2.1. Monitoring the physical characteristics of the snow layer

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Abstract

The presence, distribution, and duration of the snow layer in Sierra Nevada is one of the physical characteristics that make this mountain range such a peculiar spot. This resource serves as the basis for economic activities such as skiing. It is a water reservoir that extends in time and alleviates the scarcity of water in dry summer periods and buffers Mediterranean torrentiality; it modulates ecosystems that bear exclusive and/or relict flora from cold periods. The accurate understanding of its properties, dynamics, and vulnerability to climate change is fundamental for managing and planning all the ecosystem services that it affects [1]. In the present work, periodic *in situ* monitoring campaigns of the snow layer are combined with fixed monitoring stations of the meteorological values that determine its behaviour, a photographic station to make detailed studies of the time course of the surface cover, and the application of all this into a physical modelling of the snow using the software WiMMed [2]. This aids in the forecasting of the behaviour of the snow layer with respect to meteorological predictions or to past and present hypothetical scenarios as well as the effect of this layer on the hydrology of the rivers of Sierra Nevada.

Aims and methodology

The objective is to delve into the physical properties of the snow, its distribution, and its dynamics at different spatial scales in an effort to understand better the real effects of snow on the hydrological cycle and on ecosystems. In addition, the aim is to design tools to forecast the evolution of the snow layer in a context of climate-change scenarios or meteorological events (droughts, cold fronts, etc.). For this purpose, different monitoring methodologies have been combined, such as complete fixed weather stations and video monitoring stations directly over the snow. This monitoring has been complemented with the use of a simulation model of the snow from a physical approximation (WiMMed)[2], enabling the prediction with the support of the *in situ* monitoring work.

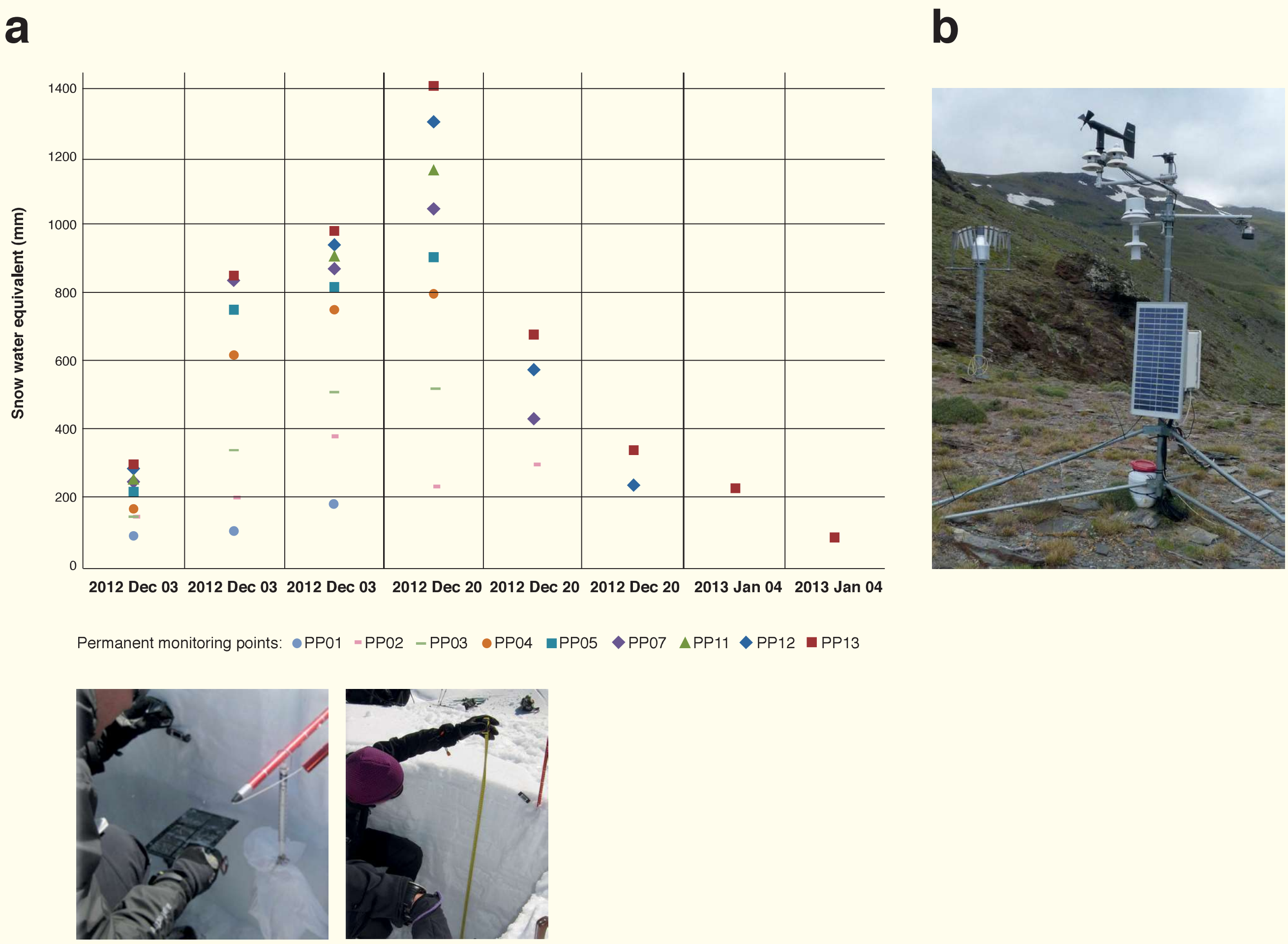
Results

The *in situ* monitoring confirmed the great spatial and temporal variability of the snow layer in Sierra Nevada. Over the study years, a systematic record was made of the values of density, snow water equivalent, thickness, number of layers, and particular properties (hardness, temperature and grain size). This made it possible not only to estimate the quality of the stored snow but also to evaluate the stability of the layer and the risk of avalanches in the most unstable areas.

