INARCH 6th Workshop, 18-20 October 2022

How can we better describe the hydrological impacts of snow droughts in semiarid environments?

María J. Polo, Rafael Pimentel, Pedro Torralbo

- **Seasonal precipitation events** between (sunny) cold and very dry periods
- Several accumulation- (total) ablation cycles during the snow season
- **Frequent shallow or patchy snowpacks during the snow season**
- Energy balance: radiative terms, latent heat, exchange with soil-shrubs
- Water balance: **non-negligible sublimation seasonal/annual volumes**
- Snow domain mainly at high altitudes, lack of stations
- **Strong spatial variability with significance of different scales**

Trends in Mediterranean mountain basins

The Pyrenees 1950-2000

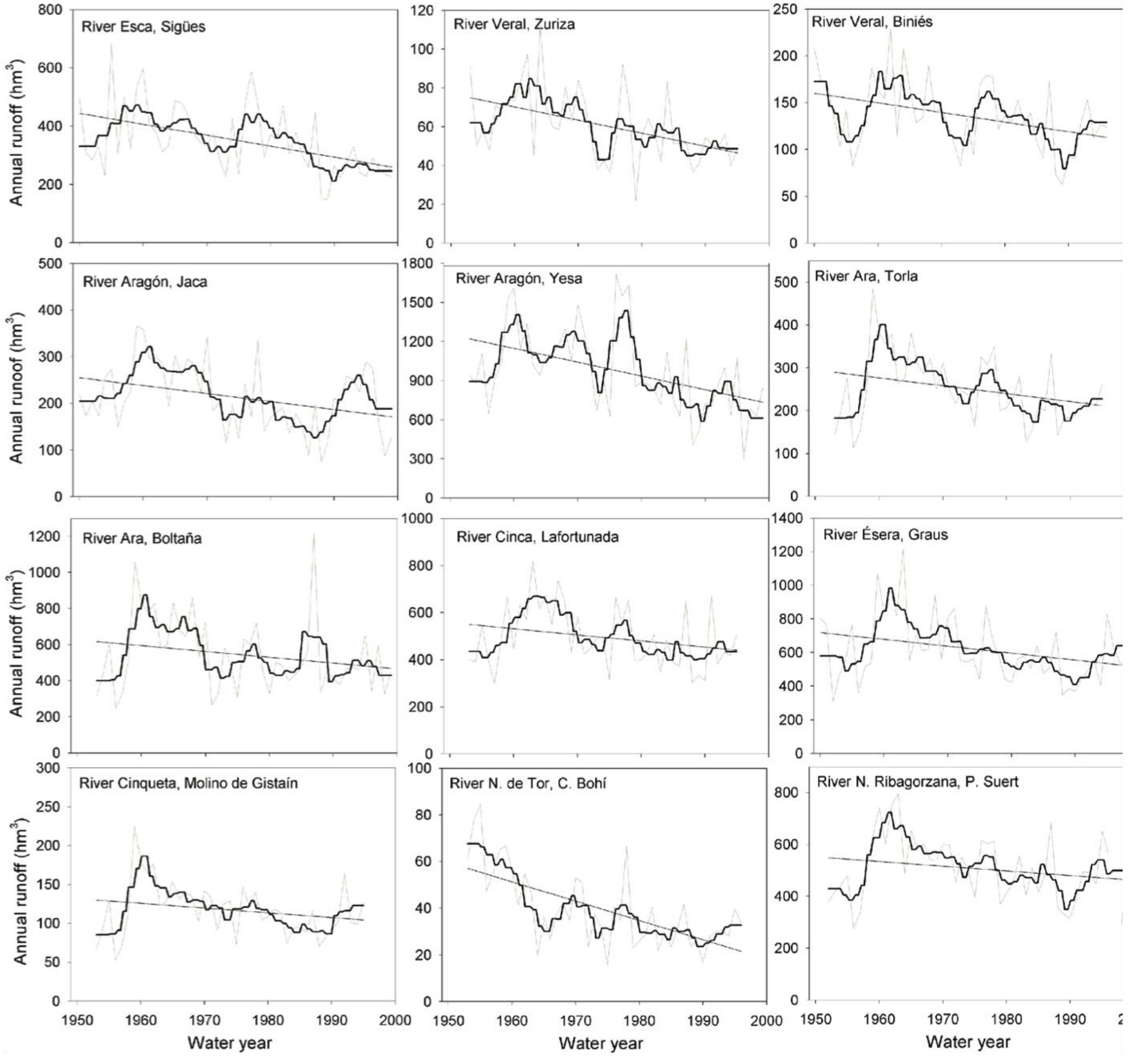
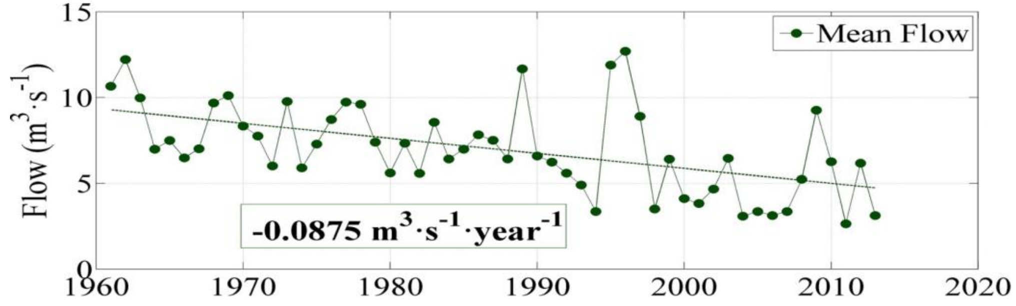
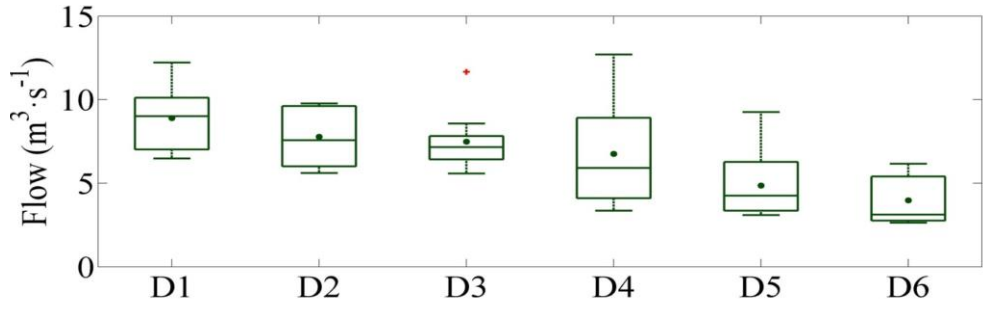


Fig. 3: Trends in annual runoff recorded at selected Pyrenean gauging stations. Grey lines represent annual trends; black lines are 5-year moving averages. (López-Moreno, J.I., Beniston, M. and García-Ruiz, J.M. 2008).

