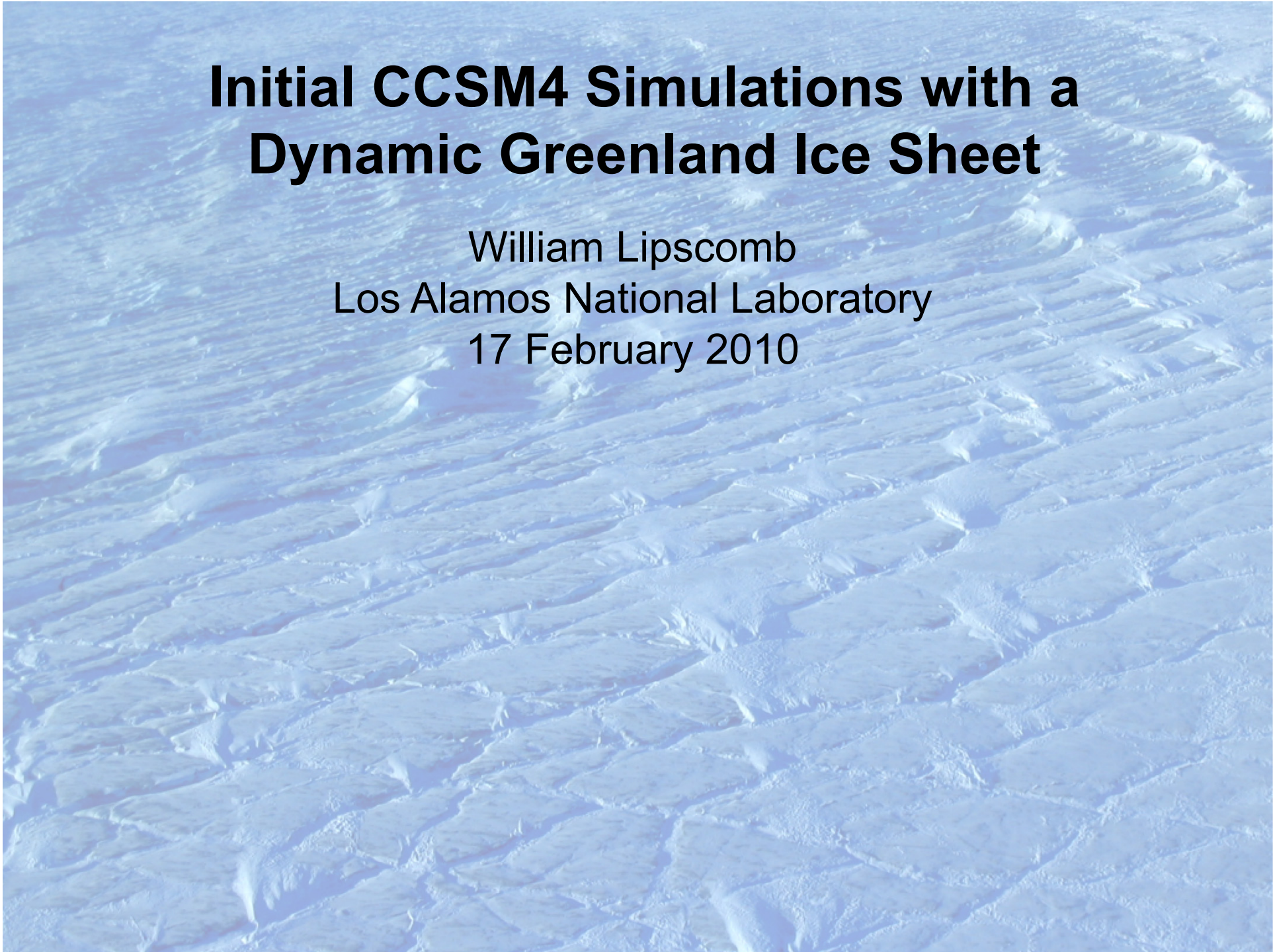


Initial CCSM4 Simulations with a Dynamic Greenland Ice Sheet

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17 February 2010



A brief history of the CCSM ice sheet model

2006

- I was funded by the DOE SciDAC2 project to implement an ice sheet model in CCSM. I estimated this would take one person (me) about a year.
- I began coupling the Glimmer ice sheet model (developed by Tony Payne and others in the U.K.) to CCSM.

