Recommendation on the best predictor variables for extreme precipitation
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Introduction

Analysis of daily precipitation data from stations distributed in the German part of the Rhine basin for the second half of the 20th century has shown an increasing trend in the extreme events in the winter and the transition seasons and a decreasing trend in the summer (D9 report). Although different atmospheric variables can interact to bring about the observed changes, it is more prudent to select the variables that are likely to contribute more to the changes and try to establish their relationship with the extreme.

The purpose of this study is to investigate the relationship between the trends in the precipitation extremes and their potential causes and make a recommendation on their viability in explaining the observed changes.

Data and Method

Daily values of relative humidity, air temperature, geopotential heights at the 500, 700, and 850hPa levels, and sea level pressure all at a resolution of 2.5° _ 2.5° from the NCEP reanalysis data set were used. In addition, the average monthly sea surface temperature pertaining to the northern hemisphere was used.

The sea level pressure distribution was classified into objective circulation patterns (CPs) that can explain the space-time variability of precipitation extremes in the Rhine basin. The CP classification was performed by using a fuzzy rule optimisation technique for the classification of large scale pressure fields into circulation patterns (Bárdossy, et.al.,1995). Instead of the observed precipitation, the difference in discharge between a given day and the previous day was used as a variable whose distribution is to be explained by the optimised CPs. Twelve different circulation patterns were defined according to this classification scheme.

The CPs that are associated with wet days were selected based on the magnitudes of the mean seasonal precipitation conditioned on each of the CPs and the frequencies of the CPs associated with wet days. Further, those CPs associated with extreme precipitation were identified by calculating the frequencies of the CPs on the days on which the magnitude of precipitation is above the 90th percentile annual seasonal rainfall.

In order to find out whether a particular CP is responsible for the observed trends in the extreme, the trend in the frequency of the CPs on the days having precipitation above the threshold magnitude is calculated. If it happens to have a similar trend pattern with the extreme, that would suggest that the CP in question can potentially explain the occurrence of the extreme. Finally, the overall trends of the CPs, without any reference to extremes were calculated to see if the CPs have become more frequent through time.

In addition to the above analysis, the predictive power of each of the other selected potential indicator variables was investigated by calculating the correlation between the seasonal mean values of the indicators at each grid point and the seasonal values of the selected extreme precipitation indices averaged over all the 611 precipitation stations distributed over the study area.

Results

Three CPs were identified to be associated with wet days, and particularly one among them was found to account for most of the rain days. The same CPs were found to account for the majority of the rainfall days above the threshold precipitation magnitude as shown in table 1. The largest percentage of both the wet days and the extreme precipitation is associated with CP02, which is identified by a depression over North western Europe and an anticyclone over north western Africa. The other two CPs, which are associated with wet days and extremes are CP09 and CP11. They are shown in Fig. 1.

As shown in table 2, CP02 is potentially the cause of the winter extreme precipitation. The increase in the winter extreme precipitation is accompanied by an increase in the frequency of CP02 on extreme precipitation days for the majority of the stations. In the summer, a decrease in the extreme precipitation was observed. From table 2, it can be seen that the increase and decrease in the frequencies of CP02 and CP11 conditioned on the extreme are balanced and more decrease in the frequency of CP09 was obtained. Therefore, CP09 can possibly be responsible for the summer intense precipitation. Although the trends in the frequency of occurrence of these critical CPs is consistent with the explanation given here for the increase and decrease in the winter and summer extremes respectively, the magnitudes of the trends are very small and none of them are significant as shown in table 3.

The correlation analysis for the other indicators shows that the winter extremes are best explained by the relative humidity at all the three pressure levels investigated. The correlations between the other variables and the winter extreme indices are very low, suggesting that they have very poor predictive power for the season's extreme precipitation. For the other seasons and annually, relative humidity and geopotential heights at all levels, together with air temperature at 700 and 850 hPa level show fairly high correlation with the extreme indices, making them potential predictors for all seasons except winter (tables 4 – 9). Sea surface temperature and temperature at the 500hPa level show the least correlation with all the extreme indices for all the seasons with maximum values of 0.27 for both. This makes the variable less desirable as a predictor variable for extreme precipitation.

