Supplement for Changing drivers of regional large magnitude avalanche frequency throughout Colorado, USA

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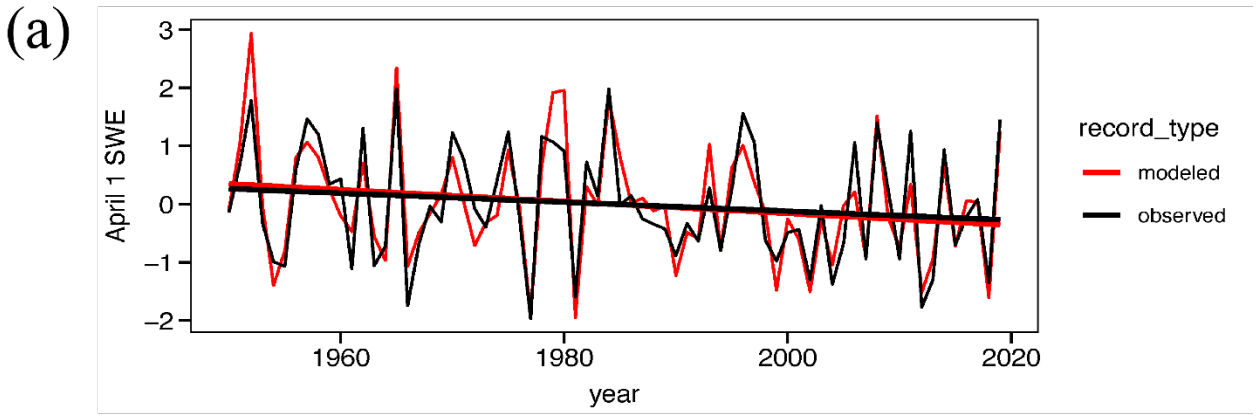
Figures



