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The role of teleconnections in extreme (high and low) precipitation events: The case of the Mediterranean region

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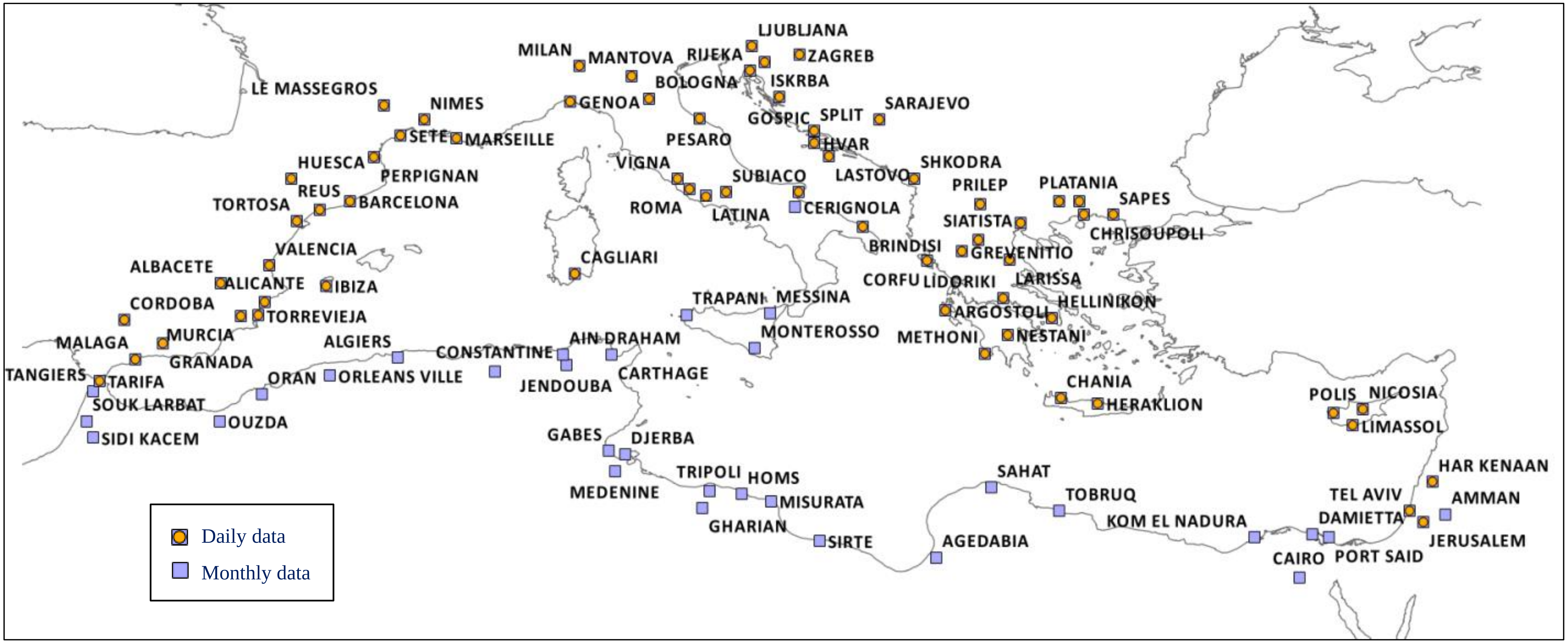
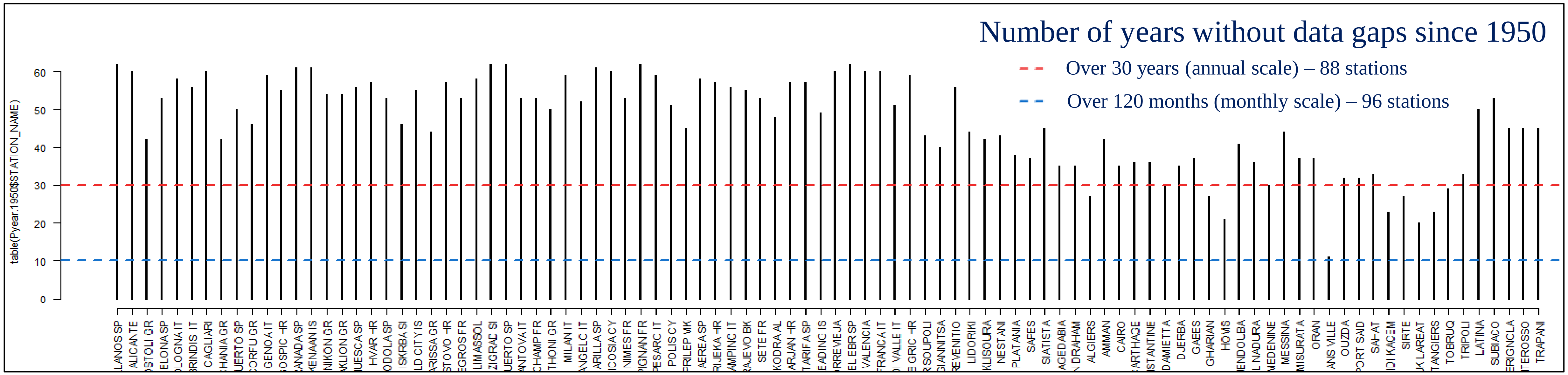
1. Abstract

During the last years large-scale climatic indices, such as North Atlantic Oscillation (NAO) and El-Niño Southern Oscillation (ENSO), have been used to describe a certain portion of climatic variability in different temporal and spatial scales. In this context, the climate in the Mediterranean region has been mainly correlated with the NAO index, while there is also some evidence for seasonal associations with the Dynamic Indian Monsoon Index (DIMI) during the summer, and the Siberian High during the winter. Here, we explore the possible links between extreme (high and low) precipitation events in the Mediterranean basin and several large-scale climatic indices, such as these mentioned above and also East Atlantic Pattern, Scandinavia Pattern, Polar/Eurasia Pattern, Mediterranean Oscillation Index, West Africa Monsoon Index and Siberian High. In order to achieve that, we use precipitation data from the Global Historical Climatology Network (GHCN) and index data from National Oceanic and Atmosphere Administration (NOAA).

