Geophysical Research Abstracts
Vol. 12, EGU2010-8231, 2010
EGU General Assembly 2010

A predictive model for routing of supraglacial meltwater to the bed of glaciers: application to Leverett Glacier, western Greenland Ice Sheet

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Recent studies have shown that Greenland outlet glacier velocities may be responding to increased meltwater generation (Shepherd et al, 2009; Zwally et al, 2002). Where sufficient supraglacial meltwater is routed into crevasses and moulins it could act to lubricate the bed, resulting in dynamic thinning and accelerated transfer of ice mass to glacier termini. The extent to which this mechanism contributes to mass loss is largely unknown, but may be increasingly important if current trends of warming are to continue, particularly in high northerly latitudes. This study introduces a modelling routine for prediction of moulin formation and quantification of meltwater delivery to the bed from digital elevation models, ice surface velocity data and meteorological input data. Supraglacial meltwater pathways are predicted from ice surface topography using a single flow direction hydrological flow routing algorithm. A temperature-index model driven by measured air temperature is used to produce values of distributed ice surface melt, integrated within stream accumulation to produce estimates of supraglacial stream discharge throughout the predicted network. Ice surface strain rates are calculated from satellite-derived surface velocities acquired using feature tracking. Strain rates are converted to stresses through the constitutive relation for glacier ice, after Nye (1957). Surface tensile stresses are calculated from the resultant principal stresses using the Von Mises criteria for failure of ductile materials, with areas of crevassing predicted where tensile stresses exceed a prescribed value of fracture toughness.

Where supraglacial streams and areas of crevassing intersect, surficial moulin locations are predicted. A simple model for propagation of water-filled crevasses is applied to determine where moulins will penetrate through the full ice thickness, delivering meltwater to the bed. Derived from linear elastic fracture mechanics, the model calculates crevasse penetration depths based on surface tensile stresses and the extent to which water pressure, which is controlled by surface meltwater influx rates and water depth, offsets the closure of crevasses due to the lithostatic stress of the ice (Van der Veen, 2007). The blunting effect of multiple crevasses on the stress intensity factor associated with tensile stress is also considered, as propagation depth of closely-spaced crevasses is significantly reduced in comparison to a single water-filled crevasse. Development of this modelling routine will allow for a rigorous quantitative evaluation of one of the key processes controlling ice sheet dynamic thinning. Representative incorporation of the mechanisms of ice mass change within ice sheet modelling is crucial, since estimates of future sea level change remain limited by major uncertainty surrounding the contribution from polar ice sheets. It is, therefore, timely that models of ice fracture and glacial hydrology be coupled.

References

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