Supplement of The Cryosphere, 13, 1681–1694, 2019
https://doi.org/10.5194/tc-13-1681-2019-supplement
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The Cryosphere

Supplement of

Sensitivity of a calving glacier to ice–ocean interactions under climate change: new insights from a 3-D full-Stokes model

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Section S1: Duration Sensitivity Experiments

To investigate the effect of varying forcing *durations*, we concurrently scale the ice mélange and melt seasons first by 1 month and then by 2 months. As we are interested in changes relating to a warming Arctic climate, we increase the length of the melt season while decreasing the length of the mélange season. These changes are applied symmetrically: when increasing the melt season by 1 month (Run D1), we achieve this by adding half a month on each end of the season, and simultaneously decrease the mélange season by half a month at each end. Finally, in runs DM1 and DM2, we scale both the duration and magnitude of forcing. These four simulations are outlined in Table S1.

Table S1: Duration Perturbations

	Ice Mélange			Submarine Melt				
Run Code	Thickness (m)	Formation Date	Collapse Date	Distrib. Summer Mean (m d^{-1})	Distrib. Winter Mean (m d^{-1})	Conc. Max (m d^{-1})	Summer Start	Summer End
CONTROL	140	1st Feb	29th May	3.1	1.3	12	1st June	31st Aug
D1	140	15th Feb	14th May	3.1	1.3	12	17th May	15th Sep
D2	140	2nd March	29th April	3.1	1.3	12	2nd May	30th Sep
DM1	70	15th Feb	14th May	4.65	1.95	18	17th May	15th Sep
DM2	0	-	-	6.2	2.6	24	2nd May	30th Sep

Modifying just the duration of mélange buttressing and melting (Runs D1 and D2) had little overall effect on the terminus range (Fig S1); there is no discernible effect in the northern side of the terminus, while in the south, the terminus advances slightly less in winter (a maximum of 500m less for Run D2 compared with the control). The pattern of mean terminus position through time (Fig S2a) reveals that this is a consistent but small effect. Despite the shorter mélange season, Run D1 extends just as far into the fjord as the control; Run D2 also advances in response to mélange buttressing, but the mean advance is up to 400m less in some years. In terms of *minimum* terminus extent, Run D1 showed no significant change, but in Run D2, a 1km width of the terminus retreated up to 800m further than the control. Figure S2a reveals that this extra retreat occurred only in the last year of the simulation, when the terminus retreated 400m on average, relative to the control. Overall, the effect is surprisingly muted, given that Run D2 features a 5 month summer melt season and only 2 months of mélange buttressing.

In terms of the ice velocity at the terminus, Runs D1 and D2 are predominantly affected by the shorter mélange season, which reduces the duration of mélange driven deceleration (Fig. S2a). This is reflected in the increased mean annual influx in these runs (Table S2). Mass loss from submarine melt also increases in both runs, as expected given the longer melt season. In Run D1, mean annual calving loss is reduced by 0.07 Gt a^{-1} compared to the control, to 7.12 Gt a^{-1}. In Run D2, however, calving increases by 0.17 Gt a^{-1} to 7.36 Gt a^{-1}.

Compared with the ‘duration’ experiments, combining both magnitude and duration perturbations significantly changes the terminus behaviour; the glacier responds in a manner which is qualitatively similar to the ‘magnitude’ experiments discussed in the main text. In Run DM1, mean terminus position remains fairly consistently around 200 m further upstream than the control (Fig. S2b). In the summer melt seasons of years 2 and 3, the difference between Run DM1 and the control increases to almost 500 m. As with previous perturbation experiments, this extra retreat is confined to the southern floating portion of the terminus (Fig. S2b). The velocity time series remains fairly consistent with the control for the first 4 years, apart from the reduced deceleration due to the thinner mélange and shorter mélange season. However, around the beginning of year 5, the terminus accelerates 250 m a^{-1} on average, and remains slightly faster than the control for the remainder of the simulation.

