REGIONAL ASSESMENT OF STREAMFLOW RESPONSE TO DROUGHT AT DIFFERENT TIME SCALES IN THE IBERIAN PENINSULA

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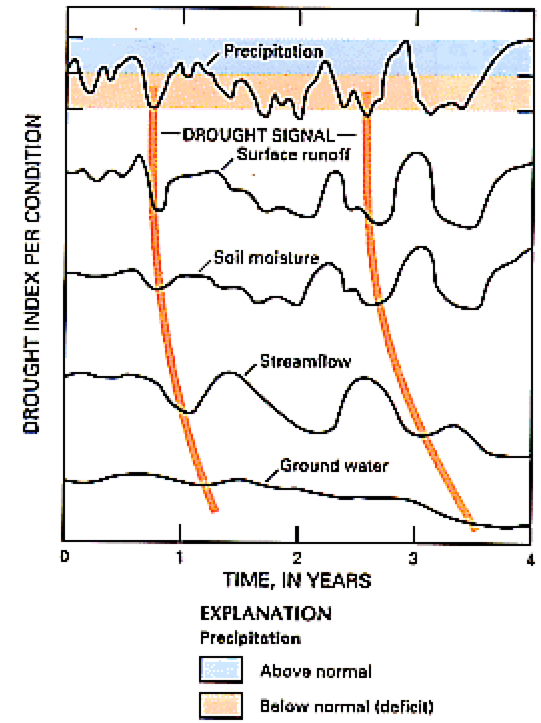
- The assessment of **global change impacts on hydrology** requires the determination of the relationships between climatic variability and river flows.

- Several factors determines and alter the **hydrological response to climatic droughts** (water regulation, revegetation processes, delayed snow melting, aquifer recharge, etc.)

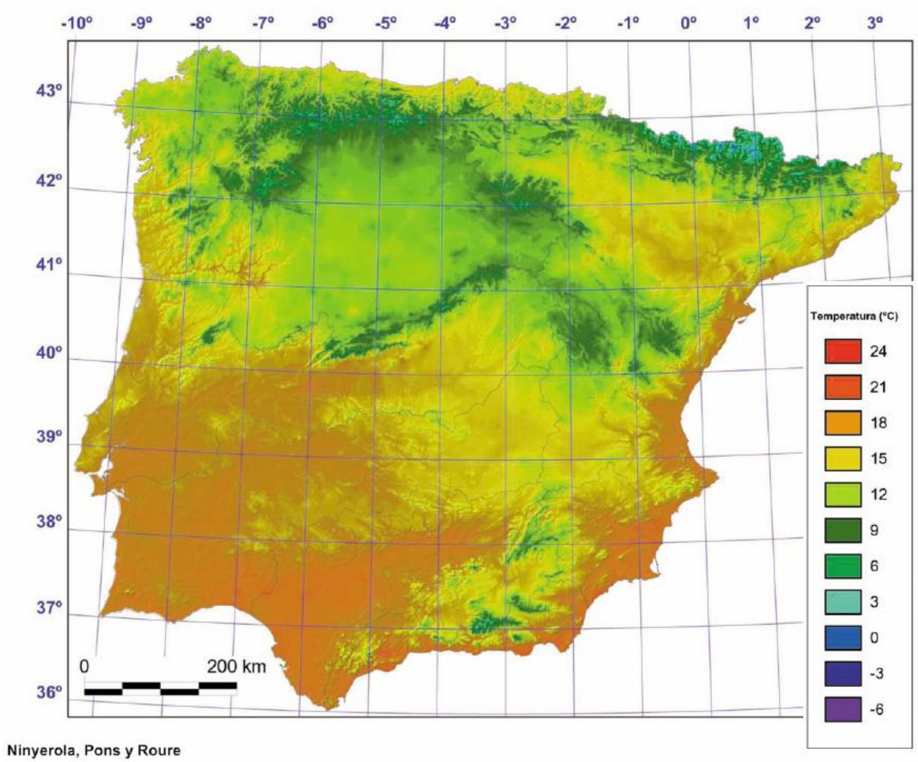
- Traditionally **droughts types** have been classified according to the time scale in which the effects of low precipitation rates become evident in the different systems integrating the hydrological cycle (Changnon & Easterling, 1989). **Streamflow drought** generally occurs several months after the precipitation drought episode.

- Here we analyzed the delayed response of Iberian streamflows to accumulated climatic drought conditions at different time scales and the **alterations induced by water management.**

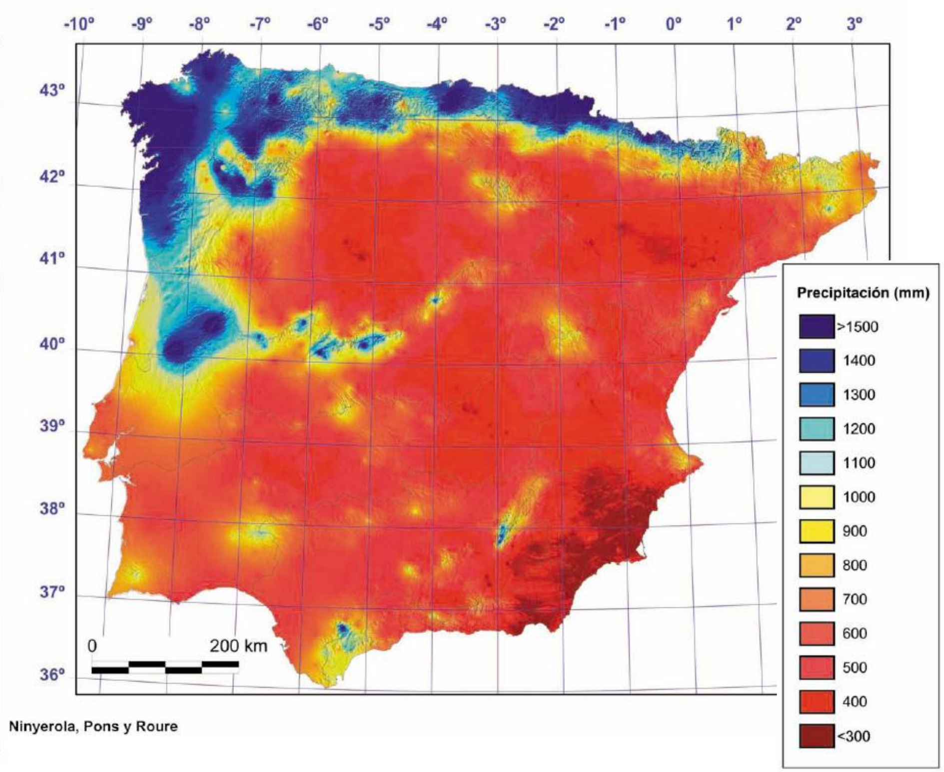


Changnon, S. A. and Easterling, W. E. (1989): *Measuring Drought Impacts: The Illinois Case*, *Water Res. Bull. 25, 27-42.*

Mean Annual Temperature



Mean Annual Precipitation



- The contrasting distribution of precipitation and temperature in the Iberian Peninsula (IP) generates a **wide variety of streamflow regimes** and **recurrent drought episodes**.