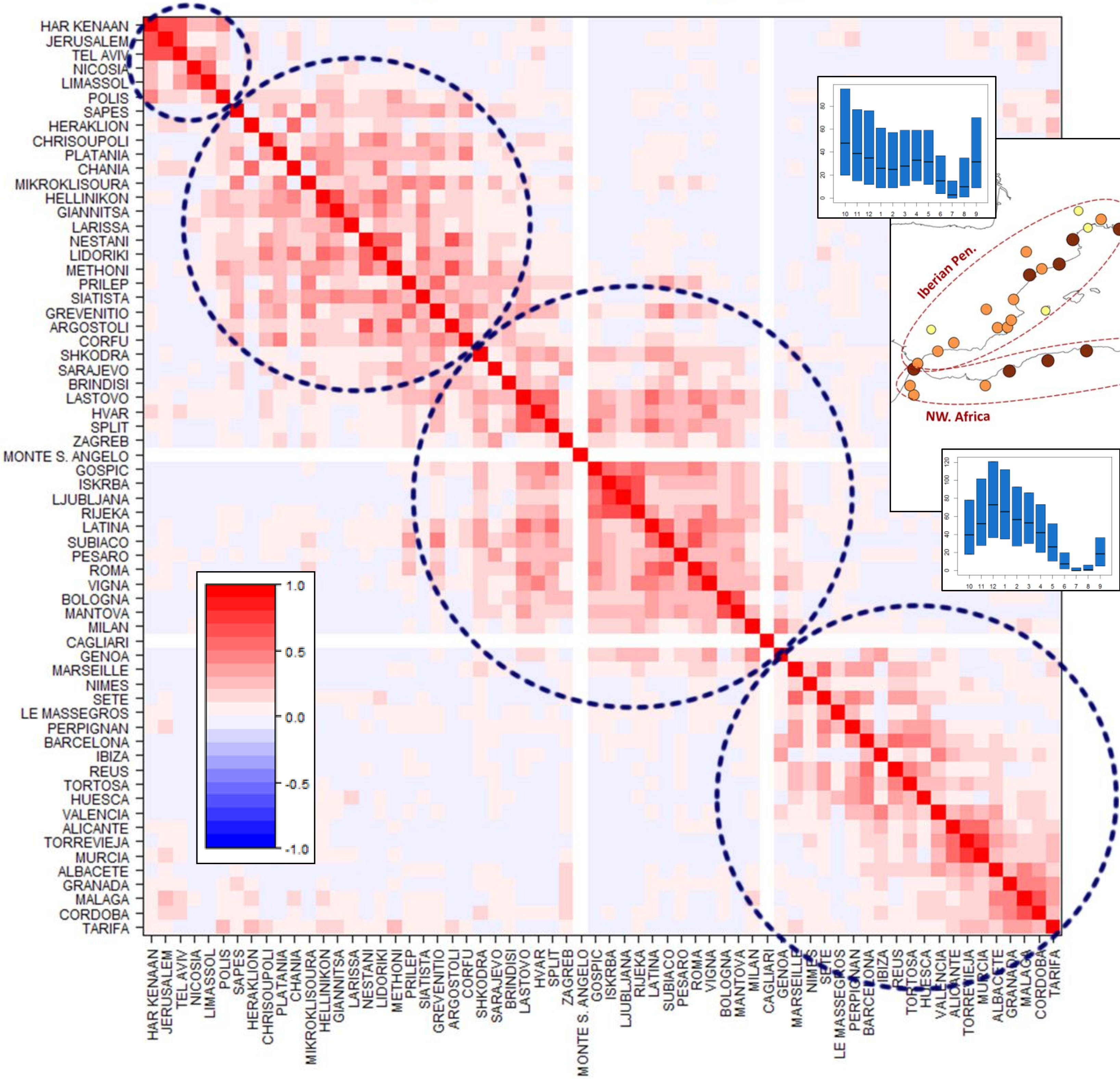
2. Rainfall data



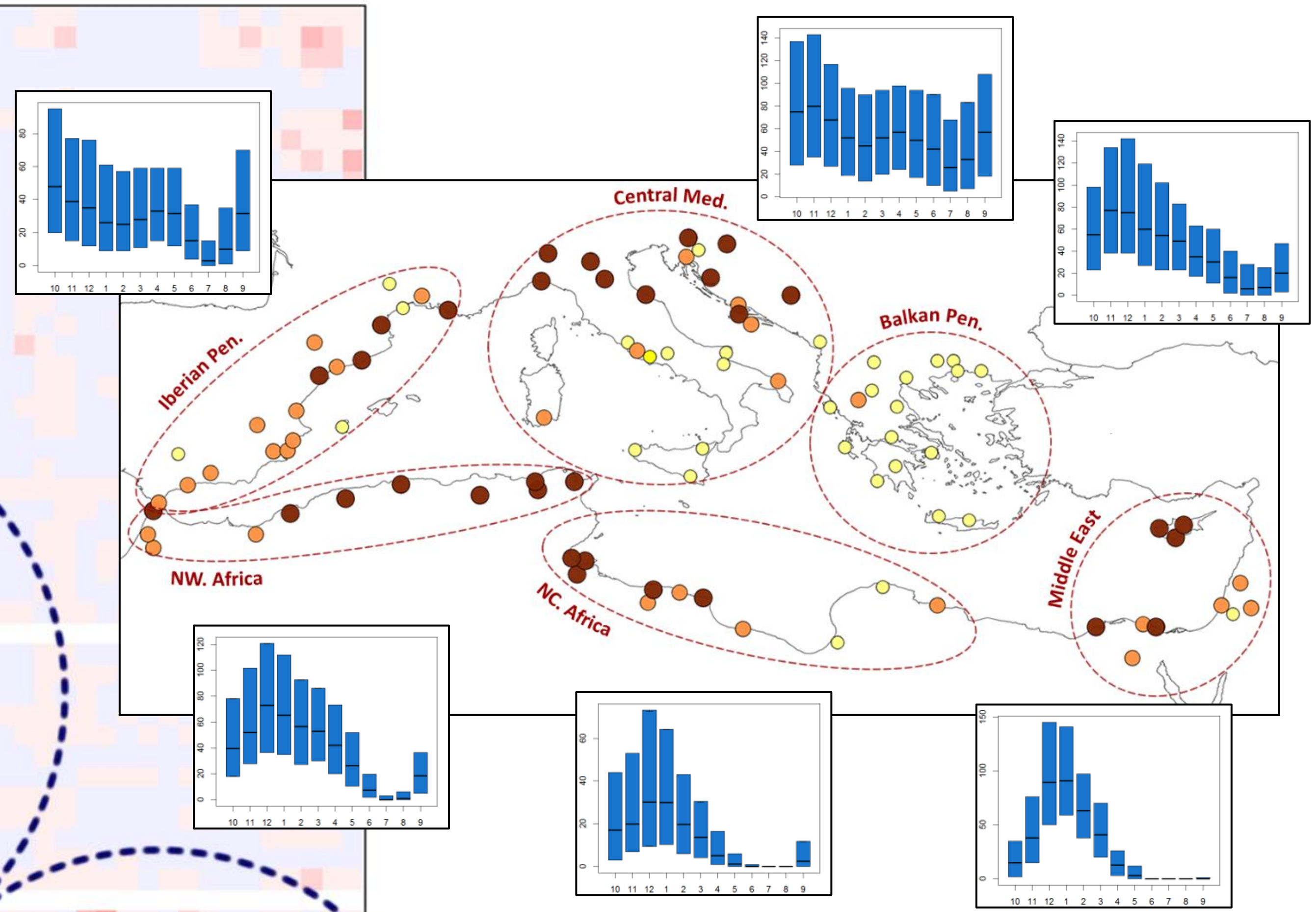


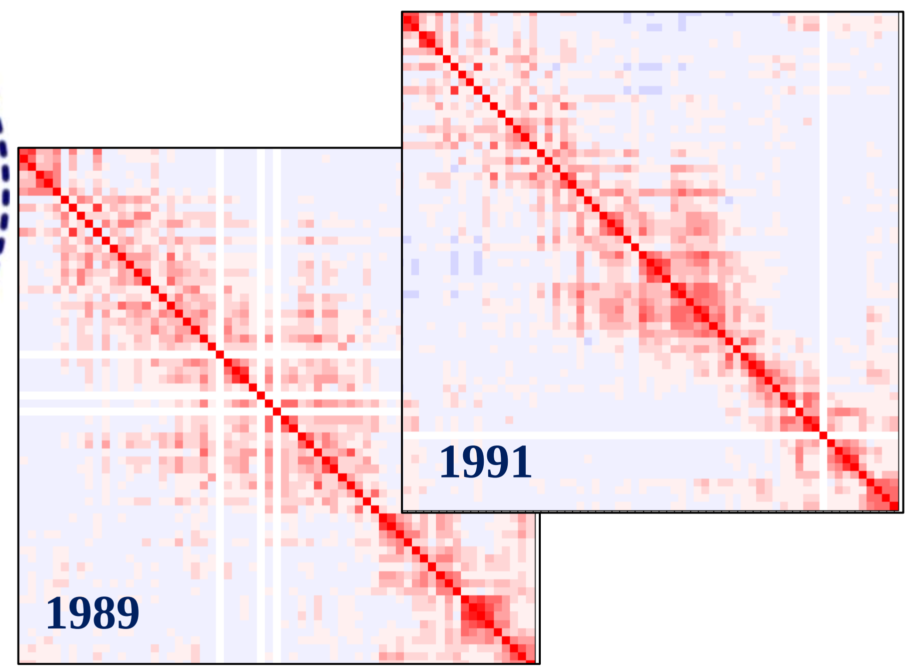
3. Homogeneous regions (with respect to rainfall)

Daily correlation matrix (1990)



