Co-funded by the Erasmus+ Programme of the European Union

DROUGHTS – GENERAL CONCEPTS

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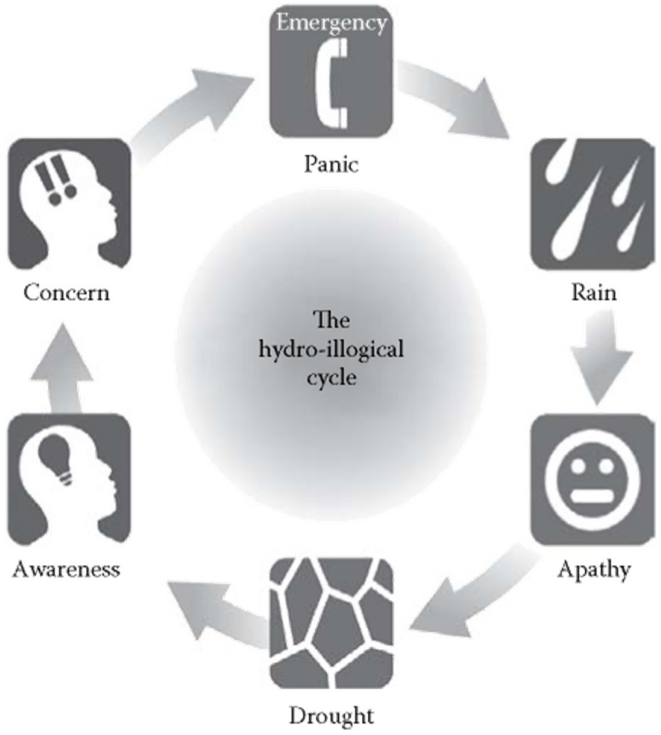
Strengthening of master curricula in water resources management for the Western Balkans HEIs and stakeholders

- ✓ **Droughts are among the most complex and least understood natural hazards, affecting more people than any other one. They are also recurrent hazards particularly in areas with pronounced natural hydrological temporal variability.**
- ✓ **Droughts are generally associated with persistence of low rainfall, soil moisture and water availability relative to the normal levels.**

(common definition)... **DROUGHT ⟷ a sustained and regionally extensive occurrence of below average natural water availability ...**

- ✓ **Although a drought can last for months to years they should not be confused with aridity**
- ✓ **Aridity is a permanent feature of the climate characterized by low rainfall**

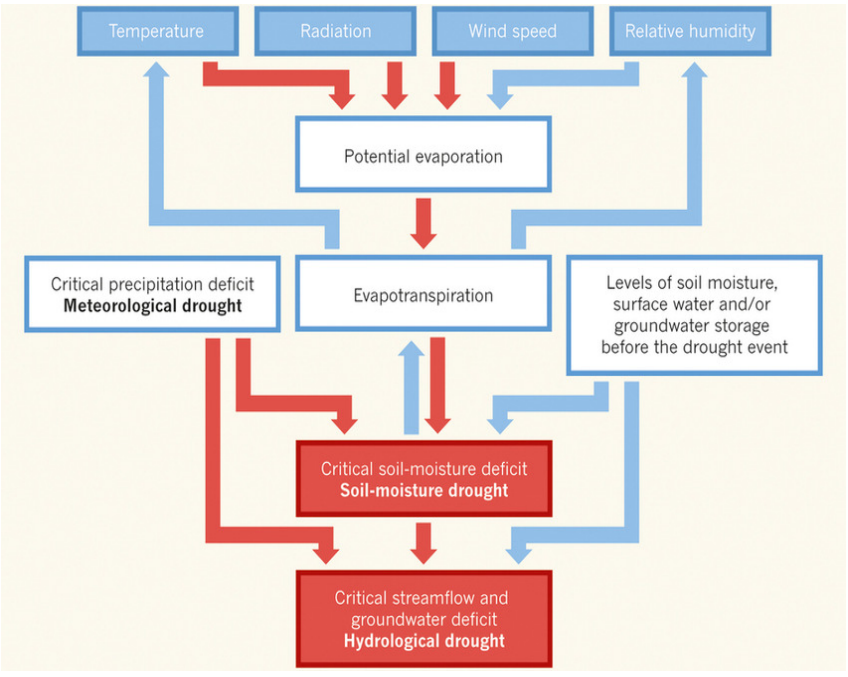


- ✓ **Different from other extreme events, like floods and earthquakes, droughts remain a less visible natural risk, whose impacts are not systematically recorded**

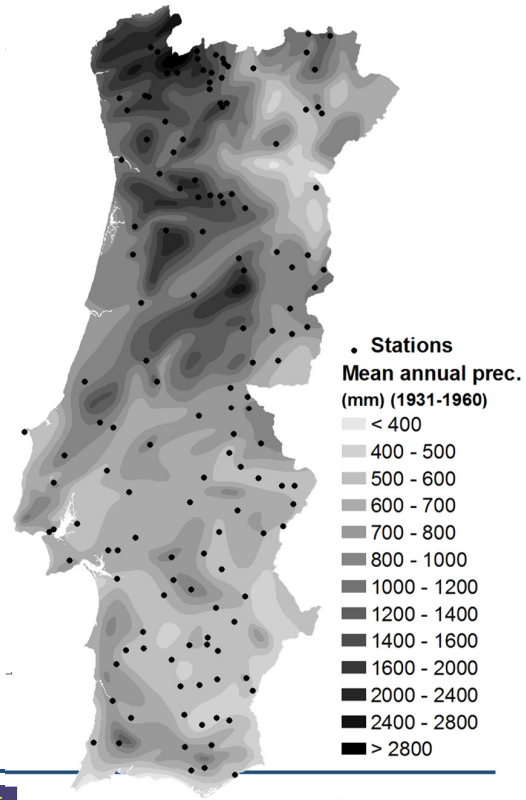
- ✓ **They develop cumulatively and quietly and by the time they are noticed it is often to late to act**

It is common to distinguish different **types of droughts**, according to their **consequences** and to the "**water resources reservoir**" affected by the water shortness (at the watershed level):

- ✓**Meteorological drought**
- ✓**agricultural**
- ✓ **hydrological**
- ✓**socioeconomic**

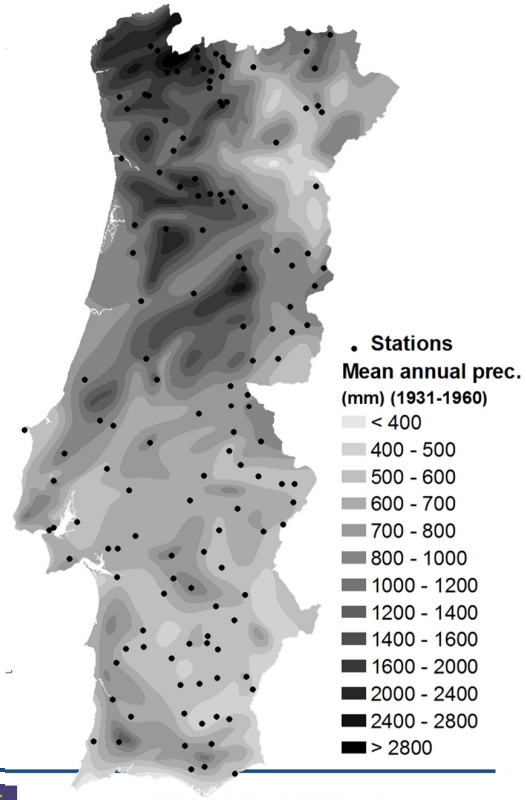


✓In **Portugal** droughts are recursive occurrences. One of the major events took place in **2005**, with about 80% of the country experiencing the worst drought since 1943/1944, with estimated associated costs of more than 285 million Euros.



✓In average, from **75% to 90%** of the precipitation occurs from **October to March** (wet semester). The mean annual precipitation varies from more than **2800 mm**, in the north-western region, to less than **400 mm**, in the southern region, following a complex spatial pattern in close connection with the relief

✓The **natural temporal variability** of the precipitation results in frequent **water shortages**, posing a great threat to nature, quality of life and economy and originating conflicts among competing water uses

