Supplementary Material
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The effects of the NAO on the ice phenology of Spanish alpine lakes

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Fig. S1 a Climograph of Peñalara Lake. Climatic data are from the Navacerrada weather station. **b** Climograph of Redon Lake. Precipitation and temperature data are from the La Bonaigua weather station; snow depth data are from the weather station located in the lake area. Both climographs show precipitation (grey bars), temperature (black lines) and snow days or snow depth (black asterisks). See Table S1 for data time periods

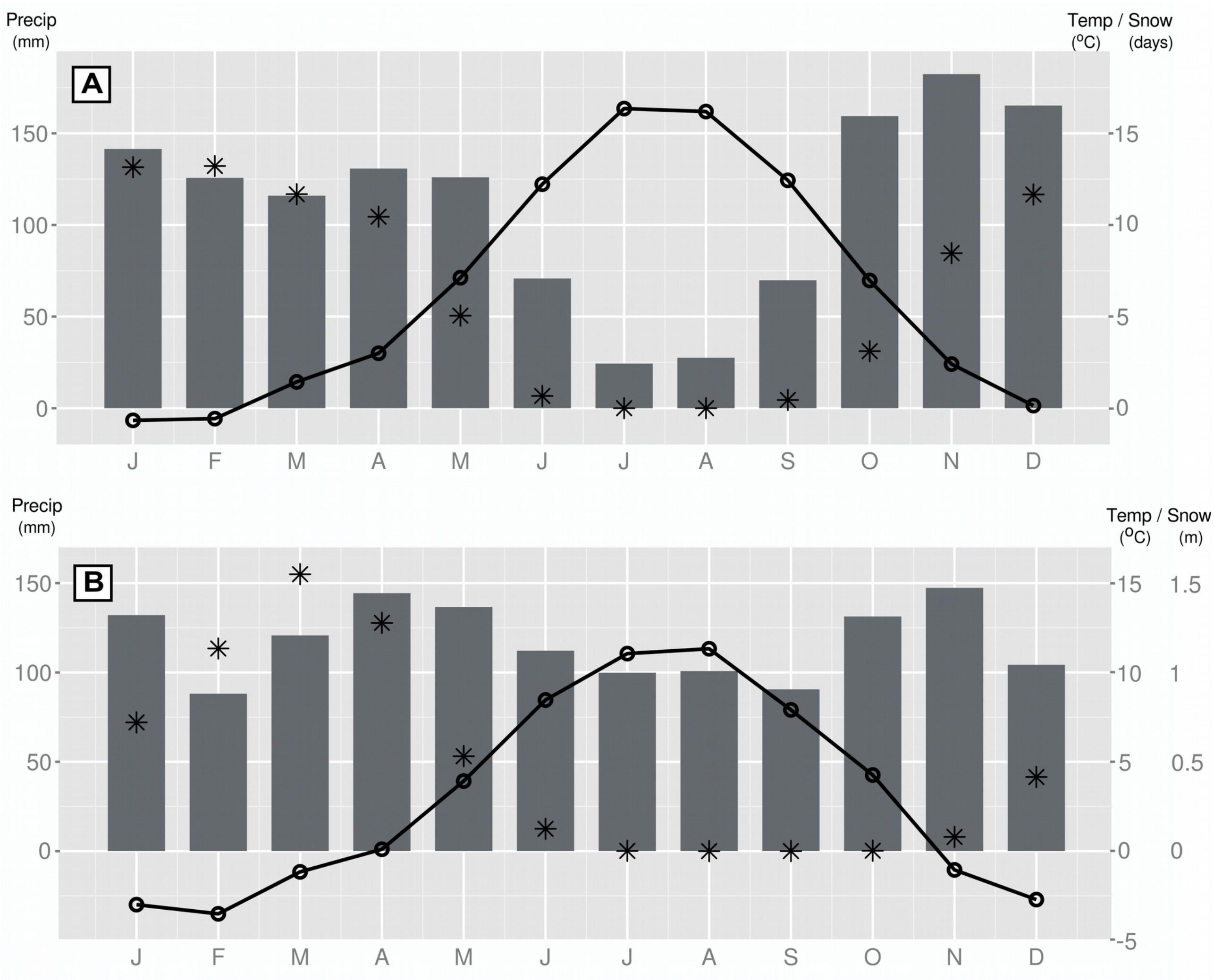


Table S1 Data time periods for Peñalara Lake, Cimera Lake and Redon Lake

Lake	Dataset	Studied Period
Peñalara	Limnological data (*lake water surface temp.*) Limnological data (*ice-phenology*) Meteorological data and NAO index	1998-2013 1993-2013 1950-2011
Cimera	Limnological data (*lake water surface temp. and ice phenology*) Meteorological data *(snow depth)* Meteorological data (*Precip. and Temps*.) and NAO index	2006-2013 2010-2013 1950-2013
Redon	Limnological data (*lake water temp. and ice phenology*) Meteorological data *(snow depth)* Meteorological data (*Precip. and Temp*.) and NAO index	1997-2013 2008-2013 1950-2013

Text S1

