21. THE EXTREME SNOW ACCUMULATION IN THE WESTERN SPANISH PYRENEES DURING WINTER AND SPRING 2013

Juan A. Añel, Juan Ignacio López-Moreno, Friederike E. L. Otto, Sergio Vicente-Serrano, Nathalie Schaller, Neil Massey, Samuel T. Buisán, and Myles R. Allen

Natural climatic variability was apparently the main driver in the extreme cumulative snowfall that fell in the Pyrenees in 2013.

Introduction. Snow accumulation in the Pyrenees has shown a statistically significant negative trend since 1950 (López-Moreno 2005) in a similar way to other European mountain areas (Marty 2008). In the Pyrenees, the reduction in snow cover has mostly been associated with decreasing winter precipitation, which in turn has been related to a positive trend of the North Atlantic Oscillation index (NAOi, López-Moreno and Vicente-Serrano 2007; López-Moreno et al. 2010). However, this long-term trend is superimposed upon a high interannual variability, which leads to frequent changes between snow-poor and snow-rich years (Buisán et al. 2014). In the last decade the Pyrenees have recorded 5 years that have clearly exceeded the long-term average (above 75th percentile) winter precipitation, leading to deeper than normal snow-cover. This has been associated with a continuing trend of negative NAO conditions (Vicente-Serrano et al. 2011). Thus we investigate whether a different driver, anthropogenic emissions, played a role in changing the frequency of occurrence of deep and extensive snow cover using the example of the wet and snow rich winter and spring 2013. This year, despite having temperatures close to the long-term average for winter and spring, recorded far above normal precipitation from January to June over the Atlantic coast of the Iberian Peninsula and western Pyrenees. This wet anomaly was a consequence of an above average frequency of advections from the north and north-west, leading to the January–June precipitation events exceeding 100–200 year return periods (considering a reference period of only 33 years, 1980–2012, and using a generalized Pareto distribution). In the case of the Pyrenees, the anomaly of recorded precipitation was less extreme in the east than in the west (Fig. 21.1a).

Empirical evidence. The accumulated precipitation in this very wet winter and spring (January to June, both included) exceeded by far the 95th percentile in the western Pyrenees with only slightly above average snow cover in the central and eastern Pyrenees (Fig. 21.1b). In terms of snowfall days (snow precipitating within 24 hours), the anomaly was only measured at stations in the western Pyrenees at mid-and high elevation, where they exceeded the 95th percentile by a large margin. In contrast, low elevation stations in the western Pyrenees (i.e., Valcarlos) and inland stations (Torla and Eriste) observed values consistent with the normal long-term interannual variability (Fig. 21.1c). At Linza station (1330 m a.s.l.), at which a continuous snowpack is not guaranteed (López-Moreno et al. 2007), snow cover remained from early January to late April, recording a snow depth of 235 cm in only 31 days and a snow net accumulation of 554 cm between January and April. In Izas station (2080 m a.s.l.) snow lasted until early July and the snowpack exceeded 4 meters depth, accumulating 355 net cm in 35 days from mid-January to mid-February, and maintained a thickness above 300 cm until mid-June (Fig. 21.1d). Table 21.1 shows the values of the total snow water equivalent (SWE) and estimated snowfall computed from SWE for some stations where it was available. SWE was measured with GMON3 sensors from Campbell Scientific operated by the Ebro Basin District Authority. The snow data (both precipitation and number of days) were provided by the Spanish national weather service (Agencia Estatal de Meteorología; AEMET) except for Izas, a station operated by the Instituto Pirenaico de Ecología-Spanish national research council (IPE-CSIC).

The hydrological consequence of this extremely wet and snow-rich year was that the river flow of the Ebro in Zaragoza, where the river has collected the main tributaries that drain headwaters of western Pyrenees, exceeded the 90th percentile of average flow from January to June. This is clear from the analysis of the data provided by the Ebro Basin District Authority (Fig. 21.1e). The largest anomalies occurred in February as a consequence of heavy rains at low elevation, and in June in response to the melting of the anomalously deep snowpack, which lasted until late in the season in the mid and high elevated areas of the Pyrenees.

The anomalous snow accumulation in 2013 is of great interest if it suggests that, despite a clear warming trend occurring in the region since the early 20th century (El-Kenawy et al. 2012), it is still possible to observe snow-record years. However, at low and midelevation accumulation of snow in wet years is expected to decrease with increasing regional temperatures in a globally warming world.