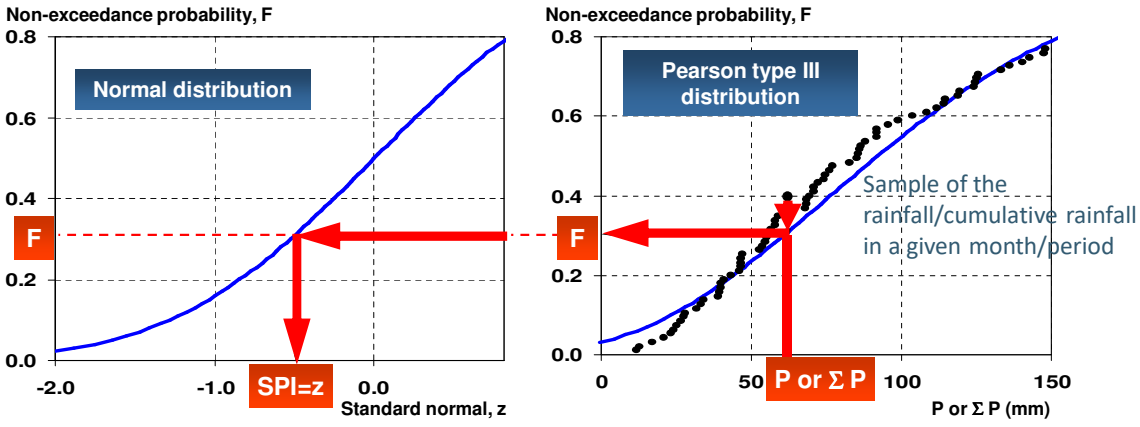


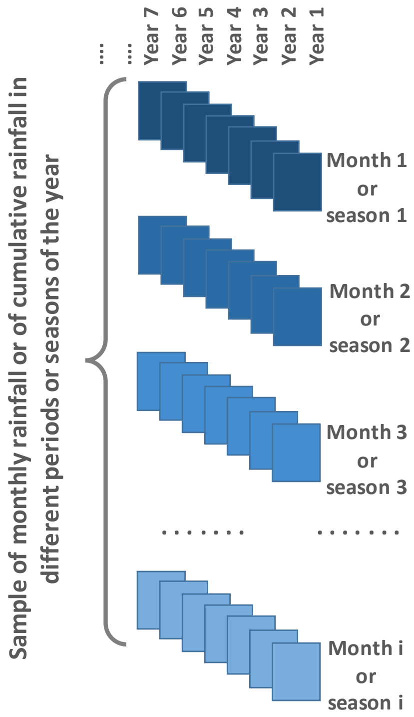
- ✓ **The characterization of the droughts uses indexes derived based from long-term time series of rainfall but also of other hydrological variables** (temperature, streamflow) **depending on the index applied**
- ✓ **One of the most common drought index is the Standardized Precipitation Index, SPI**
- ✓ **The SPI can be computed at different time scales – 1, 3** (meteorological droughts) **, 6, 12** (hydrological drought) **or 24 months – by adjusting a statistical law to the rainfall series at the considered time scale**
- ✓ **The Pearson Type III distribution with parameters given by the L-moments**

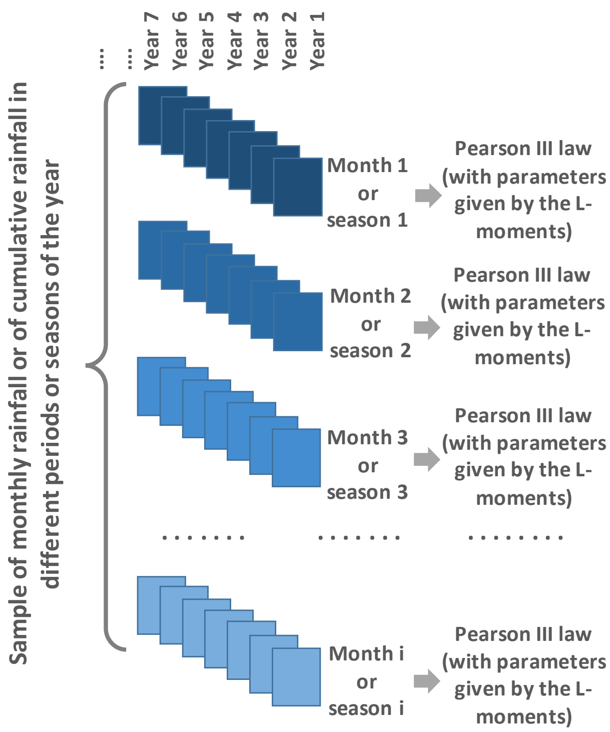
$$P_i \qquad \sum_{i}^{i+2} P_i \qquad \sum_{i}^{i+5} P_i$$

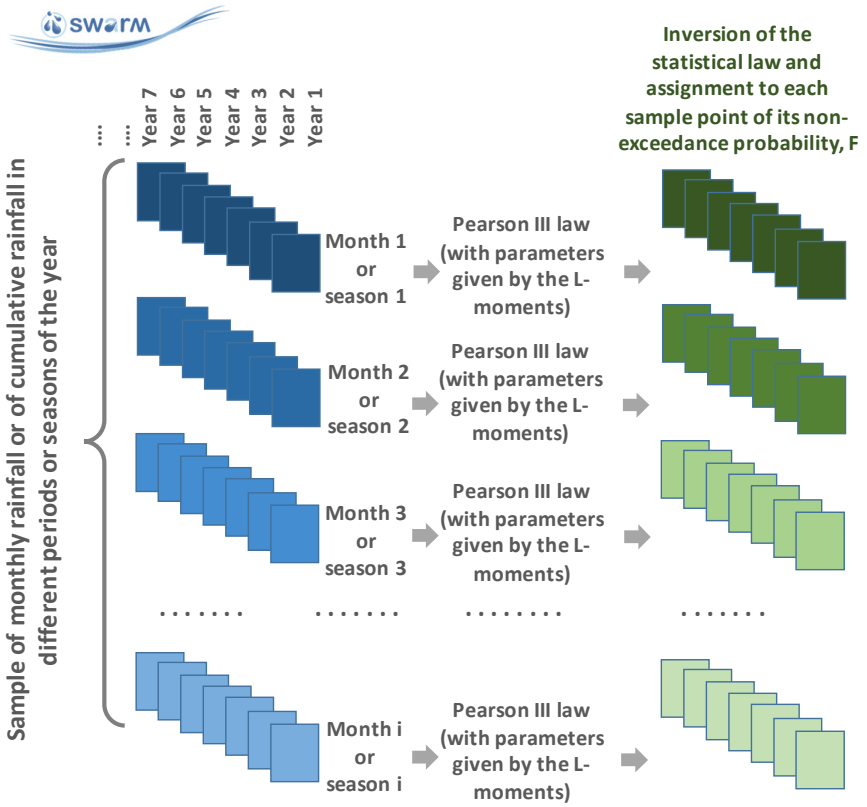
Precipitation series for computation of SPI		
SPI1	**SPI3**	**SPI6 …**
P_1	$\sum_{i=1}^{3} P_i$	$\sum_{i=1}^{6} P_i$
P_2	$\sum_{i=2}^{4} P_i$	$\sum_{i=2}^{7} P_i$
P_3	$\sum_{i=3}^{5} P_i$	$\sum_{i=3}^{8} P_i$
…	…	…
P_{12N-24}	$\sum_{i=12N-24}^{12N-22} P_i$	$\sum_{i=12N-24}^{12N-19} P_i$
P_{12N-23}	$\sum_{i=12N-23}^{12N-21} P_i$	$\sum_{i=12N-23}^{12N-18} P_i$
P_{12N-22}	$\sum_{i=12N-22}^{12N-20} P_i$	$\sum_{i=12N-22}^{12N-17} P_i$
…	…	…

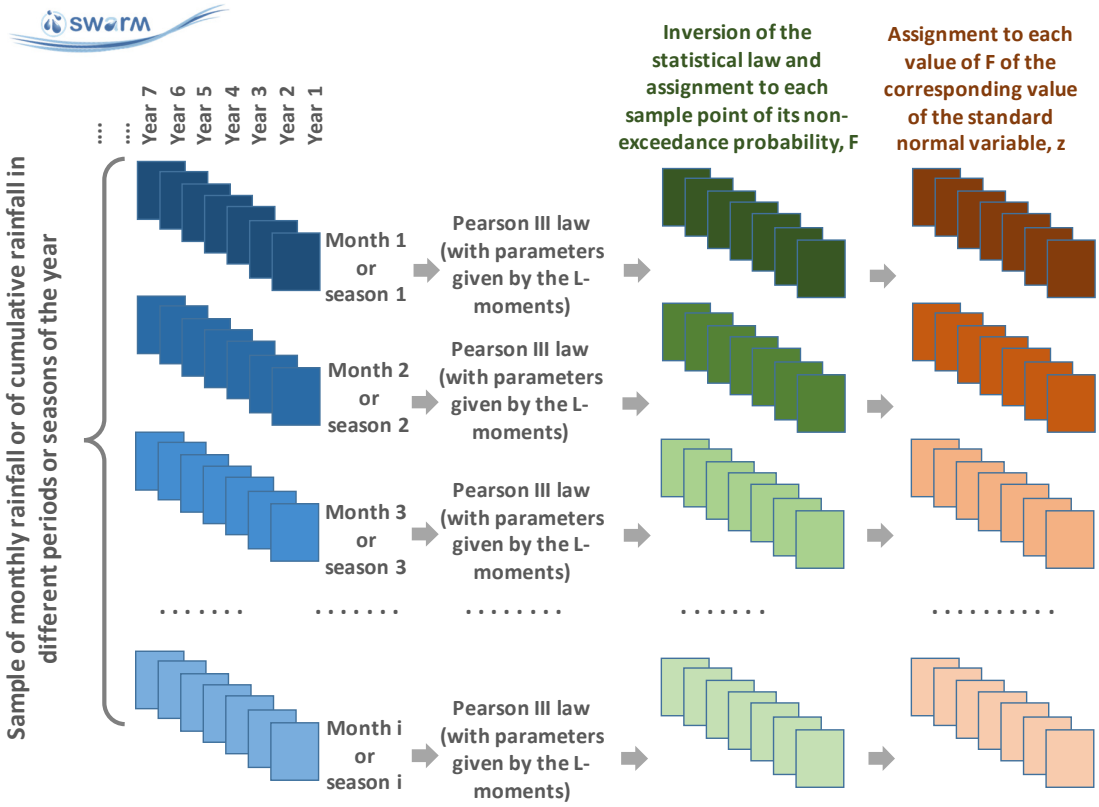
- ✓ **For the observed rainfall in a given month -** or for cumulative rainfall in a given period, depending on the time scale adopted in accordance with the type of drought being characterized **- the value of SPI is equal to the standard normal, z, for the non-exceedance probability, F, that corresponds to such rainfall, according to the Pearson Type III distribution,**