2007

- IPCC AR4: “Understanding of ice sheet dynamic effects “is too limited to assess their likelihood or provide a best estimate or an upper bound for sea level rise.”
- Release of Glimmer version 1.0. First implementation of Glimmer in CCSM, using a positive-degree-day scheme.
- Decided a PDD scheme was inappropriate for climate modeling and began working on a surface mass balance (SMB) scheme in the land component, CLM.
- Realized that coupling an ice sheet model to CCSM was at least a two-person job and started looking for help.

2008

- Steve Price came to LANL from U. Bristol and began implementing the Payne-Price higher-order ice-flow model in Glimmer.
- Jesse Johnson et al. were funded by NSF to develop a Community Ice Sheet Model (CISM) based on Glimmer.
- Realized that this was at least a 10-person job and looked for more help.

A brief history of the CCSM ice sheet model

2008 (continued)

- LANL workshop: Building a next-generation community ice sheet model.
- Beginning of SeaRISE modeling effort led by Bob Bindshadler (http://webserv.cs.umt.edu/isis/index.php/SeaRISE_Assessment).
- Beginning of IMPACTS project on abrupt climate change, led by Bill Collins. Includes project on marine ice sheet instability and ice-ocean interaction. (http://esd.lbl.gov/research/projects/abrupt_climate_change/)
- Implemented a surface-mass-balance scheme for ice sheets in CLM.

2009

- DOE ISICLES project: computational advances in ice sheet modeling (details after lunch). Develop scalable ice sheet models with realistic physics (full-Stokes, higher-order) on adaptive and unstructured grids. (<http://www.csm.ornl.gov/ISICLES/>)
- Formation of CCSM Land Ice Working Group. First meeting in Breckenridge. (<http://mailman.cgd.ucar.edu/mailman/listinfo/ccsm-liwg>)
- Merging of U.K. and U.S. development efforts: Glimmer-CISM (<http://developer.berlios.de/projects/glimmer-cism>)
- Summer ice sheet modeling school, Portland, OR (http://webserv.cs.umt.edu/isis/index.php/Summer_Modeling_School)
- Migrated ice sheet code from CCSM3.5 to CCSM4.

Plans for this year

CCSM

- **Complete the initial ice sheet implementation** (spring)
 - Update Glimmer code to glimmer-cism2 trunk
 - Merge ice sheet SMB changes into CLM trunk
 - Complete coupled control run with dynamic Greenland ice sheet
- **Include ice sheets in release of the Community Earth System Model** (June)
 - Basic Glimmer: serial, shallow-ice approximation, Greenland only
 - Elevation-class option for all glacier gridcells (inc. Antarctica, Himalayas, etc.)
 - Hourly feedback between ice sheet surface and atmosphere
 - One-way coupling between CLM and Glimmer (surface mass balance downscaled to Glimmer grid; ice sheet can advance and retreat; CLM and CAM do not see changes in ice sheet extent and elevation)
 - Multiple compset options (glc-Ind, glc-Ind-atm, glc-Ind-atm-ocn-ice)
 - Multiple grid resolutions for CLM (T31, FV2, FV1) and Glimmer (5, 10, 20 km)
 - Documentation included
- **IPCC AR5 simulations**
 - Control (pre-industrial, 20th century)
 - Greenhouse forcing (RCP 4.5 and 8.5, ~200 years)
 - Multi-century asynchronous runs to assess Greenland stability

Plans for this year

Glimmer-CISM

- **Beta release** (early spring)
 - Two higher-order solvers (Payne-Price and Pattyn-Bocek-Johnson)
 - Suite of test cases (e.g., EISMINT, ISMIP-HOM, Ross ice shelf)
- **Glimmer-CISM2** (late spring)
 - GCM hooks, exact restart
 - Reorganized directory structure
- **Parallel branch**
 - Trilinos solver packages for higher-order velocity schemes
 - Will enable high-resolution (~1-2 km) simulations of whole ice sheets
 - Available for CCSM AR5 simulations
- **Initial coupling to ocean**
 - Plume model (Gladish, P. Holland, D. Holland)
 - Sub-ice-shelf circulation in ocean GCM (Asay-Davis)
 - Regional Antarctic ice sheet simulations
- **Improved ice sheet physics**
 - Basal water transport
 - Plastic till rheology
 - Calving

