Chapter 7

Using Climate Analogues to Estimate Spatial Correlation in Future Climate

Contents

7.1. Introduction

The previous chapter has demonstrated that at least some models simulate a shift towards a higher proportion of convective rainfall under a warmer climate. However, these studies proved inconclusive with regards to changes in spatial correlation that might be expected to accompany such a shift towards more local-scale precipitation. This chapter proposes an alternative approach to estimating and quantifying a change in spatial correlation in future climate that might be associated with a shift towards a higher fraction of convective over synoptic rainfall. Here, the projected changes in the convective fraction of rainfall from RCM simulations are used to select an analogue region, from which the correlation values in observed data can be used as an indication of those which may apply to the UK in the future.

This quantification of the change in spatial correlation allows the relationships between spatial and temporal variability, which have been developed in the earlier chapters of this thesis, to be applied to GCM projections of future climate to give an indication of the changes in variability that might be experienced at point scale. This approach to downscaling or disaggregating areal rainfall simulated by GCMs provides a useful tool for investigating the differences between the characteristics of point and areal rainfall, and the affect that a change in spatial variability might have on temporal variability at point scale in the future. As a ‘downscaling’ tool for predicting the changes in point or local scale precipitation for a region for climate impacts research, however, the use of this approach may not give reliable predictions if the grid-box precipitation simulated by the GCM model is unreliable, which is often the case. Other downscaling approaches use GCM variables which represent features of the large-scale circulation to estimate point or local scale rainfall, which tend to be more reliable than the precipitation values simulated.

In this chapter, one HadCM3 grid box is used to investigate the temporal variability at points within the grid box, using the relationships developed and tested in earlier chapters. The convective and synoptic precipitation amounts simulated by HadRM3H are used to identify a suitable ‘analogue’ region from which observed station data is used to determine correlation statistics that might apply to the UK in the future. The implications of any changes in correlation that are proposed, for changes in temporal variability at individual points, are then investigated. The methods used for the selection of analogue regions, and the estimation of the characteristics of point rainfall are described in **Section 7.2,** and the results presented and discussed in **Section 7.3.** The chapter is summarised in **Section 7.4.**

7.2. Method

In Chapter 6, the proportions of convective rainfall in simulations of current (1961-90) and possible future (2070-2100) climate are examined and shown to increase over most of Europe, particularly in summer, in regional climate model simulations of climate under the SRES A2 scenario. In this approach, the fraction of total rainfall that is, according to the model, attributable to convective or synoptic processes is used as a proxy for estimating the degree of spatial variability.

Several inherent assumptions are made in taking this approach.

- Firstly, it is assumed that the model reproduces the synoptic/convective splits or total rainfall realistically. This cannot easily be tested against observed data because observed rainfall cannot be divided simply into that which is convective and synoptic, in the same way that model data can (this is discussed in further detail in Section 7.5.3).

- Secondly, it is assumed that the proportion of synoptic or convective rainfall is a major factor in determining the spatial correlation of rainfall in a region. This is unlikely to be the case in high elevation regions, and so these areas will be avoided in the selection of a suitable analogue.

- Thirdly, this approach ignores the possibility that the spatial characteristics of either convective or synoptic rainfall might change, assuming instead that any change in spatial variability occurs entirely due to a change in the relative proportions of each rainfall type.

It should be noted here, that this approach is intended to be exploratory and not predictive. The intention of this study is to make a feasible estimate of how spatial correlation *might* change in the future, if the other changes to the climate that are simulated by the GCM were to occur, and to assess the implications of such a change on the temporal variability at points within a grid box. This will help to determine the relative importance of changes in the spatial variability of precipitation for the future.

7.2.1. Selection of an Analogue Region

The convective fractions of total rainfall in current and future climate simulations, for a single UK grid box, are listed in Table 7-1. The greatest change appears to be in the summer, with HadRM3H simulations suggesting in increase in convective fraction from 0.62 to 0.7 by 2070-2100.