From López-Moreno et al. (2008)-Global&Planetary Change

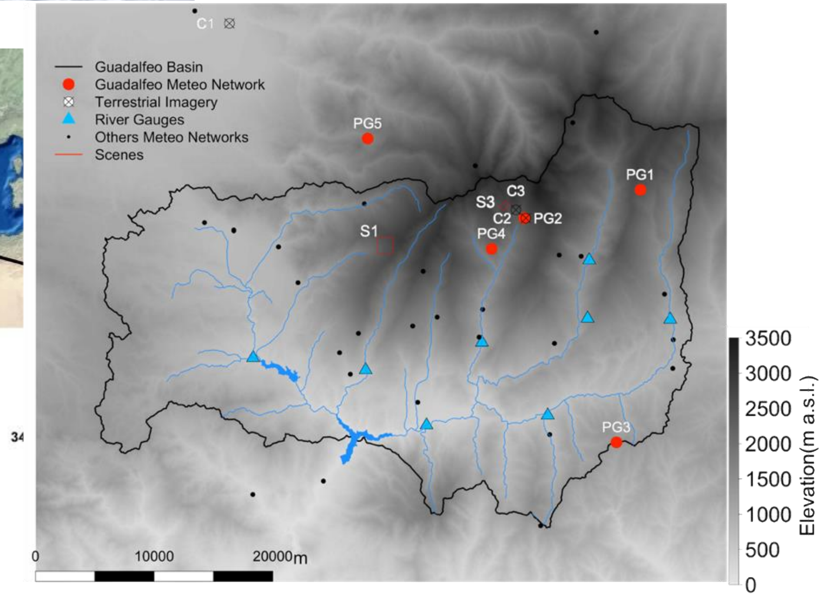
Guadalfeo River, annual mean flow
Sierra Nevada-Spain 1960-2015





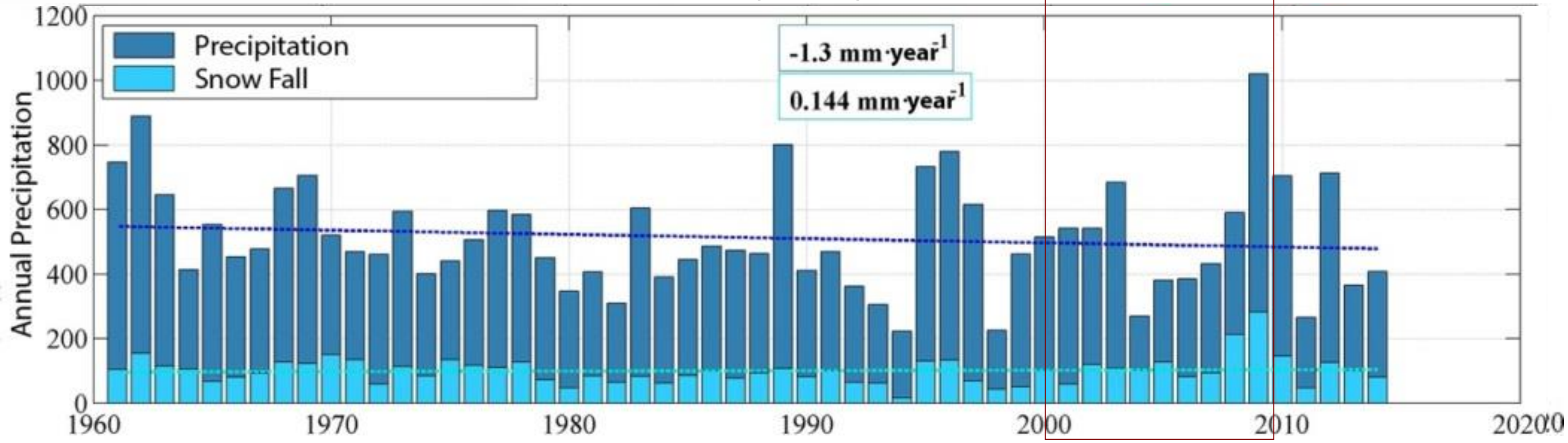
Pérez-Palazón et al. (2018)-PIAHS

Experimental basin: the Guadalfeo River basin in Sierra Nevada (Spain)



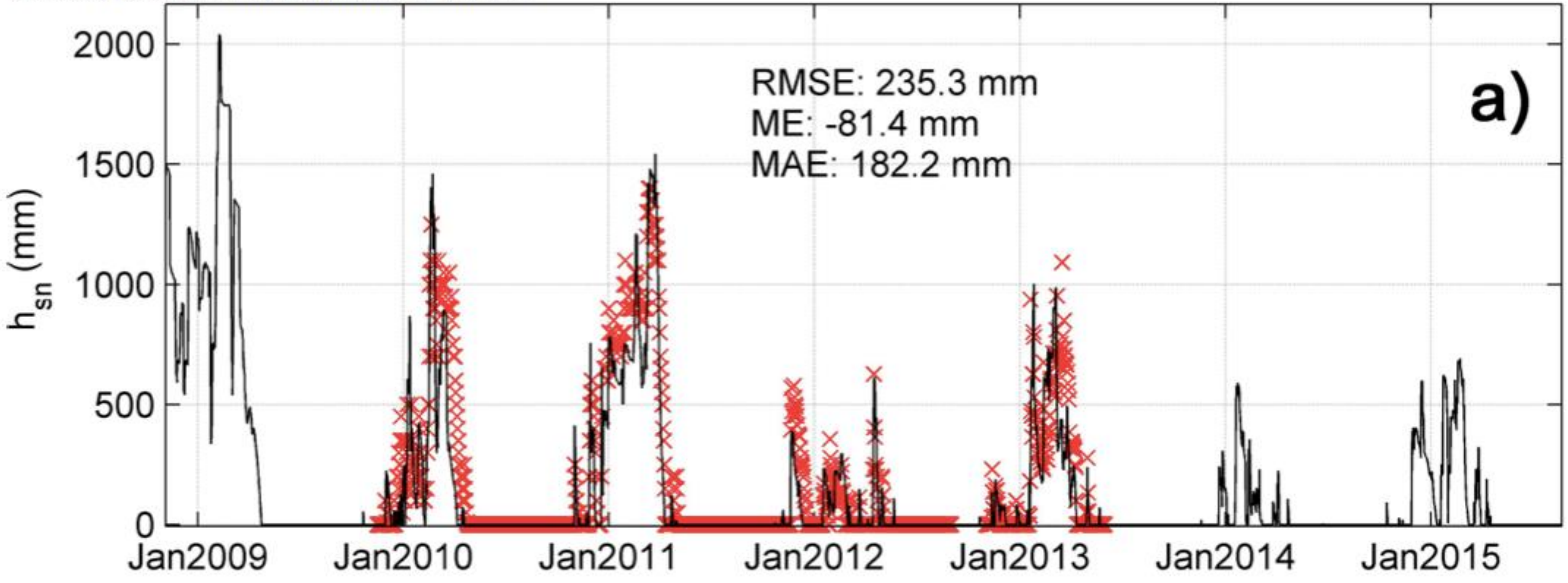
1345 Km^2
1418 m a.s.l. (avg.)
3479 m a.s.l. (max.)