Reference

Bardossy, A., Duckstein, L., and Bogardi, I. (1995): Fuzzy rule based classification of atmospheric circulation patterns. *Intl. J. Clima.* **15**, 1087 – 1097.

Appendix

Table 1: Frequencies of the CPs associated with wet days on wet and extreme days.

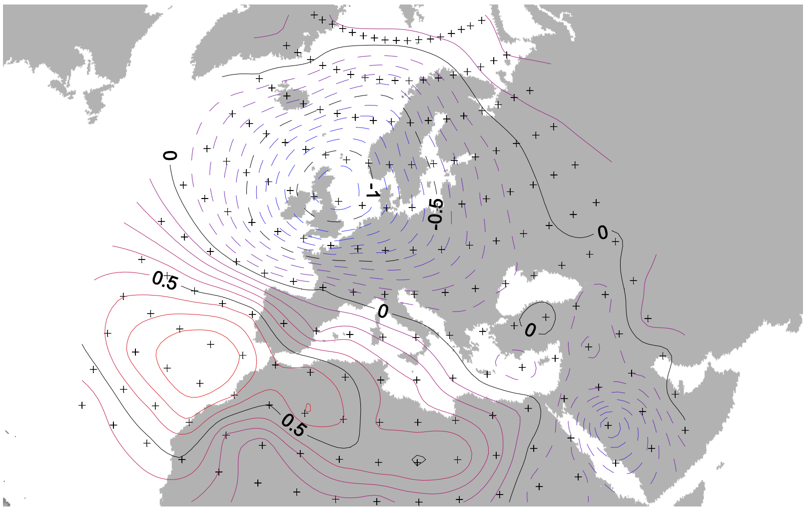
	Winter			Spring			Summer			Autumn		
	CP02	CP09	CP11	CP02	CP09	CP11	CP02	CP09	Cp11	CP02	CP09	CP11
Wet days (%)	0.281	0.144	0.125	0.238	0.142	0.130	0.191	0.112	0.140	0.268	0.146	0.144
Mean prec.(mm/day)	2.13	0.976	0.610	1.456	0.896	0.791	1.349	0.858	1.149	2.016	1.067	0.967
Above prec90 (%)	0.452	0.180	0.089	0.263	0.176	0.140	0.188	0.132	0.177	0.348	0.187	0.159

Table 2: Number of precipitation stations showing positive/negative trends on frequency of days above prec90 conditioned to a given CP.

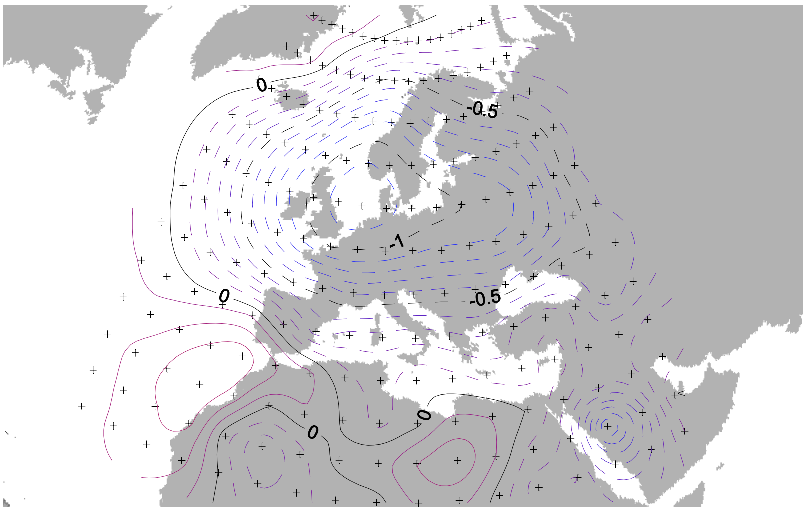
	Winter			Spring			Summer			Autumn		
	CP02	CP09	CP11	CP02	CP09	CP11	CP02	CP09	Cp11	CP02	CP09	CP11
Positive trend	566	309	100	221	464	406	304	212	308	171	369	81
Positive significant	129	4	1	6	37	13	7	7	9	1	2	0
Negative trend	45	302	511	390	147	205	307	399	303	440	242	530
Negative significant	0	11	48	25	3	3	7	26	9	9	0	73

Table 3: Trends in the frequency of occurrence of the critical CPs.