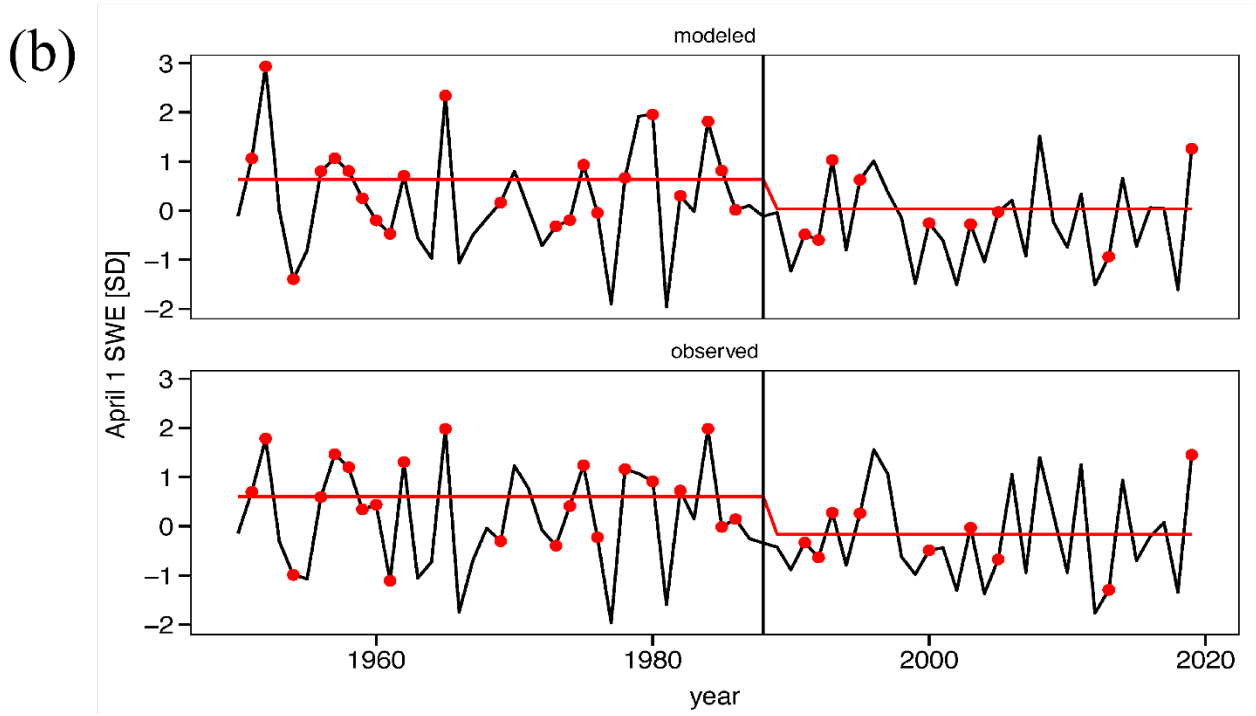


Figure S1: Modelled and observed regional snowpack. Panel (a) shows modelled April 1 SWE and April 1 SWE from regional snowcourse estimates for the period that the two records overlap (1950-2019), with simple linear regression derived trends included. Panel (b) shows the two records with avalanche years (red dots) and their mid- and late-period means (orange lines). We utilized the NClimGrid 1/24th degree gridded monthly temperature and precipitation data (Vose et al., 2014) and coupled those data with gridded monthly water balance model estimates of monthly snowfall and total snowpack snow water equivalent (SWE) based on NClimGrid inputs (Wieczorek et al., 2022) for water-years (October-September) 1901 to 2020. To assess the skill of the monthly water balance model at estimating snowfall over the study area, we compared the gridded snow product with local snow course records from the United States Department of Agriculture Natural Resources Conservation Service (NRCS) (Nrcs, 2024). We linked each avalanche path to its 1/24th degree grid cell and aggregated path-level April 1 modeled SWE estimates across the full study area to provide a regional modeled estimate of April 1 SWE from 1901-2020.