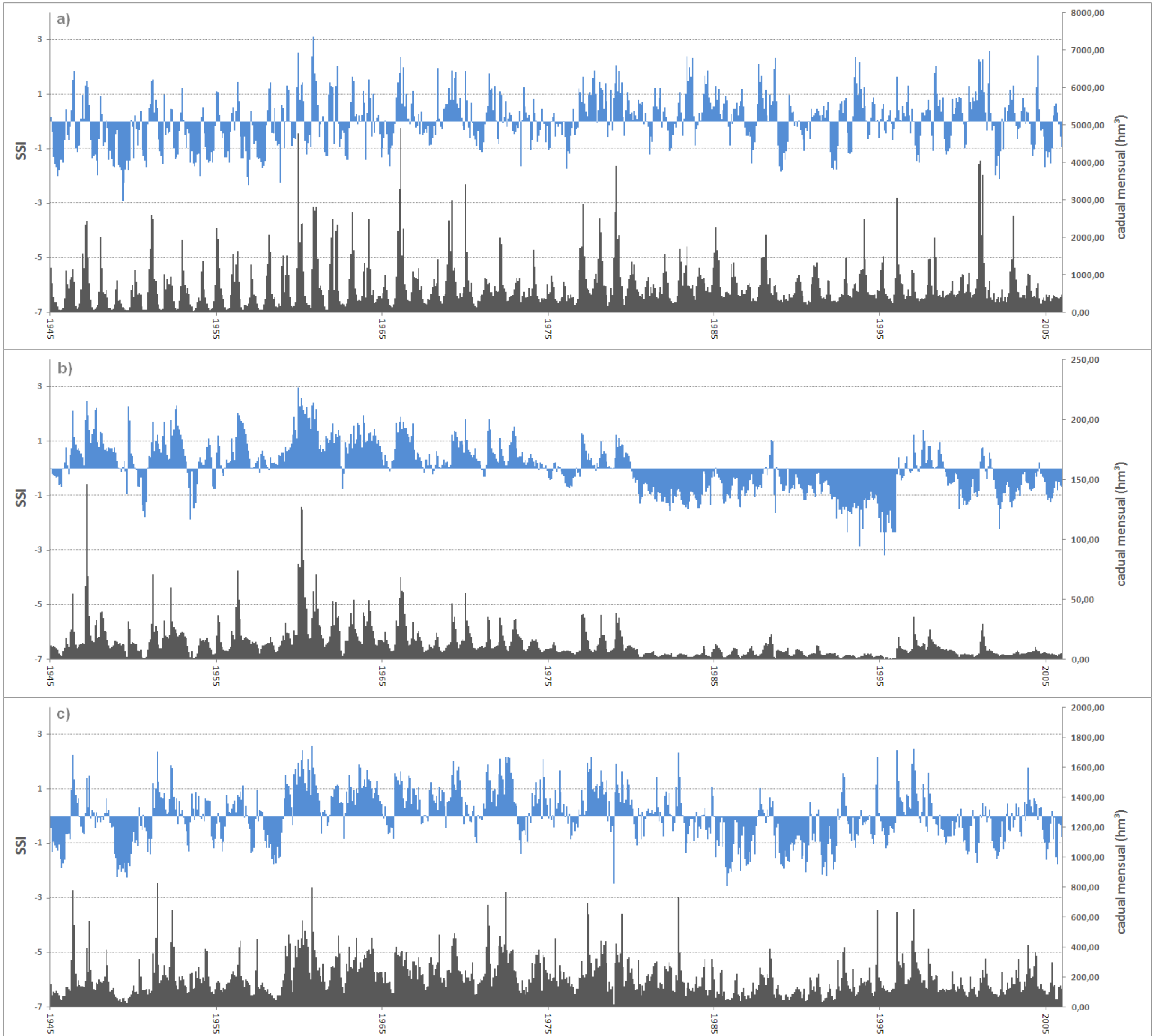
- The iberian rivers are **highly regulated**. There are 1195 great reservoirs in IP which together accounted for a total storage capacity of 56500hm³, the equivalent to the mean annual streamflow of the eight major rivers.

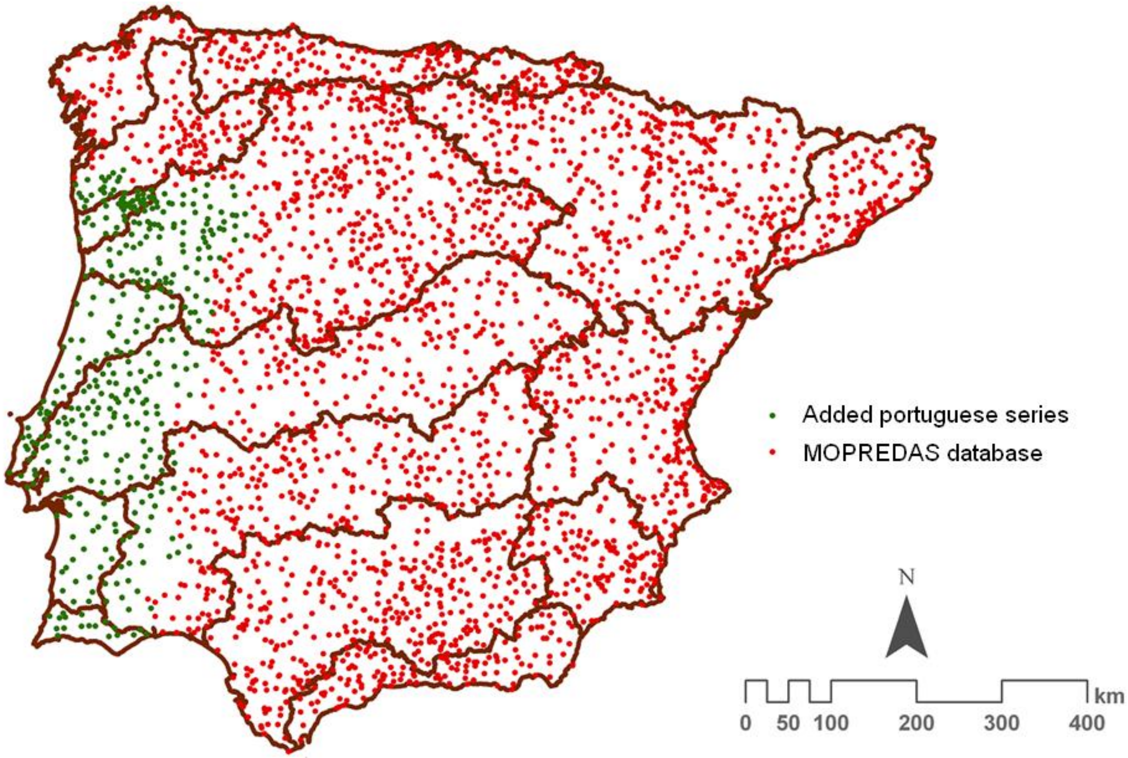
- **Hydrological database**

The final database (after the gap filling process and quality control) was composed by **187 monthly streamflow series** (for the period 1945-2005) of contrasted and tested quality. This database covers the entire IP and the most important basins (Lorenzo-Lacruz et al., 2012). We calculated a robust streamflow index (**Standardized Streamflow Index**; Vicente-Serrano et al., 2011) by standardizing every monthly streamflow series using the most suitable probability distribution among the general extreme value (GEV), Pearson III, log-logistic, lognormal, generalized Pareto and Weibull distributions.