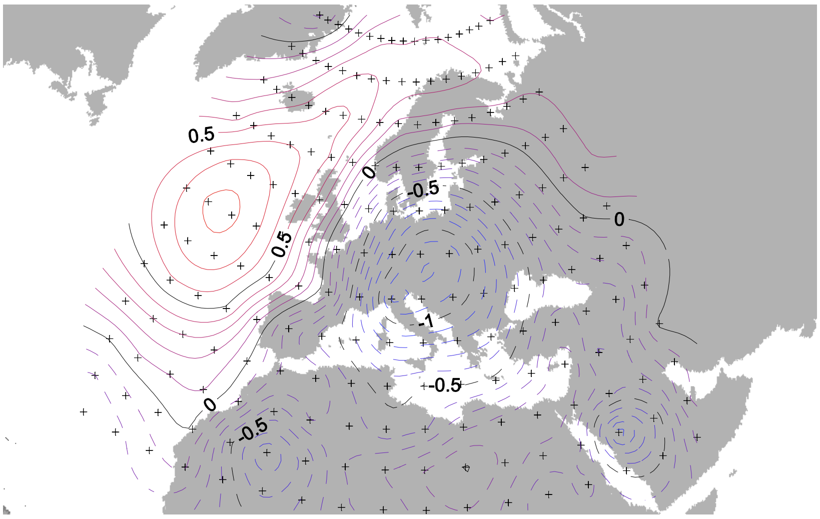
CPs	Winter		Spring		Summer		Autumn	
	Trend (%/yr)	Signif.	Trend (%/yr)	Signif.	Trend (%/yr)	Signif.	Trend (%/yr)	Signif.
CP02	0.05	no	-0.08	no	-0.05	no	0.02	no
CP09	-0.03	no	0.09	no	-0.03	no	-0.02	no
CP11	-0.09	no	0.0	---	0.02	no	0.01	no



CP02



CP09



CP11

Fig. 1: Distribution of pressure anomalies for the three CPs associated with wet days.

Table 4: Maximum positive and negative correlations between indicators and prec90

Indicator Variable	Winter		Spring		Summer		Autumn		Annual	
	Max. pos.	Max. Neg.	Max. pos.	Max. neg.	Max. pos.	Max. neg.	Max. pos.	Max. neg.	Max. pos.	Max. neg.
RH_500	0.342	-0.572	0.436	-0.426	0.404	-0.439	0.489	-0.465	0.484	-0.493
RH_700	0.390	-0.519	0.441	-0.422	0.451	-0.501	0.344	-0.393	0.498	-0.437
RH_850	0.458	-0.513	0.482	-0.445	0.470	-0.461	0.460	-0.487	0.476	-0.529
Geo. Ht_500	0.000	-0.131	0.396	-0.558	0.248	-0.492	0.512	-0.378	0.384	-0.353
Geo. Ht_700	0.000	-0.169	0.375	-0.582	0.268	-0.430	0.479	-0.374	0.390	-0.338
Geo. Ht_850	0.036	-0.253	0.376	-0.607	0.320	-0.296	0.503	-0.371	0.458	-0.309
Tem_500	0.000	-0.033	0.109	0.000	0.095	0.000	0.190	0.000	0.159	0.000
Tem_700	0.000	-0.092	0.445	-0.381	0.211	-0.522	0.415	-0.322	0.411	-0.561
Tem_850	0.000	-0.100	0.453	-0.358	0.193	-0.580	0.437	-0.432	0.393	-0.445
SST	0.002	------	0.214	------	0.151	-------	-------	-0.086	0.125	-------

