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Statistical Modelling of Extreme Winter Temperatures in Europe with Atmospheric Blocking as Covariate

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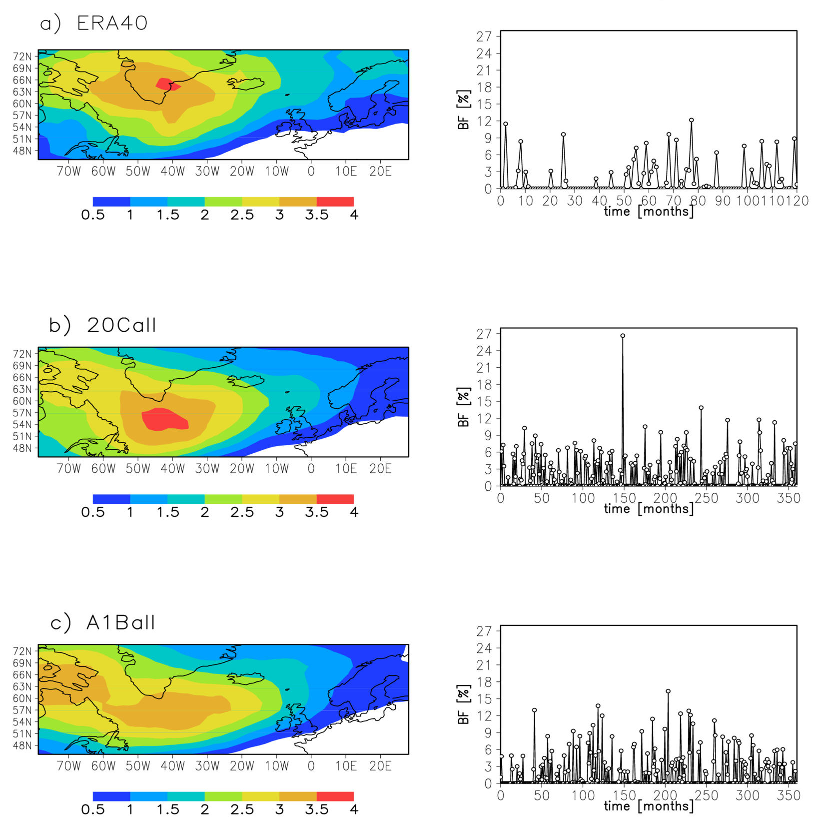
Introduction

The Generalized Extreme Value distribution (GEV) is fitted to monthly minima of daily **European winter (DJF) minimum surface temperatures** (T2MIN).
We try to improve the fit by conditioning the GEV parameters to a covariate derived from a large-scale atmospheric circulation pattern. We particularly concentrate on **North Atlantic atmospheric blocking as covariate** as it explains parts of the winter climate variability in Europe and is associated with anomalous cold winter temperatures (Sillmann & Croci-Maspoli 2009).

Data

- **ERA-40 Re-analysis** (ERA40)
- **ECHAM5/MPI-OM** global climate model simulations with 3 ensemble members for the 20th century (20C) and A1B scenario. 40-year time slices from the respective ensemble members are concatenated and referred to as 20Call (1961-2000) and A1Ball (2160-2199) hereinafter.

Atmospheric Blocking



Blocking detection
- Two-dimensional dynamical blocking detection by Schwierz et al. (2005)
- Based on a vertically averaged Potential Vorticity (PV) measure
- Only blocks with life-times longer than 10 days are considered

Covariate Atmospheric Blocking (CAB)
- time series of spatially averaged blocking frequencies (Fig. 1 right column)

Fig 1. Temporal (left) and spatial (right) averaged climatologies of the Euro-Atlantic (80°W,30°E,45°N,75°N) atmospheric blocking frequencies for a) ERA40, b) 20Call and c) A1Ball.

Non-stationary GEV

- GEV with a distribution function G, representing the 3 members of the **GEV family**:

$$G(x) = \exp\{-[1+\xi(x-\mu)/\delta]^{-1/\xi}\}$$

with location (μ), scale (δ), and shape (ξ) parameter

- **Parameters of the GEV** are conditioned on the time varying covariate atmospheric blocking (CAB)

$$F(x|CAB(t) = z) \sim GEV(\mu(z),\delta(z),\xi)$$

- **Linear relationship** between CAB and the location and log-transformed scale parameter

$$\mu(t) = \beta_0 + \beta_1 * CAB(t)$$
$$\ln\delta(t) = \gamma_0 + \gamma_1 * CAB(t)$$

where β_1 and γ_1 denote the slope of the location [°C] and scale parameter with respect to CAB

Statistical models to represent extreme minimum temperatures (T2MIN) in Europe

TABLE 1. Model collection of the GEV for the stationary case (model 0) and the non-stationary case (model 1, 2), where one or more parameters are conditioned on CAB and their corresponding degrees of freedom (d.f.).

