ACDC 2010 students' summaries of lectures on June 14, 2010

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1 Jesse Johnson (U Montana)

The SeaRISE project

In this lecture Jesse described the SeaRISE project which is a collaboration of volunteer participants who wish to establish an upper bound on the possible contribution of Earth's ice sheets to global sea-level rise (SLR) over the next 200 years. The project's primary motivation is to improve upon the estimates given in previous IPCC Assessment Reports (AR) 3 and 4 in which SLR estimates explicitly did not include the contribution due to the dynamical reponse of ice sheets to a changing climate.

In particular, Jesse explained that in a NOAA GFDL meeting in January 2007 members of the glaciological community agreed that such an estimate would require that ice models include so-called higher order stresses in the force balance equation in order to capture ice stream dynamics, in which rapid basal sliding implies that the shallow-ice approximation (SIA) usually used in whole ice-sheet models would not adequately model the flow of ice. Models should also contain an adequate representation of basal processes, calving of icebergs, hydrology and ocean interaction.

Jesse expressed some concern that inclusion of so many new processes would lead to over-fitting of the model parameters to existing data, leading to avoidable model errors at out-of-sample points.

The timeline for contributions to AR 5 are:

- Submission of drafts of work to be included in AR5: March 2011
- Draft of working group contributions to AR5: Sept 2011
- Deadline for publishing papers with results included in AR5: Aug 2012
- Date of publishing AR5: Jun 2013

The methodology of SeaRISE is to use an ensemble of ice models that will simulate ice response to extreme climate scenario experiments. The output of each model will be compared to its own output in certain control runs. As this is not a model inter-comparison project the main aim of the project is to obtain a meaningful range of possible ice responses rather than obtain quantitative agreement between models for given climate experiments. Another accomplishment of the project has been to create a standard set of data for modelling experiments.

Models participating in SeaRISE are assumed to spin-up or reach their initial states each in their own way as it is not specified by the project. After spin-up, the control runs are: to run in a constant present-day climate for 500 years and to run forced by the IPCC A1B climate for 100 years followed by 400 years of contant climate (the 100th A1B year).

The climate experiments to be run are: perturb the Greenland Ice Sheet by doubling the surface velocities over the entire ice sheet (by changing any single parameter chosen by the modeller) and to perturb Antarctica by increasing ice shelf basal melt rates by $2m/a$, $20m/a$ and $200m/a$ (effectively removing all ice shelves).

Jesse concluded by showing some figures of results from early submitters showing that there is indeed significant variation between models in control runs and scenario runs but that meaningful results are likely attainable.

2 Richard Hindmarsh (Brit. Ant. Survey)

Ice2Sea Project

In this lecture Richard described Ice2Sea, the European effort corresponding in scope to the SeaRISE project. Ice2Sea is a well funded program headed by David Vaughn (BAS) aiming to quantify SLR contributions over the next 200 years from the whole cryosphere (ice sheets, ice caps, mountain glaciers). It has 23 partners in 13 countries and began in April 2009.

The project will perform climate simulations of the next 200 years , which is the time horizon of policy-makers, in which global climate models drive regional general circulation models which in turn drive ice sheet models. The response of ice sheets will not feed back into the global circulation models, which will be forced by AR4 climate scenario projections. Several models will be used at each stage.

The project will also carry out certain process studies to better understand grounding line movement, lubrication by basal meltwater and calving of icebergs.

Unlike SeaRISE, Ice2Sea is not using extreme climate scenarios. Their intention is to obtain *most likely* SLR changes due to cryospheric mass loss.

Data sets of relevant climate variables on a 5km grid will become available at http://pangaea.de.

3 Andreas Vieli (U Durham)

Greenland marine outlet glacier dynamics: observations and modeling

Andreas began by detailing the rapid dynamical changes that have been observed in certain Greenland outlet glaciers in the past decades. Thinning, retreat and acceleration have been observed in marine-based glaciers, especially Jakobshavn Isbrae on the west coast and Helheim and Kangerdlugssuaq glaciers on the east coast. The contribution to SLR by changes in outlet glaciers has been estimate at $0.4 mm/a$, which is 10 percent of the total rate of SLR. However, the dynamics leading to this contribution take place on a small scale which it is not possible to resolve using current whole ice-sheet models. Other challenges to understanding these changes are a lack of basal topography measurements and inadquate grounding-line parametrizations in existing whole ice-sheet models.

