Chapter 6

Changes to the Spatial Variability of Daily Rainfall in Scenarios of Future Climate

Contents

6.1. Introduction

The techniques which have been developed and applied throughout the research presented in this thesis have made use of spatial and temporal properties of rainfall which have been observed in records of recent climate. Under a warmer future climate, however, those spatial and temporal properties may alter. The review of literature in chapter 2 discusses theoretical, observational and model evidence that suggests that rainfall in the future may become more intense as a warmer atmosphere will have a larger water-holding capacity (e.g. Fowler and Hennessy, 1997; Trenberth 1998, 1999). This means that that future rainfall may become more variable, in both space and time, as a warmer atmosphere allows deeper convection, and thus more frequent extreme, but perhaps more localised, rainfall events (Hennessy *et al*., 1997; Trenberth *et al*., 1999). This expected shift towards more convective rainfall might result in an overall increase in the spatial variability of rainfall as it is well documented that convective rainfall occurs more intensely but more locally than large-scale stratiform/synoptic rainfall (e.g. Tremblay, 2005).

The increase in temporal variability of rainfall is widely explored in observational (e.g. Groisman *et al*., 1999, 2005; Frich *et al*., 2002 and Alexander *et al*., 2006) and model data (e.g. Gordon *et al*., 1992; McGuffie *et al*., 1999; Kharin and Zwiers, 2005; Tebaldi *et al*., 2006), but the potential changes in spatial variability, have been less well documented. This is partially due to the difficulties in investigating spatial patterns from model data which is most commonly generated at coarse spatial scale by general circulation models, or by regional models which still operate at relatively large grid-scales compared to the small scale processes, such as convection, which are involved in the generation of rainfall.

If spatial variability is assumed to remain stable in future climate, then the relationships between point and areal rainfall that have been developed in earlier chapters of this thesis could simply be reversed to allow estimates of future rainfall at point scale to be made from the coarse-scale GCM simulations. Whilst this approach would rely on the assumption that the precipitation simulated by the GCM for the grid box is reliable (which may not be the case) it would provide a tool for investigating the likely levels of precipitation variability that might be expected at the point-or-local-scale, under scenarios of future climate change, that is simpler than the more complex downscaling techniques that are currently available to impacts groups.

A potential change in sub-GCM-grid-scale spatial variability is, however, important to consider as it will alter the relationships that exist in observed climate. The use of existing values of spatial variability may cause an under-estimation of the degree of temporal variability at points within a grid box if a potential increase in spatial variability is ignored. Osborn (1997) demonstrates that the change in mean intensity at points within a model grid box can differ substantially in magnitude, and even in direction, from those changes at grid-box scale if the spatial variability is altered by an arbitrary amount. This will also affect the distribution of values, and extremes at those points within the grid box, and thus potentially have considerable implications for impacts studies that apply point or local-scale projections. If such a change in spatial variability could be quantified, this would allow these relationships to be applied to future climate to provide an indication of the parameters of point-scale temporal rainfall variability which account for changes in spatial as well as temporal variability. The quantification of changes in spatial variability would also have useful applications in existing multi-site downscaling models (e.g. Wilby *et al*, 2003).

The aim of this section of the thesis, therefore, is to assess whether a change in the level of spatial variability within a GCM grid box is expected to occur as the climate warms, and if so, to attempt to quantify that change in a way that can be applied to scenarios of future climate. This is investigated using a Regional Climate Model (RCM) simulation of recent and future climate of Europe to provide some information about the sub-GCM-grid-scale variability of simulated rainfall.

The model data are used to address the following research issues:

1) Do model projections suggest any shift towards a greater proportion of convective rainfall in the future?

If so,

2) Is a difference between the correlation structures in synoptic and convective rainfall evident in Regional Climate Model simulations of recent climate?

3) Is a change in spatial correlation structure evident between simulations of recent and future climate?

The chapter is structured as follows. First, the model data and details of the method are described (**Section 6.2**). Then an overview of the changes in mean daily rainfall according to the model simulations is given in order to set the changes in rainfall characteristics in context of the general changes to rainfall amount and seasonal distribution (**Section 6.3**). **Section 6.4** addresses Question 1 above, by looking at the changes to the synoptic and convective components of total rainfall in recent and future climate simulations from HadRM3 over Europe. **Section 6.5** addresses research Questions 2 and 3 above, looking at the spatial correlation characteristics of simulated precipitation in recent and future climate. Conclusions are drawn in **Section 6.6.**

6.2. Data and Methods

Daily precipitation data from HadRM3H simulations are used to investigate the spatial variability of daily rainfall in recent (1960-1990) and future (2070-2100) climate runs over Europe. These data are made available through the PRUDENCE Project, hosted by the Danish Meteorological Institute.[1] HadRM3H is driven by GCM HadCM3 and operates on a 50 x 50 km grid, which whilst still too coarse a resolution to be treated as point scale, allows some scope for investigating sub-GCM-grid scale variability.

HadRM3H simulated precipitation, has, for some runs, been divided into that which is generated by cumulus convection and that caused by synoptic-scale uplift resolved by the model dynamics. This division can give some indication of the relative contributions of the two processes to total rainfall in recent and future climate. The synoptic and convective splits are only available for one run from each of the present day runs and future scenarios. The study is therefore based on the analysis of a single 1960-1990 run and a single perturbed run under emissions scenario A2. Further details about the development and use of emissions scenarios can be found in the IPCC Special Report on Emissions Scenarios (SRES) (2000). The A2 scenario is within the upper half of the spectrum of SRES emissions scenarios, and therefore provides a stronger climate signal and easier identification of changes related to greenhouse-gas-induced warming in climate model simulations, compared with lower emissions scenarios.

Firstly, the amounts and relative proportions of synoptic and convective rainfall in each season are analysed for both present (1961-90) and future (2070-2100) climate. Secondly, the spatial correlation between grid boxes is studied to look for differences between the spatial characteristics of synoptic and convective rainfall, and/or changes in the characteristics of total precipitation between recent and future climate.

Spatial correlation for every RCM grid box is calculated using a correlation decay curve fitted to the correlations (r) and separation distances (d) from surrounding boxes. The curve fitted uses the same function, $r=ae^{-bd}$, that has been used in previous chapters to fit correlation decay curves for UK stations (See Section 4.4.1.1 for details of this method). In order to express the overall

---

[1] Data are available from : http://prudence.dmi.dk/

level of spatial variability with a single value, rather than the two parameters, *a* and *b*, which define the decay curve, the average spatial correlation value for stations separated by 0 to 400 km (calculated as the area under the curve for $0 < d < 400$, divided by 400) is also calculated for each grid-point. This allows easy comparison of spatial variability between regions, seasons or periods of time.

6.3. Mean Daily Rainfall in Recent and Future Climate

In the first instance it is useful to gain an indication of the overall changes in mean daily rainfall over the area of interest. Figure 6-1 and Figure 6-2 show simple maps of the mean daily rainfall over Europe in recent (1961-1990) and future (2070-2100) climate. Figure 6-3 shows the change field in mm for these periods.

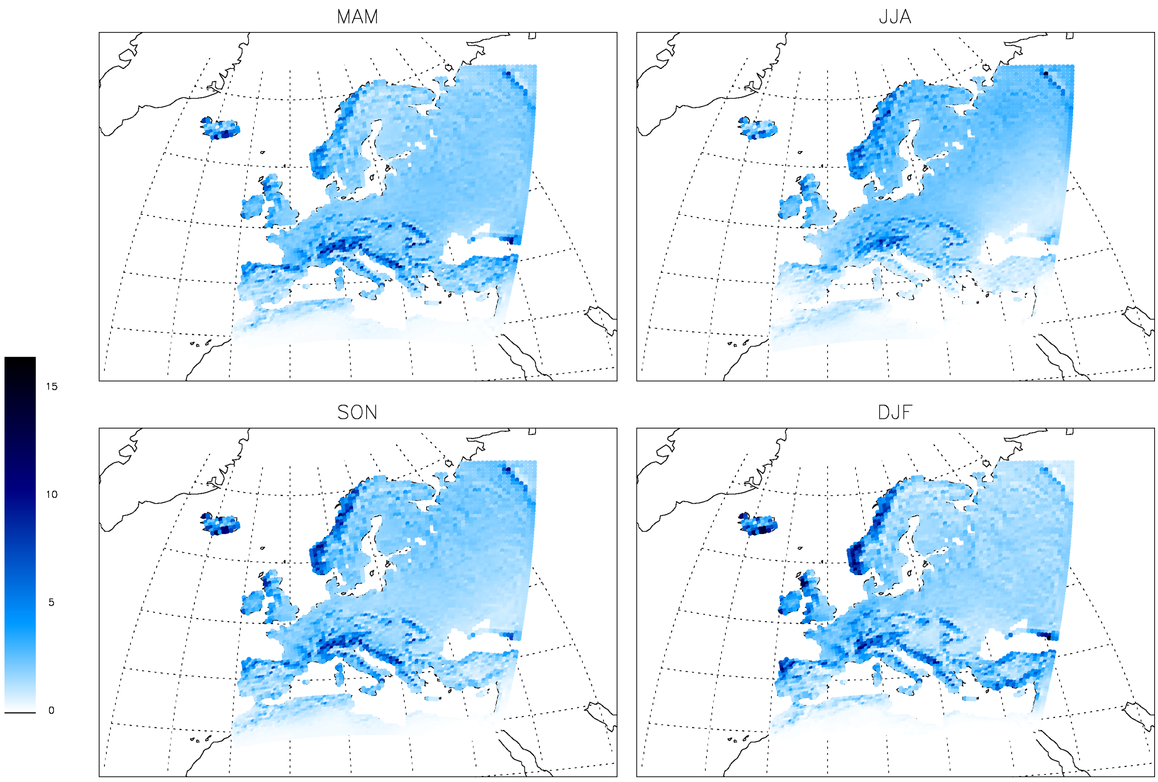

Figure 6-1: Mean daily rainfall (total in mm) simulated by HadRM3H for Europe – Control run 1960-1990.