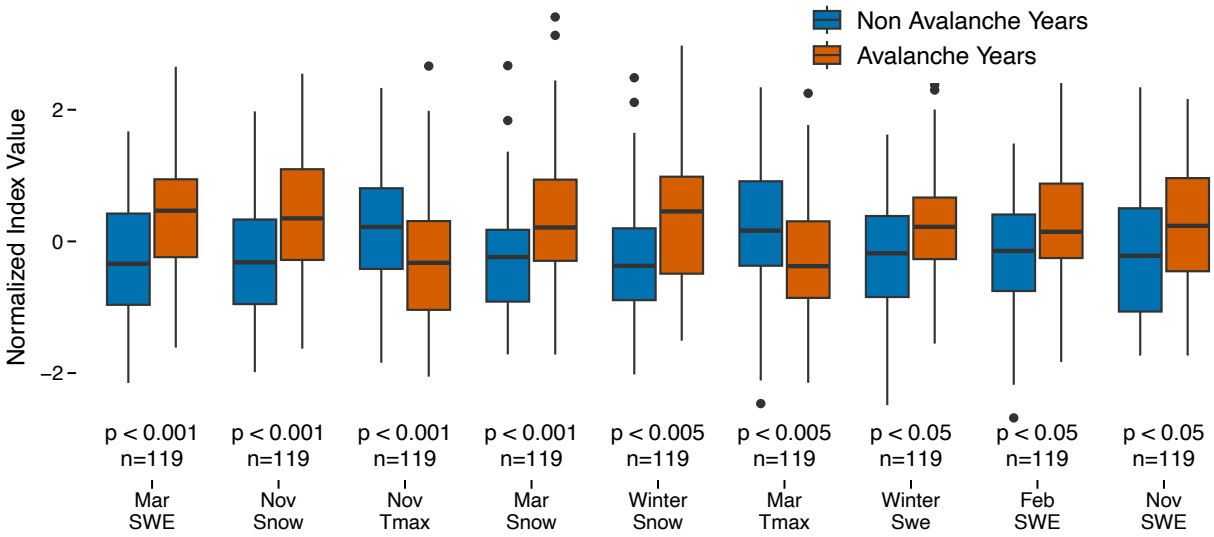
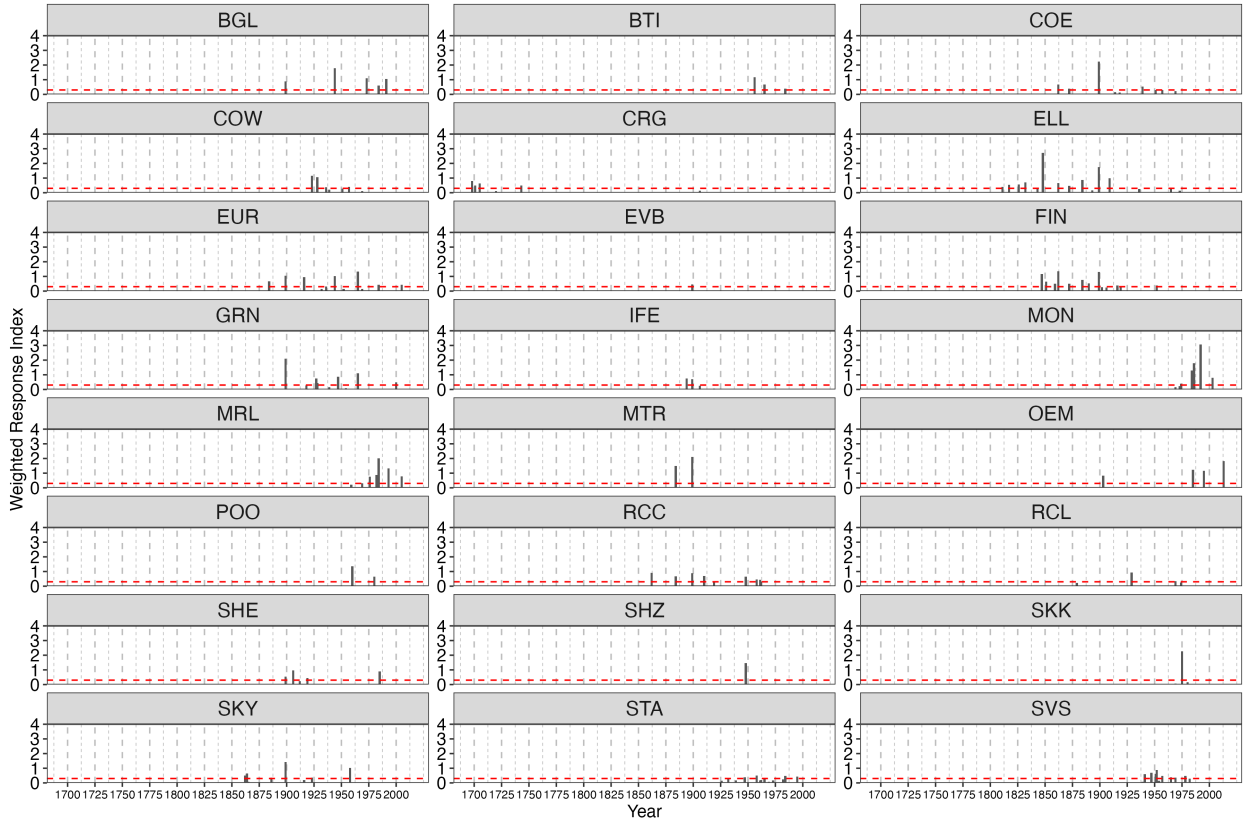


Figure S2: Box plot comparisons of monthly snowfall total, accumulated snowpack (SWE), and temperature means across avalanche years vs. non-avalanche years within the full study period 1901-2019. Only those climate variables with monthly means that differed significantly between avalanche and non-avalanche years are shown with significant differences (alpha=0.05) assessed by the Wilcoxon's rank sum test. The box represents the interquartile range (IQRl, 25th -75th percentile), the whiskers represent the range of values within 1.5 times the IQR, and the dots represent outliers >1.5 times and <3 times either end of the box.

a)



b)