In Peñalara Lake, between 1998 and 2005 only one Tinytalk thermistor was used at a depth of 0.5 m and from 2005 to 2013, HOBO Water Temp Pro V1 & V2 thermistor chains (0.5, 1, 2, 3 and 4 m) were used for measuring water temperatures every ten minutes. Linear regression models were employed to inter-calibrate the different devices and to obtain a daily homogeneous dataset. In Cimera Lake, water temperatures were measured every hour with HOBO Water Temp Pro V1 & V2 thermistors at depths of 0.5, 3, 6, and 9 m for the period 2006-2013. Daily temperature data were obtained from these measurements. Finally, Redon Lake water temperatures were measured with VEMCO minilog thermistors at depths of 2, 44, and 60 m every hour for the period 1997-2013; daily temperature data were obtained from the measurements collected at different depths. In the three lakes, the thermistor chains were located at the maximum lake depth.

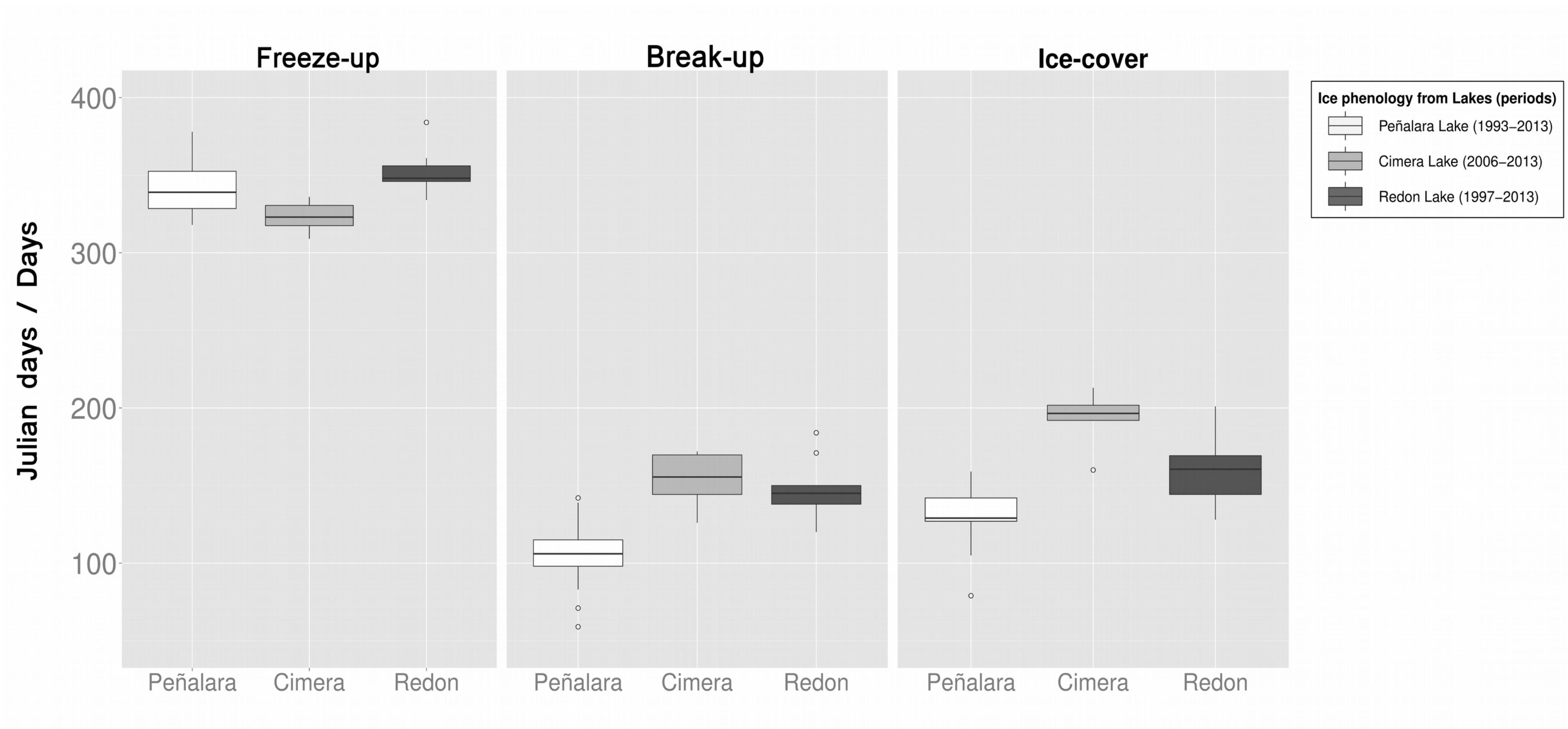
In Peñalara Lake, the ice data were obtained from daily visual observations of the lake. In the case of Cimera and Redon Lakes, ice phenology was deduced from lake water temperatures measured using the thermistors at different water depths. In these two lakes, freeze-up corresponds to the date when the lake water temperature changes from an autumn overturning pattern to winter stratification, whereas the break-up is the date when the lake water temperature changes from winter stratification to a spring overturning pattern.

