# Report of the CESM Land Ice Working Group
## 30 - 31 January 2014
## National Center for Atmospheric Research
## Boulder, Colorado

The CESM Land Ice Working Group (LIWG) held its annual winter meeting on Thursday and Friday, 30-31 January 2014 at the NCAR Mesa Lab in Boulder, Colorado. The meeting was co-chaired by Jesse Johnson and Stephen Price. The first Thursday session of the meeting was held jointly with the Polar Climate Working Group.

On Friday Jan. 31, the co-chairs led a discussion on LIWG plans and priorities for the next one to two years. After further discussion by Johnson, Price, co-chair William Lipscomb, and software liaison William Sacks, a list of plans was sent to the CESM Scientific Steering Committee.

Meeting presentations are posted here:
http://www2.cesm.ucar.edu/working-groups/liwg/meetings/20140130

Abstracts are below. Some talks had more than one author, but only the presenter's name is shown.

The next LIWG meeting will be held in June 2014 at the annual CESM workshop in Breckenridge, Colorado.

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**LIWG talks in the joint session (Jan. 30):**

**Jeremy Fyke (LANL) – Recent CESM science and model development: SMB variability, emergent SMB signals, and CESM/CISM atmosphere-topography**

In this talk I will first summarize a recent analysis of CESM-simulated Greenland SMB variability and trends between 1850 and 2100. This SMB variability grows significantly over the course of the simulation, and is attributable primary to high-variability ablation area expansion. Ongoing analysis is attempting to identify the spatial emergence pattern of the anthropogenically-forced signal in Greenland SMB.

I will then summarize progress in coupling the Community Atmospheric Model (CAM) topography to the evolving CISM ice sheet geometry. An evaluation of CAM behavior under an extreme prescribed ice sheet geometry change scenario suggests that CAM 1) is robust to realistic rates elevation change; 2) can dissipate shock waves associated with topography change successfully; and 3) realistically responds to transiently evolving ice sheet topography.

**Steve Price and Jeremy Fyke (LANL) – Ice sheet model validation**

We review the observations and analogous CESM and CISM diagnostic fields that could be used for coupled ice sheet and climate model validation, and discuss additional model and software development necessary in order for these fields to be compared as a standard step in the post processing and analysis of model runs. For CESM, these include a wide range of global and regional scale fields, many of which are already available as standard diagnostic outputs from CESM component models. For CISM, these include a wide range of 1d (vector), 2d, and 3d fields within the ice sheet itself, many of which are currently either not provided as standard ice sheet model outputs (e.g., ice age) or for which additional data set processing and organization are required before regular comparison to ice sheet model output is practical. We conclude by discussing current efforts and collaborations focused on filling these gaps.

**Miren Vizcaíno (TU Delft) – CESM over Greenland: ice sheet versus ice-free regions**

In this talk, I analyze the relevance of the first results published with CESM with its new land ice component, I point to the limitations of these results and paths for improvement, and explain the suitability and added value of using Surface Mass Balance (SMB) data from CESM as off-line forcing of ice sheet models. Until very recently, GCMs have been considered unsuitable to capture the high SMB gradients at the ice sheet margins due to climate biases, coarse resolution and non-inclusion of relevant snow-ice surface processes. With the first CESM results for 1850-2100 Greenland Ice Sheet (GrIS) SMB, published in the CESM Special Collection of the Journal of Climate (Vizcaino et al., 2013, 2014), we show that CESM is the first global climate model capable of realistic simulation of ice sheet SMB. We evaluate CESM with remote sensing

(GRACE) and in-situ observations, and with the output from regional climate models. Patterns of end-of-the-century SMB change are similar to projections from higher-resolution models (e.g. RACMO2, MAR). CESM's success is due to realistic simulation of the local atmospheric forcing, explicit simulation of snow process (e.g. albedo evolution, refreezing), and sub-grid representation of vertical variations in SMB.

