, James
Worked for more than 160 Hours: No
Contribution to Project:

Post-doc

Graduate Student

Undergraduate Student

Organizational Partners

Other Collaborators or Contacts

Jens Naslund, University of Stockholm
Johan Kleman, University of Stockholm
Wibjorn Karlen, University of Stockholm
Per Holmlund, University of Stockholm
Kathy Licht, University of Colorado
Eric Steig, University of Pennsylvania
Mikhael Grosswald, Russian Academy of Sciences

Jon Thomas, a Masters student in the Computer Science Department here at the University of Maine, did his thesis work on the problem of sparse matrix solutions on a parallel supercomputer (an SGI Origin2000 at Boston University). While not directly working on the problem of temperatures within the ice sheet, he did use as a demonstration matrix, the stiffness matrix generated by the Finite-element Method which is the core of the ice sheet model which is the focus of this grant. In the future, the ice sheet model will need to migrate to the high-performance platform of a parallel supercomputer. Jon's work will expedite this transition.

Activities and Findings

Project Activities and Findings:
The thermodynamic code was tested in the EISMINT arena. I attended an EISMINT meeting in Grindelwald, Switzerland, where results of several experiments were compared and discussed with leaders in the ice modeling community. A major bug in units conversion was discovered as a result of the model intercomparison and corrected. I participated in two of the EISMINT experiments, the Greenland experiment (Ritz et al, submitted to Climate Dynamics) and the Basal Sliding experiment (Payne et al, submitted to Journal of Glaciology).

With the thermodynamics code now tested, several application experiments have been performed. Jens Naslund, a student of Per Holmlund's from the University of Stockholm applied the model to his field study area in Western Dronning Maud Land (Naslund et al, accepted Journal of Glaciology 1999). A major component of this work involved the generation of a new DEM for the area, as the Drewry Folio data was found to be severely lacking. A second experiment involved applying the ice sheet model to the advance of an ice sheet model across Lake Baikal, which blocked the flow of a major river and left discernible glacial deposits (Fastook and Grosswald, 1998). A third experiment involved modeling of a valley glacier on the flanks of Mt Kenya in East Africa (Karlen et al, AMBIO 1999). It is worth noting that these three experiments span the full range of scales of glacier modeling, from full ice sheet modeling to regional studies to small valley glaciers.

Most recently an application of the model to the Ross Embayment catchment area provided insight into potential changes in interior ice thicknesses in West Antarctica (Ackert et al, Science 1999).

Work continues on extending the temperature calculation into 3D. The 1D temperature profile was compared and matched with the full 3D temperature calculation. A major problem in 3D with the aspect ratio (elements in an ice sheet are meters thick, but kilometers wide) has made the implementation of this difficult with the full ice sheet model. However, an application of the 3D code with a more rectangular domain (a section of an ice stream spanning the shear margin) was successfully completed, and the results reported on at the Fall 1998 Chapman Conference in Orono (Fastook, 1998)

The availability of the temperature field in the ice sheet model, which was originally incorporated to provide an internally consistent calculation (as opposed to arbitrary external specification) of the ice material properties through the ice column, also provides information about the state of the bed. I had hoped that knowledge of the basal temperature (below or at the pressure melting point) would provide the necessary information to predict where sliding would occur. The match was not as good as one might hope for, and so an investigation of the movement of basal water produced by melting at the bed was begun. Preliminary results of this were reported at the 1997 WAIS meeting (Fastook, 1997) and a proposal to expand this avenue was submitted to and funded by the NSF.

Project Training and Development:

The thermodynamic calculation, as a component of the ice sheet model, has greatly improved both the range of questions that can now be asked of the model, and its perceived accuracy in predicting or describing actual ice sheet behavior. Climatic events, such as climate warming, or cooling during ice ages can now be much more rigorously simulated. Where the old model without thermodynamics required the manual specification of ice hardness as climate warmed or cooled, with more or less arbitrary changes to the material properties, the model with thermodynamics now calculates these fundamental properties from first principles, thus eliminating from the modeling process yet another adjustable parameter that limited the realism of any simulation or experiment. I have attempted to keep the various components of the model compartmentalized, so that the effects of one component can be studied without interaction with other competing processes. This allows a more clear understanding of both positive and negative feedback processes in the physics of the ice sheet.

