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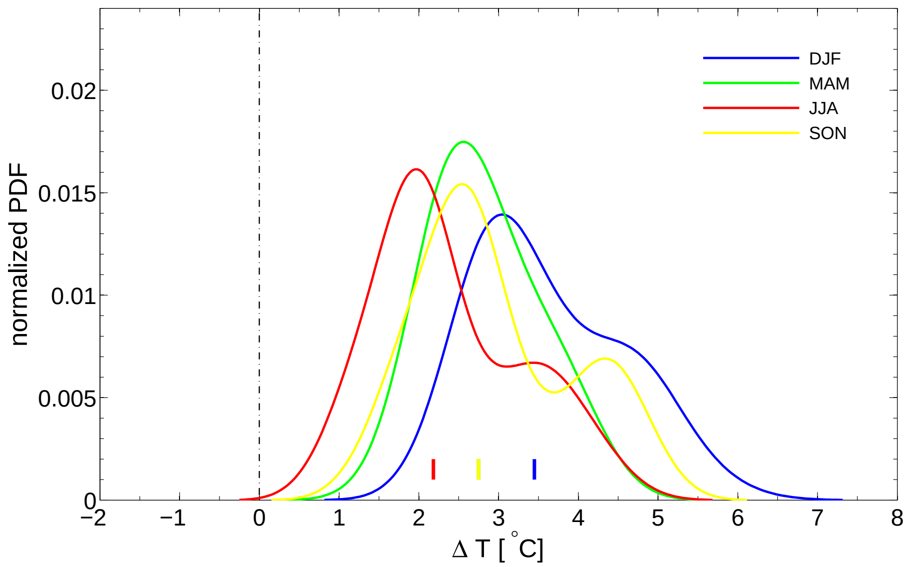
Weighted scenario temperature and precipitation changes for Denmark using probability density functions for ENSEMBLES regional climate models

Fredrik Boberg



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Contents

1. Dansk resumé

Vi bruger 19 regionale klimamodeller med en 25 km opløsning i ENSEMBLES-projektet for at estimere nedbørs- og temperaturændringer for forskellige byer i Danmark for to forskellige scenarie-perioder (2021-2050 og 2071-2099) i forhold til kontrolperioden 1961-1990. Det vægtede modelgennemsnit af nedbørs- og temperaturændringer vises for alle fire årstider med Gaussisk-filtrerede sandsynlighedsfordelinger. Modelvægtningen er baseret på modelresultater fra en særskilt undersøgelse med ERA40-forcerede simuleringer og et griddet observationsdatasæt for kontrolperioden 1961-1990. Alle danske byer der er medtaget i denne undersøgelse viser cirka den samme temperaturstigning fordelt omkring 1.5 °C for alle årstider for perioden 2021-2050. For perioden 2071-2099 viser undersøgelsen en bredere fordeling med en temperaturstigning på cirka 3 °C for alle årstider samt en sekundær top fordelt omkring 5 °C. For nedbørsfordelingen ser vi kun små positive ændringer på cirka 0.1 mm dag^{-1} for 2021-2050 med den største ændring om vinteren. I perioden 2071-2099 ser vi en negativ ændring på cirka 0.1 mm dag^{-1} for sommerperioden og en positiv ændring for de tre andre sæsoner på cirka 0.5 mm dag^{-1}. Disse sandsynlighedsfordelinger for nedbør og temperatur er desuden samlet i bivariate funktioner.

2. Abstract

We use 19 25 km resolution regional climate models within the ENSEMBLES project to estimate precipitation and temperature changes for different cities in Denmark for two different scenario periods (2021–2050 and 2071–2099) relative to the reference period 1961–1990. The weighted model means of precipitation and temperature changes are presented for all four seasons using gaussian filtered probability density functions. The model weights are based on their performance in a separate study using ERA40 driven simulations and a gridded observational data set for the period 1961–2000. All Danish cities included in this study show similar results with a temperature distribution around 1.5 °C for all seasons for the early scenario period and a more widened distribution around 3 °C for all seasons for the later scenario period including a second peak around 5 °C. For the precipitation distribution, we see only small positive changes of a few 0.1 mm day^{-1} for the early scenario period with the largest change in winter. For the later period we see a negative change of a few 0.1 mm day^{-1} for the summer period and a positive change for the other three seasonal periods reaching 0.5 mm day^{-1} for the winter period. These probability density functions for precipitation and temperature are further combined into bivariate functions.

3. Introduction

There is a large public interest for how the climate will change during the 21st century. Precipitation amounts and temperature are expected to increase globally as the climate warms due to human activities. Furthermore, the increases in extremes are likely to be larger than those in their means. In this report, we will focus on local climate changes in Denmark using a few selected cities (see Figure 3.1). The idea is to produce probability distribution functions (PDFs) for precipitation and temperature changes using regional climate models (RCMs). To improve the statistical significance, we use all currently available RCMs with a spatial resolution of 25 km within the ENSEMBLES project and attach weights to each model PDF according to their performance taken from Christensen et al. (2010). The temperature and precipitation changes are calculated by subtracting the reference values from the scenario values, and the scenario period is divided into two periods, 2021–2050 and 2071–2099.

