Report of the CESM Land Ice Working Group

22 June 2011
Breckenridge, Colorado

The CESM Land Ice Working Group (LIWG) held its annual summer meeting on Wednesday, June 22, 2011 at the 16th Annual CESM Workshop in Breckenridge, Colorado. The meeting was co-chaired by William Lipscomb and Stephen Price.

Here is the URL for the CESM meeting agenda, with links to presentations:

http://www.cesm.ucar.edu/events/ws.2011/Agendas/agenda.pdf

And here is a list of meeting participants:

http://www.cesm.ucar.edu/events/ws.2011/participants.pdf

Most of the LIWG meeting consisted of short presentations. Abstracts are below.

William Lipscomb and Stephen Price: *Welcome and overview*

The CESM Land Ice Working Group (LIWG) is working to develop improved land-ice models and couple them to other climate components, in order to provide useful, physically-based sea-level predictions. LIWG efforts to date have led to the inclusion of a dynamic ice-sheet model (the Glimmer Community Ice Sheet Model, or Glimmer-CISM) in the initial version of CESM, which was released in June 2010. CESM also includes a new surface-mass-balance scheme for ice sheets in the Community Land Model. Initial modeling efforts are focused on the Greenland ice sheet. Preliminary results are promising; in particular, the simulated surface mass balance for Greenland is in good agreement with observations and regional model results. The current model, however, has significant limitations: The land-ice coupling is one-way; we are using a serial version of Glimmer-CISM with the shallow-ice approximation; and there is no ice-ocean coupling. During the next year we plan to implement two-way coupling (including ice-ocean coupling with a dynamic Antarctic ice sheet) with a parallel, higher-order version of Glimmer-CISM. We also plan to add parameterizations of small glaciers and ice caps. With these model improvements, CESM will be able to simulate all the major contributors to 21st century global sea-level rise.

Sebastian Mernild, William Lipscomb and David Bahr: *Accelerated melting and disappearance of glaciers and ice caps*

Glaciers and ice caps (GIC) are losing mass and raising global sea level. The rate of glacier retreat has been difficult to quantify because long-term mass-balance observations have been available for only a few dozen of the Earth's estimated 300,000 to 400,000 GIC. An easily measured property, especially for remote sensing, is the AAR, the ratio of the accumulation area to the total area of a glacier. For a glacier in balance with its local climate, the average mass balance is zero and the AAR is equal to its equilibrium value, AAR_0. Given a sustained value of AAR < AAR_0, a glacier will retreat from lower elevations until the AAR is restored to its equilibrium value. Here, we present a data set of 84 observed GICs from 1995–2009 and show that most GICs are even farther from equilibrium than previously estimated. For the past decade, 2000–2009, these GICs have an average AAR of 35%, far below the mean equilibrium value of 58%. Our analysis suggests that in order to be in balance with the present climate, the Earth's GICs must lose ~40% of their volume, raising global sea level by ~240 mm. Extrapolation of recent trends suggests that if the climate continues to warm for another two decades, GIC volume will ultimately decline by 75% or more.

Alex Gardner and Mark Flanner: *The need for improving the simulation of glacier surface energy and mass budgets within CESM*

Over the last decade Arctic glaciers, ice caps and the Greenland ice sheet have experienced accelerated ice losses and have become major contributors to rising sea levels. Much of the acceleration in ice loss is due to increased melt resulting from warmer summer temperatures and amplified by cryosphere-albedo feedbacks. Correctly resolving those processes that govern the energy budget of the glacier surface is necessary for simulating glacier-climate feedbacks and essential for producing credible projections of meltwater runoff and sea level rise. Improving estimates of meltwater runoff is also the first step in constraining subglacial and englacial hydrology, which in turn influence glacier dynamics, another important contributor to glacier loss. As a first effort to improving the energy budget of glacier surfaces within CESM, we have modified the SNICAR snow radiative transfer scheme to include shortwave absorptance and reflectance within glacier ice, supraglacial lakes, and snow covered ice.

Miren Vizcaino, William H. Lipscomb, Janneke Ettema, and Michiel Van den Broeke: *Surface mass balance of the Greenland ice sheet simulated with CESM: 20th and 21st century simulations with MOAR forcing, validation and sensitivity to key parameters*

The Community Earth System Model (CESM) is the first US climate model with interactive coupling between the AOGCM and the ice sheet components. Here we present results for the climate and surface mass balance of the Greenland ice sheet forced with atmospheric data from previous CESM runs (1850, 20th century and RCP8.5. MOAR runs) and from first coupled simulations with surface mass balance calculations at several elevation classes.

