THE EFFECT OF SLOPE ASPECT ON THE RESPONSE OF SNOWPACK TO CLIMATE WARMING IN THE PYRENEES

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Abstract. The aim of this study was to analyze the effect of slope aspect on the response of snowpack to climate warming in the Pyrenees. For this purpose, data available from five automatic weather stations were used to simulate the energy and mass balance of snowpack, assuming different magnitudes of climate warming (increases of 1, 2 and 3°C). Snow energy and mass balance was simulated using the Cold Regions Hydrological Modelling platform (CRHM). CRHM was used to create a model that enabled correction of the all-wave incoming radiation fluxes from the observation sites for various slope aspects (N, NE, E, SE, S, SW,W,NW and flat areas), which enabled assessment of the differential impact of climate warming on snow processes on mountain slopes. The results showed that slope aspect was responsible for substantial variability in snow accumulation and the duration of the snowpack. Simulated variability markedly increased with warmer temperature conditions. Annual maximum snow accumulation (MSA) and annual snowpack duration (ASD) showed marked sensitivity to a warming of 1 degree Celsius (C). Thus, the sensitivity of the MSA in flat areas ranged from 11 to 17% per degree C amongst the weather stations, and the ASD ranged from 11 to 20 days per degree C. There was a clear increase in the sensitivity of the snowpack to climate warming on those slopes that received intense solar radiation (S, SE and SW slopes) compared with those slopes where the incident radiation was more limited (N, NE and NW slopes). The sensitivity of the MSA and the ASD increased as the temperature increased, particularly on the most irradiated slopes. Large interannual variability was also observed. Thus, with more snow accumulation and longer duration the sensitivity of the snowpack to temperature decreased, especially on south-facing slopes.

Keywords: snow, climate change, slope aspect, Cold Regions Hydrological Model (CRHM), Pyrenees

1 Introduction

A significant increase in air temperature has been detected in the majority of the world’s mountain regions in recent decades (Pepin and Seidel, 2005; Díaz and Eeischeid,2007; Pepin and Lundquist, 2008; Ohmura, 2012). The warming has been generally accompanied by a shift toward earlier snowmelt and declining snow accumulation (Mote, 2003; Barnett et al., 2005). This change in snowpack thermodynamics is a consequence of the great sensitivity of snow to air temperature increase, which causes a decreasing proportion of snowfall relative to rainfall, and an increase in available energy for snow melting (Rood et al., 2008). Thus, a change of +1°C was reported to cause a 20% reduction in accumulated snow water equivalent, and a noticeable shortening of the snow season in a small basin in the Pyrenees (López-Moreno et al., 2013). For the Washington Cascades area, a similar rate of reduction (20% per 1°C warming) was reported by Casola et al. (2009), and Minder (2010) reported a decrease of 14.8–18.1% per 1°C, depending on the vertical structure of the warming. For the Swiss Alps, Beniston et al. (2003) reported a decrease of 15% in snow accumulation per 1°C of temperature warming. Howat and Tulacyck (2005) predicted a 6–10% decrease in spring snow water equivalent per 1°C in Sierra Nevada. In each of the studies noted above it was emphasized that the values reported were highly dependent on altitude and changes in precipitation.

Despite widely recognized uncertainties and large regional variability, climate models project that the temperature will continue to increase in coming decades (Ganguly et al., 2009). Mountain areas are expected to be particularly affected by high rates of warming (Nogués-Bravo et al., 2007), with consequent impacts on the accumulation and duration of mountain snowpacks (Adam et al., 2009; Hamlett, 2001; García-Ruiz et al., 2011). Much research effort has been directed at assessing what environmental and socioeconomic effects a thinner snowpack of shorter duration might have, including on water resources availability (Barnett et al., 2005; Adam et al., 2009), the ecology of affected areas (Tague and Dugger, 2010; Trujillo et al., 2012), the viability of ski resorts (Uhlmann et al., 2009; Pons et al., 2012) and hydropower production (Finger et al., 2011).

Most of the studies relating the sensitivity of snow to warmer climate, and its associated environmental and socioeconomic impacts, highlight the necessity to consider the regional and local characteristics of particular mountain areas. Thus, shifts in precipitation patterns may balance or accelerate the magnitude of changes in snowpack characteristics caused by warmer temperatures (López-Moreno et al., 2013). Altitude is also a key variable to be considered, as the sensitivity of snow to rising air temperature decreases markedly from areas close to the snow line to areas at higher altitudes (López-Moreno et al., 2009; Jefferson, 2011; Wi et al., 2012). Because of the complex topography of mountain areas, slope angle and aspect are also very likely to influence the sensitivity of snowpack to temperature change (Uhlmann et al., 2009). Snowmelt energetics is largely dominated by solar irradiance (Marsh et al., 2012). Slope angle and aspect are large contributors to the spatial variability of the surface energy balance, and modulate the partition in their components: radiative, sensible and latent heat fluxes

(Carey and Woo, 1998; Pomeroy et al., 2003; Hopkinson et al., 2011). Thus, snowpack thermodynamics is strongly influenced by slope aspect (Hincley, 2012), which affects snow accumulation and melting, especially in areas having a marginal snowpack (McNamara et al., 2005). Consequently, it can be hypothesized that the sensitivity of the snowpack to climate warming will change over very short distances, depending on the aspect.

In this study, data from five meteorological stations located at high altitudes in the Pyrenees (>2000 m a.s.l.) were used to simulate the snow energy balance of the snowpack under temperatures 1, 2 and 3°C above observed conditions. Incoming solar radiation was altered to simulate the snowpack thermodynamics under various slope aspects. This enabled assessment of how the snowpack and its sensitivity to air temperature change will respond to self-terrain shadows resulting from slope aspect. Particular focus was placed on assessing whether the effect of aspect is constant, or varies depending on the dominant climatic conditions during each snow season. The results of this study provide new insights for evaluating the response of snowpack to climate change, and could improve assessment of its environmental and socioeconomic impacts.

2 Data and methods

The snow energy balance was simulated using the data available from five meteorological stations located across the southern Pyrenees (see Fig. 1). The stations range from 2056 to 2415 m a.s.l. (Table 1), lie in an eastward transition zone from Atlantic to Mediterranean climatic conditions, and represent the majority of the available meteorological records for high altitude parts of the southern Pyrenees. The instrumentation at the stations is meticulously maintained, and it records reliable data on air temperature (T_{air}), precipitation (P), relative humidity (R_h), wind speed (W_s), incoming solar radiation ($K\downarrow$) and snow depth at a minimum temporal interval of 1 h. The available data spans the 1996–2010 snow years (October–September) for the Izas station, 2001–2009 for the Bonaigua station, 2004–2010 for the Sasseuba station, and 2009–2012 for the Perafita and Bony Neres stations. Although the data from the various stations covered different periods, each recorded contrasting interannual meteorological and snow conditions, which enabled comprehensive analysis of the sensitivity of the snowpack to increasing air temperature conditions.