Rules dam (2004)



Annual variability and seasonality of snowpacks at the Refugio Poqueira experimental site in Sierra Nevada

Figure A.4: a) Snow depth in mm simulated for each snow season at Refugio Poqueira site from hydrological year 2008/09 to 2014/15. The red crosses show the observed snow depth for years 2009/10 to 2012/13. b) Observed versus simulated annual maximum snow depth in mm at the meteorological station. c) Observed versus simulated annual duration of the snow depth in days at the meteorological station. The line at b) and c) indicates a 1:1 relationship between observed and simulated values.



Herrero and Polo (2016; The Cryosphere)

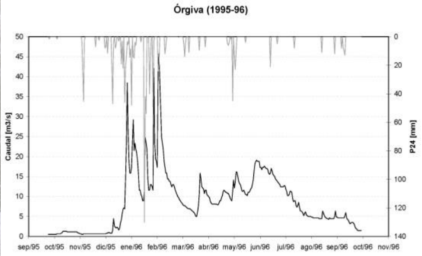
Dinámica Fluvial e Hidrología
UNIVERSIDAD DE CÓRDOBA

Focus Questions...



Science Question

What (and why…) are the major impacts of the snowpack dynamics on the fluvial regime on different time scales ?

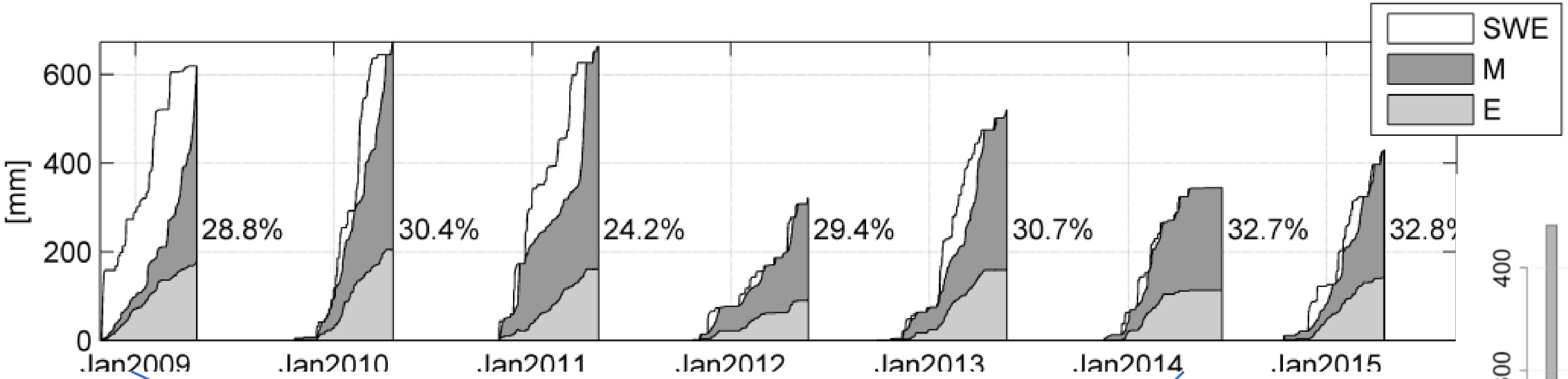



Societal Challenge

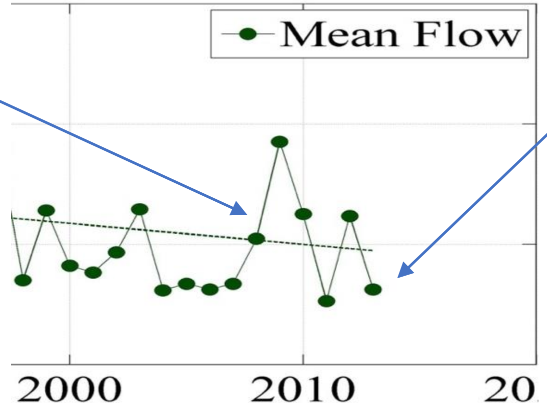
How to improve river flow assessment on different time scales for operation of facilities (reservoirs, hydropower…)?