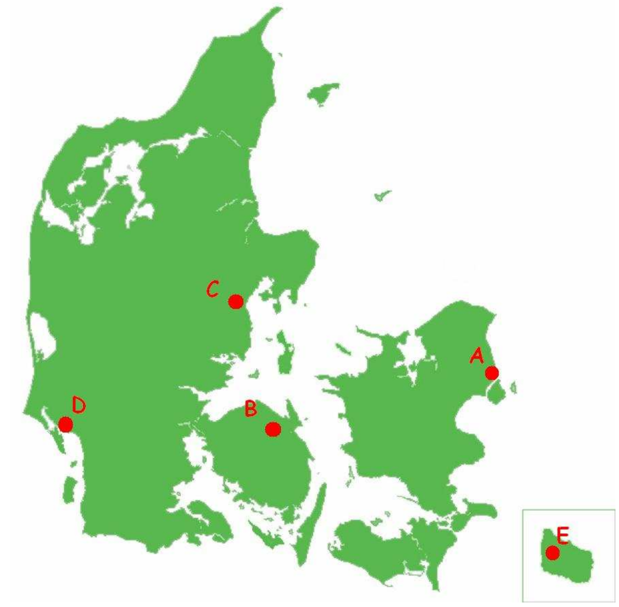

Figure 3.1: Map of Denmark with cities used in this study highlighted. A: Copenhagen, B: Odense, C: Århus, D: Esbjerg and E: Ronne (Bornholm). Also, the entire land region of Denmark, excluding Bornholm, is used as one final location.

With a spatial resolution of 25 km for the RCMs and the fact that we are only looking at a very restricted part of the models with a uniform climatology, we are not expecting any large differences in PDF change for the different Danish locations (see Figure 3.1).

4. Data

A total of 19 RCM simulations are currently available within the ENSEMBLES project (Hewitt, 2005) at a 25 km resolution for the A1B forcing scenario (Nakićenović et al., 2000). These RCMs are listed in Table 4.1 together with their driving models, the extent of their simulations and their model weights according to Christensen et al. (2010). Models 3, 5, 10, 17 and 18 were not used by Christensen et al. (2010) so we applied weights to these models according to their neighboring models using a different driving GCM (see Table 4.1). This study uses seasonal (DJF, MAM, JJA, SON) means of 2m temperature and precipitation.

5. PDF calculation

Probability density functions are calculated for all four seasons (DJF, MAM, JJA and SON) using seasonal means of daily precipitation and 2m temperature from 19 RCMs. The reference period is defined as 1961–1990 whereas the two scenario periods are defined as 2021–2050 and 2071–2099. Data for the year 2100 have been omitted as some of the models extending to the end of the 21st century stopped their simulation in 2099 (see Table 4.1).

The PDF calculations presented here are based on the work by Déqué (2009), where 16 simulations within the ENSMBLES project were used for the 2021–2050 scenario period. Déqué (2009) calculated monovariate and bivariate PDFs for 32 European capitals whereas we only do calculations for cities in Denmark. We also decided to use a second, later, scenario period and also to remove all sea grid points before finding the grid point closest to the city in question. We furthermore define the winter season as a contiuous DJF period and not the three winter months JFD belonging to the same

Table 4.1: RCMs used in this study with their driving GCMs, extent of simulation and weights. 15 of the models, given in red, were run until the end of the 21st century and can be used for PDF calculations for the second scenario period 2071–2099.

	Model	Driving GCM	End of simulation	Weight
1	C4I RCA3	HadCM3	Nov. 2099	0.0538
2	CNRM ALADIN	ARPEGE	Dec. 2100	0.0484
3	DMI HIRHAM	ARPEGE	Dec. 2100	0.0491
4	DMI HIRHAM	ECHAM5	Nov. 2099	0.0491
5	DMI HIRHAM	BCM	Nov. 2099	0.0491
6	ETHZ CLM	HadCM3Q0	Nov. 2099	0.0523
7	ICTP REGCM	ECHAM5	Dec. 2100	0.0593
8	KNMI RACMO	ECHAM5	Dec. 2100	0.0725
9	METNO HIRHAM	BCM	Dec. 2050	0.0476
10	METNO HIRHAM	HadCM3Q0	Dec. 2050	0.0476
11	HC HADRM Q0	HadCM3Q0	Nov. 2099	0.0484
12	HC HADRM Q3	HadCM3Q3	Nov. 2099	0.0351
13	HC HADRM Q16	HadCM3Q16	Nov. 2099	0.0538
14	MPI REMO	ECHAM5	Dec. 2100	0.0562
15	OURANOS MRCC	CGCM3	Dec. 2050	0.0468
16	SMHI RCA	BCM	Nov. 2099	0.0616
17	SMHI RCA	HadCM3Q3	Nov. 2099	0.0616
18	SMHI RCA	ECHAM5	Dec. 2100	0.0616
19	UCLM PROMES	HadCM3Q0	Dec. 2050	0.0460

year.

The individual PDFs calculated for the 19 different RCMs are linearly combined using model weights obtained by Christensen et al. (2010) who evaluated daily and monthly statistics of maximum and minimum temperatures and precipitation for ENSEMBLES RCMs forced by boundary conditions from reanalysis data for 1961-2000 compared to a high-resolution gridded observational data set. The normalized weights applied to our PDFs are listed in the rightmost column of Table 4.1.

The PDFs are calculated from the change in temperature and precipitation (scenario minus reference) using 300 bins in the range -2 to +8 °C and 300 bins in the range -2 to +8 mm day^{-1} according to the range of responses of the individual models. We then replace the probability in each bin by a gaussian distribution with the mean as the center of the bin and a standard deviation of 0.4 °C and 0.1 mm day^{-1} respectively (Déqué, 2009). This gaussian filter is applied due to the possibility that the response may be between two models.