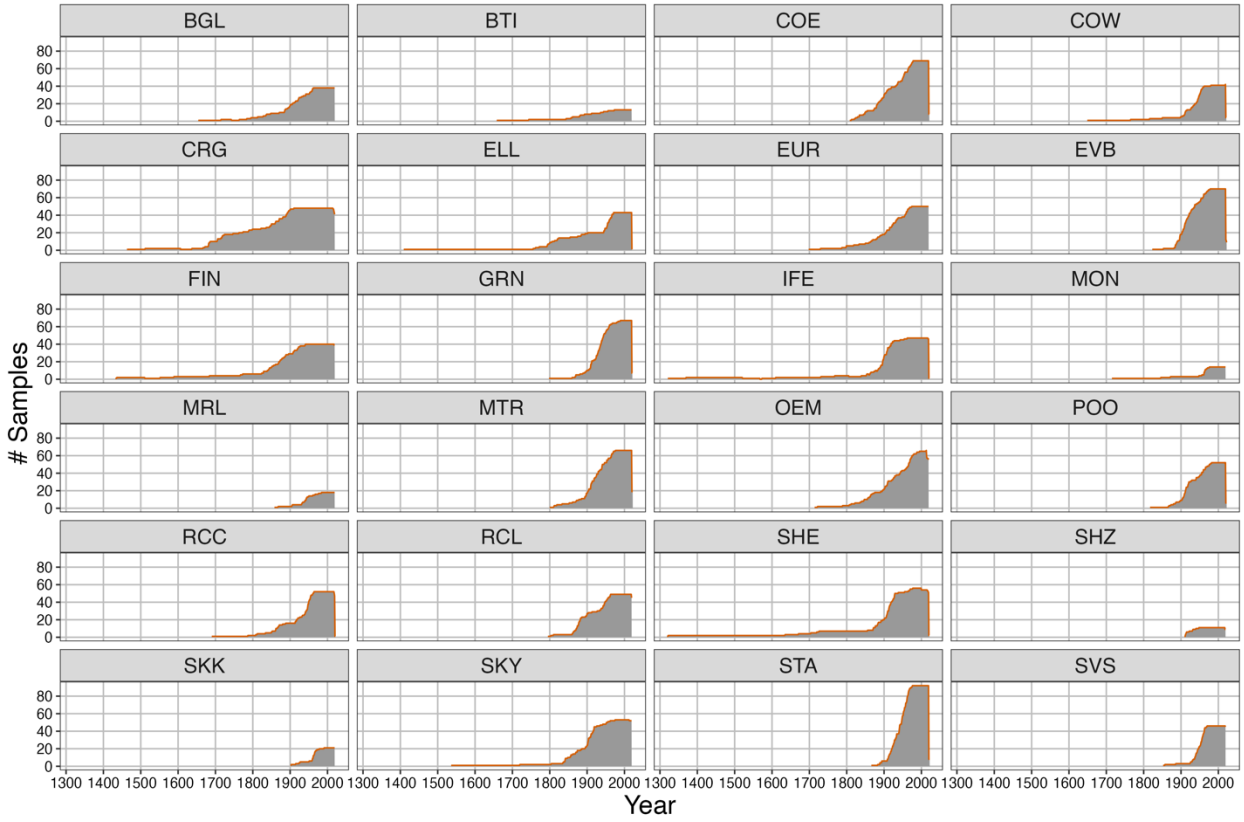


Figure S3: a) Each panel represents the reconstructed avalanche years within an individual avalanche path. All bars above the red dashed line indicate a medium and high level of confidence (> 0.02 W_{it} value) and, thus, an "avalanche year". W_{it} is a weighted index based on growth response quality (Favillier et al., 2018; Favillier et al., 2017; Peitzsch et al., 2021b). A full description of this method can be found in Section 2.4 in Peitzsch et al. (2021b). N = 76 avalanche years identified within 24 individual avalanche paths. b) shows the number of tree-ring samples (sample depth, *n*) collected in each avalanche path through time (years). Refer to Table 1 for abbreviations of avalanche path names.

