Covariate-dependent modeling of extreme events by non–stationary Peaks Over Threshold analysis

A review and a case study

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Motivation, I

- The extreme value theory (EVT) provided an excellent framework for the analysis of climatic hazard: it's elegant, simple, and provides useful and understandable results in terms of magnitude / frequency curves.
- The stationarity assumption, though, is an important limitation of the EVT.
- Recent extensions of the EVT allow for non-stationary analysis (Coles, 2001), and an increasing number of authors are exploring their possibilities for the analysis of climatic hazard.

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Motivation, II

- Most studies up to now focused on identifying temporal trends in the occurrence of extreme events, i.e. making time a covariate.
- In the last few years other covariates with an expected influence on the occurrence of extreme events are being used, too –> high relevance for the statistical downscaling of reanalysis or model data, which typically cannot be used for local impact studio.

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Summary

In this talk I will present ongoing research on the relationship between extreme precipitation and teleconnection indices in Spain, using non-stationary EVT techniques. The talk is organized as follows:

- A review of non-stationary Peaks Over Threshold analysis
- Case study: relationship between teleconnection indices and extreme rainfall events in Spain
- Conclusions and future work

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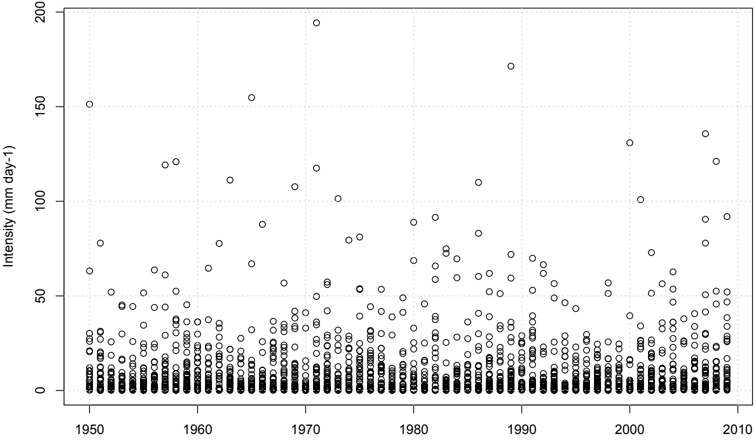
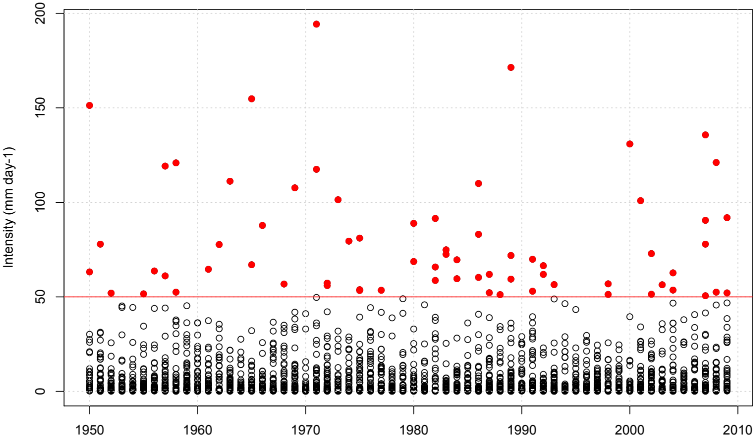
Short review of NSPOT analysis, I



Peaks-over-threshold (POT) sampling: take only exccedances over a threshold, $X > x_0$

Short review of NSPOT analysis, II



Peaks-over-threshold (POT) sampling: take only exccedances over a threshold, $X > x_0$

Short review of NSPOT analysis, III

Stationary POT: assuming independent inter-arrival times, the POT data follows a Generalized-Pareto distribution.

Probability of exceedance:

$$P\left(X > x | X > x_0\right) = 1 - \lambda\left(1 + \kappa\frac{x - x_0}{\alpha}\right)^{-1/\kappa} \tag{1}$$

Quantile corresponding to a return period T:

$$X_T = x_0 + \frac{\alpha}{\kappa}\left[1 - \left(\frac{1}{\lambda T}\right)^{\kappa}\right] \tag{2}$$

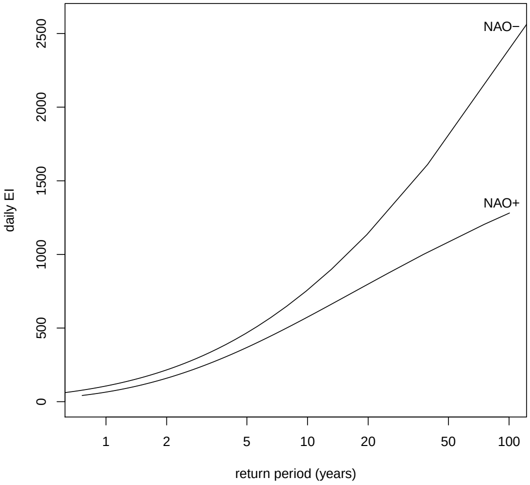
(beware of alternative conventions: $x_0 = u$, $\alpha = \sigma$, $\kappa = \xi$)

Short review of NSPOT analysis, IV

Approaches for assessing non-stationarity in POT modeling:

