Daily Rainfall Variability at Point and Areal Scales: Evaluating Simulations of Present and Future Climate

Carol Frances McSweeney

A thesis submitted for the degree of Doctor of Philosophy at the University of East Anglia, Norwich.

April 2007

Climatic Research Unit
School of Environmental Sciences
University of East Anglia
Norwich NR4 7TJ

Abstract

The daily variability in point observations of rainfall is not comparable to that found in grid-box average rainfall simulated by climate models due to the temporal smoothing effect of spatial averaging. This creates problems for (a) the comparisons of rainfall observations to climate model simulations that are necessary for the quantitative evaluation of daily variability in model-simulated rainfall, and (b) the application of climate model simulations at spatial scales that are smaller than the grid resolution, for climate impact assessment.

This thesis describes the development of statistical relationships between the characteristics of point and areal daily rainfall variability using measures of spatial correlation. These relationships allow estimates of 'true' areal average precipitation to be made, using a limited number of available stations, with an assessment of the uncertainty surrounding those estimates. Relationships are developed between the dry-day probabilities of point and areal-mean rainfall, and for the parameters of the gamma distribution of wet-day amounts for point and areal rainfall, using daily station data from the UK, Zimbabwe and China.

The application of these relationships to climate model evaluation is demonstrated using three General Circulation Models (HadCM3, CGCM3 and PCM). Estimates are made of 'true' grid-box average values of dry-day probability, mean wet-day amount (mean daily intensity), the gamma distribution parameters for wet-day amounts and the 95th percentile values of wet-day amounts for grid boxes from the three GCMs over the UK and South Africa.

The relationships can also be used to make estimates of the daily variability in point rainfall from an areal average series simulated by a climate model if the values of spatial variability are known. For future climate, it may not be valid to assume that spatial correlation will be stationary, because there is evidence that suggests that rainfall in a warmer climate may become more convective, and thus potentially become more localised. Investigation using rainfall simulations for Europe from the Regional Climate Model (RCM) HadRM3H found that these simulations do indicate a shift towards a greater proportion of convective rainfall in future climate (2070-2100) under SRES scenario A2. Investigation of the level of spatial correlation between RCM grid boxes, however, indicated an increase in sub-GCM-grid-scale spatial correlation, rather than the

decrease that might be expected. An alteration to the spatial correlation of rainfall under warmer conditions cannot be ruled out, however, because the model's spatial resolution might limit its ability to represent the spatial characteristics of convective rainfall realistically.

A spatial analogue approach is used to make an estimate of the spatial correlation that might be experienced under future climate. A region is selected (The Netherlands) that, according to the RCM simulations, experiences a similar proportion of convective rainfall in its recent climate as is projected for the south-east UK in summer in 2070-2100 under SRES scenario A2. The values of spatial correlation for stations from this region are used as an estimate of the future levels of spatial correlation that might accompany the changed proportion of convective rainfall for the south-east UK. Observed UK spatial correlation values, and the possible future values estimated via this spatial analogue are both applied to the summer GCM grid-box precipitation simulated for this future period to estimate the characteristics of rainfall at points within that grid box. Even when spatial correlation is unchanged in future climate, the 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. Applying the changes in spatial correlation causes the magnitude of the changes to be greater still, demonstrating that failure to take into account potential decreases in spatial correlation (even if those decreases are relatively small) when downscaling or disaggregating from grid-box projections could lead to an under-estimation of the temporal variability at points within the grid box.

Acknowledgements

There are many people to be thanked who have contributed to this thesis through their assistance, expertise, provision of data and funding, support and helping to preserve my sanity.

For funding, I thank the Natural Environmental Research Council (NERC), and also the Centre for Ecology and Hydrology, Wallingford, (CEH). The data I have used comes from a number of sources; The British Atmospheric Data Centre (UK station data), Zimbabwean Meteorological Service (Zimbabwean station data), Oak Ridge National Laboratory in the United States (Chinese station data), The South African Weather Bureau (South African station data, via David Foxall), RCM data made available by the PRUDENCE Project at the Danish Meteorological Institute, and GCM data made available by the Program for Climate Model Diagnosis and Inter-comparison for the IPCC.

I am very grateful to my supervisory committee Tim Osborn, Phil Jones, Nick Reynard and Kevin Hiscock for their guidance and support. Thanks go to Tim particularly who, as my primary supervisor, has guided me through every stage of my PhD research with great expertise, patience and good humour.

I'd also like to thank everyone in CRU for their help, encouragement and friendship which have made working in the unit so enjoyable. Particular thanks go to Marie Ekström for her help and advice, and also to Mike Salmon for providing top-rate IT support.

The last few months spent finishing my thesis have been made considerably easier thanks to the flexibility that my new employer, Mark New, has allowed me in my work for Oxford University. I am very grateful to Mark for his support and generosity in this.

Finally, thanks go to all the people who have provided the encouragement, reassurance and much needed distractions; Fellow PhD students who have helped me to consume the vast majority of Columbia's coffee exports over the last three-and-a-half years: Kate, Oli, Jade, Matt, Charlotte, Sian and David; former CRU PhD students Mark, Stephen and Craig; My family; and Paul.

Contents

List of Tables and Figures

Chapter 1

Chapter 2

Chapter 3

Chapter 4

Chapter 5

Chapter 6

Chapter 7

Chapter 8