Table 5: Maximum positive and negative correlations between indicators and 641CDD

Indicator Variable	Winter		Spring		Summer		Autumn		Annual	
	Max. pos.	Max. Neg.	Max. pos.	Max. neg.	Max. pos.	Max. neg.	Max. pos.	Max. neg.	Max. pos.	Max. neg.
RH_500	0.400	-0.414	0.600	-0.420	0.463	-0.475	0.532	-0.566	0.465	-0.363
RH_700	0.432	-0.422	0.590	-0.461	0.464	-0.461	0.617	-0.707	0.509	-0.378
RH_850	0.496	-0.457	0.551	-0.523	0.390	-0.585	0.667	-0.657	0.509	-0.395
Geo. Ht_500	0.000	-0.222	0.644	-0.479	0.440	-0.356	0.556	-0.485	0.445	-0.405
Geo. Ht_700	0.000	-0.247	0.660	-0.481	0.455	-0.328	0.539	-0.485	0.466	-0.396
Geo. Ht_850	0.000	-0.316	0.654	-0.485	0.456	-0.329	0.523	-0.495	0.479	-0.372
Tem_500	0.000	-0.032	0.123	0.000	0.000	-0.044	0.000	-0.270	0.000	-0.240
Tem_700	0.000	-0.210	0.513	-0.436	0.435	-0.396	0.520	-0.410	0.419	-0.427
Tem_850	0.000	-0.214	0.478	-0.476	0.497	-0.347	0.452	-0.433	0.471	-0.470
SST	0.097	------	-------	-0.198	-------	-0.145	-------	-0.115	------	-0.080

Table 6: Maximum positive and negative correlations between indicators and 644R5d

Indicator Variable	Winter		Spring		Summer		Autumn		Annual	
	Max. pos.	Max. Neg.	Max. pos.	Max. neg.	Max. pos.	Max. neg.	Max. pos.	Max. neg.	Max. pos.	Max. neg.
RH_500	0.299	-0.619	0.411	-0.432	0.514	-0.360	0.421	-0.425	0.502	-0.405
RH_700	0.354	-0.695	0.478	-0.408	0.649	-0.479	0.411	-0.448	0.440	-0.433
RH_850	0.439	-0.555	0.471	-0.457	0.595	-0.374	0.434	-0.395	0.313	-0.503
Geo. Ht_500	0.000	-0.127	0.371	-0.585	0.434	-0.651	0.458	-0.454	0.383	-0.312
Geo. Ht_700	0.000	-0.148	0.389	-0.599	0.499	-0.624	0.434	-0.444	0.376	-0.321
Geo. Ht_850	0.020	-0.198	0.422	-0.631	0.524	-0.586	0.421	-0.438	0.382	-0.359
Tem_500	0.000	-0.034	0.044	0.000	0.054	0.000	0.021	0.000	0.120	0.000
Tem_700	0.000	-0.097	0.402	-0.457	0.303	-0.577	0.477	-0.404	0.416	-0.338
Tem_850	0.000	-0.103	0.416	-0.444	0.386	-0.629	0.376	-0.402	0.394	-0.241
SST	------	-0.015	0.191	-------	0.270	------	------	-0.092	0.090	-------

Table 7: Maximum positive and negative correlations between indicators and 646SDII