The meteorological data was used as the input to the Cold Regions Hydrological Model platform (CRHM; Pomeroy et al., 2007), which uses a modular modeling object-oriented structure (Leavesley et al., 2002) to simulate a range of hydrological processes in mountainous and cold regions (including blowing snow, interception, energy balance snowmelt, and infiltration of rain or melting water to frozen soils). A more comprehensive description of the model and a scheme illustrating the model structure can be found in Pomeroy et al. (2012). Because there is a high level of confidence in the representation of cold regions processes in the modules, and good flexibility in the model structure, there is less need for calibration of parameters to streamflow observations for discharge simulations (Pomeroy et al., 2012). Calibration can often be limited to streamflow routing and baseflow aspects of the model, or omitted completely; thus, the model can be used for both prediction, diagnosis and understanding of the hydrological processes. The CRHM has been applied to a wide variety of environments including alpine and subalpine areas, forests and arctic basins (Pomeroy et al., 2007;

Dornes et al., 2008; Essery et al., 2009; DeBeer and Pomeroy, 2010; Ellis et al., 2010; Fang et al., 2010; Knox et al., 2012), and was also successfully applied in the Izas basin in the Pyrenees (López-Moreno et al., 2013), which was included in the present study.

Selection of the CRHM modules was mainly based on data availability and the adequacy with the climatic characteristics of the Pyrenees. Evapotranspiration was calculated using the Penman-based equation of Granger and Pomeroy (1997). The energy balance snowmelt model (EBSM) developed by Gray and Landine (1988) was used for simulating snowmelt.. Air temperature thresholds of +3°C and 0°C were used to define precipitation falling as rain and snow, respectively. Snow albedo decays from a value of 0.85 for fresh snow to 0.55 due to ageing (Gray and Landine, 1988). To isolate the effect of slope aspect in the response of snowpack to changing temperature, which could be masked by wind redistribution, the transport and sublimation of blowing snow were not included in the study.

The routines for slope correction for all-wave irradiance to the slope implemented in CRHM (Ellis et al., 2011) were based on Garnier and Ohmura (1970) formulations. With no change in the amount of the overlying sky view obscured by surrounding topography, adjustment of level Ro for slope effects is made by the following correction of direct-beam shortwave irradiance (Kb)

$R_o(S)= \omega K_b + K_d + L_o$ (equation1)

where $R_o(S)$ is the all-wave irradiance to the slope, K_d and L_o are the respective non-directional fluxes of diffuse shortwave and longwave irradiance; the geometric slope correction factor ω (dimensionless) scales direct-beam shortwave irradiance from a horizontal surface to a sloped surface by the following ratio:

$\omega = \cos(Z_s) / \cos(Z)$ (Equation2)

where Z and ZS are the angles between the direct-beam sky position to the zenith of a horizontal and sloped site, respectively (radians).

Incoming solar radiation at each location was measured in open flat areas only affected by horizon shading caused by the surrounding landscape. Radiation data were modified for each location based on self-shading by a slope of 300 m length and 30° inclination, variously oriented with N, NE, E, SE, S, SW, W or NW slope aspect. Figure 2 shows that the sum of the incoming direct and diffuse solar radiation was considerably changed in the CRHM, according to the slope aspect considered.

The snowpack was simulated at each location for flat terrain and each of the eight slope aspects for the observed meteorological conditions, and also under scenarios of temperature increase from +1°C to +3°C. The annual maximum snow accumulation (MSA) and annual snowpack duration (ASD; the number of days with a snowpack thicker than 5 cm on the ground surface) were used as benchmarks to characterize the snow seasons at each location and under the various slope aspects. In addition monthly percentage of annual melt was used to characterize shifts in the timing of melting which are very likely to explain changes in MSA and ASD.

3 Results

Figure 3 shows the ability of the CRHM to reproduce the maximum annual snow depth (MSD) and annual snowpack duration (ASD) observed at the five meteorological stations. The box plots show the average and the interannual variability for the observed and simulated MSD and ASD. The CRHM reproduced the main patterns for the annual accumulation and snowpack duration. For some stations there were positive or negative biases in snow accumulation (always <40 cm); these can largely be explained by snow transport by wind, which was not accounted for in this study (see section 2). The mean absolute error in the simulated ASD ranged from 11.4 days for the Bonaigua station to 16.8 days for the Perafita station. The range between the 25th and 75th percentiles for the simulated MSA and ASD was very similar to the observed values, except for the Bonaigua station, where the simulated values were underestimates.

Figure 4 shows the differences for each meteorological station between the long-term mean maximum annual snow accumulation and duration of the snow pack for each slope aspect and the corresponding flat area. Despite some differences in magnitude, for the five locations there were marked differences in the maximum snow accumulation, especially between north-facing and south-facing slope aspects. For the observed climatic conditions, the difference between the annual maximum snow accumulation on N(S) aspects and the accumulation on flat areas was > (<) 10%. For the other slope aspects the values were intermediate between those for the N and S aspects. The W and E aspect slopes had slightly greater snow accumulation than the flat areas for all analyzed stations. In some cases (e.g. the Izas station) there was a large difference between the N aspect (approximately +10%) and S aspect slopes (approximately –20%).

With increased temperature the differences in snow accumulation amongst the slope aspects at the five locations became much more evident. It is noteworthy that the magnitudes of change in accumulation with increasing temperature were non linear, as were the responses of the various slope aspects to climate warming. Thus, in many cases there was an abrupt increase in the difference between the slope aspects and the flat areas at a certain temperature change. In most cases this occured when the temperature increased by 2°C. In general, the differences in snow accumulation between the flat areas and the north-facing slopes (N, NW and NE) were greater than between the flat areas and the south-facing slopes (S, SW and SE). Thus, for all five analyzed locations under a scenario of +3°C warming, relative to flat areas, the percentage increase in accumulation for north-facing slopes clearly exceeded the percentage decrease for south-facing slopes.

Figure 4 also shows that the differences in the long-term mean annual snowpack duration between each slope aspect and the corresponding flat area are, as overall, similar to those for annual maximum accumulation. The main difference was that in general the response of ASD to increasing temperature was more linear, and lacked the abrupt changes that were observed for annual maximum accumulation. Meanwhile, the increasing difference between N and S aspect slopes as the temperature increased was much less evident than was observed for annual maximum snow accumulation.

