Chapter 8

Conclusions and Recommendations for Further Work

Contents

8.1. Summary and Main Conclusions

Following the review of literature (Chapter 2), two main research objectives for this thesis were identified.

1) 'The development of robust approaches for estimating characteristics of the variability of areal rainfall where only a few stations are available, and are suitable for application to climate model evaluation.'

2) 'To investigate further the suggestion that future rainfall might be more convective in nature, whether this might cause a significant change in the spatial correlation of daily rainfall and hence whether this will affect the validity of point/areal scaling relationships for rainfall variability and extremes in the future.'

We now refer back to these objectives, summarising the methods used to approach them and the main points of conclusion that can be drawn from the research.

8.1.1. Developments and Findings Relating to Research Objective 1

New techniques for estimating the dry-day probability and parameters of the gamma distribution for areal mean rainfall have been proposed, tested and demonstrated. These techniques have been applied to the evaluation of climate model simulations of daily rainfall from three GCMs and have demonstrated clear advantages over using simple station averages, particularly where the network of station observations is sparse.

- The new techniques are based on the approaches employed by Osborn and Hulme (1997), using measures of spatial dependence between the available stations to estimate the characteristics of a 'true' areal mean.
- When tested for precipitation from the UK, Zimbabwe and China, the estimates performed well for all regions, indicating that they are likely to be robust when applied to a range of climatic regimes. The estimates of the gamma distribution parameters were found to be unreliable only when applied to very dry regions, where mean daily rainfall is less than 0.3mm, and therefore is very little rainfall to model.
- The uncertainty margins on those estimates were estimated empirically, as 95% confidence limits (magnitudes given in Table 8-1). The reliability of the estimates depends partly on the number of available stations on which they are based. An indication of the magnitude of this additional uncertainty (based on investigation of one grid box) is also given in Table 8-1. Whilst the uncertainty associated with the estimates is largest where fewest stations are available, these regions are also those for which the techniques yield the greatest benefit.
- Evaluations of the daily precipitation simulated by HadCM3, CGCM3 and PCM for the UK and South Africa were made. The new techniques allowed quantitative estimates of the models ability to simulate rainfall with realistic dry-day probability, mean wet-day amount, parameters of the gamma distribution and values of the 95th percentile of wet-day amounts, as well as mean daily rainfall, at their spatial scale.

	Dry-day Probability	Gamma Scale Parameter *(mm^d-1)*	Gamma Shape Parameter
95% confidence intervals	+0.1, -0.03	+0.74, -0.64	+0.18,-0.09
***Additional uncertainty when* based on <10 stations**	+/-0.06	+/0.6	+/-0.12
***Additional uncertainty* when based on 10-30 stations**	+/-0.03	+/-0.3	+/-0.06

Table 8-1: Estimated uncertainty margins for estimates of dry-day probability and the gamma distribution parameters for wet-day amounts for 'true' areal mean rainfall.

8.1.2. Developments and Findings Relating to Research Objective 2

The investigation of precipitation simulated by a Regional Climate Model for the future suggests that whilst there is evidence to support a shift towards a greater proportion of convective rainfall under a warmer climate, there is no evidence from the same model simulations to suggest that a decrease in spatial correlation might accompany that shift.

- HadRM3H simulations under SRES scenario A2 suggest a shift towards a greater proportion of convective rainfall, due to different relative changes that affect convective and synoptic rainfall amounts.
- The convective rainfall field simulated by HadRM3H actually show greater spatial coherency than the synoptic rainfall fields. This opposes what might be expected given that convective rainfall, by nature tends to be more localised than synoptic rainfall. This means that, according to the model, the shift towards a greater fraction of convective rainfall in the simulations results in an overall *increase* in spatial correlation in the future.
- It is unclear, however, whether the spatial characteristics in synoptic and convective rainfall are realistic, or are unrealistic and arise due to the limited resolution of the model. This would be problematic to test against observed rainfall due to the difficulty in separating convective and synoptic rainfall fields in observed rainfall. This part of the study is therefore considered inconclusive.

