

Report of the CCSM Land Ice Working Group

17 June 2009

Breckenridge, Colorado

The inaugural meeting of the CCSM Land Ice Working Group was held 17 June 2009 in Breckenridge, Colorado at the 14th annual CCSM workshop. The meeting was co-chaired by Jesse Johnson (University of Montana) and William Lipscomb (LANL) and was attended by approximately 80 workshop participants.

There were ten short presentations during the meeting; abstracts follow. Some talks had more than one author, but only the name and affiliation of the presenter is shown here.

William Lipscomb, Los Alamos National Laboratory
Introduction to the Land Ice Working Group

As the Greenland and Antarctic ice sheets lose mass at an increasing rate, there is more urgency than ever to develop realistic ice sheet models that can be used to predict sea-level rise. To support this task, a new CCSM Land Ice Working Group (LIWG) has been formed. The LIWG is one of twelve working groups responsible for developing and applying different components of CCSM. The primary goals of the LIWG are (1) to couple a well-validated, fully dynamical ice sheet model to CCSM and (2) to determine the likely range of sea-level rise associated with the loss of land ice. Jesse Johnson and William Lipscomb are co-chairing the group, and Stephen Price is the working group liaison. The LIWG will meet twice per year: once in summer at the annual CCSM workshop and once during the winter. These meetings will be held jointly with the SeaRISE sea-level assessment project, at least in the near term. For more details, see http://www.ccsm.ucar.edu/working_groups/Land+Ice/.

Work continues on coupling an ice sheet model to CCSM. The Glimmer ice sheet model was recently ported to CCSM4, which will be used for IPCC AR5 climate change experiments. A new surface mass balance scheme for ice sheets has been added to the land component, CLM. Next we will test the mass balance scheme and try to reproduce a realistic Greenland ice sheet in a control climate. We will then undertake a series of climate change experiments, including standard IPCC scenarios as well as paleoclimate simulations. Meanwhile, there are ongoing collaborative efforts to develop an improved Community Ice Sheet Model (CISM) based on Glimmer. The new model, Glimmer-CISM, will be a parallel code with higher-order dynamics and more realistic treatments of key physical processes such as surface melting, subglacial water transport, grounding-line migration, and iceberg calving.

Jeff Ridley, U.K. Hadley Centre
Ice2sea: A European Initiative

Ice2sea is a formal 4-year project within the Framework-7 science programme of the European Union. Its objective is to provide new results to the IPCC AR5 on the

impact of ice sheets on global sea level rise. New field observations will be used to drive the development of ice sheet models such that processes under ice shelves, tidewater glaciers and melt-water percolation can be explicitly modelled. This will allow the impact on sea level of fast ice dynamics processes to be quantitatively assessed. The project will embed the ice sheet models (Antarctica and Greenland) in regional climate models, driven by the future projections of climate models (E1 and A1B scenarios). New observational datasets will be used to evaluate ice sheet model performance over the recent past to provide an uncertainty assessment of future predictions.

Robert Bindshadler, NASA Goddard Space Flight Center

SeaRISE: A community effort to inform IPCC AR5 of reasonable ice sheet contributions to sea level

While acknowledging rapid ice-sheet changes, the IPCC-AR4 stated that the “. . . understanding of these effects is too limited to assess their likelihood or provide a best estimate or an upper bound for sea level rise.” Through workshops and conversations, a coordinated effort has emerged that seeks to address this weakness in ice sheet models on a schedule to inform the next IPCC Assessment Report. This effort’s goal is to provide quantitative estimates of ice sheet contributions to sea level for the 21st and 22nd century, along with appropriate uncertainties. Confidence in these estimates will be gained by subjecting a number of models to a common set of scenarios to reduce the impact of unrealistic characteristics of any single model from affecting the predictions.

Because the IPCC-AR4 clearly stated that their upper estimates could not be considered upper bounds, many of the first experiments are intentionally extreme in their physical realism to help determine the upper bound of possible future ice sheet response. Subsequent experiments representing more likely scenarios will then be run to help lower the upper bound. All models will quantify their calculated ice sheet responses relative to a control run of the same model. This “normalization” process will help minimize unrealistic aspects of any single model and attempt to isolate the impact of the difference in forcing between the experiment and the control runs.