Indicator Variable	Winter		Spring		Summer		Autumn		Annual	
	Max. pos.	Max. Neg.	Max. pos.	Max. neg.	Max. pos.	Max. neg.	Max. pos.	Max. neg.	Max. pos.	Max. neg.
RH_500	0.351	-0.592	0.437	-0.394	0.429	-0.422	0.483	-0.462	0.409	-0.459
RH_700	0.402	-0.563	0.485	-0.378	0.454	-0.476	0.363	-0.408	0.459	-0.437
RH_850	0.454	-0.560	0.486	-0.447	0.487	-0.453	0.445	-0.447	0.438	-0.476
Geo. Ht_500	0.001	-0.128	0.349	-0.536	0.285	-0.509	0.475	-0.350	0.409	-0.391
Geo. Ht_700	0.019	-0.171	0.373	-0.558	0.287	-0.454	0.462	-0.351	0.403	-0.379
Geo. Ht_850	0.069	-0.267	0.390	-0.579	0.330	-0.338	0.454	-0.350	0.448	-0.354
Tem_500	0.000	-0.030	0.145	0.000	0.090	0.000	0.146	0.000	0.223	0.000
Tem_700	0.000	-0.087	0.400	-0.374	0.251	-0.514	0.468	-0.311	0.414	-0.383
Tem_850	0.000	-0.093	0.429	-0.408	0.197	-0.577	0.400	-0.394	0.382	-0.347
SST	-------	-0.026	0.291	-------	0.156	-------	-------	-0.134	0.181	-------

Table 8: Maximum positive and negative correlations between indicators and 691R90T

Indicator Variable	Winter		Spring		Summer		Autumn		Annual	
	Max. pos.	Max. Neg.	Max. pos.	Max. neg.	Max. pos.	Max. neg.	Max. pos.	Max. neg.	Max. pos.	Max. neg.
RH_500	0.325	-0.564	0.457	-0.378	0.414	-0.431	0.513	-0.450	0.513	-0.480
RH_700	0.371	-0.550	0.446	-0.461	0.449	-0.501	0.371	-0.418	0.485	-0.475
RH_850	0.460	-0.509	0.481	-0.468	0.505	-0.426	0.498	-0.440	0.499	-0.545
Geo. Ht_500	0.000	-0.133	0.406	-0.481	0.290	-0.481	0.458	-0.317	0.351	-0.331
Geo. Ht_700	0.000	-0.166	0.385	-0.519	0.312	-0.406	0.451	-0.310	0.343	-0.312
Geo. Ht_850	0.024	-0.236	0.375	-0.565	0.359	-0.312	0.498	-0.303	0.413	-0.293
Tem_500	0.000	-0.104	0.080	0.000	0.105	0.000	0.055	0.000	0.075	0.000
Tem_700	0.000	-0.106	0.451	-0.284	0.260	-0.512	0.389	-0.331	0.343	-0.692
Tem_850	0.000	-0.116	0.465	-0.281	0.216	-0.541	0.386	-0.402	0.345	-0.486
SST	-----	-0.026	0.213	-------	0.132	------	-------	-0.158	0.076	-------

Table 9: Maximum positive and negative correlations between indicators and 692R90N

Indicator Variable	Winter		Spring		Summer		Autumn		Annual	
	Max. pos.	Max. Neg.	Max. pos.	Max. neg.	Max. pos.	Max. neg.	Max. pos.	Max. neg.	Max. pos.	Max. neg.
RH_500	0.310	-0.592	0.568	-0.429	0.515	-0.429	0.428	-0.520	0.447	-0.441
RH_700	0.323	-0.606	0.578	-0.483	0.624	-0.490	0.441	-0.471	0.504	-0.426
RH_850	0.407	-0.599	0.462	-0.467	0.560	-0.422	0.520	-0.472	0.432	-0.432
Geo. Ht_500	0.000	-0.119	0.430	-0.566	0.256	-0.540	0.491	-0.483	0.460	-0.586
Geo. Ht_700	0.014	-0.158	0.423	-0.622	0.272	-0.521	0.492	-0.479	0.427	-0.595
Geo. Ht_850	0.058	-0.246	0.439	-0.673	0.317	-0.471	0.441	-0.463	0.386	-0.614
Tem_500	0.032	0.000	0.100	0.000	0.077	0.000	0.145	0.000	0.212	0.000
Tem_700	0.000	-0.074	0.480	-0.497	0.248	-0.557	0.546	-0.423	0.455	-0.508
Tem_850	0.000	-0.080	0.495	-0.508	0.327	-0.616	0.451	-0.362	0.393	-0.331
SST	------	-0.042	0.162	------	0.217	-------	------	-0.034	0.145	------