This approach using PDFs of seasonal changes in precipitation and temperature reveals both the mean changes but also the extent of extremes shown by the tail of the PDFs.

6. Results

Figure 6.1 shows PDFs of precipitation change for the period 2021–2050 relative 1961–1990 for four seasons and for six Danish locations. All centroids are above zero as shown by the vertical

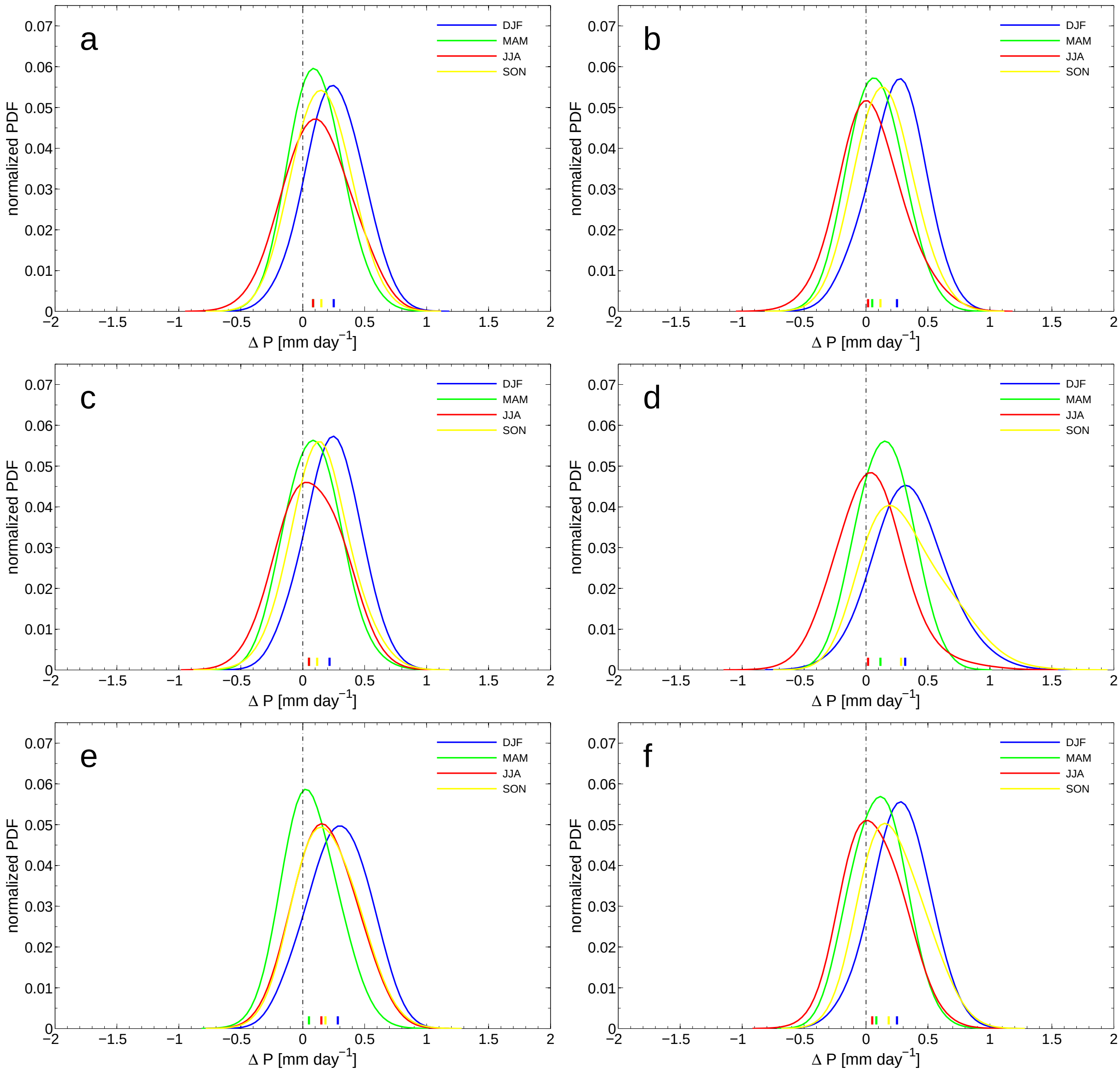

Figure 6.1: Probability density functions for precipitation response 2021–2050 relative 1961–1990 using seasonal mean data for a: Copenhagen, b: Odense, c: Århus, d: Esbjerg, e: Bornholm and f: Denmark. The centroids for each PDF is given by a corresponding vertical line at the bottom of each panel.

colored lines at the bottom of each panel. The change in precipitation is largest for the winter season with about 0.25 mm day^{-1}. The PDFs for Esbjerg are wider that the other PDFs. The summer PDFs show, on average, the smallest change.

Figure 6.2 shows PDFs of precipitation change for the period 2071–2099 relative 1961–1990 for four seasons and for six Danish locations. The PDFs for the summer season now show a clear negative change for some locations whereas the PDFs for the other three seasons show a positive change. The DJF and SON PDFs have centroids around 0.45 mm day^{-1}. The PDFs also show some secondary peaks, especially for the SON period on the left wing.

