

D3 Highly resolved climate scenarios from stochastic model Until 2030 for the Neckar river basin

1 Introduction

The aim of this paper is to describe stochastic models developed for downscaling meteorological parameters: precipitation and temperature. The models are capable to generate local variables by means of output of global circulation model and fulfil requirement of high resolution at both temporal and spatial scales. The work is a contribution to water resource management model applying for Neckar river basin in Germany.

2 Data sets and Methodology

The rainfall generating model is a stochastic model, built based on concept of statistic downscaling. Rainfall is linked with the atmospheric circulation patterns using conditional distribution and conditional spatial covariance functions. It is a transformed conditional multivariate autoregressive model, whose parameters are dependent on circulation patterns.

The atmospheric circulation patterns is required to be first generated, that are classified based on concept of fuzzy sets (Zadeh, 1965) and assessed through optimization process by means of defined objective functions. In the updated version, increase of daily discharge difference is selected as an indicator to reflect climate impact on local region. The CPs for Neckar river basin is generated by using normalized pressure anomalies of sea level pressure (SLP) taken from NCEP reanalysis data set at spatial resolution of 2.5° X 2.5°.

Additionally, daily moisture flux is incorporated as a potential predictor, which has been proved to have dominant impact on the rainfall process. The state-of-art model is modified to include it as one of important predictor. Zonal wind components combined with specific humidity at 700 hpa pressure level is chosen for application of model in Neckar river basin.

The precipitation model was calibrated by 117 stations over Baden Württemberg for the period from 1960 to 1990. Model's validation was done for period from 1991 to 2000. Observed and simulated average monthly precipitation is compared for specific years and for selected stations. Model's capability for representing inter-annual variability is evaluated by precipitation related indices.

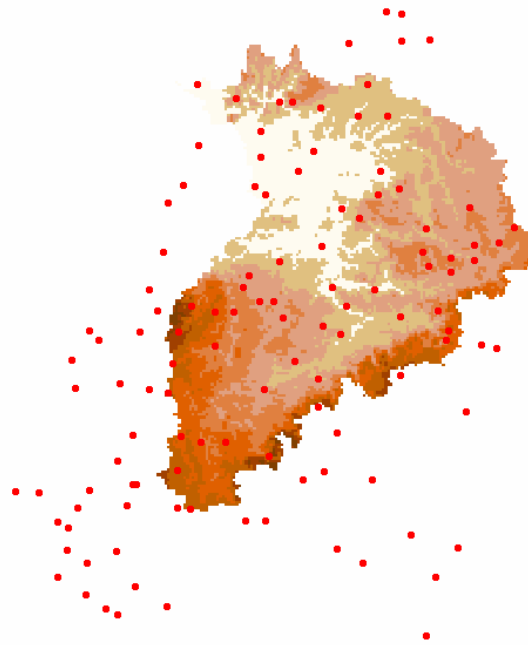


Figure 1 Distribution of precipitation stations within Neckar river basin [stations selected for downscaling process]

In contrast to daily precipitation, daily temperature is much less variable in space. Similar as precipitation downscaling process, specific circulation patterns presenting variability of temperature are classified prior to downscaling procedure. Regression method is applied to set up model to generate daily temperature, which is as a function of geopotential height on the same day.

Instead of SLP, geopotential height at 700 hpa is used as indicator for Neckar river basin and temperature related objective function is used.

Daily temperature during the period from 1960 to 1990 at 10 selected stations within Neckar river basin are used for CP classification and optimization. Total 34 stations were used for model calibration. The average annual temperature cycle at single station is generated to validate model output.

Besides, temperature related diagnostic indices are calculated to evaluate inter-annual variability. The indices used are listed in the table below.

Table 1: Diagnostic indices for long-term precipitation

Precipitation related indices	
Pav [mm/day]	Average precipitation
P90 [mm/day]	90 th percentile of rainy day's amounts
PfI90	% of total rainfall from events > long-term 90 th percentile
PnI90	No. of events > long-term 90 th percentile of rainy days

Table 2: Diagnostic indices for long-term temperature

Temperature related indices	
Txav [°C]	Average Tmax
Tnav [°C]	Average Tmin
Tmin [°C]	Tmin 10 th percentile
Tmax [°C]	Tmax 90 th percentile

Before downscaling process is driven by ECHAM4s, capability of ECHAM4 is needed to be analyzed. The output of model run is compared with NCEP reanalysis data. As to circulation patterns of precipitation and temperature, CPs derived from NCEP reanalysis data and that derived from ECHAM4 is compared in terms of frequency and persistence of specific CPs. The difference of moisture flux between ECHAM4 and NCEP is represented by bias and ratio of standard deviation on seasonal basis.

Later, ECHAM4 scenarios are downscaled for first 30 years of current century, from the year 2000 to 2030. In this paper, ECHAM 4 developed by Max-Planck institute in Hamburg is chosen to provide climate information at large-scale. Its model output under control run is used to evaluate predictor used for downscaling process and its output in terms of A2 and B2 are 2 scenarios recommended by IPCC to analyze possible development in the future.



3 Result

Precipitation downscaling model

The circulation patterns classified for Neckar river basin are derived by mean sea level pressure from NCEP reanalysis data and optimized by local daily discharge. The circulation patterns consist of total 12 types and some of these 12 types dominate specific climate conditions. For example, CPs list out in Table3. It is obvious to recognize that CP11 and CP04 are wet CPs. These 2 CPs occur seldom, but contribute to most of rainfall, especially to extreme events. That is why they are named as “wet CPs”. In contrast to “wet CPs”, CP05 and CP08 are clearly 2 “dry CPs”. They occur quite often, but their contribution to rainfall processes is very limited.

Table 3: Frequency and amount of precipitation of specific CPs in winter

Winter	Frequency [%]	> Mean precipitation [%]	> 90th precipitation [%]
CP05	14.2	6.1	2.6
CP08	12.8	6.7	4.6
CP11	8.3	20.9	33.8
CP04	6.2	12.4	14.3

Conditioned to each CP the variability of precipitation is captured by distribution function and daily precipitation is to be generated stochastically, together with consideration of spatial correlation amongst stations and auto-correlation at each single station.