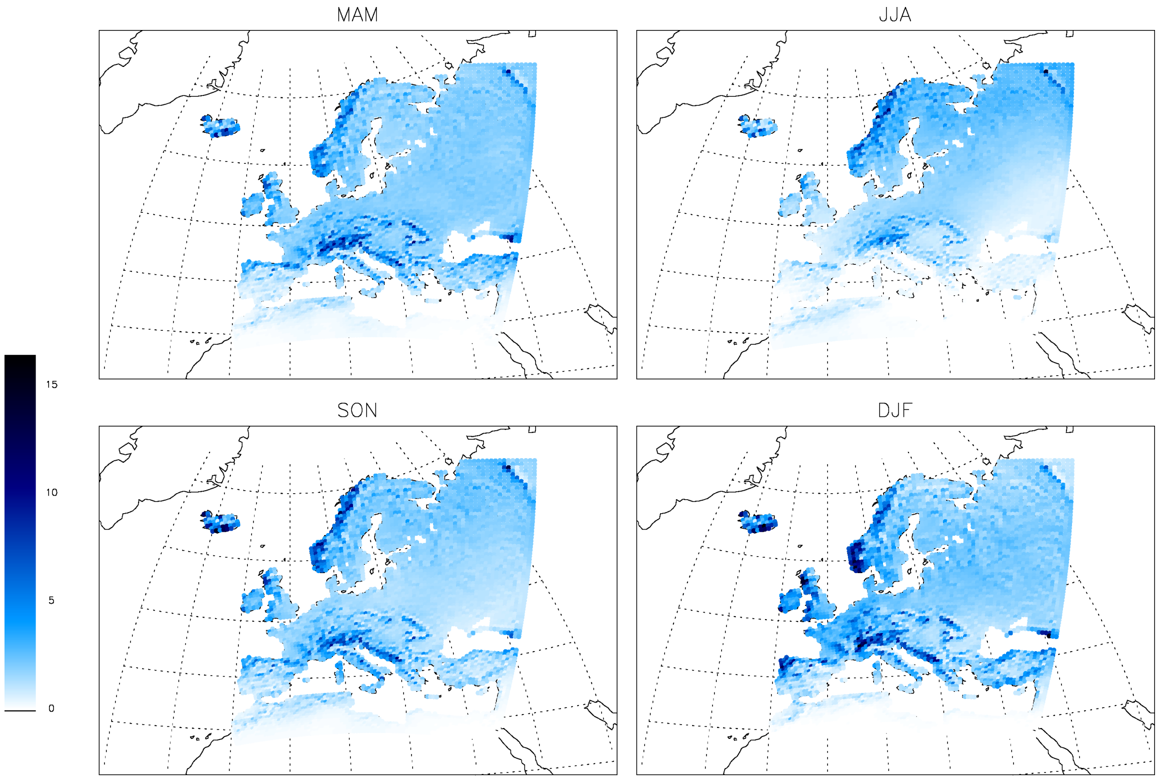

Figure 6-2: Mean daily rainfall (total in mm) simulated by HadRM3H for Europe –2070-2100 under scenario A2.

The general seasonal trend appears to be towards decreases in rainfall in summer and increases in winter, with more mixed results for spring and autumn. There are some regions, such as the coastal regions of the Mediterranean, where rainfall decreases are projected for all seasons. The magnitude of these changes is generally within +/- 3mm, but some regions are expected to experience particularly large changes (in both the summer decreases and winter increases). These regions appear to be those which have the highest elevations, such as the Alps and the mountainous regions of Scandanavia.

The average seasonal changes for the UK, compared to the European average, are shown in Figure 6-4. This shows a substantially enhanced seasonal cycle in rainfall amount, which is considerably more pronounced in the UK than for the European average. The decrease in summer (JJA) rainfall for the UK is particularly pronounced, decreasing by an average 1mm per day, compared to a decrease of around 0.3mm over the whole of Europe over the same time period.

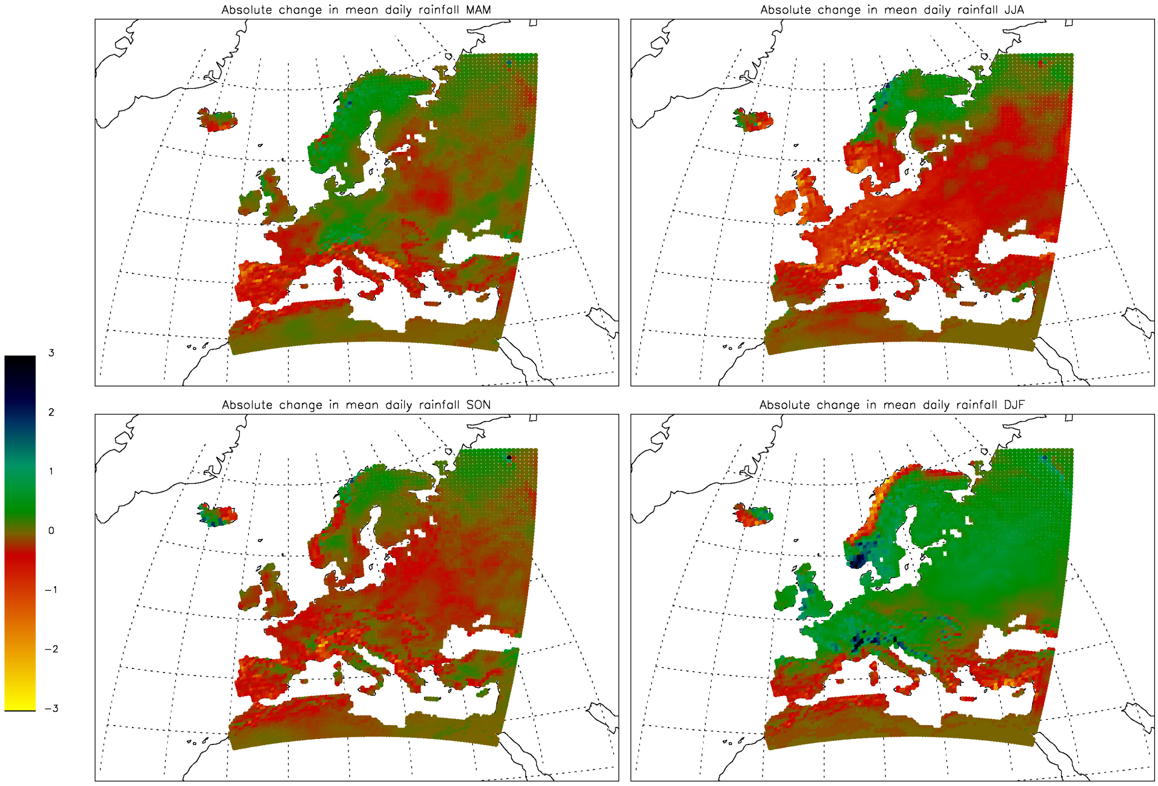

Figure 6-3: Change in mean daily rainfall (total) simulated by HadRM3H for Europe from 1960-1990 to 2070-2100 under scenario A2.

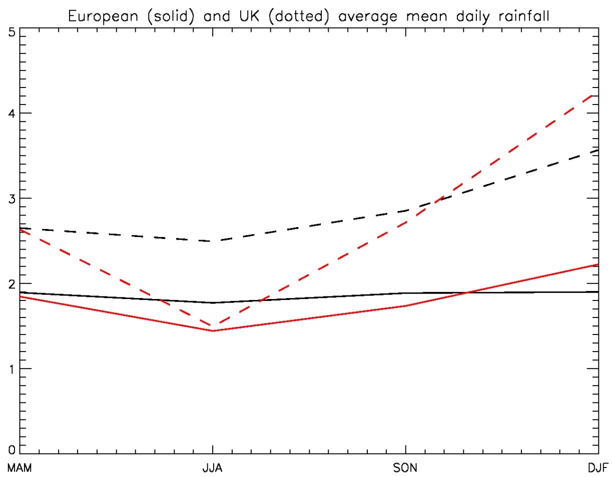

Figure 6-4: Seasonal changes in mean daily total rainfall (mm) between 1961-90 (black) and 2070-2099 (red) under scenario A2 for the UK (dotted) and Europe (solid).

6.4. Synoptic and Convective Rainfall in Recent and Future Climate

Figures 7-5 to 7-10 show the convective and synoptic components of mean daily rainfall in control and perturbed model runs, and the change fields in mm.

6.4.1. Synoptic Rainfall

The orographic influences on rainfall are clearly evident in the synoptic rainfall over Europe (Figure 6-5), with greatest amounts of this type of rainfall occurring over mountainous regions in all seasons. The rain shadow effect is clearly visible in DJF, but less pronounced in JJA. The seasonal contrast in synoptic rainfall is not particularly strong. There is, however, a reversal of seasonal trends between Northern and Southern Europe in summer and winter. In summer, the model simulates very little synoptic rainfall in southern Europe (with the exception of the alpine region) whilst much of Northern Europe (Scandanavia and Northern Russia) receives around 5mm synoptic rainfall. In winter, however, with the exception of the western coast of Norway, Northern Europe receives very little synoptic rainfall while central Europe (for example, the Iberian Pensinsula, Italy and other Mediterranean regions) receives more substantial quantities of synoptic rainfall.