Monthly variability

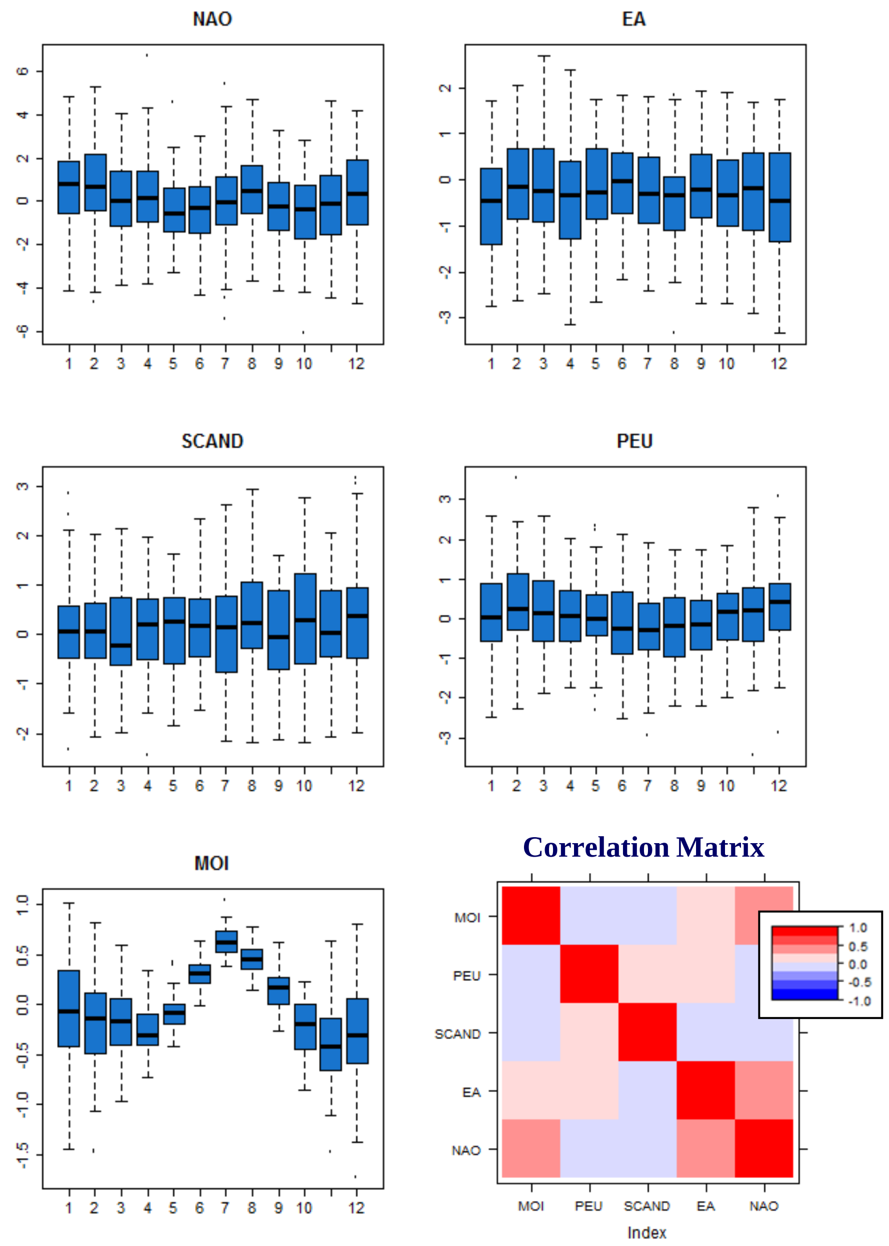




4. Climatic indices

Abbr.	Index	Short description	Positive phase effect	Period	Data source
Monthly data					
NAO	North Atlantic Oscillation	North-south dipole: One center located over Greenland and the other at the central latitudes of the North Atlantic between 35°N and 40°N.	Below-average precipitation	1825-2011	http://www.cru.uea.ac.uk/cru/data/nao/
EA	East Atlantic Pattern	Southward shifted NAO pattern (strong subtropical link in association with modulations in the subtropical ridge intensity and location).	Below-average precipitation	1950-2012	ftp://ftp.cpc.ncep.noaa.gov/wd52dg/data/indices/ea_index.tim
SCAND	Scandinavia Pattern	Circulation center over Scandinavia, with weaker centers of opposite sign over western Europe and eastern Russia/ western Mongolia.	Above-average precipitation	1950-2012	ftp://ftp.cpc.ncep.noaa.gov/wd52dg/data/indices/scand_index.tim
PEU	Polar/Eurasia Pattern	Pressure difference between the polar region, and northern China and Mongolia.	Varying	1950-2012	ftp://ftp.cpc.ncep.noaa.gov/wd52dg/data/indices/poleur_index.tim
MOI	Mediterranean Oscillation Index	Pressure difference between Gibraltar's Northern Frontier (36.1°N, 5.3°W) and Lod Airport in Israel (32.0°N, 34.5°E) .	Above-average precipitation	1958-2010	http://www.cru.uea.ac.uk/cru/data/moi/
Annual data					
ENSO	El Niño–Southern Oscillation	SST Difference between 170°W and 120°W at East Central Tropical Pacific (5°N – 5°S).	Varying	1871-2011	http://www.esrl.noaa.gov/psd/people/cathy.smith/best/
SHI	Siberian High Index	Winter SLP defined within the area 40 – 60°N and 80 – 120°E.	Above-average precipitation	1911-2001	Panagiotopoulos F. et al. (2005) Observed Trends and Teleconnections of the Siberian High: A Recently Declining Center of Action, Journal of Climate, 18:1411-
WAMI	West Africa Monsoon Index	Mean June through September African rainfall (20-8°N, 20°W-10°E).	Below-average precipitation	1900-2011	http://jisao.washington.edu/data/sahel/
DIMI	Dynamic Indian Monsoon Index	The difference of the 850-hPa zonal winds between 5–15°N, 40–80°E and 20–30°N, 70–90°E during summer (June-July-August).	Below-average precipitation	1880-2008	http://www.lasg.ac.cn/staff/ztj/DIMI.tar.gz

Seasonality & correlation of monthly indices



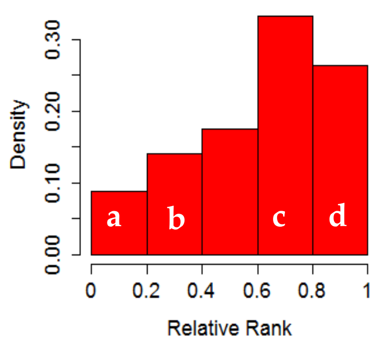
5. Daily maxima

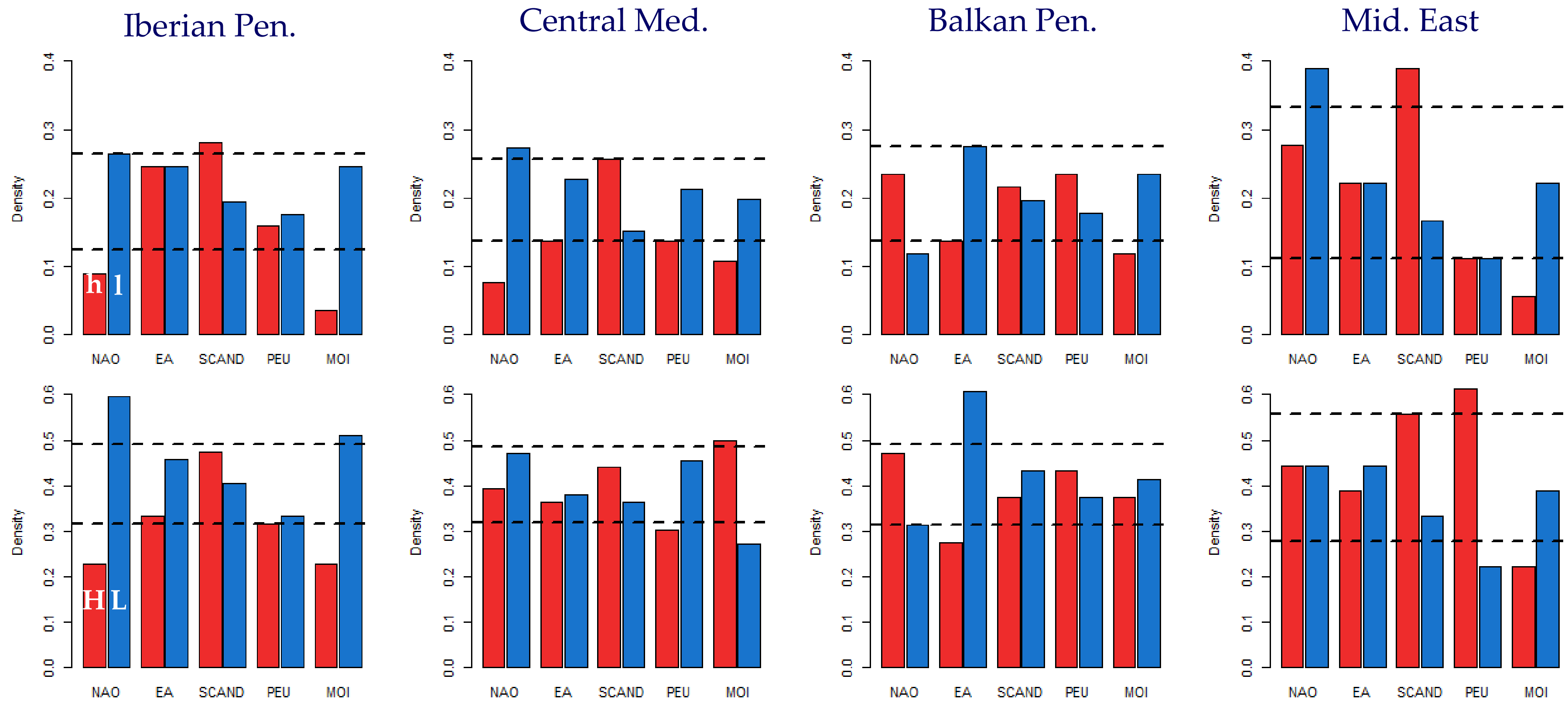
The histograms on the right refer to the relative rank of a given index monthly value during a month that a daily precipitation maximum occurred (the three highest values have been taken per station). Red bars are connected to the index maxima (low relative ranks) above 20% for the upper row and 40% for the lower, while blue bars to minima below these values. Dashed lines represent 90% Monte Carlo confidence interval.

For example, if the distribution of NAO index relative ranks is given by the histogram in the figure below (referring to the Iberian Pen.), then: h = a and l = d; H = a + b and L = c + d. As a and b are smaller than c and d, very extreme daily rainfall events are unlikely to occur when NAO index is very high (h) or just high (H) and more likely to occur in a negative phase (L).

