Report of the CESM Land Ice Working Group
18 June 2014
Breckenridge, Colorado

The CESM Land Ice Working Group (LIWG) held its annual summer meeting on Wednesday, 18 June 2014 as part of the 19th Annual CESM Workshop, held at The Village in Breckenridge, Colorado. The meeting was co-chaired by Jesse Johnson, William Lipscomb, and Stephen Price.

At the end of the meeting, Jeremy Fyke and Stephen Price discussed community plans to develop an ice-sheet Model Intercomparison Project (MIP) that could be part of CMIP6. Jeremy and Jesse, among others, participated in an ice-sheet MIP planning meeting at NASA Goddard Space Flight Center on July 16-18.

Meeting presentations are posted here:
https://www2.cesm.ucar.edu/events/ws-2014/liwg/20140618/presentations

Abstracts are below. Some talks had several authors, but only the presenter's name is shown here.

The next LIWG meeting will likely be held in winter 2015 at the NCAR Mesa Lab in Boulder, Colorado.

LIWG talks:

Stephen Price (LANL) **–** (1) Update on DOE ice sheet modeling activities. (2) Optimal Initial Conditions for Coupling Ice Sheet Models to Earth System Models

We address complications in the coupling of a dynamic ice sheet model (ISM) and forcing from an Earth System Model (ESM), which arise because of the unknown ISM initial condition. Unless explicitly accounted for during ISM initialization, the surface mass balance forcing from the ESM is far from equilibrated with the ISM flux divergence. Upon coupling to ESM forcing, the result is a shock and unphysical and undesirable transients in ice geometry and other state variables. Under the assumption of thermomechanical quasi-equilibrium, we present an optimization approach for obtaining optimal ISM initial conditions when coupling to ESMs. This approach targets finding an ISM initial condition---characterized by the basal sliding coefficient and the basal topography fields---that balances a best fit to surface velocity observations against the minimization of undesirable and unphysical transients when coupling to ESM forcing for forward model simulations. A quasi-Newton method is used to solve the resulting large-scale, PDE-constrained optimization problem, where the gradients with respect to the parameter fields are computed using adjoints. After studying properties of our approach on a synthetic test problem, we apply the method to the initialization of the Greenland ice sheet. Our results show that, in the presence of uncertainties in the basal topography, ice thickness should also be treated as an optimization variable. While the focus here is on the coupling between an ISM and ESM-derived surface mass balance, the method is easily extended to include optimal coupling to forcing from an ocean model through submarine melt rates.

William Lipscomb (LANL) **–** Update on CISM2 development

Version 2 of the Community Ice Sheet Model (CISM) is nearly ready for release. This version has been in development for several years, beginning with the SEACISM project under the DOE Ice Sheet Initiative for Climate Extremes (ISICLES). CISM2 has a parallel dynamical core called Glissade, which includes a first-order velocity solver based on finite-element methods, along with an incremental remapping scheme for mass and tracer transport. The solver has been shown to be robust for standard test problems and for Greenland Ice Sheet simulations at resolutions as fine as 1 km. There are two linear solver options: a native Fortran preconditioned conjugate gradient (PCG) solver, and a solver linked to Trilinos. The native PCG solver is several times faster, but the Trilinos solver supports methods likely to be more robust for flow dominated by horizontal-plane stresses (e.g., in West Antarctica). Recent work includes a modification to the surface elevation gradient to suppress checkerboard noise in the ice thickness field. The model is now being tested in CESM, with a target release in 2015 as part of CESM1.3.

William Sacks (NCAR) **–** Dynamic landunits in CLM

One of the key elements needed for two-way coupling between CISM and the rest of CESM is the capability for dynamic landunits in CLM. This capability will allow CLM's subgrid breakdown to respond to changing ice sheet areas prescribed by CISM. I discuss some of the scientific challenges that needed to be addressed to put this capability in place, and demonstrate that this capability is now basically working for dynamic glacier areas.

Jeremy Fyke (LANL) **–** Progress in full coupling between ice sheets and climate in CESM

Recent progress in coupling the ice sheet model CISM into the CESM is presented. New developments that enable 2-way coupling include dynamic CAM topography updating, routing of CISM-calculated ice sheet discharge to POP, utilization of new dynamic land unit capabilities in CLM, and the ability to incept ice sheets over bare land. Ongoing work involves stress-testing the new coupled configuration, carrying out preliminary scientific validations, and beginning new model developments. These include explicit icebergs, multiple ice sheet instances, explicit firn, and atmospheric model tuning.