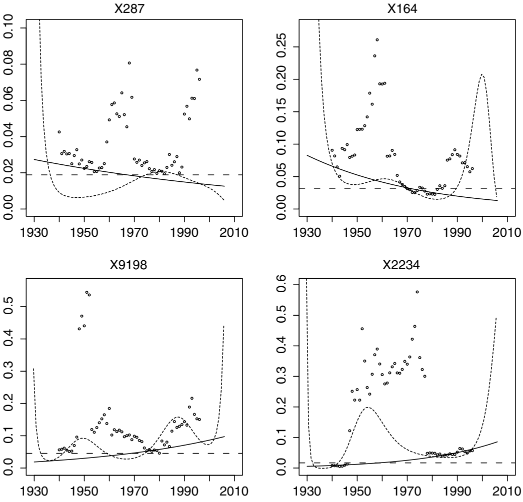
- Split-sample approach (Li et al., 2005)
- Moving kernel (Hall and Tajvidi, 2000)
- Non-stationary POT (NSPOT) modeling

Short review of NSPOT analysis, V



Split-sample approach: independent models for positive and negative phases of NAO (Angulo et al., 2011).

Short review of NSPOT analysis, VI



Moving kernel approach: time variability in the P10 quantile, based on a moving window of the previous 20 years of data (Beguería et al., 2011).

Short review of NSPOT analysis, VII

Stationary POT:

$$P\left(X > x | X > x_0\right) \;=\; 1 - \lambda\left(1 + \kappa\frac{x - x_0}{\alpha}\right)^{-1/\kappa}$$

Non-stationary POT:

$$P\left(X > x | X > x_0, C\right) \;=\; 1 - \lambda(c)\left(1 + \kappa(c)\frac{x - x_0(c)}{\alpha(c)}\right)^{-1/\kappa(c)} \tag{3}$$

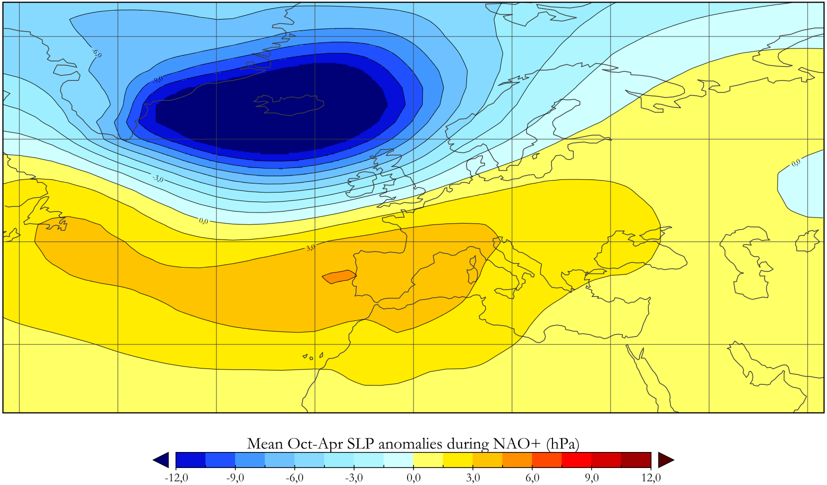
Short review of NSPOT analysis, VIII

Some examples of NSPOT analysis of climatic variables:

- Time dependence of T and P (Smith, 1999)
- Nogaj et al. (2006) time trends of T extremes over the NA region
- Laurent and Parey (2007), Parey et al. (2007), T extremes in France
- Méndez et al. (2006), trends and seasonality of POT wave height
- Yiou et al. (2006) trends of POT discharge in the Czech Republic
- Abaurrea et al. (2007) trends of POT T in the IP
- Acero et al. (2011), Beguería et al. (2011), trends in POT P, IP

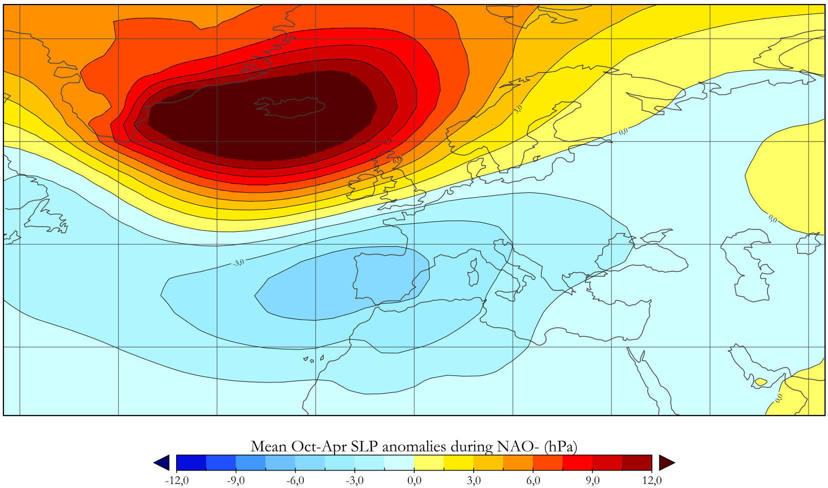
- Friederichs (2010), Kallache et al. (2011), downscaling of POT P based on reanalysis / GCM data
- Tramblay et al. (2012), covariation between POT P extremes and atmospheric covariates, SE France

Teleconnections affecting precipitation in the IP, I



The North Atlantic Oscillation (NAO).