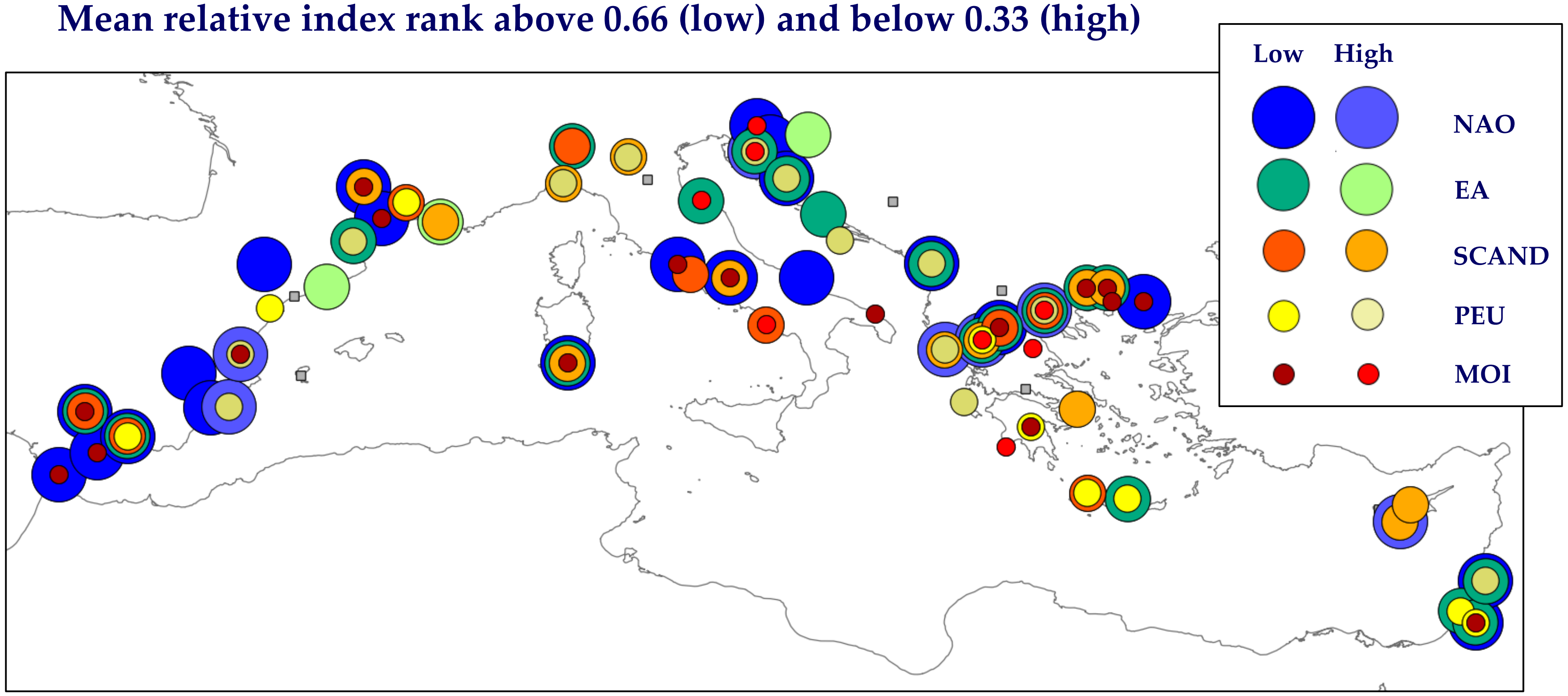
This analysis was also applied to the 10 highest rainfall values per station and the results were similar.

NAO index

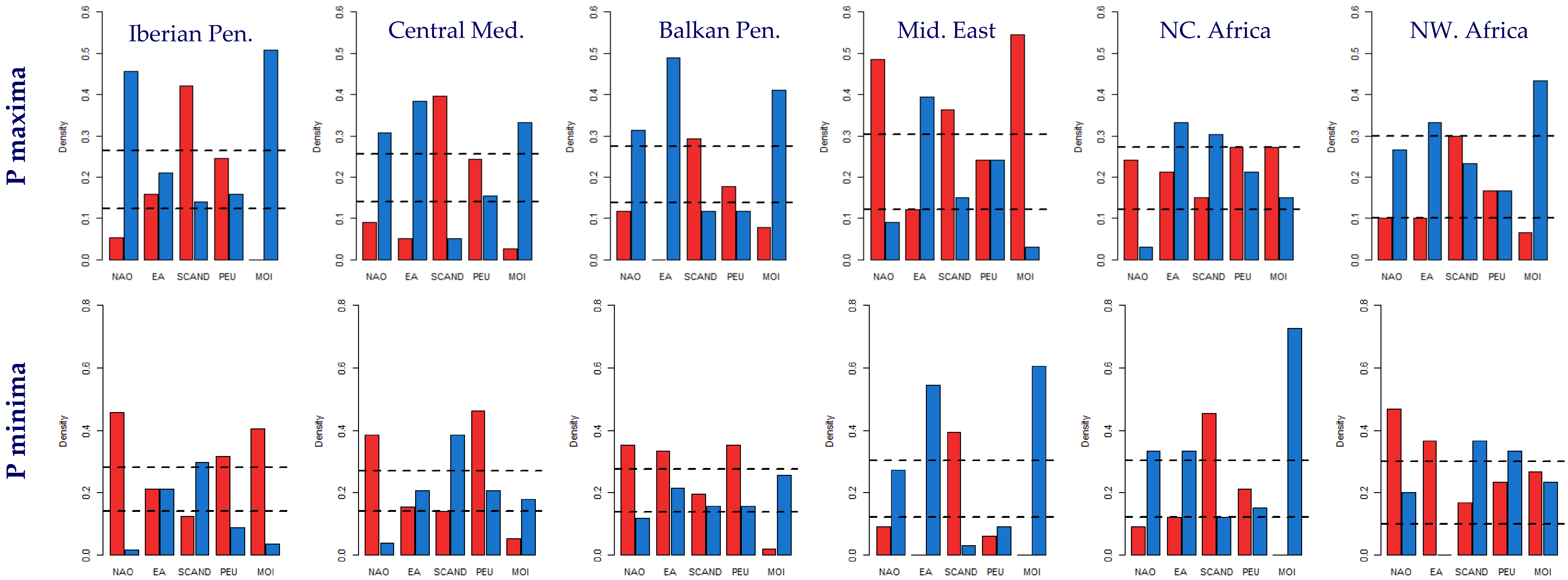




Mean relative index rank above 0.66 (low) and below 0.33 (high)

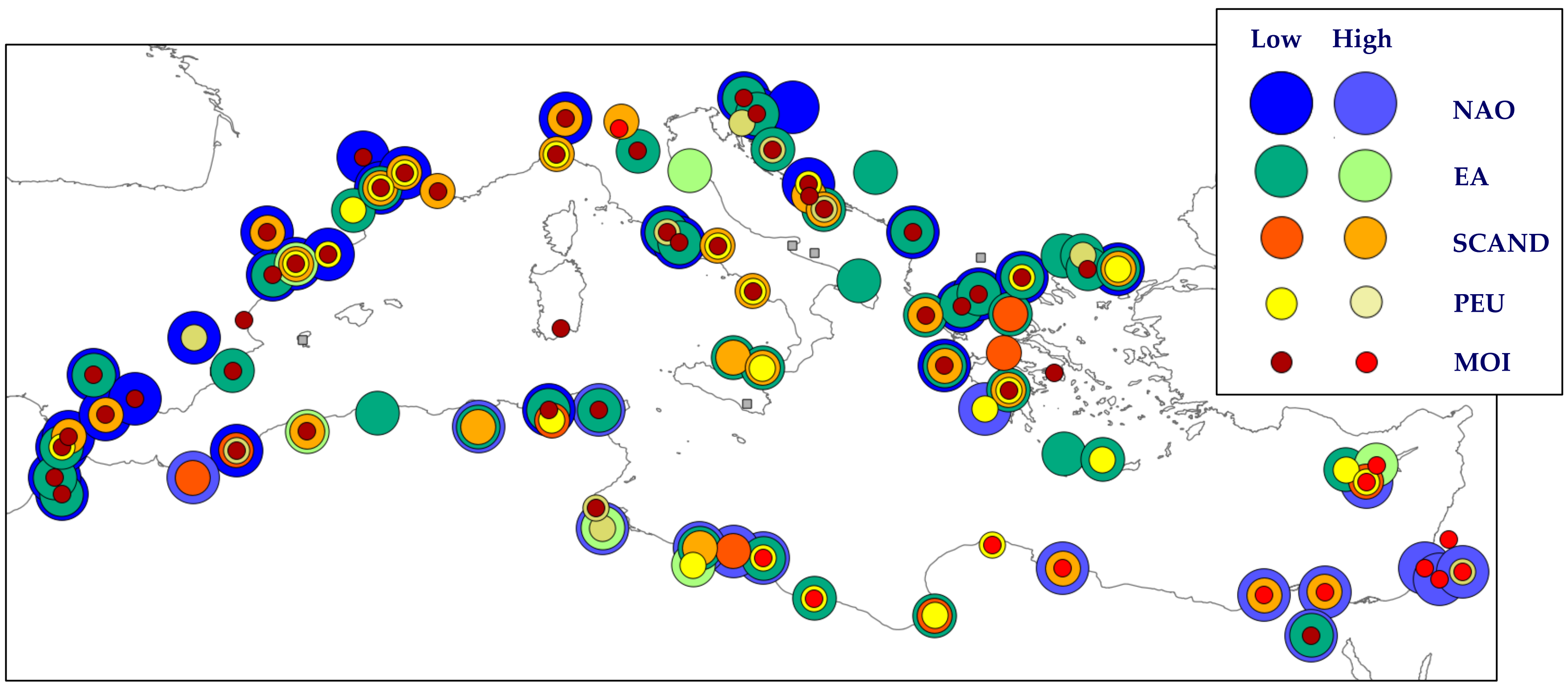


6. Monthly extremes



A similar approach is followed as in the daily maxima. Here, the rainfall minima for the wet months (September to March) is also examined. In general, index ranks for maxima and minima are opposite to each other, but interestingly, there are some exceptions (e.g. MOI in Balkan Pen.). This shows that a given index may be linked more strongly to either maximum or minimum rainfall.

It can be seen that as the scale becomes larger the effect of general circulation grows stronger .

