Russell Glacier Catchment Modelling

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1 Introduction

Understanding the non-linear relationship between surface meltwater and glacier speedup is essential in projecting glacier and ice sheet contributions to sea-level. Critically the ice dynamic response to meltwater is dependent on subglacial drainage morphology and evolution. The key variable of interest at the ice-bed interface is the effective pressure as this controls the glaciers ability to slide. The distribution of effective pressure (the difference between ice overburden and subglacial water pressure) at the glacier bed is directly related to the configuration of the subglacial drainage system. The effective pressure also acts at the subglacial and groundwater exchange and thus is of vital interest in aiding the study of groundwater flow beneath ice-sheets.

Previous work [4] has involved coupling a flow-band ice dynamics model with an areally-averaged two-component subglacial model. The challenge now is to couple a 3D ice-dynamics model to a 2D plan-form subglacial hydrology model that allows for switches between distributed and channelized drainage networks.

2 Numerical Model

2.1 Subglacial Drainage

Subglacial drainage systems are usually classified into two distinct forms: distributed and channelized flow. A distributed drainage network consists of a network of interconnected cavities this system exhibits inefficient ('slow') flow and is representative of the winter season. A channelized system consists of an arterial network of water filled conduits; this is a more efficient ('fast') drainage system typical of conditions in summer. We shall use the recent subglacial hydrology model of Christian Schoof at UBC [7]. This 2D planform model unifies the two forms of drainage within a single mathematical formulation and allows for switching between cavities and channels within a spatially extended drainage catchment.

2.2 Ice Dynamics

Variability in basal topography together with a patchwork of stick/slip zones and regions of fast basal sliding suggest a strong contribution from membrane stresses to the force-balance within the Russell glacier catchment. These stresses are properly accounted for in the so-called higher-order ice dynamic models of which we intend to use the 3D model developed by Frank Pattyn at ULB [3].

2.3 Basal Sliding

Effective pressure dependent sliding at the base of an ice mass can have a leading-order effect on the mechanics of the flow. A phenomenological sliding rule in the form of a Coulomb friction law ([6], [5]) will be used to dynamically couple the subglacial water pressure to basal sliding motion.

2.4 Additional hydrological components

The multicomponent hydrology model of Gwenn Flowers at SFU [2] will be used as a basis for modelling and coupling supraglacial, englacial and groundwater hydrological sub-systems.

3 Data

Extensive use of remotely sensed observations and in-situ measurements from Russell glacier field campaigns will be vital for our modelling endeavours. Required model inputs include: surface and bed topography (DEM); spatial and temporal surface meltwater amounts (derived from a distributed energy balance model using AWS data); supraglacial lake locations (moulins), volumes, drainage times and hydrographs.

Velocity data will be used to constrain model parameters and test model output. Remotely-sensed TerraSAR-X, SPOT, ASTER, Landsat, RADARSAT and MODIS datasets can provide information on annual, seasonal and specific temporal snap-shots of surface velocities. Detailed high-resolution time series of horizontal and vertical velocities at the GPS sites along the Russell flow line, surrounding two lake/moulin sites and into the ELA.

Additional information that could prove helpful for model improvement include: information on subglacial channels - their spacing and where they are located, when they appear and how quickly they evolve in response to subglacial flooding (bed wetness, basal reflection); englacial storage and surface to bed transition times (dye tracing, basal reflection); as well as the capacity and transmissivity of the distributed drainage system, till properties - depth of saturated layer (seismics).

4 Research Questions

The following are key research questions to be address within this modelling study:

- How does the subglacial drainage system evolve in response to variable inputs of meltwater on diurnal to seasonal timescales as well as supraglacial lake-tapping events?
- What is the effect and influence of englacial storage and surface-to-bed melt-water routing transition times on the basal hydrological system?
- How does interaction between subglacial processes and the overlying ice affect the temporal and spatial pattern of basal traction/decoupling?
- What is the ice sheet's dynamic response to the basal boundary layer stress distribution; in particular, the influence of longitudinal stress gradients in transmitting glacier speedup?
- How does annual variability on the Russell glacier catchment differ in response to different volumes and patterns of meltwater over a complete melt season? For example, comparing the record warm season of 2010 (which could become typical) to the comparatively moderate melt season of 2009.
- What is the likely responds of the Russell glacier catchment under projected climate scenarios?

5 Modelling Strategy

Initially subglacial and ice dynamical model components will be used in an independent and uncoupled manner, boundary conditions will be held fixed to allow output from steady-state snap-shots to be validated against representative mean seasonal/diurnal patterns of surface motion determined from observations. A data assimilation approach will be used to minimize model-observation misfits by modifying and fine-tuning individual model components and their parameters (similar optimization procedures have been successfully conducted in associated contexts e.g. [1]). Once constrained, coupled transient simulations can be performed and validated against ice motion kGPS timeseries data. The model will also be hindcast with archived AWS and surface elevation data from the K-transect and model output compared with the observed mean slow-down of the K-transect margin since 1990.

Model forcing from meltwater input will be broken down into its constituent components (seasonal melt cycle, seasonal and diurnal melt cycles, lake drainage events only - individually at different locations and then sequentially, combined seasonal and diurnal melt cycles with lake drainage events) to examine the influence and effect on subglacial channel formation and network evolution.

Assuming a winter background steady state as an initial condition the model will be deployed over an annual cycle comparing forcing from the moderate 2009 melt season with the anomalously warm 2010 season.

Experiment with model representations of englacial water storage and transport including varying englacial storage volumes and surface-to-bed meltwater transitions times. The influence of explicitly modelling groundwater, englacial and supraglacial hydrology components on the dynamics of the system. There is also the potential for comparing Schoof's model with more explicit subglacial formulations.

The transient model will be used to examine near-future projections under a range of climate scenarios. The model could be nested within a whole ice-sheet scale model to help with upscaling to full Greenland Ice Sheet simulations.

References

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