Research Training:

Two students participated directly on the project.

Jens Naslund, a PhD student at the University of Stockholm, included a major section in his thesis on Western Dronning Maud Land glaciology. He visited the University of Maine twice during the project to work directly with me on the modeling of his field area. He learned to use the model himself and has a version working on a computer in Sweden, although the bulk of the experiments were performed here at Maine. Jens has finished his PhD and is currently an instructor at a Swedish University.

The second student involved was Jon Thomas, a Masters student in Computer Science here at the University of Maine. His work involved investigations into the feasibility of porting the ice sheet model to a parallel (multiple CPU) supercomputer. He focused particularly on the sparse matrix solution phase, which is central to the solution of the ice sheet model equations. He has finished his MS and is currently enrolled as a PhD student to continue his work in Parallel Computing.

Outreach Activities:

I regularly give presentations to new students here at the University on 'Glaciology as a Computer Science Problem.' This involves motivating them as to why glaciology is worth studying (climate change, ice ages, CO2 warming, ice cores, etc.). I also meet with prospective students from Maine High Schools during their visits to the University campus.

Journal Publications

P. Huybrechts, T. Payne, A. Abe-Ouchi, R. Calov, J. Fastook, R. Greve,
R. Hindmarsh, O. Hoydal, T Johannesson, D. MacAyeal, I. Marsiat, C.
Ritz, M. Verbitsky, E. Waddington, and R. Warner, "The EISMINT
benchmarks for testing ice-sheet models", *Annals of Glaciology,*, p. 1, vol. 23, (1996).) Published
Jens-Ove Naslund, Per Holmlund, and J. Fastook, "Modelling the Maudheimvidda Ice Sheet, East Antarctica - A compliment to the discussion of the age and process relationships between subglacial land forms and the ice sheet (Abstract)", *Annals of Glaciology*, p. 0, vol. 23, (1996).) Published
J.L. Fastook, "Control methods applied to inverse modeling of ice sheets: The use of finite-element basis functions", *Third Annual West Antarctic Ice Sheet Initiative Workshop, 25-27 Sept. 1996, Sterling, Virginia*, p. 0, vol. , (1996).) Published
J.L. Fastook, "Where does all the water go?", *In Fourth Annual West Antarctic Ice Sheet Initiative Workshop, 10-12 Sept. 1997, Sterling, Virginia*, p. 0, vol. , (1997).) Published
J.L. Fastook, "Heat generation in the shear margin: A Finite-Element model", *Chapman Conference on the West Antarctic Ice Sheet, September 13-18, 1998*, p. 0, vol. , (1998).) Published
K. J. Licht and J. L. Fastook, "Constraining a numerical ice sheet model with geologic data over one ice sheet advance/retreat cycle in the Ross Sea", *Chapman Conference on the West Antarctic Ice Sheet, September 13-18, 1998*, p. 0, vol. , (1998).) Published
J.L. Fastook and M.L. Grosswald, "Quaternary glaciation of Lake Baikal
and adjacent highlands: modelling experiments", *In S. Horie, editor, International Project on Paleolimnology and Late Cenozoic Climate. No. 11. IPPCCE, Innsbruck, Austria*, p. 0, vol. 11, (1998).) Published
Wibjorn Karlen, James L. Fastook, Karin Holmgren, Maria Malmstrom, John
A. Matthews, Eric Odada, Jan Risberg, Gunhild Rosqvist, Per Sandgren,
Aldo Shemesh, and Lars-Ove Westerberg, "Holocene glacier fluctuations on Mount Kenya, East Africa, between 5700 cal. years BP and the present", *AMBIO*, p. 409, vol. 28, (1999).) Published
J.O. Naslund, J.L. Fastook, and P. Holmlund, "Numerical modelling of the ice sheet in Western Dronning Maud Land, East Antarctica - impacts
of present, past, and future climates", *Journal of Glaciology*, p. , vol. , (1999).) Accepted
A. J. Payne, P. Huybrechts, A. Abe-Ouchi, R. Calov, J. L. Fastook, R.
Greve, S. J. Marshall, I. Marsiat, C. Ritz, and L. Tarasov, "Results
from the eismint phase 2 simplified geometry experiments: The effects
of thermomechanical coupling", *Journal of Glaciology*, p. , vol. , (1998).) Submitted
C. Ritz, P. Huybrechts, A. Fabre, J. Fastook, R. Greve, D. R. MacAyeal, S. J. Marshall, A. J. Payne, L. Tarasov, and R. S. W. van de Wal, "Intercomparison of greenland ice sheet models: A tool to assess the validity of past and future ice sheet reconstruction", *Climate Dynamics*, p. , vol. , (1998).) Submitted
Robert P. Ackert, David J. Barclay, Harold W. Borns Jr., Parker E. Calkin, Mark D. Kurz, James L. Fastook, and Eric J. Steig, "Measurements of Past Ice Sheet Elevations in Interior West Antarctica", *Science*, p. 276, vol. 286, (1999).) Published