Lorenzo-Lacruz, J., Vicente-Serrano, S.M., López-Moreno, J.I., Morán-Tejeda, E. , Zabalza, J. (2012*): Recent trends in Iberian streamflows (1945-2005),* Journal of Hydrology 414-415, 463-475.

Vicente-Serrano, S.M., López-Moreno, J.I., Beguería, S., Lorenzo-Lacruz, J., Azorin-Molina, C., Morán-Tejeda, E. (2011): *Accurate Computation of a Streamflow Drought Index*, Journal of Hydrologic Engineering, doi: http://dx.doi.org/10.1061/(ASCE)HE.1943-5584.0000433


a)
b)
c)
SSI
3
1
-1
-3
-5
-7
cadual mensual (hm³)
8000,00
7000,00
6000,00
5000,00
4000,00
3000,00
2000,00
1000,00
0,00
250,00
200,00
150,00
100,00
50,00
2000,00
1800,00
1600,00
1400,00
1200,00
1000,00
800,00
600,00
400,00
200,00
1945
1955
1965
1975
1985
1995
2005



- **Precipitation database**

  We added 386 monthly precipitation series of Portugal to the **MOPREDAS** database (Monthly Precipitation Database of Spain; González-Hidalgo et al., 2011) following the same approach for the quality control (anomalous data detection), the inhomogeneity analysis (Standard Normal Homogeneity Test; Alexandersson, 1986) and the reconstruccion process (using stations located at 10 and 25 km), in order to create the precipitation database used in this study (**3056 monthly precipitation series**).

González-Hidalgo, J.C., Brunetti, M., De-Luis, M. (2011): *A new tool for monthly precipitation analysis in Spain: MOPREDAS database (monthly precipitation trends December 1945–November 2005)*, International Journal of Climatology 31(5), 715–731.
Alexandersson, H. (1986): *A homogeneity test applied to precipitation data*, International Journal of Climatology 6, 661-675.

- **Regional precipitation series calculation**
  - Monthly values were **interpolated by an Ordinary Kriging**, using a local neighbourhood of nearest 15 station points for each prediction and a spherical variogram at a resolution of 10km.
  - The regional precipitation series for each drainage basin was calculated as the **mean value of each 10km pixel** contained in the catchments flowing at each gauging station.
  - We **calculated the mean SPI of the 187 basins** included in the study at different time scales (1 to 48 months) to account for the climatic variability of each basin.

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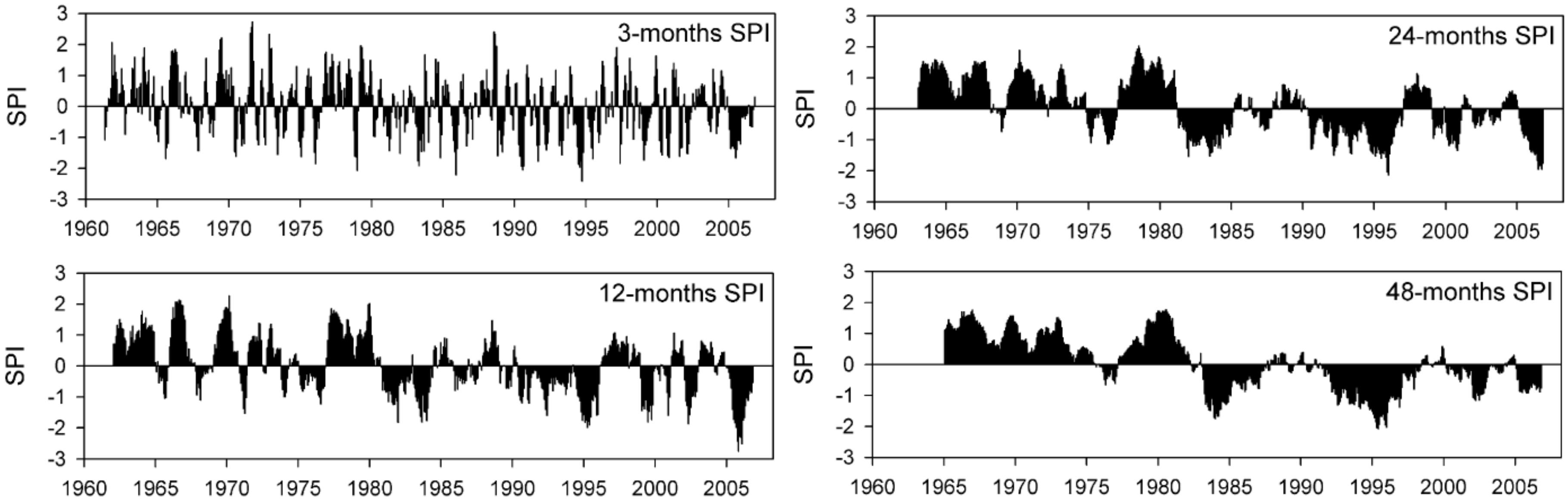