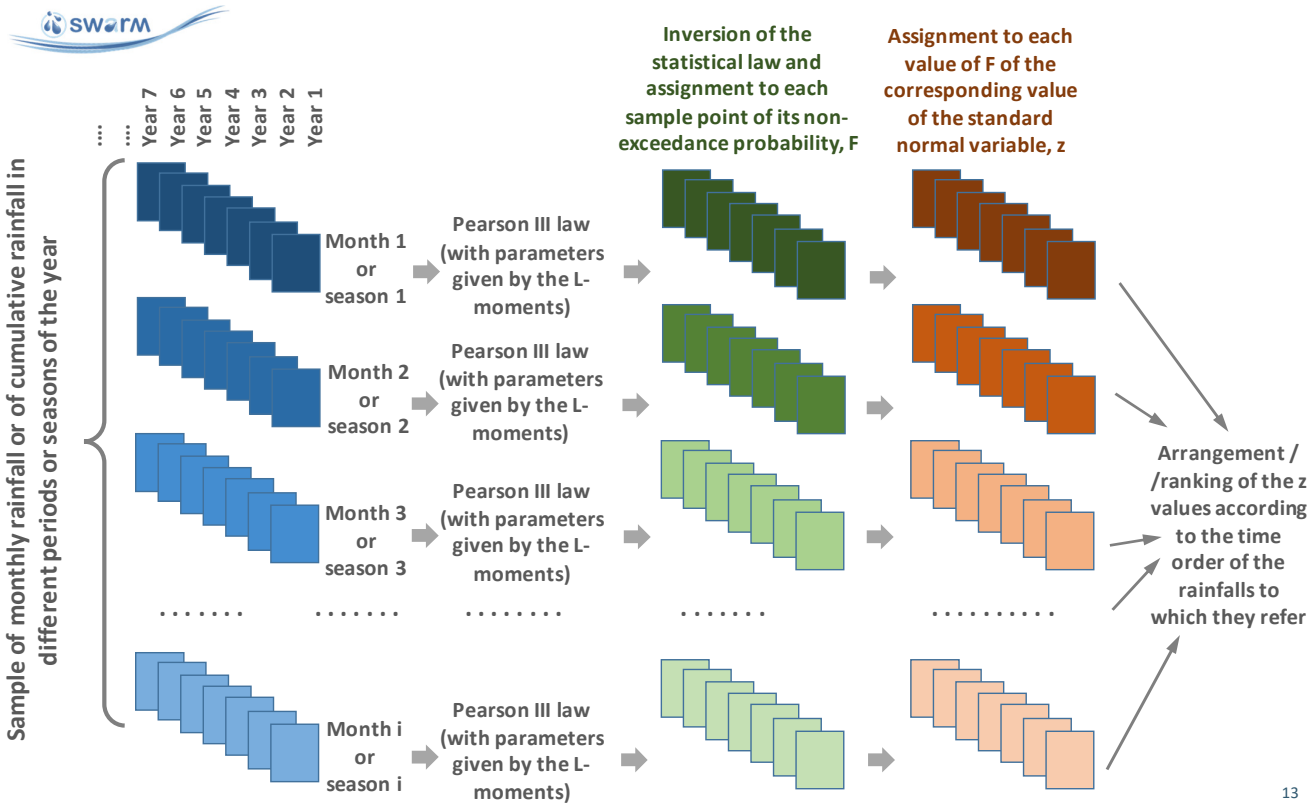



Sample of monthly rainfall or of cumulative rainfall in different periods or seasons of the year
....
....
Year 7
Year 6
Year 5
Year 4
Year 3
Year 2
Year 1
Month 1 or season 1
Month 2 or season 2
Month 3 or season 3
....
....
Month i or season i

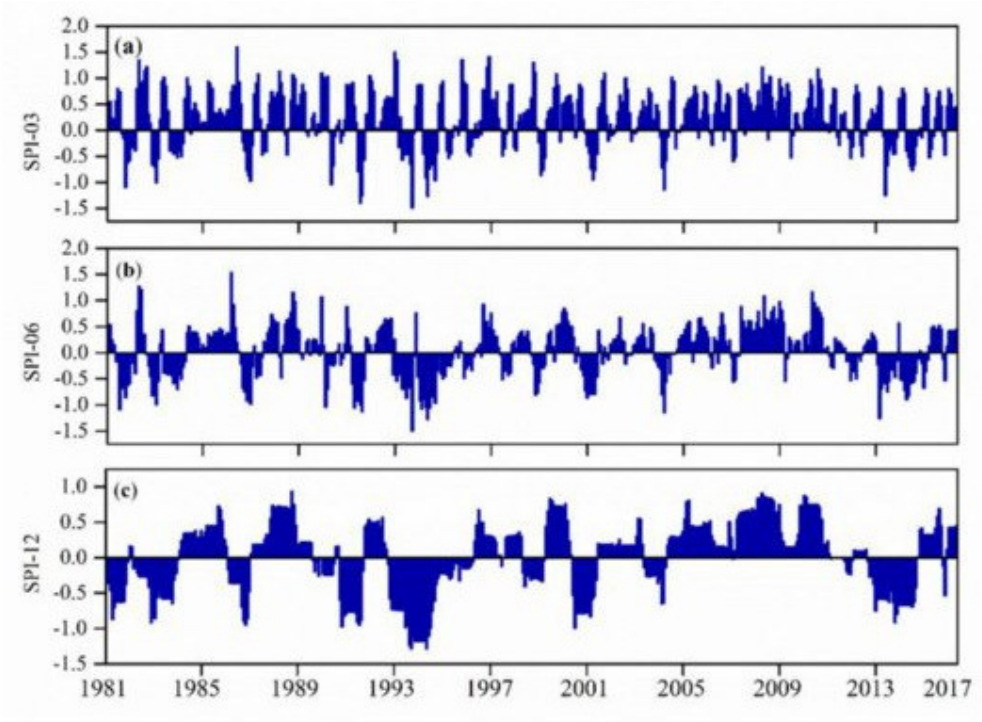

Sample of monthly rainfall or of cumulative rainfall in different periods or seasons of the year
....
....
Year 7
Year 6
Year 5
Year 4
Year 3
Year 2
Year 1
Month 1 or season 1
Pearson III law (with parameters given by the L-moments)
Month 2 or season 2
Pearson III law (with parameters given by the L-moments)
Month 3 or season 3
Pearson III law (with parameters given by the L-moments)
....
....
....
Month i or season i
Pearson III law (with parameters given by the L-moments)


Inversion of the statistical law and assignment to each sample point of its non-exceedance probability, F
Year 7
Year 6
Year 5
Year 4
Year 3
Year 2
Year 1
Sample of monthly rainfall or of cumulative rainfall in different periods or seasons of the year
Month 1 or season 1
Month 2 or season 2
Month 3 or season 3
Month i or season i
Pearson III law (with parameters given by the L-moments)

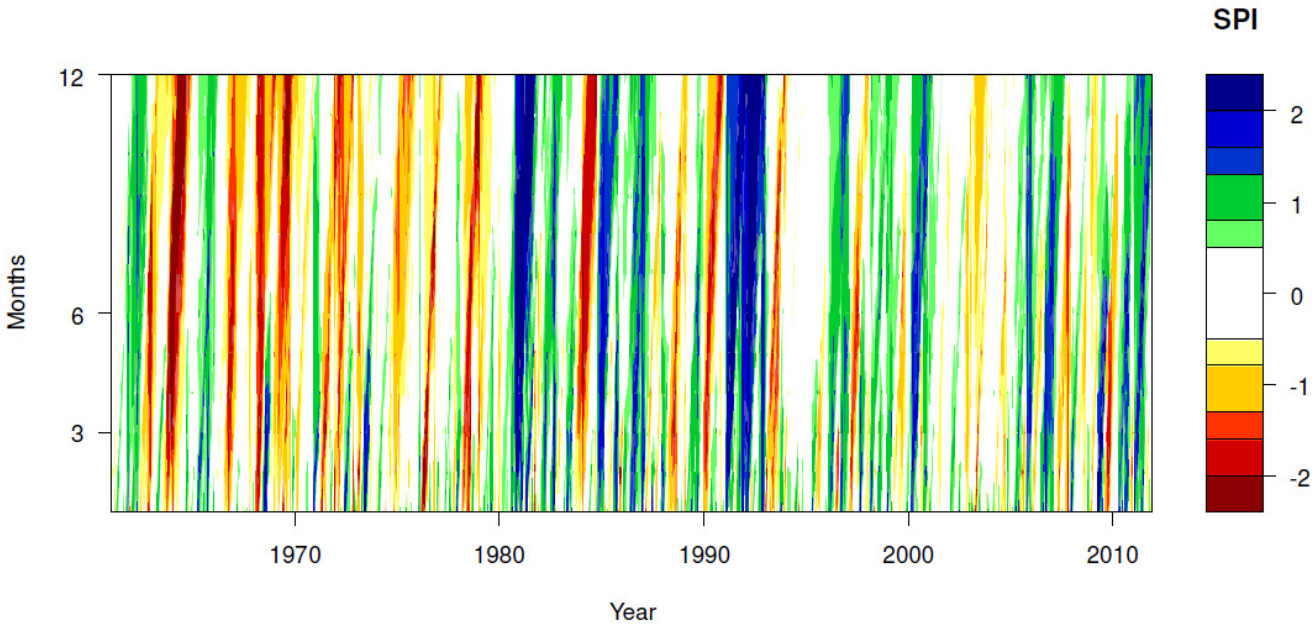

Inversion of the statistical law and assignment to each sample point of its non-exceedance probability, F
Assignment to each value of F of the corresponding value of the standard normal variable, z
Year 7
Year 6
Year 5
Year 4
Year 3
Year 2
Year 1
Sample of monthly rainfall or of cumulative rainfall in different periods or seasons of the year
Month 1 or season 1
Month 2 or season 2
Month 3 or season 3
Month i or season i
Pearson III law (with parameters given by the L-moments)