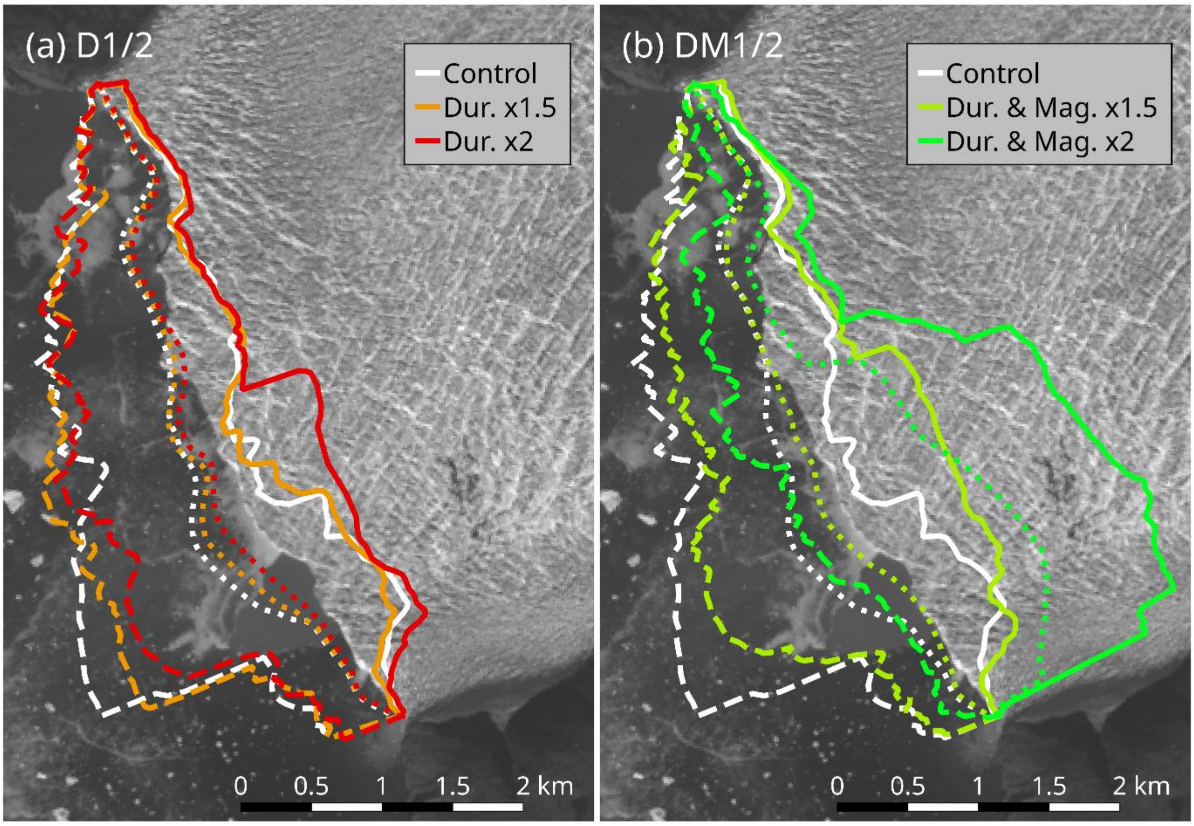


Figure S1: Maximum (dashed), mean (dotted) and minimum (solid) terminus positions for step changes in (a) melt and mélange season length only, and (b) both season length and forcing magnitude. White lines indicate the control simulation, and increasingly bright colour indicates more severe environmental forcing.

Run DM2 represents the most ‘aggressive’ perturbation experiment performed in this study. Melt rates are doubled and the summer melt season is increased by 2 months, while mélange is completely absent throughout. The modelled terminus rapidly retreats in the first melt season, retreating 750 m on average, to a position which is then maintained for almost 1 year, before retreating another 100 m, at which point the simulation broke down. Again, this retreat is constrained to the southern portion of the terminus, most of which retreated over 1 km compared with the control (Fig. S1b). The significant retreat in Run DM2 results in an increase in mass flux through the terminus region; annual flux towards the terminus increases from 9.4 Gt a^{-1} in the control to 10.16 Gt a^{-1}, calving rate increases from 7.19 Gt a^{-1} to 7.8 Gt a^{-1}, and submarine melt losses more than double to a total of 4.35 Gt a^{-1}.