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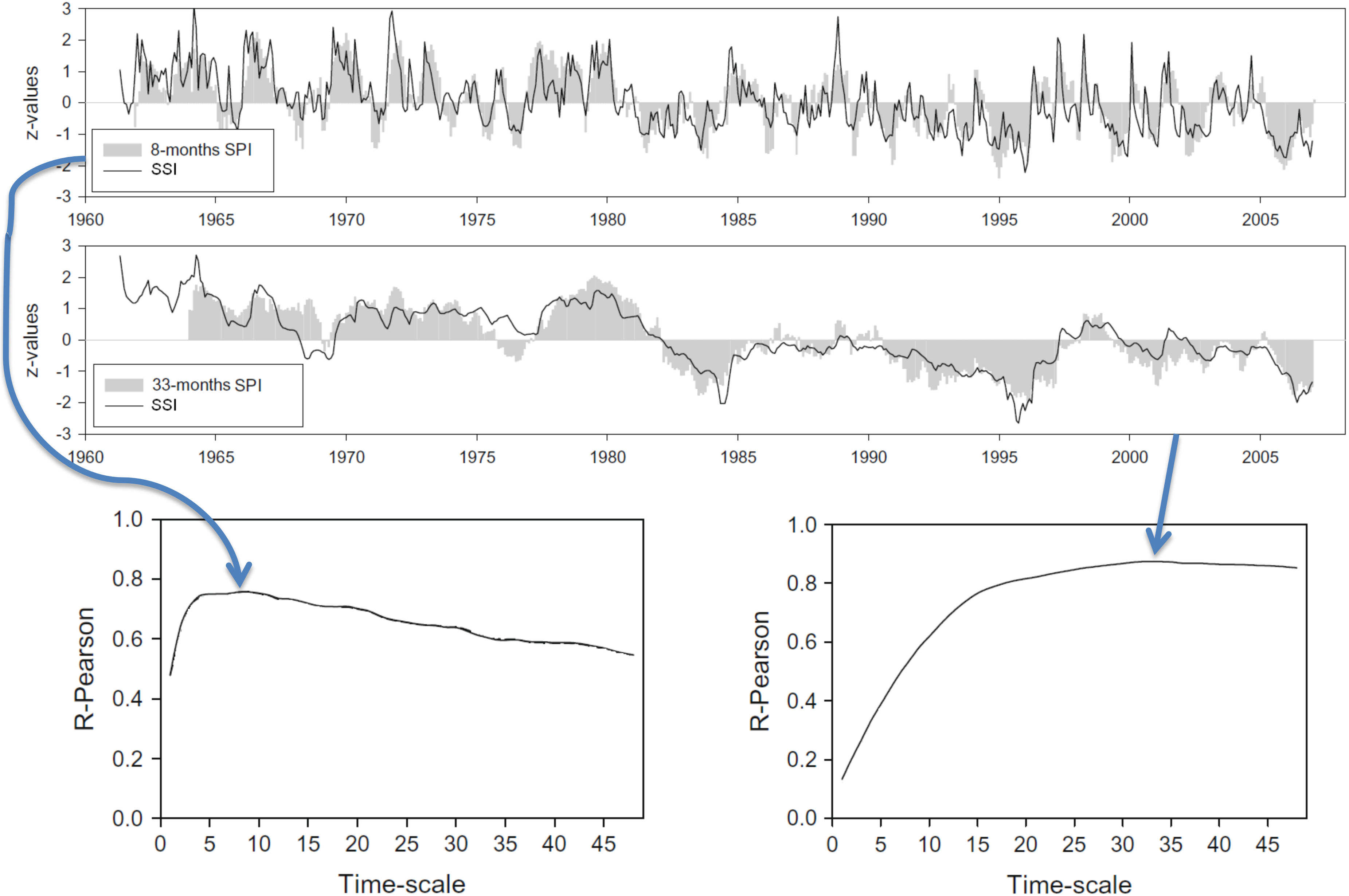
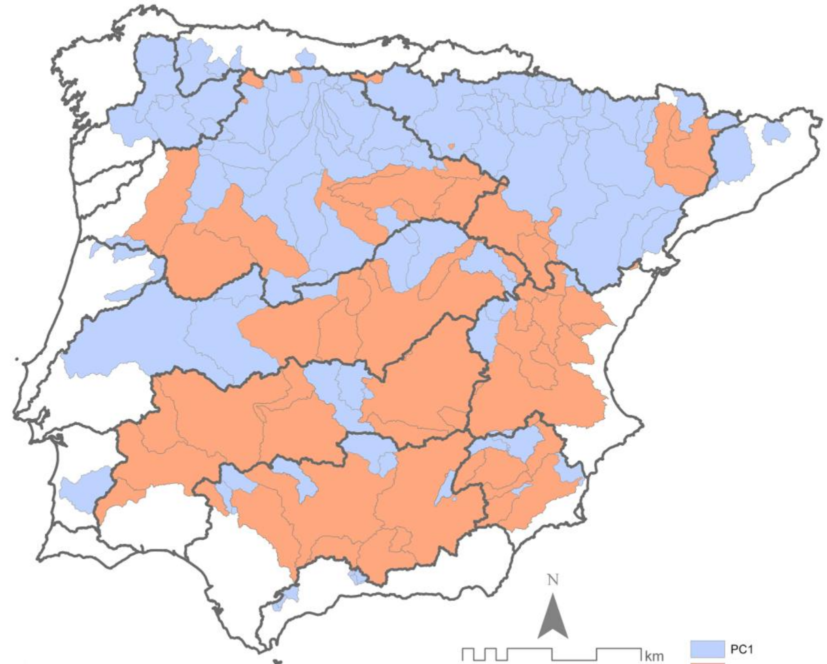
- **Statistical analysis**
  - We conducted **correlations (R Pearson) between the SSI and the SPI** of each basin at different time scales in order to obtain continuous correlation curves to summarize the hydrological response to climatic drought.
  - This analysis was carried out in three stages, distinguishing among non-regulated basins, basins regulated before 1945 and basins regulated during the study period (1945-2005).
  - For the last ones two correlations curves were calculated, before and after the damming. In each case the year of construction of the reservoir immediately upstream of each gauging station was considered.
  - We performed a Principal Component Analysis (PCA) in S mode in order to obtain general patterns related to the hydrological response to precedent climatic conditions. The basins area classified into the different Principal Components according to the maximum loading rule.

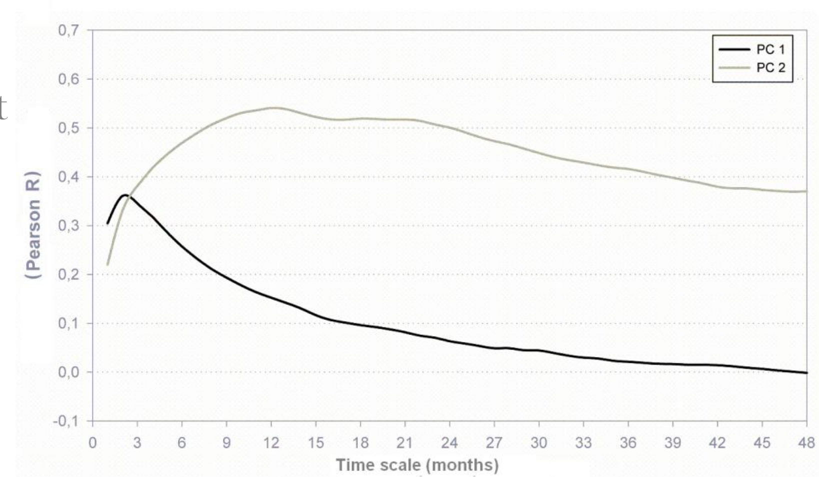

z-values
8-months SPI
SSI
33-months SPI
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
R-Pearson
Time-scale

- **187 basins included in the study**

  - **PC1** explains the 65.17% of the variance. It shows an **enhanced response during short time-scales**, especially between 1 and 4 months. (maximum correlation at 2-months scale). Spatially distributed along the great northern basins. This pattern was observed before in the **Pyrenees** by Vicente-Serrano y López-Moreno (2005) and in **Hungary** by Slazai et al., (2000).

  - **PC2** explains the 25.95% of the variance. The hydrological sensitiveness is low during short time-scales and it rises from 6-months scale and on. The maximum correlation is located at the 12-months scale (R=0.55) although a **sustainment of the response is registered at the longest time scales**. This pattern was observed before in the **headwaters of the Tagus river** (Lorenzo-Lacruz et al., 2010).