In a given rain gauge (or homogenous region)

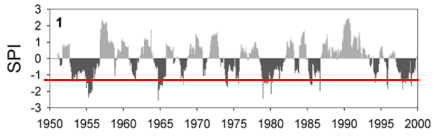


In a given rain gauge (or homogenous region)



Droughts categories (Agnew, C. T. 2000, "Using the SPI to identify drought", *Drought Network News*, 12, 6-12)

Non-exceedance probability, F	SPI	Drought category
0.05	>1.65	Extremely wet
0.1	>1.28	Severely wet
0.2	>0.84	Moderately wet
0.6	>-0.84 and <0.84	Normal
0.2	<-0.84	Moderate Drought
0.1	<-1.28	Severe Drought
0.05	<-1.65	Extreme Drought



Sequence of SPI, drought threshold and droughts occurences for such threshold.

Droughts categories (Agnew, C. T. 2000, "Using the SPI to identify drought", *Drought Network News*, 12, 6-12)

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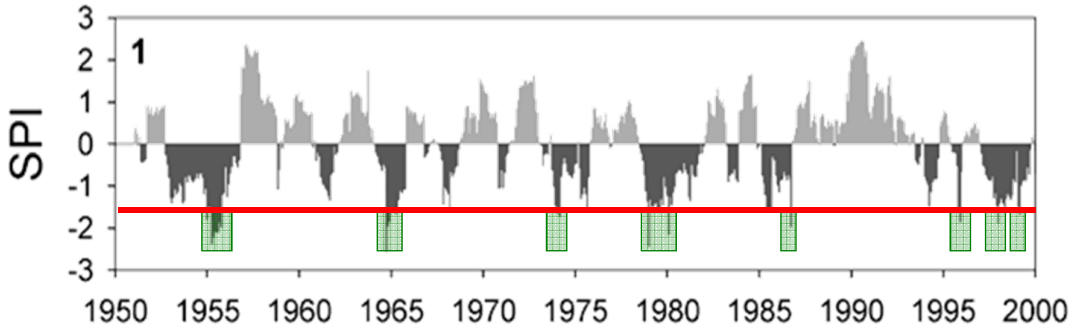
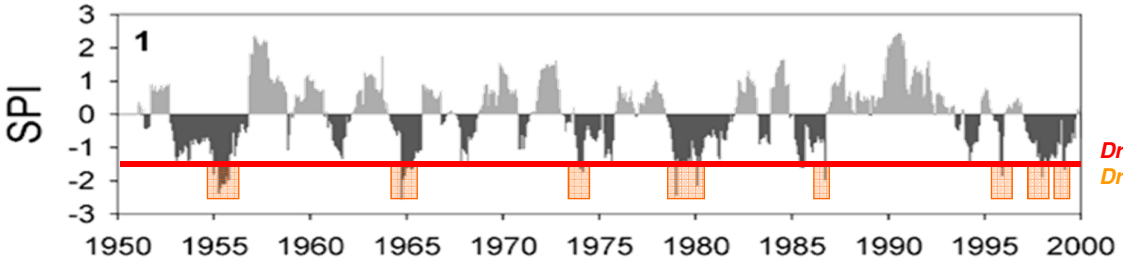
0.05	<-1.65	Extreme Drought

Representation of a sequence of SPI, the drought threshold (—) and the drought occurences for such threshold (▯).

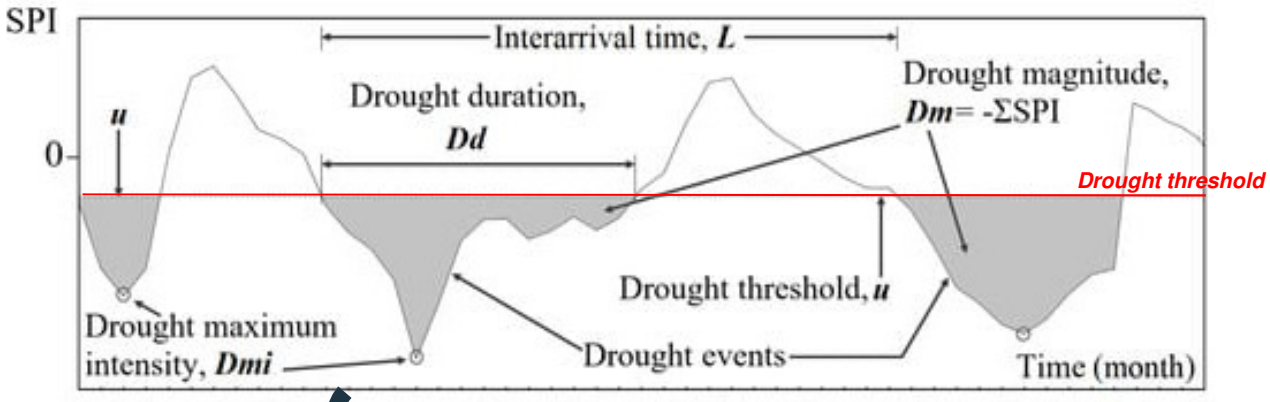


- ✓ **Basically, the SPI quantifies the precipitation deficit at different time scales (from 1 to 24 months), which reflect the impact of droughts on the different types of reservoirs of fresh water at the watershed level** (atmosphere, rivers, soil, artificial reservoir, ground water … society)

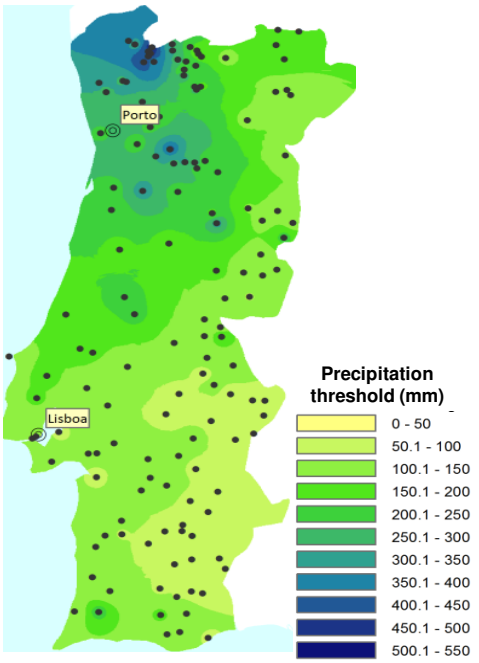


Drought threshold
Drought events

Characteristics of the droughts



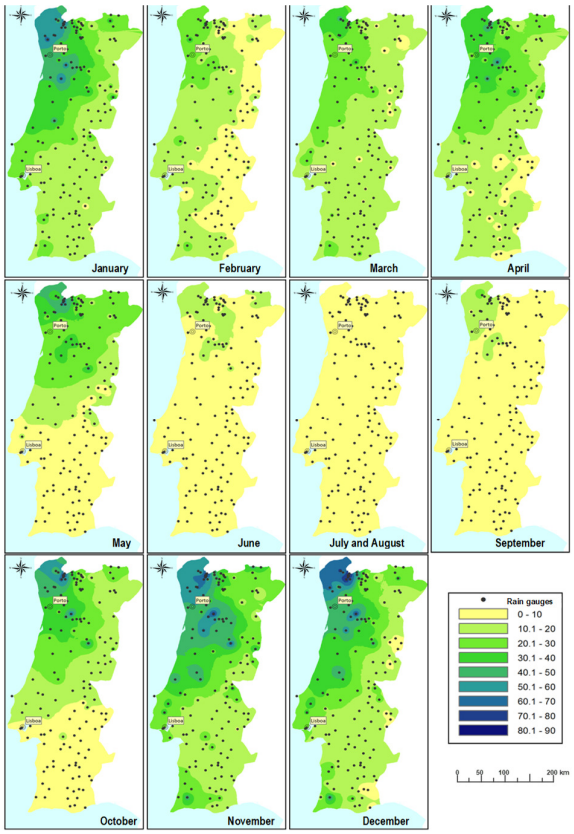
For each drought event, duration, magnitude and maximum intensity +
+ frequency



October to December SPI3=-1.28 (severe drought)