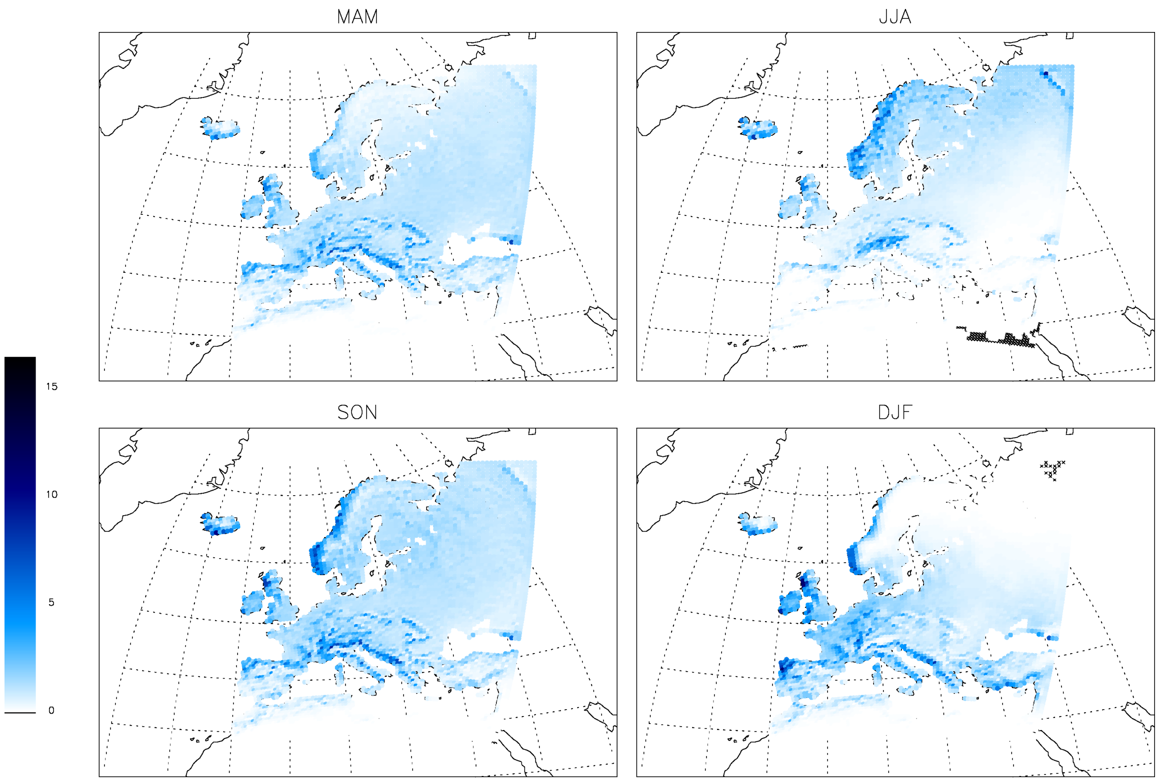

Figure 6-5: Mean daily synoptic rainfall (mm) simulated by HadRM3H for Europe – Control run 1960-1990.

The changes to the synoptic portion of total rainfall seen under the A2 emission scenario are similar in nature to those of total precipitation (Figure 6-6 and Figure 6-7). The seasonal contrast is expected to increase, with increases expected in most of central Europe in winter, particularly in regions of high elevation. The only regions to experience reductions in synoptic rainfall in winter are the coastal regions of the Mediterranean countries, and the western-most edge of Norway. In Summer, however, synoptic rainfall decreases in much of Europe, particularly in central regions (In Mediterranean regions no summer decrease in synoptic rainfall is possible because it is already close to zero in the present day).

Similarly to the total rainfall in Figure 6-4, the seasonal changes seen in synoptic rainfall averaged over the UK and Europe (Figure 6-8) show an enhancement of the seasonal cycle in rainfall amount which is particularly pronounced for the UK compared to the European average.

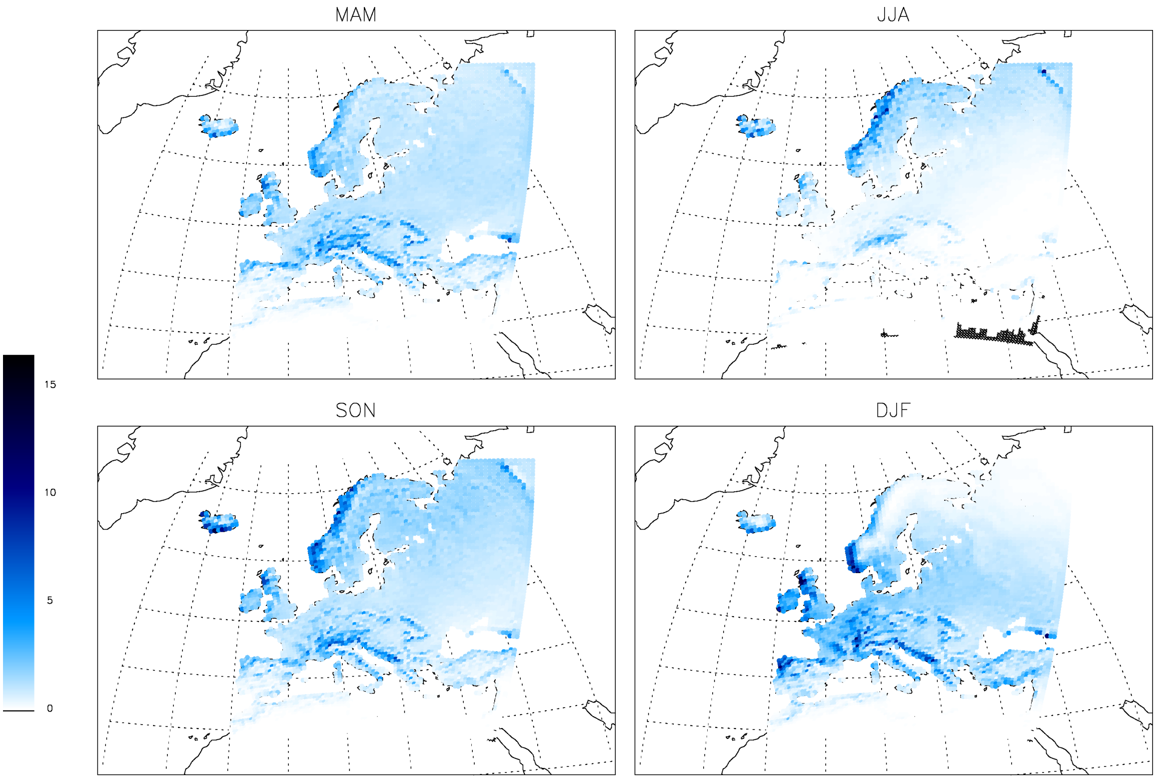

Figure 6-6: Mean daily synoptic rainfall (total in mm) simulated by HadRM3H for Europe – 2070-2100 under scenario A2.

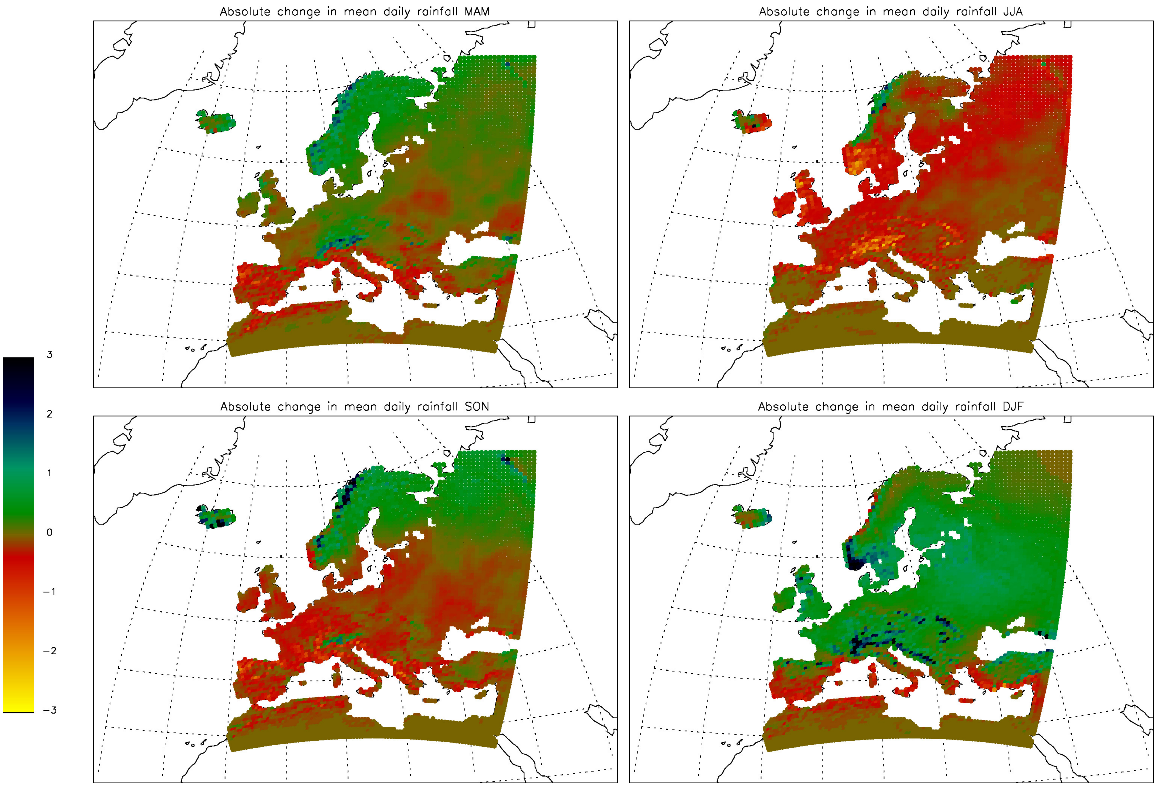

Figure 6-7: Change in mean daily synoptic rainfall (mm) simulated by HadRM3H for Europe from 1960-1990 to 2070-2100 under scenario A2.

