Report of the CCSM Land Ice Working Group

30 June 2010

Breckenridge, Colorado

The CESM Land Ice Working Group (LIWG) held its annual summer meeting on Wednesday, June 30, 2010 at the 15th Annual CESM Workshop in Breckenridge, Colorado. CESM is the Community Earth System Model, the successor to the Community Climate System Model (CCSM). The LIWG meeting was co-chaired by Jesse Johnson and William Lipscomb and was attended by approximately 55 registered participants.

The meeting was held a few days after the initial CESM release. CESM includes an active ice sheet component to which LIWG members contributed significantly.

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

http://www.cesm.ucar.edu/events/ws.2010/Agendas/agenda.pdf

And here is a list of meeting participants:

http://www.cesm.ucar.edu/events/ws.2010/participants.pdf

Most of the LIWG meeting consisted of short presentations. Abstracts are below. Some talks had more than one author, but only the names of presenters are shown here.

William Lipscomb — *A community ice sheet model in CESM*

Unlike previous versions of the Community Climate System Model (CCSM), the initial release of the Community Earth System Model (CESM) includes an ice sheet component. The dynamic ice sheet model is Glimmer, the Community Ice Sheet Model (Glimmer-CISM), an open-source model developed by researchers at U. Bristol, U. Montana, Los Alamos National Lab, and elsewhere. Also, there is a new surface-mass-balance (SMB) scheme for ice sheets in the Community Land Model. The SMB scheme is giving excellent agreement with results from a high-resolution regional model. Coupled simulations with a dynamic Greenland ice sheet are supported for various grid resolutions. The initial implementation is fairly basic; 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.

Miren Vizcaíno —*Simulation of the Greenland Ice Sheet in CESM*

First results of the simulated Greenland surface mass balance with CESM1.0. are presented. The calculation is done in the land model (CLM) with the same energy balance scheme used for other snow-covered surfaces, at ten elevation classes. The surface mass balance field is linearly interpolated between adjacent elevation classes for downscaling to the ice sheet model. Two data sets are used to force CLM: NCEP/NCAR reanalysis data from 1958-1998, modified as in Qian et al. 1999, and a 30-year-length pre-industrial (year 1850) simulation from CCSM4.0. CLM is run at 1 degree resolution. The ice sheet grid has a resolution of 10 km. The simulated Greenland near-surface climate and surface mass balance are validated against data from the regional model RACMO (Ettema et al., GRL, 2009). The simulated Greenland surface mass balance shows a very good agreement with RACMO. The model captures well the two high-precipitation bands along the southeastern and eastern margins, although its magnitude is underestimated in the (very steep) areas with highest precipitation. Precipitation rates are overestimated in northern interior, possibly due to the smoother topography at 1 degree resolution. The major ablation zones are well represented. Major biases are shown in the northern and eastern margins, with lower areas of the ablation zones. In the north, the cold bias is attributed to inaccuracy of the prescribed ice mask. In the east, the bias is attributed to the very complex topography. Comparison of the near-surface climate (in particular, annual and summer temperatures, incident longwave radiation and annual albedo) shows a good agreement with RACMO. These results are very encouraging, suggesting that a stable control ice sheet will be attained with minor parameter tuning (e.g.ice albedo, lapse rates) and without any anomaly coupling, an usual practice in previously coupled ice sheet-climate models. The use of an energy balance scheme will provide more physically based results for climates different than today's than those obtained with (extensively used) temperature-index methods.

David Holland — *Overview of the IPCC WG1 meeting on sea level rise*

The purpose of this Workshop was to bring together the leading world experts on all issues related to sea level rise, including the field of ice sheet dynamics and ice sheet instabilities, in order to accelerate scientific research that will feed results into the AR5. Experts discussed the latest results from observations related to sea level rise from oceanographic, cryospheric and paleo records, including information on thermal expansion of the ocean, melting of glaciers and small ice caps, changes in the mass balance of Greenland and Antarctica, changes in ocean circulation, and changes in water storage on land. The Workshop addressed the current understanding, and limitations, of ice sheet and ice stream dynamics, including information on their sensitivity to changes in the forcings and on potential irreversibility associated with ice stream or whole ice sheet instabilities and critically evaluate modelling tools used to project sea level rise, the resulting projections, and assess and constrain the associated uncertainties.