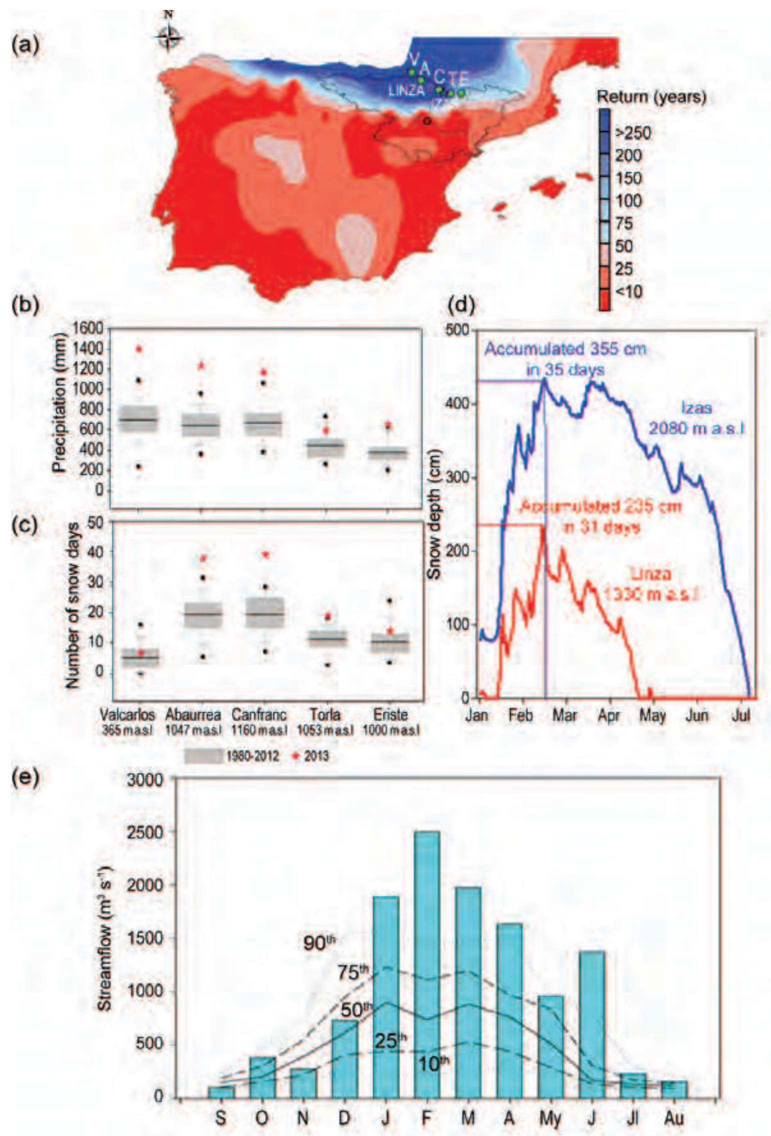

Fig. 21.1. (a) Return period of accumulated precipitation from January to June in the Iberian Peninsula; (b) Box plots showing the median, 5th, 25th, 75th, and 95th percentiles of precipitation in selected observatories [Valcarlos (V), Abaurrea (A), Canfranc (C), Torla (T) and Eriste (E)] during the period 1980–2012; red stars indicate the value for 2013; (c) Same as (b) for snow days; (d) daily snow accumulation in Linza (1330 m a.s.l.) and Izas (2080 m a.s.l.) observatories; (e) Monthly average river flow in the Ebro river at Zaragoza, and the long-term (1980–2012) average, 10th, 25th, 75th, and 90th percentiles.

Evaluation of the impact of climate change. In order to assess whether and to what extend anthropogenic climate change has played a role in the chances of occurrence of such an extreme event, we performed a series of climate simulations using the ClimatePrediction.net (Allen 1999) / weather@home system (Massey et al. 2014). We used the same model and configuration as the study by Schaller et al. ("The heavy precipitation event of May–June 2013 in the upper Danube and Elbe basins" in this report). We used the atmosphere only general circulation model HadAM3P to drive the regional version of the same model, HadRM3P, over Europe at 50-km resolution. The region considered for the evaluation of cumulative precipitated snow from the model was 2°W–3.5°E and 41.5°–44°N, covering the full Pyrenees with 49 grid points from the model (see Fig. 21.2). The variable from the model is the amount of snow, computed for each time step in kg m^{-2}. Two different ensembles of possible weather in the relevant seasons in the Pyrenees were simulated: one using observed greenhouse gases, sea surface temperatures (SSTs) and sea ice to drive the model, the other one using preindustrial values of aerosols and greenhouse gases, 14 small ensembles with different SST patterns of warming removed and a sea ice fraction equivalent to observed values in 1985 (see "The heavy precipitation event of May–June 2013 in the upper Danube and Elbe basins" in this report). Given that we have no method or metric of deciding within the warming-removed ensemble which pattern of warming is closer to the truth, we treat them as equally likely and thus increase the robustness of the statements we can make by increasing the sample size to one large ensemble instead of 14 small ones. The number of members in each ensemble were 261 and 583 respectively. They were all the members available.

