Application of an improved surface energy balance model to two large valley glaciers in the St. Elias Mountains, Yukon: Supplementary material

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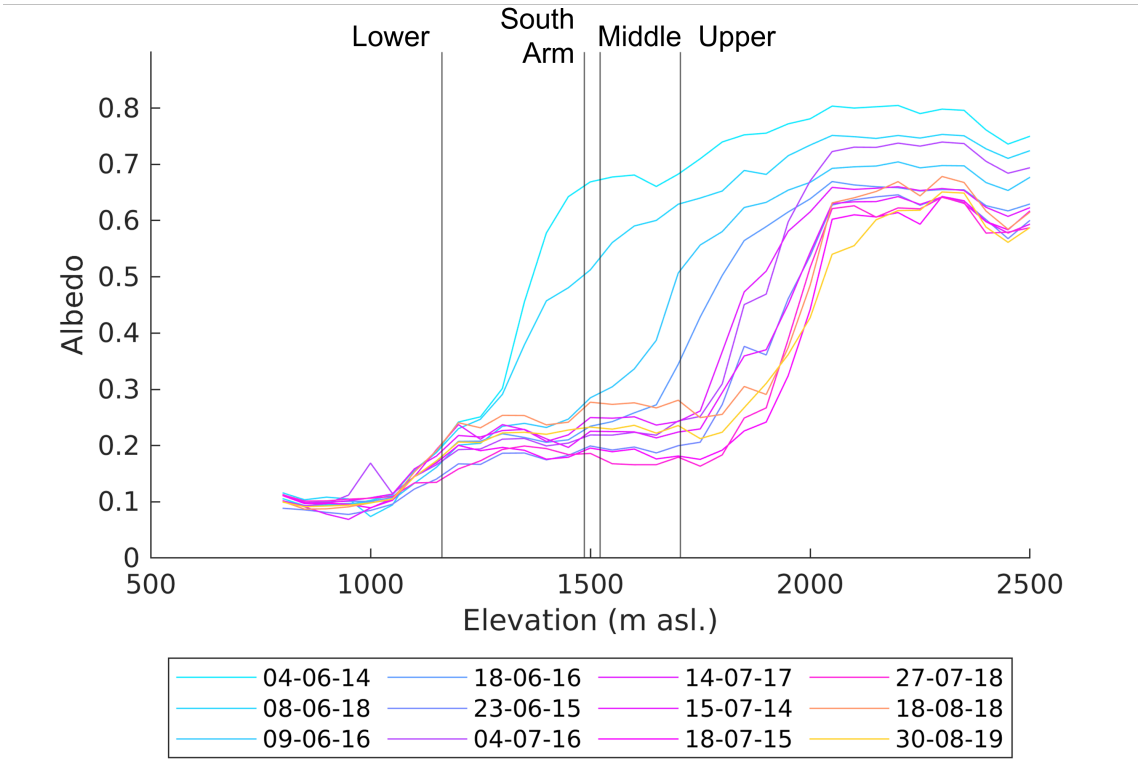

Figure S1: Mean albedo as a function of elevation on Kaskawulsh Glacier, using 12 Landsat 8 scenes from 2014–2019. Vertical black lines indicate the elevation of the lower, midde, south arm, and upper HOBO stations.