Table 4: Precipitation related diagnostic analysis in winter and summer

		Winter			Summer		
		Bias	Correlation		Bias	Correlation	
		Aver	Max	Aver	Aver	Max	Aver
Pav	CP + MF	-0.57	0.80	0.53	-0.14	0.58	0.34
90T	CP + MF	-0.03	0.41	0.18	0.07	0.18	0.007
90N	CP + MF	-0.07	0.62	0.31	-0.13	0.37	0.12
P90	CP + MF	-0.06	0.56	0.22	1.16	0.27	0.06

Table 5: Precipitation related diagnostic analysis in spring and autumn

		Spring			Autumn		
		Bias	Correlation		Bias	Correlation	
		Aver	Max	Aver	Aver	Max	Aver
Pav	CP + MF	-0.22	0.76	0.51	0.58	0.68	0.47
90T	CP + MF	-0.05	0.40	0.12	-0.03	0.41	0.16
90N	CP + MF	-0.66	0.59	0.27	0.66	0.58	0.25
P90	CP + MF	-0.38	0.46	0.17	0.31	0.41	0.16

Shown by diagnostic analysis, model can well perform with respect to average precipitation “Pav” in most of seasons except summer, which is relatively smaller. The average correlation between simulated and observed precipitation can reach high value of 0.53. For the rest of indices, the average correlation is not as high as indice Pav, but the maximum correlation of single station can still reach significant level. Generally, all indices achieve high correlation in

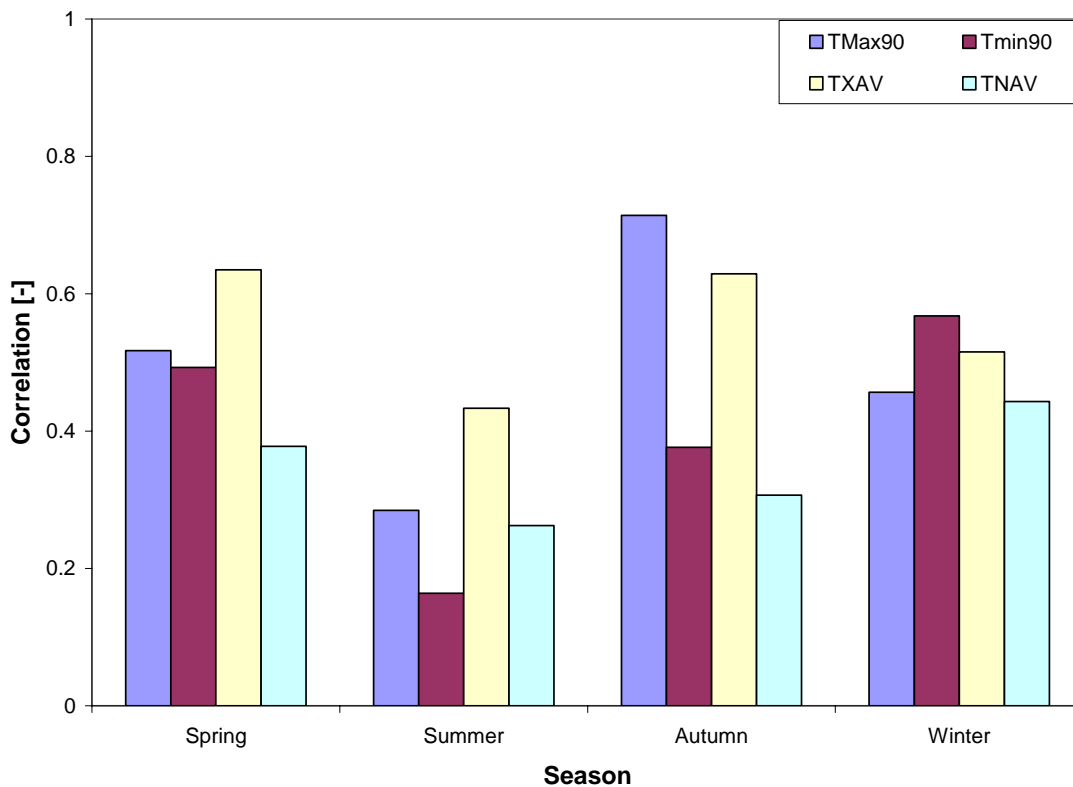
winter, even for extreme indices, followed by transition season, spring and autumn. The model is relatively weak for modelling precipitation occurs in summer.

The monthly average precipitation for unfavourable year 1965 and 1991 is calculated. Figure 3, 4 in Appendix indicates that simulated precipitation is consistent with observed precipitation at both selected stations. The model is able to capture main distribution of precipitation annual cycle and peak monthly precipitation within the year.

Temperature downscaling model

Total 10 stations over Neckar river basin are chosen and their daily maximum and daily minimum temperature are used for optimization process. Finally, 12 temperatures CP has been classified which shows out different behavior of temperature under condition of circulation patterns. Average annual cycle was analyzed to evaluate the performance of CPs [Figure 5-6 in Appendix]. Of 12 CPs, CP01 and CP10 are considered as “warm” CPs, while CP04 and CP12 are obvious “cold” CPs. Cold and warm conditions are able to be differentiated.

Table 6: Temperature related indices over stations in Neckar river basin on seasonal scale



After downscaling process is done, the simulated daily Tmax and Tmin are evaluated by both average temperature annual cycle and temperature related indices. The indices are calculated on seasonal basis. From above figure, it is noticed that most of indices in most of seasons can reach higher correlation except summer. Compared with other seasons, the model's capacity is relatively weak for summer.

Since there is good consistence between observed and downscaled meteorological parameters, our models are further used to generate temperature and precipitation data from global circulation model (GCM).

Circulation patterns derived from ECHAM4

The circulation patterns for precipitation and temperature for ECHAM4 scenarios are derived by mean sea level pressure and geopotential height (700 hpa level) from ECHAM4 output. The patterns are similar as that derived from NCEP for current climate conditions. The mean seasonal frequency and mean persistence of specific CPs are compared amongst NCEP derived CPs and ECHAM4 derived CPs.

Table 7: Frequency of precipitation CPs in winter and summer [%]

	Winter				Summer			
	NCEP	CTL	A2	B2	NCEP	CTL	A2	B2
CP11	8.83	9.55	9.25	9.10	9.00	8.34	9.80	9.80
CP05	14.96	16.4	18.0	15.8	13.00	14.6	13.76	13.0

Table 8: Frequency of precipitation CPs in spring and autumn [%]

	Spring				Autumn			
	NCEP	CTL	A2	B2	NCEP	CTL	A2	B2
CP11	8.30	9.00	8.30	8.8	8.16	10.7	10.0	10.4
CP05	14.00	14.2	16.5	15.1	15.00	15.3	16.0	16.7

Table 9: Mean persistence of precipitation CPs in winter and summer [day]

	Winter				Summer			
	NCEP	CTL	A2	B2	NCEP	CTL	A2	B2
CP11	1.75	1.56	1.44	1.37	1.40	1.31	1.43	1.44
CP05	1.96	1.84	1.95	1.91	1.85	1.73	1.76	1.63