Figure 5 shows the sensitivity of the long-term average annual maximum accumulation and the duration of the snowpack to an increase of 1°C for the flat areas, and the north- and south-facing slopes. In the flat areas the maximum annual snow accumulation decreased by 11–17% (depending on the station involved) when the temperature in the observed series is increased by 1°C. This effect was greater for south-facing slopes (which varied between 15 and 22%) than for northing slopes (8–15%). For the majority of locations the difference between north- and south-facing slopes was approximately 5%. The sensitivity of the duration of snowpack to a warming of 1°C showed a similar pattern to that observed for annual maximum accumulation. This increase in temperature caused an average decrease in snow duration of 11–20 days per year. The decrease for south-facing slopes ranged from 14 to 24 days, whilst for north-facing slopes the range was 9–16 days. For the Izas and Bony Neres stations the difference in sensitivity between north- and south-facing slopes was greater than10 days, and for the other locations was approximately 5 days.

Figure 6 shows the long-term average sensitivity per 1°C of the maximum annual snow accumulation and the mean annual duration of snowpack for each slope aspect under different magnitudes of warming (1, 2 and 3°C). The figure indicates a slightly greater sensitivity of the W and E aspect slopes relative to flat areas, but markedly less than that of the S, SW and SE aspect slopes. For most sites and slope aspects, as the temperature increased the sensitivity of the annual maximum accumulation also increased. For the Izas, Perafita and Bony Neres stations the rate of increase in sensitivity was relatively continuous. However, for the Bonaigua and Sasseuba stations the change in temperature is much sharper when an increase of 2°C occurred, than for the other intervals of temperature increase. The increase in sensitivity with higher temperatures was greater for south-facing slopes than those with a northerly slope aspect, except for the Izas station, where slopes of all slope aspect responded in a similar fashion.

The sensitivity of the snowpack duration to increasing temperature was very similar to that observed for the annual maximum snowpack duration. For all stations the sensitivity of this parameter increases as the magnitude of the warming does. The Izas station again exhibited a somewhat continuous rate of change in sensitivity, while for the other stations the increase in sensitivity changed noticeably with the warming rate and the slope aspect. As occurred for maximum accumulation, the increase in sensitivity with increasing temperature was greater for south-facing than north-facing slopes.

Figure 7 shows the evolution of melting (monthly percentage of the annual melting) in north and south slope aspects during the period from March to June in two selected stations (Izas and Bonaigua). The figure shows that evolution of melting in the two selected stations behaves similarly, and that the differences in melt caused by slope aspect may largely explain the observed effect of aspect on the response of snowpack to climate warming. Thus, under observed climatic conditions (T 0ºC) a noticeable portion of the total melting in south facing slopes occurs in March and April. In this period the phase of precipitation at high elevation is generally solid, and snow accumulation dominates to melting. In north facing slopes, melting is mainly concentrated in June, with a very low percentage in March and April. It explains that aspects receiving less radiation flux (Ro(S) in equation 1) accumulate more snow and it lasts for longer in spring time. As temperature is warmer (T+1ºC; T+2ºC), melting in north facing slopes is still concentrated in May and June, whereas in south facing slopes the most of the melting occurs in March and April. Thus differences between in accumulation and duration of snowpack are even more accentuated. Under a warming of 3ºC, snow in the south faces has almost disappeared in May, and March is the month with higher melting. Most of the melting in north faces is observed in April and May, followed by March and June. Thus differences in snow accumulation and duration between high and low irradiated slope aspects continue increasing.

Figure 8 shows the interannual variability of the sensitivity of annual maximum snow accumulation to a temperature increase of 1°C, and its correlation with the maximum annual accumulation for the three stations having records covering longer periods. For these stations there was great variability in the sensitivity among different years. The variability was greater for south-facing slopes (coefficient of variation, standard deviation divided by the arithmetic mean, greater than 0.55) than for north-facing slopes, where the coefficient of variation ranged from 0.35 for the Izas station to 0.51 for the Sasseuba station. A positive correlation was found for all stations and slope aspects between the sensitivity and the annual maximum accumulation. Thus, those years that accumulated a deeper snowpack were largely unaffected by a 1°C increase in temperature. However, the annual maximum accumulation was severely affected (a decrease greater than 40%) by an increase of 1°C during the poorest snow years, especially on south-facing slopes. Figure 9 shows the correlation between the maximum annual snow accumulation and its sensitivity to an increase of 1°C for north-and south-facing slopes. A high degree of interannual variability and a positive correlation with snow duration were also observed. Thus, those years with a shorter period of snow cover exhibited much greater sensitivity to climate warming.

4 Discussion and conclusions

Although slope aspect is known to play a major role in snow distribution (Elder et al., 2000; Anderton et al., 2004; Marofi et al., 2011), this study represents the first detailed analysis of the effect of slope aspect on the response of snowpack to climate warming. At all five stations in the study slope aspect exerted control over the accumulation, timing of melting and duration of snowpack. As temperature increased the effect of slope aspect on accumulation and melting increased, and resulted in greater differences in the maximum snow accumulation and snowpack duration. This result is consistent with the results of McNamara et al. (2005), who reported that in conditions less favorable for snow development, incoming solar radiation had an increasing effect on snowpack dynamics.

This study also highlights that snowpack thickness and the length of the snow season is highly sensitive to increased temperature, but the magnitude of this effect varied among the analyzed locations. These differences as well as the different effect of slope aspect on snow sensitivity among studied locations is likely caused by the specific meteorological conditions during the snow seasons, elevation and horizon shading at each meteorological station, which lead to differences in the partitioning of the components of the mass and energy balance of the snowpack (Pomeroy et al., 2003; Hopkinson et al., 2011). The sensitivity of snow accumulation to an increase of 1°C in flat areas ranged from 10 to 17%, which is consistent with reports for other areas (Beniston et al., 2003; Casola et al., 2009; Minder, 2010). However, this sensitivity is expected to increase as warming becomes more intense, which suggests a non-linear response of snow thermodynamics to temperature change. In some cases the response of the snowpack was particularly abrupt when a particular threshold of warming (commonly 2°C) occurred. Such abrupt response of snowpack to climate warming is probably due to the temperate climatic conditions of the Pyrenees. Thus, when snowpack is near to isothermal conditions, or snowfall generally occurs at temperatures close to the snow-rainfall threshold, a small change in temperature may trigger large changes in the onset of the melting time or deep shifts in the precipitation phase. The snowpack on south-facing slopes appears to be particularly vulnerable to climate warming; the slopes most exposed to solar radiation accumulate less snow and undergo earlier melting (López-Moreno et al., in press), which causea much greater sensitivity of maximum annual snow accumulation and annual snow duration to air temperature increase. Moreover, we showed that snow accumulation and duration on the most irradiated slopes will be subject to greater interannual variability. Keller et al. (2005) simulated the snow cover response to climate warming at fine-scale resolution in a small area of the Swiss Alps, and found that the greatest decrease in snow cover duration occurred in the lower altitude parts of their study area and on south-facing slopes. This is consistent with our finding of a major influence of direct solar energy on snow sensitivity, which increased with increasing temperature. Thus, the snow profile gets warmer earlier in the season, especially in thinner snowpacks, and solar radiation is more efficient for melting, which increases the role of the slope aspect in the snow energy balance. This also explains why studies that have related altitude and snow sensitivity to climate change have found an attenuated response of the snowpack to temperature at higher altitudes (Howat and Tulaczyk, 2005; Keller et al., 2005; López-Moreno et al., 2009; Özdogan, 2011).