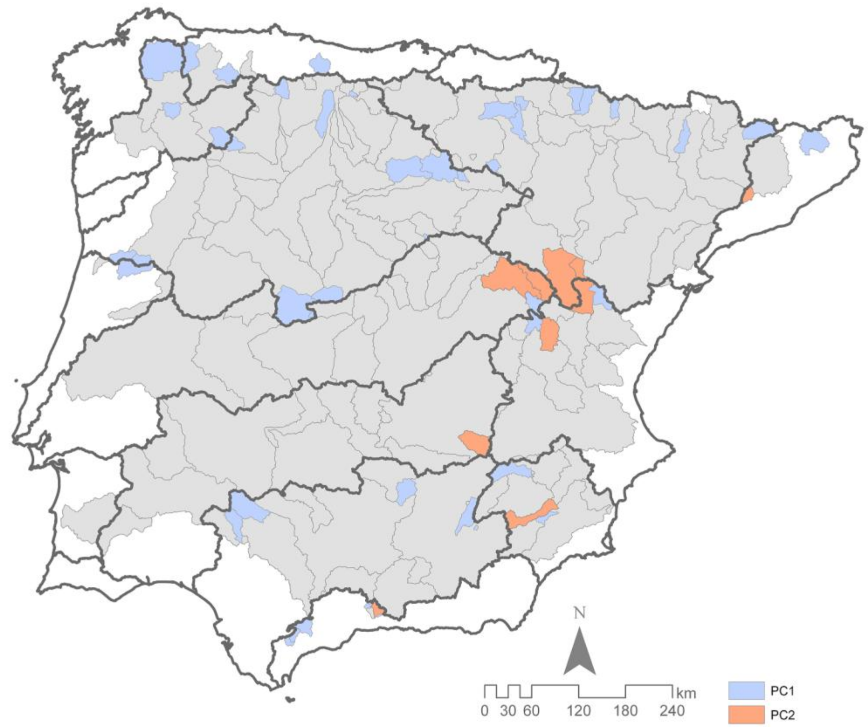
Szalai, S., Szinell, C. S., and Zoboki, J. (2000): *Drought monitoring in Hungary, in: Early warning systems for drought preparedness and drought management*, World Meteorological Organization, Lisboa, 182–199.

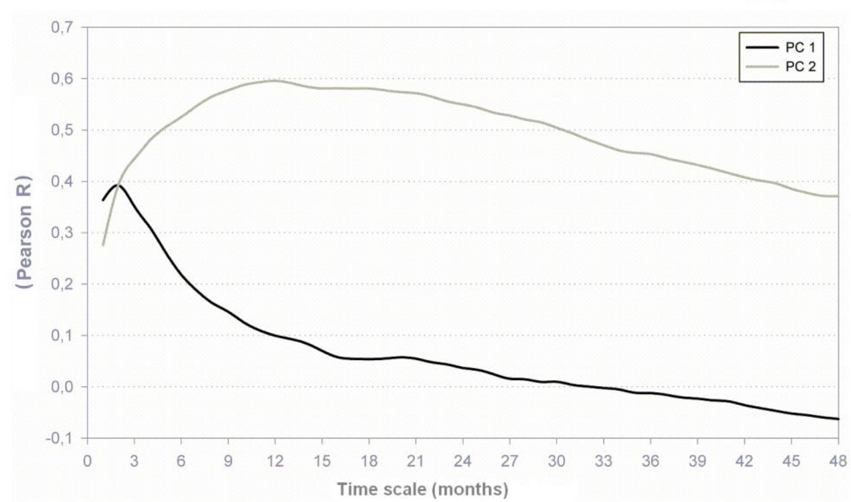
Vicente-Serrano, S. M. and López-Moreno, J. I. (2005): Hydrological response to different time scales of climatological drought: an evaluation of the Standardized Precipitation Index in a mountainous Mediterranean basin, Hydrology and Earth System Sciences 9, 523-533.

- **58 non-regulated basins**

  - **PC1** explains the 67.47% of the variance. The pattern of **response at short-time scale** is observed again, with the maximum correlation located at the 2-months scale. Spatially related to little **mountainous basins** draining from the Central, Cantrabrian and Pyrenean ranges with a low degree of permeability which generates fast and intense runoff processes.

  - **PC 2** explains the 19.29% of the variance. Characterized by a **low response at short time-scales which is enhanced from 6-months scale and on.** The maximum correlation is located at 12-months scale (r=0.59) and it is sustained and still significant during the rest of time-scales. This pattern encompasses the **headwaters of the Tagus, Jucar and Guadiana** basins. This **great temporal inertia** is closely related to **aquifer recharge** processes allowed by permeable lithologies.