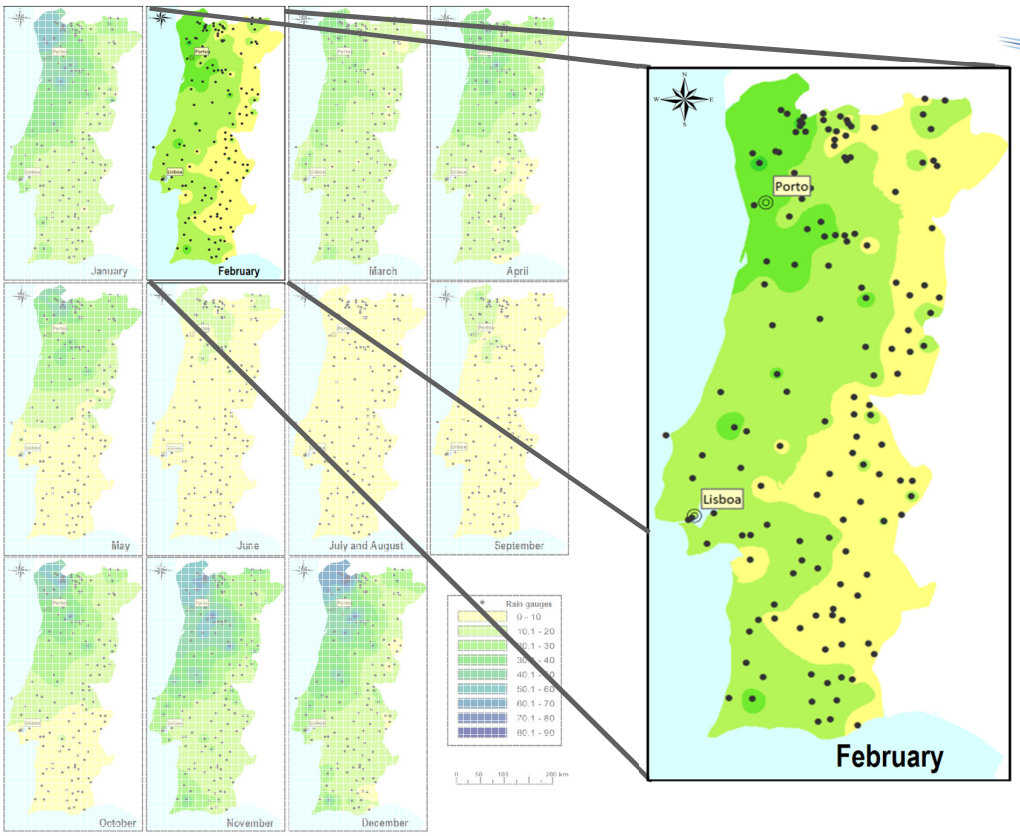
✓ **….. based on the results from the inversion of the SPIs → maps with the spatial distribution of the precipitation in 1, 3, 6, 12 and 24 months for different droughts thresholds: if in a certain location the precipitation that occurred in any of the considered time intervals falls below the value given by the map, then a drought is occurring (… *severe* or *extreme* according to the threshold to which the map relates)**

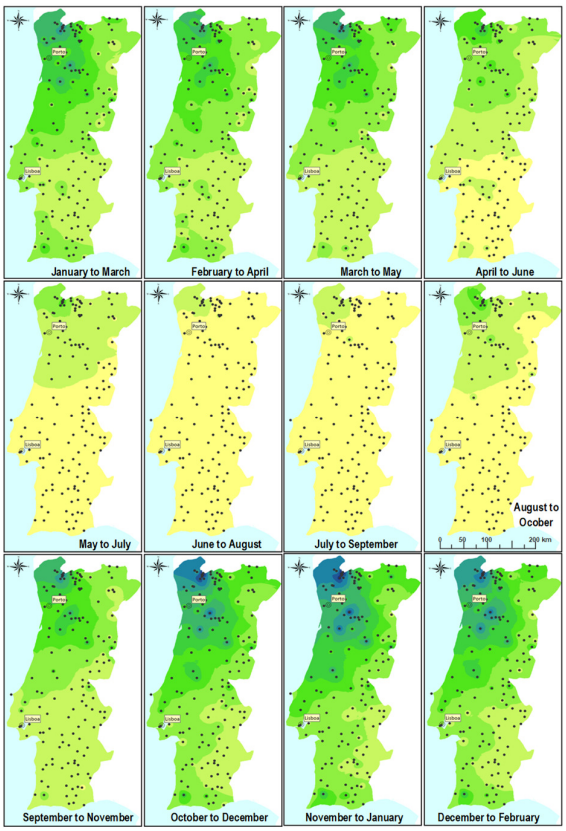
Surfaces of monthly and cumulative precipitation thresholds for drought recognition



Surfaces of monthly precipitation (for the consecutive months of the years) for recognition of severe droughts

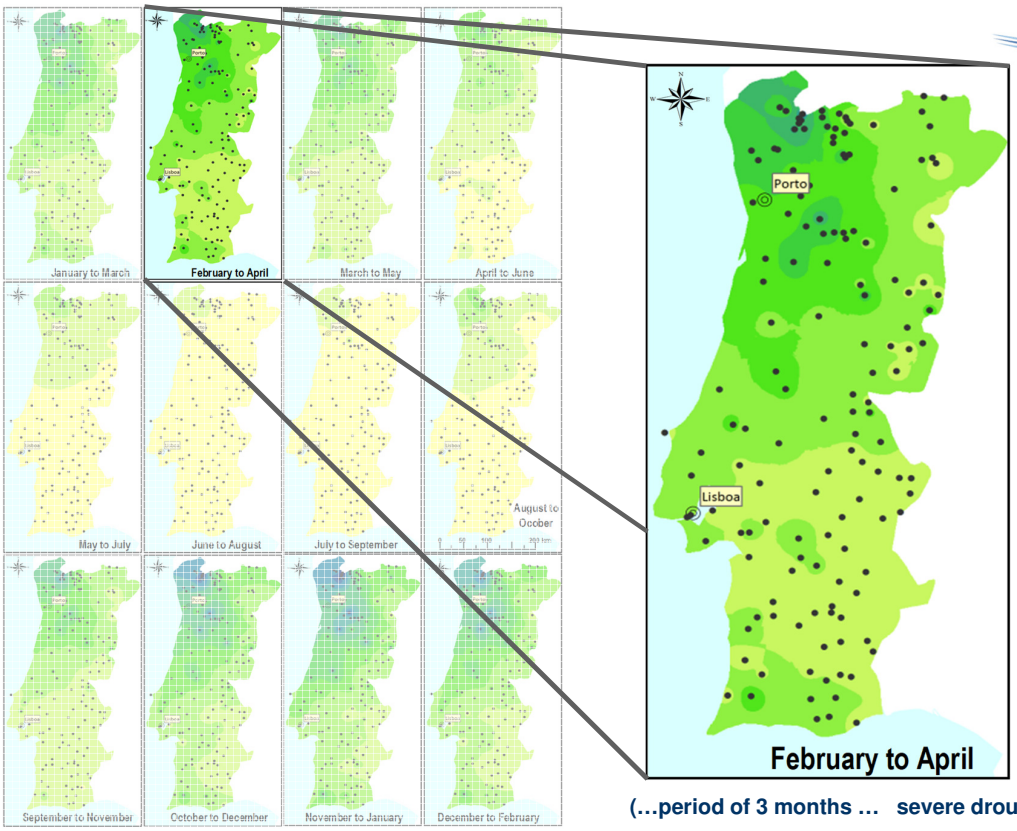
(SPI1=-1.28)





Surfaces of monthly precipitation in the successive periods of 3 consecutive months (beginning in each one of the months of the civil year) for recognition of severe droughts

(SPI3=-1.28)



(…period of 3 months … severe drought)