Model	μ	σ	ξ	GEV function	d.f.
0	0	0	0	$F(x) \sim GEV(\mu, \sigma, \xi)$	3
1	CAB	0	0	$F(x\mid CAB(t)=z) \sim GEV(\mu(z), \sigma, \xi)$	4
2	CAB	CAB	0	$F(x\mid CAB(t)=z) \sim GEV(\mu(z), \sigma(z), \xi)$	5

Deviance statistic as selection criteria for best fitting model:

$$D = 2\{nllh_0(M_0) - nllh_1(M_1)\} > c_{\alpha=0.05}$$

which distinguishes between the negative log-likelihood (nllh) of two models, M_0 and M_1, where M_0 is a subset of M_1 by limiting the d.f.

M_0 will be rejected in favor of M_1 if $D > c_\alpha$, where c_α is the (1-α) quantile of the χ^2_k distribution (with k being the differences of d.f. between M_0 and M_1)

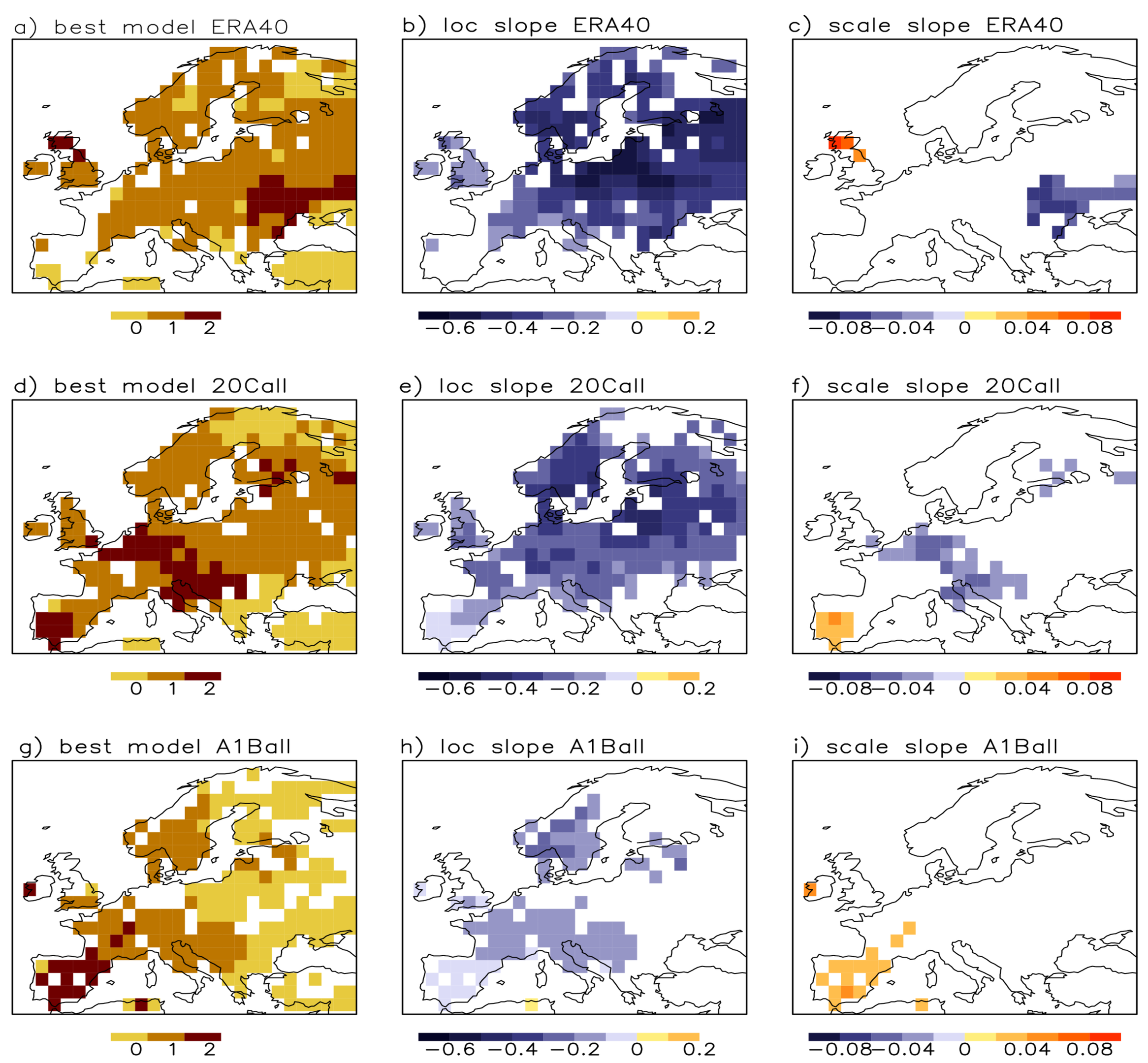


Fig 2. Best statistical model (cf. Table 1) for ERA40 (a), 20Call (d) and A1Ball (g). Grid points where the Goodness-of-Fit (Kolmogorov-Smirnov) test failed are left blank. Further shown are the slope of the location parameter β_1 [°C] (b, e, h) and the slope of the scale parameter γ_1 (c, f, i) for grid points with non-stationary GEV models selected as best in ERA40, 20Call and A1Ball.

References

Schwierz, C., M. Croci-Maspoli, and H. Davies, 2004: Perspicacious indicators of atmospheric blocking. Geophys. Res. Lett., 31, L06125, doi:10.1029/2003GL019341.

Sillmann, J. and M. Croci-Maspoli, 2009: Present and future atmospheric blocking and its impact on European mean and extreme climate. Geophys. Res. Lett., 36, L10702, doi:10.1029/2009GL038259.