Several issues are examined, such as spin-up, implementation of a new glacier mask, and the sensitivity of model results to the choice of key parameters (ice albedo, lapse rate, choice of initial snow thickness). Results from the regional model RACMO (Ettema et al, GRL, 2009) are used for validation. The 20th century and 21st century evolution of the surface mass balance is analyzed with a focus on the role of the different energy fluxes in changes in the simulated surface mass balance.

Xylar Asay-Davis: *Dynamic land-ice/ocean interactions in CESM*

I present the latest progress on a modified version of POP that includes an immersed boundary method (IBM) to represent ice-shelf/ocean interfaces. The IBM is designed to allow simulation of a fully dynamic land-ice/ocean interface, while requiring minimal modification to POP. The interface geometry is represented accurately without requiring modification of the computational grid as the simulation progresses. I present preliminary results of flows in ice shelf cavities, and discuss plans for coupling this modified version of POP to the CISM within CESM.

Ute C. Herzfeld, Brian McDonald, Bruce F. Wallin, Phillip A. Chen, Ralf Greve, James Fastook, Andreas Aschwanden, Ed Bueler, Carlton J. Leuschen, and John Paden: *A new DEM of Greenland bed topography and implications for results from dynamic ice sheet models*

The objectives of this talk are (1) to derive a Greenland bed that includes major outlet glaciers in the bed topography of Greenland, using recently collected data, and (2) investigate the effect of bed topography on results from dynamic ice-sheet models. A critical part of the problem is how to best bridge high-resolution observations and lower-resolution modeling in a way that those morphological properties of the glacier that control ice dynamics are preserved. A math-morphological algorithm is derived as a solution, and new radar data collected by CReSIS as part of Operation IceBridge and other missions are utilized to create regional bed topography DEMs of Jakobshavn Isbrae, Helheim Glacier, Kangerdlussuaq and Petermann Gletscher, representing simply connected trough systems. Model runs with SICOPOLIS, UMIS and PISM are presented, and resultant differences in basal water and surface velocities investigated. A result of our studies is that total mass loss predicted for up to 500 years in the future increases significantly for several SEARISE-type experiments when the glacier troughs are included in bed topography, and consequently expected sea-level rise increases several decimeters.

Matthew Pratola and Stephen Price: *Quantifying the uncertainty in ice sheet model parameters via model calibration*

Recently, the potential for rapid ice-sheet response to changes in climate has drawn concern and attention from climate scientists. As demonstrated by recent observations, changes in melting and discharge from ice sheets may impact global sea level on much shorter time scales than previously thought. To better understand and assess the risk of such changes, it is important to quantify the sources of uncertainty in coupled models of ice sheet and climate evolution. We present initial results from three idealized experiments using CISM, the land-ice component of CESM. In these experiments, we use synthetic, model-generated data and a statistical calibration approach to quantify the uncertainty in model physical parameters and in the resulting model predictions. From these initial experiments we confirm the utility of the methodology, identify areas of the methodology that require improvement, and identify potential future research applications.

Helene Seroussi, Mathieu Morlighem, Eric Larour, Eric Rignot, Denis Aubry, and Hachmi Ben Dhia: *A numerically optimized, computationally efficient method to couple Full-Stokes and simpler models of ice sheet flow*

The recent development of new higher-order, higher-resolution ice sheet models has shown that sophisticated models, such as Full-Stokes, were essential in some parts of the ice sheets, including the grounding line region. These areas are crucial for ice flow projections and can only be rigorously simulated using full 3d models. Higher-order models are well-suited to ice stream dynamics, whereas the shallow-shelf approximation is sufficient for modeling ice shelf flow. Higher-order and full-Stokes model are computationally intensive and prohibitive for large-scale modeling. There is therefore a strong need to combine such different models in order to balance computational cost and physical accuracy for the whole ice sheet.

Here we present a new methodology adapted from the Arlequin framework (Ben Dhia and Rateau, 2001, 2005) to couple finite element shelfy- stream, higher-order and Full-Stokes models. We achieve this by strongly coupling the different approximations within the same large scale simulation. This technique is applied to Pine Island Glacier, where Morlighem et al (2010) showed that a full-Stokes model is required to correctly capture the physics in the vicinity of the grounding line as the bridging effect cannot be neglected. We compare the results found with the hybrid models to single-model approaches.

Our new method preserves the conditioning number of the stiffness matrix, and ensures seamless stress regimes across model transition zones, hence improving numerical accuracy compared to existing techniques that use penalties or kinematical constrains. Furthermore, it optimizes the number of degrees of freedom leading to reduced computational cost.