	MAM	**JJA**	**SON**	**DJF**
1961-1990	0.386	0.618	0.247	0.125
2070-2100	0.380	0.727	0.321	0.145
Change	-0.006	+0.109	+0.074	+0.020

Table 7-1: Convective fraction of total rainfall in HadCM3 'South east UK' grid box, simulated by HadRM3H under scenario A2.

Figure 7-1 shows all regions of Europe, for which the model simulates a similar (+/-5%) convective fraction in 1961-90 as simulated for the UK 'South East' grid box in 2070-2100, for the summer (0.727 +/- 0.035). The suitable regions occur in a band which extends across Europe, and becomes slightly more northern as it extends eastward.

In order to reduce the likelihood that other climatic or geographical influences will have a substantial effect on the spatial variability of a chosen analogue region's rainfall, it is necessary to select a region that not only matches the appropriate convective fraction of simulated rainfall, but also has similar physical characteristics to the South East of England. In particular, a region of similar topography is required in order to limit the influence of elevation on the spatial variability of its climate.

For these reasons, the region highlighted in Figure 7-1, a grid box of the same dimensions as the HadCM3 boxes, covering The Netherlands and part of Western Germany is selected.
A further test of the robustness of this estimate of spatial correlation might to be to look at the consistency of the spatial correlation across this whole 'band' which the model suggests has the appropriate convective/synoptic split and assess whether this is similar across a region with a similar convective fraction.

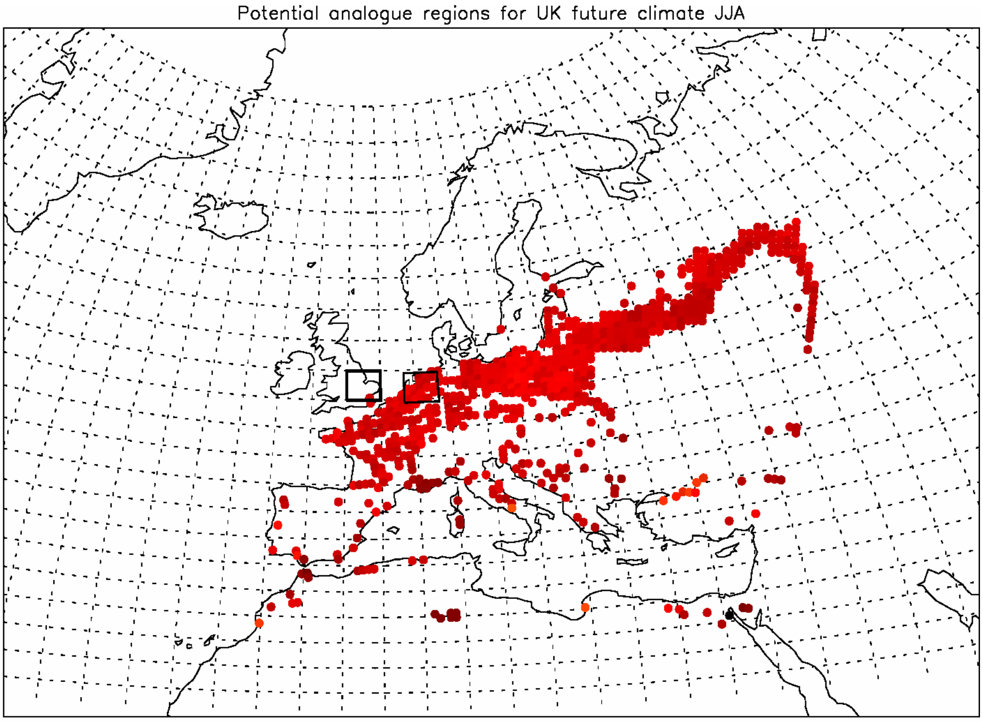

Figure 7-1: Potential analogue areas with present day convective fraction between 0.692 and 0.762. the UK grid box and the selected grid box are highlighted.