Table 10: Mean persistence of precipitation CPs in spring and autumn [day]

	Spring				Autumn			
	NCEP	CTL	A2	B2	NCEP	CTL	A2	B2
CP11	1.56	1.42	1.37	1.37	1.54	1.45	1.45	1.38
CP05	1.81	1.90	1.87	1.92	1.79	1.89	1.86	1.83

Table 11: Maximum persistence of precipitation CP in winter and summer [day]

	Winter				Summer			
	NCEP	CTL	A2	B2	NCEP	CTL	A2	B2
CP11	7	5	6	5	5	4	4	4
CP05	9	9	16	11	11	7	7	6

Table 12: Maximum persistence of precipitation CP in spring and autumn [day]

	Spring				Autumn			
	NCEP	CTL	A2	B2	NCEP	CTL	A2	B2
CP11	7	9	5	5	9	5	4	4
CP05	12	8	8	8	7	9	7	8

Generally speaking, the frequency of both wet and dry CPs derived from ECHAM4 is a little more frequent than that derived from NCEP in all seasons. But both mean and maximum persistence of CPs within each season are shorter than NCEP derived CPs.

Moisture flux provided by ECHAM4

The calculated bias of the seasonal mean moisture flux represents variability in different seasons. It shows deficit between NCEP moisture flux and ECHAM4 moisture flux¹. In winter, it is clear to find that the moisture flux is underestimated by ECHAM4 above central Europe and increases in all directions. Similar trend has been found in autumn, but the underestimated moisture flux center is shifted towards southwestern direction. In spring and summer, the opposite situation is noticed. The moisture flux in spring is obviously overestimated by ECHAM4. The deficit of moisture flux above central Europe is generally above 2. -3 g/kg*m/s.

The variability of moisture flux at local points is estimated by ratio of standard deviation derived from NCEP to that derived from ECHAM4. In most of seasons, variability of moisture flux from ECHAM4 is slightly higher, except summer. Even in summer, the variability is near to 1, which means both NCEP and ECHAM4 have similar variability of moisture flux.

Downscaled precipitation and temperature for A2 and B2 scenarios

Daily precipitation and temperature are downscaled conditioned to A2 and B2 scenarios respectively. There is no clear increase in both A2 and B2 scenarios, while there is clear difference in both Tmin and Tmax. The average annual cycle for next 30 years indicates that there is temperature increment in the future regardless of A2 or B2, especially, in winter there is larger increment than rest of the year [Figure 8-9 in Appendix].

¹ Positive bias indicates that moisture flux derived from NCEP is higher than that derived from ECHAM4; ratio of standard deviation (>1) means that moisture flux derived from NCEP is more variable than that from ECHAM4

Appendix

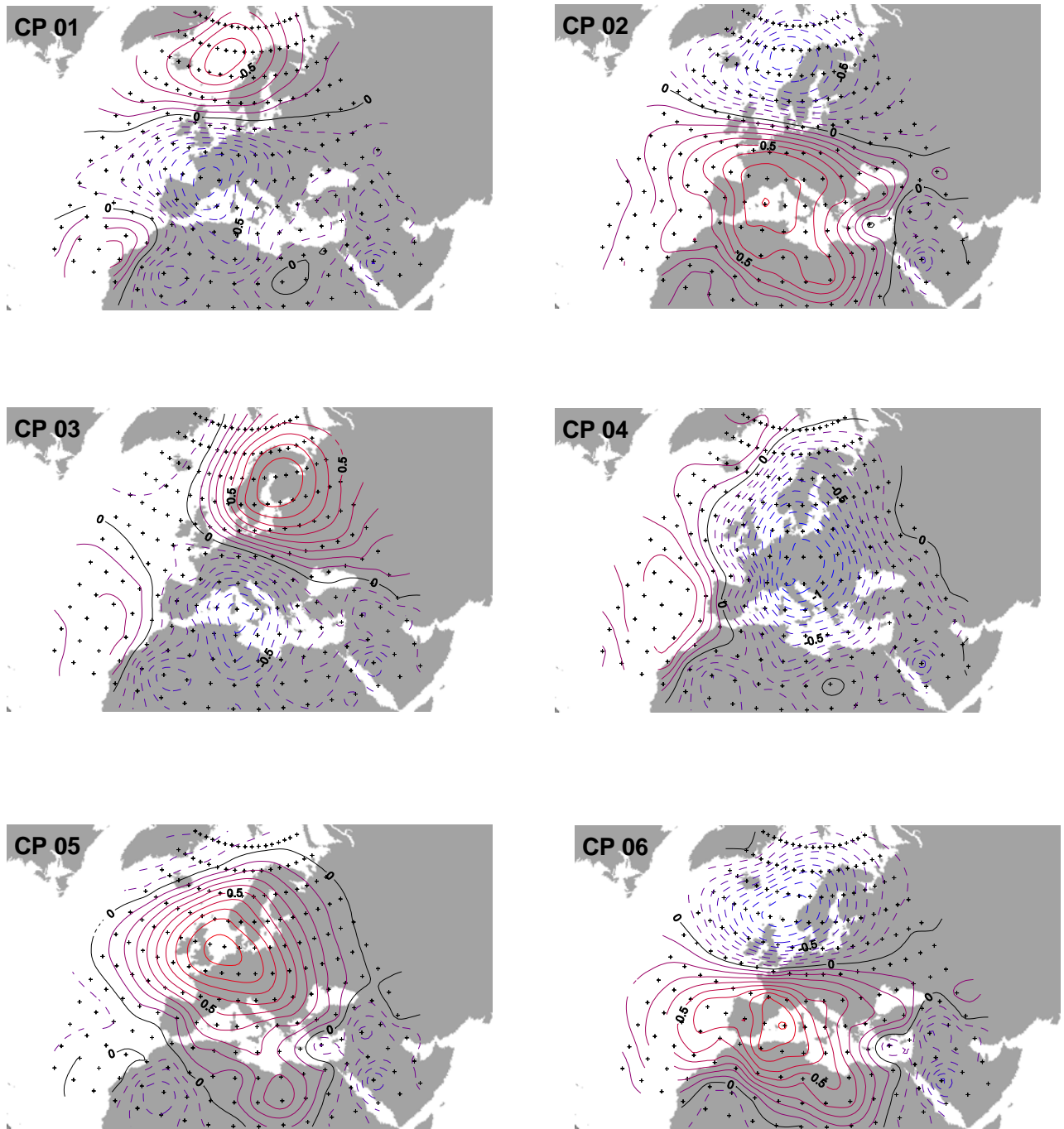


Figure 1: Pressure anomaly maps for Neckar river basin [CP01 – CP06]