Teleconnections affecting precipitation in the IP, II



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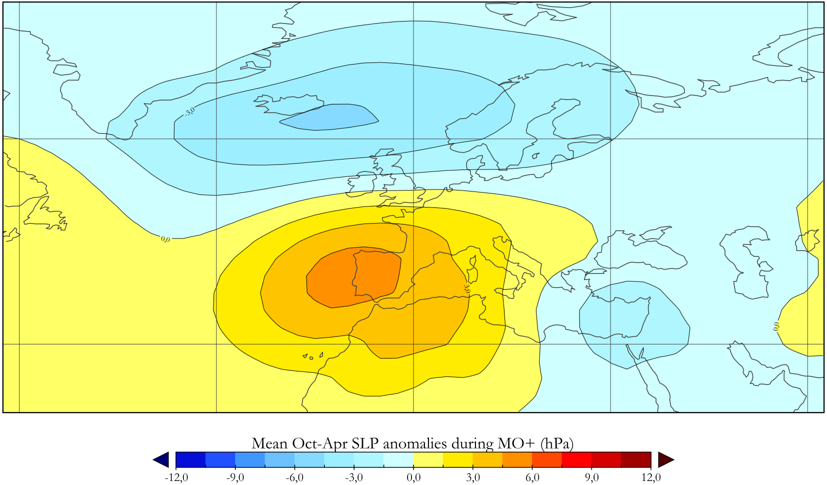
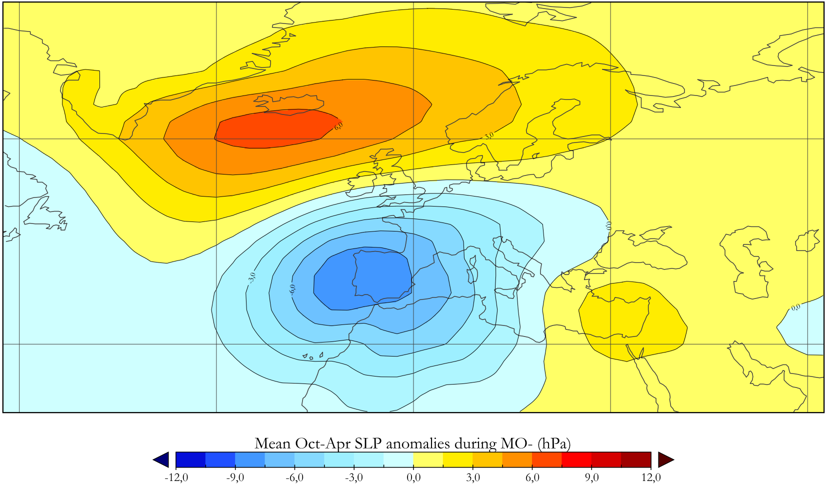
Teleconnections affecting precipitation in the IP, III



The Mediterranean Oscillation (MO, Palutikof 2003).

Teleconnections affecting precipitation in the IP, IV



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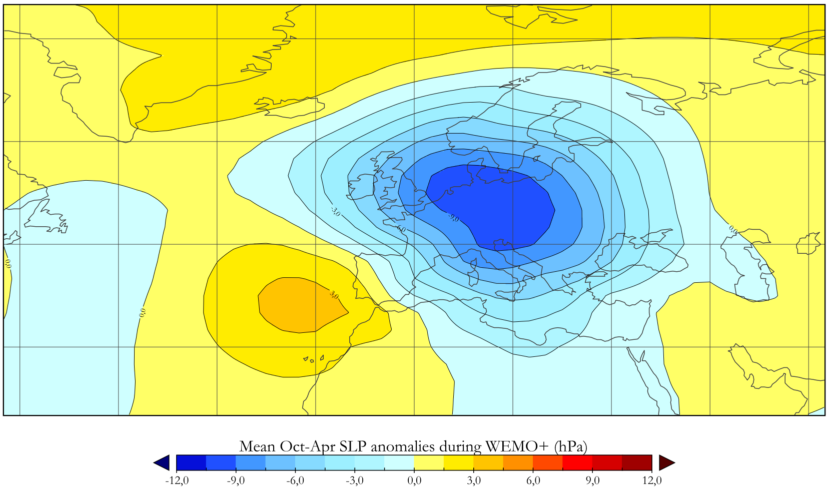
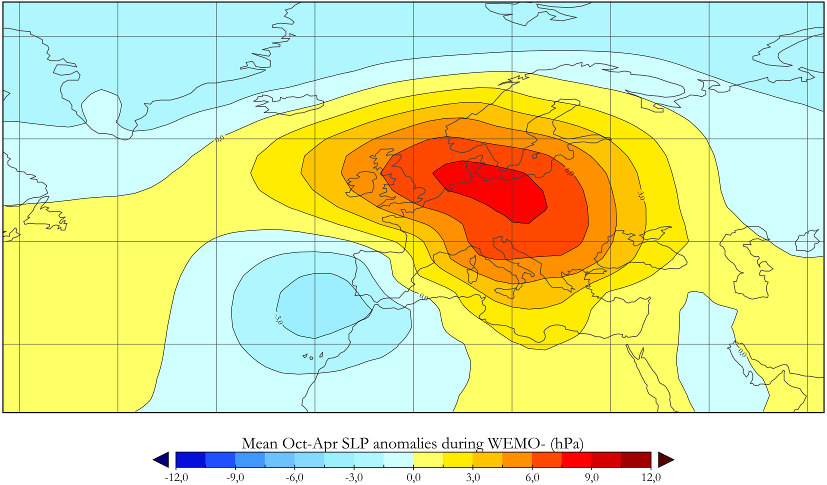