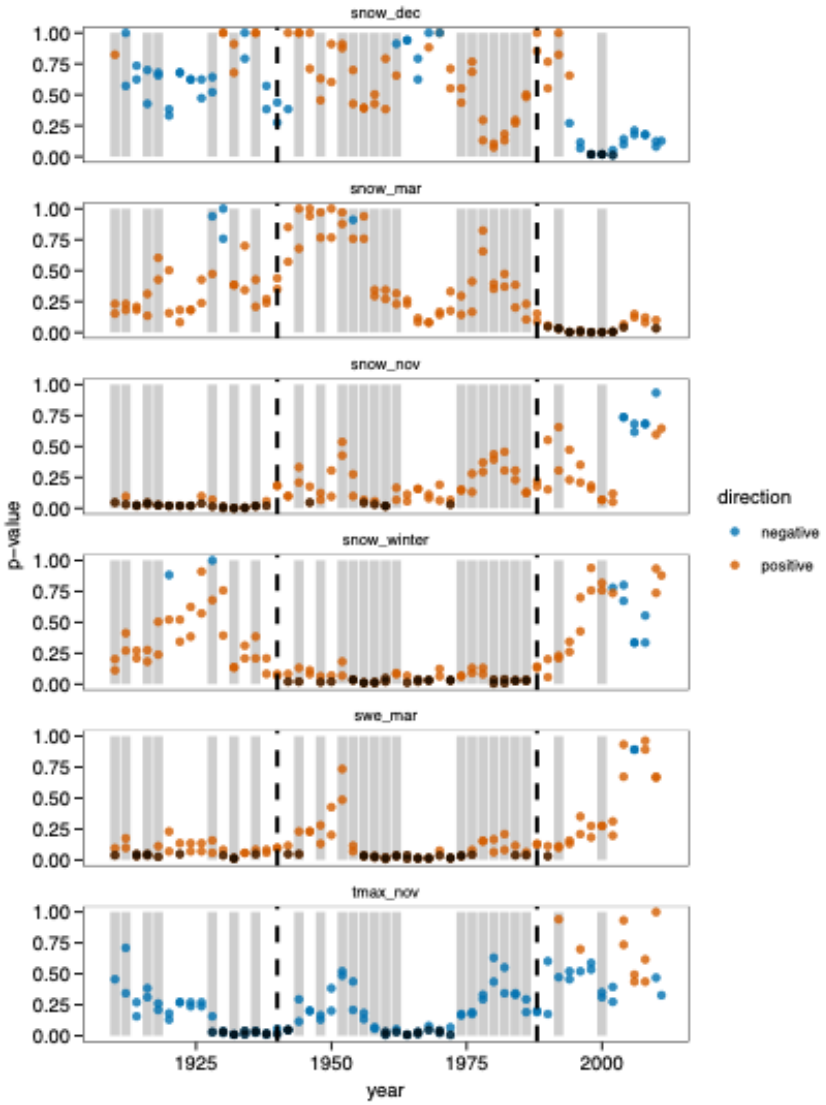


Figure S4: Moving window (20-year) analysis showing the sign and significance in relationship between avalanche years and different seasonal climate conditions (variable listed at top of each panel) from 1901-2019. Points show p-values from a Wilcoxon's Rank Sum Test with n=20 and are plotted on the center year of each window. Black points indicate p-values showing significant differences (alpha=0.05) in climate conditions between avalanche and non-avalanche years given. Vertical dashed lines denote breaks between early, mid, and late periods as previously defined while grey bars show years with RLMA activity. Note that the time series is truncated by 10 years at the beginning and end due to the points being plotted at the middle of the moving window.