7.2.2. Calculation of Spatial Correlation over the Analogue Region

Daily precipitation observations form the Netherlands (15 stations), Germany (20 stations) and Belgium (1 station) provided a dataset from which to calculate correlation statistics for the analogue region. The locations of these stations are shown in Figure 7-2. The stations from The Netherlands come from KNMI Climatological Services [1], whilst those for Germany and Belgium come from the European Climate Assessment (ECA) data archives[2].

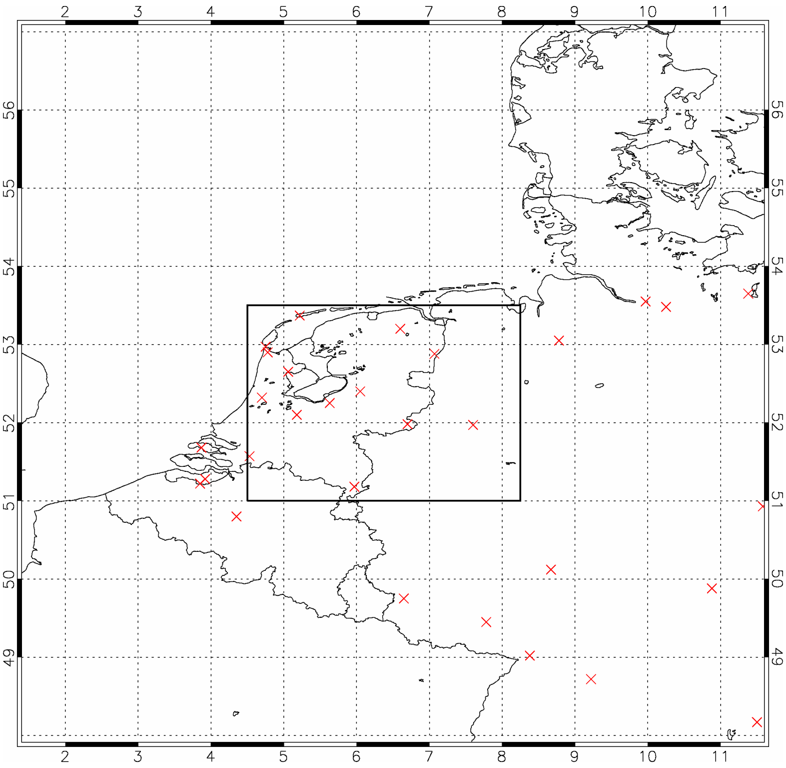

Figure 7-2: Station locations for analogue region, the Netherlands, Germany and Belgium.

All 36 stations were used to fit correlation decay curves to those 12 stations that lie within the chosen analogue region grid box, for the correlation parameters *r*, *r(wet)* and *r(w/d)*, where *r(wet)*

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[1] Available at: http://www.knmi.nl/klimatologie/daggegevens/nsl-download.cgi?language=eng

[2] Available at: http://eca.knmi.nl/dailydata/datadictionary.php

is the correlation between wet-day amounts only and *r(w/d)* is the correlation between wet and dry day occurrences, ignoring wet-day values (see sections 4.3.1 and 3.4.3, respectively, for further details of these statistics). Mean inter-station 'correlation' values for each of *r, r(wet) and r(w/d)* over the grid box are calculated using the same approach as has been applied in previous chapters:

1.) the parameters of the decay curves fitted to the data for each of the 12 stations within the box are averaged to give a grid-box decay curve
2.) 10000 pairs of points within the grid box are selected randomly to give a distribution of separation points
3.) the corresponding 'correlation' values for each separation distance, estimated form the grid-box decay curve) are averaged to give an estimate of the mean inter-station 'correlation'.

The resulting values are given in Table 7-2, and are compared with those obtained earlier for the UK grid box. The correlation values in the Netherlands region are, as expected, lower than in the UK by 0.04-0.06, and these values therefore become the estimated spatial correlation values for the UK grid box in 2070-2100.

	UK (*r*-UK)	**NETHERLANDS (*r*-NL)**
r	0.40	0.36
r(wet)	0.29	0.23
r(w/d)	0.49	0.43

Table 7-2: Average grid-box correlation statistics for grid boxes in UK and the Netherlands.