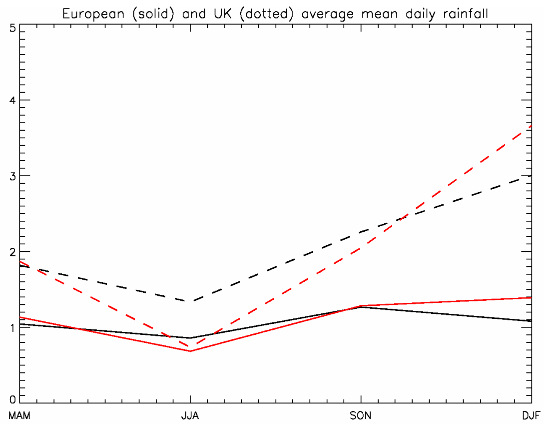

Figure 6-8: Seasonal changes in mean daily synoptic rainfall (mm) between 1961-90 (black) and 2070-2099 (red) under scenario A2 for the UK (dotted) and Europe (solid).

6.4.2. Convective Rainfall

The current patterns in convective rainfall over Europe (Figure 6-9) show a strong seasonal dependence, with most of this rainfall, as would be expected, falling in the summer. The geographical distribution of this rainfall is relatively even in the summer, with little dependence on orography. In winter, there is very little convective rainfall in any region. In autumn and spring, a small amount of convective rainfall is simulated over the central latitudes, but with very little or none at all in the most northern and southern regions.

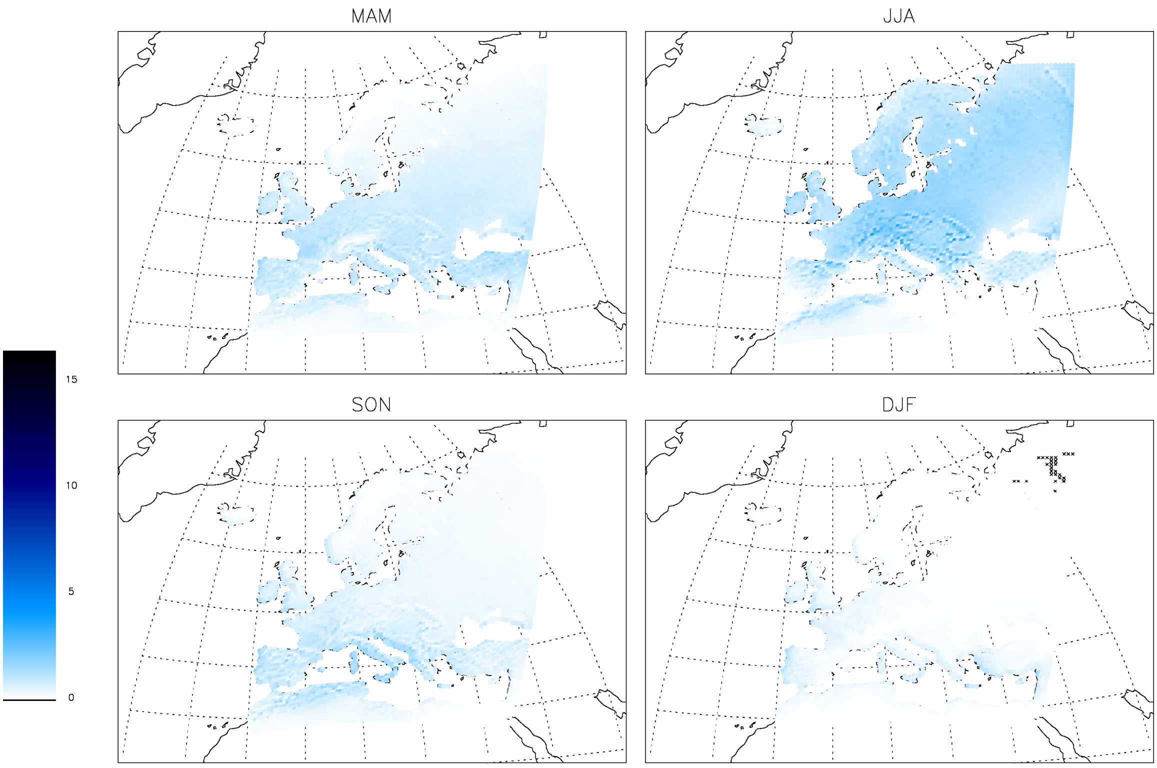

Figure 6-9: Mean daily convective rainfall simulated by HadRM3H for Europe – Control run 1960-1990.

The change in convective precipitation amount is difficult to identify by visual comparison of Figure 6-9 and Figure 6-10 due to the small values, but is clearer from the change field (Figure 6-11). The most notable change to the convective rainfall simulated for the future under the A2 scenario (Figure 6-10 and Figure 6-11) is the large region of reduction during summer in the central latitudes. This does not occur in the more northern regions, where increases in convective rainfall occur, or in the southern regions, where very little change is seen. The other three seasons appear to exhibit little change or very small increases in convective rainfall over much of Europe, with coherent decreases seen only in small regions of the Iberian Peninsula.

Studying the seasonal changes in the UK and European averages (Figure 6-12) again shows small changes only. The seasonal patterns however, are similar to those of the total, and synoptic-only precipitation changes, with decreases in summer and slight increases in winter.

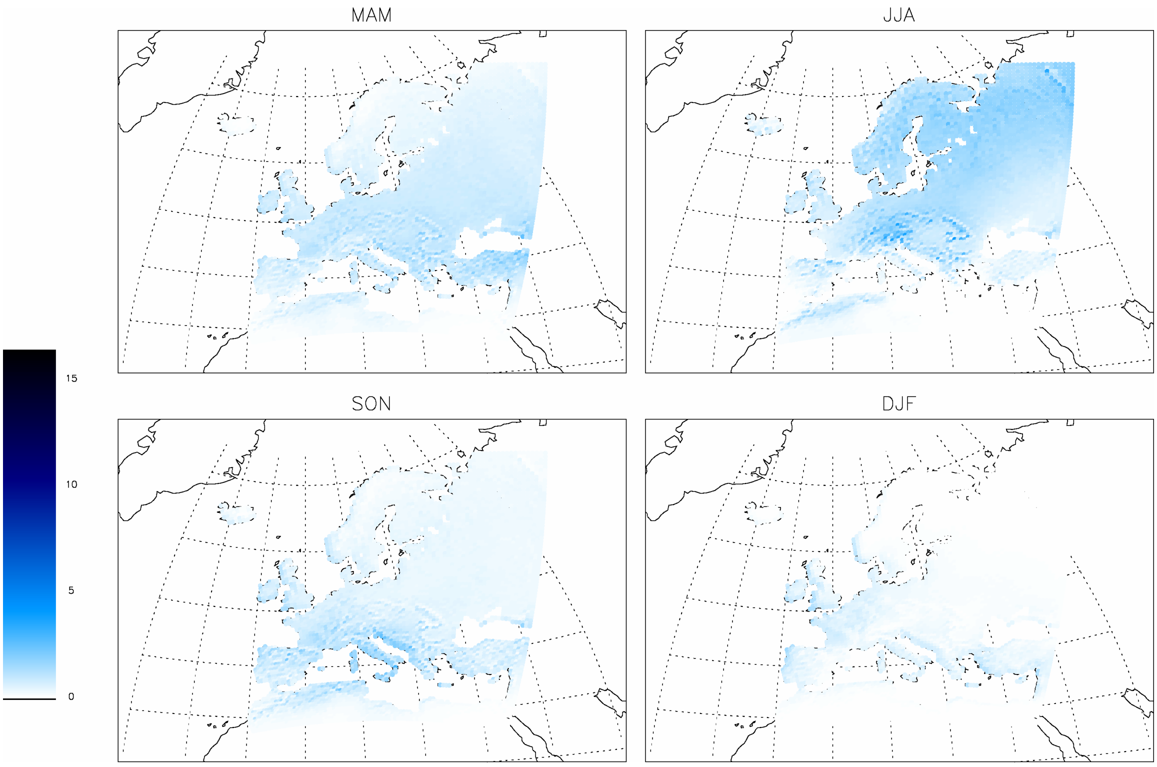

Figure 6-10: Mean daily convective rainfall simulated by HadRM3H for Europe – 2070-2100 under scenario A2.

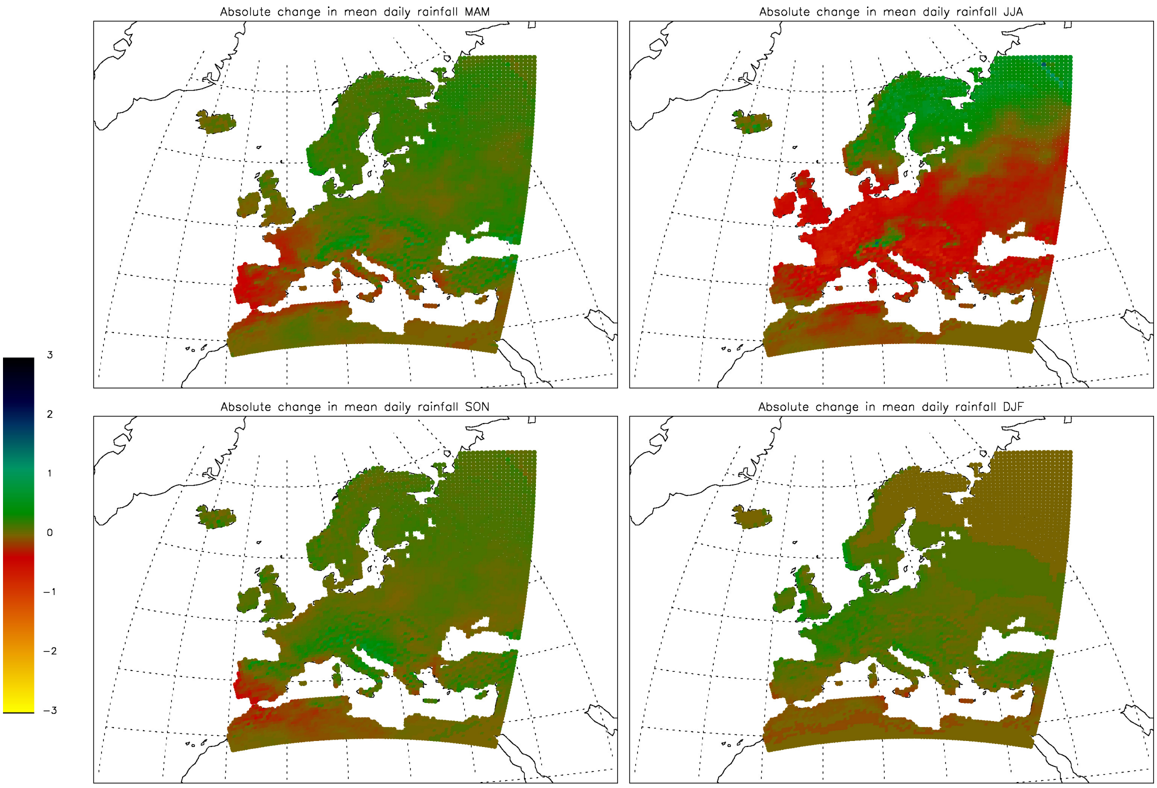

Figure 6-11: Change in mean daily convective rainfall simulated by HadRM3H from 1960-1990 under scenario A2.