We verified that both data distributions ("all forcings" and "natural forcings") are statistical independent using a Kolmogorov-Smirnov two-sample test (Wilks 2006). Figure 21.2 shows the return times (chances of exceeding the threshold of snow cover on the vertical axis in a given year) for the two different ensembles. These model simulations suggest that return times (a measure of the probability of occurrence) for a given snowfall value over the Pyrenees have slightly increased with climate change but the two curves representing the different ensembles are not statistically significant for return times above 10 years.

As pointed out for most of the stations the snow accumulated was above the 95th percentile. Therefore to assess such an extreme event we should look for a return time exceeding this value in the simulations. In the all-forcings ensemble the 95th percentile corresponds to 1687 mm with a return time of 18.8 years. The equivalent in the natural has a return time of 16.8 years. As said, the return time has increased in comparison to a scenario without climate change effects. When comparing the observations and the model results, several issues need to be taken into account. First, the mean climatological value of cumulative SWE for January–June over the period 1980-2012 for the five stations of Figure 21.1a is 565 mm but for the all-forcings simulations from Fig. 21.2b it is 287 mm. This implies the existence of a dry bias in the model (Pope et al. 2000). Elevation affects the amount of snow precipitation but comparing the extreme values from Table 21.1 with the median values in Fig. 21.1b we can see that the differences are similar for all the cases. Therefore to use a comparison of the percentile seems to be enough to assess potential changes in the return time. However the size of the horizontal grid probably has an effect reducing the maximum height represented in the region and therefore prevents getting the extreme snow values observed in the highest locations.

Table 21.1. Snow water equivalent for nine stations in the Pyrenees from January to June 2013.

Station	Altitude (m above sea level)	Snow Water Equivalent (mm)
Quimboa	1810	2033.7
Izas	2080	2431.5
Canal Roya	1971	1963.1
Bachimaña	2220	2349.8
Lapazosa	2140	2604.0
Ordiceto	2380	2235.8
Renclusa	2180	1971.6
Salenques	2600	2023.4
Eriste-2	2350	1645.1

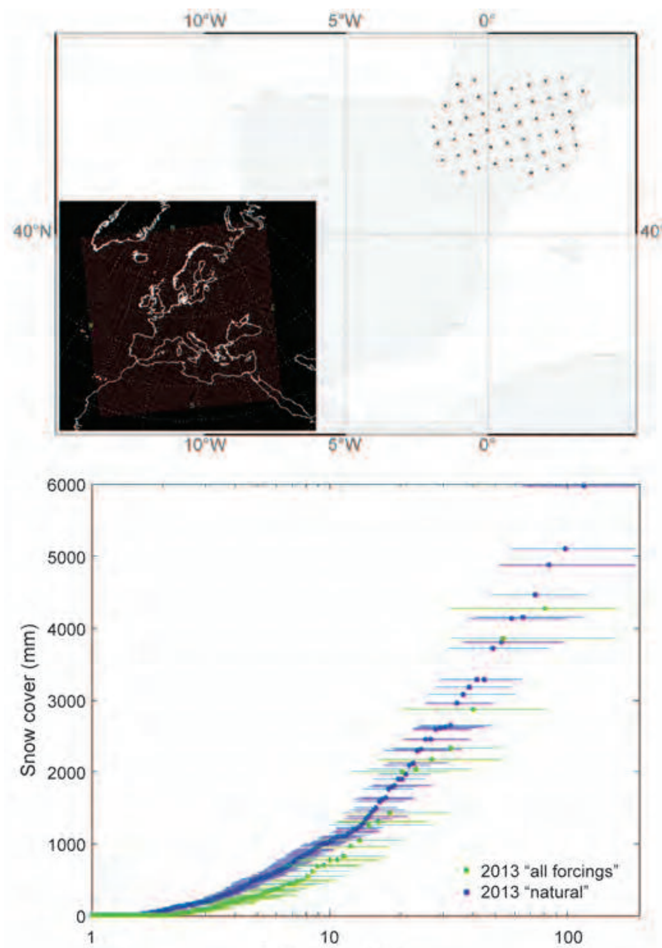

Fig. 21.2. (Upper) Grid points from the model used for the study. The map in the lower corner shows the grid of the regional model for Europe. (Lower) Return time plot for the accumulated snow for January to June 2013. Blue dots correspond to the simulations having into account preindustrial atmospheric conditions and green dots correspond to the simulations with 2013 values of CO_2, sea surface temperature and sea ice fraction. The horizontal error bars represent 5%–95% confidence intervals obtained by nonparametric bootstrapping (resampling with replacement) on the two ensembles.