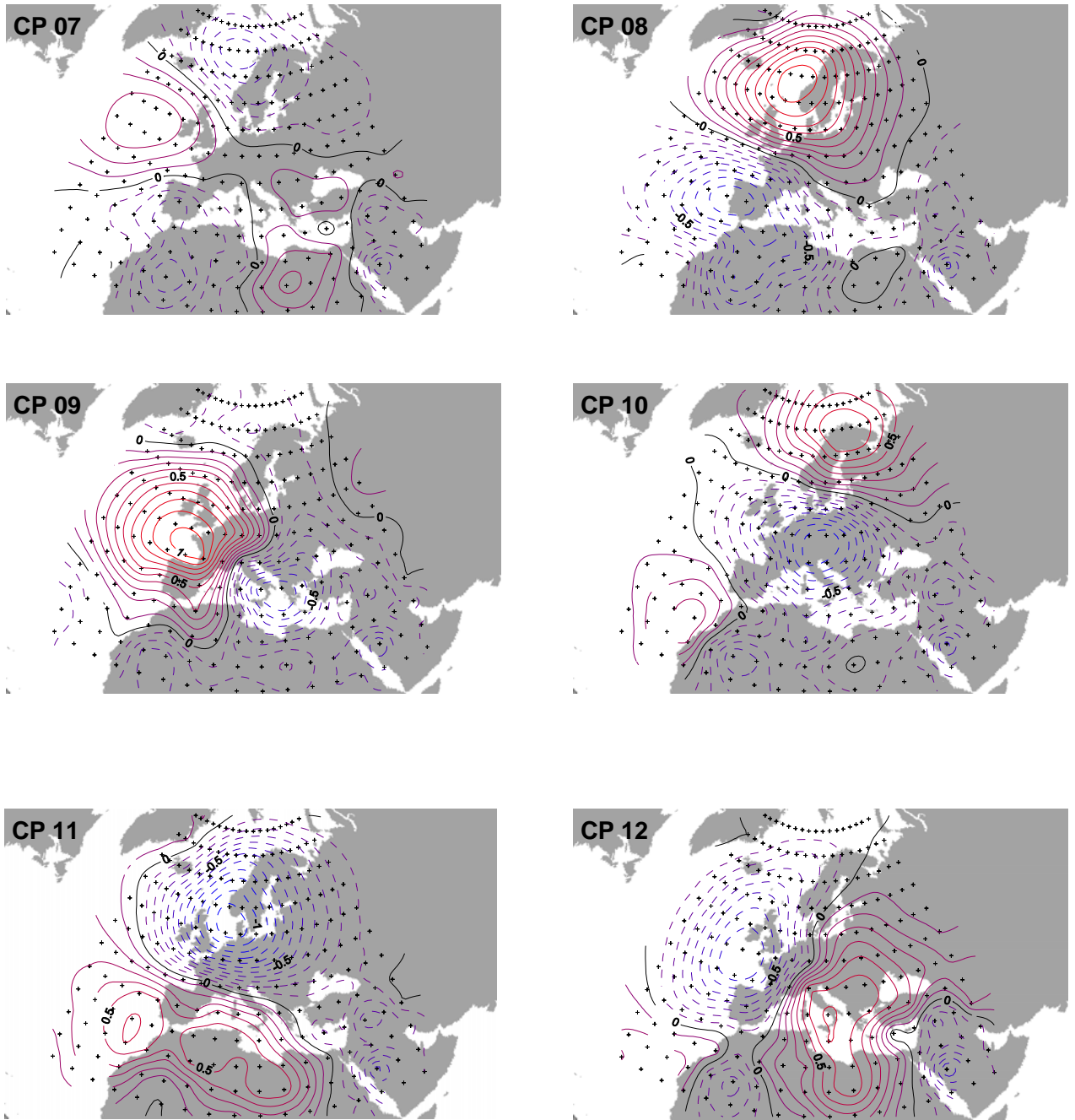


Figure 2: Pressure anomaly maps for Neckar river basin [CP07 – CP12]

