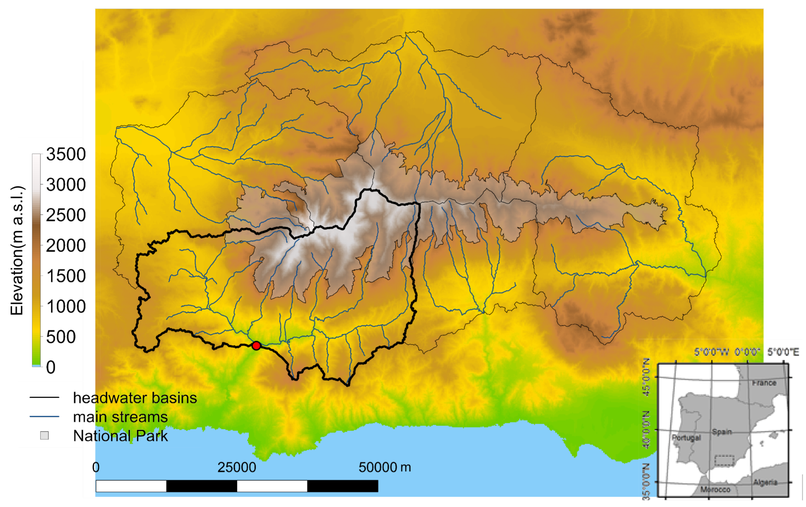
The key role of terrestrial imagery in semiarid mountainous areas: The snow monitoring system in Sierra Nevada (Spain)

Pimentel, R. [1], Pérez-Palazón, M.J. [1], Herrero, J. [1] and Polo, M.J. [1]

(1) Fluvial Dynamics and Hydrology Research Group, Andalusian Institute for Earth System Research. University of Cordoba. Córdoba, Spain.

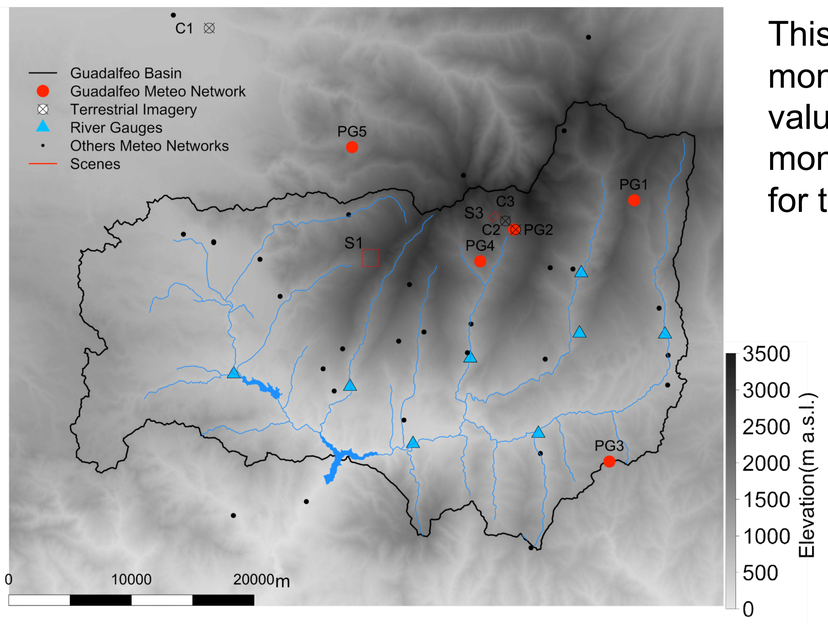
1. INTRODUCTION

Snow resources play a key role in the hydrological regime in mountain areas in Mediterranean regions. However, the **high variability of snow** over these areas (i.e. the **several accumulation-melting** cycles throughout the year, with very different duration; the **wide range of snow depth states**, close to the order of magnitude of the surrounding micro-relief (1-1000m); and the **particular patched snow distribution**, ranging from one to hundreds of square meters) makes necessary accurate monitoring system that cover all these particularities. On one hand, the correct representation of precipitation, partially solved with the installation of more dense precipitation network at high elevation, but still with problems related with the discrimination between rainfall and snowfall. On the other hand, the need of high resolution snow cover maps, highly improved with a recent increasing number of high resolution satellite missions launched and the development of fusion algorithms that combines them with traditional ones, but without standardized ground-truth datasets to verify those algorithms and validate the new products