Dan Martin (LBNL) **–** Toward high-resolution simulations of coupled, Antarctic ice-ocean evolution using POP2x and BISICLES

We present initial results from Antarctic, ice-ocean coupled simulations using large-scale ocean circulation and land ice evolution models. The ocean model, POP2x, is a modified version of POP, a fully eddying, global-scale ocean model (Smith and Gent, 2002). POP2x allows for circulation beneath ice shelf cavities using the method of partial top cells (Losch, 2008). Boundary layer physics, which control fresh water and salt exchange at the ice-ocean interface, are implemented following Holland and Jenkins (1999), Jenkins (1999), and Jenkins et al. (2010). Standalone POP2x output compares well with standard ice-ocean test cases (e.g., ISOMIP; Losch, 2008; Kimura et al., 2013) and with results from other idealized ice-ocean coupling test cases (e.g., Goldberg et al., 2012). The land ice model, BISICLES (Cornford et al., 2012), implements a modified form of the L1L2 momentum balance (Shoof and Hindmarsh, 2009) and uses block structured adaptive-mesh refinement to more accurately model regions of dynamic complexity, such as ice streams, outlet glaciers, and grounding lines. For idealized test cases focused on marine-ice sheet dynamics, BISICLES output compares very favorably relative to simulations based on the full, nonlinear Stokes momentum balance (MISMIP-3d; Pattyn et al., 2013).

We have constructed an offline-coupling scheme between the ice and ocean models. POP2x is run with fixed ice shelf geometries, which are used to obtain subshelf melt rates. These melt rates are, in turn, used to force evolution of the BISICLES model. The new ice sheet configuration is then used to sequentially update the sub-shelf cavity geometry seen by POP2x. Results progressing from standalone ice- and ocean-model simulations followed by a simple test case (Goldberg et al, 2012), leading to large-scale (southern ocean coupled to full-continent Antarctic ice sheet) simulations will be presented.

Irina Kalashnikova (SNL) **–** An update on the Albany/FELIX first order Stokes finite element solver and its coupling to land ice dycores

This talk gives an update on the Albany/FELIX (Finite Elements for Land Ice eXperiments) dynamical core (dycore) that is currently under development at Sandia National Laboratories as a part of the PISCEES (Predicting Ice Sheet and Climate Evolution at Extreme Scales) project. The Albany/FELIX dycore is based on the "First Order" Stokes equations for ice sheet flow [1], an attractive alternative to the full Stokes model because of its reduced computational cost. The dycore is implemented within an open-source C++ Trilinos code called Albany [2] and uses various Trilinos libraries [3], which have enabled the rapid development of the code. Several methods for importing Greenland/Antarctica data (geometry, topography, surface height, basal friction, etc.) into Albany/FELIX are described, in addition to some recent work on coupling Albany/FELIX to other land ice dycores (the CISM and MPAS codes). This latter effort enables dynamic simulations of the ice sheet evolution, and facilitates the integration of the Albany/FELIX dycore into a global earth system model (ESM) to be used to support DOE climate missions by providing sea-level rise predictions. Results for some steady-state as well as dynamic Greenland and Antarctica simulations obtained on three different kinds of meshes (structured hexahedral grids, structured tetrahedral grids, true unstructured Delaunay triangle grids) are presented. Convergence of the code on a realistic Greenland geometry is demonstrated. It is shown that the Albany/FELIX code is scalable, robust and portable to new architecture machines (hybrid, multi-core, many-core, GPUs). Finally, attention is turned from forward to inverse ice sheet problems. These problems are solved for the optimal Greenland/Antarctica initial state and basal sliding coefficient, and entail minimizing a merit functional involving the mismatch between measured and computed fields (e.g., surface mass balance, surface velocities), either in a deterministic or stochastic (Bayesian) setting.

Charles Jackson (UT Austin) – Representation of Thwaites Glacier bed uncertainty in modeling experiments

Thwaites catchment includes a landward sloping bed and a marine ice sheet. The sensitivity of this glacier to a warming ocean is likely dependent on specific details of its bed. Goff et al., (submitted to JGR Earth Surface) has created a conditional simulation of Thwaites Glacier bed that includes inhomogeneous statistics and channelized morphology that takes advantage of the high resolution inferences of bed geometry taken from flight paths of aerogeophysical surveys to make inferences of the type of features that are likely to exist between flight paths. This effort is now being extended to represent the uncertainties due to 1) off-nadir radar energy being interpreted inappropriately as being from bed features at nadir, 2) mischaracterization of roughness, 3) flight track spacing density, and 4) the failure to identify individual glacier carved channels. Estimates of the high-resolution bed (at 250 meter resolution) and its uncertainty will be compared against a so-called “mass conserving” bed. The point of this effort is to capture the elements of the way ice-penetrating radar data is used to estimate ice thickness for use in modeling experiments where bed uncertainties are likely to play an important role. This exercise is interesting from an uncertainty quantification point of view insofar as while the actual uncertainties are high dimensional (i.e. every grid point that has not been observed directly), what matters to sea level rise experiments is some low-dimensional summary of what is important to glacier dynamics.