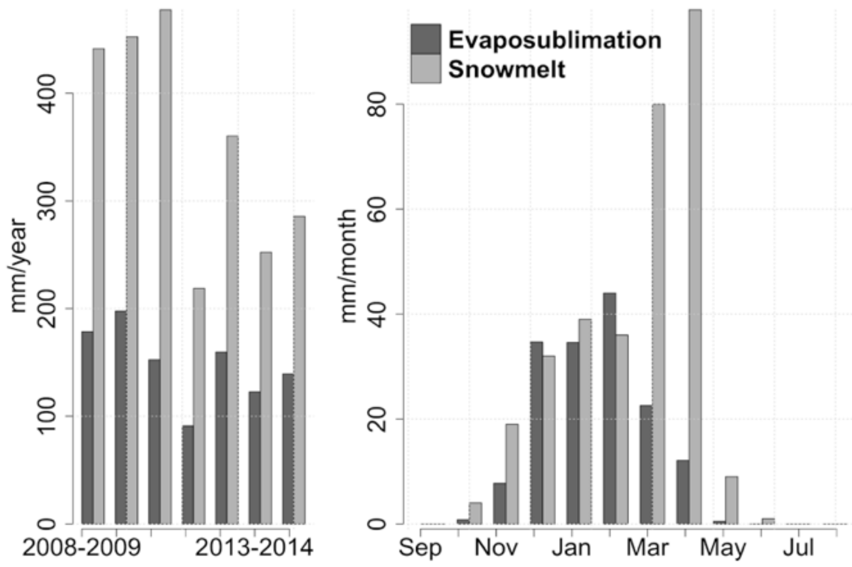

HYPOTHESIS AND OBJECTIVES, THE ROLE OF EVAPOSUBLIMATION

Figure A.4: Cumulative snowfall together with the stacked cumulative snowmelt (*M*) and cumulative evaposublimation (*E*) (in mm) for each snow season at Refugio Poqueira site from hydrological year 2008/09 to 2014/15. The white area between the snowfall and the stacked *M* and *E* represents the instant SWE. The percentage at the end of every season indicates the ratio of total evaposublimation compared to total ablation.



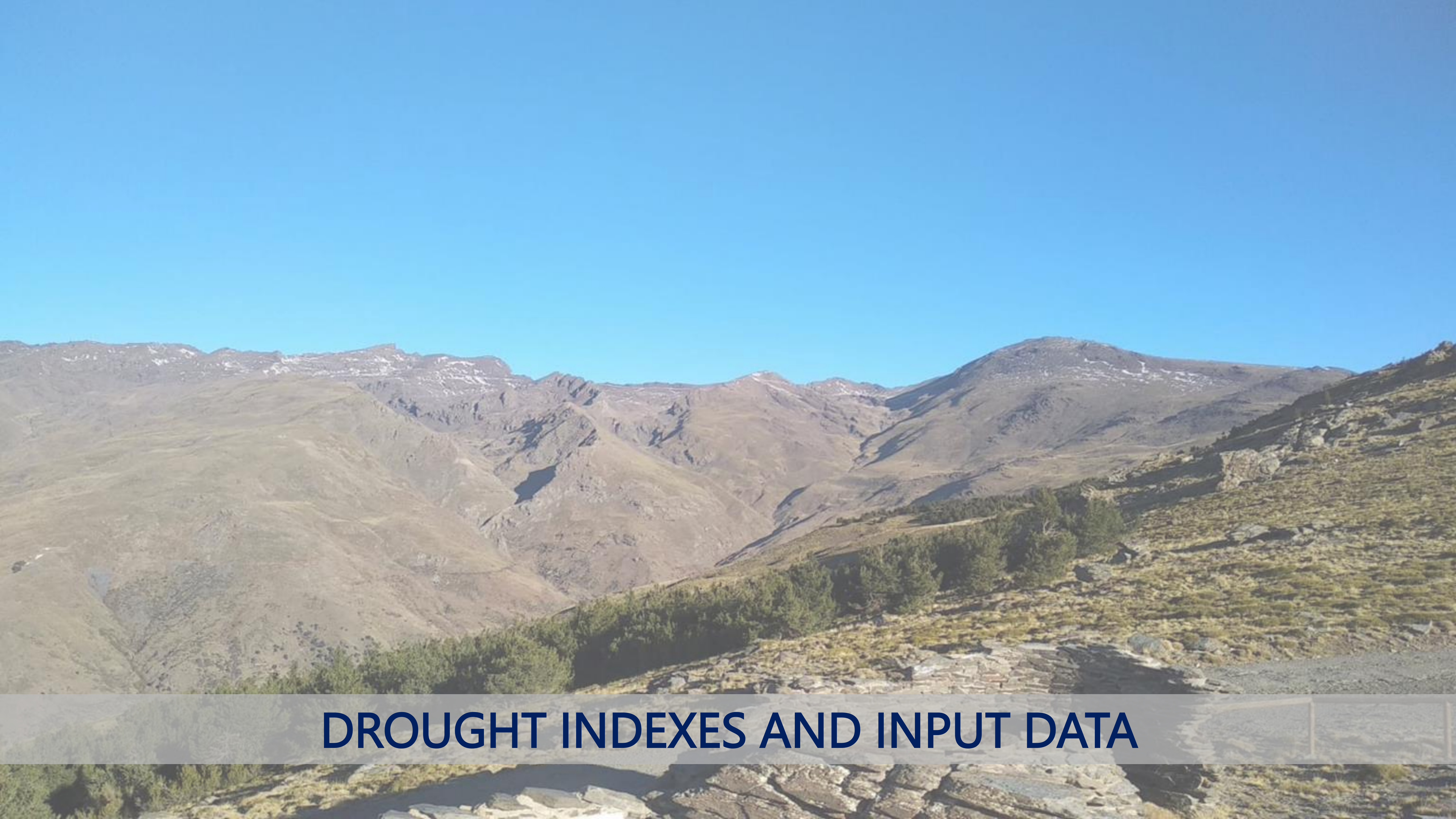
Herrero and Polo (2016); The Cryosphere





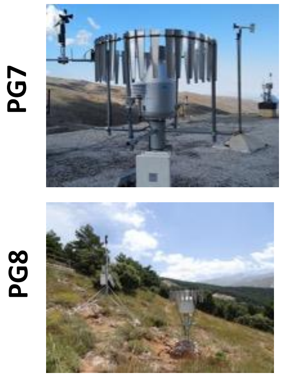
To test the capability of drought indexes to assess hydrological drought for operational decision making in snowfed reservoirs in Mediterranean/semiarid regions