7.2.3. Estimation of Point-scale Daily Precipitation Characteristics using Estimates of Changes in Spatial Correlation for the Future

The estimated values of spatial correlation that might apply to future climate can be used to reverse the relationships, which are demonstrated in earlier chapters to reliably estimate 'true' areal precipitation characteristics from available station data, to now estimate characteristics of station data from the GCM simulated area-scale (i.e. grid-box) precipitation. This can be described as a method of 'downscaling' from areal-scale GCM projections to determine point scale rainfall characteristics.

The relationships used in previous chapters to estimate areal dry-day probability, $P(d)_N$, and gamma scale parameter, β_N, become as below, when reversed to estimate point values.

$$P(d)_N = [\overline{P(d)_{i,n}}]^{N'}$$

Equation 7-1

becomes

$$\overline{P(d)_{i,n}} = [P(d)_N]^{1/N'},$$

Equation 7-2

where N′ is the effective number of independent stations, *1/r(w/d),* when N is infinity and

$$\beta_N = \overline{\beta_{i,n}}\left[a(N')^b + (1-a)\right]$$

Equation 7-3

becomes

$$\overline{\beta_{i,n}} = \frac{\beta_N}{a(N')^b + (1-a)}$$

Equation 7-4

where N′ is the effective number of independent stations, *1/r(wet)),* when N is infinity.

7.3. Results

The parameters of daily precipitation from simulations of current (1961-90) and future (2070-2099) climate are listed in Table 7-3 as areal and point values, and are plotted as distributions in Figure 7-3. The percentage change factors from present to future climate, for precipitation at grid-box and point scale are listed in Table 7-4.

First, compare the distribution of rainfall values for the future at areal and point scales, estimated when existing spatial correlation parameters are used in the downscaling process (*r*-UK, i.e. no change in the spatial correlation of precipitation). The percentage changes highlight some important differences in the predicted changes of areal and point values. A 20% reduction in mean daily rainfall is accompanied by increases in dry-day probability by 36% (areal) and 16% (point). Mean wet-day amount shows differences in both direction and magnitude of change depending on which spatial scale is studied. The areal average mean wet-day amount for the grid box shows a *decrease* of 4% under the climate change scenario, but *increases* by 2% at point scale. Osborn (1997) observed that even the direction of change in mean intensity (or mean wet-day amount) can differ at points within a grid box if the mean spatial extent of events is altered, but the results shown here demonstrate that this can occur even if a change in the spatial characteristics of rainfall is not applied.

	1961-1990			2070-2099		
	GCM Grid Box	Station observations	GCM downscaled to point scale using *r*-UK values	GCM Grid Box	GCM downscaled to point scale using *r*-UK values	GCM downscaled to point scale using *r*-NL values
Mean daily rainfall *(mm d^{-1})*	2.63	1.76	2.63	2.08	2.08	2.08
Dry-day probability	0.33	0.63	0.58	0.45	0.67	0.71
Mean wet-day amount (mean daily Intensity) *(mm d^{-1})*	3.93	4.76	6.26	3.76	6.37	7.10
Gamma shape (α)	1.00	0.67	1.03	0.77	0.62	0.62
Gamma scale (β) *(mm d^{-1})*	3.64	6.72	6.09	4.50	10.29	11.56
P(95) of wet days *(mm d^{-1})*	11.27	17.01	18.77	12.51	22.11	24.86

Table 7-3: Parameters of daily rainfall for the south-east UK simulated using HadCM3, at areal (grid-box) spatial scale and modified to represent the point spatial scale.

	Areal	**Point (*r*-UK)**	**Point (*r*-NL)**
Mean daily rainfall *(mm d^{-1})*	-20%	-20%	-20%
Dry-day probability	+36%	+16%	+22%
Mean Intensity *(mm d^{-1})*	-4%	+2%	+13%
P(95) *(mm d^{-1})*	+11%	+19%	+33%

Table 7-4: Change factors in parameters of daily rainfall simulated for south-east UK by HadCM3 at areal (grid-box) spatial scale and modified to represent the point spatial scale.