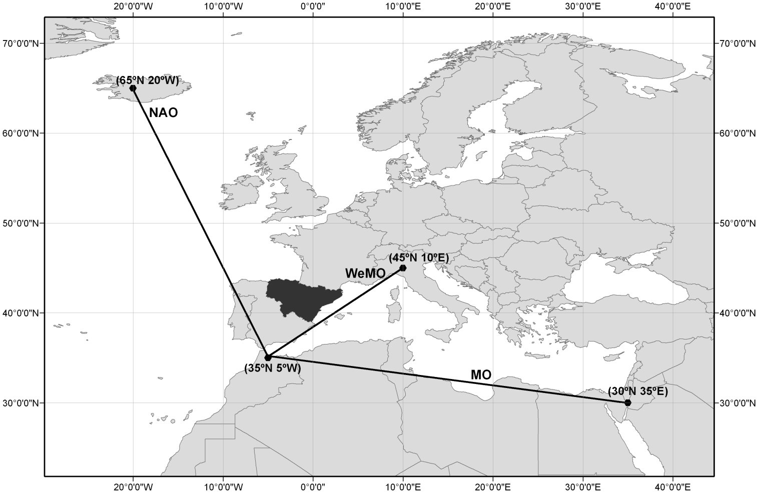
The Western Mediterranean Oscillation (WEMO, Martín-Vide and López-Bustins 2006).

Teleconnections affecting precipitation in the IP, VI



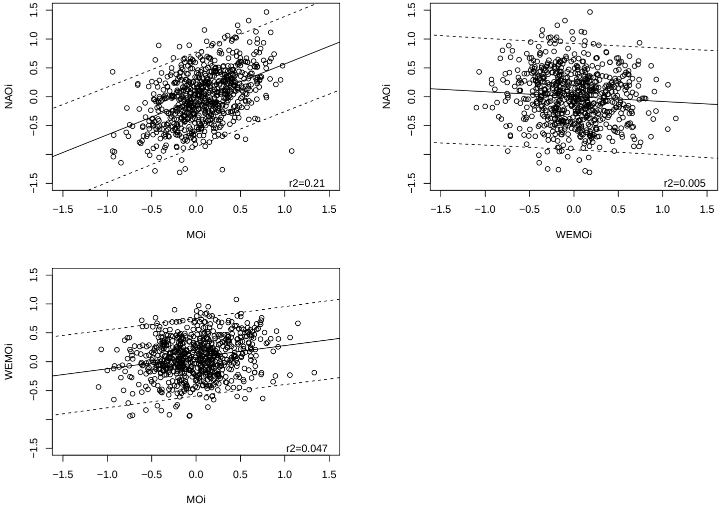
The Western Mediterranean Oscillation (WEMO, Martín-Vide and López-Bustins 2006).

Dataset, II



Teleconnection indices (Reykjavik, Padova, Lod and Gibraltar). Sources: http://www.cru.uea.ac.uk, http://www.ub.es.

Teleconnections affecting precipitation in the IP, VII

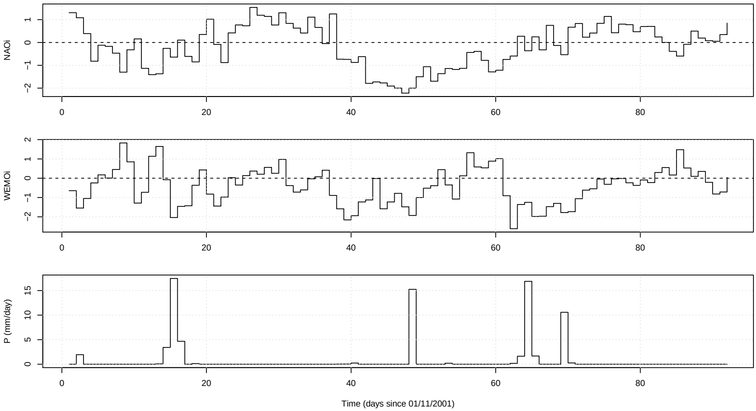


Correlations between teleconnection indices.

Dataset, I

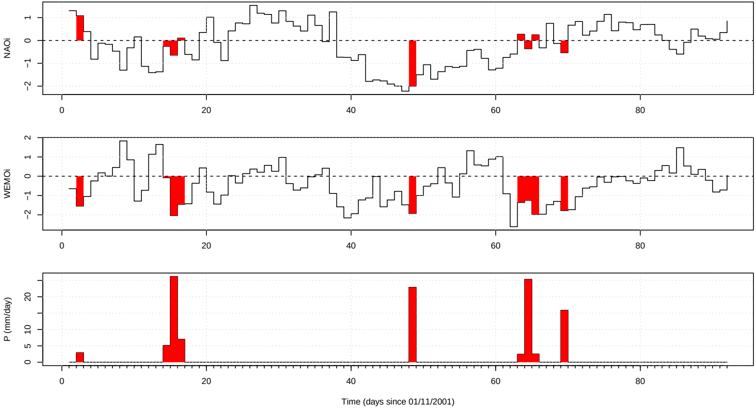
106 stations, 58 daily precipitation series reconstructed for the period 1950-2009 (source: AEMET).

Dataset, III



Declustering: intensity and magnitude series and associated teleconnection indices.