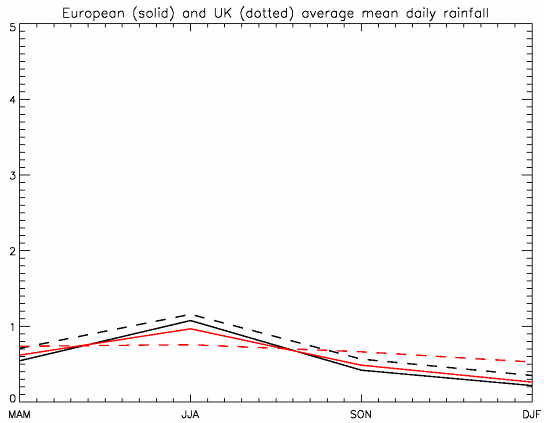

Figure 6-12: Seasonal changes in mean daily convective rainfall (mm) between 1961-90 (black) and 2070-2099 (red) under scenario A2 for the UK (dotted) and Europe (solid).

6.4.3. Proportional Contribution of Convective Rainfall to the Total Rainfall

The mean daily values for synoptic and convective rainfall show similar seasonal patterns of increase in winter and decrease in summer. However, the magnitude of the change differs between the precipitation types and varies in space. In order to assess whether any significant 'shift' towards one precipitation type or the other is evident, it is more useful to look at the changes in proportional contribution of the rainfall types to total rainfall.

Figure 6-13 shows the proportional contribution of convective rainfall to total rainfall in simulations of recent climate. The seasonal patterns in the proportion of convective rainfall in recent climate are dominated by the contrast between summer and winter. The highest proportion of convective rainfall is experienced in Summer whilst the lowest proportion is in Winter, and this effect is uniform throughout Europe. Geographical variations in the proportion of convective rainfall occur most strongly in Spring and Autumn, but are also evident in summer and Winter. There is a strong North-South gradient with the Northern regions consistently receiving the lowest proportion of convective rainfall. Variations in this gradient are evident in some of the higher elevation regions, such as the Alps, where synoptic rainfall is more dominant, even in summer, due to this orographic influence.

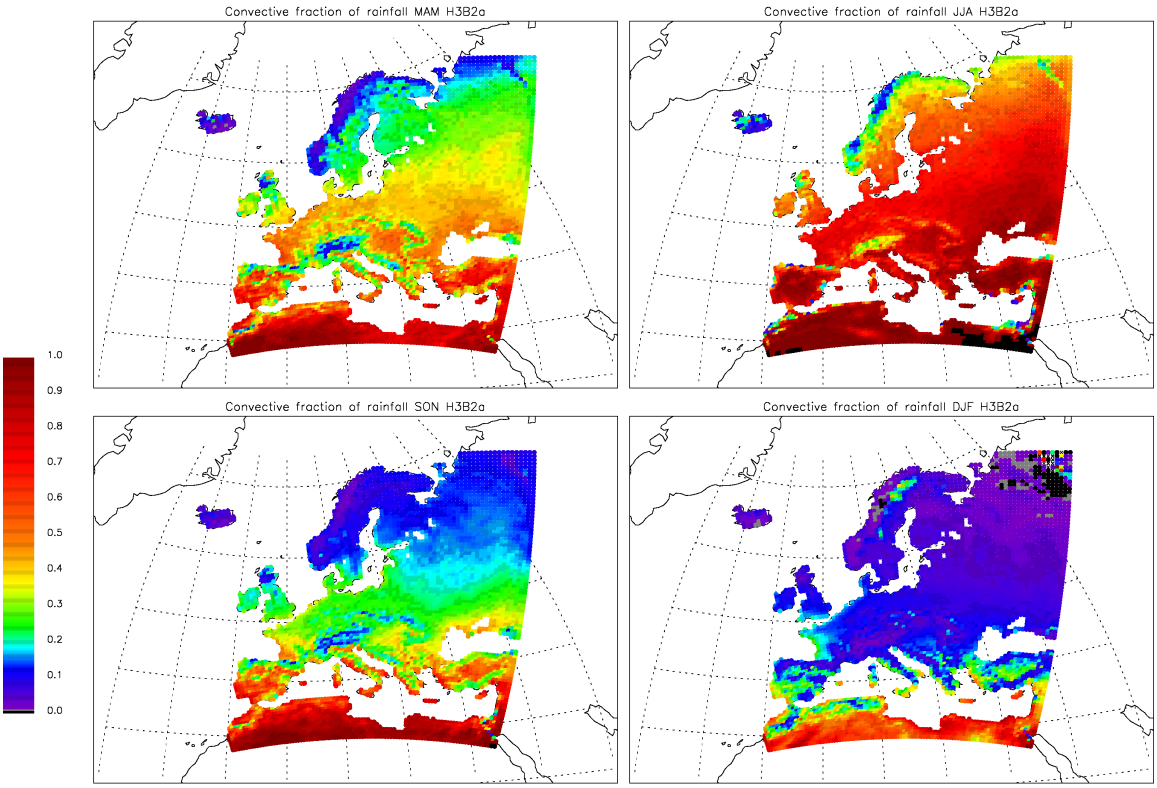

Figure 6-13: Convective fraction of mean daily rainfall over Europe simulated by HadRM3H – Control run 1960-1990.

The changes in the proportion of convective rainfall are difficult to identify from Figure 6-14, but can be seen more clearly in the change field Figure 6-15. Generally, there is an increase in the proportion of convective rainfall in all seasons over all but a few patchy regions where it decreases. The increases are largest in the summer, where they exceed 0.2 in some regions.

The UK and European averages in Figure 6-16 show that while, on average, the UK tends to experience a lower fraction of convective precipitation than the European average. The magnitudes of the changes are similar, generally increasing by 0.05 in summer and autumn, but changing little in spring and winter.

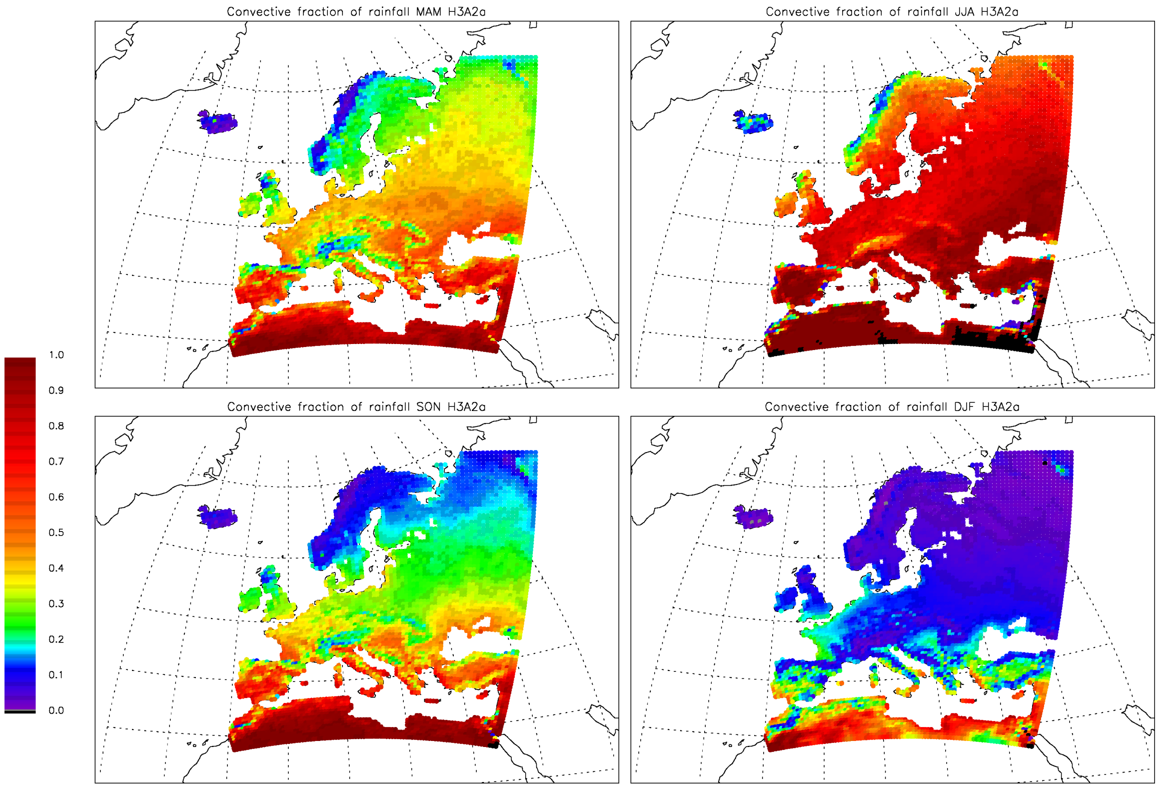

Figure 6-14: Convective fraction of mean daily rainfall in HadRM3H simulations for Europe under scenario A2 – 2070-2100.