This is the first time that systematic data on the properties of the snow in Sierra Nevada have been compiled *in situ* [4], and this project extend them to both slopes of the Sierra Nevada. These measurements represent a major point of reference to quantify the time evolution of the snow properties.

The photographic monitoring gave rise to detailed maps of the snow in the high part of the Trevélez river basin, enabling the study of the dynamics of the snow and its behaviour

Figure 1

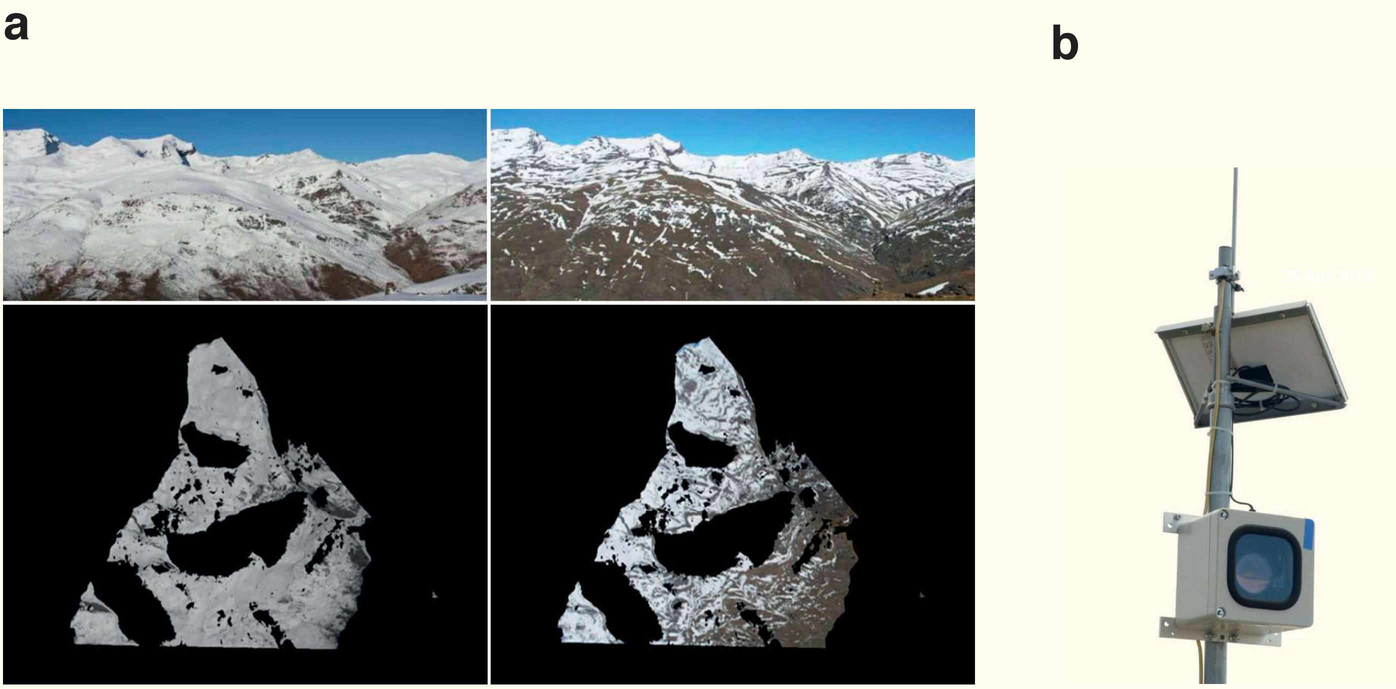


Variation of the snow water equivalents at the permanent monitoring points taken in the same basin (Genil river) from 2012 Dec 03 to 2013 Jan 04 (a). The high variability by date and sampling point was striking. On the right, one of the complete weather stations installed in an area of snow in the Trevélez river valley (b).

in spatial distribution according to elevation and orientation. It was found that, due to the south-eastern orientation of the slope, the snow maintained a rather even distribution, growing in thickness with elevation, which was successfully simulated with WiMMed [3]. A simulation technique was developed for direct assimilation of the data of the surface snow cover depicted by the photograph in the model, improving the prediction of the Trevélez river flow rate.

The weather stations installed enabled not only the monitoring of certain environmental conditions in the high areas of Sierra Nevada, but also the measurement of energy flows that determine the behaviour of the snow layer [4].

Figure 2



a) Example images on two different dates after restitution and georeferencing. Source: [3].
b) Camera for snow monitoring in the Trevélez river valley.

Discussion and conclusions

For the *in situ* monitoring, the standard recommendations described [5] were followed but adapted to the peculiarities of the snow on Sierra Nevada. Notable among these are thin layers of snow, except in very particular areas of snow accumulation, and high variability in time and space, with patchy snow and differences between contiguous slopes with different orientations. It bears noting the exceptional accumulation of snow during the 2010-2011 season.

In Mediterranean ecosystems, snow cover a basic determinant of the temporal distribution of water, which is especially scarce in these areas. Water use for irrigation and consumption cannot be effectively planned without knowledge of the evolution of the snow cover.