Dataset, IV



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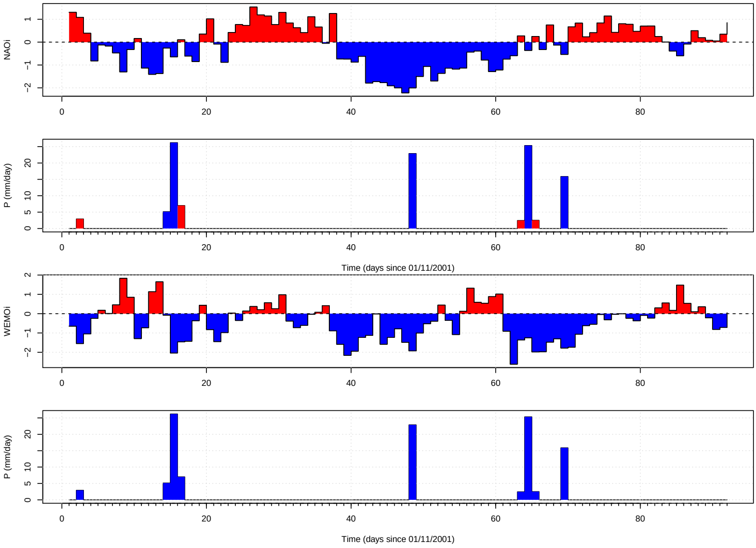
Dataset, V



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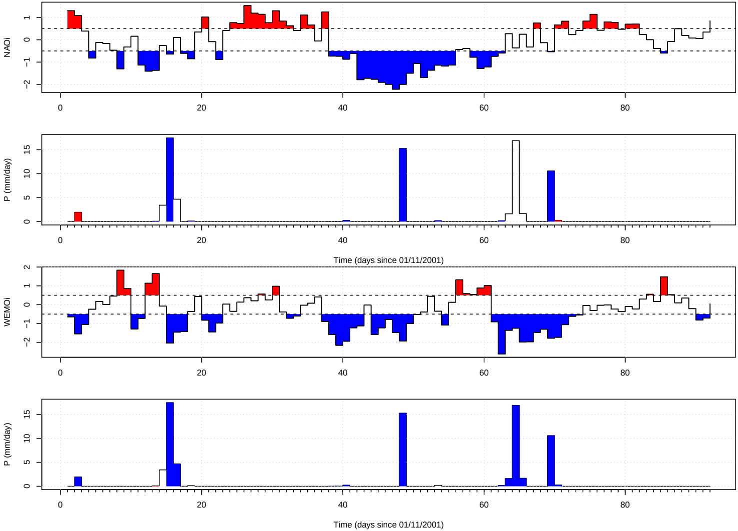
Dataset, VI



Declustering: intensity and magnitude series and associated teleconnection indices.

Analysis, I

M0: $P(X > x | X > x_0) = 1 - \lambda\left(1 + \kappa\frac{x-x_0}{\alpha}\right)^{-1/\kappa}$

M1: $P(X > x | X > x_0, C) = 1 - \lambda\left(1 + \kappa\frac{x-x_0(c)}{\alpha(c)}\right)^{-1/\kappa}$

$$x_0 = \beta_0 + \beta_i c \tag{4}$$

$$\alpha = \gamma_0 \gamma_i^c \tag{5}$$

$$\kappa = \delta \tag{6}$$

$$\lambda = \varepsilon \tag{7}$$

Likelihood ratio test:

$$D = -2\left(\ell_1(M_1) - \ell_0(M_0)\right) \tag{8}$$

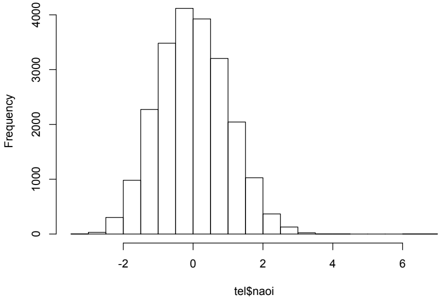
distributed according to χ_k^2 (with d.f. $k = 4$).

Analysis, II

R, package ismev (Stuart Coles, ported to R by Alec Stephenson).

```
...
m0 <- gpd.fit(xdat=dat, threshold=u, npy=rate)
...
uu <- predict(lm(v~cdat))
m1 <- gpd.fit(xdat=dat, threshold=uu, npy=rate, ydat=cdat,
sigl=1, siglink=exp)
```

Analysis, III

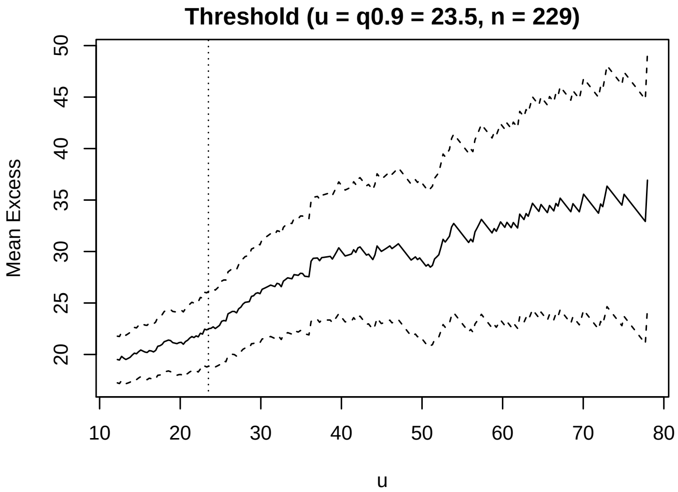


Covariates: NAOi and pnorm(NAOi)