The magnitude of change in snow thermodynamics as a function of slope aspect found in this study was determined by the selection of slope characteristics (300 m length and 30° slope) used in the snowpack simulations, and also the specific characteristics of the stations (including altitude, horizon shading and meteorological conditions). Moreover, wind-blowing snow and its accumulation could markedly affect these specific numbers (Green and Pickering, 2009), as was shown in the Izas catchment, where the slopes that receive higher radiation often accumulate snow drifted from areas in shadow (López-Moreno et al., in press). Nonetheless, the results highlight the necessity of conducting studies that account for local topography in assessing the impact of climate variability and change on particular environmental processes and socioeconomic activities. Thus, as stated by Uhlmann et al. (2009) and Pons et al. (2012), a comprehensive assessment of the impact of climate change on winter tourism needs to consider the specific locations and characteristics of the ski resorts, as snowpack may respond differently in adjacent areas. Location is also important in assessment of the effect of climate warming on mountain vegetation, which is very dependent on slope aspect, and snowpack thickness and duration (Keller et al., 2005). For instance, in the Pyrenees, north- and south-facing slopes commonly represent abrupt limits between Atlantic and

Mediterranean ecosystems. The results of the present study suggest that the differences between these environments may be enhanced, with south-facing slopes being particularly affected by earlier snowmelt, and frequent cycles of freezing and thawing of soils as a consequence of thinner snowpack (Cherkauer and Lettenmaier, 2003). Increases in soil freezing events could significant effects on root and microbiological mortality, the cycling and loss of nutrients, and the chemistry of drainage water (Groffman et al., 2001).

In the majority of the mountain regions of the world a marked increase in temperature is expected as a consequence of enhanced greenhouse gas emissions (Nogués-Bravo et al., 2007; García-Ruiz et al., 2011). However, the local magnitude of change is uncertain because of the differing emissions scenarios (Solomon et al., 2007), local effects caused by topography and distance to the ocean (López-Moreno et al., 2008), and uncertainties in the response of the climatic system and its feedback mechanisms to altered atmospheric composition (Raisänen, 2007). In view of the marked and non-linear response of snowpack to different magnitudes of climate warming, the ensembles of various climate projections should be quantitatively assessed in terms of their potential effects on snowpack under local topographic conditions in mountain areas.

Acknowledgements: This work was supported by the research projects CGL2011-27536/HID: “Hidrologia nival en el Pirineo central español: variabilidad espacial, importancia hidrológica y su respuesta a la variabilidad y cambio climático”, financed by the Spanish Commission of Science and Technology, and FEDER; ACQWA (FP7-ENV- 2008-1-212250): “Efecto de los escenarios de cambio climático sobre la hidrología superficial y la gestión de embalses del Pirineo Aragonés”, financed by “Obra Social La Caixa”; and “Influencia del cambio climático en el turismo de nieve-CTTP1/10” and CTTP1/12 “Creación de un modelo de alta resolución espacial para cuantificar la esquiabilidad y la afluencia turística en el Pirineo bajo distintos escenarios de cambio climático”, financed by the Comunidad de Trabajo de los Pirineos, CTP.Financial contributions from the Canadian Rockies Snow and Ice Initiative supported by the IP3 Cold Regions Hydrology Network of the Canadian Foundation for Climate and Atmospheric Sciences, the Natural Sciences and Engineering Research Council of Canada, and the Canada Research Chairs Programme are gratefully acknowledged.

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Table 1. Altitude and long term average meteorological conditions (November–April) for the five meteorological stations in the study.

	Izas	**Bonaigua**	**Sasseuba**	**Perafita**	**Bony Neres**
Altitude (m a.s.l.)	2056	2266	2228	2415	2098
Climatic type	Atlantic influence	Continental-Atlantic influence	Continental-Atlantic influence	Continental-Mediterranean influence	Continental-Mediterranean influence
Available record	1996-2010	2001-2009	2004-2010	2009-2012	2009-2012
Temperature (°C)	0.28	-0.71	-1.1	-1.2	0.88
Precipitation (mm)	1260	596	751	926	670
Relative humidity (%)	66.7	48	70.1	62.3	65.1
Wind speed (ms^{-1})	2.1	1.98	1.6	3.2	1.4
Solar Radiation (MJ/m^{-2}day^{-1})	147.7	145.5	128.9	152.9	145.3
Maximum snow depth (cm)	174	207	149	137	100
Duration snow depth (days)	179	194	188	181	170

Figure captions

Figure 1. Study area and location of the five meteorological stations.

Figure 2. Direct and diffuse solar radiation under clear sky conditions from November to June as a function of the applied slope and aspect correction.

Figure 3. Observed (O) and simulated (S) maximum annual snow depth (upper panel) and duration (lower panel) of the snowpack. Horizontal lines indicate the interannual mean, the boxes indicate the 25th and 75th percentiles, and the bars indicate the 10th and 90th percentiles. MBE and MAE indicate the mean bias error and the mean absolute error, respectively.

Figure 4. Long-term average difference (%) in the annual maximum snow accumulation (MSA) and snow duration of the snow pack (ASD) for each slope aspect compared with flat conditions.

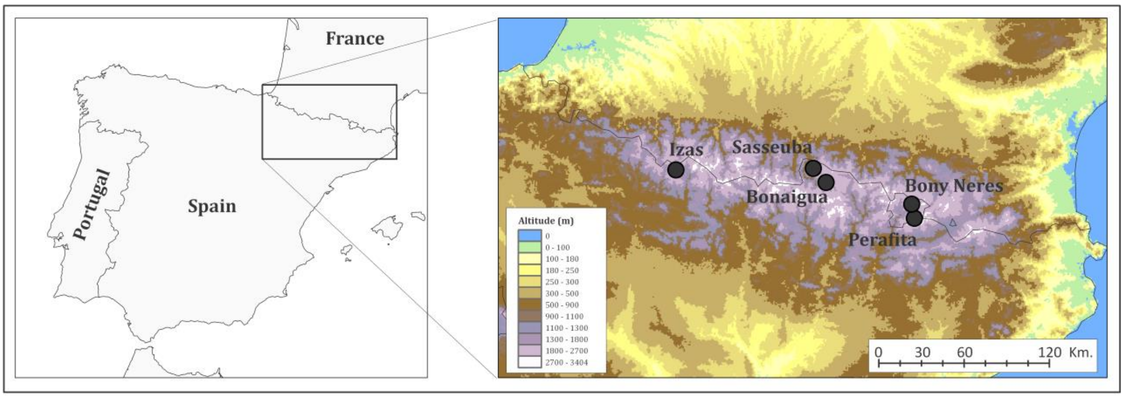
Figure 5. Sensitivity of the long-term average annual maximum snow accumulation (A) and duration of the snowpack (B) to an increase of 1°C for flat areas and slopes with north-facing or south-facing aspects.