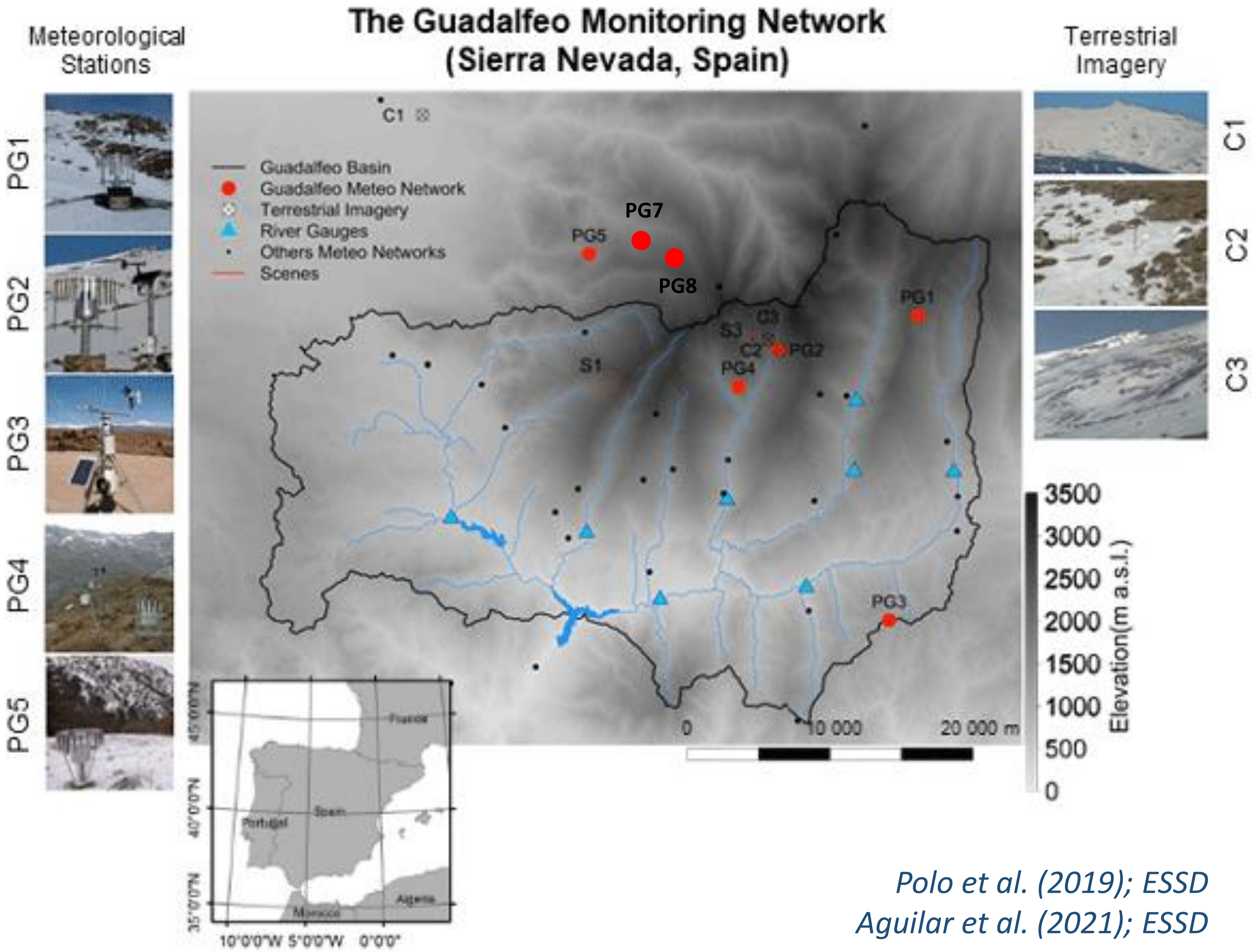
DROUGHT INDEXES AND INPUT DATA



GMS-SNOWMED IN SIERRA NEVADA-SPAIN (1): THE INPUT DRIVERS

- Weather variables data from the Guadalfeo Network
- Weather variables from other public networks on a quasi-real time (1 day lag) access
- River flow data from gauge data
- River inflow to reservoirs





Polo et al. (2019); ESSD
Aguilar et al. (2021); ESSD

GMS-SNOWMED IN SIERRA NEVADA-SPAIN (2): DROUGHT INDEXES

- SPI, standardized precipitation index (SPI < 0, meteorological drought)

$$SPI_{MONTH\ i} = [SUM(P_J)_{N\ PRECEDENT\ MONTHS} - mean_{period}] / deviation_{period}$$

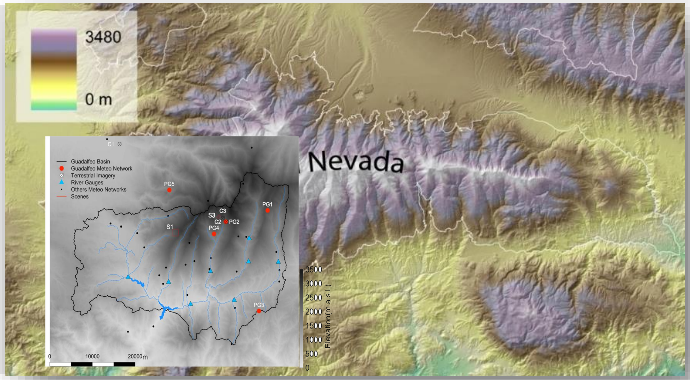
- SSI, standardized snowfall index (SSN < 0, snowfall drought)
- SFI, standardized flow index (SFI < 0, hydrological drought)

Different time scales: for this study, SPI and SSI are calculated over 6 months, SFI over 6 and 1 month

$$SxI_{MONTH\ i} = [SUM(x_j)_{MONTH\ j-5\ ..\ MONTH\ j} - mean_{period}] / deviation_{period}$$

Study area, the Guadalfeo River Basin headwater area, 1961-2015

Precipitation data: Monthly precipitation averaged over the study area
Snowfall data: Obs/simulated monthly snowfall averaged over the study area
Flow data: Observed monthly flow, gauge station (1989-2015)



RESULTS

Precipitation (SPI) and snowfall (SSI) 6-month drought indexes in the study area (1961-2015)