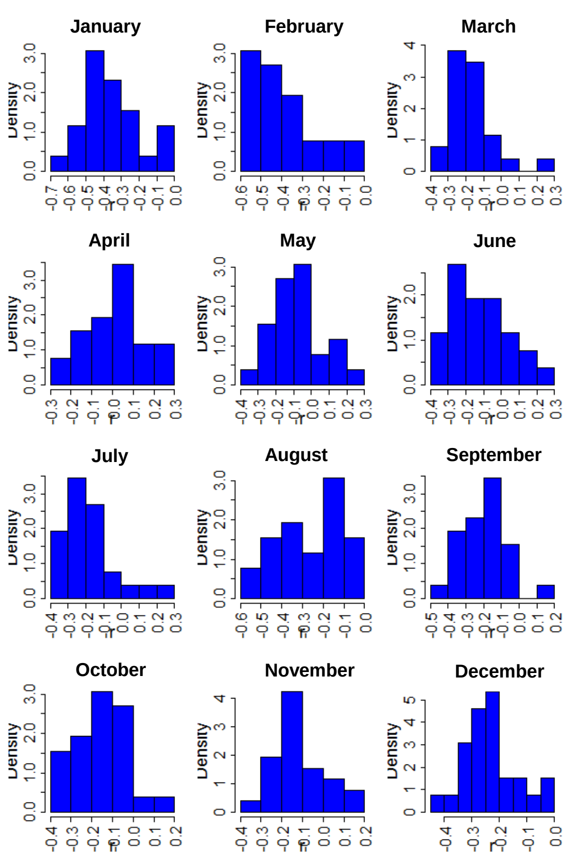


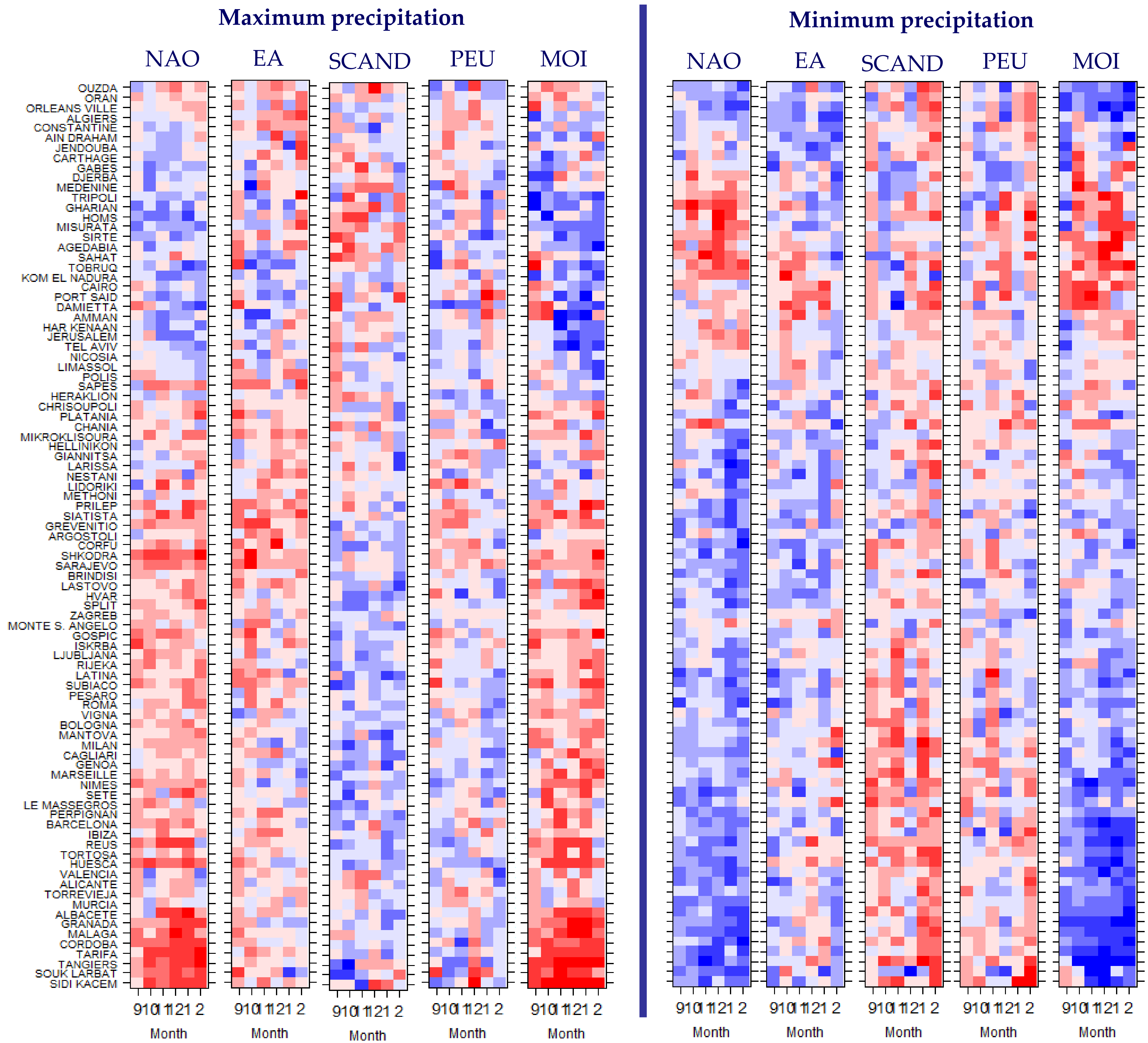
7. Monthly extremes (cont.)

The comparison between the mean index relative ranks which correspond to monthly maxima/minima reveals that in most cases winter rain is linked more strongly to each of the indices.

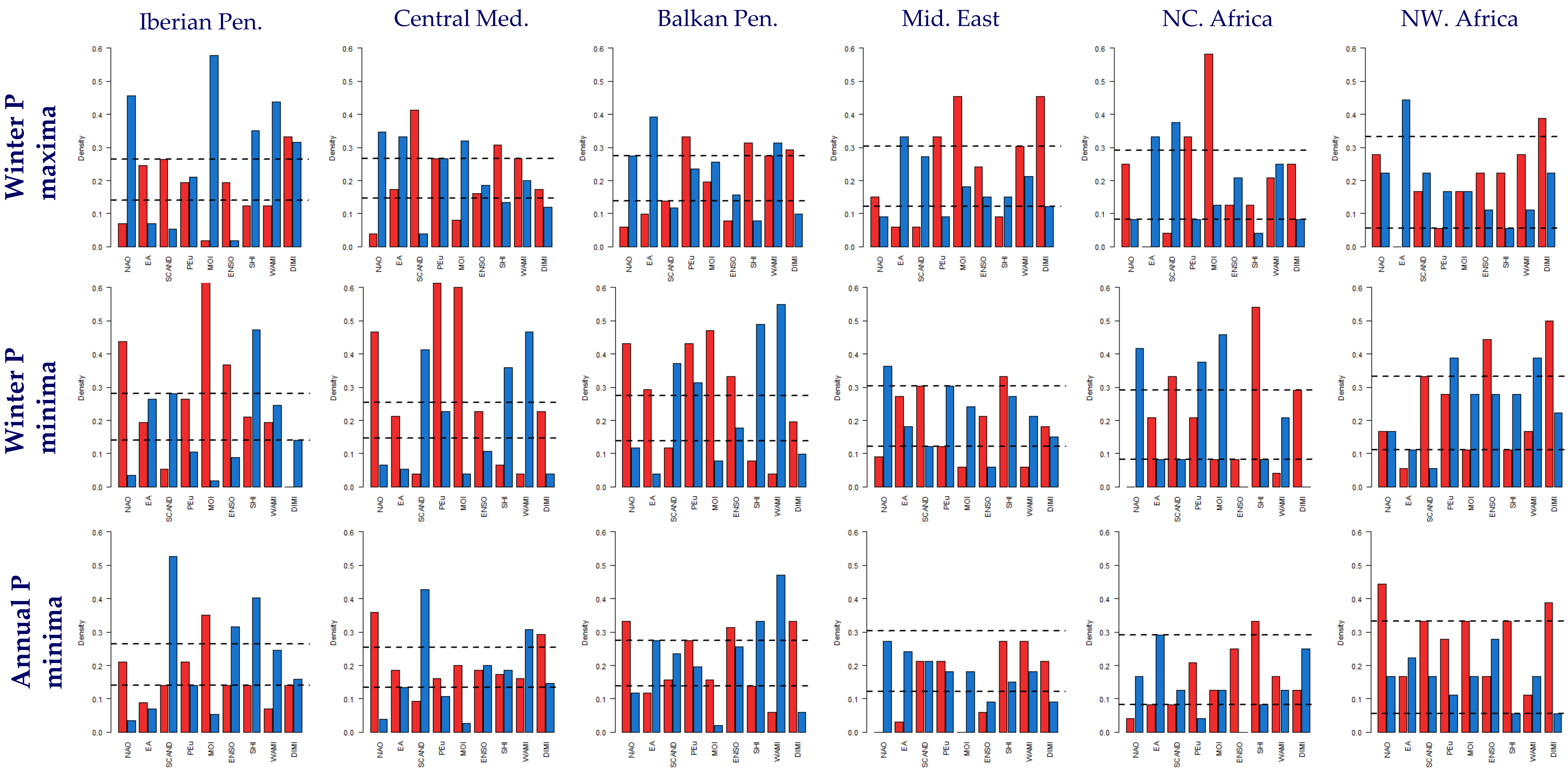
This is also confirmed if the cross-correlation coefficient is calculated for each index and month, as can be seen below for NAO and monthly rainfall at the Iberian Pen.