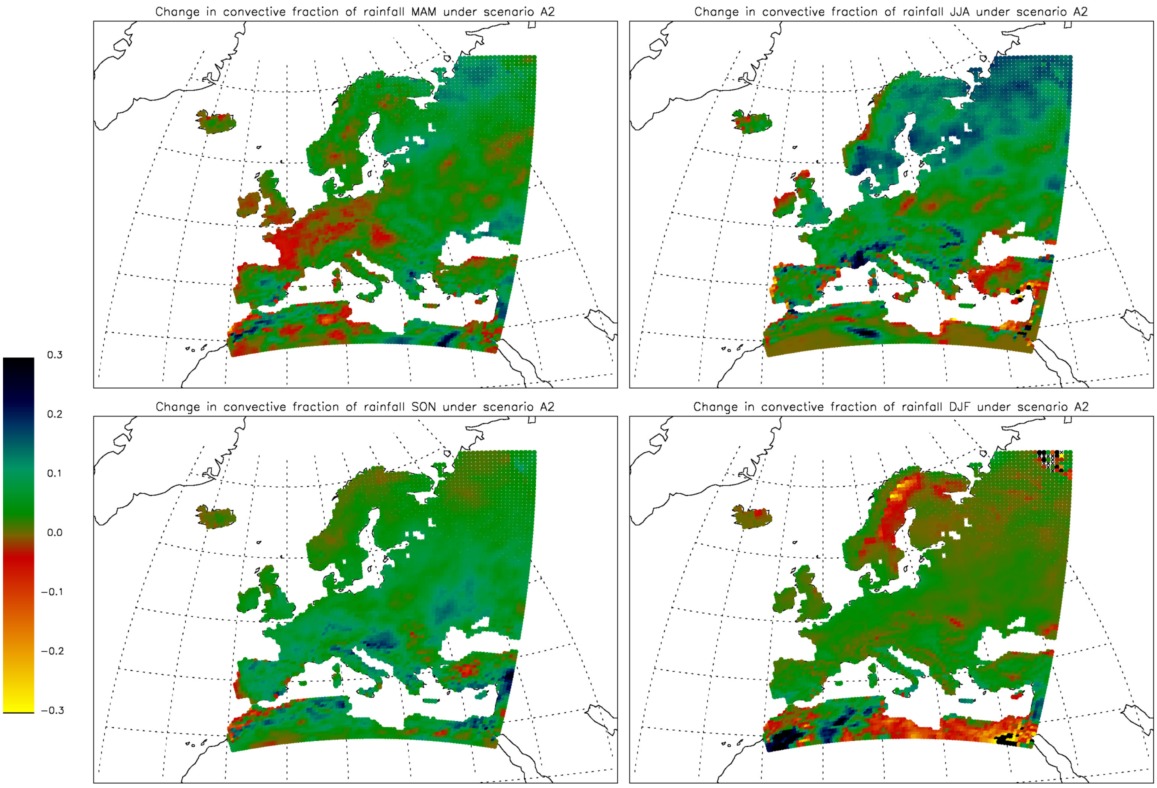

Figure 6-15: Change in convective fraction of mean daily rainfall simulated by HadRM3H from 1960-1990 to 2070-2100 under scenario A2.

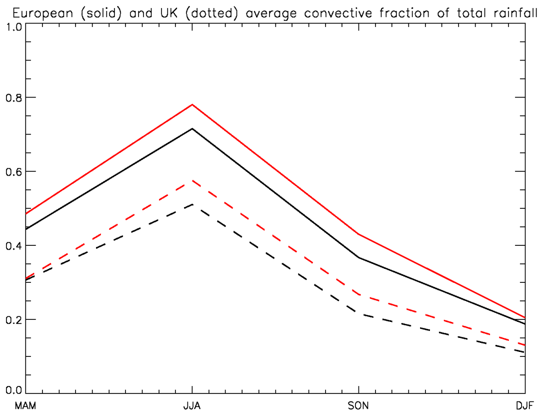

Figure 6-16: Mean convective fraction of total rainfall over Europe (solid) and UK (dotted) in control run 1960-1990 (black) and A2 scenario perturbed run 2070-2100 (red).

6.4.4. Summary

The simulations of future climate for Europe under scenario A2 suggest that, on the whole, summers are expected to become drier and winters wetter as the climate becomes warmer. When rainfall is divided into the synoptic and convective fractions for both current and future model runs, this trend is evident in both the types of rainfall. However, the difference in the magnitude of the changes in the two types of rainfall causes a change in the proportion of each rainfall type. The result is an overall increase in the proportion of convective rainfall over most of Europe, affecting all seasons, and most regions, but with the largest shifts evident in Summer (JJA) and Autumn (SON).

6.5. Spatial Correlation in Recent and Future Climate

Given the different spatial characteristics of convective and synoptic rainfall, it might be expected that as a shift towards a higher fraction of convective rainfall in scenarios of future climate occurs, a reduction in spatial correlation will also occur. However, while RCM simulations are relatively fine in spatial resolutions and provide some potential for the assessment of sub-grid-scale variability, they do not contain the level of variability that would be expected at point scale. HadRM3H simulation that is used here was run at 50km spatial resolution; processes operating at smaller scales than this are important for precipitation but cannot be fully resolved. Even those processes which are reproduced more accurately at RCM than at GCM scale are subject to parameterizations which introduce error and can result in the inaccurate representation of variability at this scale (e.g. Iorio, 2004; Emori *et al.*, 2005).

This section investigates the spatial correlation in rainfall simulated in the HadRM3H control and perturbed simulations of climate over Europe. The patterns of correlation found in control simulation are studied to assess whether the expected geographical and seasonal variations in spatial correlation are simulated by HadRM3H. The separated simulations of synoptic and convective rainfall are also assessed to see whether the model demonstrates differences between the spatial characteristics of these rainfall types. Finally, the perturbed simulations of future climate are assessed for changes in the correlation between grid boxes.

6.5.1. Recent Climate

The seasonal and geographical variations in the spatial correlation of the simulated present-day precipitation are shown, in Figure 6-17 in order to assess qualitatively the realism in the spatial variability. This plot shows some important feature that would be expected; primarily, that of the four seasons, the lowest correlations occur throughout most of the region in the summer months and the highest in winter. The magnitude of this difference, averaged over the UK and Europe (Figure 6-18) is relatively small, with lowest average correlation at about 0.55 (JJA) and the highest at 0.63 (DJF).

Qualitatively, this pattern is consistent with what may be expected given that summer precipitation is more commonly caused by local convection due to warm conditions, whilst winter precipitation is more frequently caused by large-scale synoptic weather systems. Relatively low correlations – and thus enhanced spatial variability - are also expected over regions of high topographic variation, such as Scotland, the Alps and Jotunheim Range in Scandinavia and these are also clear in this plot. This demonstrated ability that the model is able to produce the expected seasonal and geographical differences in spatial variability gives us some confidence that it might also be able to simulate changes in that spatial variability that might occur with a shift towards more local-scale convective rainfall with increasing temperature. The differences in spatial correlation arising from differences in precipitation mechanism may change in a future climate in which the contributions of these mechanisms might be different. The low spatial correlations over regions of high topographic variation could be expected to remain even in an altered climate.

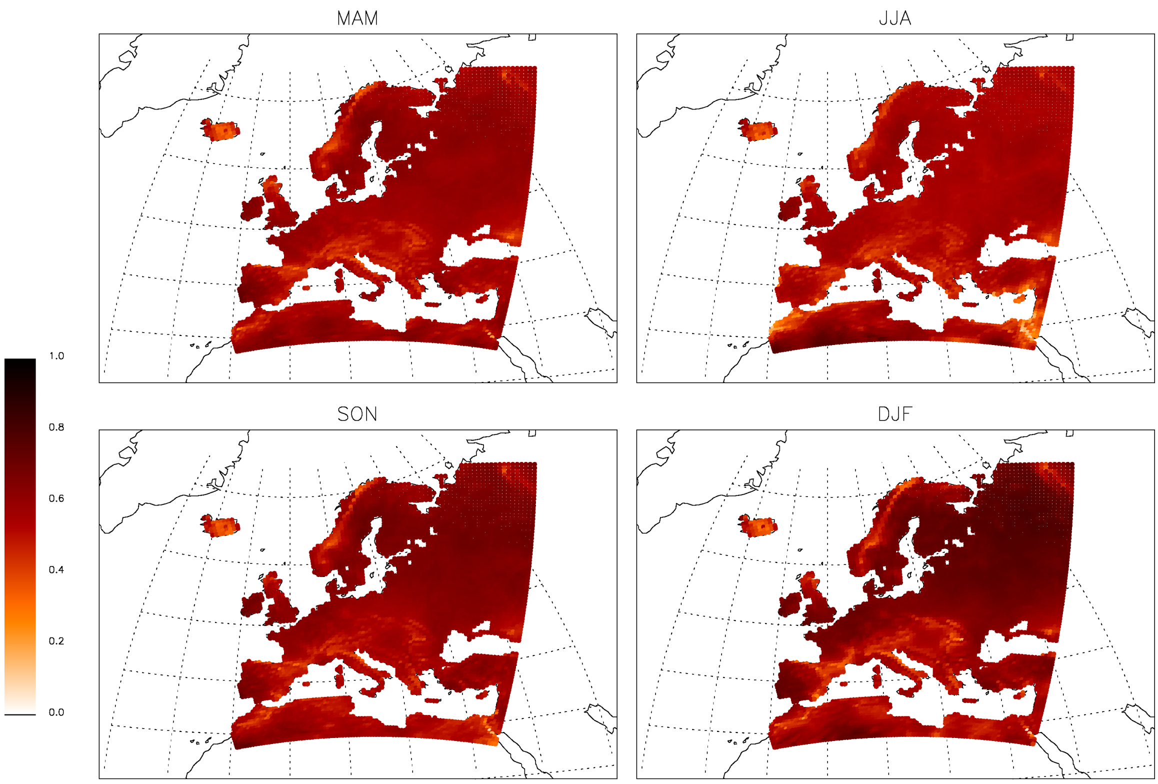

Figure 6-17: Spatial correlation (measured as the mean correlation over distances up to 400km) over Europe in control run (1960-1990) precipitation simulated by HadRM3H.