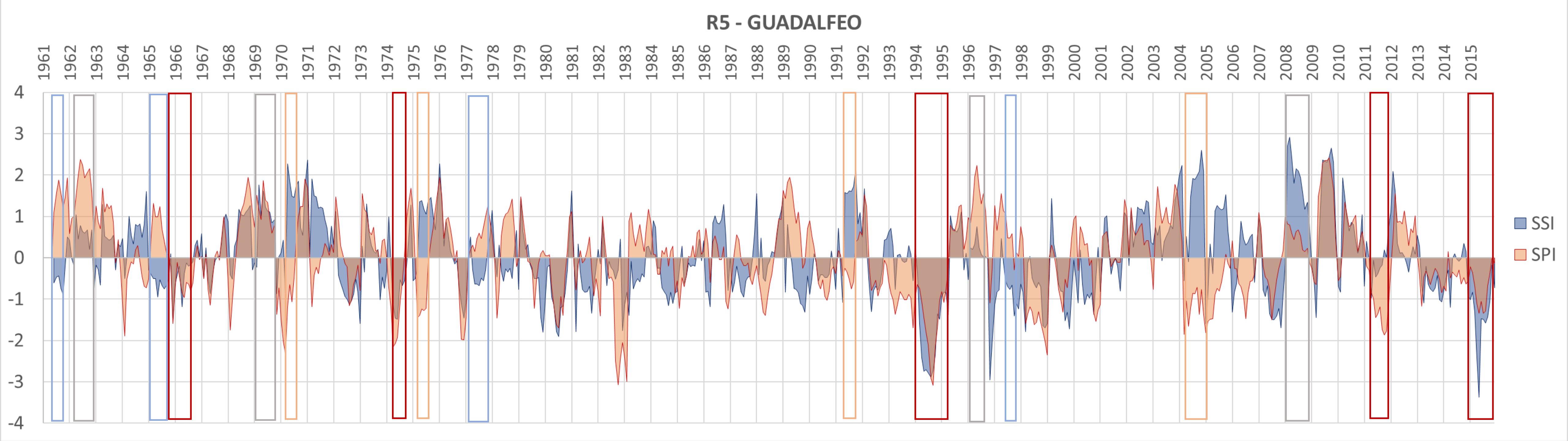
CLASSIFICATION

1 → SPI <0 , SSI <0 METEOROLOGICAL DROUGHT

2 → SPI <0 , SSI >0 RAINFALL DROUGHT

3 → SPI >0 , SSI <0 SNOWFALL DROUGHT ("T-drought")