Long-term plans

New dynamic cores (ISICLES)

- Adaptive mesh refinement (e.g., Chombo, Rhea)
- Unstructured meshes (e.g., MPAS framework)
- Conforming finite elements
- PETSc, Trilinos
- Adjoints, uncertainty quantification

Coupling to ocean GCMs

- Initially one-way; force regional ice-ocean model with ocean GCM output
- Ultimately two-way (ocean GCM with continuously varying resolution?)

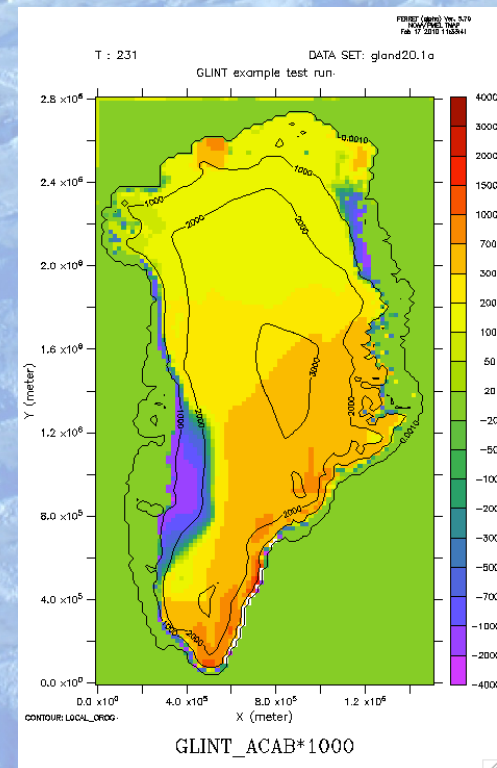
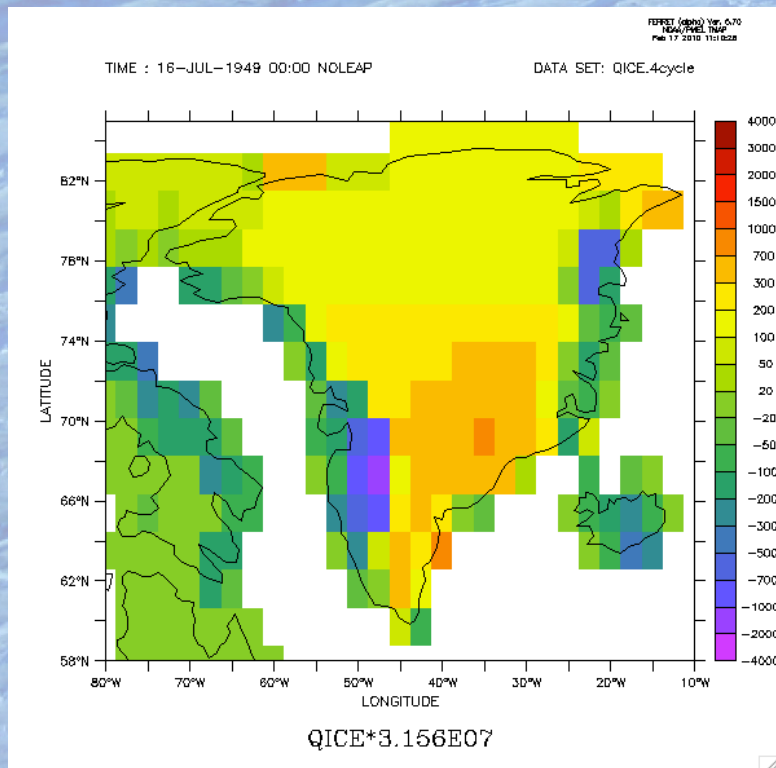
Paleo ice sheets

- Eemian interglacial (Greenland)
- Ice age cycles (Laurentide, Fennoscandian, etc.)