NAO/P monthly correlation



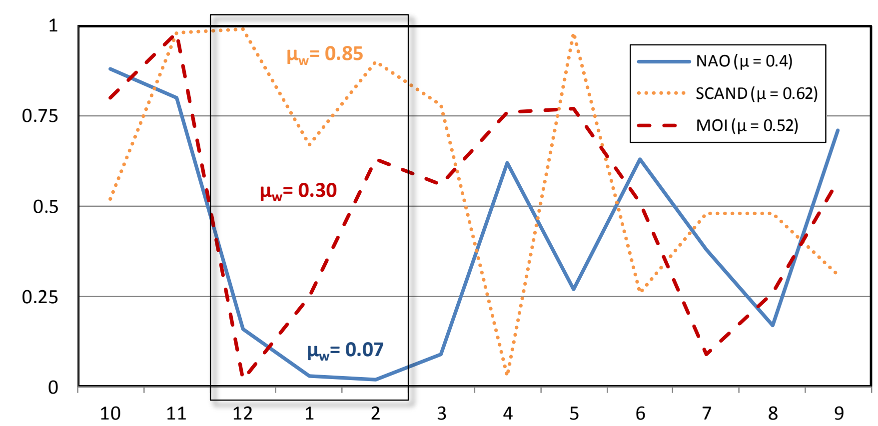


8. Winter and annual extremes



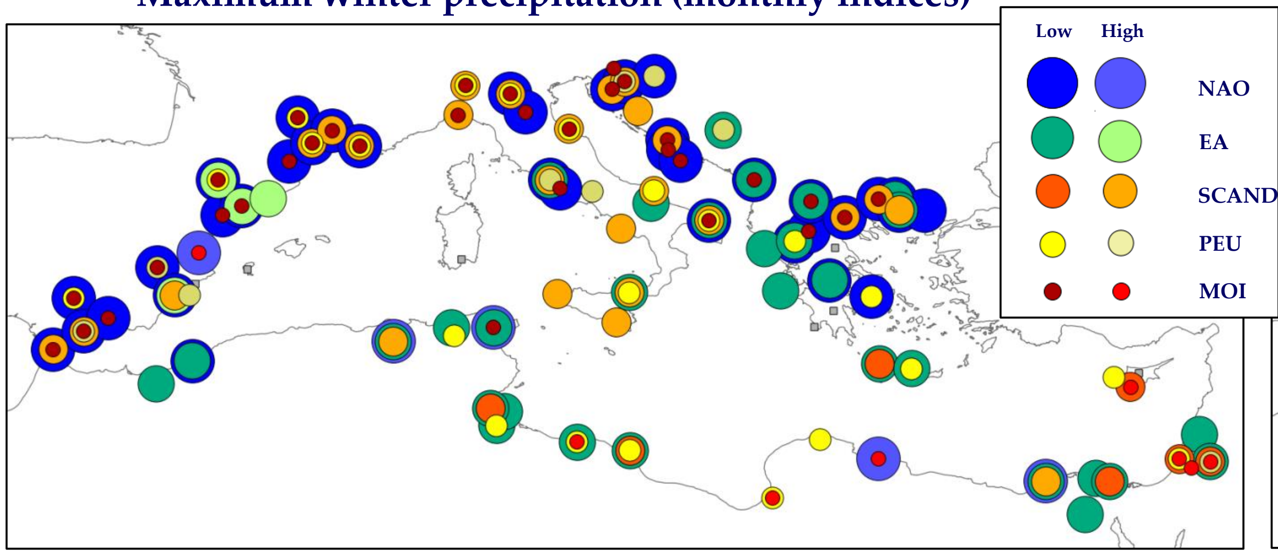
Winter rainfall extremes demonstrate even more distinct signals for the connections of high index winter values (the 20% of the highest/lowest values is shown above). In this case the 10% of the highest/lowest precipitation values is used, because the annual indices have a larger length in comparison to the monthly.

The same patterns are also observed at the annual scale, with a very important difference though. The probability densities of both high and low index ranks are obviously decreased, with a few exceptions (e.g. the SCAND in Iberian Pen.). This happens due to the difference between winter and annual values of the index as can be seen in the figure on the right for the hydrological year 1988-89.

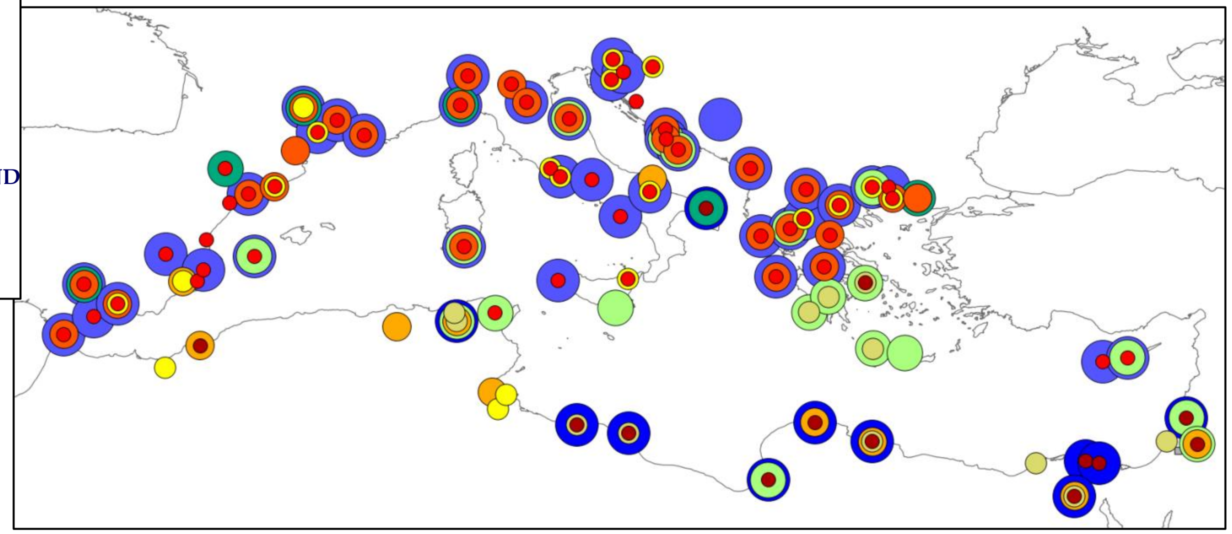


9. Winter extremes

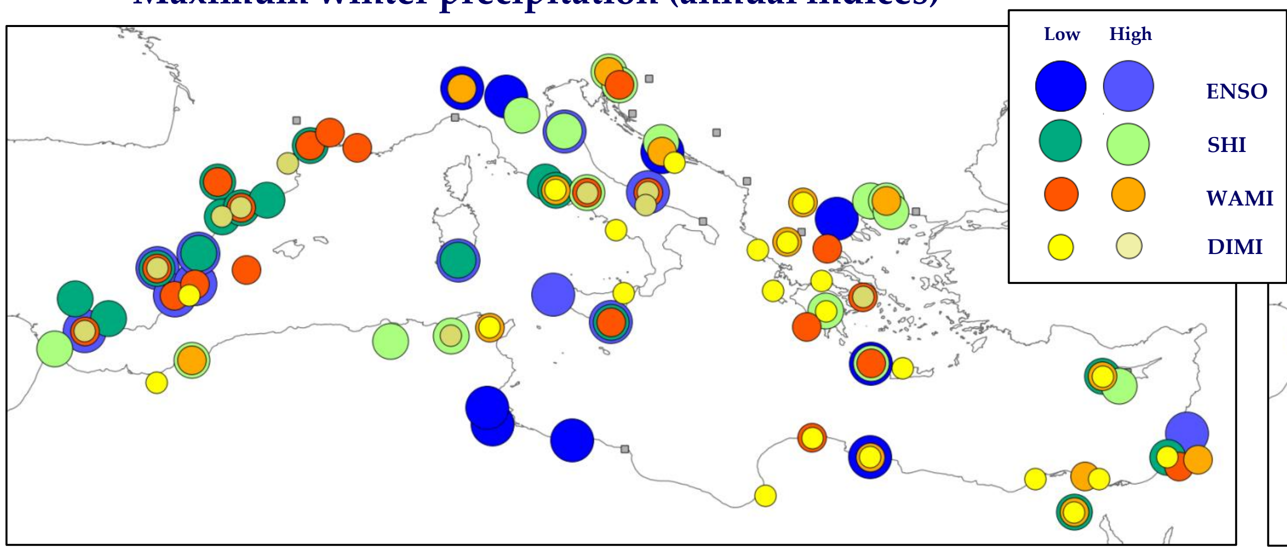
Maximum winter precipitation (monthly indices)