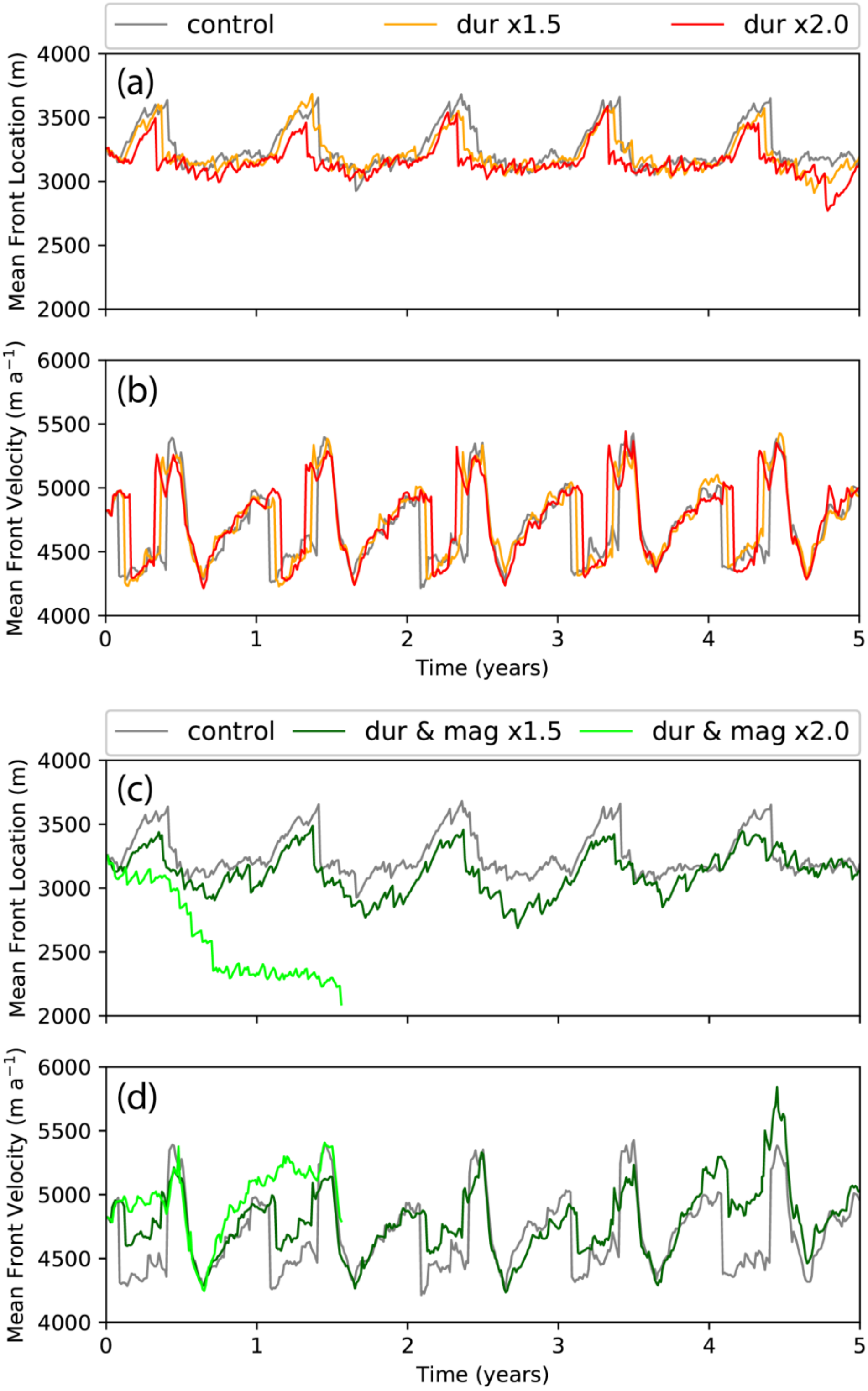
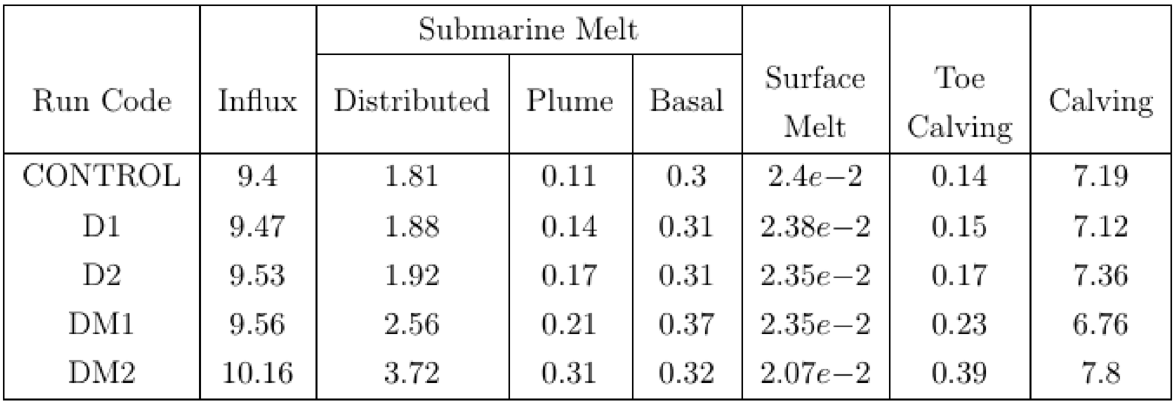


Figure S2: Mean terminus position (a) and velocity (b) over 5 years for changes in forcing duration (Runs D1 & D2). (c-d) Same for changes in both forcing duration and magnitude (Runs DM1 & DM2). Note different y-scales between simulations.