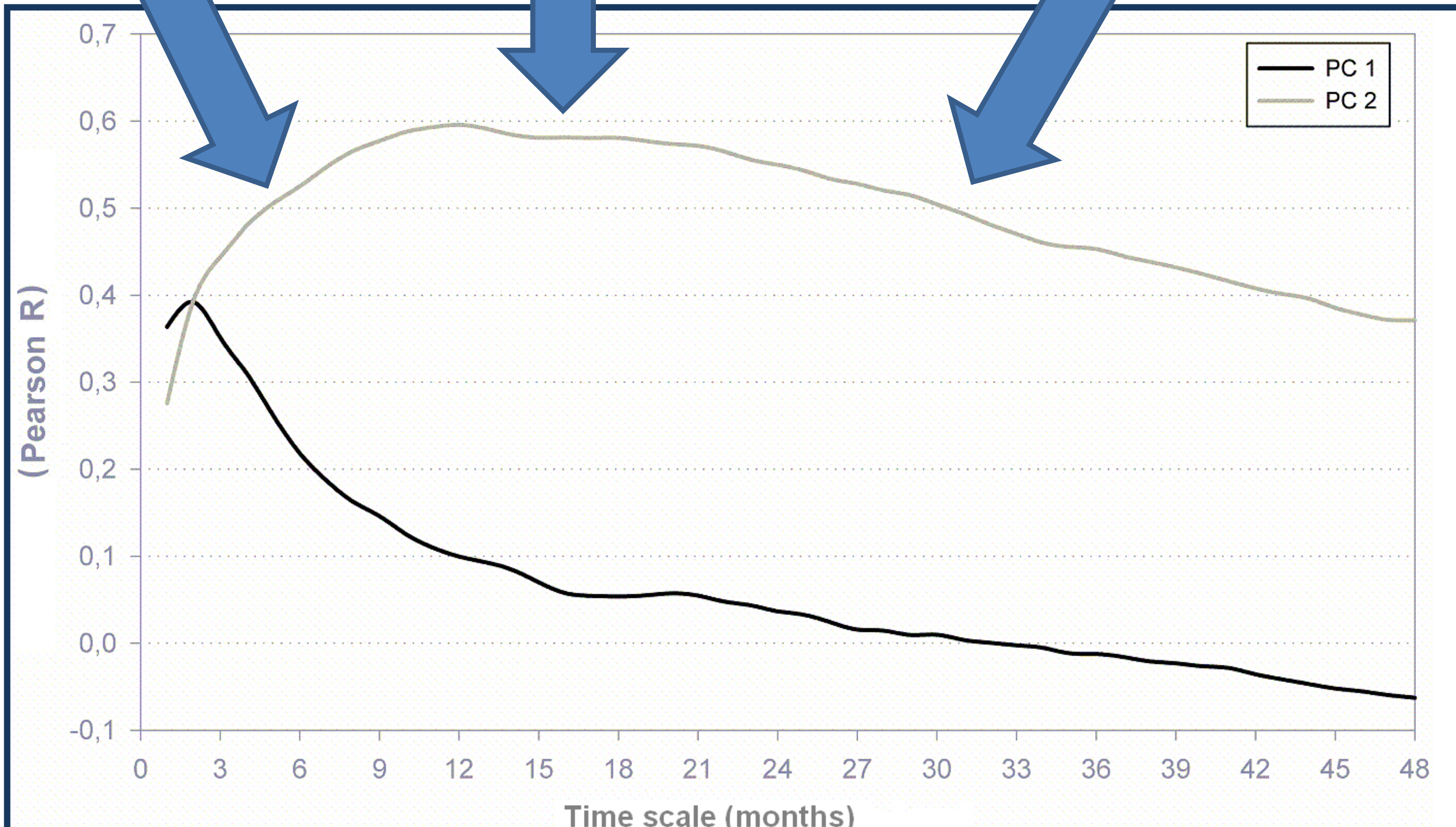


- **58 non-regulated basins**

Attenuation* of the deficits generated by droughts on discharges during the period of aquifer recharge

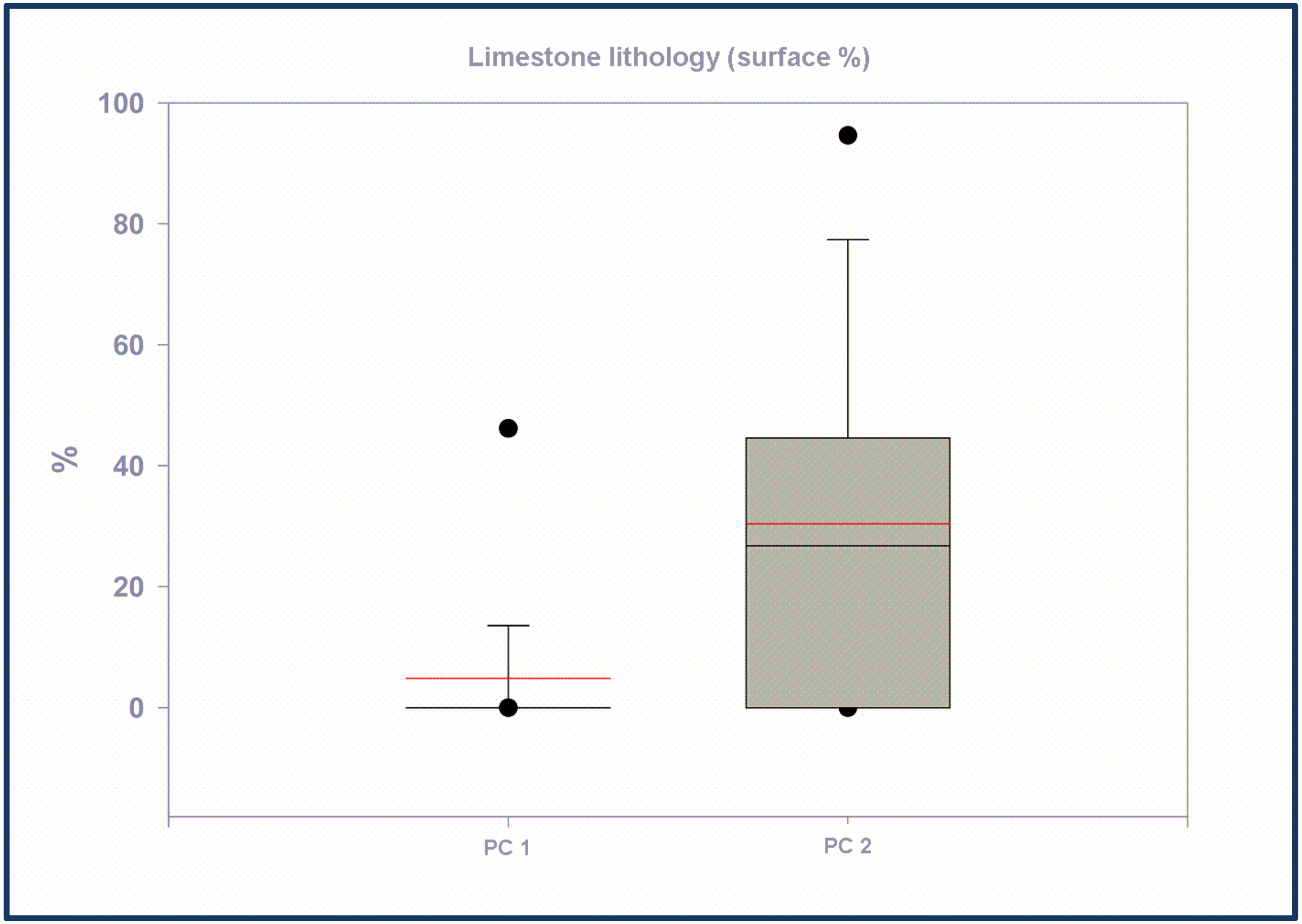
Delay* of the sensitiveness of the discharges when facing precipitation deficits

Synergistic effect * of the other two which creates long multiyear droughts



*Peters, E., Torfs, P.J.J.F., van Lanen, H.A.J., Bier, G.(2003): *Propagation of drought through groundwater—a new approach using linear reservoir theory*, Hydrological Processes 17, 3023–3040.

