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Estimating ice-melange properties with repeat UAV surveys over Store Glacier, West Greenland

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In the past decade, tidewater outlet glaciers of the Greenland ice sheet (GrIS) have thinned and retreated when compared to the 1980s when the ice sheet was in a state of dynamic balance. With a growing amount of ice discharged into the sea by tidewater glaciers as well as more ice melting on the surface, the Greenland Ice Sheet has become the single largest cryospheric source of global sea level rise. Today, the ice sheet causes sea level rise of 1 mm per year, highlighting the need to understand the ice sheet's response to climate change. Atmospheric warming will inevitably continue to increase surface meltwater production, but the dynamic response, which includes hundreds of fast-flowing tidewater glaciers, is largely unknown. To develop new understanding of ice sheet dynamics, we investigated the mechanism whereby icebergs break off tidewater glaciers and form a proglacial ice melange. This melange is rigid in winter when sea ice and friction along the sidewalls of the fjord, or even at the sea floor, hold it together. The result is a resistive force, which reduces the rate of iceberg calving when the ice melange is rigid and is lost when the melange disappears in the summer.

From early May to late July 2014, we launched unmanned aerial vehicles (UAVs) from a basecamp on a bluff overlooking the calving front of Store Glacier, a 5 km wide tidewater glacier flowing into Uummannaq Fjord in West Greenland. The Skywalker X8 UAVs had a wing-span of 2.1m and a payload containing a high resolution camera, an autopilot system and a GPS data logger. We generated almost 70,000 georeferenced images during 63 sorties over the glacier during a 10 week field season starting 13 May 2014. The images were used to construct orhorectified mosaics and digital elevation models of the proglacial melange with Photoscan structure-from-motion software. The imagery and the DEMs were analysed statistically to understand the spatial characteristics of the ice melange. By combining the observed melange height with the model of hydrostatic equilibrium, we estimate the mean thickness to be 126 m. Whereas the mean melange elevation did not change appreciably in our study area, from the date observations started on 13 May until it disintegrated 4-8 June, we found daily melange elevation change up to 140 % of the observed mean value when tabular icebergs were added to it. Observations showed this increase in melange thickness halted calving and that calving did not resume until the melange had thinned and returned to the observed mean value. We found the mean daily speed of the melange to be 46 m/day, from 13 May to 4 June, whereas the terminus of the glacier flowed with a mean daily velocity of 16 m/day while the melange was present. The higher mean speed of the melange is explained by the motion of large tabular icebergs, which travelled hundreds of metres into the fjord over the course of a single day.
The imagery collected over Store Glacier provide evidence that large tidewater glaciers are stabilized by proglacial ice mélange forming in winter. When melange was present, large calving events strengthened melange by adding to its overall thickness distribution, stopping calving altogether for up to several days following a large calving event, and slowing the flow of the glacier to half of the speed observed the previous day. When the melange was advected suddenly down the fjord, with no apparent weakening, the glacier responded by increasing both flow speed and calving rate simultaneously. The data produced from repeat UAV surveys clearly demonstrates the potential of this new and rapidly advancing method of data collection.