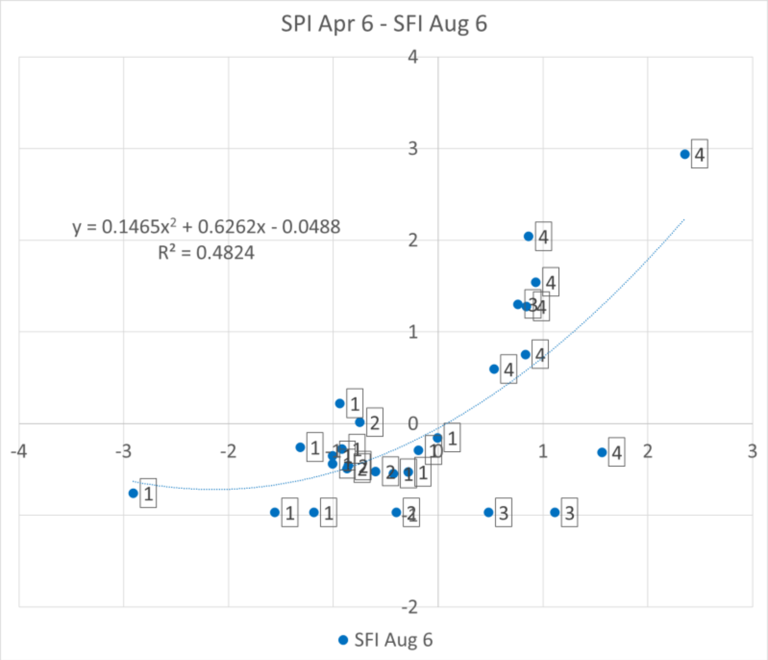
4 → SPI >0 , SSI >0 NO DROUGHT

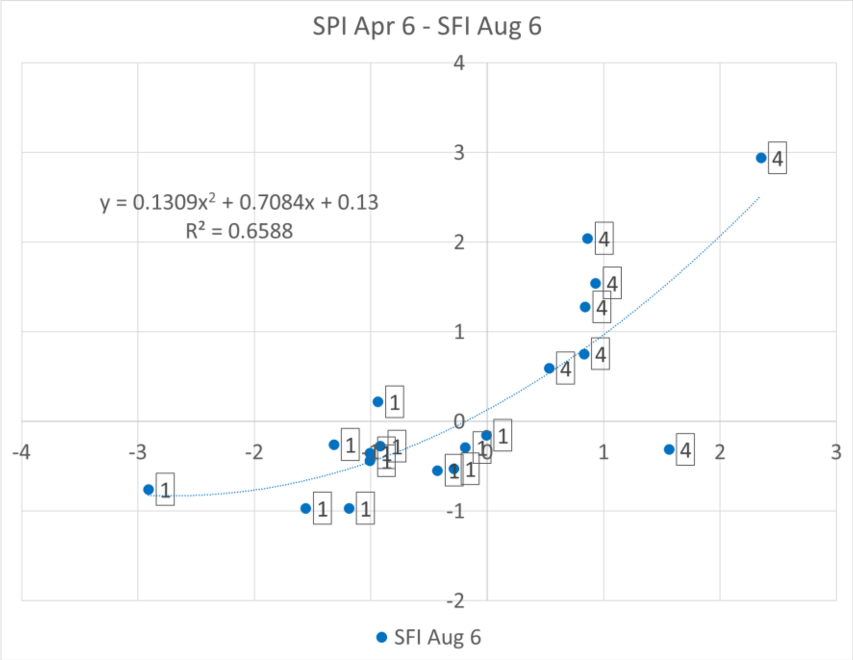


GUADALFEO	DROUGHT, 1	RAINFALL, 2	SNOWFALL, 3	NO DROUGHT, 4
(%)	34.10	15.90	18.81	31.19

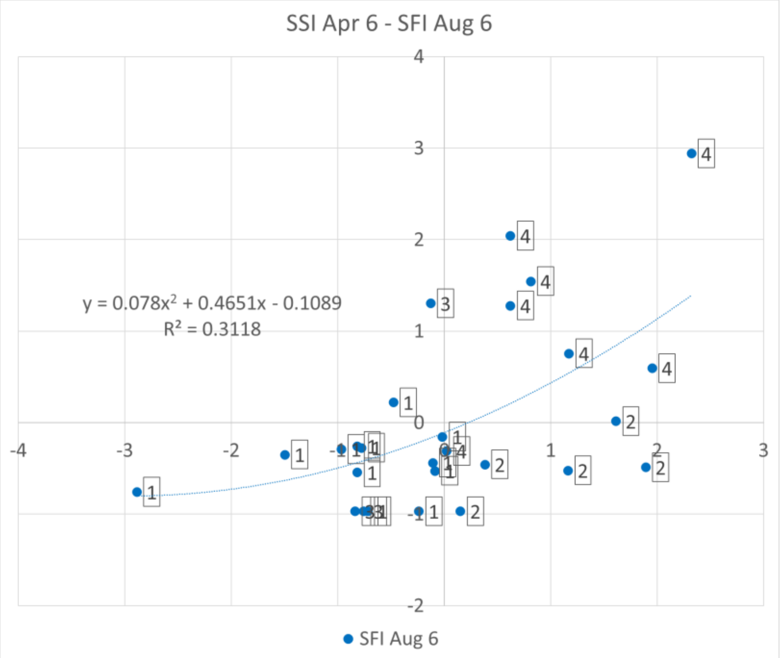
Flow (SFI) 6-month drought indexes in August in the study area (1989-2015)

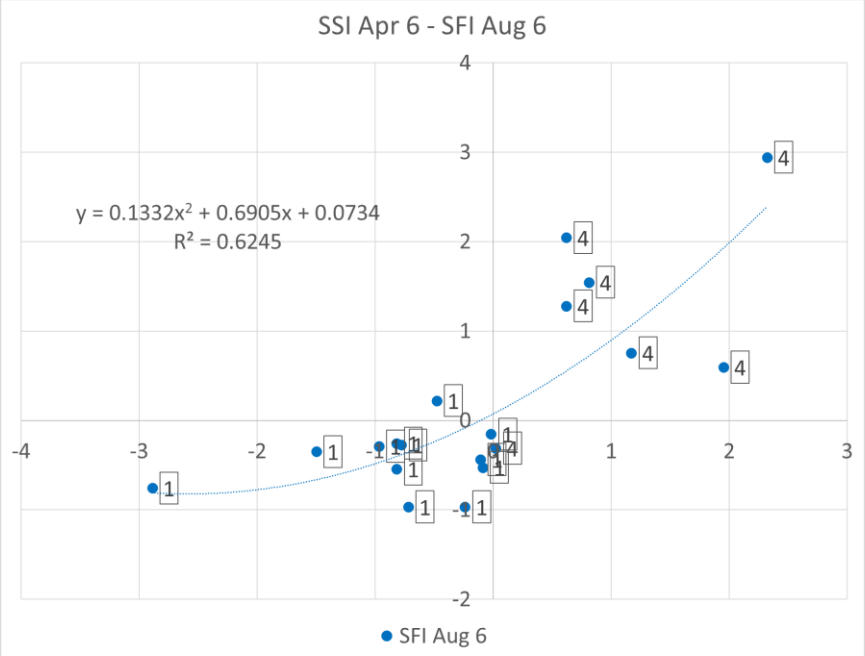
$SPI_{6\text{-m, April}}$ versus $SFI_{6\text{-m, August}}$





$SSI_{6\text{-m, April}}$ versus $SFI_{6\text{-m, August}}$

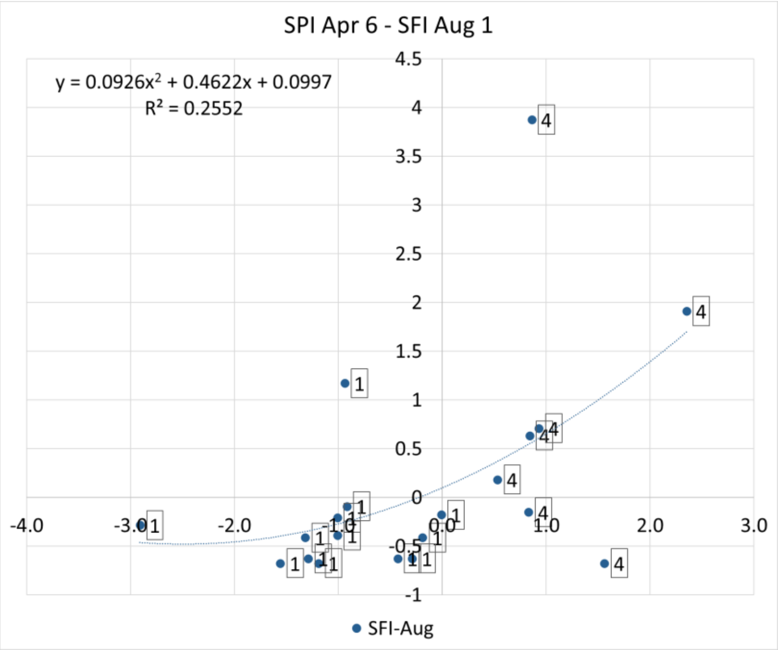




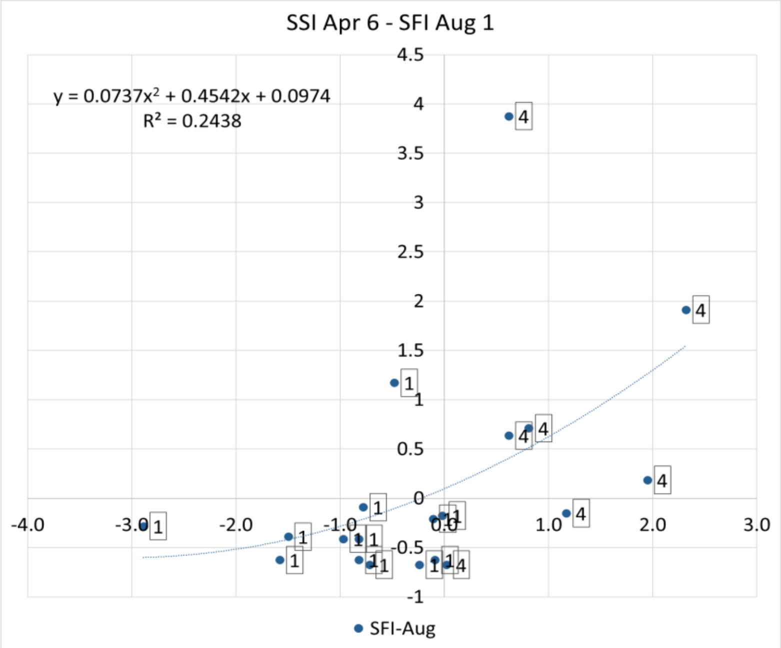
Situations 1 and 4: homogeneous behaviour P, S