The previous method used to derive the two ice phenology metrics (i.e., Cimera Lake and Redon Lake) was verified using data collected from Peñalara Lake. In Table A, differences between ice phenology dates (i.e., freeze-up and break-up dates) based on daily visual observations and water temperatures measured using the thermistors at different water depths are shown. These differences show that both dates (i.e., freeze-up and break-up) typically occur earlier based on the water temperature data compared with the daily visual observations. However, these differences are less than five days for both dates. Therefore, the differences in the dates (i.e., freeze-up and break-up) between the daily observations and the water temperatures measured using thermistors can be considered negligible.

Daily visual observation		From lake water temperatures		Differences between dates (days)	
Freeze-up date	**Break-up date**	**Freeze-up date**	**Break-up date**	**Freeze-up date**	**Break-up date**
14/11/2005	17/04/2006	-	19/04/2006	-	2
10/12/2006	19/01/2007	-	-	-	-
23/01/2007	22/04/2007	23/01/2007	20/04/2007	0	-2
14/12/2007	15/03/2008	10/12/2007	15/03/2008	-4	0
23/03/2008	08/04/2008	23/03/2008	07/04/2008	0	-1
25/11/2008	25/04/2009	-	22/04/2009	-	-3
19/12/2009	26/04/2010	-	25/04/2010	-	-1
23/11/2010	14/04/2011	-	-	-	-
18/12/2011	29/03/2012	18/12/2011	25/03/2012	0	-4
14/04/2012	10/05/2012	14/04/2012	08/05/2012	0	-2
28/11/2012	25/12/2012	27/11/2012	25/12/2012	-1	0
13/01/2013	23/05/2013	13/01/2013	23/05/2013	0	0

Table A. Ice phenology dates from Peñalara Lake

Fig. S2 Boxplots of ice phenology for Peñalara Lake (white color), Cimera Lake (light grey color) and Redon Lake (dark grey color). Freeze-up and break-up are in Julian days; ice-cover duration is in number of days. Data periods are included in the legend (see Table S2 for additional information)



Text S2

Peñalara Lake exhibits two differentiated ice-covered periods in some winters (see Table A). In order to determine the factor/s that rule these ice-free periods we have computed the daily anomalies of maximum, minimum and mean temperatures from Navacerrada meteorological station (differences with the mean values relative to the 1981-2012 period). Additionally, we have also considered the accumulated effect of these anomalies between October and May.