Figure 6. Average sensitivity per 1°C of the long-term average annual maximum snow accumulation (MSA) and duration of the snowpack (ASD) for each slope aspect under different magnitudes of warming.

Figure 7. Monthly percentage of the annual melting in north and south aspects during the period from March to June in Izas and Bonaigua stations.

Figure 8. Correlation between maximum annual snow accumulation and its annual sensitivity to an increase of 1°C for north-facing and south-facing slopes. The boxplots indicate the annual variability of the sensitivity during each studied period. CV: coefficient of variation.

Figure 9. Correlation between annual duration of the snowpack and its sensitivity to an increase of 1°C for north-facing and south-facing slopes. The boxplots indicate the annual variability of the sensitivity during each studied period. CV: coefficient of variation.



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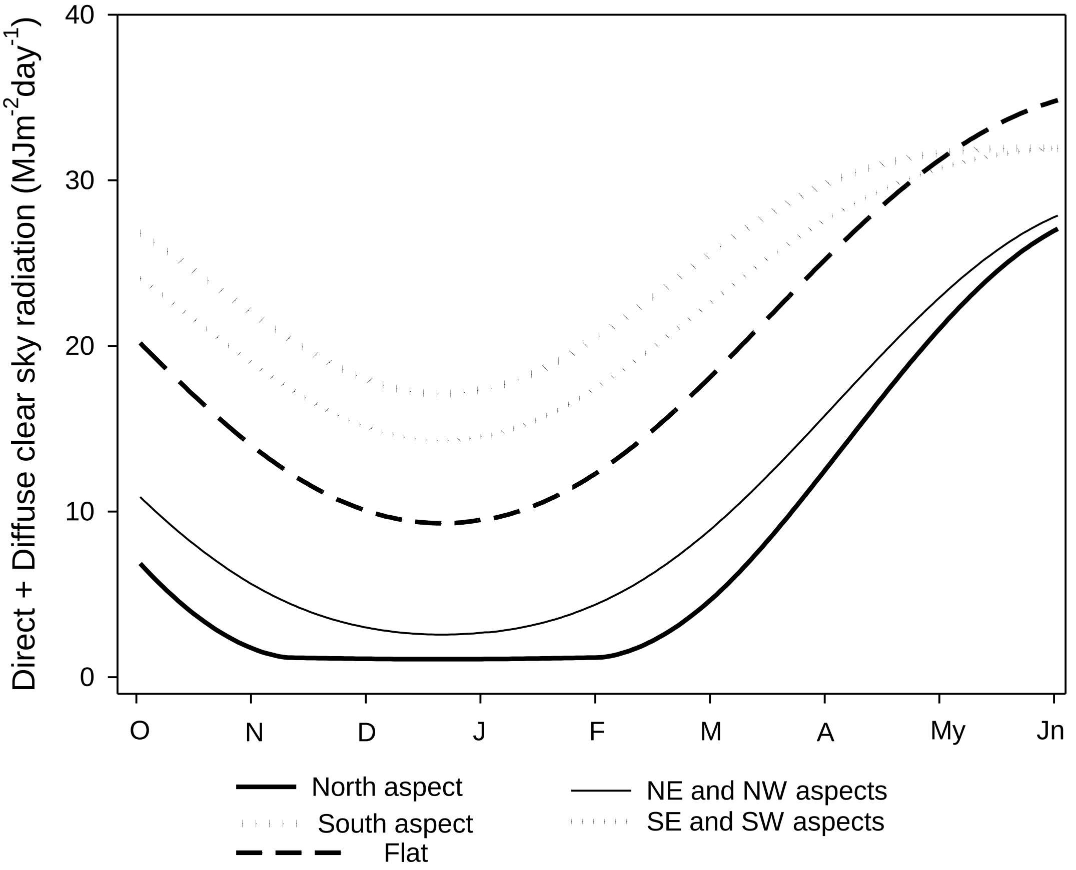

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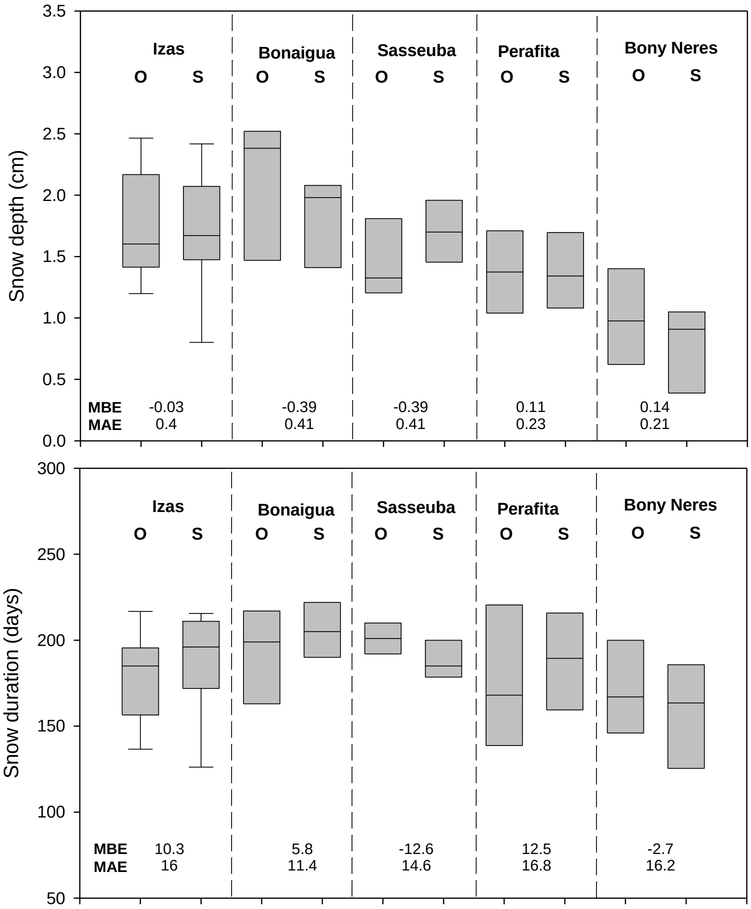