Table S2: Mean annual mass gain and loss (Gt) for duration simulations, for the final 2km of the glacier.



Run Code	Influx	Submarine Melt			Surface Melt	Toe Calving	Calving
		Distributed	Plume	Basal			
CONTROL	9.4	1.81	0.11	0.3	2.4*e*−2	0.14	7.19
D1	9.47	1.88	0.14	0.31	2.38*e*−2	0.15	7.12
D2	9.53	1.92	0.17	0.31	2.35*e*−2	0.17	7.36
DM1	9.56	2.56	0.21	0.37	2.35*e*−2	0.23	6.76
DM2	10.16	3.72	0.31	0.32	2.07*e*−2	0.39	7.8

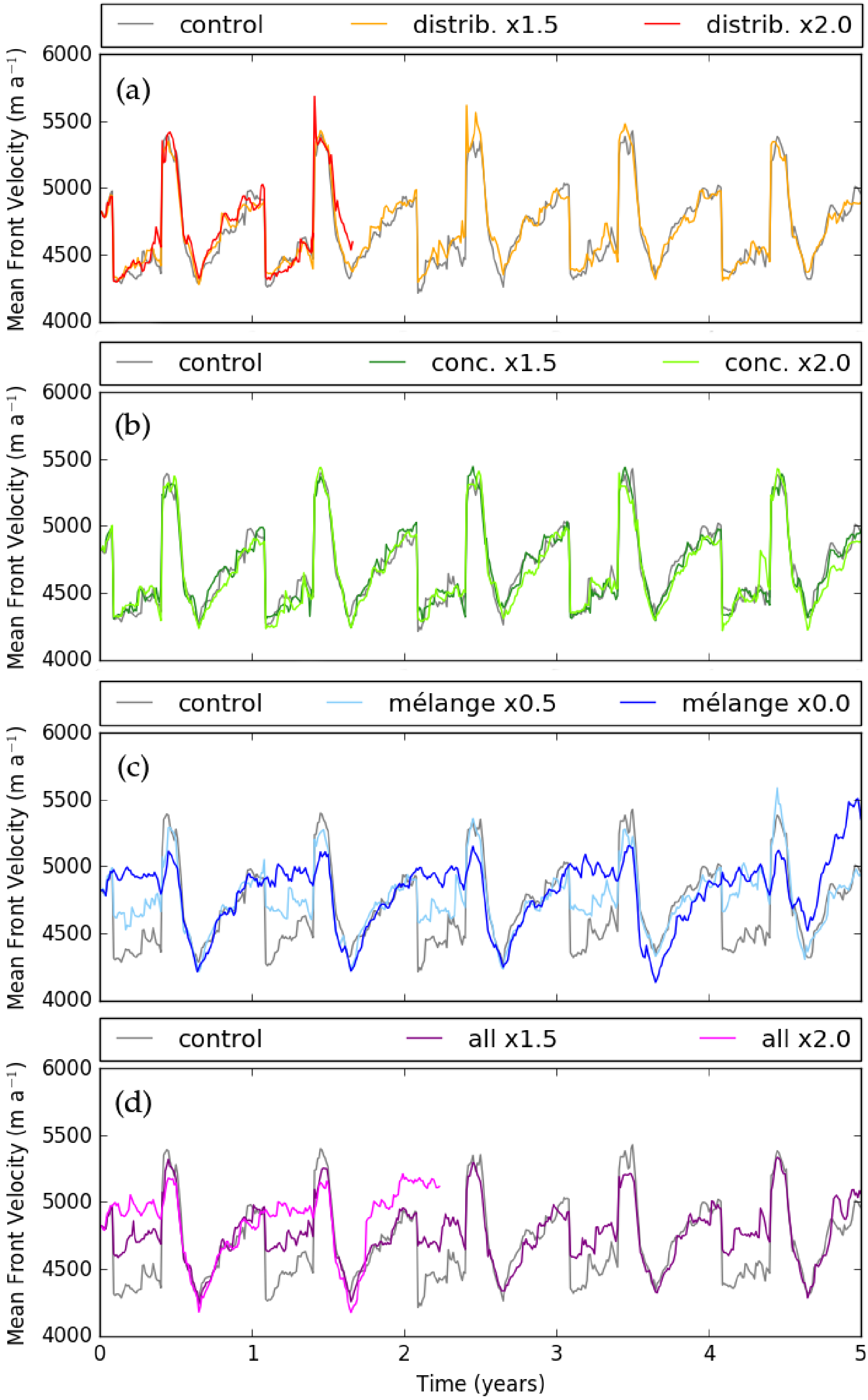


Figure S3: Seasonal trends in mean terminus velocity for each of the experiments shown in Figs. 3,4. Experiments involve perturbations to (a) distributed melt rate, (b) concentrated melt rate, (c) mélange thickness, and (d) all of the above.