The effort includes regional models as well as whole ice sheet models. The interactions are expected to be two-way: regional models will be used to help provide more reasonable forcings for selected whole ice sheet model experiments and whole ice sheet models will be used to define boundary fields that will enable regional models to refine the predicted responses of particularly dynamic areas. Another anticipated benefit is that the results of this effort will help inform the implementation of dynamic land ice into a fully coupled CCSM.

Tim Bocek, University of Montana

Development of the Community Ice Sheet Model (CISM)

The Community Ice Sheet Model (Glimmer/CISM) is based on the shallow ice approximation model Glimmer, and is now poised to become the land ice component of CCSM. This presentation covers the process of creating a next-generation ice model by extending Glimmer with a three-dimensional ice velocity diagnostic based on Frank Pattyn's first-order approximation of the nonlinear Stokes equations. We make a case

both for the choice of Glimmer as a starting point and for the use of first-order physics, describe the first-order model with an emphasis on distinctions between it and the full Stokes model, and present the software engineering decisions that arose during the integration. Preliminary verification and intercomparison results are also presented.

Stephen Price, Los Alamos National Laboratory

A higher-order ice-flow model applied to the dynamics of Greenland's outlet glaciers

We introduce a straightforward procedure for “tuning” modelled, whole-ice-sheet velocities to a target velocity field and ice sheet geometry. The procedure is applied to modern-day observations (balance velocities and geometry) from the Greenland ice sheet, in order to derive a steady-state, initial condition for a 3D, higher-order flow model. The route-mean-square difference between the modelled and target velocity fields is $\sim 38 \text{ m a}^{-1}$ for the entire ice sheet and $\sim 5 \text{ m a}^{-1}$ for individual drainage basins of interest (e.g. Jakobshavn, Helheim, and Kangerdlugssuaq basins). We use this initial condition in perturbation studies for Helheim and Kangerdlugssuaq glaciers, in which we perturb the stress boundary condition at the outlet glacier terminus; the perturbation is such that the modelled flux changes for these glaciers is in approximate agreement with observations made during the past decade. By stepping the model forward in time and integrating basin-scale changes (acceleration and thinning) in time and space, we estimate that these two outlet glaciers will contribute ~ 0.3 and ~ 1 mm to sea-level rise (SLR) over the next decade and century, respectively. These estimates represent the diffusive response of the ice sheet to outlet perturbations that have already occurred and, as such, can be regarded as minimum estimates for the dynamic contribution of these drainage basins to SLR over the next century.

David Pollard, Pennsylvania State University

West Antarctic Ice Sheet variations through the last five million years

The West Antarctic Ice Sheet, grounded mostly below sea level and fringed by floating ice shelves, is considered to be vulnerable to future anthropogenic warming. However, projections of its future behavior are hampered by limited understanding of past variations and the main forcing mechanisms. Here a combined ice sheet-shelf model, with imposed grounding-line fluxes following recent work by C. Schoof, is used to simulate Antarctic variations over the last 5 million years. We argue that oceanic melting below ice shelves is an important long-term forcing, controlled mainly by far-field influences correlated with deep-sea-core benthic delta O18 records. Modeled West Antarctic configurations range between full glacial extents with grounding lines near the continental shelf break, intermediate states similar to modern, and brief collapses to small isolated ice caps on West Antarctic islands. Transitions between these states can be relatively rapid, taking one to several thousand years. Several aspects of the simulation agree with a sediment record recently recovered beneath the Ross Ice Shelf by the ANDRILL project (MIS AND-1B core).

Jonathan Bamber, University of Bristol

Uncertainties in the present-day surface mass balance of the Greenland ice sheet from a model intercomparison

The surface mass balance (SMB) of the Greenland ice sheet has been determined for the last 50 years through a combination of observations and modelling. It has been suggested that the SMB, which accounts for roughly half the mass loss, is well constrained compared to the other component of mass loss: solid ice fluxes. Observational evidence to support this suggestion is limited, however. One approach to investigating uncertainties is through a model inter-comparison. Here, we compare four different simulations of the SMB of the ice sheet over the last five decades. Three use a regional climate model to downscale ECMWF re-analysis (ERA-40) and operational analysis data from 1957-present day, while the fourth uses the same inputs but an empirical downscaling approach and melt model.