Figure 6.3 shows PDFs of temperature change for the period 2021–2050 relative 1961–1990. All centroids are between 1 and 2 °C. The change in temperature is largest for the winter season. The

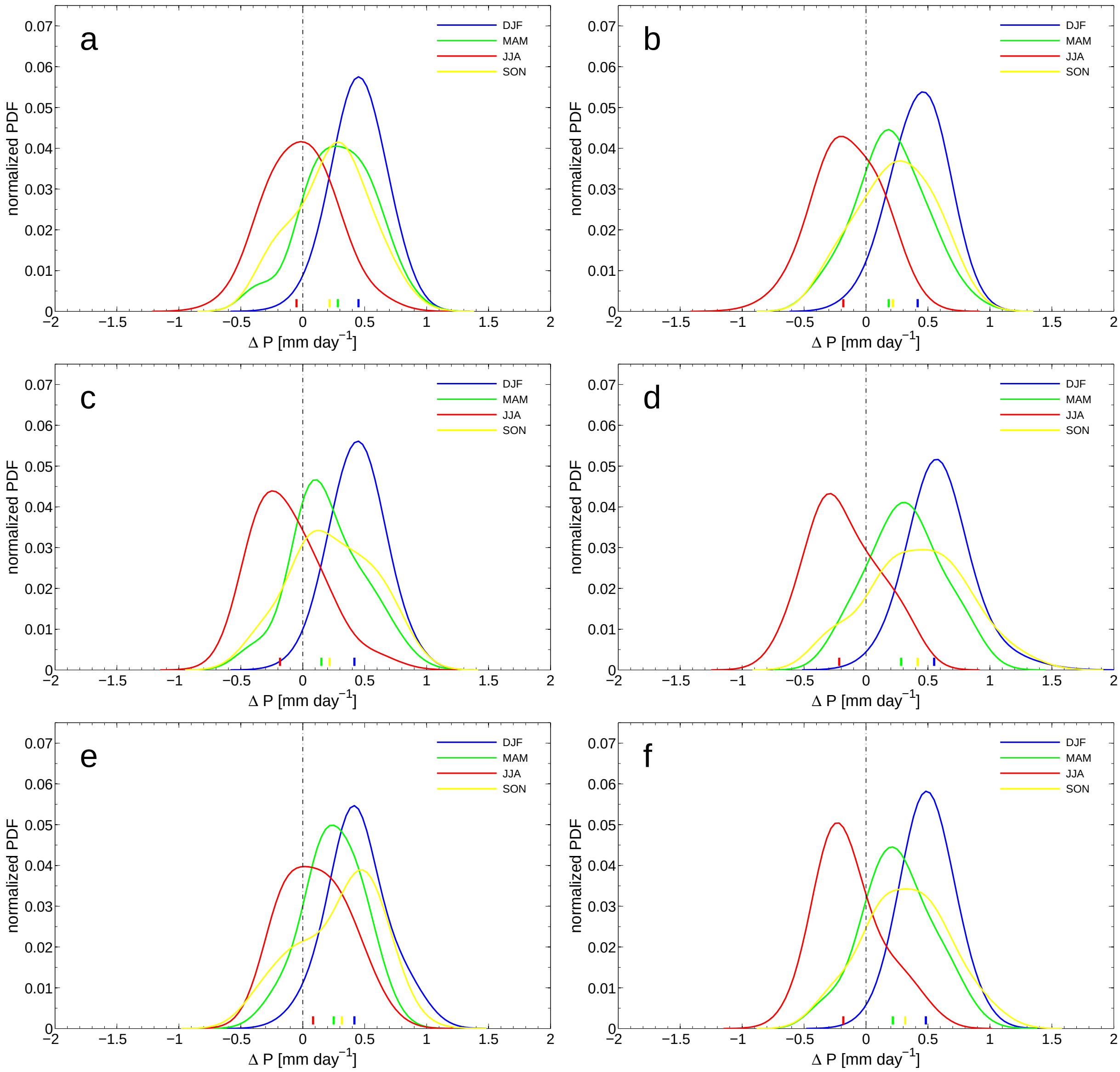

Figure 6.2: Probability density functions for precipitation response 2071–2099 relative 1961–1990 using seasonal mean data for a: Copenhagen, b: Odense, c: Århus, d: Esbjerg, e: Bornholm and f: Denmark. The centroids for each PDF is given by a corresponding vertical line at the bottom of each panel.

PDFs for the MAM and SON periods match each other well. Only a small part of the PDF distributions extend to negative temperature changes.

Figure 6.4 shows PDFs of temperature change for the period 2071–2099 relative 1961–1990. All centroids are now located around 3 °C. The change in temperature is still largest for the winter season and the smallest change is seen in summer. As in the case of precipitation for the later scenario period, we see clear secondary peaks. However, these peaks are now on the right wing of the distribution and seen for both the SON and the DJF period around 5 °C.

Figures 6.5 and 6.6 shows bivariate PDFs of temperature and precipitation change for the periods 2021–2050 and 2051-2099 relative 1961–1990, respectively. Each location is represented by four panels, one for each season.