Example: Valencia, I

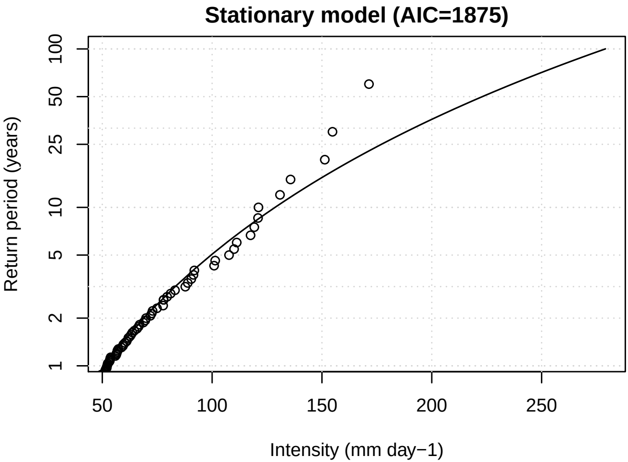
Spatial location

Example: Valencia, II



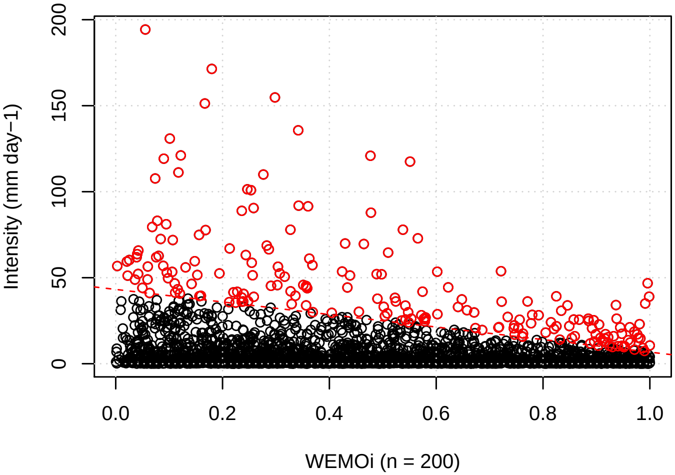
Stationary model: fixed threshold

Example: Valencia, III



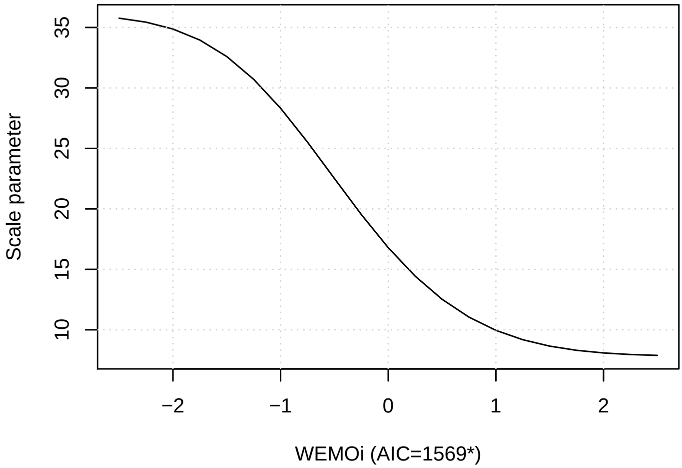
Stationary model: quantile plot

Example: Valencia, IV



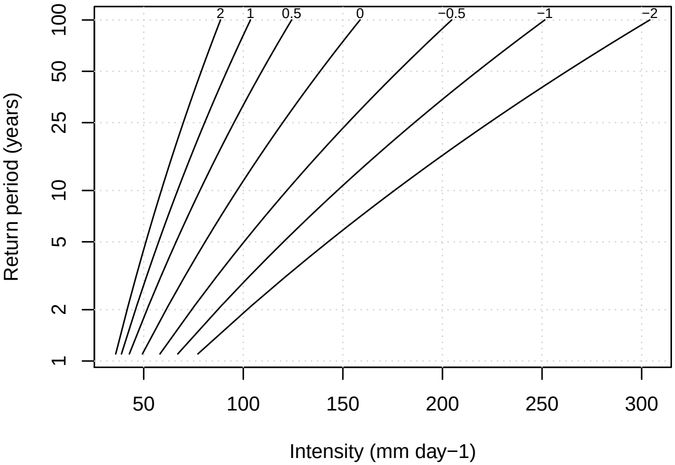
Non-stationary model: threshold model

Example: Valencia, V



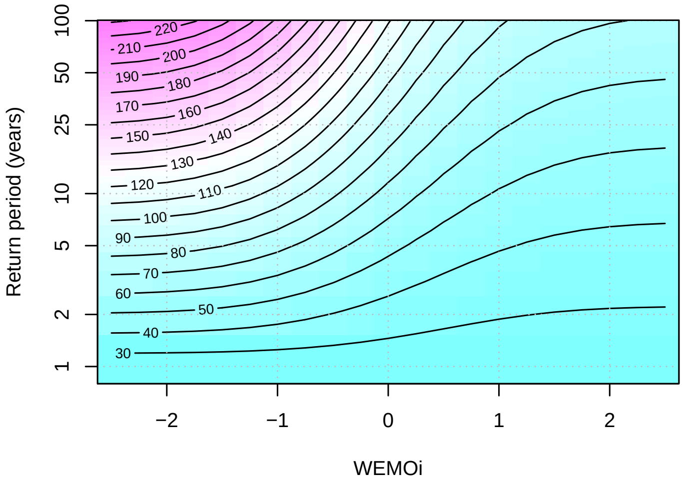
Non-stationary model: scale parameter model