The daily temperature anomalies display some days with strong positive values, between 6 and 10 °C above the mean daily average data, in the three considered datasets (i.e., maximum, minimum and mean) during the days of ice-cover breaks. Moreover, this is also observed in the accumulated anomalies between October and May. Therefore, the years with two ice-covered periods might be related to winters with warm periods prolonged during two or three weeks rather than with mild winters.

Usually, the second ice-covered period occurs either at the beginning or the end of the winter. The ice-free period between the two ice-covered periods is typically less than 13% of the total ice-cover duration (see Table B below).

Year	Freeze-up date	Julian day	Break-up date	Julian day	Ice-cover duration in days	Number of covers	Total days	% Ice free days between covers
1993	08/12/1992	343	01/04/1993	90	114	1	114	-
1994	27/12/1993	361	-	-	-	-	-	-
1995	-	-	-	-	-	-	-	-
1996	05/12/1995	339	25/04/1996	115	142	1	142	-
1997	24/12/1996	359	13/03/1997	71	79	1	79	-
1998	01/01/1998	1	08/03/1998	66	66	2	96	*34.4*
1998	10/04/1998	100	10/05/1998	129	30			
1999	30/11/1998	334	12/12/1998	345	12	2	130	3.1
1999	16/12/1998	350	13/04/1999	102	118			
2000	16/11/1999	320	29/02/2000	59	105	1	105	-
2001	19/12/2000	354	-	-	-	1		-
2002	16/11/2001	320	25/03/2002	83	129	1	129	-
2003	23/11/2002	327	25/12/2002	358	32	2	139	7.9
2003	05/01/2003	5	22/04/2003	111	107			
2004	03/12/2003	337	27/04/2004	117	146	2	159	5.7
2004	06/05/2004	127	19/05/2004	139	13			
2005	04/12/2004	339	10/04/2005	99	127	1	127	-
2006	14/11/2005	318	17/04/2006	106	154	1	154	-
2007	10/12/2006	344	19/01/2007	18	40	2	129	3.1
2007	23/01/2007	23	22/04/2007	111	89			

2008	14/12/2007	348	15/03/2008	74	92	2	108	7.4
2008	23/03/2008	83	08/04/2008	98	16			
2009	25/11/2008	330	25/04/2009	114	151	1	151	-
2010	19/12/2009	353	26/04/2010	115	128	1	128	-
2011	23/11/2010	327	14/04/2011	103	142	1	142	-
2012	18/12/2011	352	29/03/2012	88	102	2	128	
2012	14/04/2012	105	10/05/2012	130	26			12.5
2013	13/01/2013	13	23/05/2013	142	130	1	130	-

Table B. Ice phenology records for Peñalara Lake. The year 1998 is anomalous because the ice-free period between the two ice-cover periods is relative long (account for 34.4% of the total period). Therefore, these data are considered outliers and are not included in the analyses

Furthermore, we performed a sensitivity assessment (relative to the number of ice cover periods) of ice phenology parameters and NAO. Only the ice thickness displays clear differences between one and two ice-covers (see Figure A below), which are much thinner if there are two instead of only one ice-cover. Nevertheless, the ice thickness does not show any significant relationship with freeze-up, break-up or ice-cover duration (see Table C). Finally, only the winter (JFM) NAO exhibits significant relationships with break-up, ice-cover and ice thickness but not with the number of covers (see Table C). Therefore, the winter NAO influences the thawing and ice growing processes, although our results suggest that both processes are independent.