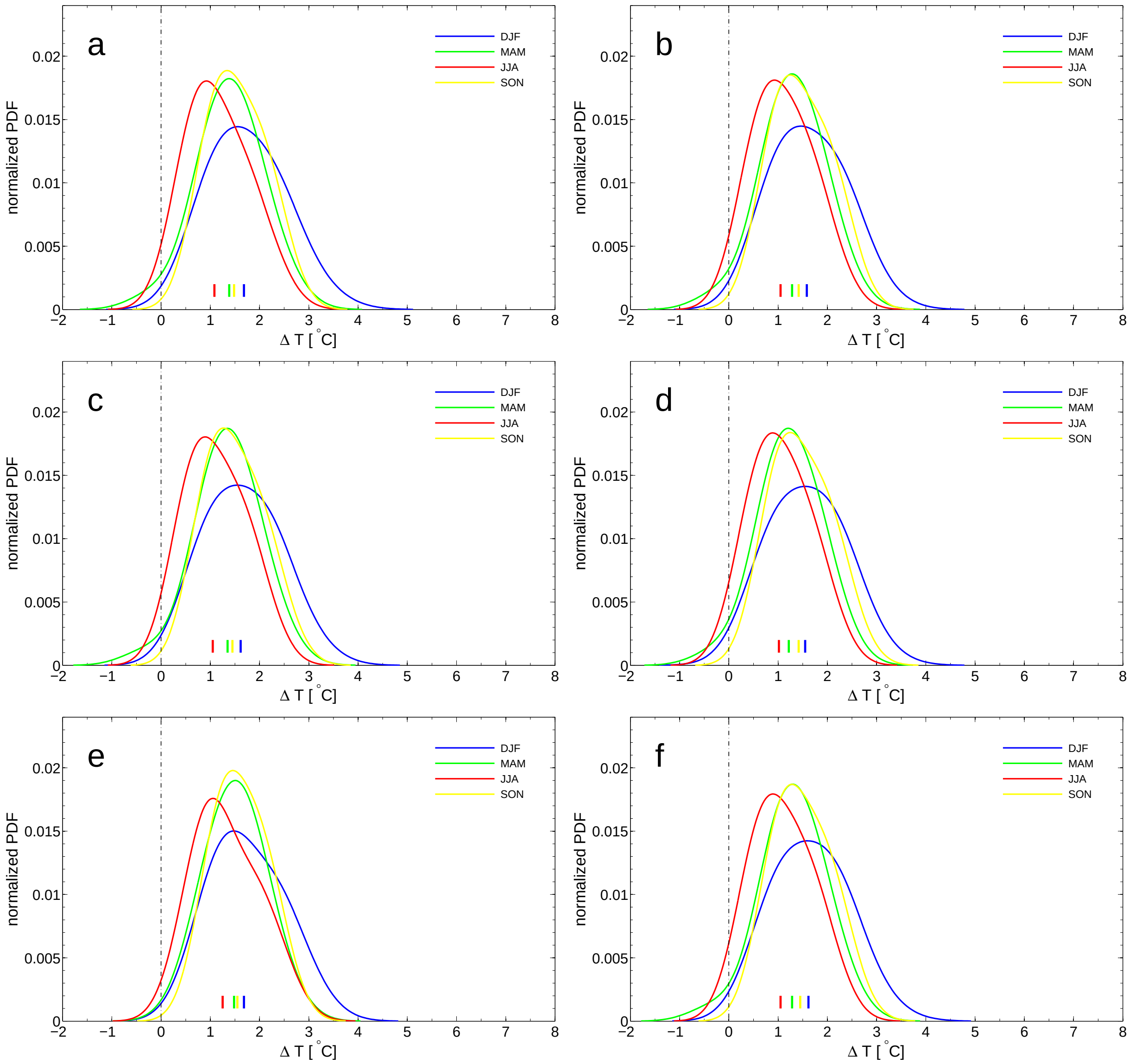

Figure 6.3: Probability density functions for temperature response 2021–2050 relative 1961–1990 using seasonal mean data for a: Copenhagen, b: Odense, c: Århus, d: Esbjerg, e: Bornholm and f: Denmark. The centroids for each PDF is given by a corresponding vertical line at the bottom of each panel.

Finally, in Figure 6.7, we show how the bivariate PDFs of temperature and precipitation change for overlapping three-month periods during the course of the year for the later scenario period relative 1961–1990 for the Denmark region. We only show the outer 95% confidence level for each three-month period (cf. Figure 6.6). Also shown are the centroids for each three-month period. The centroids, with its slanted hour-glass shape when combined, are only negative in precipitation for the two summer periods JJA and JAS.

7. Conclusions

By linearly combining PDFs for 19 RCMs within the ENSEMBLES project, we have determined the distributional change for seasonal mean temperature and precipitation for a few selected cities in Denmark for two scenario periods (2021–2050 and 2071–2099) relative to the reference period