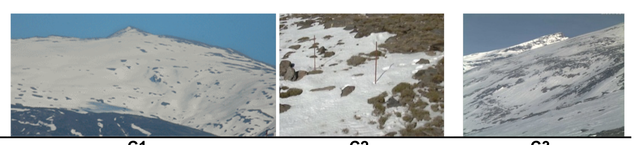


2. THE GUADALFEO MONITORING NETWORK

ID	PG1	PG2	PG3	PG4	PG5
Elevation	2470	2510	1332	2141	1675
Installation	Nov 2005-operational	Nov 2004-operational	Aug 2009-operational	Oct 2012-operational	Mar 2017-operational
Rain gauge	OTT Pluvio 2	Geonor T-200B	Young 52203	OTT Pluvio 2	OTT Pluvio 2 & Young 52203
Temperature Relative Humidity	Campbell Scientific CS215	Vaisala HMP45C	Vaisala HMP45C	Vaisala HMP45C	Campbell CS HC2S3
Pyranometer	-	Kipp&Zonnen SP Lite	Hukseflux LP02-05	Hukseflux LP02-05	Hukseflux LP02-05
Pyrgeometer	-	Kipp&Zonen CGR3	Hukseflux IR02	Hukseflux IR02	Hukseflux IR02
Alpine Wind monitor	Young 05103-45	Young 05103-45	Young 05103-45	Young 05103-45	Young 05103-45
Barometer	CS100, Setra 278	CS100, Druck RPT410F	CS100, Setra 278	CS100, Setra 278	CS100, Setra 278



This work presents **terrestrial imagery** as part of the snow monitoring network in Sierra Nevada (Spain) highlighting its value as **complementary measurements** of the traditional monitoring instrumentation and as ground-truth data source for the retrieving and validation of snow maps algorithms.



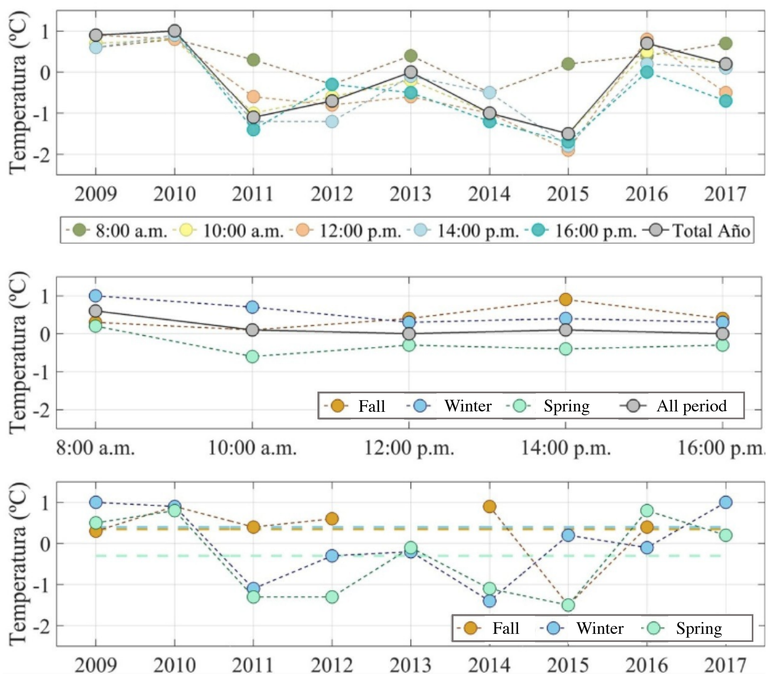
ID	C1	C2	C3
Name	Caballo hillside	Refugio Poqueira	Veleta-Carihuela
Camera	Campbell CC5MPX	CC640 Campbell Scientific	MOBOTIX M25
Installation	2011/11/20 – operational	2009/07/22- operational	2011/12/09-operational
Temporal Resolution	13 images per day	5 images per day	13 images per day
Spatial scale	Hillside (~2 km)	Detail (~30 m)	Hillside (~500 m)
Photo resolution	2592x1944 pixels	640x504 pixels	3000x2000 pixels