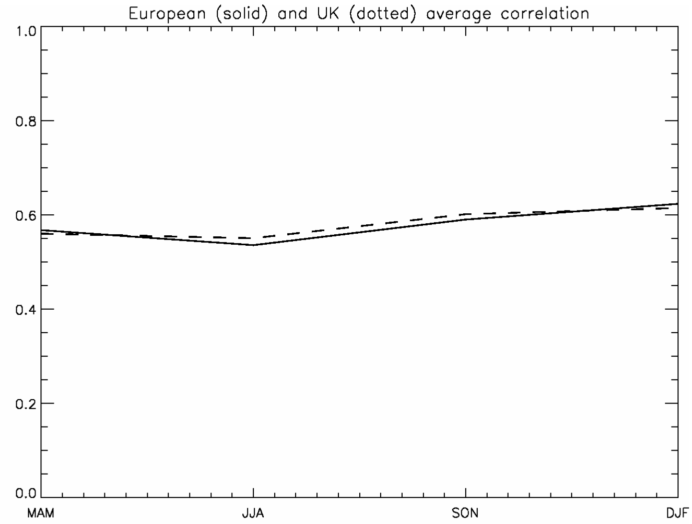

Figure 6-18: Spatial correlation of mean daily rainfall in control run (1960-1990) precipitation simulated by HadRM3H. Solid = European Average, dotted = UK average.

Differences between the spatial correlation structures in the convective and synoptic rainfall fields can also be investigated. Lower correlations might be expected in the convective rainfall than in the synoptic field due to the more localized nature of this type of rainfall. Comparison of the average correlation associated with synoptic and convective precipitation (Figure 6-19 and Figure 6-20) does not, however, show this expected. In fact, the spatial correlation in the convective rainfall fields simulated by the RCM is mostly a little *higher* than for the synoptic rainfall fields. This is more clearly seen in the spatial averages over the UK and Europe in (Figure 6-21). From this figure it becomes apparent that the seasonal variation in the pattern of spatial correlation that is seen in Figure 6-17 and Figure 6-18 does not occur because a higher proportion of that rainfall is convective, but because the synoptic rainfall that falls varies in its spatial characteristics between seasons. The synoptic fraction of rainfall simulated by HadRM3H over Europe occurs at a smaller spatial scale in summer months. There is also a similar, though less pronounced, seasonal variation in the spatial characteristics of convective rainfall. Together, the seasonal variations in the spatial coherence of the two types of precipitation dominate over the seasonal variations in the contributions of each type, resulting in the lower values of spatial correlation in summer compared to winter.

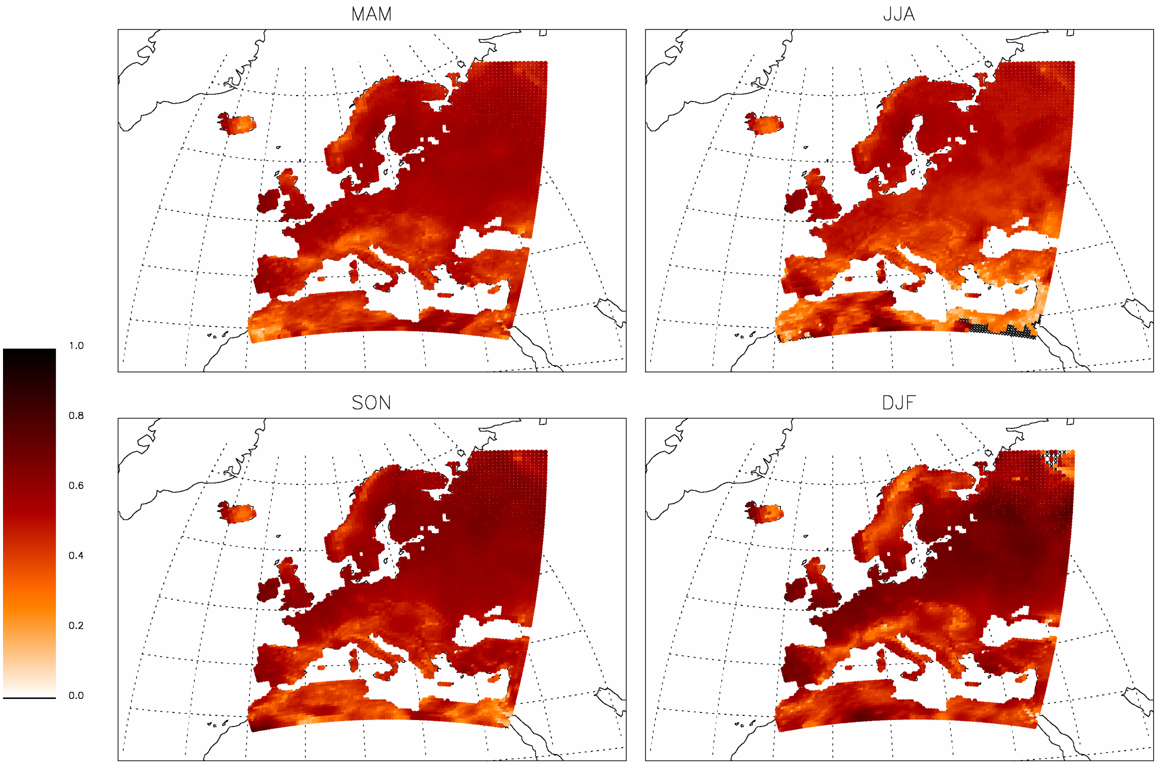

Figure 6-19: Spatial correlation (measured as the area below the correlation decay curve up to a distance of 400km) in daily rainfall over Europe from control run (1960-1990) synoptic precipitation simulated by HadRM3H.

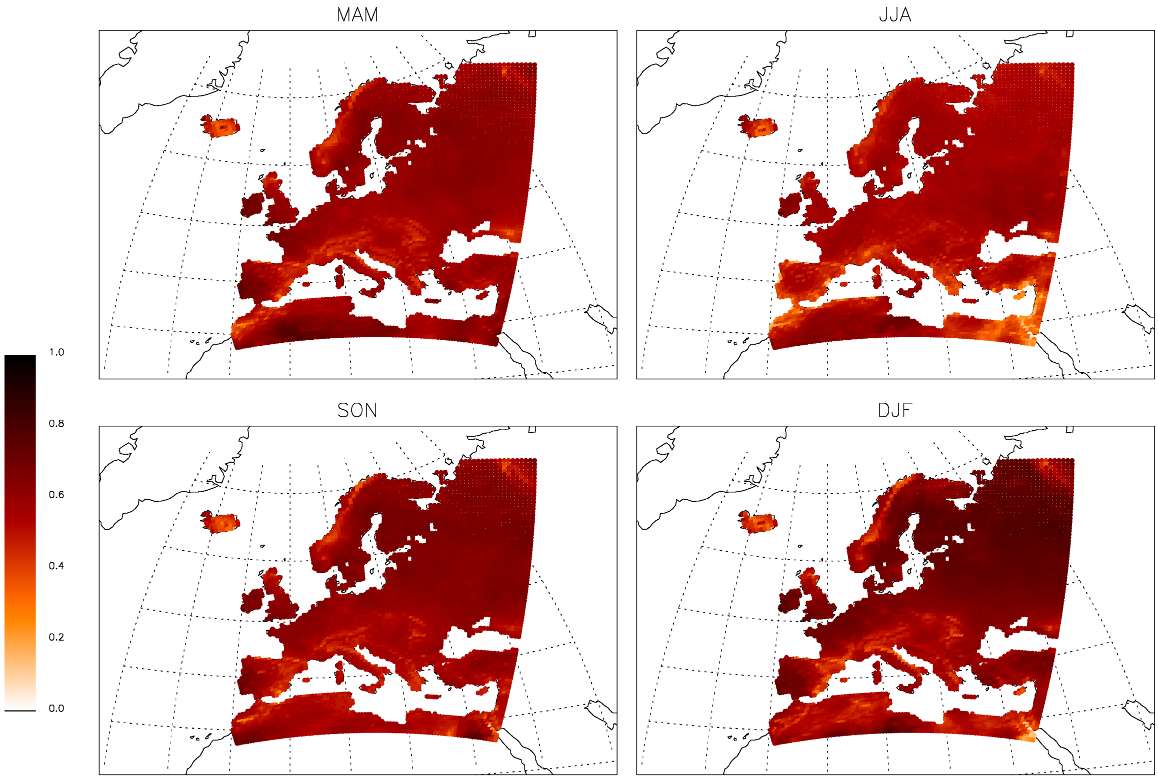

Figure 6-20: Spatial correlation in daily convective rainfall over Europe in control run (1960-1990) precipitation simulated by HadRM3H.

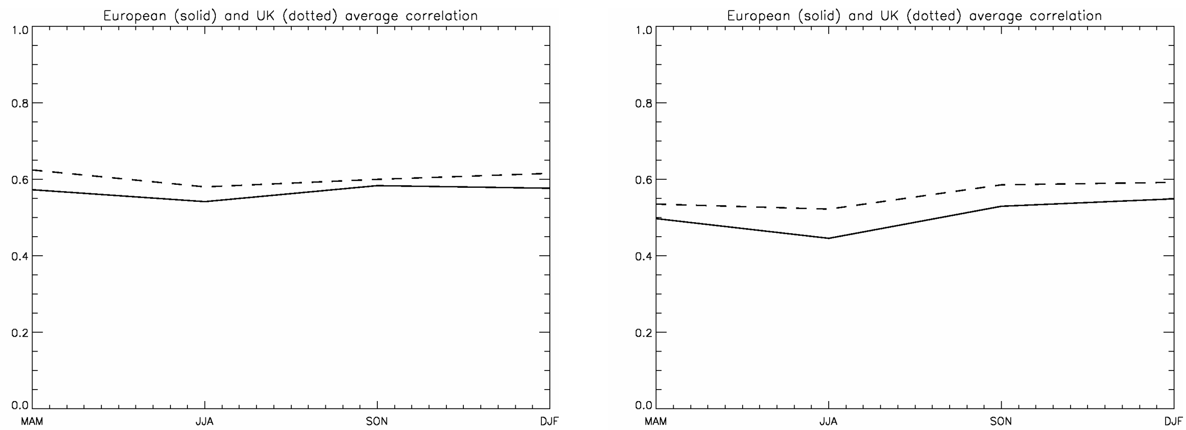

Figure 6-21: Spatial correlation averaged over Europe (solid) and UK (dotted) in the convective (left) and synoptic (right) components of total daily rainfall.