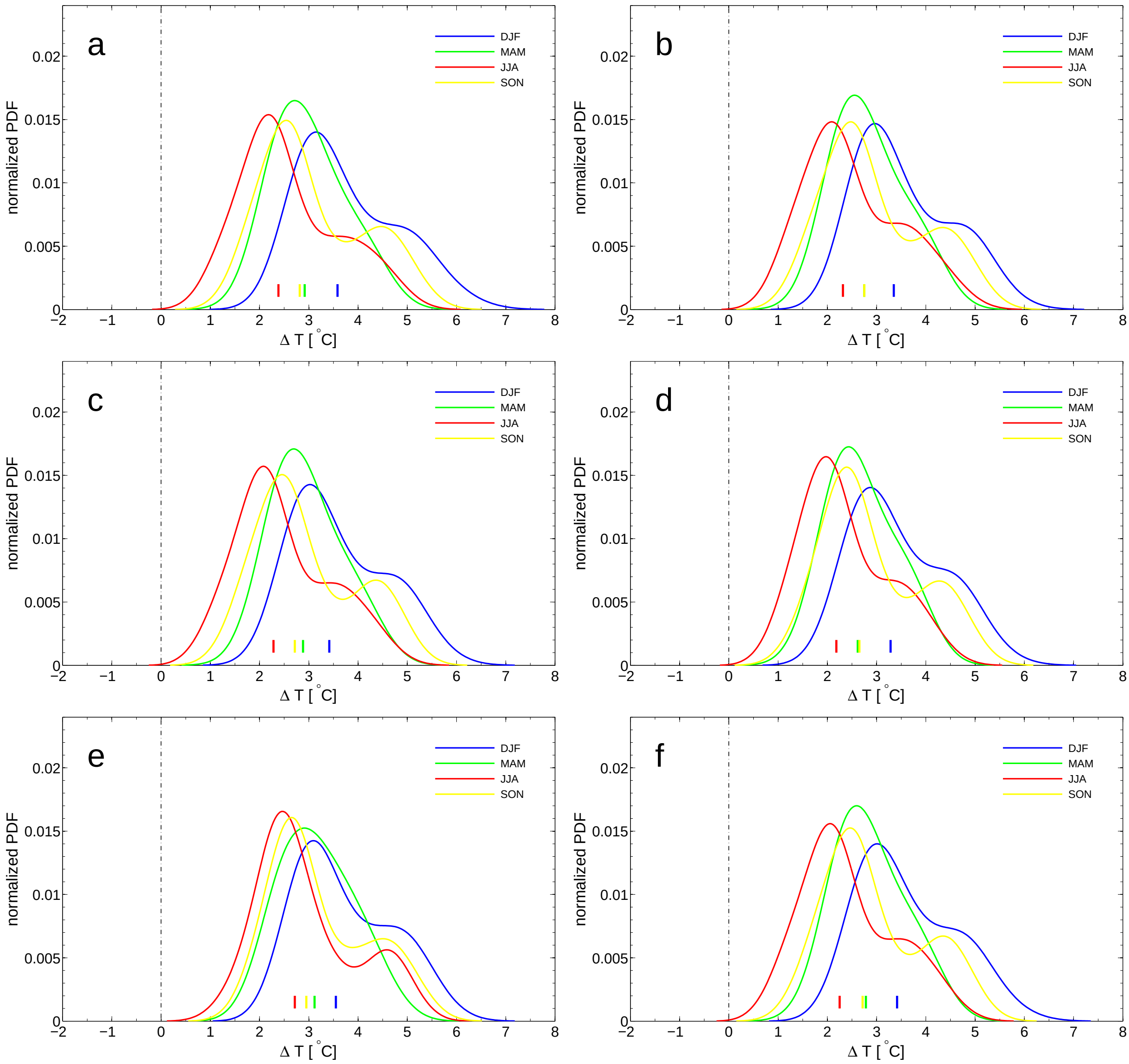

Figure 6.4: Probability density functions for temperature response 2071–2099 relative 1961–1990 using seasonal mean data for a: Copenhagen, b: Odense, c: Århus, d: Esbjerg, e: Bornholm and f: Denmark. The centroids for each PDF is given by a corresponding vertical line at the bottom of each panel.

1961–1990. The combination is done using the model weights obtained in a separate study (Christensen et al., 2010) and the monovariate and bivariate distributions show both the mean change but also the extent of extreme changes. The sign of the changes are statistically significant for temperature only (both scenario periods), and to some extent also for DJF precipitation for the late scenario period. For the other seasons during the late scenario period and for all seasons for the early period, the sign of the precipitation response is never significant since there is always a significant probability that the sign is positive or negative.

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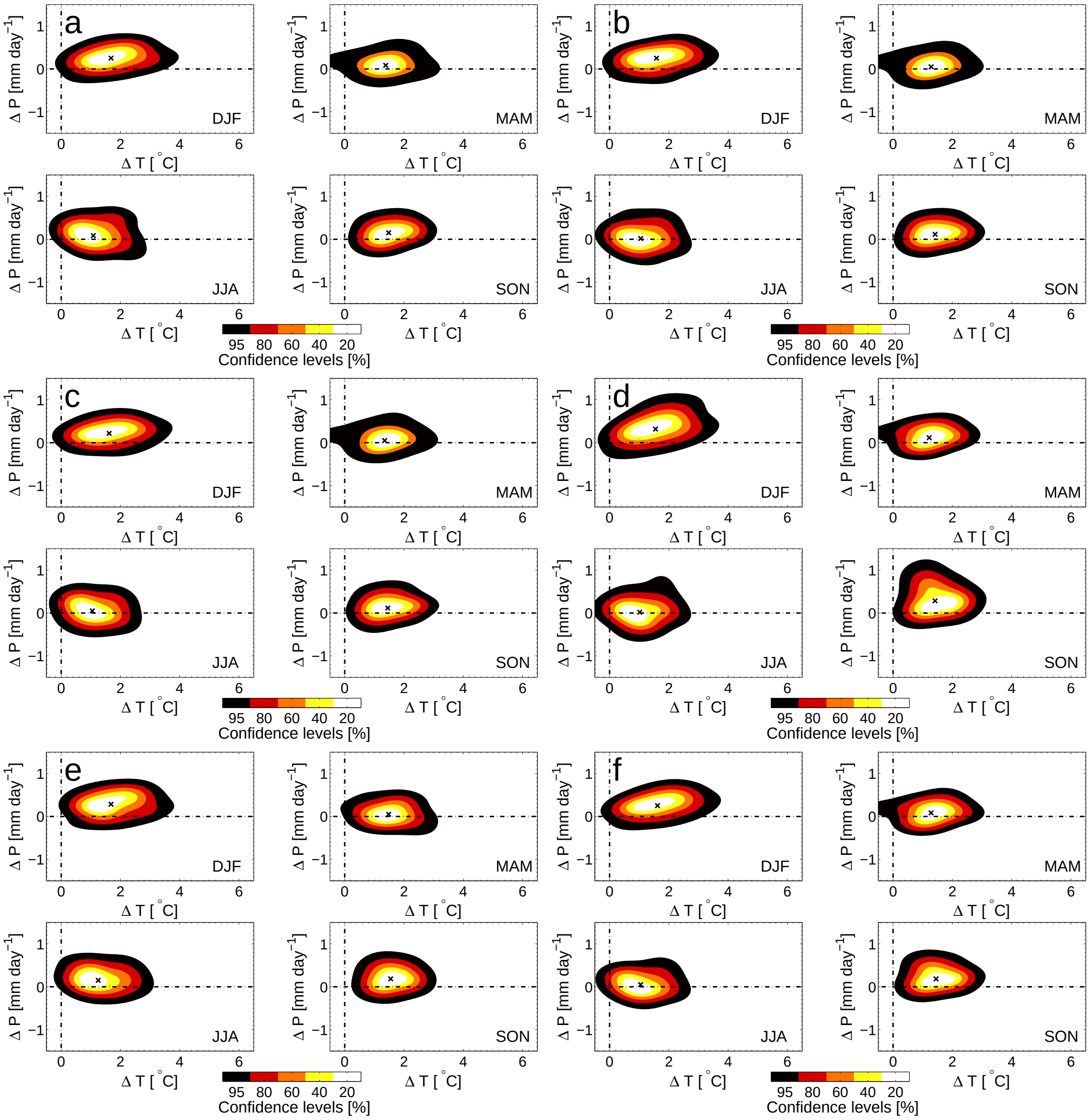