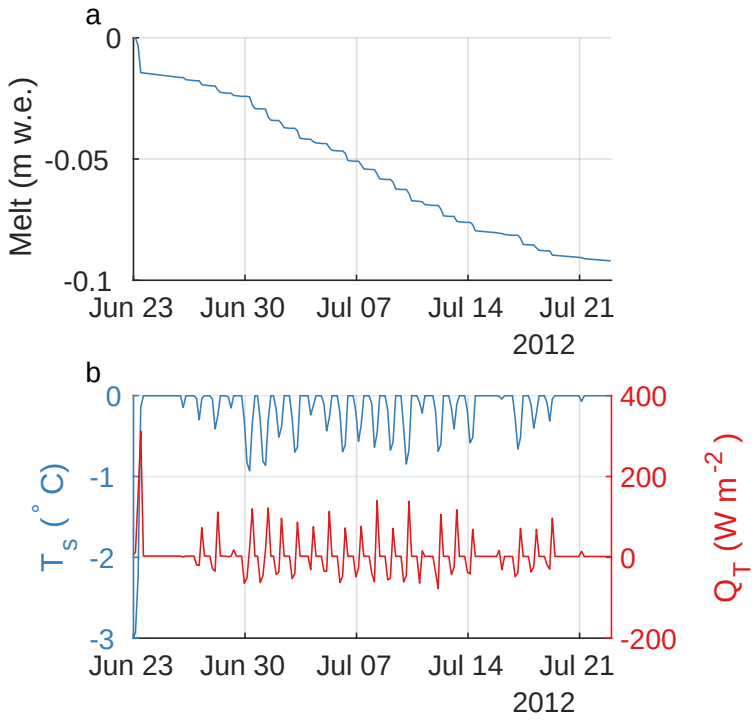

Figure S2: (a) Difference in modelled melt (m w.e.) with and without subsurface model at the Kaskawulsh Upper station during the beginning of the 2012 melt season. (b) Modelled surface temperature (blue) and heat used to warm the ice (red).

Table S1: Location of HOBOs and temporal coverage of HOBO Temperature and Relative Humidity and surface ablation measurements on Nàłùdäy and Kaskawulsh Glaciers. Note that data gaps may exist within the indicated measurement periods

Glacier	Station	Latitude	Longitude	Elevation (m asl.)	Temporal coverage HOBO	Temporal coverage Surface ablation
Kaskawulsh	Lower	60°46′3″N	138°32′26″W	1163	2010-06-05–2015-04-09; 2018-07-23–2019-05-11	2013-08-28–2015-04-09 2017-08-22–2019-05-11
	Middle	60°45′13″N	138°46′16″W	1521	2010-06-05–2015-04-09; 2018-07-23–2019-03-20	2017-08-22–2019-03-18; 2017-08-22–2019-03-18
	Upper	60°43′36″N	138°58′17″W	1705	2010-06-05–2015-04-09; 2018-07-23–2019-05-11	2010-07-06–2015-04-09 2017-08-22–2018-08-26
	South Arm	60°40′13″N	139°7′59″W	1487	2010-06-05–2014-08-12	2010-05-06–2013-07-23
Nàłùdäy	Lower	60°17′27″N	138°10′51″W	760	2018-08-25–2019-05-12	2018-07-27–2019-07-06
	Middle	60°18′27″N	138°21′30″W	1002	2017-07-25–2018-07-25	2018-07-27–2018-08-08
	Upper	60°17′2″N	138°21′33″W	1218	2017-07-25–2019-07-09	–

Table S2: Summary of weather stations on Kaskawulsh and Nàłùdäy Glacier. The data gaps are discussed in the main text

AWS	Latitude	Longitude	Start date	End data	Data gaps	Variables measured	Measurement frequency
AWSK1	60°44′32″N	139°9′57″W	2010-06-05	2018-07-26	2017-08-29 – 2018-07-26	T, SW_{in}, U, P	1 hour (T, SW_{in}, U), 3 hour (P)
AWSK2	60°44′32″N	139°9′57″W	2018-07-26	Continuing	2019-05-11 – 2019-09-11	T, RH, SW_{in}, SW_{out}, LW_{in}, LW_{out}, U, P	2 hour
AWSN1	60°18′45″N	138°33′36″W	2018-07-26	2019-06-05	None	T, RH, SW_{in}, SW_{out}, LW_{in}, LW_{out}, U, P	2 hour

Table S3: Default parameters used in the SEB model

Parameter	Description	Default value
ε_s	Ice emissivity	1
ε_a	Atmospheric emissivity	Varies
z_0	Momentum roughness length	3×10^{-3} m to 5×10^{-3} m
z_{0H}	Heat roughness length	$z_0/100$
z_{0E}	Moisture roughness length	$z_0/100$
z	Height of RH, T measurements above ice surface	1.35 m to 2 m
ρ_{ice}	Ice density	850 kg m^{-3}
T_{12m}	Ice temperature at 12 metre depth	-3 °C (Wheler and Flowers, 2011)
Δt_{SSM}	Subsurface and energy balance model timestep	900 s
Δt_{AWS}	Meteorological forcing timestep	3600 s to 7200 s
N_{SSM}	Number of vertical layers in subsurface model	12

Table S4: Total and relative model error (ME) and ablation rate error (ARE) compared to available validation data (UDS and time-lapse ablation stake measurements). Empty cells represent locations and years with no measurements to compare with. Error at the middle station of Nàłùdäy in 2018 is computed using the extended melt record derived from measurements at the lower station