We are currently working in the two-way coupling of the ice sheet model CISM to CESM, with regard to dynamical land units, interactive topography, and delivery of freshwater fluxes to the ocean in liquid and solid phase. CESM already includes the most important coupling mechanism between SMB and climate on the time scale of IPCC-type projections, the albedo feedback. A challenge to meet to improve CESM's SMB is the elimination of a positive SMB bias in Northern Greenland, in the glacier-free regions. This bias might be at least in part caused by the coexistence of land cover types of tundra and glacier and ice caps in the same grid cell of the land ice component (CLM). CESM SMB data as off-line forcing of ice sheet models is an excellent alternative to state-of-the-art approaches for three reasons: 1) quality, due to physics-based simulation of climate and snow-ice surface processes; 2) direct connection between simulated SMB and CESM simulated climate (e.g. sea-ice, clouds, atmospheric circulation); and 3) it captures part of the elevation feedback on SMB because the data is supplied at several elevations. The latter solves the current problem of SMB-elevation decoupling when ice sheet models are forced with SMB data calculated at a fixed topography. This added value of CESM has been already exploited for a new initialization technique that provides an equilibrated ice sheet with memory of past climate (Fyke et al. GMDD, 2013), and end-of-the-century GrIS projections with CISM-CESM (Vizcaino et al., 2014; Lipscomb et al., J. Clim., 2013)

**Bette Otto-Bliesner (NCAR) – CESM-CISM for paleoclimate**

Over the last two decades, the Greenland and Antarctic ice sheets have been losing mass and contributing to global mean sea level rise (SLR). SLR will continue in the 21st century and beyond, likely at an accelerating pace, but estimates of the ice sheets' contribution to SLR remain highly uncertain. The paleo record highlights the susceptibility of ice sheets and sea level, even for global warming much less severe than that predicted for future climate. CESM-CISM simulations can be benchmarked against global mean sea level estimates, the ice core records of surface temperatures, elevations, and ice extent, and ice-proximal marine sediment evidence of the dynamic behaviors of the ice sheets to provide an assessment of these models. CESM-CISM simulations allow us to simultaneously examine processes in the coupled climate system (e.g. snowfall, sea ice, and ocean circulation) that control the evolving state of the ice sheet, as well as the roles of positive and negative feedbacks that operate between the physical climate system and the ice sheet. Two examples are given in this talk: the Last Interglacial (129,000 to 116,000 years ago) and the mid-Pliocene (3.3 to 3 million years ago). The Last Interglacial is well constrained in terms of forcing (orbital), provides a large SLR response (5 to 10 meters above present), and includes a wide array of well-dated proxy records to evaluate the climate and ice sheet sensitivities. The Mid-Pliocene allows an assessment of the long-term sensitivity of climate to near-current concentrations of carbon dioxide ($CO_2$), with SLR of up to 20 meters above present.

**Talks in the LIWG session (Jan. 30-31):**

**David Pollard (Penn State) – Modeling past and future ice retreat in Antarctic subglacial basins**

Geological data indicate that global mean sea level has fluctuated on O(10,000 to 100,000-yr) time scales during the last ~25 million years, reaching ~10 to 30 m above modern. High stands of ~20 m or more would require substantial variations in the size of the East Antarctic Ice Sheet (EAIS). However, climate and ice-sheet models have not been able to simulate significant EAIS retreat from continental size, given low proxy atmospheric CO2 levels during this time. Here, we use a 3-D Antarctic ice sheet model and apply new treatments of (i) ice shelf calving including crevassing by surface melt water, and (ii) structural failure of large vertical cliffs at the grounding line. With climate forcing typical of past (Pliocene) warm periods, the two mechanisms produce up to ~20 m equivalent sea level rise, including retreat in major East Antarctic basins. In long-term (1000's yr) future simulations, we find these mechanisms produce a much more sensitive and vulnerable ice sheet than previously modeled.