Figure 6.5: Confidence contours of bivariate probability density functions for temperature and precipitation response 2021–2050 relative 1961–1990 for a: Copenhagen, b: Odense, c: Århus, d: Esbjerg, e: Bornholm and f: Denmark. While the contours are shown relative the peak probability, the centroids for each PDF and for each season are marked by an 'x' in each subpanel.

wish to thank Michel Déqué for the PDF calculation scripts.

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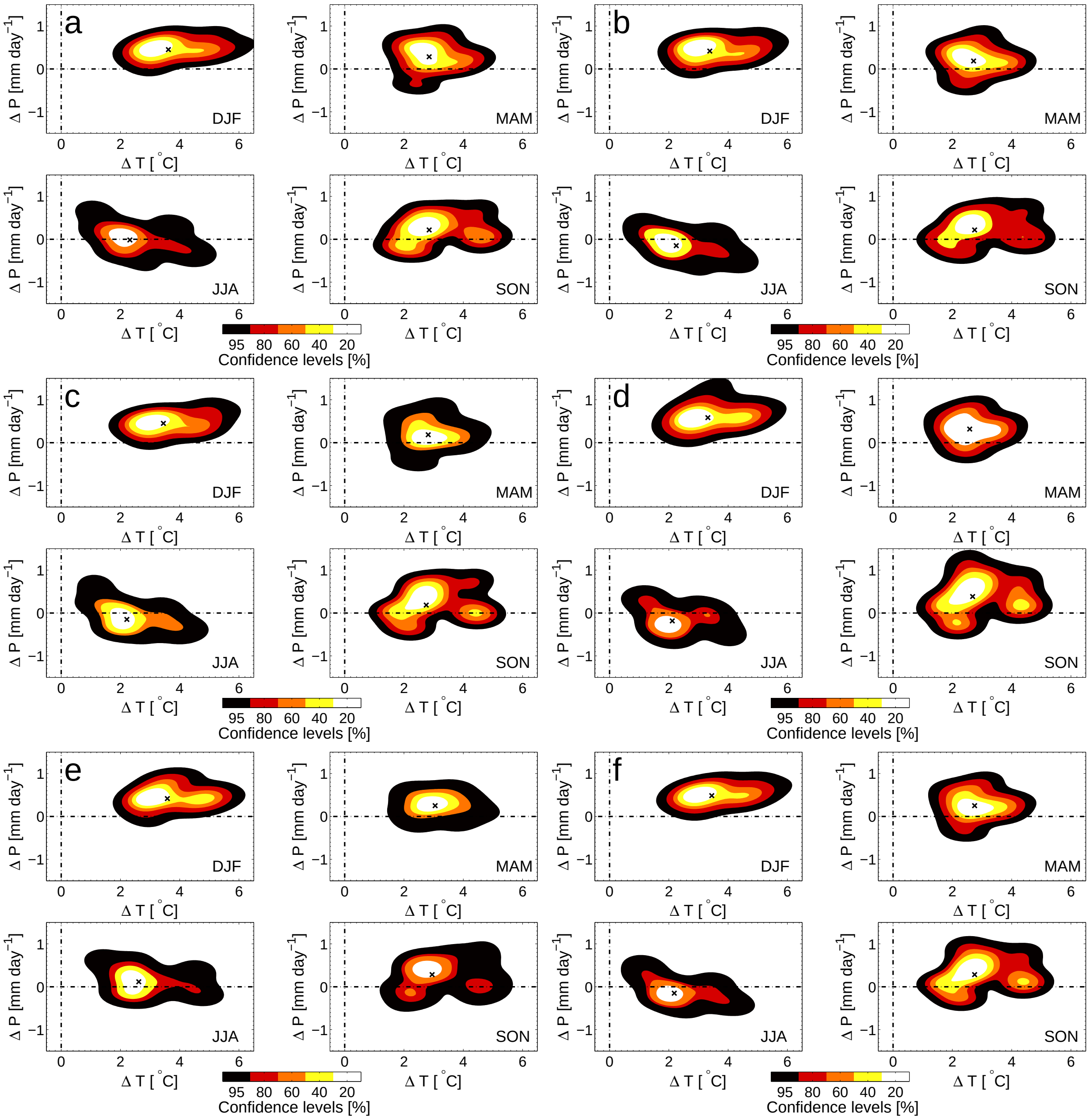