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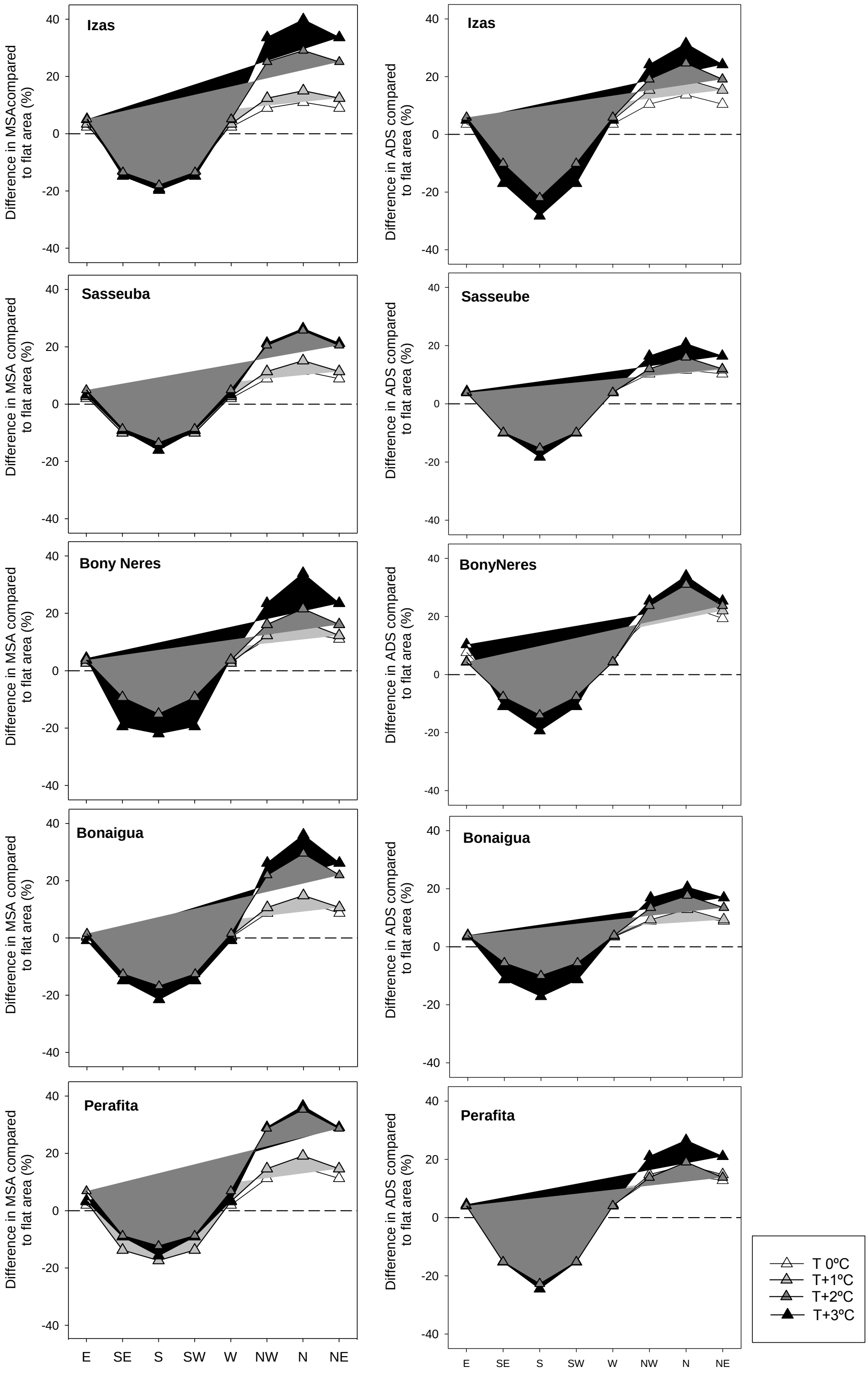

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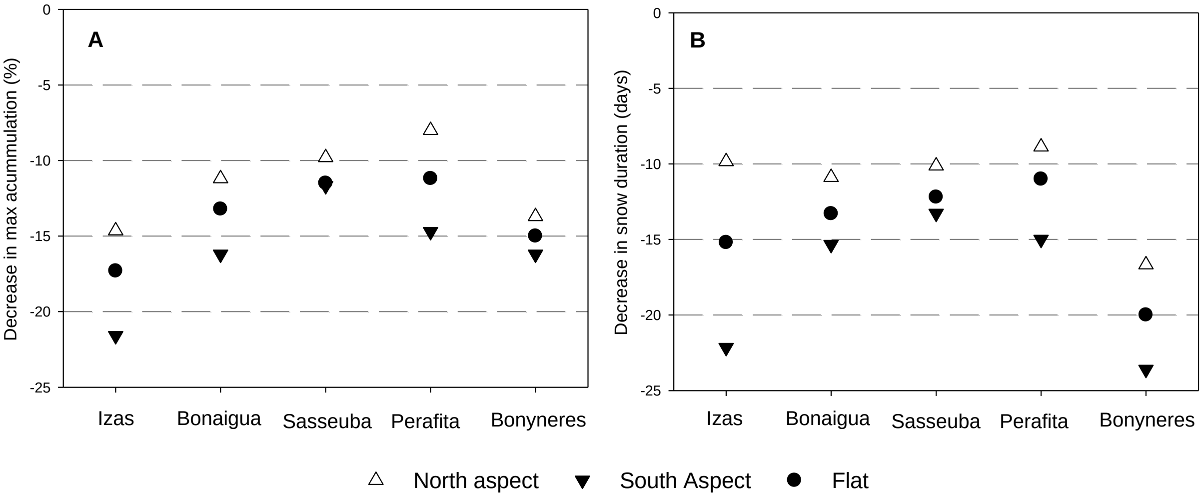