Books or Other One-time Publications

Web/Internet Sites

URL(s):
http://rose.umcs.maine.edu/~shamis/papers/wais.html
Description:
Reports and presentation slides for the WAIS workshops of 1996, 1997, and 1998.

Other Specific Products

Contributions

Contributions within Discipline:
Researchers in various areas develop theoretical frameworks within which they can interpret their experimental data. These theoretical frameworks, or models, incorporate as complete a description of the physical processes connecting different aspects of the experimental data as is possible. Comparison of the modeling results with the experimental data allows the researchers to verify their intuitions regarding the

underlying physical processes that control the system being studied. A good model can be used in a predictive fashion to describe the behavior of a system subject to a different environment or at a different time in its evolution. Within the constraints of the theoretical framework, researchers can extend their vision beyond the measurable surface of the phenomenon, allowing them to literally 'see' inside the system which they are experimentally observing.

Physics-based modeling of this type is intrinsically dependent on the modern computer to make meaningful sense of the wealth of experimental data available for many fields of study. Traditionally modelers have used restrictive assumptions and simplified domains to allow for the analytic solution of the equations describing their physical system. With the advent of modern computers numerical methods which yield an approximate solution can be applied to equations which are not amenable to analytic evaluation, thereby allowing the researchers to solve the exact equations without restrictive assumptions or simplified domains.

Contributions to Other Disciplines:
Glacial modeling ties in intrinsically to many other disciplines, but is particularly important to the study of climate change. Predictions of future climate change depends on accurate interpretation of past climate change, and glaciers are seen as sensitive indicators of such change. In addition large ice sheets serve as repositories of past climate information in the form of deep ice cores. Interpretation of these ice cores depends on modeling for chronologies as well as other aspects of the core necessary to understand the preserved record.

Contributions to Human Resource Development:
Awareness of the impact of human behavior on the environment is important to instill in our young students. Study of the past in Antarctica gives us a window into the future. There are many unanswered and controversial questions about the ice sheets that will need to be solved to address the issue of human impact.

Contributions to Science and Technology Infrastructure:

Beyond Science and Engineering:
Ice sheet modeling is but one small component in our attempt to understand how the world climate system works. Policy makers need predictions so that they can plan for future contingencies. Models can make predictions which can be trusted only so much as the models can accurately describe the past and all its changes.

Categories for which nothing is reported:

Organizational Partners
Any Book
Any Product
Contributions: To Any Science or Technology Infrastructure