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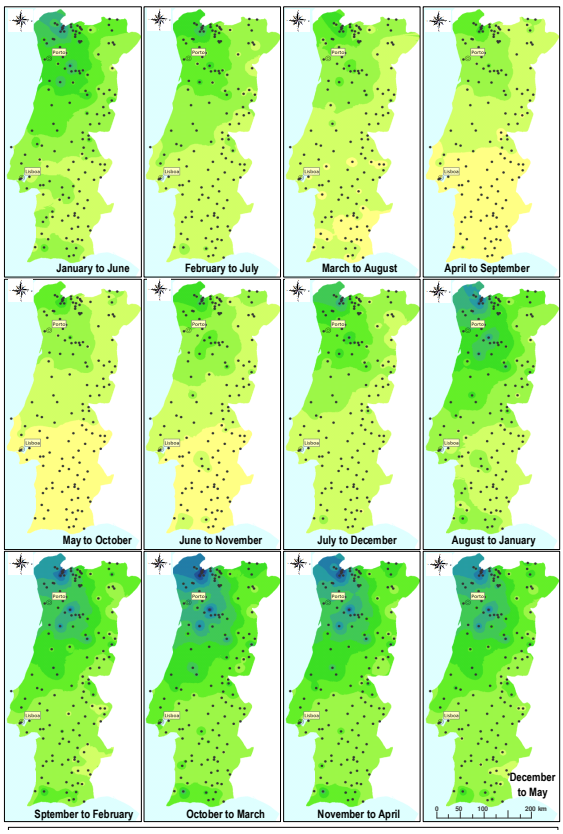
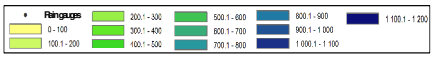
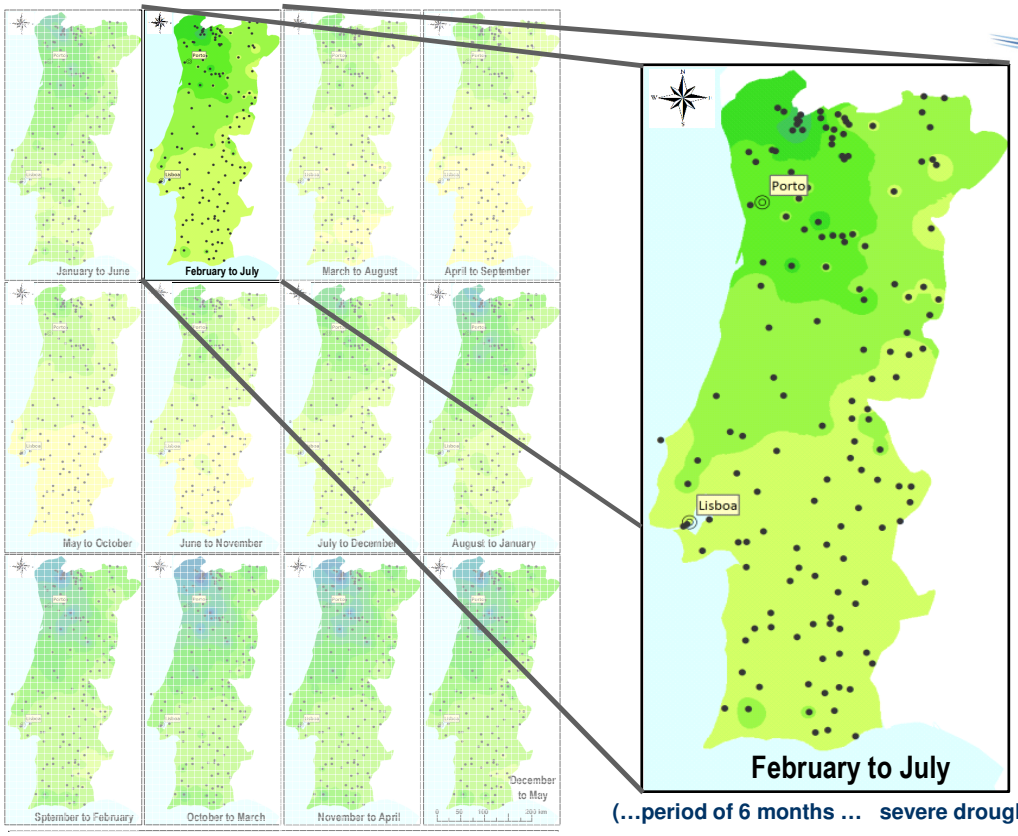


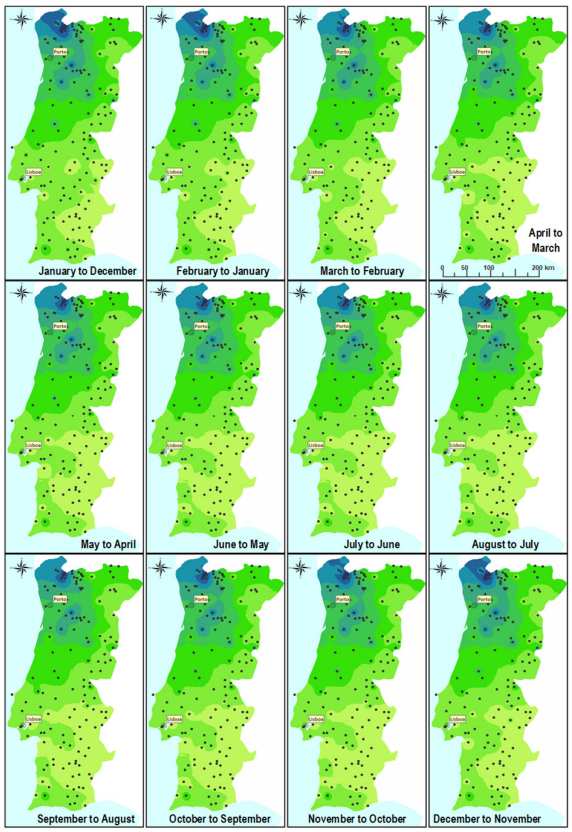
Surfaces of monthly precipitation in the successive periods of 6 consecutive months (beginning in each one of the months of the civil year) for recognition of severe droughts

(SPI6=-1.28)



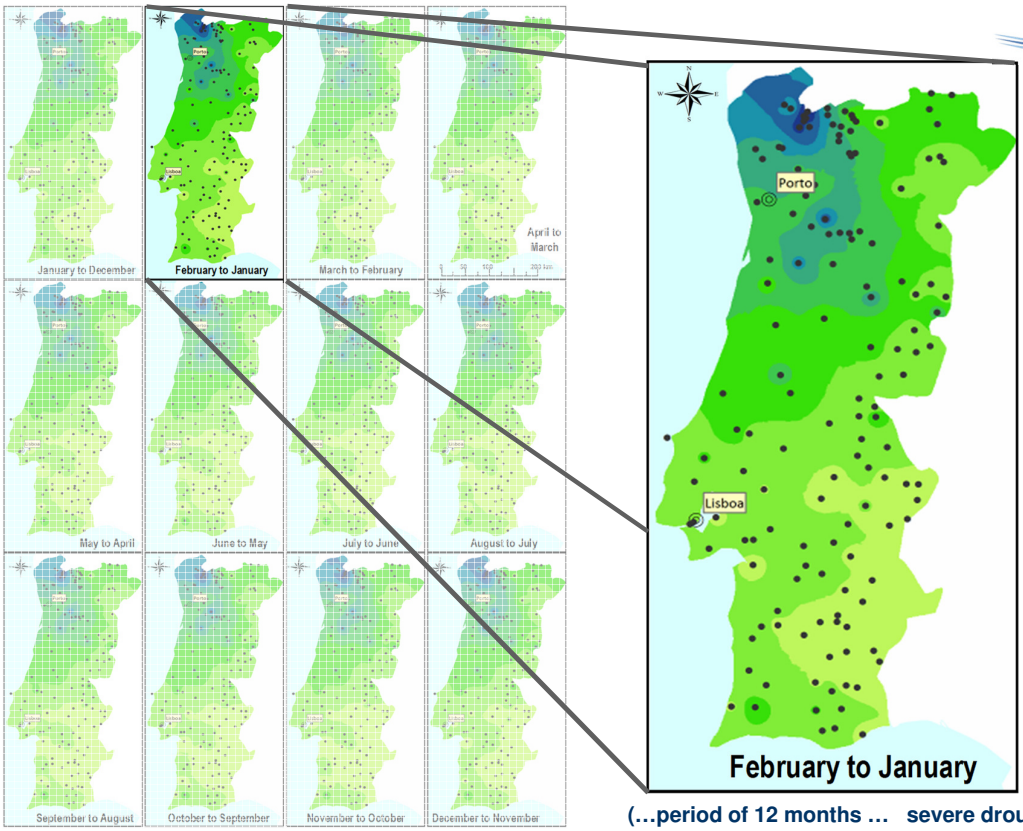


(…period of 6 months … severe drought)