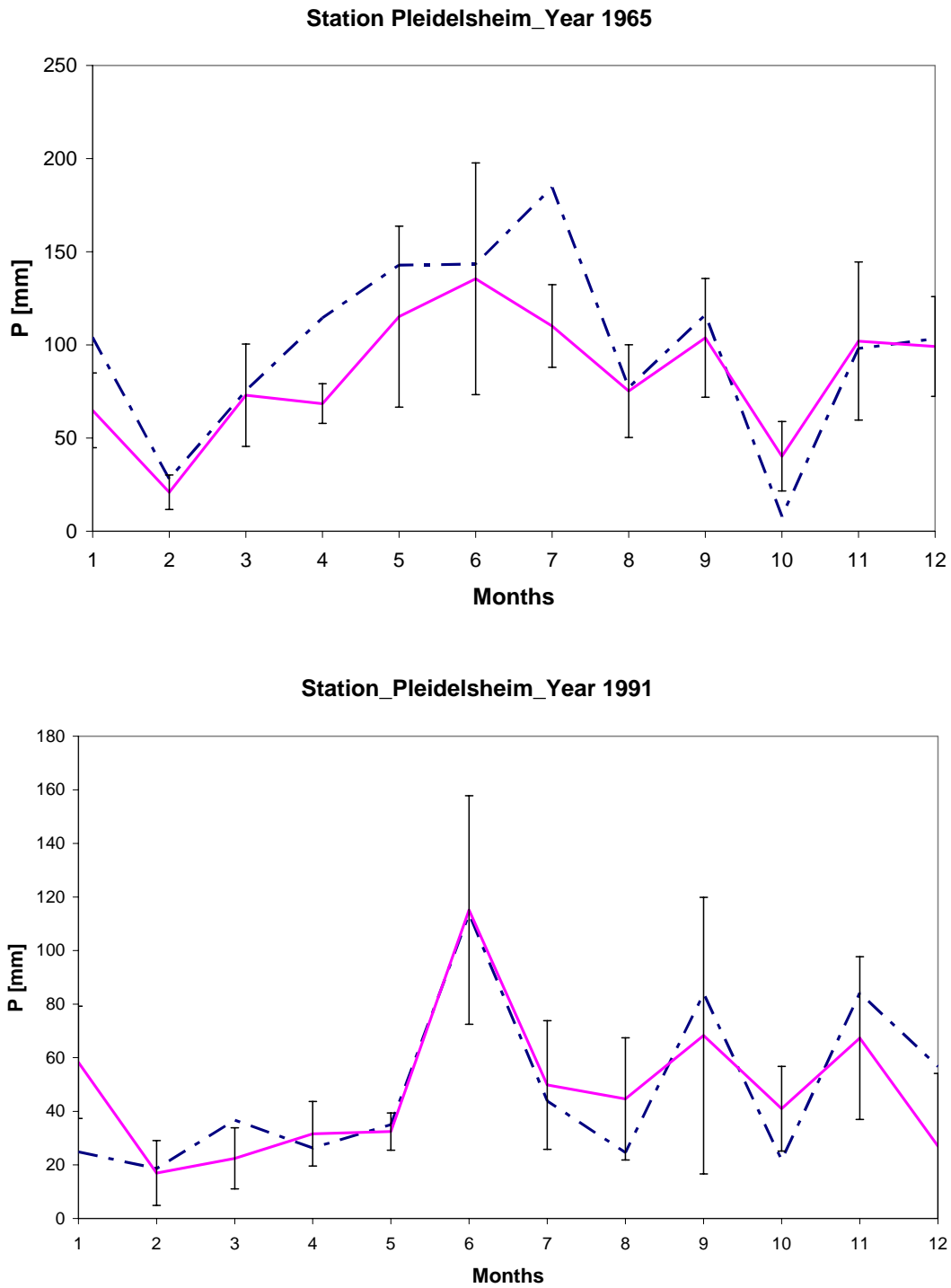


Figure 3: Observed (dashed line) and simulated (solid line) monthly annual cycle of precipitation at station Pleidelsheim (middle of Neckar river basin) in 2 unfavorable years 1965 and 1991

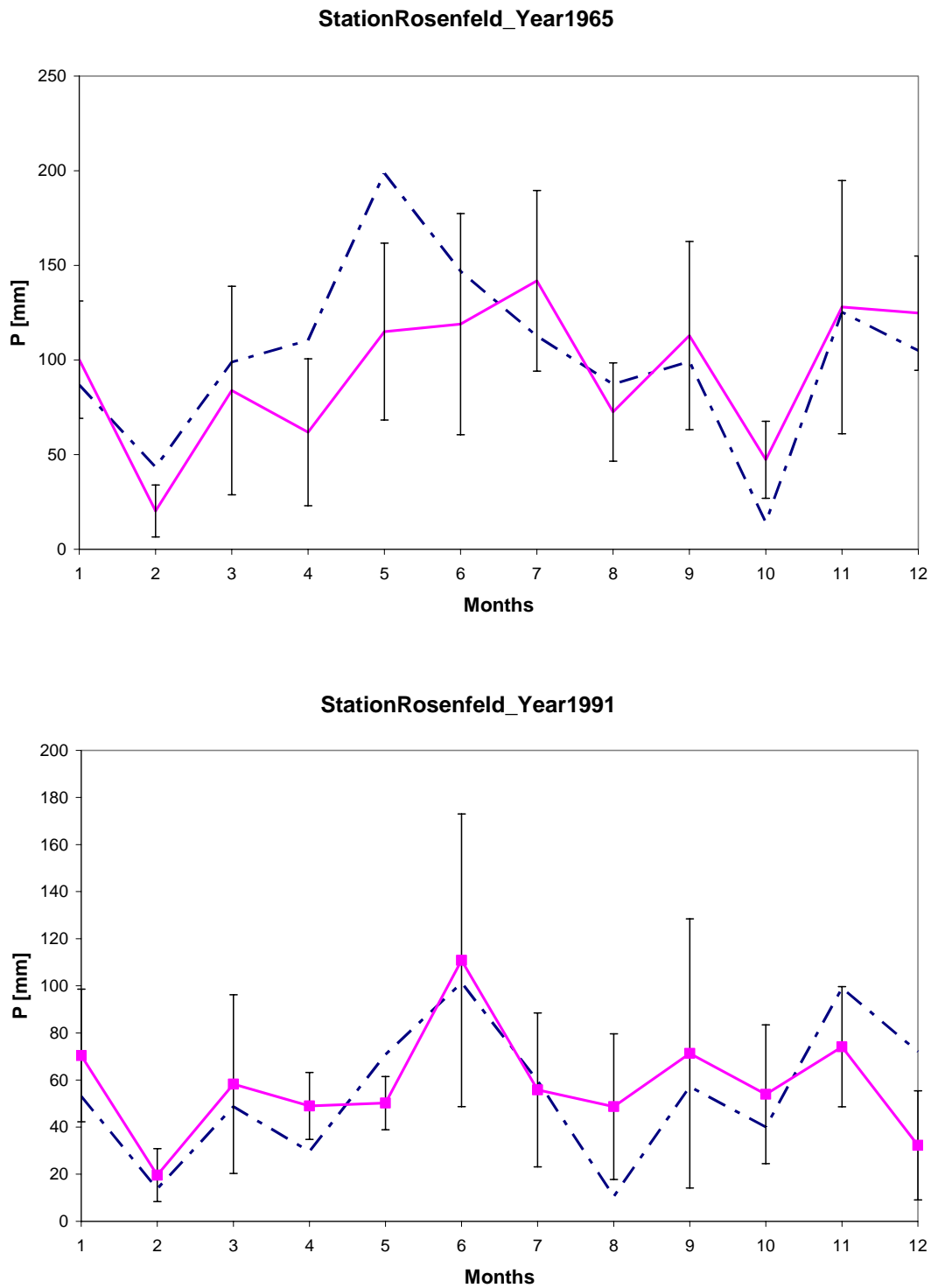


Figure 4: Observed (dashed line) and simulated (solid line) monthly annual cycle of precipitation at station Rosenfeld (upper of Neckar river basin) in 2 unfavorable years 1965 and 1991