Influence of Covariate on GEV and 20-year Return Values

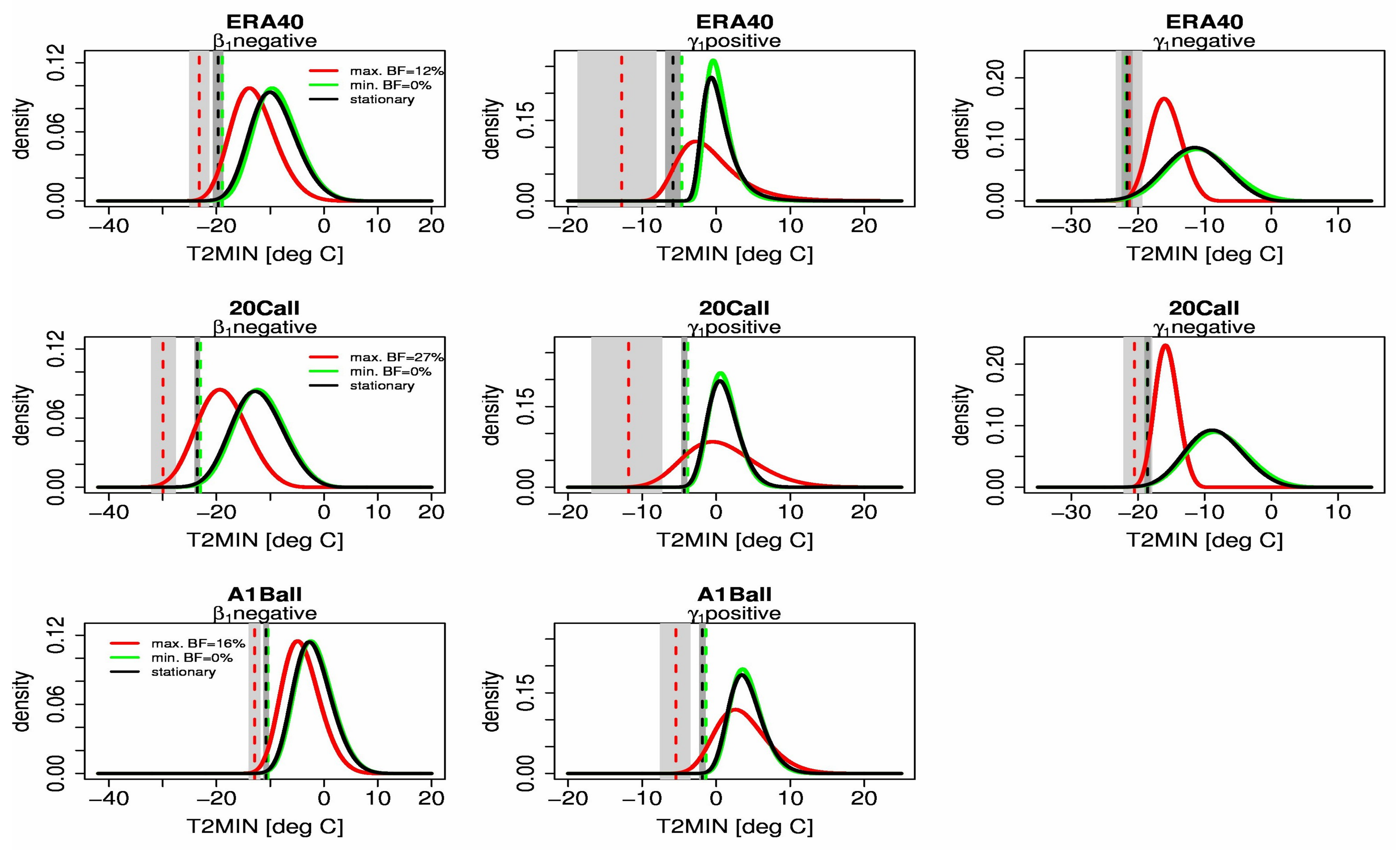


Fig 3. Density functions of the stationary (black) and non-stationary GEV for zero (green) and maximum (red) blocking frequency of ERA40 (top row), 20Call (middle row) and A1Ball (bottom row). Shown are spatial averages over regions where model 1 (left column) and model 2 with positive (middle column) or negative (right column) slope of the scale parameter got selected as best. Corresponding RV20 for the stationary and non-stationary case are indicated as vertical dashed lines with their respective 90% confidence intervals as grey shading.

Relationship RV20 versus Blocking Frequency

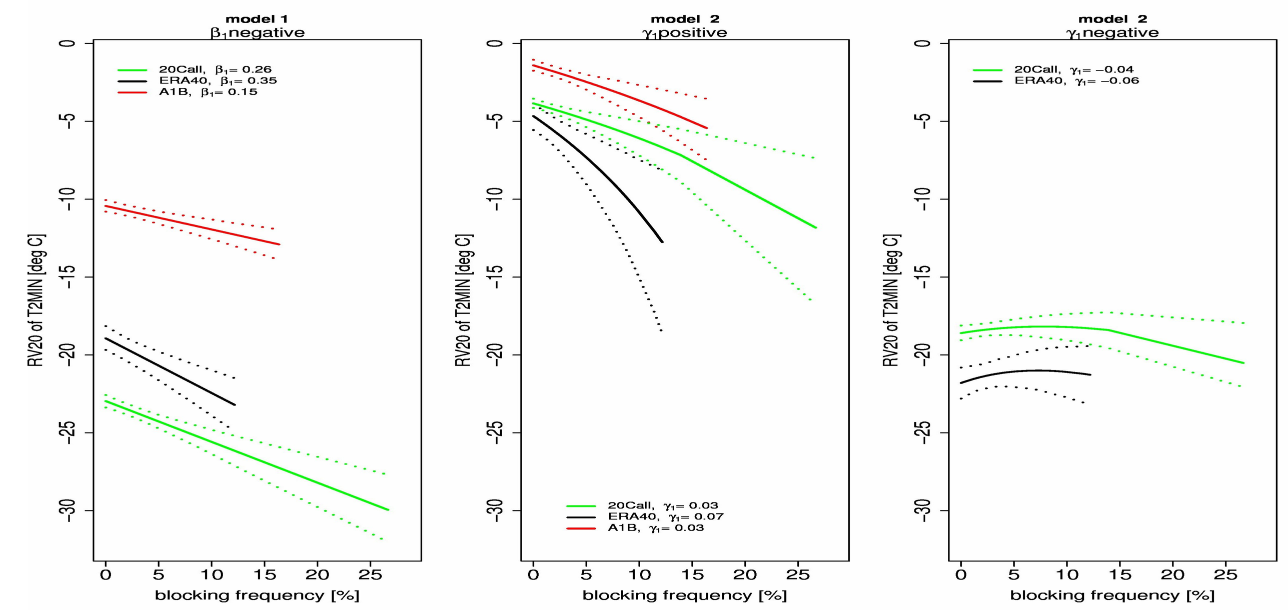


Fig 4. Non-stationary RV20 versus blocking frequencies for ERA40 (black), 20Call (green) and A1Ball (red) for regions where model 1 (left column) and model 2 with positive (middle column) or negative (right column) slope of the scale parameter got selected. The 90% confidence intervals are indicated as dotted lines.

Summary

- Atmospheric blocking as **covariate improves the fit of the GEV** to extreme T2MIN in winter in large parts of Europe
- consistently decreasing slope of the location parameter for ERA40, 20Call and A1Ball
- decrease in RV20 under the influence of CAB, enforced in regions (Southern Europe) where the slope of the scale parameter is positive, which indicates an increased variability in extreme T2MIN

→ in winters with **persistent atmospheric blocking**, we can **expect significantly colder nighttime temperatures** with strongest response in the time series with the highest blocking frequency (27% in 20Call)

- this relationship remains **robust under future climate conditions**
- the affected region however is diminished in A1B as atmospheric blocking location shifts and **blocking frequency decreases**, which adds to the general warming trend in T2MIN under enhanced GHG concentration and **reduces the chances of very cold winters in Europe**