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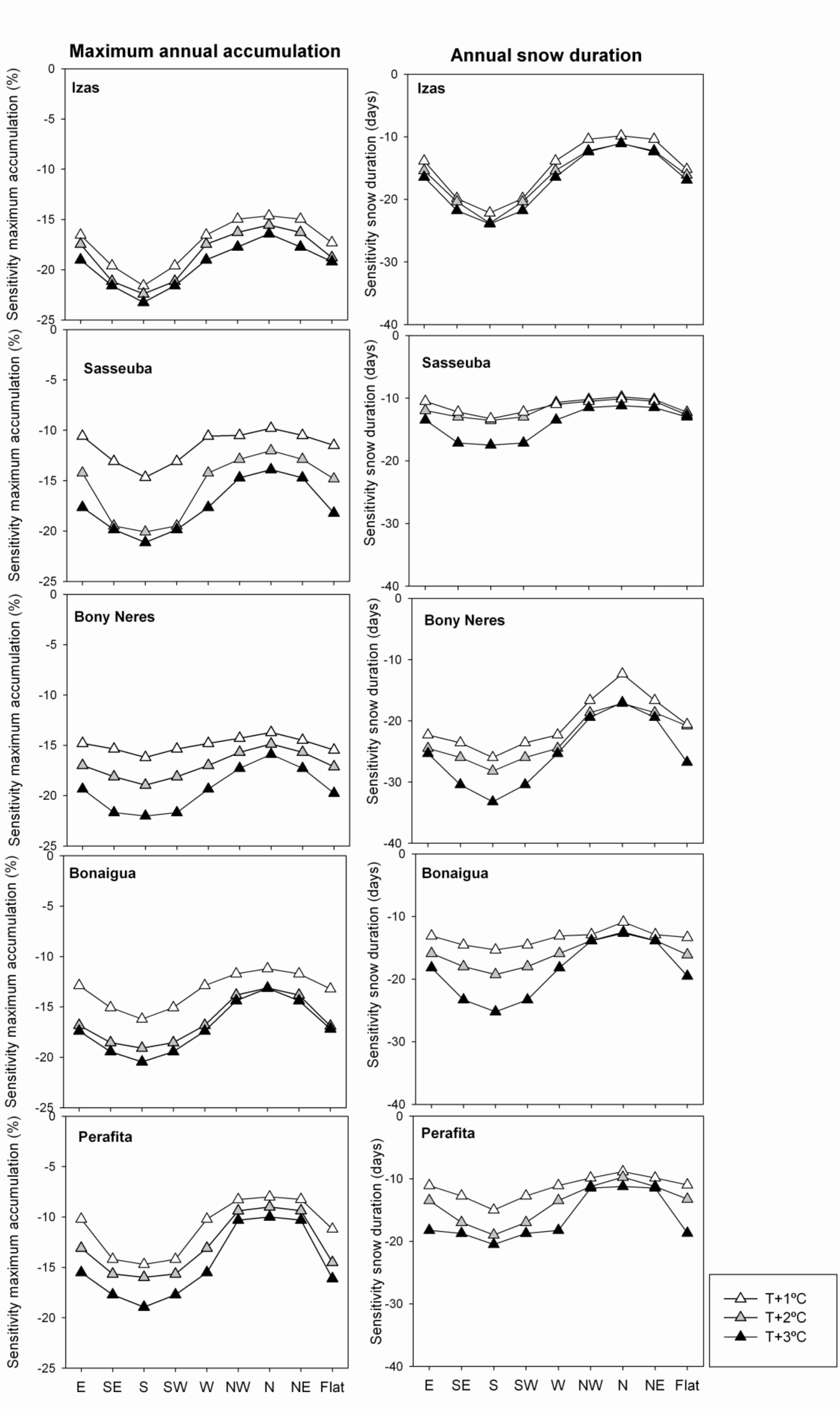

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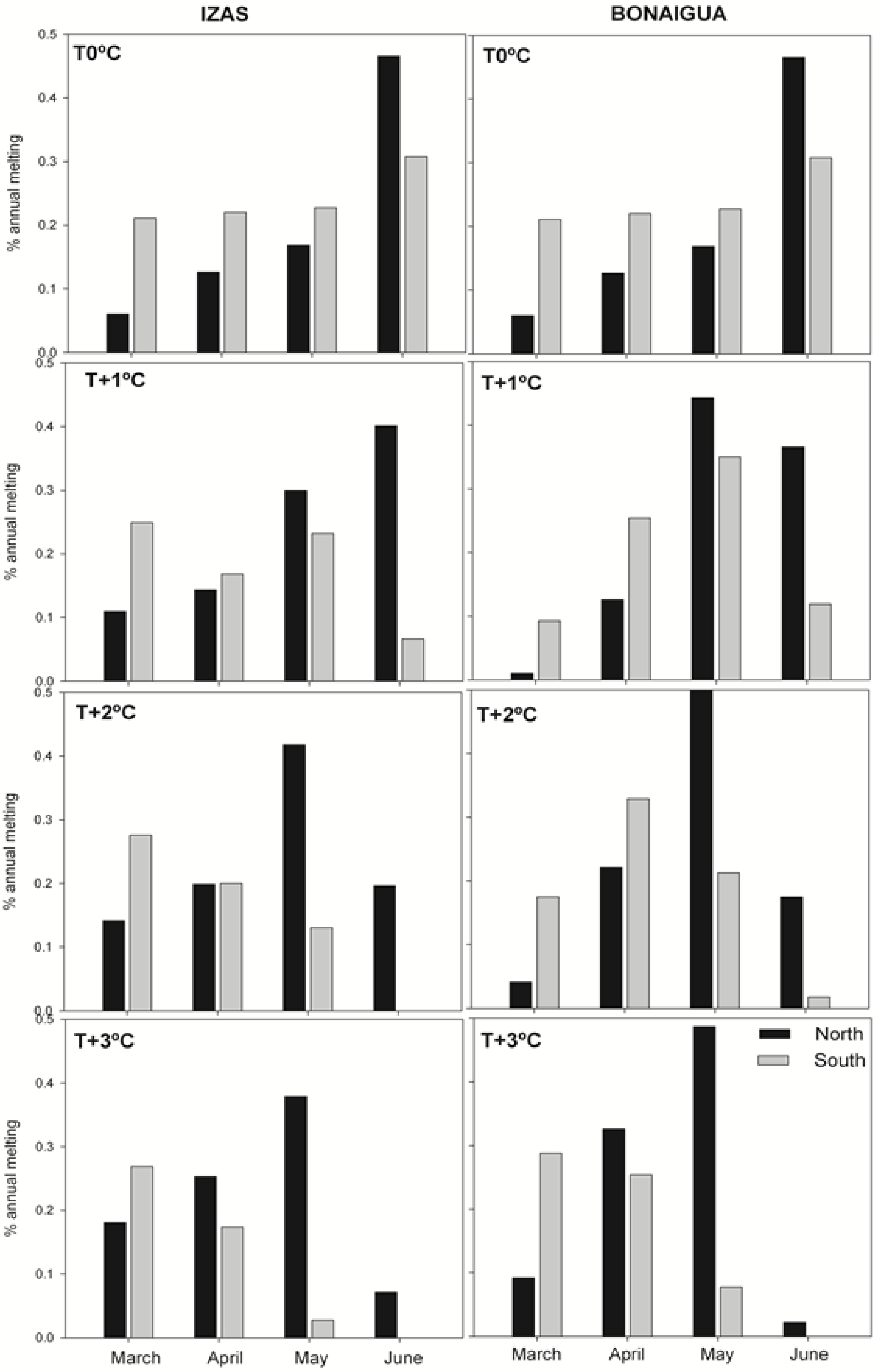