**Josh Cuzzone (Oregon State) – Simulations of the last deglaciation using the Glimmer ice-sheet model and a fully coupled GCM, GENMOM**

We force the Glimmer ice-sheet model with temperature and precipitation fields from the fully coupled AOGCM, GENMOM. Climate simulations were performed every 3 ka (thousand years ago) over the last deglaciation beginning at 21 ka and ending present day, thus providing climate snapshots over the last deglaciation. We begin by building-up the

Laurentide Ice Sheet in Glimmer using annual monthly mean temperature and precipitation fields at 21 ka. The simulated Laurentide Ice Sheet at 21ka agrees well with reconstructions, with the PDD factors and basal sliding parameters having the largest effect on ice-sheet extent and volume. We then initiate deglaciation by forcing the 21 ka ice sheet with successive climate snapshots over the last deglaciation, allowing the simulated ice sheet to reach equilibrium before forcing with the next climate snapshot. The simulated deglaciation agrees well with extent and volume estimates from reconstructions. We also perform a similar simulation over the last deglaciation using climate fields from insolation and GHG-only climate simulations. Results indicate greater mass loss when using the insolation-only climate forcing. However, the simulations also indicate that the orography boundary condition (used in the climate simulations) has the largest influence on the climatology, which ultimately governs the simulated ice-sheet volume and extent.

**Ute Herzfeld (CU) – Insights on ice-dynamic modeling from observations of fast glacier movement**

In this talk, we present results derived from observations of fast glacier movement and conclusions on certain shifts in the dynamic systems of the analyzed glaciers that have not been apparent in earlier studies. For the Bering Glacier surge, we compare observations to results from forward-modeling experiments which use Elmer Ice (full Stokes) and a classic glen's flow law. The glaciers represent different prototypes of acceleration.

(1) Pine Island Glacier: Acceleration type: Acceleration shifted from an internally forced one to a combination of an internally forced and externally forced one. Observations: satellite data including ICESat GLAS data.

(2) Bering - Bagley Glacier System: Acceleration type: Surge (currently happening). Observations: Field/ airborne observations during 2011, 2012, 2013 including laser altimeter data, image data, GPS, satellite data (CryoSat - notably, the first CryoSat data analysis over a terrestrial glacier system). Highlights are an automated classification method that now works for the entire area and allows to derive deformation types, that can be linked to ice dynamics, and model-data comparisons aimed at shedding light on the questions what causes and controls glacier surges.

(3) Jakobshavn Isbrae: Acceleration type: Acceleration and retreat most likely externally forced (unless part of a long-term Fjord cycle). Observations: Satellite and airborne data including ATM and ICESat GLAS.

**Steve Price (LANL) – Community Ice Sheet Model update**

I will provide an update on the status of Community Ice Sheet Model (CISM) development in the context of the Community Earth System Model (CESM). In particular, I will provide an update on the status of a new dynamical core, Glissade, that we are currently developing and testing. Glissade solves a 3d, 1st-order approximation to the Stokes equations using the Finite Element Method. Initial tests show robust performance on all of CISM's standard higher-order model test cases. In addition, initial tests on high-resolution (e.g., 1 km Greenland and 5 km Antarctica), realistic domains with idealized boundary conditions show good strong scaling out to several thousand processors. We aim to release this dycore as part of stand-alone, CISM 2.0 in the spring of 2014, and as part of the CESM 1.3 release planned for May of 2015. An outline of the tasks necessary to reach these release goals will be presented.

**Bill Sacks (NCAR) – Updates on CISM2-CESM coupling, and plans for the CESM1.3 release**

I will provide updates on a number of aspects of the coupling of CISM2 to CESM. This will include: (1) the status of the CISM2 code base within CESM; (2) updates on the implementation of dynamic landunits in CLM, which is necessary for the land surface to respond to changes in ice sheet area; (3) an overview of other 2-way coupling that is now in place; and (4) other plans for the CESM1.3 release.

**Kate Evans (ORNL) – Progress on the Land Ice Verification and Validation toolkit**

Recent progress to extend the basic verification capability in LIVV is presented along with instructions on how to use it. A basic performance verification and validation option is included, and we present several examples of how this capability could highlight problems with ice sheet models performance as development proceeds at scale. Specifically, it highlights performance changes and variability due to code and parameter changes.