6.5.2. Future Climate

The changes in rainfall correlation in simulated rainfall for the future are shown in Figure 6-22. Whilst changes in the correlation structure are evident, they are small and vary in direction throughout Europe. There is no apparent geographical or seasonal consistency in the direction or magnitude of these changes.

These values are averaged over the UK and Europe and shown in Figure 6-23. There is very little difference between the spatial correlation in recent and future climate simulations for either regional average. The biggest change is in spring, with both the UK and European averages indicating slightly increased spatial correlation in that season.

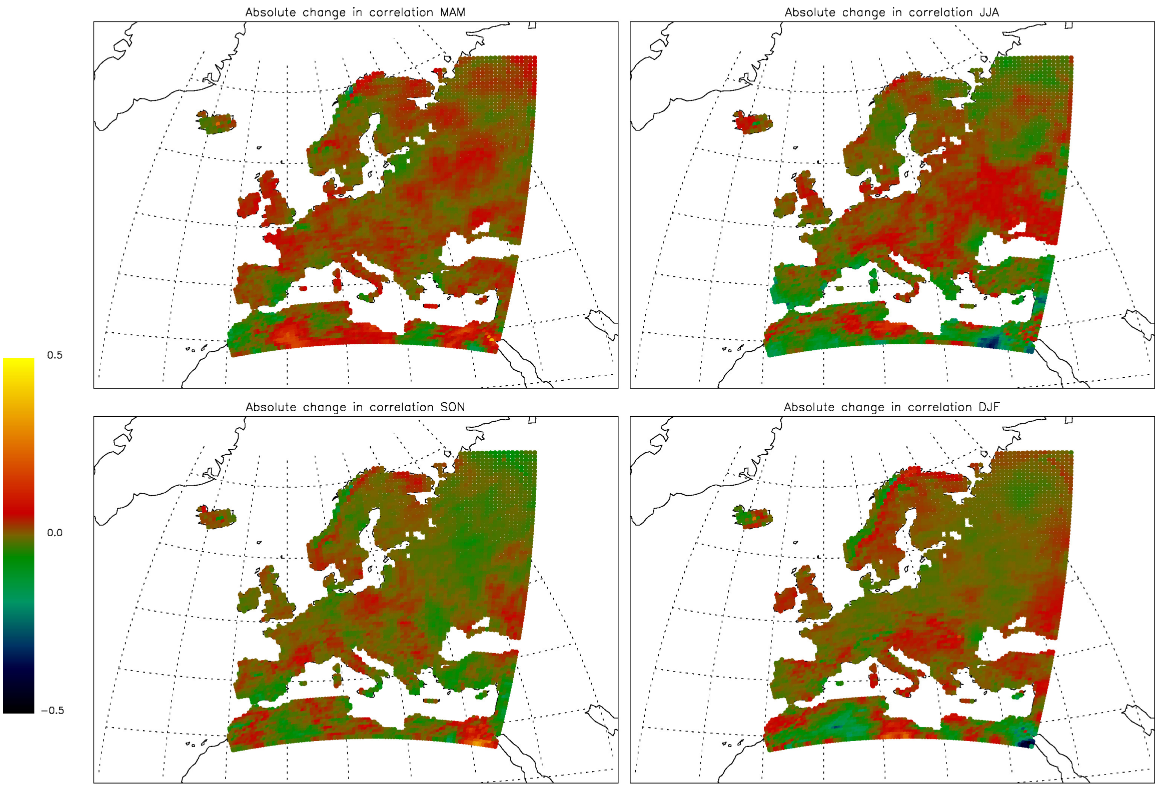

Figure 6-22: Change in spatial correlation (measured as the area below the correlation decay curve up to a distance of 400km) in total correlation simulated by HadRM3H.

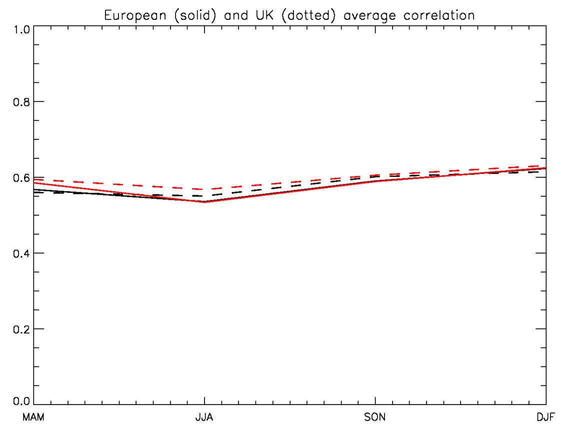

Figure 6-23: Mean change in average spatial correlation in total rainfall over Europe (solid) and UK (dotted) in control run 1960-1990 (black) and A2 scenario perturbed run 2070-2100 (red).

6.5.3. Discussion

The seasonal and geographical variations in spatial correlation appear to be well represented in the RCM simulations of daily rainfall, showing lowest correlation values in summer and highest in winter and lower correlation over mountainous regions. This suggests that the model represents the spatial scale of some aspects of the rainfall process well. The seasonal variation in spatial correlation evident in these simulations suggests that the model can account for differences in spatial correlation that relate to the climatic characteristics of a warmer climate. This might lead us to expect that if the climate becomes warmer, and conditions shift to those more like those currently experienced in summer months, the spatial correlation characteristics of simulated precipitation might also shift towards those that are more like summer.

However, the RCM simulations do not show the expected differences in spatial correlation between synoptic and convective precipitation fractions in simulations of recent climate. In fact, the synoptic component of total rainfall is demonstrated to occur with *less* spatial coherency than the convective fraction, the opposite to what might be expected given the tendency for convective rainfall to be more localised. The synoptic fraction of rainfall does, however, tend to occur with less spatial coherency in summer than winter, which is why the total rainfall displays the expected seasonal patterns in spatial correlation. The reduction in spatial correlation in a warmer climate, expected to occur in response to the increases in the proportion of convective rainfall that this model simulates does not, therefore, appear.

Testing a model's ability to simulate realistic characteristics of the convective and synoptic fractions of rainfall is very difficult because observed rainfall cannot easily be categorized by its causal processes. This is partly because rainfall often occurs because of a combination of the two processes. A number of approaches have, however, been applied to the problem; Tremblay (2005), for example, uses a statistical approach to divide weak and long-lived (stratiform/synoptic) events from those which are intense but short-lived (convective). Dai (2006b) uses a more physically-based approach to divide TRMM radar measurements of observed precipitation into its convective and stratiform (synoptic) components, which uses an algorithm based on the vertical profile of reflectivity and horizontal variability of the echo (see Schumacher and Houze, 2003). While these techniques can provide information regarding the relative contributions of the rainfall types, the definitions of the two types of rainfall are not comparable to the divisions made between stratiform and convective rainfall within a climate model. This makes it difficult to compare the characteristics of each rainfall type between models and observations. Dai (2006b) does use this approach to evaluate the ability of several climate models to produce rainfall which has a realistic proportion of the two rainfall types. Whilst the technique can be considered robust enough to examine the approximate proportions of each rainfall type, it is not precise enough to allow a worthwhile examination of the more detailed characteristics of each rainfall type, such as the spatial characteristics.

It is reasonable to suggest, however, that the limited resolution of the regional climate to model to 50km will significantly impair its ability to reproduce the finer-scale spatial variability in daily precipitation. Even at this relatively high spatial resolution, a model cannot fully resolve the sub-grid-scale processes which form an important part of the rainfall process. The possibility that a change in spatial variability will accompany a shift towards a higher proportion of convective rainfall cannot, therefore, be ruled out on the basis that it is not evident in modeling experiments such as this one. The possibility that the model is correct, and that an increase in the spatial coherency of rainfall might occur, should also not be ruled out unless it can be demonstrated that this effect arises from model deficiencies.

6.6. Conclusions

The investigation of the sub-grid-scale spatial characteristics of rainfall using the Regional Climate Model HadRM3H have demonstrated that while a shift towards a greater proportion of convective rainfall is projected in future climate, an associated reduction in the spatial correlation of rainfall does not appear.

Examination of the spatial correlation characteristics of rainfall has demonstrated that the model can produce seasonal and geographical variations in the spatial coherency of rainfall that match those expected to arise from the different precipitation-forming mechanisms. However, investigation of the spatial characteristics of the convective and synoptic precipitation components separately suggests that the model does not simulate the spatial characteristics of the two rainfall types that might be expected. The convective rainfall actually occurs with greater spatial coherency than the synoptic rainfall. Each precipitation type has a seasonal cycle in its spatial characteristics, and it is these seasonal variations in the contribution of each type that causes the seasonal variation in spatial correlation to match that expected.

The limitations of the regional climate model, in terms of its ability to produce the expected spatial characteristics of synoptic and convective rainfall, therefore means that an overall decrease in spatial correlation, that might be expected, is not seen in the simulations of future climate. In fact, an increase in spatial correlation is indicated. This does not mean that that decrease can be ruled out as there are still physical reasons to expect it given that a shift towards a greater proportion of convective rainfall *is* seen in the future climate simulations. An alternative approach to investigating and /or quantifying such a change might therefore be sought.