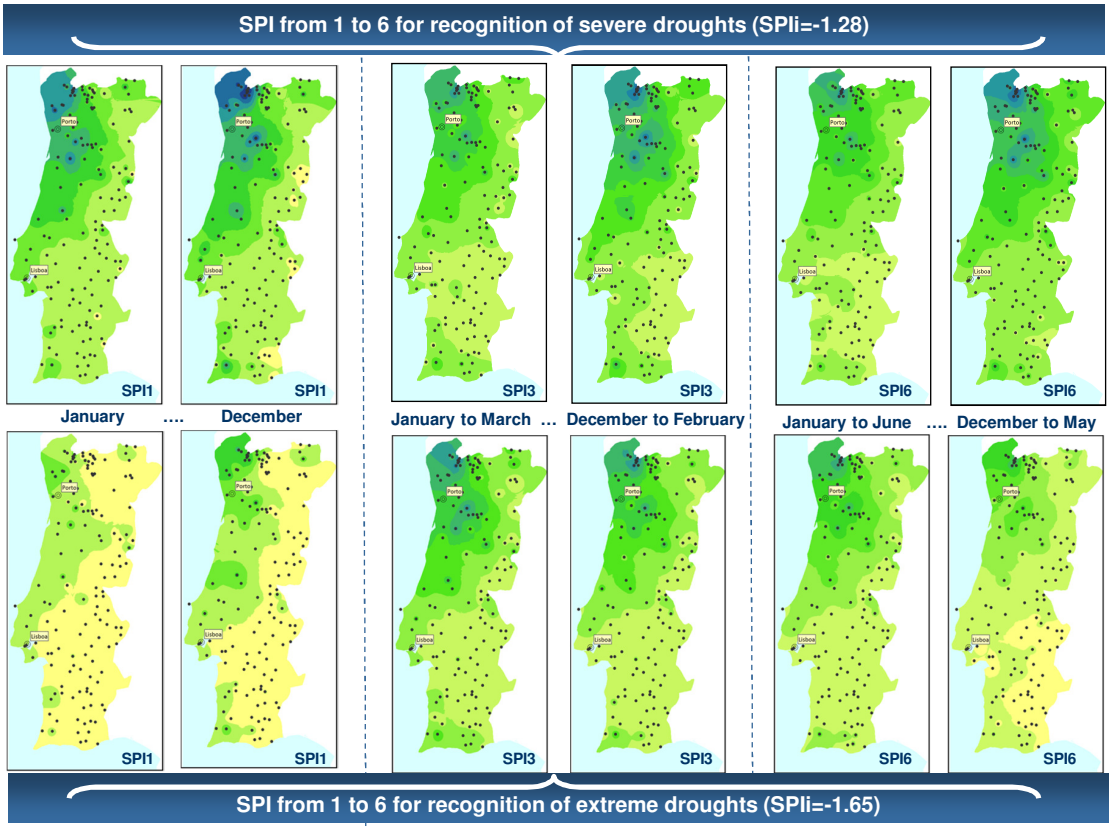


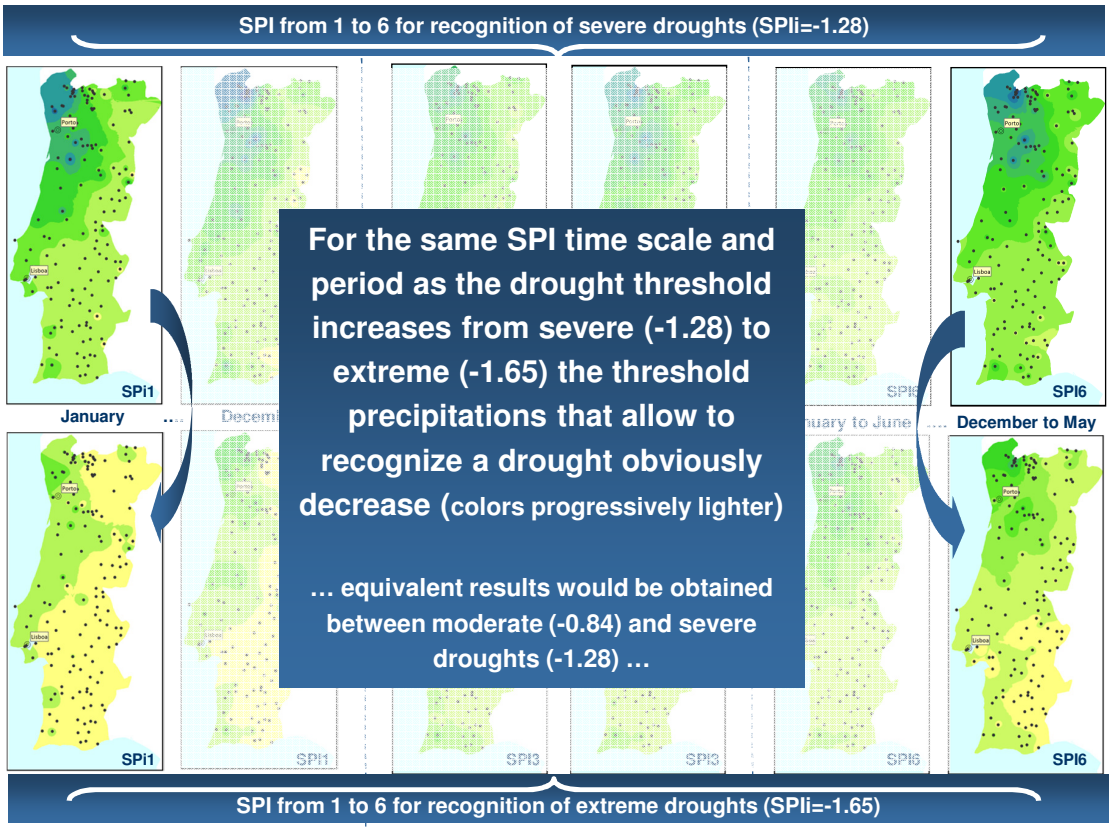
Surfaces of monthly precipitation in the successive periods of 12 consecutive months (beginning in each one of the months of the civil year) for recognition of severe droughts

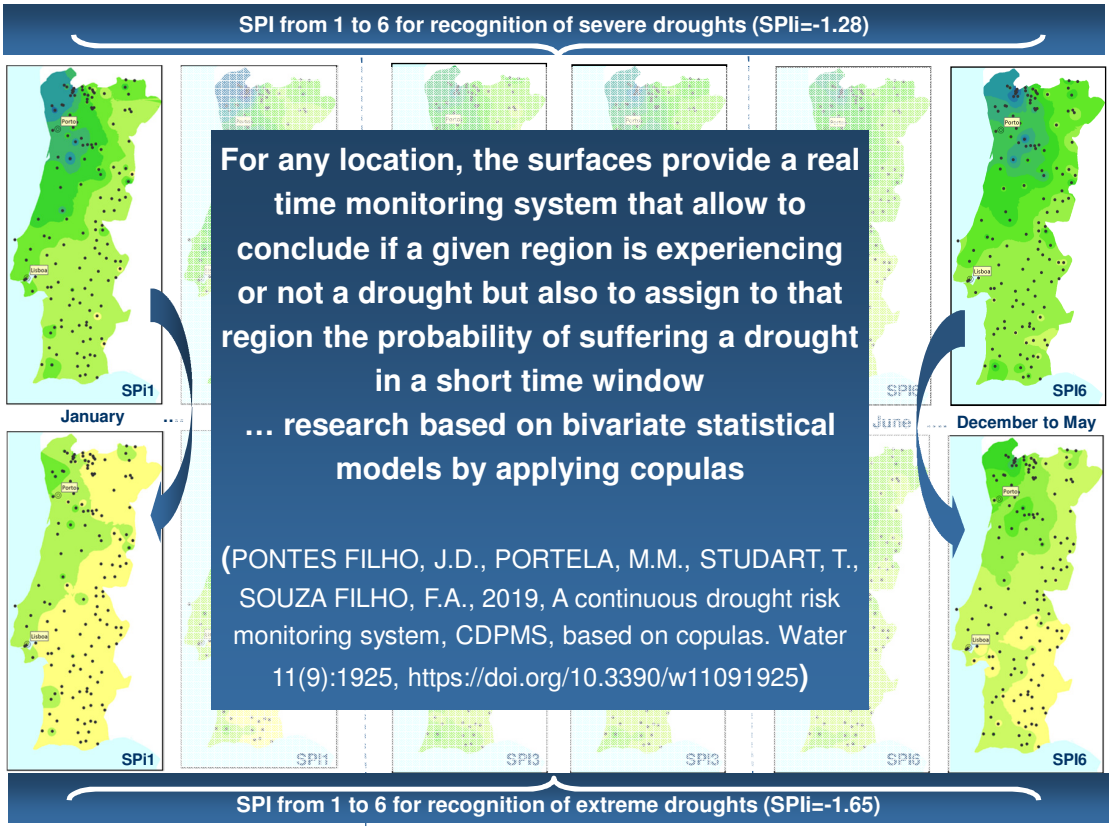
(SPI12=-1.28)

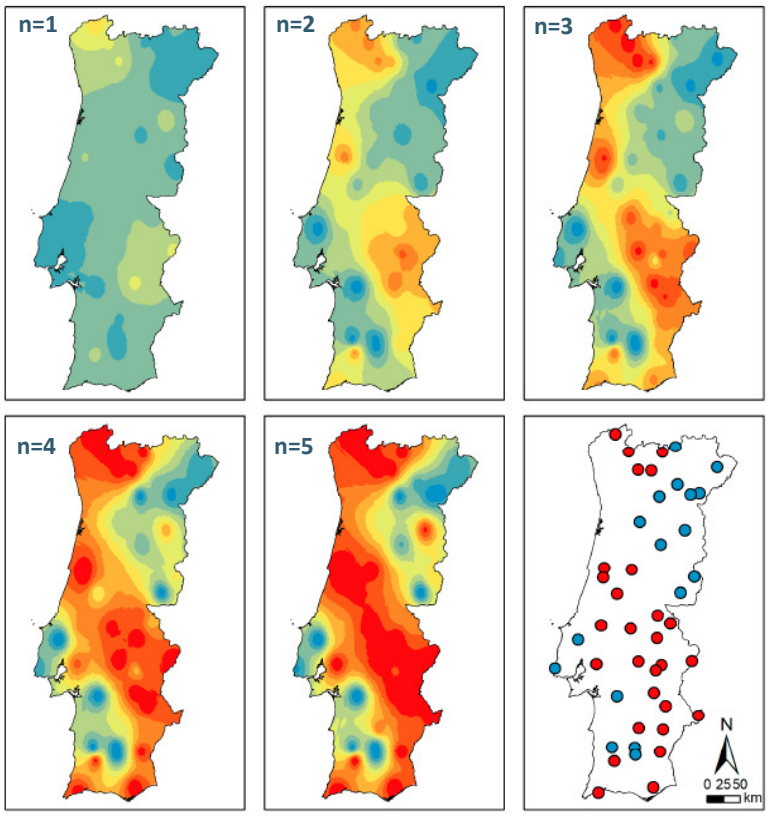


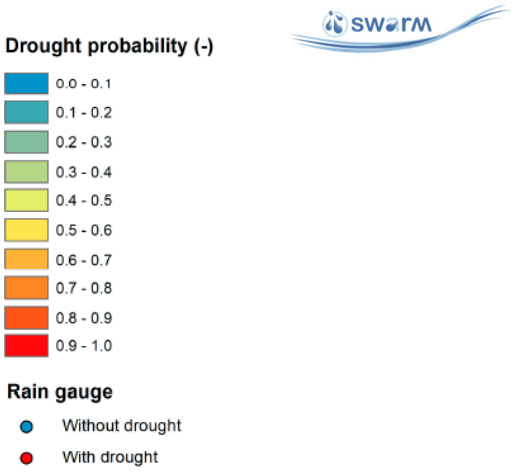
(…period of 12 months … severe drought)