Provide best estimates and upper bounds for sea level rise!

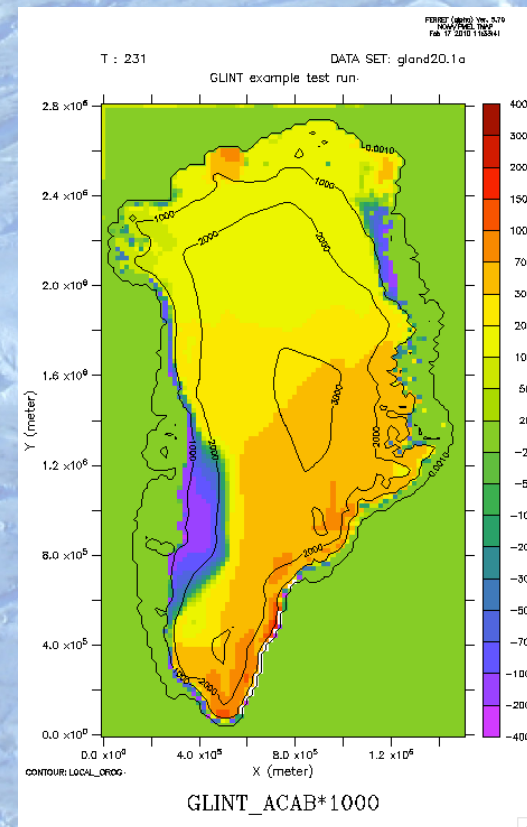
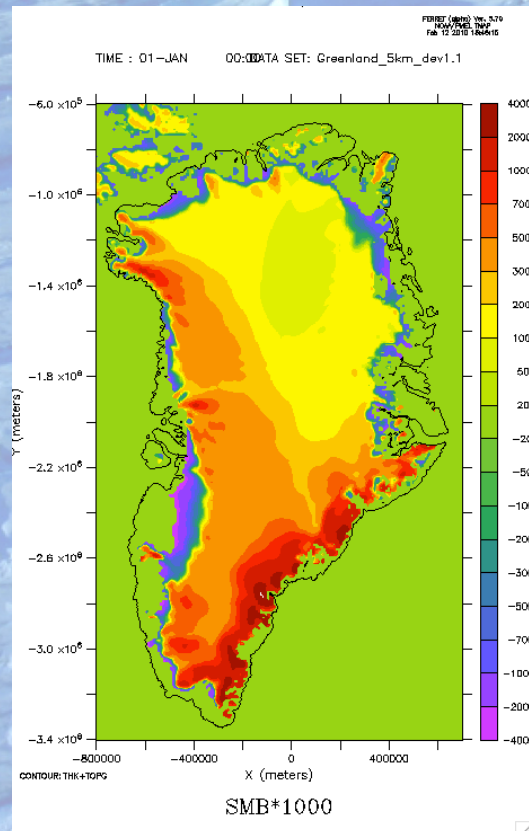
Some initial results

- The ice-sheet surface mass balance is computed in CLM using a subgrid tiling scheme (10 elevation classes per grid cell). The mass balance is passed to Glimmer-CISM via the coupler and downscaled to the Glimmer grid.
- Plot at left shows the Greenland surface mass balance computed in CLM (FV2), based on 1958-2004 NCEP atmospheric forcing. (Courtesy of Miren Vizcaino)
- Plot at right shows the SMB downscaled to 20-km Glimmer grid.
- Broad patterns of accumulation and ablation are consistent with observations and regional models.



Some initial results

- Plot at left shows the average (1958-2007) Greenland SMB from a high-resolution (11 km) regional climate model (RACMO2/GR; Ettema et al. 2009).
- Plot at right shows one-year SMB downscaled to the Glimmer grid.
- Next step: Try to compute a realistic surface mass balance using CAM.
- FV1 results will be compared to high-resolution ($\sim 0.4^\circ$ atm, 0.1° ocn) global runs to be carried out with CCSM4 later this year.



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