3. TERRESTRIAL IMAGERY APPLICATIONS

Point Scale

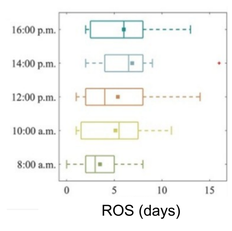
Complementary sensor in weather stations

A) Snowfall threshold temperature



- Variable snowfall threshold temperatura with values that range (-0.9, 0.3) ºC in autumn, (-1.4,1) ºC in winter and (-1.5,0.8) in spring

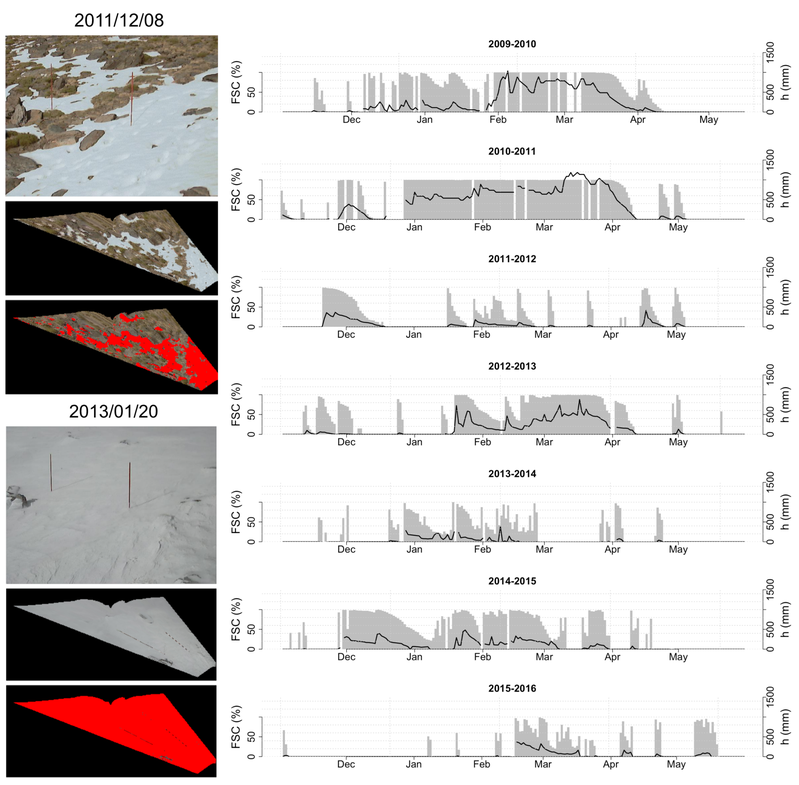
B) Rain on Snow events



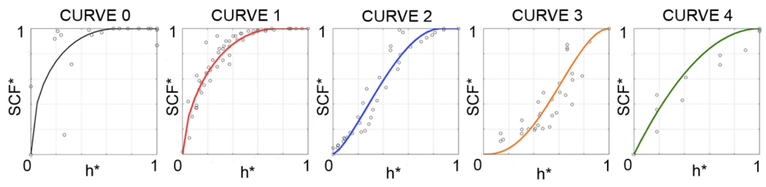
The rain on snow events are more likely in wetter years than in drier ones.