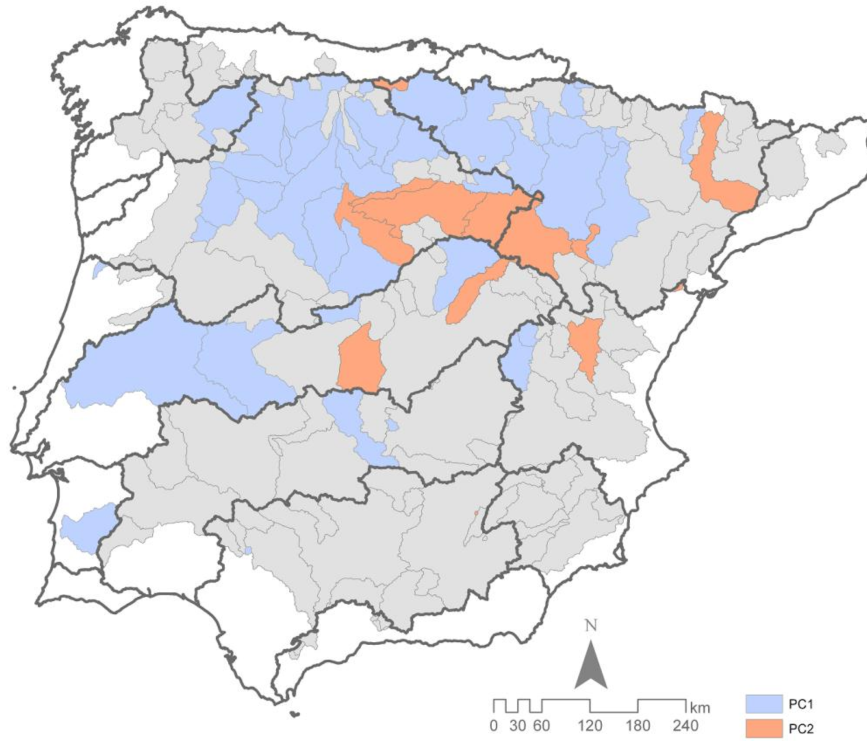
- **58 non-regulated basins**

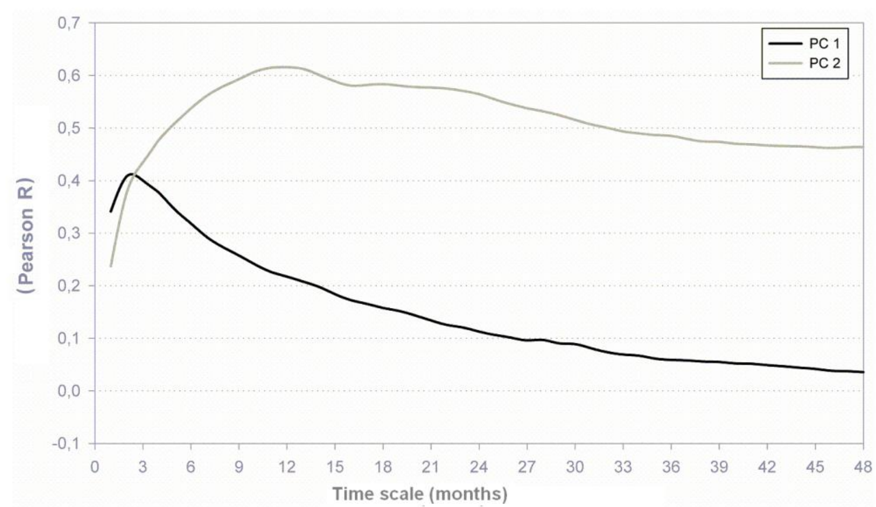


- **58 basins regulated before 1945**

  - The same patterns observed before appear again. PC1 explains the 70.2% of the variance and represents those **basins with intense responses during short time-scales:** high and medium reaches of the Ebro basin, the right bank tributaries of the Duero basin and de low Tagus basin.

  - PC2 explains the 21.7% of the variance and encompasses basins **with long temporal inertias** such as the headwaters of the Ebro and Duero rivers.

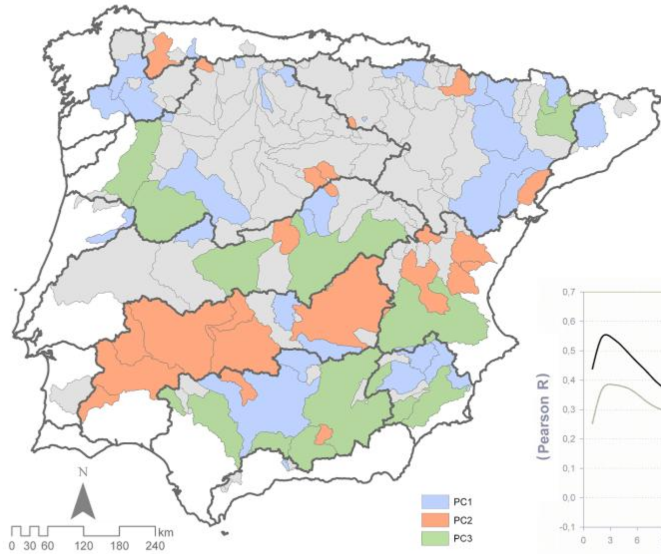


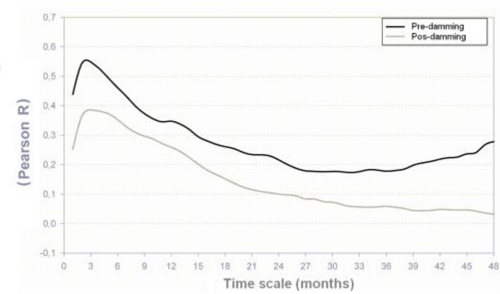


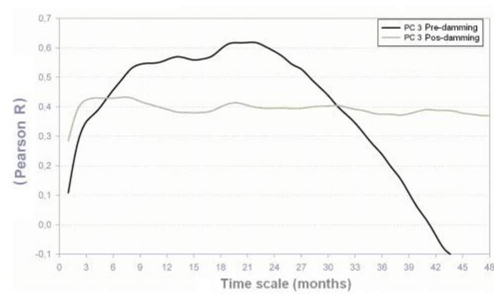
- **71 basins regulated between 1945-2005**

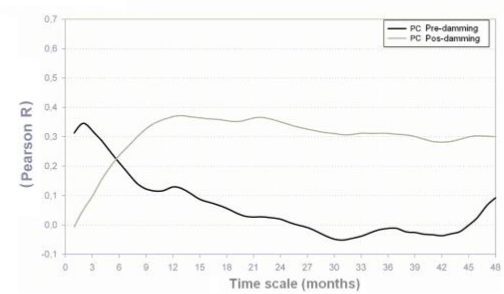
  - PC1 explain the 32.9% of the variance and shows a modification of the response pattern at short time scales already observed. Before the damming it showed high correlations (R>0.5) at the 2 and 3-months scales. **After the damming**, although the pattern of the curve was the same, **the sensitiveness to climatic conditions decreased**.

  - PC2 explains the 31.1% of the variance and shows a **inversion in the configuration of the curves:** before the damming it showed a greater response at short time-scales (maximum at 2-months scale). **After the damming correlations became significant from 6-months scale and on**, with a shape of the curve similar to the second great response pattern already observed.









  - PC3 explains the 19.6% of the variance. It is related to basins which before the damming showed a high response during medium and long time-scales. **After the damming**, they experienced a reduction in the sensitiveness to climatic variability and a **homogeneization of the temporal inertia along all the observed time-scales.**

