Supporting Information for

Snowmelt response to simulated warming across a large elevation gradient, southern Sierra Nevada, California

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Introduction

Figure S1 includes an analysis of model SWE RMSE computed on measured values from monthly snow courses at seven sites at different elevations. The analysis shows that more of the model error is explained by the distance of a grid element from the nearest precipitation gauge used to force the model than by elevation alone. Table S1 presents how the three snow years of the study compare to the climatological average SWE observations at local automated snow pillows. Tables S2 and S3 show comparisons of modeled and measured snowpack for the basin-scale surveys (Table S2) and monthly snow course surveys (Table S3). Table S4 provides the model simulated total meltwater volume and the relative atmospheric loss over the model domain for each model run.
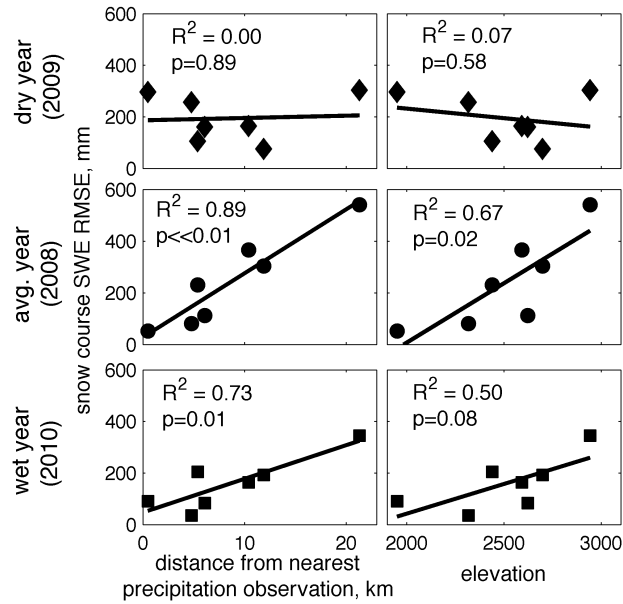
Figure S1: Linear regression relationships (lines; R^2 and p-values) between model SWE RMSE (y-axes) computed on measured values from monthly snow courses at seven sites (markers; see Figure 1) and (left panels) the linear distance of each snow course from the nearest precipitation measurement station used to force the model (x-axes) and (right panels) the snow course elevation (x-axes) for each of the three water years (panel rows). Table S4 includes the measured and modeled snow course SWE data.

Water year	Giant Forest (1951 m)	Big Meadows (2317 m)	Farewell Gap (2896 m)	Three-station mean
2008	+22 mm (+17%)	incomplete record	-14 mm (-3%)	+4 mm (+7%)
2009	-18 mm (-16%)	-53 mm (-20%)	-158 mm (-34%)	-76 mm (-23%)
2010	+118 mm (+114%)	+89 mm (+34%)	+66 mm (+14%)	+91 mm (+54%)

Table S1. Differences, in mm and percent, between the seasonal average SWE measured at the three automated snow stations and the climatological average SWE based on 26-years of data (1988 – 2014) collected at the Giant Forest and Big Meadows stations and a 15-year record (2000 – 2014) at the Farewell Gap station.