**Irina Kalashnikova (SNL) – The Albany/FELIX first-order Stokes dycore**

This talk will give an update on the Albany/FELIX (Finite Elements for Land Ice eXperiments) higher-order Stokes dynamical core (dycore) that is currently under development as a part of the PISCEES (Predicting Ice Sheet and Climate

Evolution at Extreme Scales) project. Focus will be on the forward stress-velocity simulator for the first-order Stokes partial differential equations (PDEs) developed using the Trilinos \cite{trilinos} libraries, and implemented within the Albany code base. The use of Trilinos libraries has enabled the rapid code development of an efficient parallel unstructured grid finite element code, termed "Albany/FELIX", which uses non-linear Newton solvers based on domain decomposition, which leverage dozens of Trilinos capabilities such as distributed-memory linear algebra and automatic differentiation. Following a review of the first-order Stokes physics and the structure of the Albany/FELIX code, some new developments within this code and corresponding results will be presented. We will describe several capabilities for importing Greenland/Antarctica data (geometry, topography, surface height, basal friction, etc.) into Albany/FELIX. We will also give an update on the development of interfaces between Albany/FELIX and the CISM and MPAS codes. Results for some steady-state Greenland and Antarctica simulations obtained on three different kinds of meshes (structured hexahedral grids, structured tetrahedral grids, true unstructured Delaunay triangle grids) will be shown, followed by preliminary results for some dynamic simulations obtained using the MPAS-Albany and CISM-Albany interfaces. We will end by discussing various analyses of the performance of the Albany/FELIX code, including a mesh convergence study, an examination of the code's robustness, and a study of the code's scalability.

**Mauro Perego (SNL) – Ice sheet initialization and uncertainty quantification**

In this talk we mainly focus on the problem of finding an optimal initial state for the Greenland ice sheet via the estimation of the friction coefficient at the ice-bedrock interface and/or the bedrock topography. The problem consists of minimizing a merit functional which may include the mismatch between a specified and computed surface mass balance and/or the mismatch between observed and modeled surface velocities.We first address this problem by solving a deterministic optimization problem constrained by the governing model equations using adjoints. The optimization is preformed using the Rapid Optimization Library (ROL) and other Trilinos packages. We consider a set of reasonable merit functions and parameters to be estimated and we present and discuss the corresponding results.

We then consider the Bayesian calibration approach in order to account, in a statistical way, for measurement errors and other uncertainties in the measured quantities used in the initialization. In order to make this approach affordable, and to overcome the "curse of dimensionality" encountered in uncertainty quantification (UQ), we first reduce the dimension of the parameters' space using a Karhunen Loeve Expansion. We then compute a cheap surrogate model that returns an approximate value of the merit functional as a function of the parameters. The calibration is then performed using Markov Chain Monte Carlo. The implementation uses Dakota/QUESO, the Albany code base, and several Trilinos packages. We present preliminary results for the Greenland ice sheet.

**Jesse Johnson (U. Montana) – Mass conservation as a tool for ice sheet data interpolation and modeling**

Increasingly, the demands of computational models challenge the limits of observational data. For instance, models require first and higher derivatives of velocity and thickness measurements, however numerical derivatives of data are often characterized by noise that makes their interpretation difficult. Specific examples include strain-rates and flux divergences computed from observations of velocity and thickness. Two approaches to physics based interpolation of observational data are presented here. The first is known as the ``mass conserving bed", and entails using the continuity equation to interpolate between measurements of ice thickness. Our favoured approach utilizes least squares rather than Lagrange multipliers, and is shown to be accurate, robust, and scalable to large problems. The second application is to InSAR surface velocity observations. In order to smooth these frequently discontinuous data we again look to the continuity equation, this time solving for vertically averaged velocity. Attaching a Lagrange multiplier to the forward model, and adding misfit over the domain, we find adjoint, control, and objective equations allowing minimization of differences between model and observed surface velocity. Bounds set in the minimization algorithm ensure optimal velocities are consistent with reported errors in thickness, surface mass balance, surface velocity, and surface rate of change. The resulting velocity field is in excellent agreement with observation, provides complete coverage, and satisfies stronger requirements for continuity. Both bed and velocity fields produced by these techniques are of use to the community for initialization of ice sheet models, calculation of the force budget, inversion for parameter estimation, assessment of ice sheet sensitivity to perturbation, and mission planning. Neither of the techniques used is possible without a solution to the conservation of mass equations. Solution of this hyperbolic PDE is numerically challenging, and a new method for its solution is presented.