The typical properties of Greenland marine-terminating outlet glaciers are:

- flow on the order of km/a
- ice volume flux of 10 km^3/a
- steep surfaces leading to driving stresses of approx. $100 kPa$
- calving rates of km/a
- melt rates of m/day
- effect of sea ice floating at the ice front (Sikkusak)

Andreas then showed observational results that quantify and support these general observations. Observations of these outlet glaciers show that there is significant temporal and spatial variability in the dynamical behavior. One characteristic commonly observed is that dynamical changes at the ice front propagate diffusively upstream. For instance, loss of floating ice at a glacier terminus leads to acceleration, thinning and further retreat which leads to thinning and acceleration upstream according to the estimates

$$\frac{\partial h}{\partial t} \propto -\frac{\partial}{\partial x}(uh)$$

$$uh \propto (\rho g \frac{\partial s}{\partial x})^m h^k.$$

In general the signal seems to propagate at about four times the glacier speed and decays away from the ice front.

Possible controlling mechanisms for this behavior are speculated to be:

- Surface Mass Balance
- Basal lubrication
- reduced butressing

- sea-ice (Sikkusak)
- ocean induced melting at the ice front
- calving

Andreas provided observational evidence for or against these effect where available.

Next, Andreas provided a detailed explanation of his modeling work. This work focuses on cases resembling Helheim Glacier and Crane Glacier (Antarctic penninsula). He uses a one-dimensional shelfy-stream equation with the effect of varying glacier width included. The momentum equation is

$$-2\frac{\partial}{\partial x}(h\sigma'_{xx}) + \tau_{basal} + \frac{h}{w}\tau_{side} = \tau_{driving}$$

or

$$-2\frac{\partial}{\partial x}(h\nu\frac{\partial u}{\partial x}) - \beta u^{1/m} - \frac{h}{w}(\frac{5u}{2Aw})^{1/n} = \rho_{ice} g\frac{\partial s}{\partial x}$$

where u is the velocity, A is the Glen's law flow constant, h is the thickness of the ice, ν is the effective viscosity (from Glen's flow law), β and m are parameters for basal traction, w is the glacier width and s is the surface of the ice.

The calving criteria is either to remove all floating ice or to use a well-known crevasse-depth criteria.

The marine boundary condition is

$$\frac{\partial u}{\partial x} = A\left(\frac{\rho g}{4}(1-\rho_{ice}/\rho_{ocean})\right)^n h^n$$

The numerical grid is moved to track the grounding line and calving front.

The model experiements Andreas carried out were:

- 1. Helheim. Fixed ice front. Perturb the grounding line by reducing A in the boundary condition. The result was a rapid dynamical adjustment that propagated upstream where thinning was greatest at the front and velocity speed-up observed over the whole domain.
- 2. Helheim. Moving ice front (no floating ice). After a stress perturbation the glacier was found to thin, accelerate and retreat until the grounding line reached a point where the basal topography began to slope upwards towards the ice front.
- 3. Increasing ablation by a factor of 10 led to only a small dynamical response, as did reducing β by a small amount and reducing lateral stresses along the glacier.
- 4. Crane Glacier. Prescribed retreat to follow observed ice front movement (beginning after the sudden collapse of Larsen B ice shelf down stream). It was found that the response was initially quite slow, corresponding to the glacier being quite wide at the initial ice front position. The dynamical

reponse was much faster as the ice front was artificially moved back to a narrower part of the glacier. Thinning rates were comparable to observed thinning rates at various positions along the glacier.

- 5. Crane Glaicer. Calving was prescribed so that an ice shelf of lengths $0km$, $1km$ or $2km$ was preserved at all times. Calving according to a crevasse-depth law was also used. It was found that the short shelves and crevasse-depth calving approaches led to results that matched observations quite well suggesting that short-shelves can be dynamically significant.

  The lecture concluded with a discussion of observations of rates of Greenland mass loss during the 1990's and 2000's, juxtaposing the mass loss due to ice discharge and that due to surface mass balance changes.