The disproportionate nature of the change factors between areal and point scale (Table 7-3) is particularly distinct in the threshold values of the 95th percentile of wet-day amounts. These values increased by 11 % in areal, but by 19% at point scale. These percentile values should be compared with caution, because whilst they represent the changes in the tails of the distribution of wet day amounts, the probabilities of these events occurring over all days differ when changing wet-day probability is taken into account. Nonetheless, this comparison does highlight both the proportionately large changes in the more extremes of the distribution, and the proportionally larger change factors that apply to the extremes when looking at the point scale rather than a grid-box average.

These results highlight the important differences between the proportion of change at different spatial scales, and demonstrate that factors of change that are determined directly from grid-box data are not necessarily appropriate at smaller spatial scales. Studies which might apply percentage change factors in parameters of rainfall variability, such as mean intensity, dry-or-wet-day frequency or percentile values; that are determined at grid-box scale should therefore be interpreted with caution. An example of the implications of this difference in magnitude and/or direction of change factors in these parameters can be illustrated by examining a study by Kiktev *et al.* (2003). Kiktev *et al.* (2003) attempted to assess how well the atmospheric model HadAM3 reproduced the trends in climate extremes that were found in observed climate data over the period 1950-1995. The indices used were a subset from Frich *et al.* (2002) and included the simple daily intensity index (equivalent to the mean wet-day amount, where a wet day >1mm), number of consecutive dry-days in a year, maximum 5-day precipitation totals, and number of days per year with greater than 10mm. The indices of extremes for the observed data were gridded to allow comparison with model data, but as the indices were calculated for each station *before* they were gridded, these values represent the daily variability of *point* rainfall and not the areal average. The study found that whilst significant decreases in consecutive dry-days, and increases in wet-days greater than 10mm and increases in the simple intensity index were found in the observed station data, no such signal was found in the HadAM3 simulations. Given the findings presented in Table 7-3 and Table 7-4, it may not be surprising that corresponding trends are not seen in the point observations and the areal model simulations.

Secondly, we investigate how the parameters of point values are changed for the future when an estimate of a change in spatial variability is included. The distributions of daily values at point scale are shown compared to those of the grid-average are shown in Figure 7-3 (left). The differences between these distributions are subtle; the shape parameters of the distributions are identical, but the scale parameter is slightly larger when a change in spatial variability is included in the downscaling process, reflecting a slightly higher level of variability (Table 7-3). The effect of this difference on the extremes of the distribution is clearer when the distribution is plotted with a logarithmic y-axis (Figure 7-3, right); the increased magnitude of the extremes at the point compared with the areal scale is evident.

When, however, the factors of change in Table 7-4 are considered, the implications of considering a change in spatial variability when downscaling the model simulations become clear. Dry-day probability increases to 0.71 instead of the 0.67 change that results from using existing spatial variability values. This translates to an increase of 22% rather than by 16%. The reduction in wet-days over which the grid-box rainfall is distributed results in a more pronounced increase in mean intensity (7.10 mm d^{-1} rather than 6.37 mm d^{-1}), an increase of 13% rather than 2%.