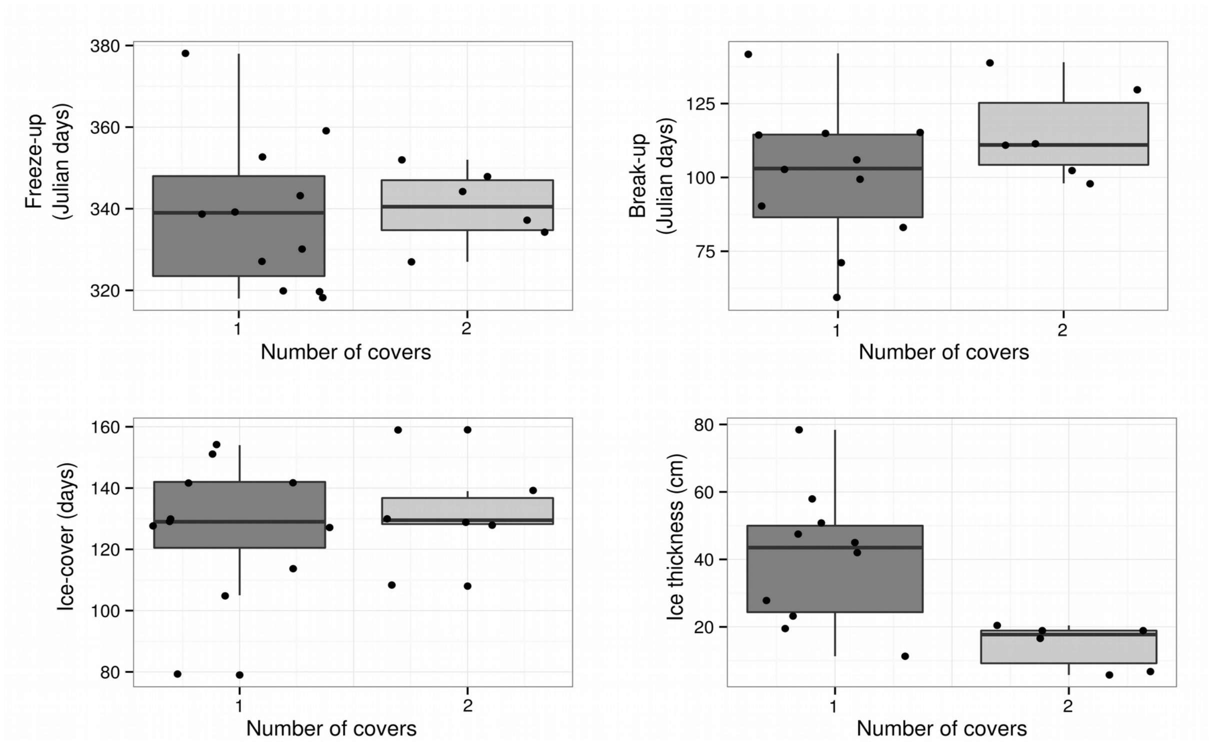


Figure A. Box plots of ice phenology from Peñalara Lake

	Freeze-up	Break-up	Ice-cover duration	Ice thickness	Number of covers	NAO JFM	NAO MAM
Freeze-up	1						
Break-up	0.41	1					
Ice-cover duration	-0.37	0.67**	1				
Ice thickness	0.28	0.39	0.35	1			
Number of covers	0.05	0.35	0.12	-0.63**	1		
NAO JFM	-0.09	-0.52*	-0.53*	-0.77**	0.36	1	
NAO MAM	-0.19	0.04	0.35	-0.09	0.10	0.29	1

Table C. Pearson's correlation coefficients between ice phenology from Peñalara Lake and NAO winter (JFM) and spring (MAM) index. ** denotes that the correlation is significant at 0.01 level and * at the 0.05 level, with $n \geq 16$, for the period 1993-2013

Fig. S3 Bar graphs of the winter (JFM) NAO index (i.e., positive phase in red bars, and negative phase in blue bars). The lines correspond to winter (JFM) anomalies in the maximum (black line, top) and minimum (thin line, top) temperatures and precipitation (black dashed line, bottom) from **a** the Navacerrada weather station, **b** regional data and **c** the La Bonaigua weather station