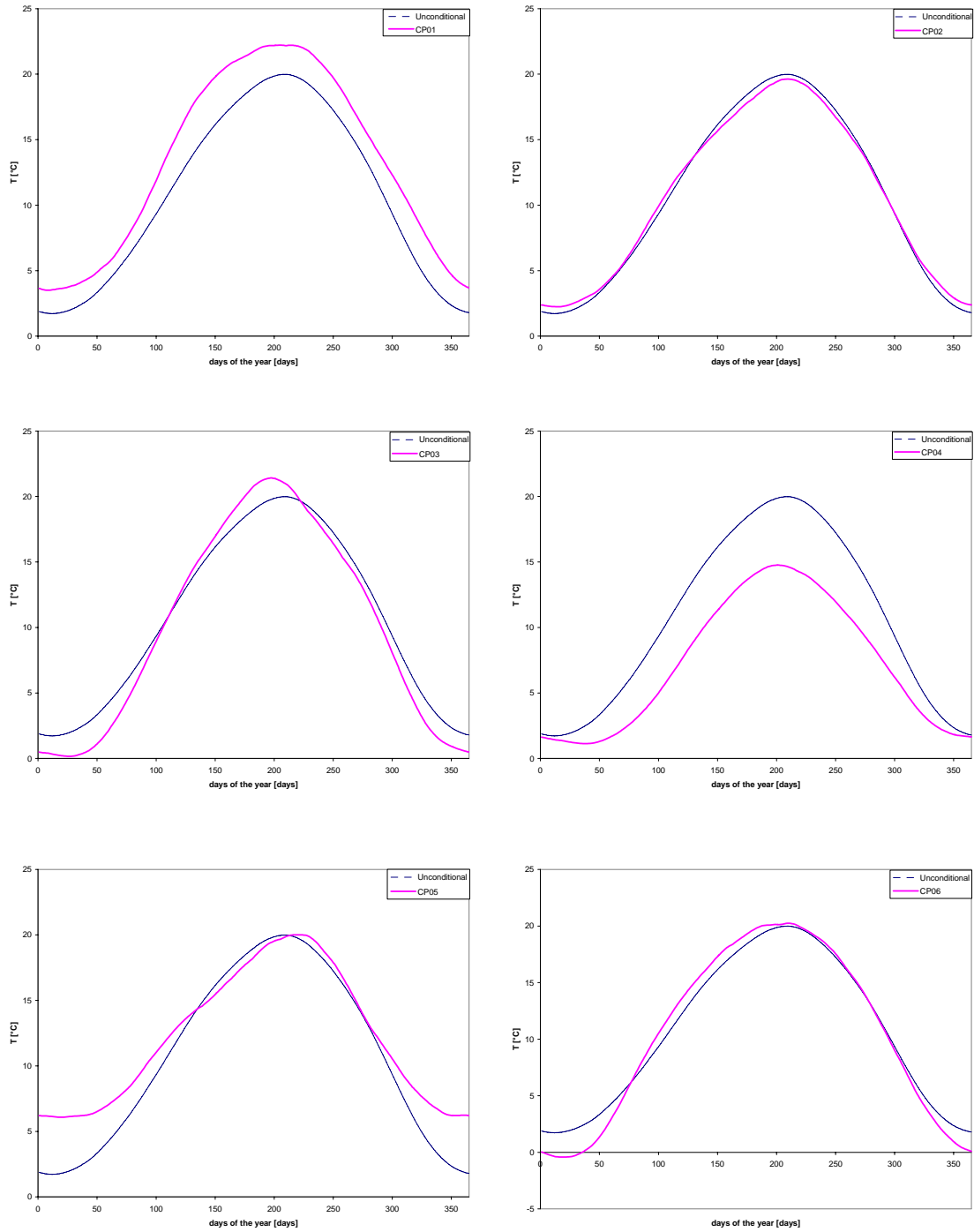


Figure 5: Average annual cycle of temperature under condition of different CPs [CP01-CP06]

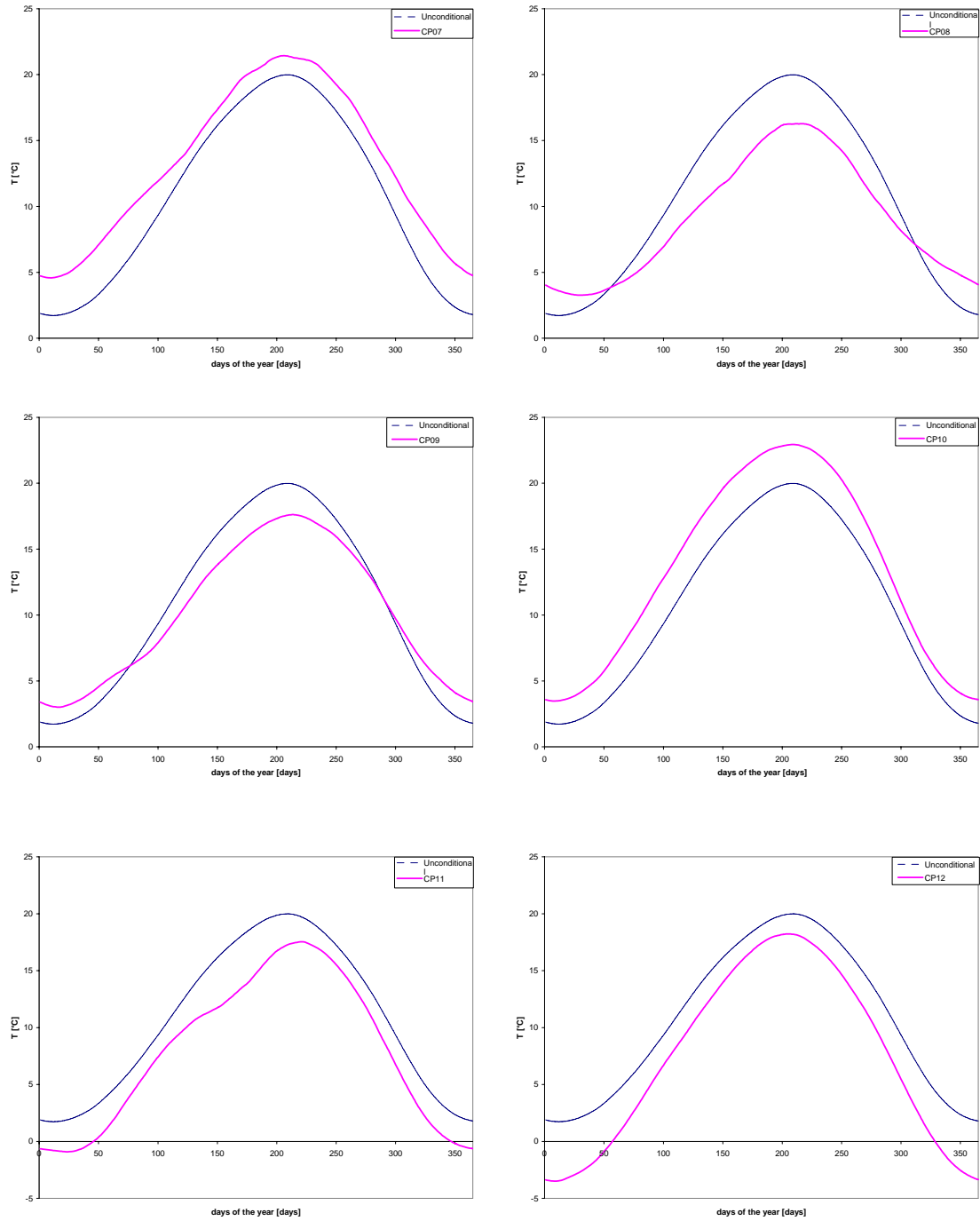


Figure 6: Average annual cycle of temperature under condition of different CPs [CP07-CP12]