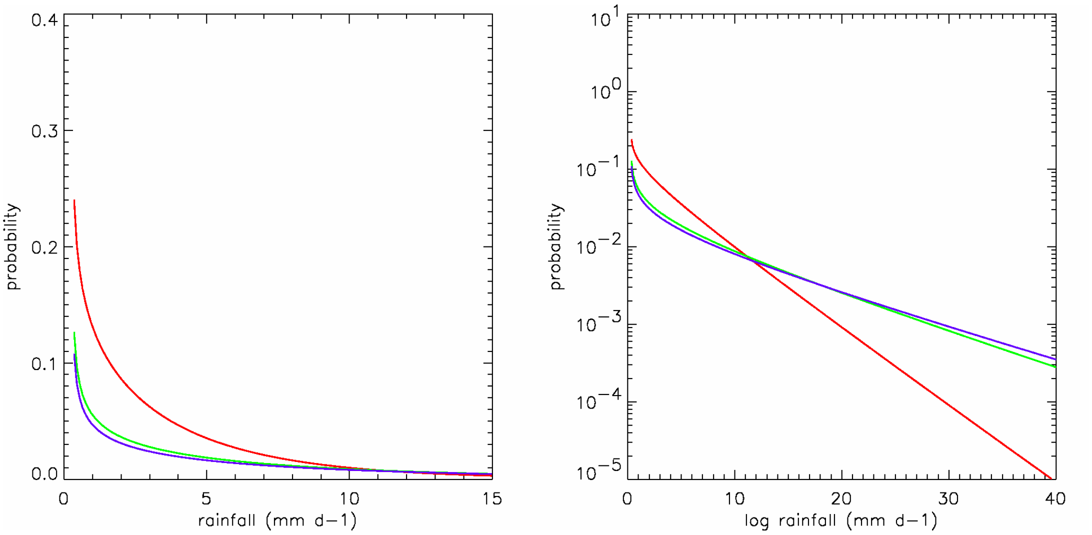

Figure 7-3: Distribution of wet-day amounts, taking into account wet-day frequency, at grid-box scale (red) and point scale based on present-day spatial variability (green) and an estimate of possible future spatial variability (purple). Right hand plot is the same but with uses a logarithmic y-axis.

The factors of change in the extreme values (95th percentile) demonstrate that the extremes are disproportionately affected by the change in spatial variability. The point-scale 95th percentile value of 22.11 mm becomes 24.86 when spatial variability is considered, an increase of 32% rather than 19%, and compared to 11% when only the grid-box values are compared.

The distinct differences between those changes at point scale when an estimate of future spatial variability is applied demonstrate the importance of taking account of a potential change in the spatial properties of rainfall in downscaling studies. The relatively small reductions in the correlation values from 0.29 and 0.49 to 0.23 to 0.43 (for *r(w/d)* and *r(wet),* respectively) have manifested substantial alterations to the parameters of the daily rainfall at points within the grid box, particularly in the mean intensity and extremes of the distribution.

Whilst the correlation values used here, using rainfall data from the Netherlands as an analogue, are not a prediction of the changes that are *expected* to occur in the future, they represent a feasible, hypothetical change in spatial variability that might accompany the shift towards a higher proportion of convective rainfall which is seen in model simulated rainfall. The changes which result from this estimated change in spatial variability serve to highlight the need for further investigation of likely changes in spatial variability of rainfall in order to give accurate estimates of temporal variability in point or local scale rainfall.

The use of these statistical relationships to downscale (i.e. to disaggregate from grid-box to point scale) parameters of daily rainfall variability is likely to have several useful applications. Whilst this approach does not, as other downscaling approaches do, give rainfall time series at point or local scale, it does provide a simple approach to estimating the level of variability expected at point scale which may be usefully applied to weather generator experiments which sample daily values from a pre-determined distribution.

7.4. Summary

The ‘downscaling’ of parameters of daily rainfall variability from one HadCM3 grid box over South-East England, using statistical relationships between point and areal rainfall and sub-grid-scale spatial variability in the previous chapters of this thesis, has demonstrated that:

- The percentage change factors of temporal variability in daily rainfall at grid-box and point spatial scales can differ significantly in magnitude, and even in direction. It is therefore inappropriate to apply a variability change factor, such as mean intensity, wet/dry day frequency, or extreme values that is based on a grid-box average to rainfall at local (e.g. a small river catchment) or point scale.

- Relatively small changes to the level of spatial variability within a grid box can have a further effect on the level of temporal variability at points within that grid box. It is important, therefore, to take into account a possible change in spatial variability when comparing or converting between point and areal variability parameters.

- Further investigation and quantification of the likely changes in spatial variability are required, therefore, in order to make more reliable estimates/projections of temporal rainfall variability at sub-grid-scale resolution.