# Understanding Unseasonal Melt and Runoff from the Greenland Ice Sheet

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## Background

The Greenland ice sheet has experienced longer melt seasons, increased melt area and runoff, and more negative mass balance in the recent decade compared to previous decades (e.g., Tedesco et al. 2013). In summer 2012, surface melt covered nearly the entire ice surface, likely for the first time in more than a century (Nghiem et al. 2012). Most of the melt and runoff from the inland ice occurs during the summer season, but several discharge events coinciding with ice sheet runoff production are documented in small pro-glacial streams outside of the regular melting season. What is unclear is the spatial extent to which melt from the ice margin and inland ice contributes to unseasonal discharge. Unseasonal runoff events are identified in discharge observations made near Kangerlussuaq, in southwestern Greenland, between 2008 and 2010. Surface melt occurrence derived from microwave remote sensing, measures of regional atmospheric circulation, and output from the MAR regional climate model are examined to ascertain the source of these unseasonal events.

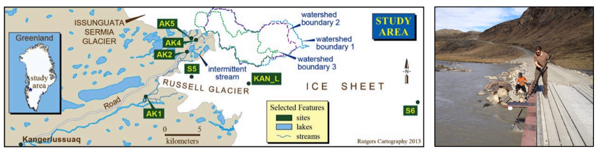


*Fig. 1. Map of study area near Kangerlussuaq, Greenland, with river discharge, air temperature, and lake level monitoring sites indicated, from Rennermalm et al. (2013) (left). Photo of Åsa Rennermalm and John Mioduszewski of Rutgers University collecting water level measurements on the Akuliarusiarsuup Kuua River (site AK4) in June 2013 (photo by T. Mote) (right).*

## Data and Methods

The study catchment is situated along the Greenland ice sheet's southwestern margin, 30 km northeast of Kangerlussuaq (Fig. 1). The study watershed is small (36–64 km$^2$), and the ice sheet surface elevations within this catchment range from 500 to 860 m a.s.l, well below the equilibrium line altitude, which averages 1553 m a.s.l. Hydrometeorological observations have been collected at three sites along the Akuliarusiarsuup Kuua River (Rennermalm et al. 2012) since 2008, including river discharge, stream water level and stream temperatures (Site AK4, Fig. 1) and air temperature (Site AK1 and AK2, Fig. 1). Meteorological observations on the ice sheet were acquired at PROMICE AWSs labeled S5, KAN_L, and S6 in Fig. 1.

ERA-Interim reanalysis at 0.5° spatial resolution was used to create a daily time series of the Greenland Blocking Index (GBI). GBI is defined as the mean 500 hPa height over the Greenland region from 60°- 80°N latitude and 20°-80°W longitude (Hanna et al. 2012). The GBI time series was low-pass filtered and subsequently standardized to remove the seasonal cycle.

MAR is a three-dimensional atmosphere-land surface regional climate model, coupled to the SISVAT vegetation scheme, which includes a version of the CROCUS snow model (Brun et al. 1992). CROCUS is more sophisticated than most snow models used in RCMs, capable of more fully simulating evolution of snow properties and refreezing of melt water. Daily MAR output on a 25km resolution for Greenland are available from Tedesco et al. (2013). MAR output of runoff, surface mass balance, and energy balance components were examined. To corroborate MAR output, passive microwave remote sensing of surface melt occurrence is used. Brightness temperatures of the 37GHz, horizontally polarized channel from SSM/I were compared to modeled TBs associated with 1% liquid water in the snow/firn, and surface melt was identified when the observed exceeded the modeled threshold (Mote 2007).

## Results

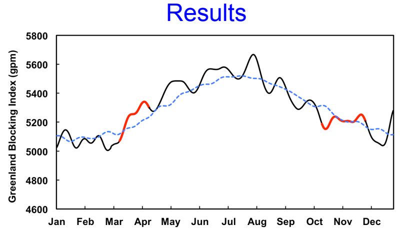


*Fig. 2. Daily time series of the Greenland Blocking Index (GBI, Hanna et al. 2012) from 1 January – 31 December 2008. Daily GBI observations for the following two unseasonal GrIS melt/runoff events (adapted from Rennermalm et al. 2013) are highlighted in red: (a) 10 March – 10 April 2008 and (b) 15 October – 1 December 2008.*