Snow survey results	Wolverton basin (forested)			Tokopah basin (alpine)		
2008	*Feb.*	*Mar.*	*Apr.*	*Mar.*	*Apr.*	*May*
survey date	$17^{th} - 18^{th}$	$23^{rd} - 24^{th}$	$27^{th} - 28^{th}$	-	$10^{th} - 13^{th}$	-
# of depth waypoints[N]	112	85	111	-	252	-
mean depth, cm	190	190	115	-	202	-
standard deviation, cm	30	37	58	-	88	-
maximum depth, cm	253	353	314	-	523	-
# of density snow pits	2	2	3	-	2	-
mean density, ± std., kg m^{-3}	364±24	399±12	439±12	-	445±65	-
mean SWE, ± std., mm	691±134	758±170	544±284	-	1000±476	-
model SWE RMSE, mm	146	285	276	-	539	-
model SWE bias, mm	88±117	229±171	43±274	-	313±440	-
normalized MSE	0.04	0.13	0.24	-	0.21	-
2009	*Feb.*	*Mar.*	*Apr.*	*Mar.*	*Apr.*	*May*
survey date	$14^{th} - 15^{th}$	$21^{st} - 22^{nd}$	$25^{th} - 26^{th}$	$1^{st} - 2^{nd}$	$9^{th} - 12^{th}$	$13^{th} - 16^{th}$
# of depth waypoints[N]	85	95	109	160	183	183
mean depth, cm	156	122	81	219	213	117
standard deviation, cm	34	35	46	57	95	79
maximum depth, cm	242	199	179	405	484	393
# of density snow pits	3	2	2	2	3	4
mean density, ± std., kg m^{-3}	262±9	333±30	415±5	302±6	372±57	435±30
mean SWE, ± std., mm	408±100	405±130	691±134	659±207	849±401	508±366
model SWE RMSE, mm	102	181	227	193	390	352
model SWE bias, mm	-47±91	127±129	52±222	83±175	113±375	121±332
normalized MSE	0.07	0.15	0.40	0.18	0.18	0.66
2010	*Feb.*	*Mar.*	*Apr.*	*Mar.*	*Apr.*	*May*
survey date	-	-	-	-	$2^{nd} - 3^{rd}$	-
# of depth waypoints[N]	-	-	-	-	119	-
mean depth, cm	-	-	-	-	281	-
standard deviation, cm	-	-	-	-	63	-
maximum depth, cm	-	-	-	-	532	-
# of density snow pits	-	-	-	-	1	-
mean density, ± std., kg m^{-3}	-	-	-	-	450.6	-
mean SWE, ± std., mm	-	-	-	-	1265±310	-
model SWE RMSE, mm	-	-	-	-	295	-
model SWE bias, mm	-	-	-	-	24±295	-
normalized MSE	-	-	-	-	0.05	-

[N] At each waypoint, three snow depth measurements separated by five meters were made in north-south directions.

Table S2. Summary statistics of the Wolverton and Tokopah basin snow surveys in 2008, 2009, and 2010. Missing data (-) values indicate no survey was conducted on that date.

year	month	Monthly snow course sites ranked by elevation						
		#1 1951 m	#2 2317 m	#3 2439 m	#4 2592 m	#5 2622 m	#6 2698 m	#7 2942 m
2008	Feb.	295 (353)	668 (582)	-	-	-	505 (731)	493 (813)
	Mar.	607 (550)	879 (878)	762 (1034)	533 (1077)	1245 (1093)	-	-
	Apr.	493 (429)	802 (691)	714 (904)	945 (1093)	1115 (1147)	808 (1174)	620 (1314)
	May	20 (34)	-	155 (376)	643 (1147)	889 (1006)	-	-
2009	Feb.	348 (129)	224 (122)	279 (192)	-	404 (343)	284 (341)	239 (505)
	Mar.	582 (240)	516 (272)	373 (402)	-	826 (581)	-	-
	Apr.	455 (127)	513 (158)	368 (304)	554 (616)	861 (684)	599 (687)	554 (890)
	May	279 (0)	-	198 (20)	312 (535)	732 (645)	-	-
2010	Feb.	450 (411)	495 (527)	432 (550)	-	638 (587)	476 (594)	467 (652)
	Mar.	640 (614)	757 (802)	724 (836)	671 (876)	965 (888)	-	-
	Apr.	726 (596)	876 (848)	671 (935)	892 (1018)	1156 (1031)	798 (1043)	699 (1150)
	May	668 (552)	-	653 (920)	1128 (1279)	1394 (1335)	-	-

Table S3. Monthly snow course SWE measurements with corresponding modeled SWE (parentheses), in mm of water equivalent, for water years 2008, 2009 and 2010. Snow course numbers (e.g., '#3') correspond to those in Table 1 and Figure 1. Surveys were conducted on the first day of each month. Missing data values (-) indicate no survey was conducted on that date.

Water year		Nom.	+1°C	+2°C	+3°C	+4°C	+5°C	+6°C
2009	Total melt, km^3	0.84	0.75	0.66	0.56	0.49	0.39	0.32
	Atmos. loss, %	9.3	10.0	11.0	11.9	12.4	13.1	13.6
2008	Total melt, km^3	1.15	1.05	0.93	0.81	0.68	0.54	0.42
	Atmos. loss, %	6.4	6.6	6.9	7.4	8.2	9.4	10.7
2010	Total melt, km^3	1.37	1.28	1.16	1.03	0.92	0.75	0.61
	Atmos. loss, %	4.8	5.1	5.5	6.1	6.6	7.4	8.3

Table S4. Total meltwater volume (km^3) and the relative atmospheric loss (%) over the model domain for the moderately dry (2009), average (2008) and moderately wet (2010) snow seasons simulated in the nominal (Nom.) and six perturbed temperature scenarios.