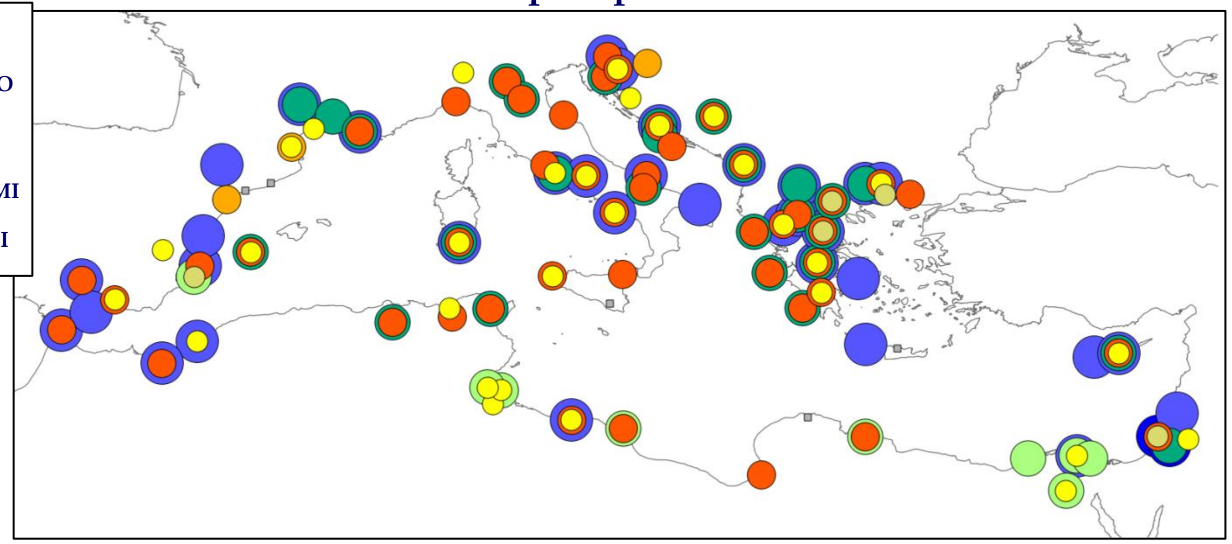
Minimum winter precipitation (monthly indices)



Maximum winter precipitation (annual indices)



Minimum winter precipitation (annual indices)



The spatial effect of the index extremes to the Mediterranean maximum/minimum winter precipitation is also more distinct in this scale (mean relative rank with marginal precipitation below 0.33 is considered as a high index value and above 0.66 as a low index value). For the annual indices, the winter index is used for ENSO; the index values of the previous year are used for WAMI and DIMI as they refer to summer rainfall, and the SHI is used as is, because it corresponds to winter rainfall. The annual indices demonstrate a more homogenous connection with winter precipitation minima than maxima.

In general the driest winters show a slightly better correlation to the index extremes. A possible explanation to this could be that the increased amount of precipitable water that reaches Mediterranean due the atmospheric global circulation is not linearly proportional to increased precipitation, which is a complex process affected by many other factors as well. On the opposite case, the lack of water within the aerial masses leads to decreased precipitation in a more straightforward way.

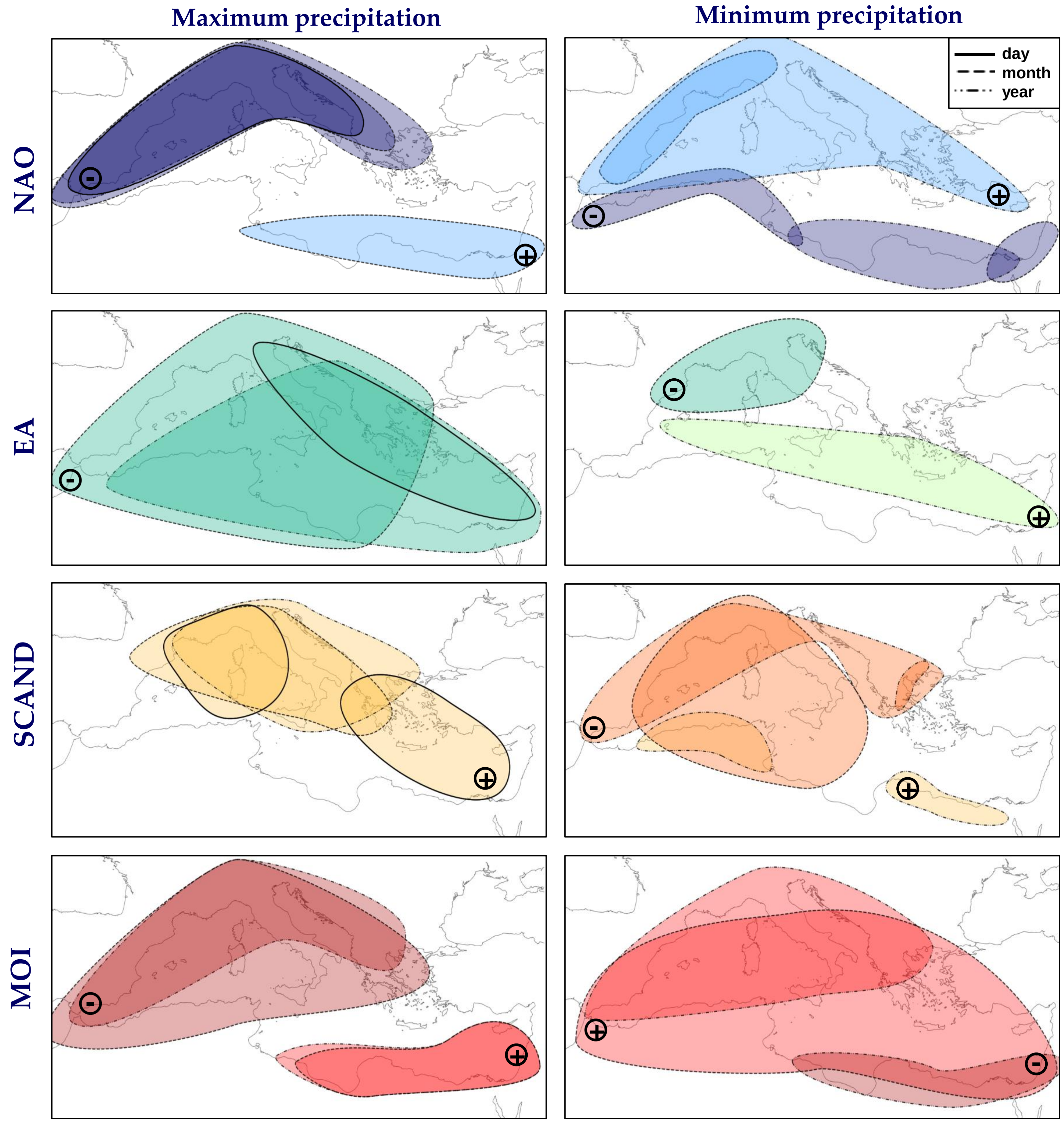
10. Discussion of the results

If we combine the results for each time scale (daily, monthly and seasonal) to a single figure, the correlation between large scale pressure systems and precipitation extremes becomes more evident for 4 of 5 monthly indices.

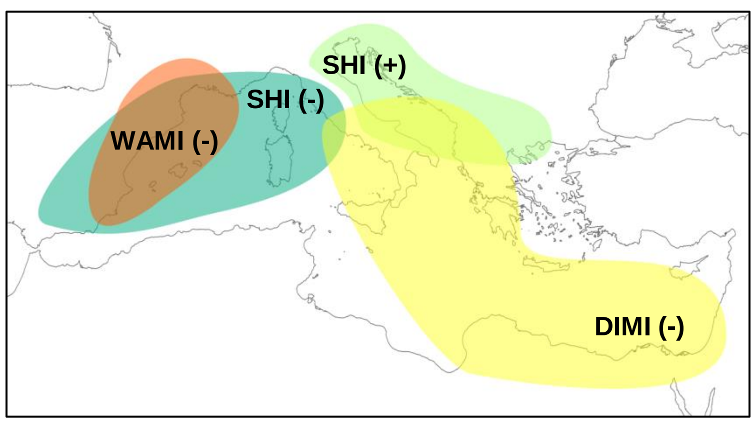
Obviously, in the case of precipitation minima only the monthly and seasonal scale can be examined. In the figures on the right, a different surrounding line is used for each scale: continuous for daily, single dash for monthly and triple dash for winter.

The patterns observed are in good agreement with our current understanding of how general atmospheric circulation affects rainfall at the Mediterranean region (Hurrel, 1995; Wibig, 1999; Haylock and Goodess 2004; Trigo et al. 2006; Hoerling et al., 2012).

The annual indices show stronger correlation to minimum rainfall, but this could not be demonstrated here as the areas overlapped each other. The results for the most wet winters are shown below.