Example: Valencia, VI



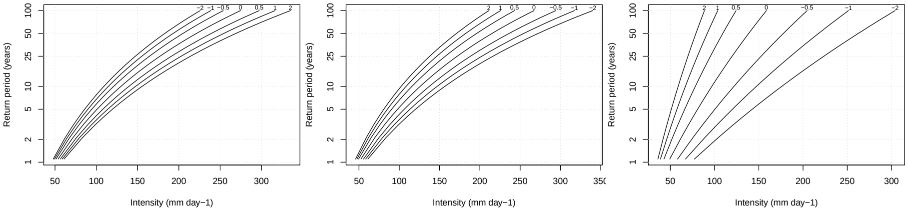
Non-stationary model: quantile plot

Example: Valencia, VII



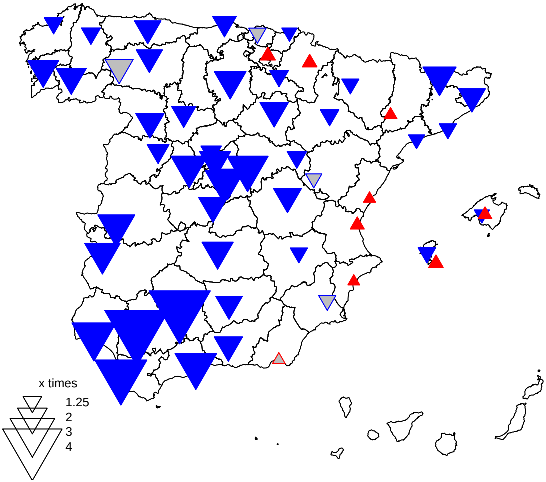
Non-stationary model: quantile plot

Example: Valencia, VIII



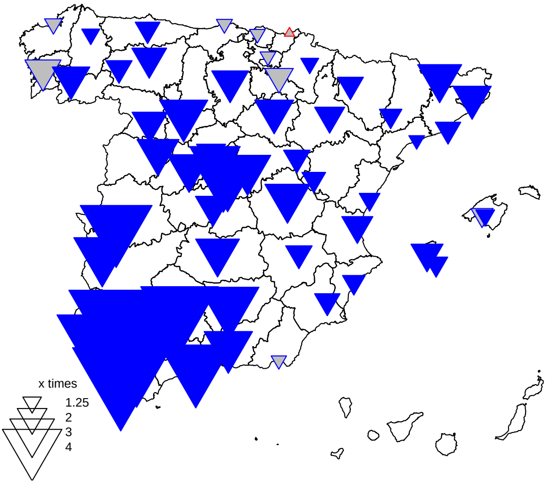
Non-stationary model: NAO (left), MO (center), WEMO (right)

Results: event's magnitude, I



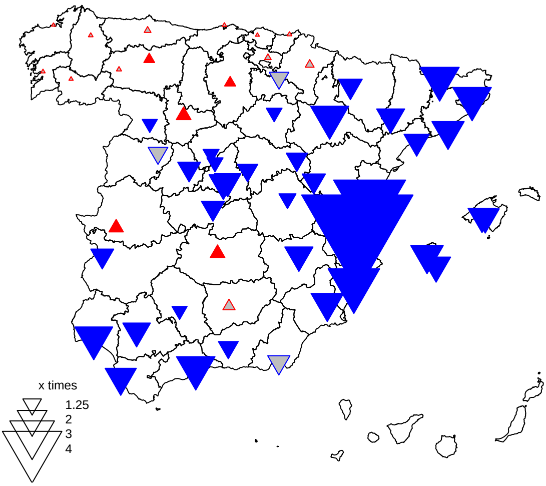
Effect of NAO on the 100-years return period event:

Results: event's magnitude, II



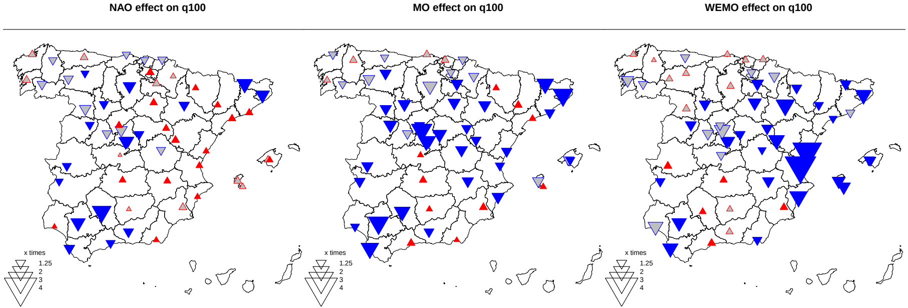
Effect of MO on the 100-years return period event