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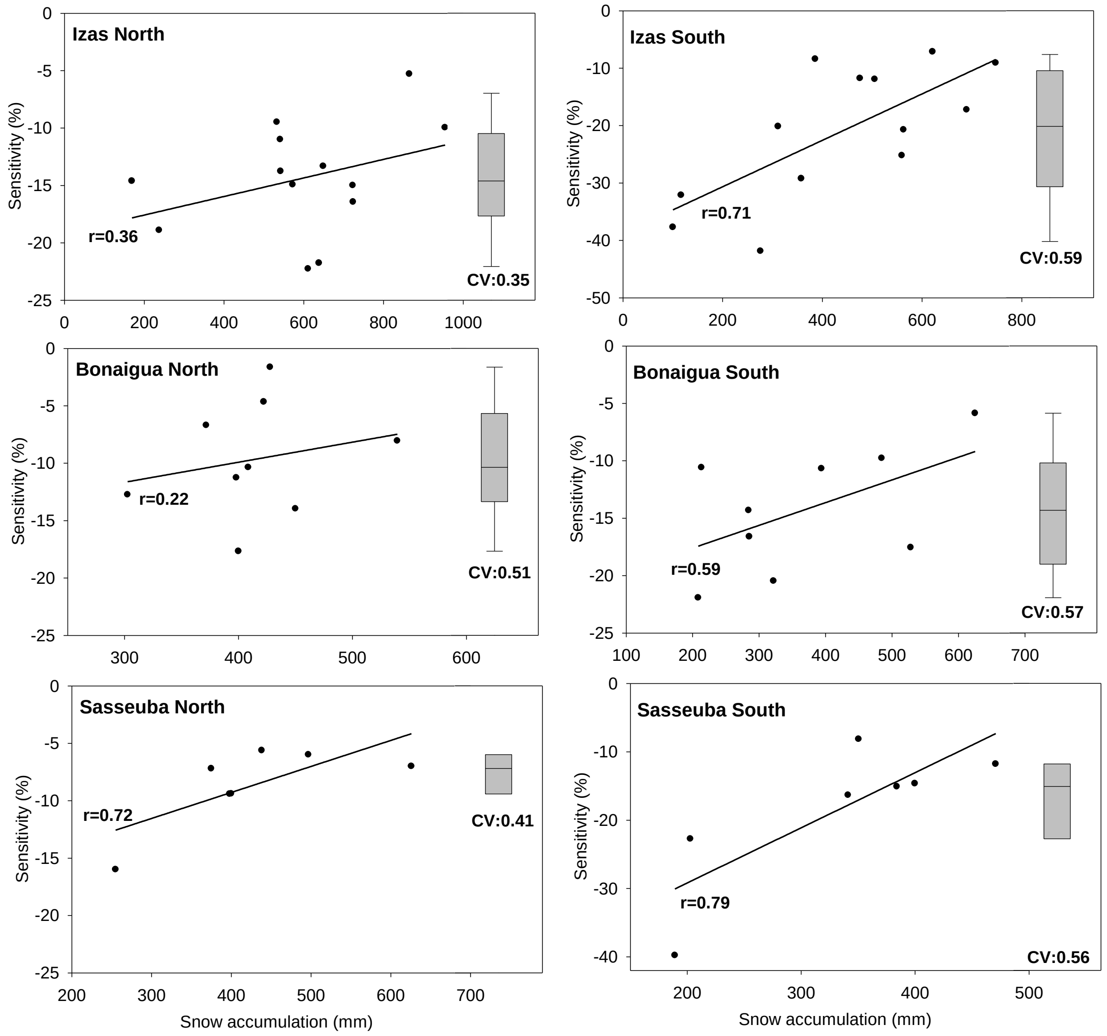

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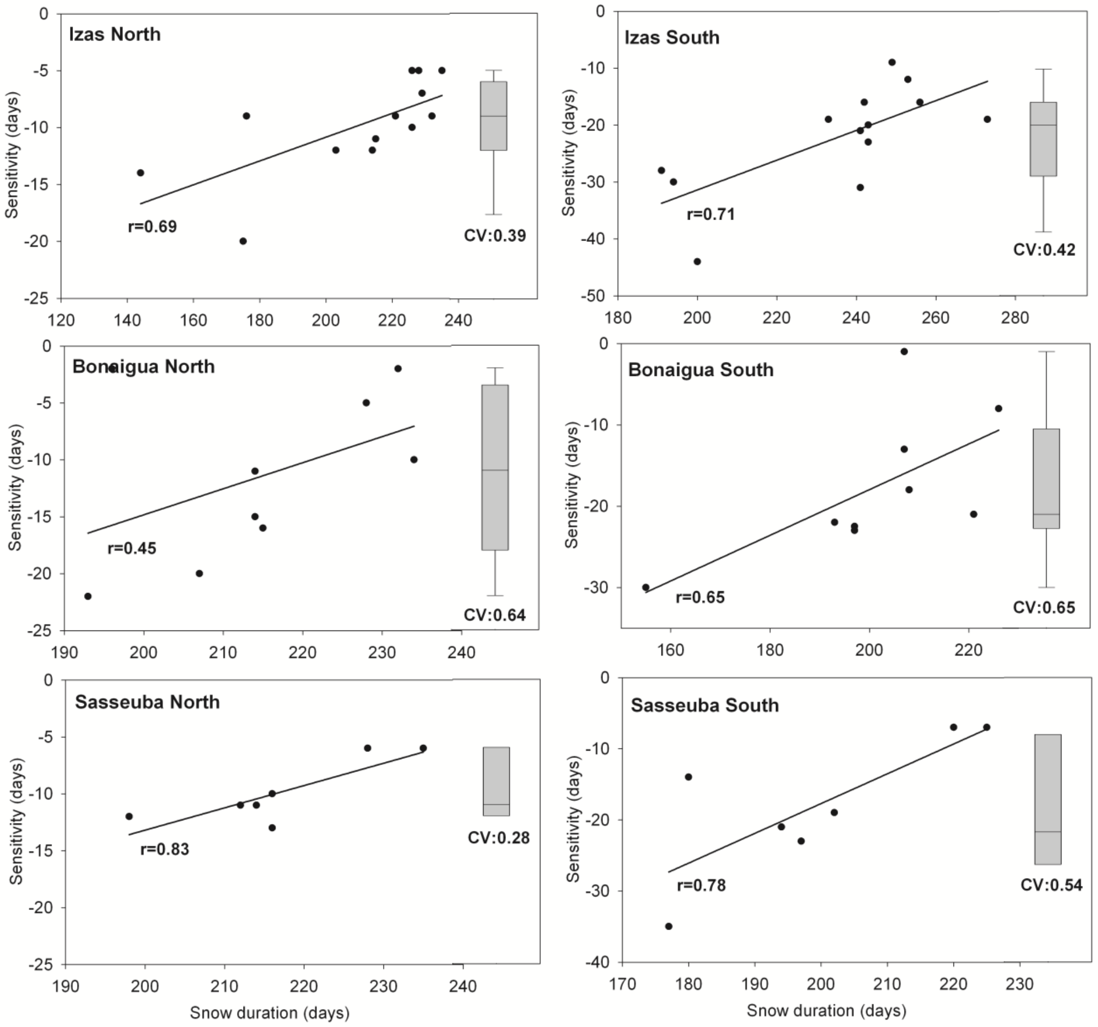

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