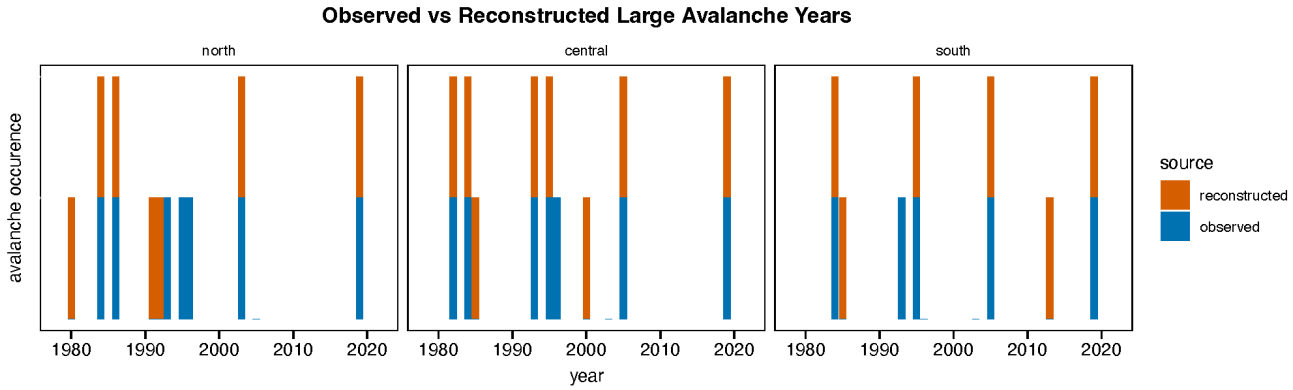


Figure S5: Comparison of avalanche years in the CIAC observed record and the tree-ring reconstructed avalanche history over 1980 to 2019. The three boxes represent avalanche paths in three sub-regions within Colorado: north, central, and south. The orange (reconstructed large magnitude avalanche year) and blue (historically observed large magnitude avalanche year) bars represent the presence of an avalanche year from each dataset (source). The presence of two bars for a given year indicates avalanche year identified in both datasets.