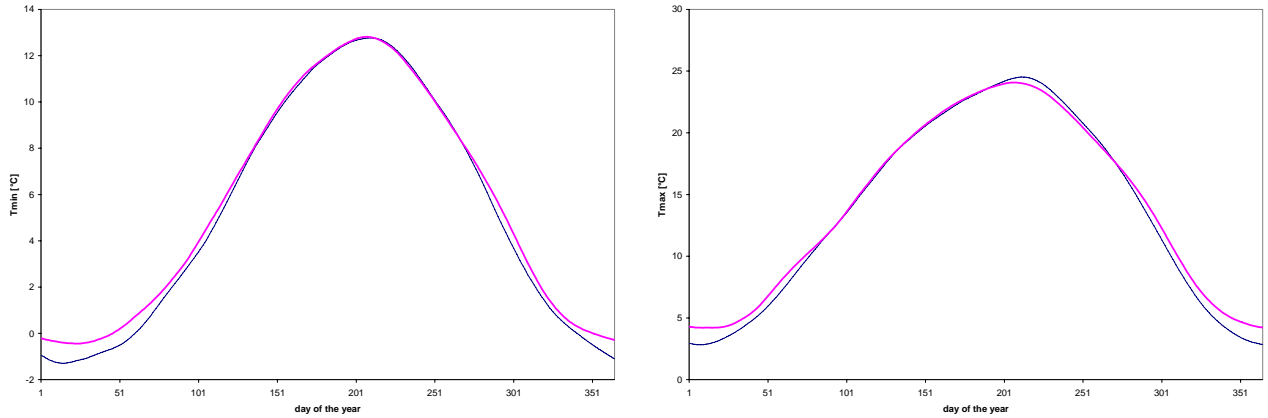


Figure 7: Observed (dashed line) and simulated (solid line) Tmax and Tmin of annual cycle at station NEUDENAU [Left: Tmin; Right: Tmax]

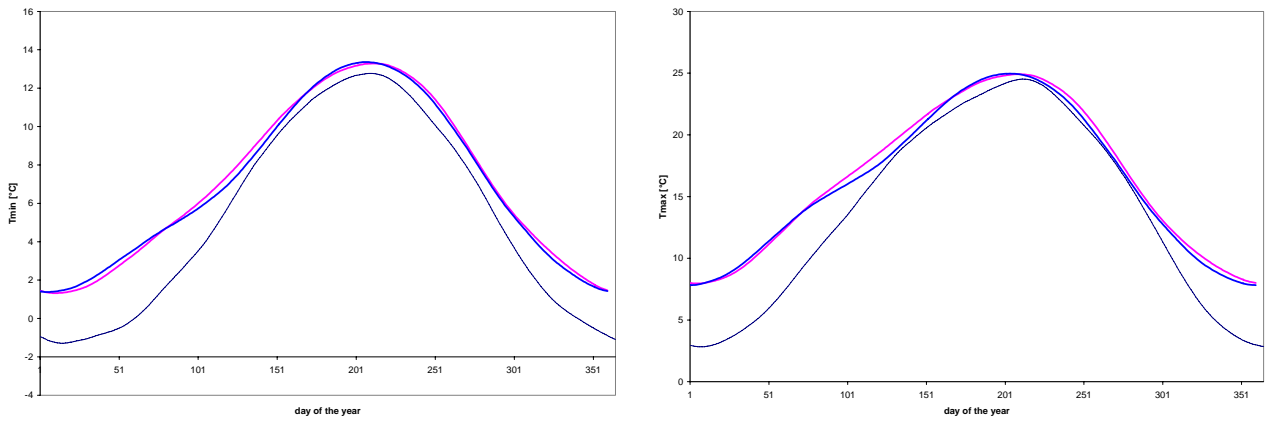


Figure 8: Observed (dashed line) and simulated Tmax and Tmin of annual cycle for ECHAM4 scenarios at station NEUDENAU [A2: pink line; B2: blue line; Left: Tmin; Right: Tmax]

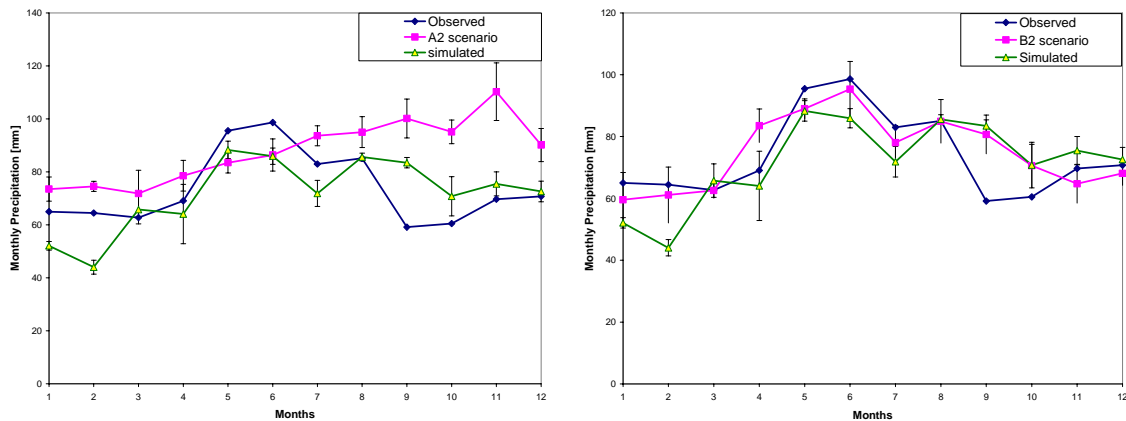


Figure 9: Observed, simulated and downscaled precipitation for A2, B2 scenarios for station Pleidesheim