Figure 6.6: Confidence contours of bivariate probability density functions for temperature and precipitation response 2071–2099 relative 1961–1990 for a: Copenhagen, b: Odense, c: Århus, d: Esbjerg, e: Bornholm and f: Denmark. While the contours are shown relative the peak probability, the centroids for each PDF and for each season are marked by an 'x' in each subpanel.

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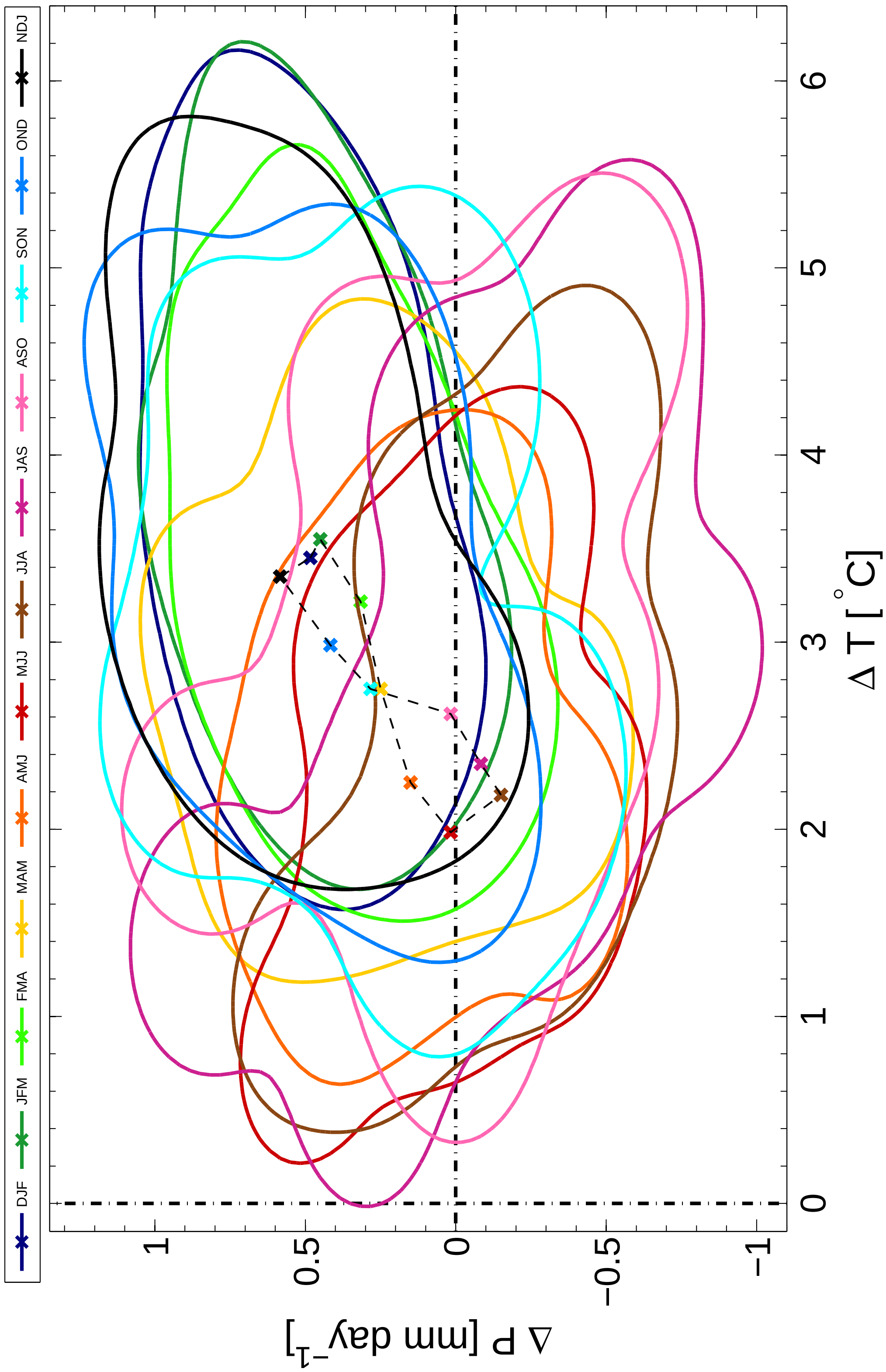

Figure 6.7: 95 percent confidence contours of bivariate probability density functions for temperature and precipitation response 2071–2099 relative 1961–1990 for Denmark. Each contour represents a three-month ("seasonal") mean for the overlapping periods DJF, JFM, FMA, ..., NDJ. The centroids for each three-month period are marked by an 'x'. Note that the axis limits are not the same as for Figures 6.5 and 6.6

8. Previous reports

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