Stephen Price — *Steps towards an initial condition for higher-order, coupled simulations of the Greenland ice sheet in CCSM*

We review a straightforward procedure for tuning modeled ice sheet velocities to a target velocity field and geometry and apply the method to modern-day observations (balance velocities and geometry) from the Greenland ice sheet (GIS). The result is a steady-state, initial condition for a three dimensional, higher-order ice flow model of the GIS. The route mean-square difference between the modeled and target velocity fields is ~20 m/yr for the entire ice sheet and <10 m/yr for individual drainage basins of interest. We demonstrate how this initial condition is made consistent with initial surface mass balance and temperature fields provided by CCSM and argue for its use in deriving a pre-industrial, initial condition from which 21st century, coupled simulations of Greenland ice sheet evolution can be conducted.

Sophie Nowicki — *SeaRISE: an Update*

SeaRISE (Sea level Response to Ice Sheet Evolution), initially labeled the "Assessment Group" of the Community Ice Sheet Model, aims to provide a quantitative estimate of potential sea level contribution from the Greenland and Antarctic ice sheet in the coming 100-200 years, along with associated error bounds. To date, SeaRISE has attracted the participation of 13 whole ice sheet models. It is neither a model development project nor is it a model inter-comparison project in the sense that model results will not be compared to external standards or analytic solutions. It accepts that all models have strengths and weaknesses and seeks to determine the most likely ice sheet response to imposed climatic forcing by initializing an ensemble of models with common data sets and applying the same forcing to each model, interpreting the range of responses as a proxy of uncertainty.

Xylar Asay-Davis — *Representing ice shelves in POP using an immersed boundary: Preliminary results*

We present work in progress on an immersed boundary method for representing the interface between ice shelves and the ocean within CCSM. The longer-term goal is to couple POP to Glimmer-CISM in order to obtain a global scale simulation of the southern ocean together with the full Antarctic ice sheet. We are making the first tests of the method using idealized, fixed ice shelf geometry, based on the Ice Shelf-Ocean Model Intercomparison Project (ISOMIP) experiment 1, which allows for comparison with other models. The interface physics is represented in POP using an immersed boundary method (IBM). The IBM will eventually allow us to represent the boundary conditions at the complex, time-evolving geometry of the ice shelf without the need for a modeling grid that conforms to the boundary or that changes in time. We show success in representing the boundary geometry using the IBM, with work remaining to be done on implementing the boundary conditions themselves.

Ute Hertzfeld—*Thoughts on connecting geophysical observations and dynamic ice sheet models -- surface elevation, bed topography, roughness and turbulence*

The objective of the paper is to present thoughts on connecting geophysical observations and dynamic ice sheet models. Specifically, surface elevation, bed topography, roughness and turbulence are considered, using observations at several scales. The talk builds on ideas, concepts and results from IceBridge, ICESat, CReSISm SeaRISE and MICROTOP projects. Examples stem from Jakobshavns Isbr\ae, Greenland and Lambert Glacier/Amery Ice Shelf, Antarctica. The first part of the talk introduces to relationships among the above-mentioned variables. In the second part of the talk, a new algorithm for adjusting topography to grids while preserving sub-scale morphologic characteristics is derived. This algorithm solves the problem of creating a Greenland bed topography DEM that includes the Jakobshavns trough at the resolution used for input in dynamic ice sheet models. The new bed is available on the SeaRISE website and wiki (as bed data set v1.2) and used by modeling groups.

Sasha Carter— *Implementing and validating a model for basal water*

Ice sheet basal hydrology and its relation to basal sliding continues to constitute a source of significant uncertainty in ice sheet modeling. Most basal water models currently employed construct the hydraulic head surface as the sum of the basal elevation and the normalized water pressure, assuming water pressure is equal to overburden pressure everywhere. Although computationally simple, models that make this assumption tend to channelize most water into narrow streams. Actual water pressure is the overburden pressure minus the effective pressure. Effective pressure is estimated at 0-15 meters water equivalent for the Siple coast, and varies spatially. In our model it increases with estimated basal shear stress and decreases with water sheet thickness. This formulation effectively raises the hydraulic potential of channelized cells relative to their neighbors and causes water to spread more laterally resulting in a better agreement between final water distribution and inferred basal traction results. Additionally this formulation increases the supply of upstream water to areas of net basal freeze on, in locations such as the Whillans Ice plain. Complications however result from the iterative relationship between water thickness distribution and hydraulic potential associated with the inclusion of effective pressure. Although successive iterations of this calculation tend toward a stable distribution of subglacial water for most of the Siple Coast, several loci of instability occur where effective pressure oscillates from one iteration to the next. These loci may represent areas of unstable ice-water dynamics and warrant further investigation.