Table S3: Annual mean mass gain and loss (Gt) for magnitude perturbation simulations, for the final 2km of the glacier.

Run Code	Influx	Submarine Melt			Surface Melt	Toe Calving	Calving
		Distributed	Plume	Basal			
CONTROL	9.4	1.81	0.11	0.3	$2.4e{-2}$	0.14	7.19
MD1	9.43	2.5	$9.28e{-2}$	0.38	$2.38e{-2}$	0.18	6.66
MD2	9.57	3.38	$8.98e{-2}$	0.44	$2.39e{-2}$	0.27	7.07
MC1	9.41	1.79	0.17	0.29	$2.39e{-2}$	0.17	7.08
MC2	9.4	1.84	0.23	0.28	$2.36e{-2}$	0.2	6.87
MM1	9.51	1.81	0.11	0.29	$2.38e{-2}$	0.14	7.56
MM2	9.62	1.73	0.1	0.27	$2.33e{-2}$	0.14	7.77
MA1	9.55	2.43	0.15	0.39	$2.37e{-2}$	0.2	6.59
MA2	9.84	3.07	0.19	0.37	$2.19e{-2}$	0.28	7.07

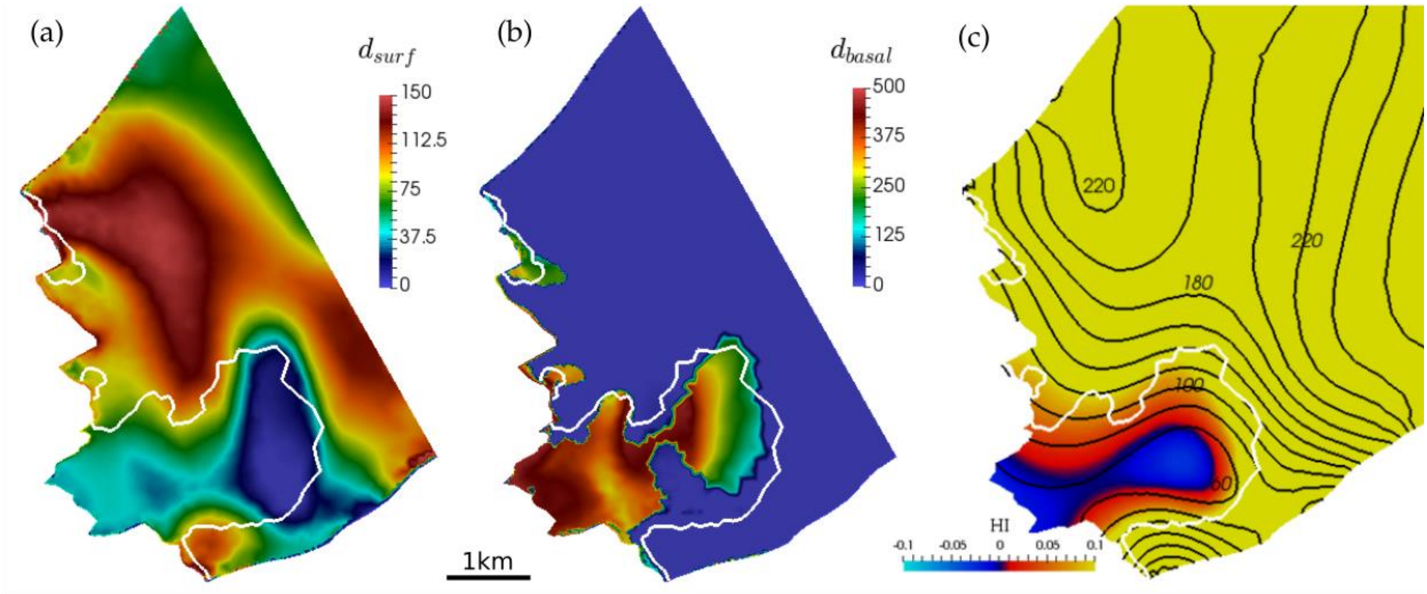


Fig S4: (a) Surface crevasse penetration and (b) basal crevasse penetration from the Year 1 mélange season of the control simulation. (Note different colour scale) (c) Hydrostatic imbalance (Eq. 1) at the terminus and 20m surface elevation contours (black lines). White line indicates the grounding line.