**Dan Martin (LBNL) – Toward 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.

**Matt Hoffman (LANL) – Progress on MPAS Land Ice model development**

The Model for Prediction Across Scales is a climate modeling framework based on unstructured centroidal Voronoi Tesselation (CVT) meshes with cores currently in development for the Atmosphere, Land Ice, Ocean, and Sea Ice. The goal of the Land Ice core is to model the ice sheets of Greenland and Antarctica with variable resolution using Finite Volume Methods for transport on the Voronoi grid and a hierarchical suite of Finite Element Method based dynamical cores (Stokes, First Order, L1L2, Shallow Shelf, Shallow Ice) on the dual triangular grid. The initial public release of the Land Ice core occurred in November 2013 with a native Fortran Shallow Ice Approximation (SIA) velocity solver, Forward Euler time integration, and first-order thickness evolution. Since then, there has been additional development on interfaces to external velocity solvers written in C++ (LifeV, Albany, PHG), implementation of adaptive time stepping, and tracer advection. The native SIA solver shows good comparison with analytic solutions and can run on spherical meshes. The Albany external solver solves the First-Order approximation to the ice sheet momentum balance and has been successfully run for realistic meshes of Greenland and Antarctica. The PHG external solver solves the full Stokes equations for the ice sheet momentum balance and has been verified against manufactured solutions. Use of Enhanced Taylor-Hood finite elements in the PHG solver exhibits superb mass conservation properties with a 24% cost over standard Taylor-Hood elements. To date, the MPAS model has been used in two sea level rise assessment studies. Finally, the MPAS-Ocean model has demonstrated robust support of sub-ice-shelf circulation, which bodes well for coupled ice-ocean simulations.

**Hari Rajaram (CU) – (1) Enthalpy-based thermodynamics and drainage model for CISM, (2) Enlargement of englacial conduits in cold ice: theory and simple experiments**

We present the development and initial testing of a new Energy Equation solver for the Community Ice Sheet Model (CISM). The new Energy Equation solver is based on an enthalpy approach, customized to be compatible with the existing CISM framework (specifically boundary conditions and water drainage to the basal hydrologic network). The new enthalpy based solver is embedded within the glissade dycore, and can be activated by the user. Enthalpy is the most rigorous thermodynamic state-variable that can be used in the formulation of the energy equation. Two related quantities, temperature and liquid water content, are derived in terms of enthalpy; unique values of both these quantities imply a unique value of enthalpy. The new energy solver deals with vertical energy transport using the enthalpy approach, then converts enthalpy to temperature and liquid water content, both of which are then advected horizontally using the existing advection algorithms within glissade. This implementation facilitated the minimum level of code rewriting. The flow law parameter "A" is expressed as a function of both temperature and liquid water content. Initial tests of the new solver on idealized model problems and the Dome test problem indicate satisfactory performance. More detailed testing will be pursued in future work.

The dynamics of the englacial cryo-hydrologic system control two important mechanisms contributing to accelerated ice flow - delivery of water to the bed to drive basal sliding, and cryo-hydrologic warming. The dynamics of englacial conduits in cold ice is influenced by refreezing, creep closure, and melt-driven enlargement resulting from viscous and turbulent energy dissipation (head loss) in flowing water. We report results from simple laboratory experiments focused on determining the critical flow rate through englacial conduits for producing enlargement (i.e., sufficient thermal energy generated from head loss). Our experiments did not incorporate the influence of creep closure. However, the competition between refreezing and melt enlargement was investigated. Theoretical and computational formulations of the thermodynamics were also developed. At low flow rates or with stagnant water, refreezing dominates. Warming of the ice surrounding the conduit by latent heat release was measured during the experiments and found to be consistent with theoretical expectations. At high flow rates, conduit growth was observed. The interesting finding from our experiments is that to explain the behavior in the high flow rate regime, an unusually high friction factor must be invoked for the conduits, because of the scalloping that naturally develops, leading to increased roughness as the conduit is enlarged. This feature is consistent with observed features of englacial and subglacial conduits, and is remarkably well reproduced even in small-scale laboratory experiments.

**Bob Fischer (NASA GISS) – A case for synchronous two-way GCM/ice model coupling with GLINT2**

The coupling of GCMs and ice models is becoming increasingly common. We review recent efforts, according to a coupling taxonomy: one-way coupling, loose two-way coupling and tight two-way coupling. We analyze the pros and cons of the approaches, focusing on the scientific questions each is best suited to address.