Maximum precipitation

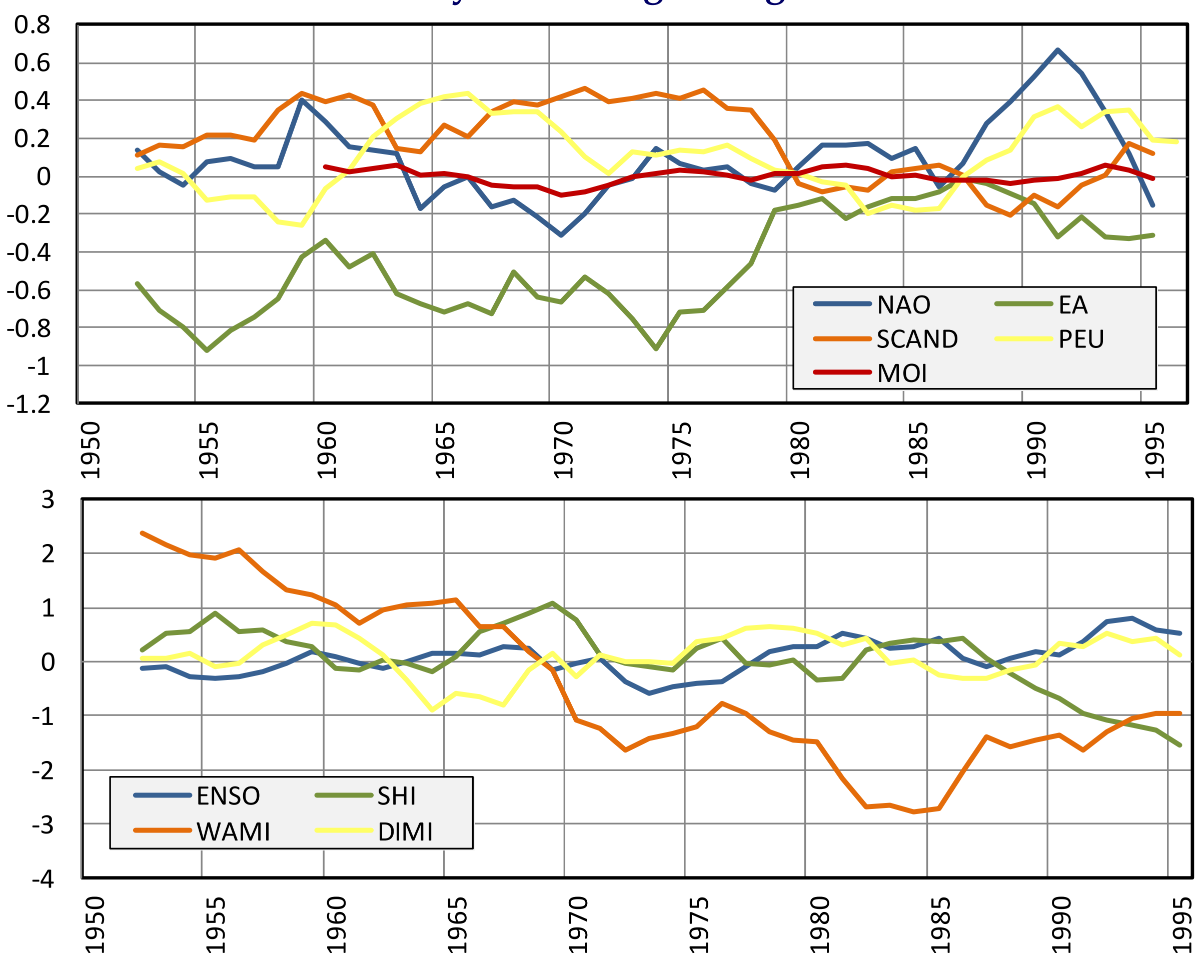


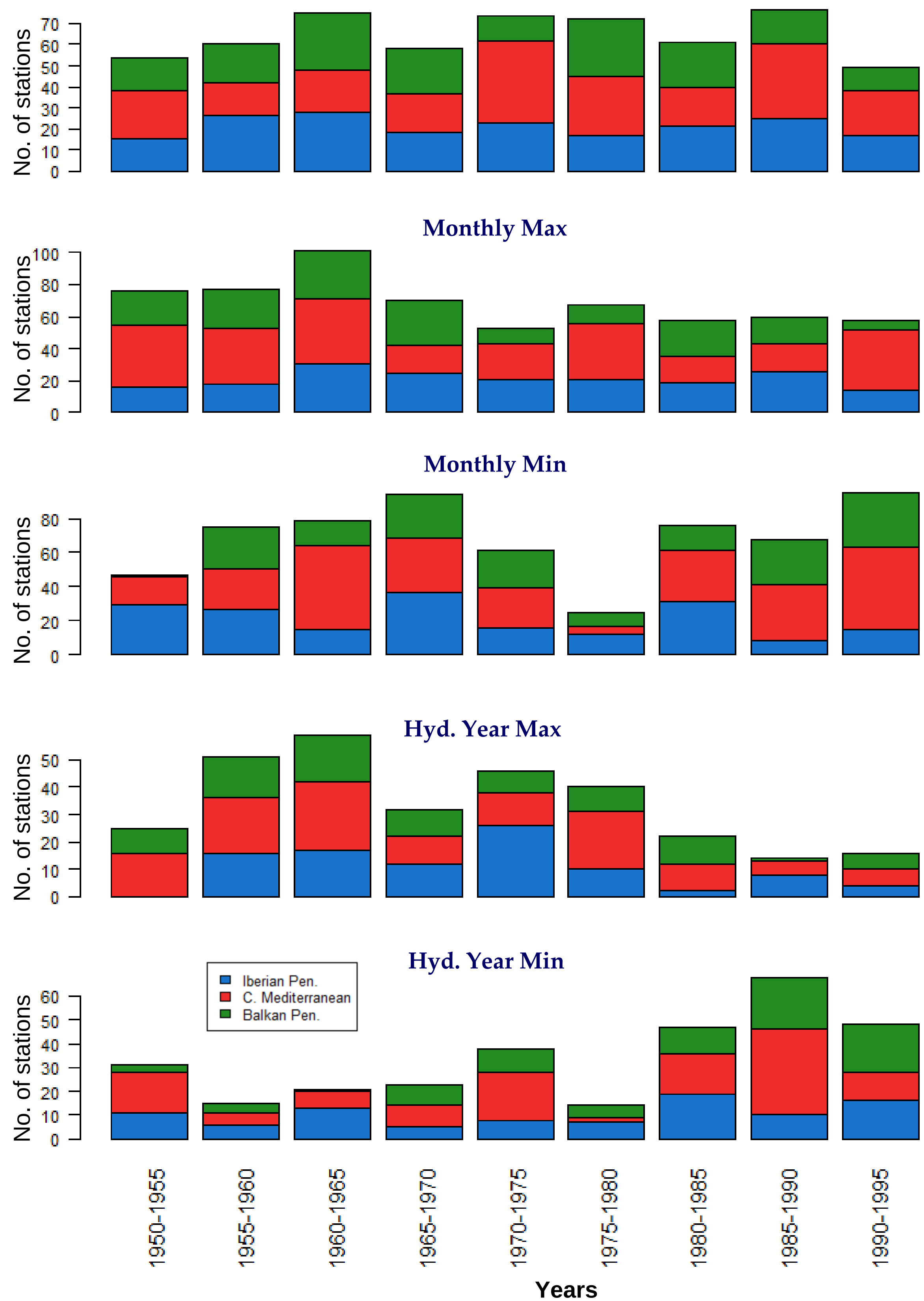
11. Moving to larger scales

The final step of our analysis examines the long-term variation of daily, monthly and annual (hydrological year) extremes in relation to the 5-year moving average of the corresponding indices for the period 1950 – 1995. The 10 highest/lowest values were used per station for the daily and monthly scales, while 5 were used for the annual scale (smaller sample size).

No correlation was found between the daily maxima and the climatic indices, and only slight correlations have been found in the other scales.

5-year moving average





12. Conclusions

The general atmospheric circulation is linked to both high and low extreme precipitation events in the Mediterranean region. This is demonstrated by the two tables below (red is used for positive index values and blue for negative). Furthermore, the main conclusions drawn by our analysis are:

- The correlation becomes higher, as scale increases. More specifically, daily precipitation maxima demonstrate the least correlation, due to a number of reasons including: the scale difference between the indices and the rain event, the convective storms which are not described by synoptic circulation, and smaller-scale cyclogenesis at the Mediterranean Sea (e.g. the Gulf of Genoa).
- Using the annual indices could be misleading, even if they refer to the hydrological year, because of their enhanced inter-annual variability. Hence the annual scale is described better if the indices are aggregated to the winter scale.
- The atmospheric circulation has a more direct effect to precipitation minima, as a consequence to the blocking of wet aerial masses towards the Mediterranean. A question left to be answered is whether it also affects the regional cyclogenesis.

Maximum precipitation

	Iberian Pen.	Central Med.	Balkan Pen.	Mid. East	NC. Africa	W. Africa
NAO	day, month, year	day, month, year	month	month	month, year	
EA		month	day, month, year	month, year	month, year	month, year
SCAND	month	month, year	month	day, month	month, year	
PEU			year	year	year	
MOI	day, month, year	month, year	month	month, year	month, year	month
ENSO						
SHI	year	year	year			
WAMI	year		year			
DIMI	year		year	year	year	year

Minimum precipitation

	Iberian Pen.	Central Med.	Balkan Pen.	Mid. East	NC. Africa	W. Africa
NAO	month, year	month, year	month, year	year	month, year	month
EA			month, year	month	month	month
SCAND	month	month, year	year	month, year	month, year	month
PEU	month	month, year	month, year		year	month, year
MOI	month, year	year	year	month	month, year	
ENSO	year		year			year
SHI	year	year	year	year	year	
WAMI		year	year			year
DIMI						year

References:

Haylock, M. R., & Goodess, C. M. (2004). Interannual variability of European extreme winter rainfall and links with mean large-scale circulation. *International Journal of Climatology*, *24*(6), 759–776. doi:10.1002/joc.1033

Hoerling, M., Eischeid, J., Perlwitz, J., Quan, X., Zhang, T., & Pegion, P. (2012). On the Increased Frequency of Mediterranean Drought. *Journal of Climate*, *25*(6), 2146–2161. doi:10.1175/JCLI-D-11-00296.1

Hurrell, J. W. (1995). Decadal trends in the North Atlantic oscillation: Regional temperatures and precipitation, *Science*, *269*, 676–679

Trigo, R. M., Osborn, T. J., & CorteReal, J. M. (2002). The North Atlantic Oscillation influence on Europe: climate impacts and associated physical mechanisms. *Climate Research*, *20*(1), 9–17. doi:10.3354/cr020009

Wibig, J. (1999). Precipitation in Europe in relation to circulation patterns at the 500 hPa level. *International Journal of Climatology*, *19*(3), 253–269. doi:10.1002/(SICI)1097-0088(19990315)19:3<253::AID-JOC366>3.0.CO;2-0