Flow (SFI) 1-month drought indexes in August in the study area (1989-2015)

$SPI_{6\text{-}m,\ April}$ versus $SFI_{1\text{-}m,\ August}$



$SSI_{6\text{-}m,\ April}$ versus $SFI_{1\text{-}m,\ August}$

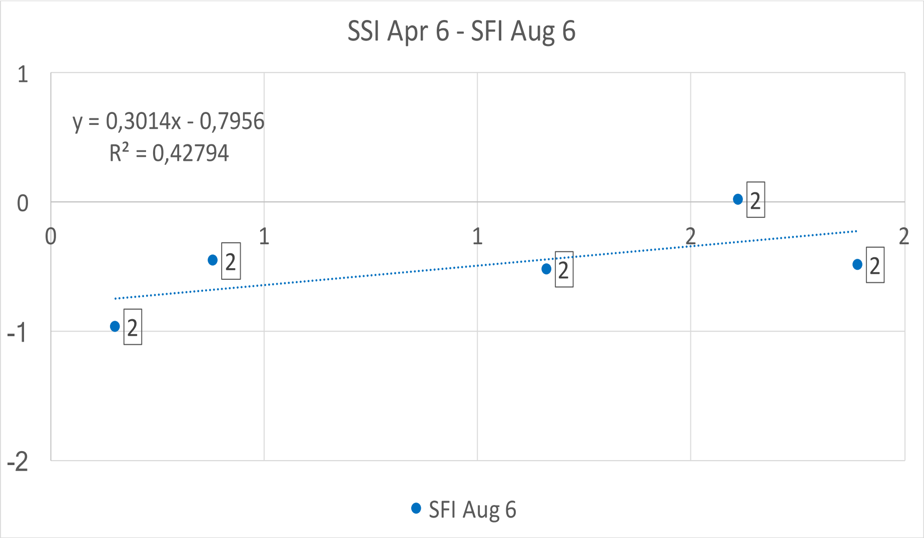


Situations 1 and 4: homogeneous behaviour P, S

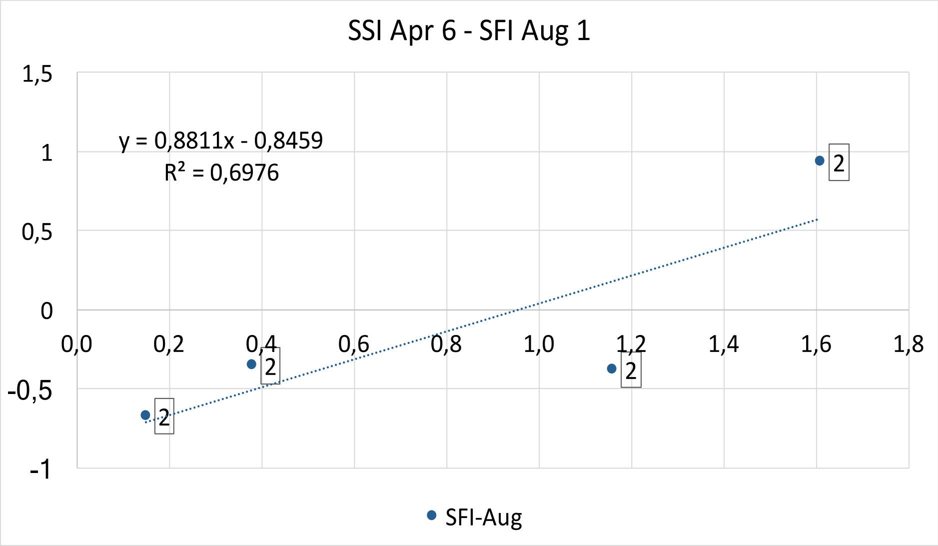
Need to include the 3-month period May-July to consider late spring precipitation as rainfall or snowfall

Flow (SFI) 1 and 6-month drought indexes in August in the study area for situation 2 (1989-2015)

$SSI_{6\text{-m, April}}$ versus $SFI_{6\text{-m, August}}$



$SSI_{6\text{-m, April}}$ versus $SFI_{1\text{-m, August}}$



Situation 2 : rainfall (only) drought (SPI <0, but SSI >0)

A critical threshold window could be identified for SSI indexes in April over which snowfall can mitigate the impact of rainfall deficit on river flow

CONCLUSIONS

Summary and on-going work

Science Question

What (and why…) are the major impacts of the snowpack dynamics on the fluvial regime on different time scales ?

- Precipitation and drought indexes can be used to identify snowfall drought typologies, and the 6-month scale is significant for hydrological impact in spring-summer
- Both SPI and SSI 6-month indexes in April are related to river flow anomalies for meteorological drought and precipitation excess, on 6- and 1-month flow in August
- SPI and SSI 6-month indexes can be jointly used to identify drought typology 2 (SSI >0, i.e. cold wet season), which seems to be related to flow anomalies in August on both 6- and 1- month scales
- Longer river flow series are needed to validate these initial results for less frequent drought typologies that, however, could increase in the future.

Societal Challenge and on-going work

These indexes constitute simple but promising tools in operational decision making for reservoir management to face potential situations of water scarcity on the medium and long term

(following our work in Sebok et al., 2022, in HESS; Pasten et al., 2022, in JH-Reg; Contreras et al., 2020, in Water)

- Use of simulated series of monthly flow to cover the whole historical period of precipitation data
- Assess the role of sublimation in hydrological drought in the study area
- Validate the results in other study areas, and establish snowfall thresholds that mitigate drought impacts on flow


Thank you very much for your attention!
https://www.uco.es/dfh/

Contact: mjpolo@uco.es

ACKNOWLEDGEMENTS:

This work was funded by the Spanish Ministry of Science, Innovation and Universities- MICINN, Research Project RTI2018-099043-B-I00. "Operability in hydrological management under snow torrentiality/drought conditions in high mountain in semiarid watersheds (OPERA)". This research line is included in the *Panta Rhei Decade* from the *International Association of Hidrological Sciences (IAHS),* Working Group on *Water and energy fluxes in a changing environment*.

R.Pimentel and P.Torralbo acknowledge the Juan de la Cierva de Incorporación and the FPU programs for senior researchers and PhD students, respectively, of the Spanish Government