SPI from 1 to 6 for recognition of severe droughts (SPIi=-1.28)
SPI1
SPI1
SPI3
SPI3
SPI6
SPI6
January
....
December
January to March
...
December to February
January to June
....
December to May
SPI1
SPI1
SPI3
SPI3
SPI6
SPI6
SPI from 1 to 6 for recognition of extreme droughts (SPIi=-1.65)


SPI from 1 to 6 for recognition of severe droughts (SPIi=-1.28)
SPI1
SPI6
January
....
December to May
SPI1
SPI6
SPI from 1 to 6 for recognition of extreme droughts (SPIi=-1.65)
For the same SPI time scale and period as the drought threshold increases from severe (-1.28) to extreme (-1.65) the threshold precipitations that allow to recognize a drought obviously decrease (colors progressively lighter)
... equivalent results would be obtained between moderate (-0.84) and severe droughts (-1.28) ...





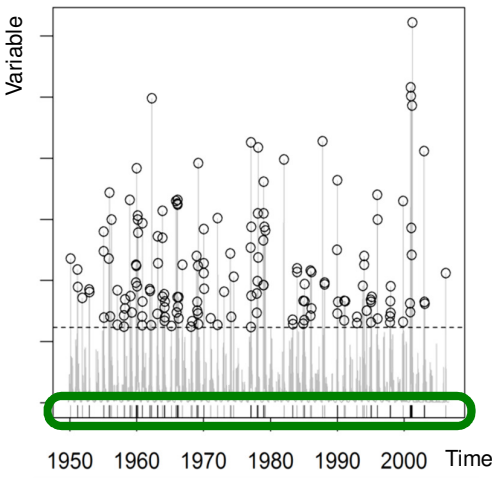


Example of the application of the system developed for continuous monitoring of the likelihood of moderate drought at the end of the six months period from October 2012 to February 2013. Drought probability from the end of October (n = 1) to the end of February (n = 5). The last map identifies the rain gauges that in fact did or did not experience drought by the end of March of 2013

- ✓ **To analyze the frequency of the droughts and approach applicable to partial duration series, PDS, also known as peaks over threshold series, POT, (**series built upon occurrences that are irregular in time by opposition to the annual maxima series that are built upon occurrences regularly spaced in time, namely one value per year**) can be used: the nonparametric method developed by Diggle, 1985 for smoothing point process data, i. e., the Kernel occurrence rate estimation, KORE (***estimativa de densidade kernel***).**

- ✓ **The KORE estimator indicates, continuously over time, the expected number of events per year above a given threshold, i.e., the frequency**

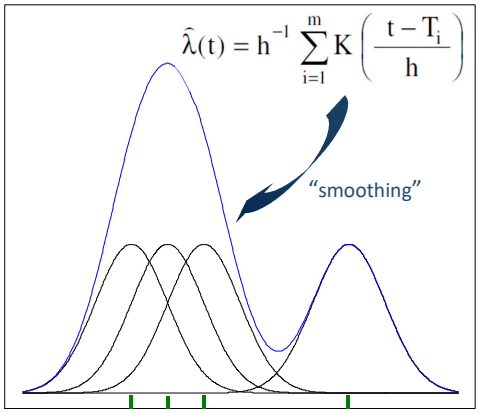
Diggle, P.: A kernel method for smoothing point process data, J. Roy. Stat. Soc. C-App., 34, 138–147, 1985. (1985)



… in each moment a Gaussian kernel is adjusted

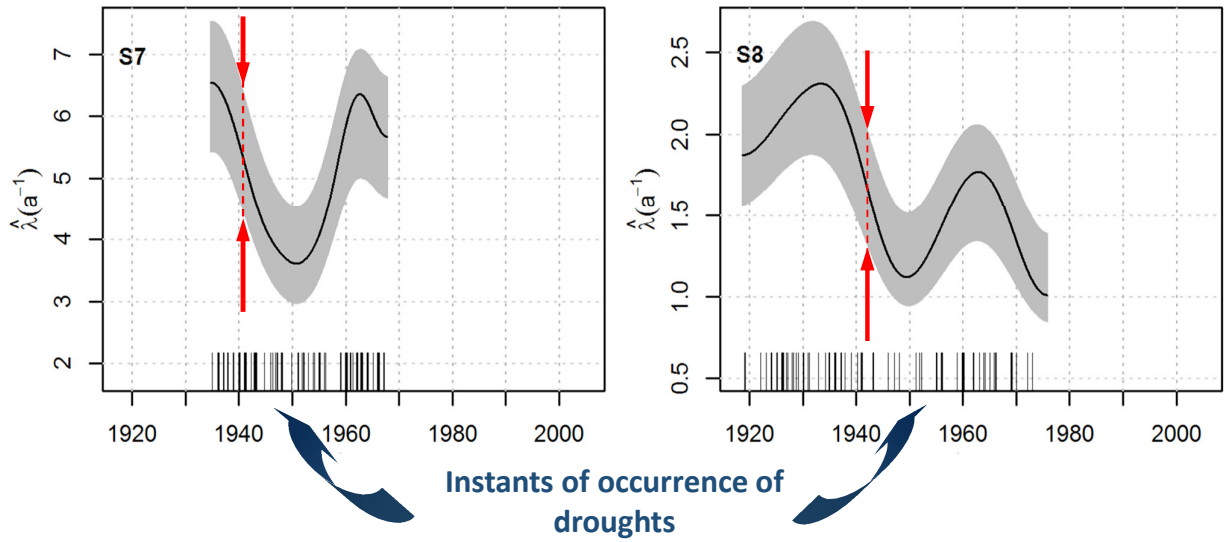
$$K(y) = \frac{1}{\sqrt{2\pi}} \exp\left(-\frac{y^2}{2}\right)$$

… the superimposition of the kernels give the KORE

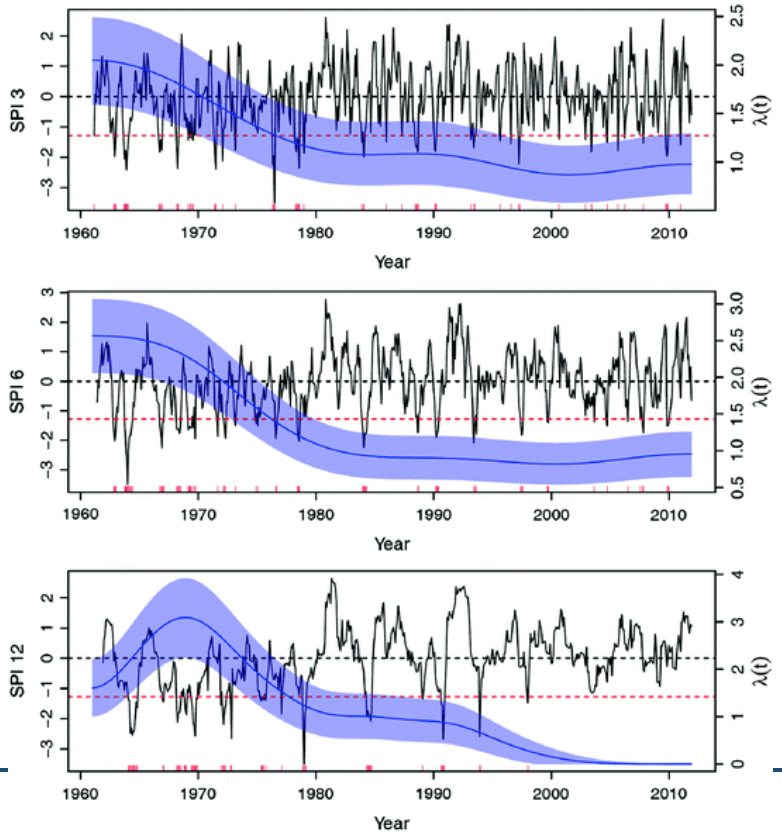


✓ **The bandwidth, h, is a smoothing factor. The higher h is, the more attenuated are the results because more instants are considered in the KORE calculation).**

To quantify the uncertainties associated with the results of the KORE, a 90% confidence band should be constructed around each frequency estimate by means of bootstrap simulations (with replacement)



✓ Drought frequency analysis based on the KORE



- ✓ However, droughts are regional occurrences, affecting large areas and with specific characteristics in each of those areas

- ✓ To identify spatially homogenous regions with similar specific characteristics of the droughts and to understand these characteristics – that is, to identify the different spatial patterns of the droughts – regionalization techniques, as presented in the following presentation (principal component analysis, PCA, non-hierarchical cluster analysis, ….)