Results: event's magnitude, III



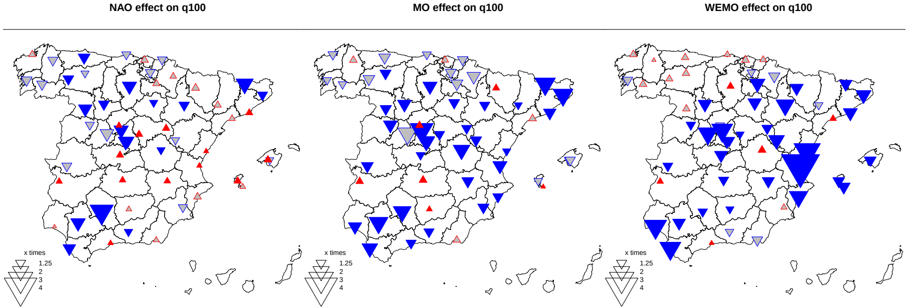
Effect of WEMO on the 100-years return period event

Results: event's intensity



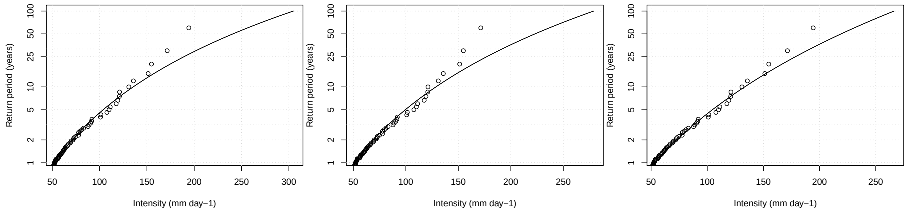
Effect of NAO, MO and WEMO on the 100-years return period event

Results: event's magnitude, winter



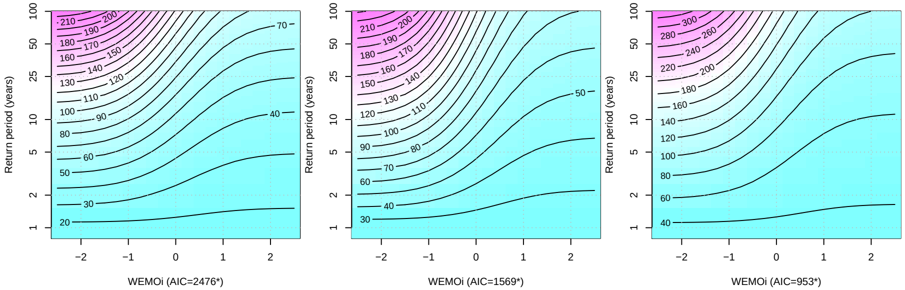
Effect of NAO, MO and WEMO on the 100-years return period event

Results: threshold independence, I



Quantile plots for rainfall intensity in Valencia, thresholds at u=q85, u=q90 and u=q95

Results: threshold independence, II



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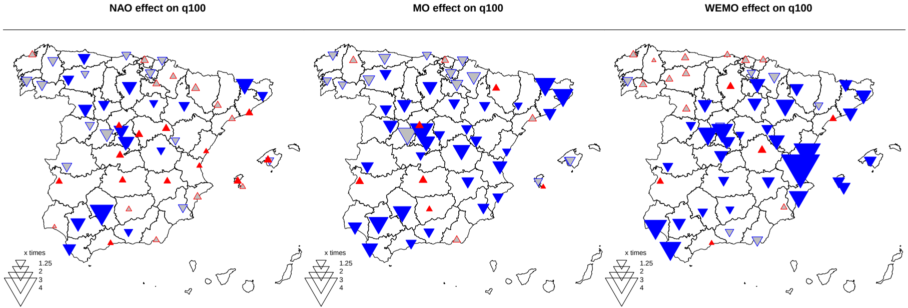
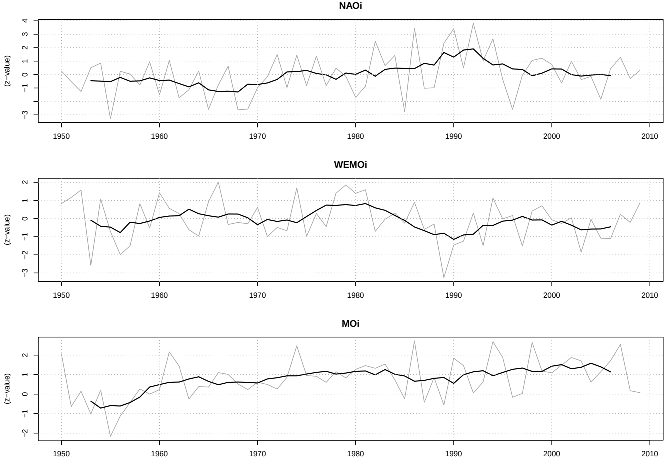
Results: threshold independence, III



Effect of WEMO in rainfall magnitude, thresholds at u=q85, u=q90 and u=q95

Projected evolution of NAOi, MOi and WEMOi



Time variation of NAOi, MOi and WEMOi in the 21th Century, INMCM3.0 model output, 48-months convolution (envelope of SRES A1b, A2 and B1 scenarios)

Conclusions and future work I

- NSPOT analysis is good at capturing the relationship between extreme precipitation processes and atmospheric circulation indices.
- The results are promising for a variety of applications, including short-term warning systems and the statistical downscaling of GCM/RCM outputs.

Conclusions and future work II

- Clustering methods based on the series of covariates (and not on P).
- Other covariates: synoptic scale airflow parameters (direction, strength, vorticity), specific humidity, etc.
- Multi-covariate analysis.
- Spatial model: take advantage of spatial dependence to reduce uncertainty.

References I

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Thank you!

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