Daniel Martin: *BISICLES: A high-performance adaptive higher-order thermomechanical ice sheet model*

The Berkeley ISICLES (BISICLES) project is building a scalable, high-performance higher-order ice sheet model. We use adaptive mesh refinement in the horizontal direction to allow fine spatial resolution where needed to resolve the dynamics of features like grounding lines, along with the vertically-integrated "L1L2" approximation of Schoof and Hindmarsh (2009). Recent progress includes incorporation of a temperature solver, as well as various solver and code improvements. We have developed an interface to permit the Glimmer-CISM code to employ the BISICLES code as an alternative dynamical core, which also allows the use of the existing CISM-CESM coupler. We show examples which demonstrate the effectiveness of our approach.

Kate Evans and Andrew Salinger: *Progress towards high-resolution continental-scale ice sheet simulations using a higher order dynamical core in Glimmer-CISM*

We outline progress towards accurate and efficient continental scale ice sheet simulations within the higher-order Glimmer-CISM. Significant speed up and enhanced robustness are

achieved for several ice sheet test cases through parallel performance and the use of a preconditioned Newton-Krylov method to converge the nonlinearities of the system.
We will present the source and limitations of these gains from a computational and computer science perspective. Glimmer-CISM uses the Trilinos framework of solvers, and an assessment of the algorithms available for preconditioning provides some insight in the transition from simple test problems to more complex yet scientifically relevant problems. We will present the current state of the higher-order Glimmer-CISM dycore in terms of test case performance, an explanation of how these model improvements will affect longer term ice sheet simulation, and progress towards the efforts to connect it to the CESM.

M. Perego, J. Burkardt, M. Gunzburger, W. Lipscomb, and S. Price: *Implementation and comparison of finite element methods for higher-order ice-sheet models*

Higher-order models represent a computationally less expensive alternative to the full-Stokes model for ice-sheet modeling. We focus on the three-dimensional first-order model by Blatter and Pattyn and the depth-integrated L1L2 model by Schoof and Hindmarsh. The models are implemented on parallel architectures, using the finite element method which is capable of naturally handling unstructured grids as well as typical physical boundary conditions. The non linear system associated with the discretized problem is solved using Newton scheme which is shown be faster than the common Picard scheme. We apply our computational models to ISIMP-HOM benchmark test cases and compare results obtained from our models with those obtained using a reliable Stokes computational model. Also, a comparison between linear and quadratic finite element approximations is carried out. Finally we present simulations on Greenland, comparing the solutions obtained using the different models.

Iulian Grindeanu, Jed Brown, Dmitry Karpeev, Barry Smith, Tim Tautges, and Jean Utke: *Towards interactive analysis of regional ice flow*

Prescribing suitable domains and boundary conditions for regional ice flow models is typically a time-consuming process. Field observations which will be used for boundary conditions or constraints for inverse modeling are often available in different formats, projections, sampling frequency, and with different conventions about missing data. In this work, we present recently developed tools to "close the loop" between defining a problem in GIS and visualizing results from an ice flow model. A geometry and topology engine relies on existing discrete observations, measurements, geographical data and polygonal description of a region of interest to create a full CAD-like, boundary represented model, suitable for mesh generation and easy application of boundary conditions. The geometry engine incorporates decimation and smoothing techniques, which aid in generation of quality unstructured hexahedral meshes. The geometry and boundary data need not be in any specific format or projection since the software transforms as needed for the simulation being run.

Since internal fields such as enthalpy (temperature/water content) are unknown or poorly constrained, it may take a large amount of computational effort to "spin up" a model such that its response can be practically assessed. As an alternative, we offer fully implicit and steady-state solvers that produce a consistent enthalpy field at a cost proportional to a single time step of a transient model. These solvers are based on Newton-Krylov methods and use an extensible system for constructing scalable preconditioners for multi-physics problems. New constitutive relations, perhaps involving additional field variables, can be defined in symbolic form using Python or written directly in C. When written in Python, manufactured solutions are automatically generated to confirm the accuracy of the method, and C code is generated for efficient evaluation of the constitutive relations. High order accuracy is demonstrated for sufficiently smooth solutions of the coupled systems.

Toby Isaac, Carsten Burstedde, Omar Ghattas, and Georg Stadler: *Scalable full-Stokes ice sheet simulation*

We treat the flow of polar ice sheets using the 3D nonlinear Stokes equations. To capture the wide range of length scales and localized flow features within a continental scale simulation, we employ adaptive mesh refinement and higher-order finite element methods. For such simulations to take advantage of current and future high performance computing resources requires numerical methods for solving these equations with good parallel performance and scalability. We will discuss the preconditioning of the systems of equations that result, as well as our work on incorporating SeaRISE data into simulations.