		Lower		Middle		Upper		South Arm	
Glacier	Melt year	ME (m)	ARE (m day^{-1})	ME (m)	ARE (m day^{-1})	ME (m)	ARE (m day^{-1})	ME (m)	ARE (m day^{-1})
Kaskawulsh	2010					-0.08	-0.0037	0.52	0.0094
						-3.0%	-6.8%	16.0%	17.5%
	2011					-0.07	-0.0053	0.10	0.0034
						-12.3%	-20.2%	22.3%	12.0%
	2012					0.27	0.0013		
						8.5%	0.3%		
	2013	0.03	0.0015			-0.68	-0.0093	-0.21	0.0011
		4.8%	3.2%			-14.4%	-17.3%	-2.3%	1.8%
	2014	0.29	0.0017			-0.13	-0.0056		
		7.1%	3.2%			-3.6%	-11.7%		
	2018	0.0025	0.0010	0.10	-0.0051	-0.14	0.0010		
		0.1%	1.8%	4.4%	-9.6%	-7.7%	1.8%		
Nàłùdäy	2018	-0.10	0.0021	-0.23	-0.0011				
		-3.3%	3.4%	-8.4%	-2.1%				

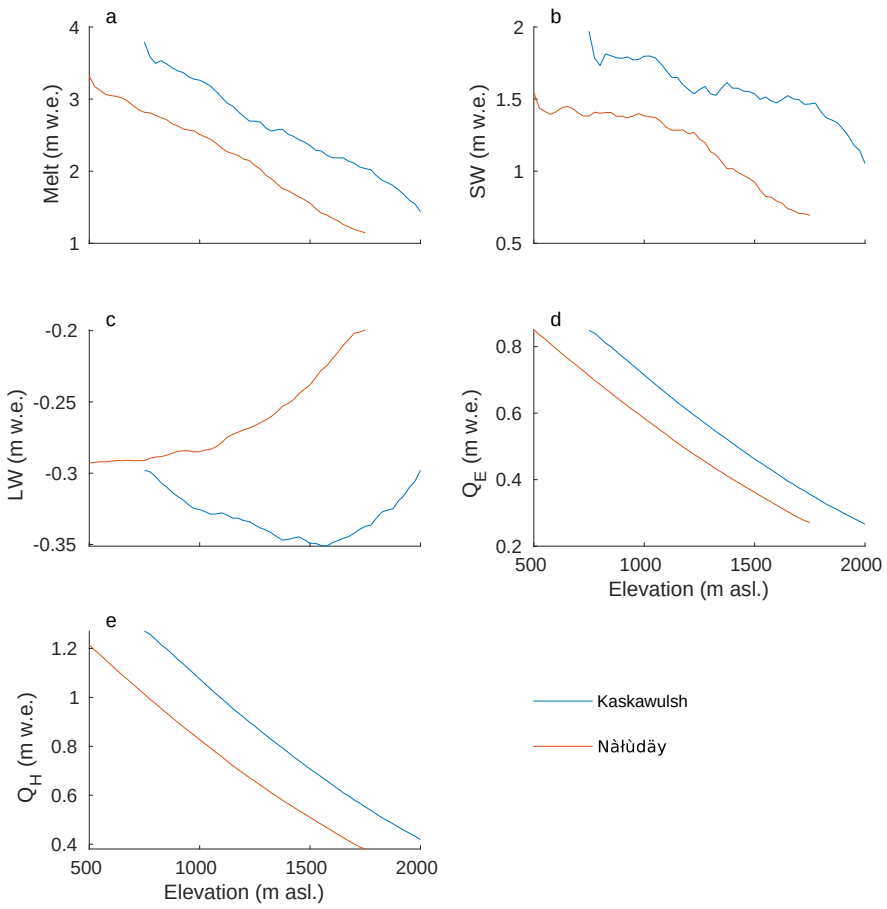

Figure S3: Melt due to individual surface energy balance components for Kaskawulsh and Nàłùdäy from 27 July to 15 September 2018. (a) Total melt, and melt due to (b) shortwave radiation, (c) longwave radiation, (d) latent turbulent heat flux, and (e) sensible turbulent heat flux. Negative melt values for LW radiation indicates the net LW heat flux was from the glacier to the atmosphere. This situtation is typical of LW radiation since the emissivity of glacier ice is much higher than that of the atmosphere.

References

Wheler BA and Flowers GE (2011) Glacier subsurface heat-flux characterizations for energy-balance modelling in the Donjek Range, southwest Yukon, Canada. *Journal of Glaciology*, **57**(201), 121–133 (doi: 10.3189/002214311795306709)