The use of an analogue approach to estimate a future reduction in spatial correlation that might be associated with a shift towards a higher proportion of convective rainfall demonstrates how important the changes in spatial correlation are in the estimation of point rainfall variability in the future. Failure to take into account decreases in spatial correlation may lead to the underestimation of the expected variability and extremes that might be experienced at points within a grid-box.

- The selected analogue region, The Netherlands, experiences a similar proportion of convective rainfall in its recent climate as is projected for the UK south-east grid box in 2070-2100 under SRES scenario A2. Station observations from the region demonstrate a lower level of spatial correlation in its rainfall.
- The relationships that link point and areal rainfall via measures of spatial dependency that were developed in this thesis were applied to the simulations of future rainfall for the UK to estimate the daily variability of rainfall at points within the south-east grid box. The values of spatial correlation that are observed for rainfall in the UK south-east in summer, and the possible future levels of spatial correlation determined using this spatial analogue, are both applied.
- Even when spatial correlation is unchanged, the percentage changes in dry-day probability, mean-wet day amount (mean daily intensity), the parameters of the gamma distribution and the 95th percentile values of wet-day amounts change by different factors depending on whether the areal or estimated point values are considered. For the mean intensity, even the direction of change differs.
- Relatively small changes to the level of spatial variability within a grid box are demonstrated to 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.

8.2. Recommendations for Further Work

The research that has been undertaken for this thesis has highlighted a number of topics on which further research would be beneficial.

Several areas where information is lacking were highlighted in the literature review. Whilst some of these were addressed by the research in this thesis, others remain. In particular, there is a lack of observational studies of any changes in the spatial characteristics of rainfall, or convective activity, that might have occurred in recent decades due to the warming that has already been experienced. Future studies might, for example, look for trends in the spatial correlation of rainfall over recent decades.

There are a number of additional areas for further research that have been highlighted by the studies undertaken for this thesis. These include the further investigation of the spatial characteristics of model-simulated rainfall. How realistic are those spatial characteristics, and do the mechanisms which generate rainfall in climate models determine the spatial characteristics of that rainfall? Does increased spatial resolution of climate models improve the representation of the spatial characteristics of rainfall? This would help to confirm, and possibly to quantify the magnitude of, any changes in spatial correlation which might result from increases in the proportion of convective rainfall. The degree to which the proportion of convective rainfall determines the spatial coherency of rainfall might also be investigated, and might give an indication of how realistic the spatial characteristics estimated using the analogue technique used here may be.

There are also several areas for further development, and applications for, the work undertaken in this thesis. The techniques developed for estimating the dry-day probability and gamma distribution parameters for wet-day amounts of areal precipitation have been applied to model evaluation for only two small regions in this study, but could be usefully applied in a global assessment of model performance in an inter-model comparison, similar to those by Sun *et al.* (2006) and Dai *et al.* (2006). This would give a better impression of overall model performance, and allow comparison between the results of these inter-model comparison when the different techniques are used.

The levels of uncertainty associated with the estimation methods might be further investigated using additional data from other regions of the world. In particular, the additional uncertainty that arises when estimates are based on a small number of stations would benefit additional investigation in order to determine how much these uncertainty bounds might vary for different regions, seasons and climatic regimes.

This study has investigated the implications of a change in spatial correlation for the temporal variability experienced at points within a grid-box in projected future climate. This has demonstrated the importance of considering changes in spatial correlation in studies where the point variability of rainfall is important. Similar approaches might be taken when multi-site downscaling models are used, particularly where the resulting projections are used for hydrological impact studies such as flood estimation. The effects of projected, estimated or hypothetical changes in spatial variability, as well as temporal variability, on the hydrological impacts of climate change (e.g. flood frequency) may be significant.

The analogue approach used here to estimate the spatial characteristics of projected future rainfall might be usefully applied to other regions and seasons for use in other studies. Some indication of how reliable or realistic the estimates of spatial correlation in future rainfall using this approach might be could be gained by choosing more than one suitable analogue, and comparing the difference in spatial correlation between them.