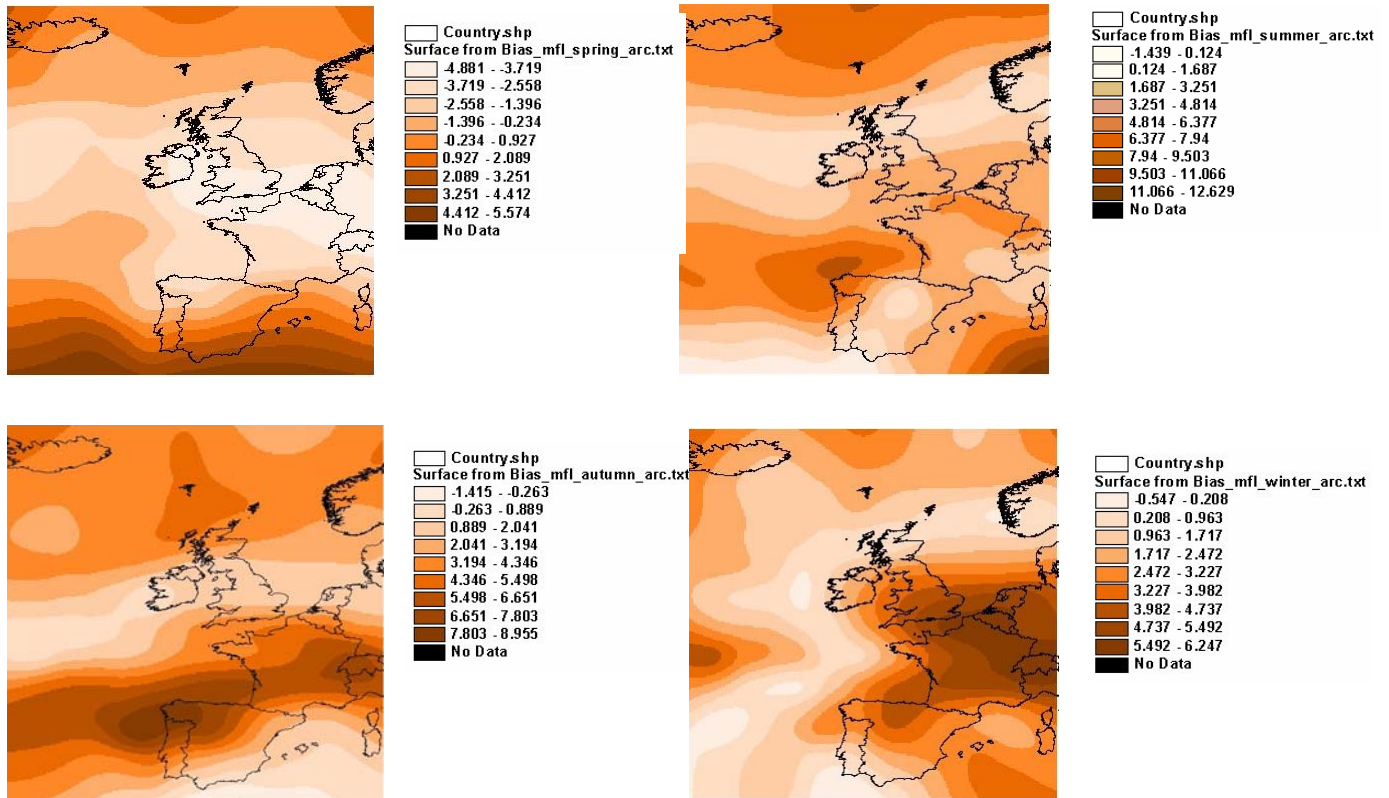


Figure 10: Bias of mean moisture flux at 700 hpa level on seasonal basis [g/kg*m/s]

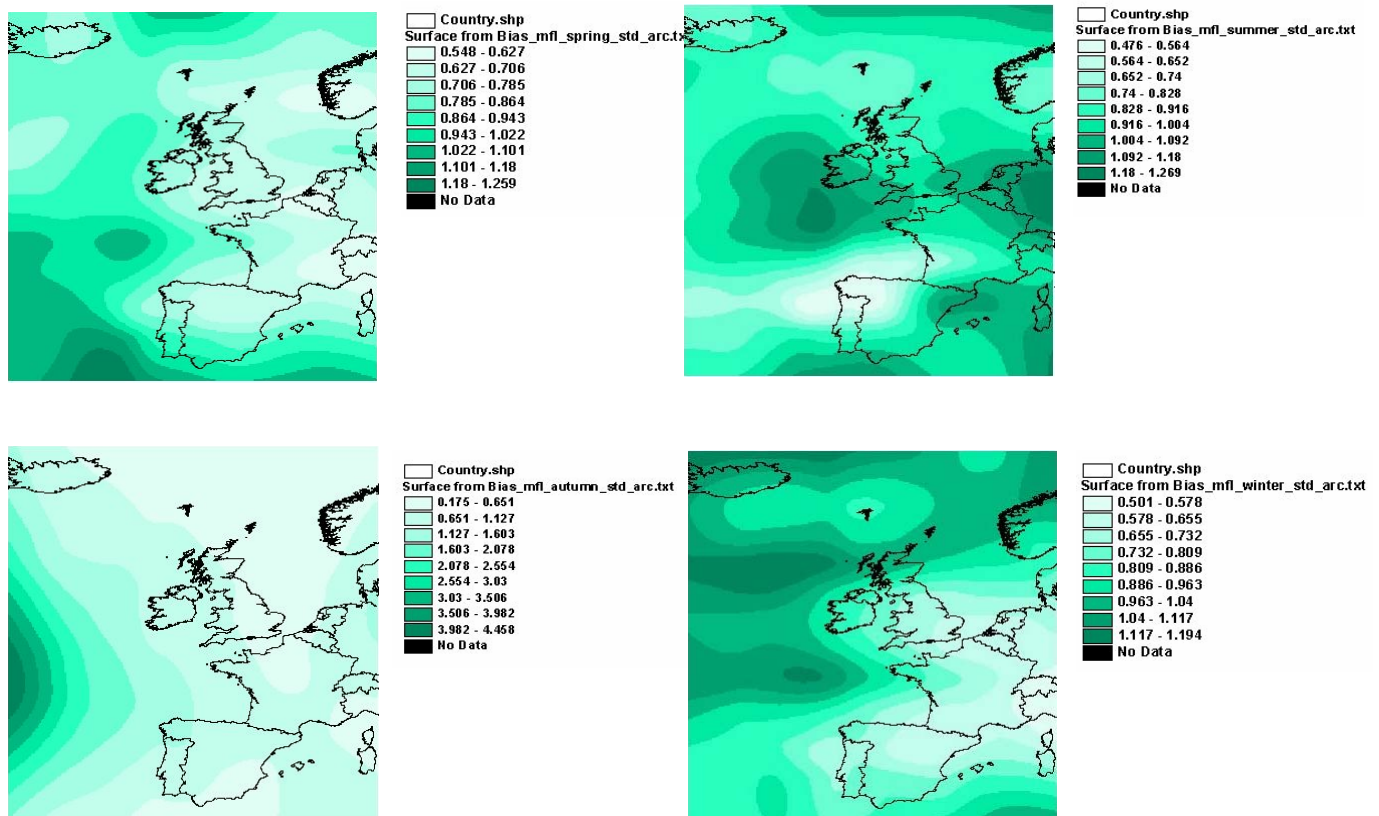


Figure 11: Standard deviation of mean moisture flux at 700 hpa level on seasonal basis [-]