## Unseasonal Runoff Event of Spring 2008

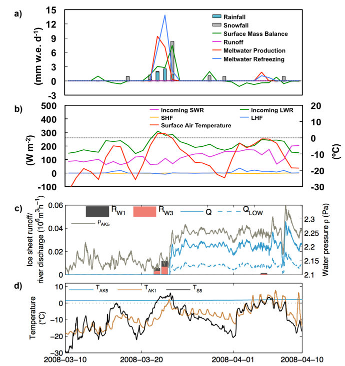


*Fig. 3. [Plots (a) and (b)] MAR model output for March 10 – April 10, 2008. [Plots (c) and (d)] Time series of ice sheet, river, and proglacial conditions from 10 March – 10 April 2008. Plot (a) provides river discharge with ($Q_{LOW}$) and without winter error compensation (Q), average hourly meltwater runoff from Watershed 1 ($R_{W1}$) and Watershed 3 ($R_{W3}$), and sensor water pressure (ρAK4). Plot (d) provides temperatures measured in the stream channel ($T_{AK4}$), in the proglacial area by site AK2 ($T_{AK2}$), and on the S5 ice sheet AWS site ($T_{S5}$), from Rennermalm et al. (2013).*

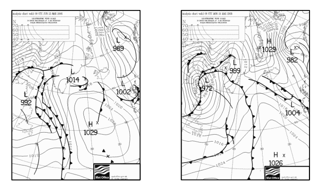

*Fig. 4. Surface analyses over the North Atlantic region at 0000 UTC 23 March 2008 (left) and 24 March 2008 (right). UK Met Office maps provided by Wetterzentrale.*

## Unseasonal Runoff Event of Fall 2008

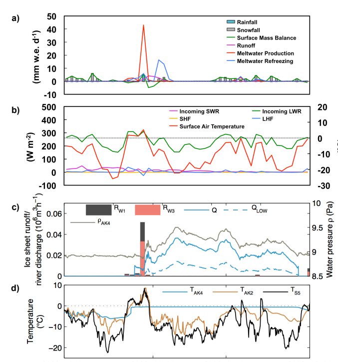


*Fig. 5. [Plots (a) and (b)] MAR model output for 15 October – 1 December 2008. [Plots (c) and (d)] Time series of ice sheet, river, and proglacial conditions from 15 October – 1 December 2008, from Rennermalm et al. (2013).*

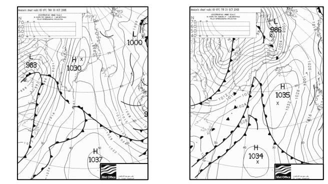

*Fig. 6. Surface analyses over the North Atlantic region at 0000 UTC 30 October 2008 (left) and 31 October 2008 (right).*

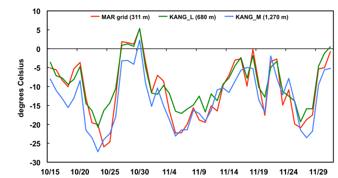


*Fig. 7. Daily time series of surface air temperature observations from 15 October – 1 December 2008 at three sites near Kangerlussuaq. The MAR grid is bounded by the following geographic coordinates: (67.05ºN, 50.51ºW), (67.20ºN, 50.0ºW). Data at the KANG_L (67.1ºN, 49.9ºW) and KANG_M (67.1ºN, 48.8ºW) sites was provided by the PROMICE AWS network (http://polarportal.dk/en/greenland-ice-shelf/nbsp/surface-conditions/).*

## Do satellite measures of surface melt corroborate these events?

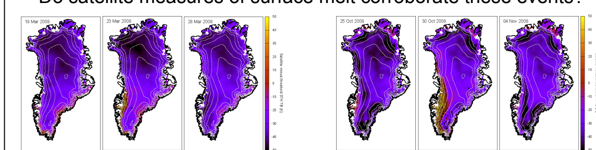

*Fig. 8. Maps of SSM/I-derived GrIS melt extent for the day during each unseasonal melt/runoff event ±5 days from the greatest melt extent value: 23 March 2008 (center left), and 30 October 2008 (center right). Warm colors indicate elevated 37 GHz, horizontally polarized, brightness temperature, and hatched areas indicate surface melting.*

## Discussion and Conclusions

- Unlike many large surface melt and runoff events during the summer, these unseasonal runoff events were not clearly tied to Greenland blocking episodes (Fig. 2).
- MAR reproduces melt production and temperature for three unseasonal runoff events in 2008 (Figs. 3, 5, 7) and in 2009 (not shown). However, an associated runoff signature is simulated only for the fall 2008 event (Fig. 5), suggesting that MAR may retain too much melt water.
- The warm sectors of strong North Atlantic cyclones traversed over southern Greenland during two of the three unseasonal runoff events in spring and fall 2008 (Figs. 4, 6). Warm air advection was concentrated within a relatively narrow band along the ice sheet.
- The melt water production identified by MAR is consistent with the surface melt captured in the satellite imagery (Fig. 8).
- An array of observational and modeling tools can be used in a complementary way to effectively reproduce runoff events that occur within a relatively small catchment area of the Greenland ice sheet.

### References

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