We compare time series of precipitation, melt, refreezing, runoff and net SMB as well variations in the spatial patterns of these variables. There is good agreement, not surprisingly, in the phase of inter-annual variability in the various terms, as this is controlled largely by the common forcing (ERA-40). The amplitudes in inter-annual variability, however, differ by as much as a factor two, while the absolute magnitudes of the individual terms that contribute to the SMB show systematic differences as large as a factor 3. Inter-model differences in melt production, for example, deviated consistently by about 100%. Despite the very large differences in the individual terms, the SMB between models showed greater consistency and agreed to within the standard deviation of the temporal variability. This suggests that a cancellation of errors in one or more of the models may be responsible for the agreement in SMB. The results also indicate that the models would likely have significantly different sensitivities to a secular trend in climate forcing. The inter-model differences in the SMB terms are ~3 times larger than the reported variations in solid ice fluxes from the ice sheet. We conclude that significant uncertainties still exist in estimating components of the SMB of the ice sheet for the recent past, and near future. We discuss areas for improvement, data/knowledge gaps, and priorities for future effort.

Sebastian Mernild, University of Alaska, Fairbanks
Greenland Ice Sheet surface-mass-balance modeling

Efforts to model the Greenland Ice Sheet (GrIS) mass-balance, its dynamic processes, changes, and contribution to the global eustatic sea level rise, still suffer from important uncertainties and limitations. The mechanisms that link climate, GrIS SMB, ice dynamics, and internal ice sheet hydrology (e.g., routing of water: melt water and liquid precipitation through glacier ice, transforming the input contributions into a runoff hydrograph at the ice sheet terminus based on seasonal changes in hydrological response and delay) are poorly understood. Current numerical ice sheet models do not simulate these changes realistically. There is a growing recognition that the SMB and the internal drainage are essential to assess a realistic impact of climate change on the GrIS. SnowModel could be the link between the surface processes and the internal ice sheet processes.

Rupert Gladstone, University of Bristol

Simulating grounding line motion in a 1D AMR (adaptive mesh refinement) ice sheet model

Grounding line migration is a key process affecting the stability of marine ice sheets such as the West Antarctic ice sheet (WAIS). Recent studies have shown that standard models employing a fixed spatial grid cannot be used to solve this problem in a robust manner but that moving-grid models (which explicitly track grounding line migration) show a great deal of promise. While the latter type of model is relatively easy to implement in one dimension, it would be very difficult to employ in full, three-dimensional ice sheet models. Here we use the AMR (adaptive mesh refinement) technique, which is based on a nested set of fixed-grid models. We have developed a 1D ice sheet model in which sub regions of the whole model domain (and sub regions thereof, etc.) are run at higher resolutions, forced at their boundaries by data from the encompassing lower resolution region, allowing very high resolution where it is needed without the high computational costs of running the whole domain at high resolution. The higher resolution regions evolve during the simulation according to predefined criteria (e.g. crossing a given threshold in estimated truncation error or proximity to grounding line). We also use linear interpolation to determine an exact grounding line position between grid points. We show that using either the AMR approach or grounding line interpolation give improvements in modelling grounding line migration as compared to the standard fixed grid model, but that using both together (i.e. linear interpolation of the grounding line within the highest resolution nest) is required in order to give a result that is truly robust to changes in model resolution.

Jed Brown, ETH Zurich

Scalable solvers for the 3D non-Newtonian Stokes problem in ice flow modeling

Numerical solution of the non-Newtonian Stokes problem is fundamental to modeling fast outlet glaciers and grounding-line dynamics in which the flow field is genuinely 3D. Due to incompressibility, the Jacobian is indefinite which causes conventional preconditioners to perform poorly or fail completely. Effective preconditioners are obtained by block factorization followed by physics-based interpretation of the resulting Schur complement using approximate commutator arguments to discretize an auxiliary problem that is suitable for multigrid. This scheme leads to optimal convergence rates and is applicable to more general indefinite problems.