Conclusion. The empirical evidence shows that the snowfall over the Pyrenees from January to June of 2013 was a rare weather event. Despite five winters in the last decade clearly exceeding the long-term average (above the 75th percentile), we have not been able to find a link between the recent increase in greater-than-normal snowfall seasons and anthropogenic forcing of climate in our model simulations. On the contrary, simulating precipitation and snow cover in the Pyrenees with and without the influence of anthropogenic greenhouse gas emissions shows a decrease in the occurrence probability of the event, although the result is not statistically significant for rare phenomena. In this assessment we find no evidence of a significant influence of anthropogenic emissions on this event.

22. A VIOLENT MIDLATITUDE STORM IN NORTHERN GERMANY AND DENMARK, 28 OCTOBER 2013

Hans von Storch, Frauke Feser, Susanne Haeseler, Christiana Lefebvre, and Martin Stendel

A strong storm on 28 October 2013 over northern Germany and southern Denmark fits a slight increase in storminess during recent decades. However, the increase constitutes part of multidecadal variability.

Introduction. In late October 2013, a strong cyclone moved across northern Europe causing massive damages and interruptions. In Germany, the storm was named "Christian", in Denmark, "Allan".

The impact of the storm was considerable. At least 15 people perished, a large number of trees were blown down, power supply broke down, train connections were interrupted, streets were impassable, and the Øresund Bridge between Denmark and Sweden had to be closed (Haeseler et al. 2013).

Synoptic analysis. The cyclone formed off the coast of Newfoundland, favored by large temperature differences between cold air behind a previous storm there and warm air related to the remnants of a former tropical storm. At 18 UTC on Sunday, 27 October, the storm was located southwest of Ireland; then, it crossed the southern part of the United Kingdom, moved across the North Sea, and made landfall in northern Denmark. In northern Germany, the first storm gusts were observed at about 1100 UTC. The storm moved on northeastward across southern Sweden and Finland towards Russia, where it weakened considerably on 29 October.

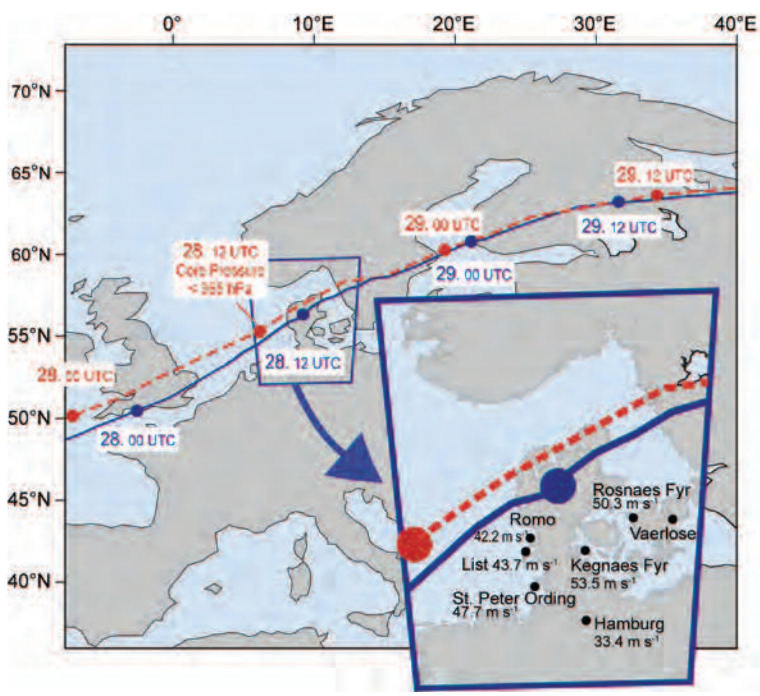

Fig. 22.1. Track of the Christian/Allan storm according to an analysis by Deutscher Wetterdienst [(German National Meteorological Service (red, dashed)] and to the reconstruction in CoastDat (blue, continuous).The box, showing the mentioned stations with measured peak gusts, marks the area for the storm statistics.