Tong Zhang (U. South Carolina) – Suitability of the application of a two dimensional thermo-mechanical ice flow model on mountain glaciers

Compared to a three dimensional (3D) full Stokes thermomechanical ice flow model, a two dimensional (2D) thermomechanical first order flow line glacier model is evaluated. Based on several numerical experiments that are steady-state/transient and thermomechanical coupled/decoupled, we study the
2D model sensitivities to ice geometry, temperature and model time, respectively. We find that the 2D thermomechanical first order model produces smaller velocity values in general, probably due to the shape factor underestimations. Among geometry parameters, e.g. glacier width (aspect ratio), slope and length, ice slope appear to have a large impact on glacier dynamics. The 2D model may become greatly unreliable when glaciers become warm and temperate ice zones (TIZs; basal sliding) appear. The model time further increases the discrepancies between the 2D/3D model results. An initial bias of the 2D model would also possibly be enlarged if basal sliding occurs. With such limitations, we argue that the 2D first-order flow line models should be carefully used, especially for modeling glacier changes under a warming climate for a long period of time.

Ute Herzfeld (UC Boulder) – Connecting observations and models for surge glaciers -- neural networks and numerical experiments

The objective of this work is to look at connecting observations and models in glaciology from two new and entirely different perspectives: neural networks and numerical experiments. The problem studied is the surge phenomenon, the form of glacial acceleration that has seen the least research. Our work is motivated by the current (2011-2013-?) surge of the Bering-Bagley Glacier Sytem (BBGS), Alaska, the world's largest surge glacier system. During a surge a glacier accelerates to multiples of its normal velocity and this sudden acceleration manifests itself in crevasse formation. We use deformation as the variable to be analyzed in both the neural network and the numerical experiments. Video imagery of the crevassed ice surface collected during 4 airborne campaigns over the BBGS during the surge is analyzed using a connectionist-geostatistical approach. Specifically, a neural network is trained for crevasse class association, using variogram parameters as information at input nodes. Recognizing that the surface types (actual crevasse types encountered in any given season) are differently overprinted by environmental processes and different crevasse types may form, we developed a semi-automated pre-processing software to train a neural network. The resultant NN is applied to all imagery collected, along the flight path. On the modeling side, we use the finite-element software Elmer-Ice. Numerical experiments are aimed at forward simulating the surge process.

Jesse Johnson (U. Montana) – The role of longitudinal stress gradients in controlling the flow of Greenland outlet glaciers

Recent observations suggest that increases in outlet glacier speed are caused by geometric changes at the margins of the ice sheet. In many cases, warmer ocean water is believed to be promoting both melting at the grounding line and thinning or breaking up of ice shelves, altering the ice geometry. The proposed mechanism relating changes in geometry to increases in velocity is increases in longitudinal stress gradients. This component of the force balance, while small, is believed to play a large role in observed changes in ice dynamics. In this talk, we investigate the relative strength of the longitudinal stress gradients in a number of glaciers. Our strategy is different from what has been done previously because our analysis is carried out using vertically averaged velocities coming from a numerical model that has assimilated data. This provides the following advantages over force budgets that take only surface velocity and thickness into account; 1) the surface velocity field is smoothed by the momentum balance enforced by the model, 2) the coverage of the surface velocity does not have any gaps, 3) the steady-state temperature field is modeled so that temperature dependent changes in viscosity are accounted for, and 4) the basal traction is computed directly from the inversion process, rather than as a residual of the force balance calculation of lateral drag and longitudinal stresses.

Our investigation is carried out using VarGlaS (Variational Glacier Simulator), a 3D, fully parallel, open source ice sheet model that uses variationally derived forms for; 1) full Stokes or first-order momentum balances, 2) enthalpy or internal energy, 3) free-surface evolution. These forms facilitate automatic differentiation and construction of adjoint operators for rapid assimilation of data. Being a finite element model, variable mesh resolution is used to finely (~1 km) resolve fast flowing areas. VarGLaS is written in Python, employing the FEniCs library for finite elements. In this work, VarGlaS is used to invert surface velocity measurements for basal traction. Once modeled surface velocity is consistent with observation, the stress tensor is projected along flow to determine longitudinal stress, and across flow to determine lateral drag. Basal drag is taken directly from model inversion, hence a complete force balance is determined everywhere on the Greenland ice sheet. Using our force balance, we investigate the role of longitudinal stresses in the dynamics of outlet glaciers, quantifying the importance of each of the stresses in observed flow. Results demonstrate that the longitudinal stresses are a very small part of the total force balance. Perturbations are carried out to investigate the role of longitudinal stress gradients in abrupt transitions. The perturbations are applied to the geometry near the terminus and to the basal traction field. In both cases, transient behavior of the stress gradients and velocities is investigated.