We present GLINT2, a library we have developed for tight conservative two-way coupling. GLINT2 is designed to couple a broad range of GCMs and ice models: we mention idiosyncrasies of particular GCMs and Ice Models, and how GLINT2 is able to handle them. We will also describe our efforts using GLINT2 to couple PISM and the GISS ModelE.

**Eric Larour (JPL) – Assimilation of surface altimetry data on the North-Eastern Greenland Ice Sheet using automatic differentiation and ISSM**

Extensive surface altimetry data has been collected on polar ice sheets over the past decades, following missions such as Envisat and IceSat. This data record will further increase in size with the new CryoSat mission, the ongoing Operation IceBridge Mission and the soon to launch IceSat-2 mission. In order to make the best use of these dataset, ice flow models need to improve on the way they ingest surface altimetry to infer: 1) parameterizations of poorly known physical processes such as basal friction; 2) boundary conditions such as Surface Mass Balance (SMB). Ad-hoc sensitivity studies and adjoint-based inversions have so far been the way ice sheet models have attempted to resolve the impact of 1) on their results. As for boundary conditions or the lack thereof, most studies assume that they are a fixed quantity, which, though prone to large errors from the measurement itself, is not varied according to the simulated results.

Here, we propose a method based on automatic differentiation to improve boundary conditions at the base and surface of the ice sheet during a short-term transient run for which surface altimetry observations are available. The method relies on minimizing a cost-function, the best fit between modeled surface evolution and surface altimetry observations, using gradients that are computed for each time step from automatic differentiation of the ISSM (Ice Sheet System Model) code. The approach relies on overloaded operators using the ADOLC (Automatic Differentiation by OverLoading in C++) package. It is applied to the 79 North Glacier, Greenland, for a short term transient spanning a couple of decades before the start of the retreat of the Zachariae Isstrom outlet glacier. Our results show adjustments required on the basal friction and the SMB of the whole basin to best fit surface altimetry observations, along with sensitivities each one of these parameters has on the overall cost function. Our approach presents a pathway towards assimilating multiple datasets in transient ice flow models of Greenland and Antarctica, which will become increasingly important as the amount of available observations becomes too large to assess on a case by case basis.

**David Bahr (CU) – Glacier volume estimation as an ill-posed inversion**

Estimating a glacier's volume by inferring properties at depth (e.g., bed topography or basal slip) from properties observed at the surface (e.g., area and slope) creates a calculation instability that grows exponentially with the size of the glacier. Random errors from this inversion instability can overwhelm all other sources of error and can corrupt thickness and volume calculations unless problematic short spatial wavelengths are specifically excluded. Volume-area scaling inherently filters these short wavelengths and automatically eliminates the instability, while numerical inversions can also give stable solutions by filtering the correct wavelengths explicitly (as frequently done when "regularizing" a model). Each of the scaling and numerical techniques has applications to which it is better suited, and there are tradeoffs in resolution and accuracy; but when calculating volume, neither the modeling nor the scaling approach offers a fundamental advantage over the other. Both are significantly limited by the inherently "ill-posed" inversion, and even though both provide stable volume solutions, neither can give unique solutions.

**Gunter Leguy (LANL) – Parameterization of basal hydrology near grounding lines in a one-dimensional ice sheet model**

Ice sheets and ice shelves are linked by the transition zone, the region where the grounded ice lifts off the bedrock and begins to float. Adequate resolution of the transition zone is necessary for numerically accurate ice sheet-ice shelf simulations. The required resolution depends on how the basal physics is parameterized.

In this talk, we propose a new, simple parameterization of the basal hydrology in a one-dimensional vertically integrated model. This parameterization accounts for connectivity between the basal hydrological system and the ocean in the transition zone. Our model produces a smooth transition between finite basal friction in the ice sheet and zero basal friction in the ice shelf. Through a set of experiments based on the Marine Ice Sheet Model Intercomparison Project (MISMIP), we show that a smoother basal shear stress, in addition to adding physical realism, significantly improves the numerical accuracy of our fixed-grid model, allowing for reliable grounding-line dynamics at resolutions ~1 km.