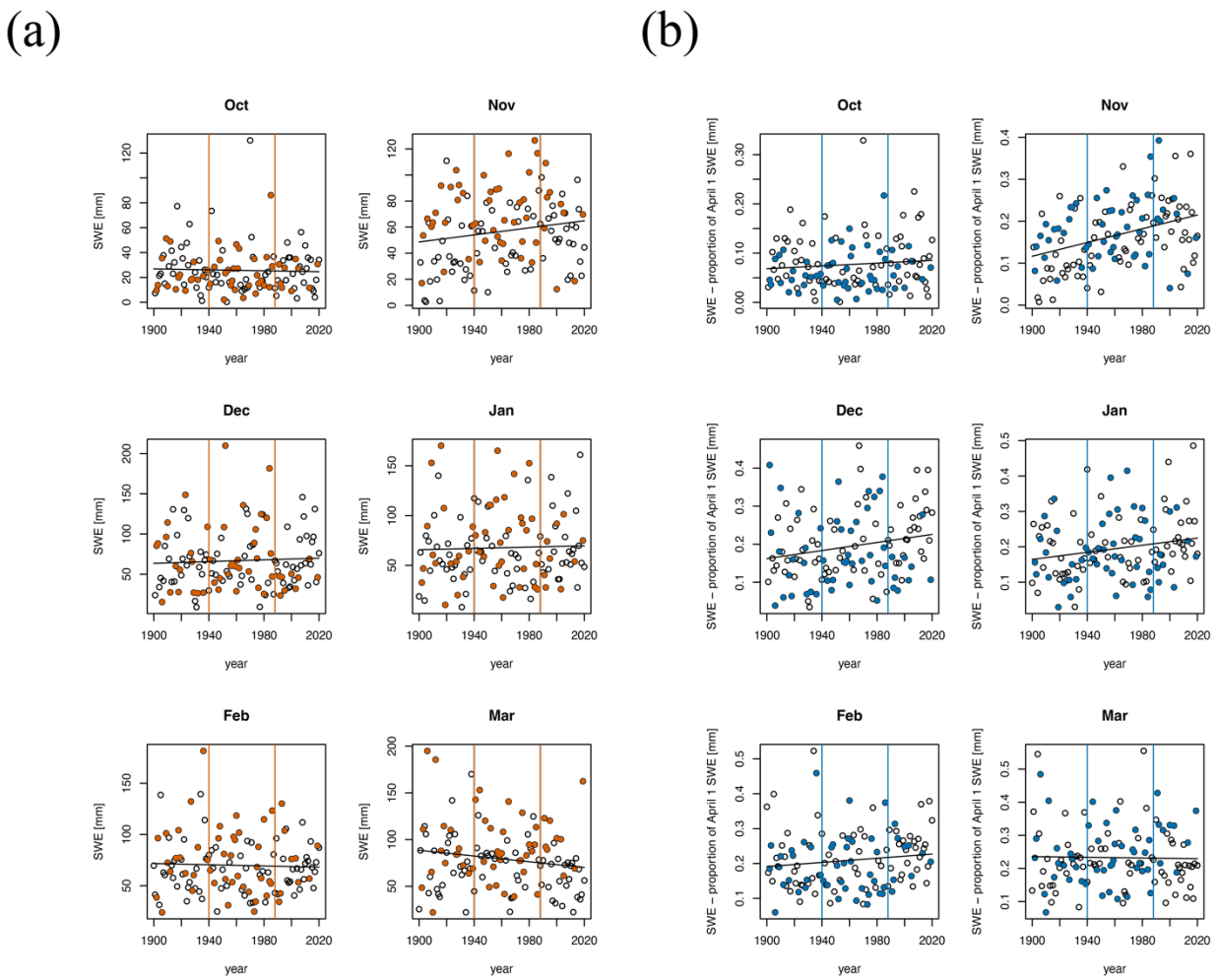


Figure S6: Changing contributions of monthly snowfall to winter totals depicted by a) average state-wide monthly SWE in mm of water over the 1901-2020 period and , b) the proportion of total state-wide April 1 SWE made up by each month of winter over the 1901-2020 period.

Tables

Table S1: Characteristics of sampled avalanche paths. Topographic variables derived from 5m digital elevation model (DEM).

County	Avalanche Path Name	Tree-ring samples (*n*)	Mean Elevation (m)	Maximum Elevation (m)	Elevation Range (m)	Mean Slope (°)	Mean Aspect (°)	Area (km^2)	Path Length (m)
Chaffee	Sheep Mountain 1 (SHE)	54	2830	3595	765	29	172	0.3	1617
Chaffee	Sheep Mountain 2 (SHZ)	11	2844	3493	649	30	142	0.2	1180
Hinsdale	Opposite Edith (OEM)	65	3396	3878	483	30	281	0.3	1006
Hinsdale	Rose Cabin Path 3 (RCC)	51	3156	4106	949	32	204	1.7	2496
Hinsdale	Rose Cabin Path 12 (RCL)	48	3253	3859	606	36	80	0.2	932
Lake	Everett B (EVB)	51	3116	4132	1016	29	193	1.2	2408
Lake	Monitor Gulch (MTR)	50	2974	3960	986	27	159	1.5	2829
Lake	Star Mountain A (STA)	68	3097	3701	603	23	87	0.5	1464
Pitkin	Fingers (FIN)	40	2648	3781	1134	32	127	1.8	2653
Pitkin	Green Mt West (GRN)	65	3083	3812	729	27	165	0.7	1600
Pitkin	Independence Mt A (Indy Far East, IFE)	50	3285	3846	561	24	134	1.1	1540
Pitkin	Maroon Lake (MRL)	20	2864	3480	615	28	260	0.3	1149
Pitkin	Sievers 1 (SVS)	42	2781	3850	1069	30	139	0.7	2358
San Juan	Crown Group (CRG)	48	2989	3977	988	36	247	0.8	1923
San Juan	Eureka 1 (EUR)	50	3015	3919	904	36	137	0.7	1574
Summit	Big Lee (BGL)	21	2830	3847	1017	38	240	0.4	1775
Summit	Big Tim (BTI)	13	2854	3889	1034	34	261	0.5	1728
Summit	Copper 2 East (COE)	64	3245	3895	650	23	179	0.3	1523
Summit	Copper 1 West (COW)	40	3214	3786	572	26	181	0.3	1255
Summit	Ellie (ELL)	42	2930	3913	982	38	238	0.6	1630
Summit	Monroe (MON)	14	2943	3744	801	40	270	0.3	1167
Summit	Poop Chute (POO)	48	2950	3862	911	29	247	0.5	2122
Summit	K Chute (SKK)	18	2976	3789	813	28	252	0.8	2096
Summit	Y Chute (SKY)	50	2990	3837	847	26	250	0.9	2331