Plot Scale

Snow time series observation



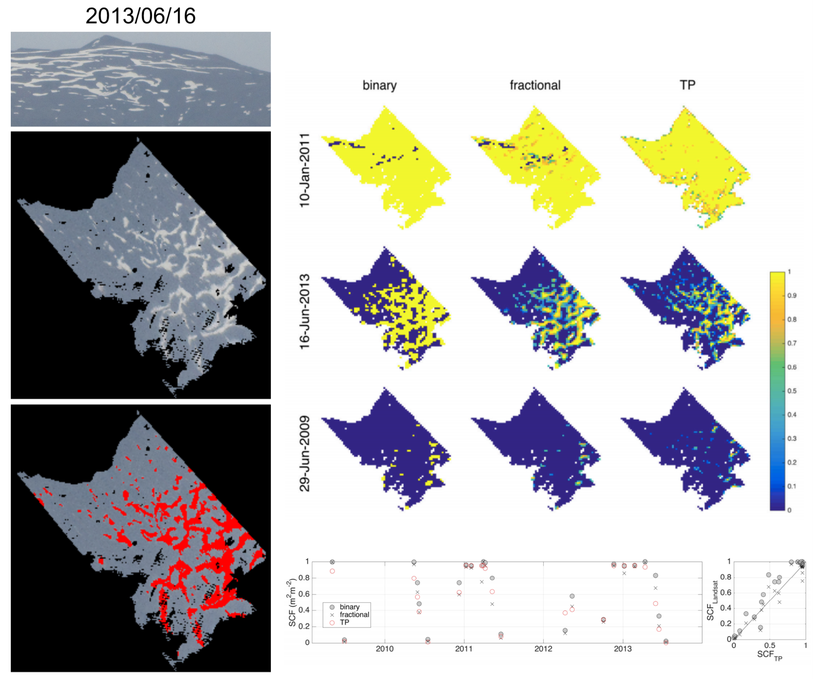
Depletion curves



Curve 0 represents accumulation cycles
Curve 1 represents cycles with a large amount of consolidated snow, which has undergone a relatively long accumulation phase.
Curve 2 characterizes cycles with a large amount of recent snow. This snow is not much compacted and consequently the initial asymptotic behaviour is shorter
Curve 3 represents cycles with a small amount of snow during autumn or winter. It is a scarcely metamorphosed snow
Curve 4, represents cycles with a small amount of snow during spring with a low degree of metamorphism and a high influence of deformation strain.

Hillslope Scale

Ground truth dataset RS validation



4.CONCLUSIONS

Snow variable times series derived from terrestrial photography (TP) constitute a validated reference datasets to test the accuracy of snow products algorithms in complex environments. The observational datasets provided by TP are useful 1) in **calibration/validation** loops of snow and hydrological models; 2) for defining **new parameterization** of snow processes, and 3) as **ground truth** to validate remote sensing products. TP provides valuable information to **complement standard weather stations.**

ACKNOLEDGEMENTS:

This study was funded by the following research projects funded by the Spanish Ministry of Economy and Development (MINECO): Research Project CGL 2014-58508R, "Global monitoring system for snow areas in Mediterranean regions: trends analysis and implications for water resource management in Sierra Nevada", and Research Project CGL 2011-25632, "Snow dynamics in Mediterranean regions and its modelling at different scales. Implication for water management"; and co-financed by the European Regional Development Fund (ERFD).

The authors want to acknowledge the International Network for Alpine Research Catchment Hydrology (INARCH) for the opportunity to share individual research experiences and data. The continuous support of the Natural and National Park of Sierra Nevada is also determinant for the development of this line of research since 2002.

REFERENCES

Pimentel, R., J. Herrero, Y. Zeng, Z. Su, and M.J. Polo. Study of snow dynamics at subgrid scale in semiarid environmnent combining terrestrial photography and data assimilation techniques, *J. Hydrometeor.,* **16**, 563–578, http://doi.org/10.1175/JHM-D-14-0046.1, 2015

Pimentel, R., Herrero, J., and Polo, M.J. Subgrid parameterization of snow distribution at a Mediterranean site using terrestrial photography, Hydrol. Earth Syst. Sci., **21,** 805-820, https://doi.org/10.5194/hess-21-805-2017, 2017a.

Pimentel, R., Herrero, J., Polo, M.J. Quantifying Snow Cover Distribution in Semiarid Regions Combining Satellite and Terrestrial Imagery. *Remote Sens.*, **9,** 995, https://doi.org/10.3390/rs9100995, 2017b.