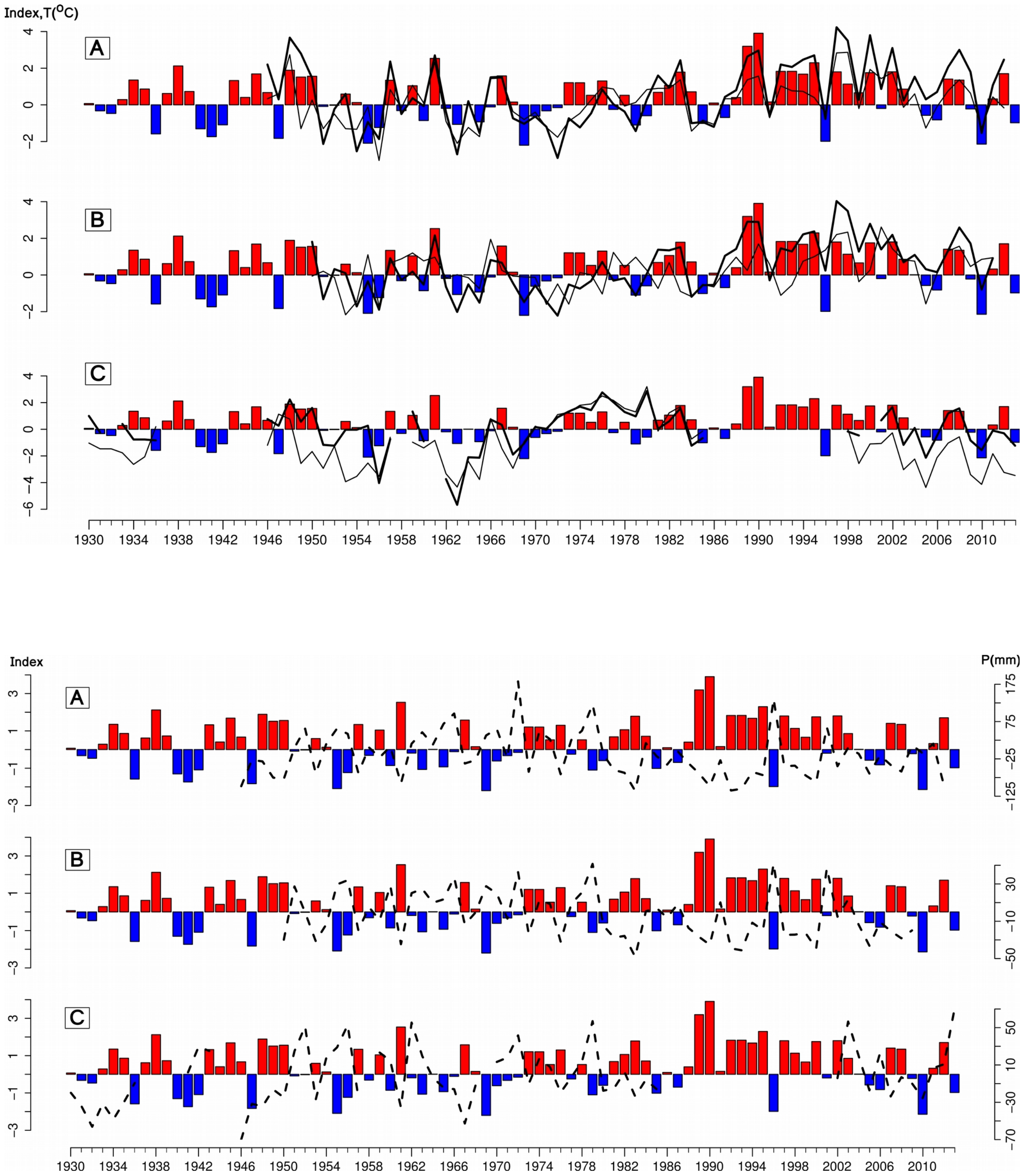


Fig. S4 Bar graphs of the spring (MAM) NAO index (i.e., positive phase in red bars and negative phase in blue bars). The lines correspond to spring (MAM) anomalies in the maximum (black line, top) and minimum (thin line, top) temperatures and precipitation (black dashed line, bottom) from **a** the Navacerrada weather station, **b** regional data and **c** the La Bonaigua weather station