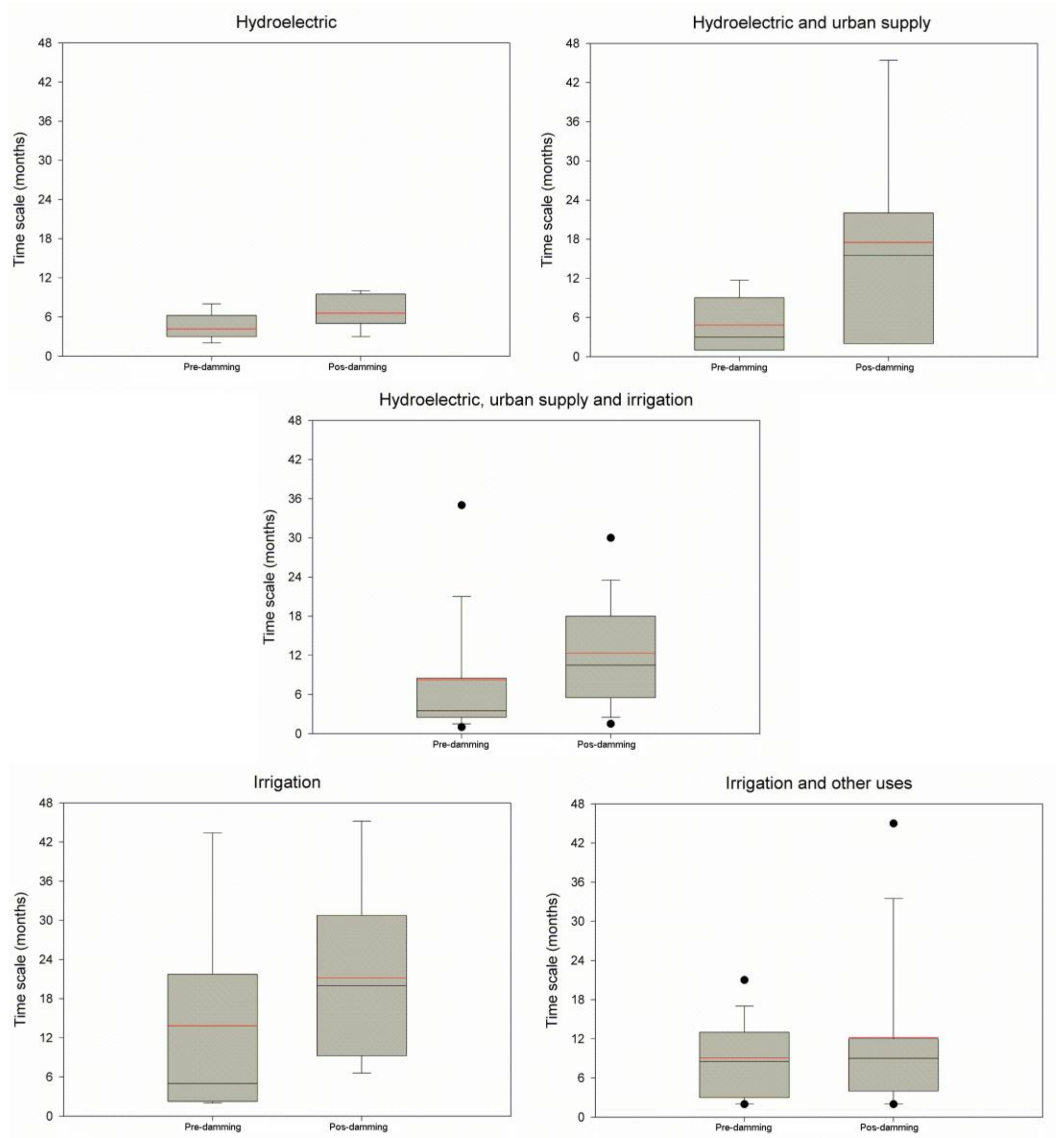
- **71 basins regulated between 1945-2005 (impact of water uses)**

  - There is a close relationship between reservoir capacity and the time-scale when the maximum correlation is reached (Kendall τ = 0.39).

  - Hydro-electric production do not introduced great temporal inertias in the response of streamflows to drought.

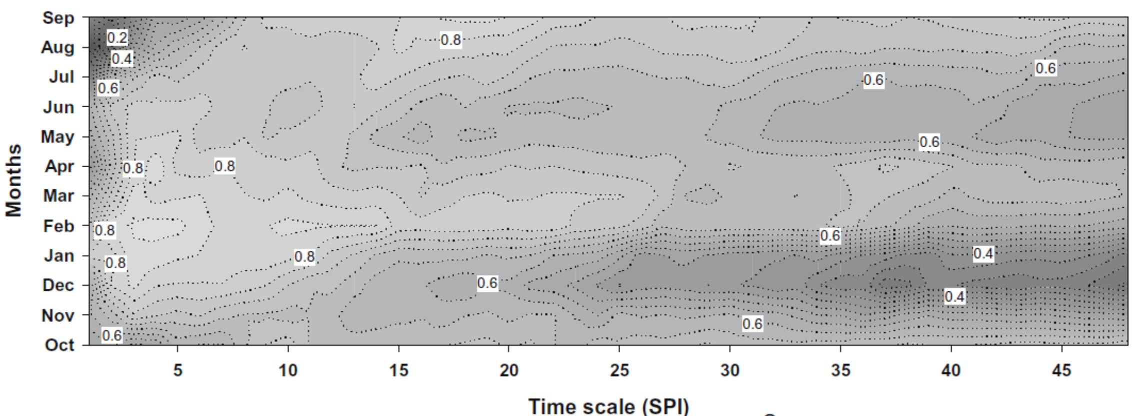
  - The mixed use (hydro-electric + urban supply or irrigation) generated great delays in the response.

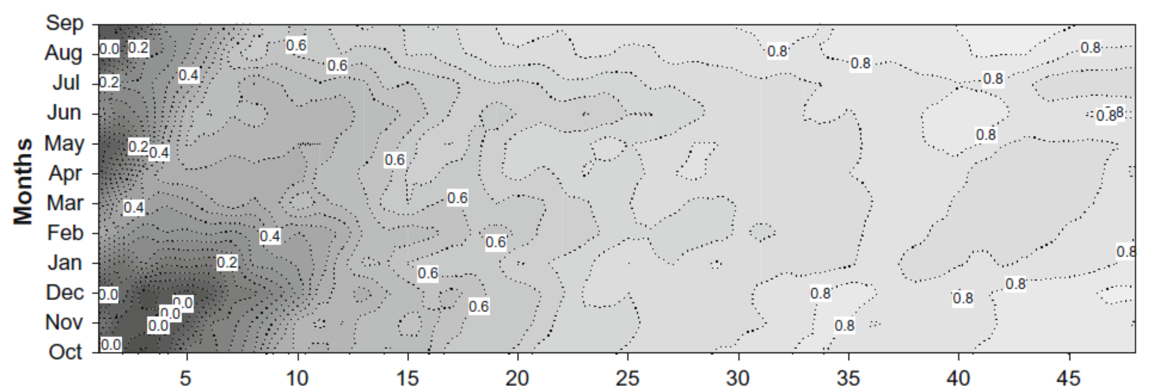
  - The exclusive use for irrigation also produced great delays in the sensitiveness of reservoir releases to precedent climatic drought conditions.



Arising questions

- **The low correlations of the basins with greater responses at short time-scales. Why this happens?:**
  - **The use of a PCA disguised some high correlations** (R≈0.7) by giving greater loadings to stations with lower correlations (R≈0.2) between the SSI and the SPI. The next stage in this work would be a **more specific analysis** of those basins with very low responses and the causes which generated them.
  - The **analysis based on continuous correlation curves also smoothed** the greatest monthly correlations (mainly observed during winter) with the lowest ones (mainly during summer). This is not the case of the pattern of response during longer time-scales, which shows a more regular monthly distribution of its sensitiveness.






THANK YOU