Kate Evans—*Progress and near-term goals of the SeaCISM project*

The SEACISM project has been tasked to produce an ice sheet model capable of high resolution predictive simulation within an ice sheet model that solves the higher-order equations for ice flow, Glimmer-CISM. Three complimentary efforts are currently underway within SEACISM and will be linked together over the next several months. The Trilinos framework has been implemented into Glimmer-CISM; currently the code uses Trilinos to solve the linear velocity equations within the higher-order framework in parallel. Also, Glimmer-CISM is being parallelized such that optimal use of the newest HPC architectures at OLCF and ALCF is achieved. As part of this, the currently the solver technology in Trilinos is being hooked up to the parallel structure implemented in Glimmer. Also, the current Picard solution method is being replaced by a Jacobian-Free Newton-Krylov (JFNK) solver with physics based preconditioning that provides a more efficient and robust solution capability. Implementation of a test bed JFNK solution method is complete and provides orders of magnitude reduced iteration count, increased solution efficiency, and enhanced robustness. Improvements to the solver and transition of JFNK to the Trilinos framework is underway.

Dan Martin—*The BISICLES project*

Ice sheet dynamics span a large range of scales. There are regions (ice streams, grounding lines) where very fine resolution is needed to accurately resolve the dynamics of the ice sheet. However, there are also large regions (most of East Antarctica, for example) where such fine resolution is unnecessary and represents a waste of computational resources. This range of scales makes ice sheet modeling a prime candidate for adaptive mesh refinement (AMR), in which the computational mesh is locally refined in regions where better resolution is desired. The goal of the Berkeley-ISICLES (BISICLES) project is to design and implement a parallel, adaptive ice sheet modeling code. The baseline model and discretization are the ones used in Glimmer-CISM, while we use the parallel Chombo AMR software framework to simplify code development. Preliminary results demonstrating the effectiveness of a vertically-integrated shallow-shelf AMR code on ice streams and grounding line example problems are presented, along with scaling results for the nonlinear ice velocity solver which demonstrate good scaling up to 64 processors.

Jesse Johnson—*Use and implementation of adjoint methods in ice sheet models*

The adjoint of the complete treatment of the momentum and energy balances in the *xz* plane is developed based on a terrestrially terminating glacier in west-central Greenland. The adjoint model and control theory are then used to 1) assimilate surface velocity data to determine a basal traction field, and 2) determine the sensitivity of the frozen to melted boundary in an ice stream to changes in geothermal heat flow and basal traction. Generalizing from this simple case to ones in higher dimensions will require the development of adjoints in larger scale codes, such as Glimmer-CISM. This in turn will require the use of automatic differentiation tools, such as Open AD. Glimmer is now being assessed as a targert for Open AD, pending Glimmer-CISM 2.0 and a new front end for OpenAD.

Jed Brown —*Fully implicit discretization for 3D grounding lines*

The grounding lines of marine glaciers present several unique computational challenges, namely nonlinear slip on irregular surfaces, anisotropic geometry and rheology, free surfaces, and stiff multiscale processes. Local conservation is crucial for obtaining meaningful solutions in the presence of less regular geometry and rheology. This is obtained by choosing compatible discontinuous spaces and utilizing ``conservative'' normals, but requires corrections within an ALE formulation, and a well-balancing scheme to avoid the spurious tangent forcing produced by standard discretizations.

On the ocean side, the boundary layers are too thin to feasibly resolve even in sub-regional models, but heat transfer and flow separation are crucial limiting processes, so high accuracy is still required. Laboratory validation indicates that modern wall-modeling, involving another nonlinear slip condition on the moving ice-ocean interface, is needed. This can be done in a natural way with the present ALE formulation. Finally, fully implicit time integration permits stepping over fast time scales and solving steady state problems without timestepping, thus facilitating efficient stability and sensitivity analysis.

Tim Tautges—*Mesh-based tools for land ice simulations*

Mesh-based tools for land ice simulations (Tim Tautges, Dmitry Karpeev): Ice sheet simulations require definitions of the basal and ice sheet top surface geometries; these models are used to generate discretizations/meshes on which the equations are solved, as well as to provide tangent and normal evaluations used to formulate boundary conditions. We describe the implementation of facet-based geometry as part of the Mesh-Oriented datABase (MOAB) mesh library, and its use to support all-quadrilateral mesh generation in the MeshKit meshing library. Geometric models and meshes at several resolutions are provided as examples, based on the Cresis dataset for the Jacobshavn glacier.