6. DEVELOPMENT OF A NEW CONDITIONAL WEATHER GENERATOR

6.1 INTRODUCTION

In the previous chapter, it was shown that the new circulation-typing scheme gives circulation types for the Guadalentin and Agri study areas which have characteristic and physically distinct underlying synoptic patterns and that the typing scheme is also discriminating in terms of the rainfall characteristics associated with each type. It was also shown that the HadCM2SUL GCM has some success in reproducing the observed circulation types, although systematic errors still occur. In this chapter, a conditional weather generator is used to translate the changes in circulation-type frequency predicted by HadCM2SUL into changes in daily rainfall and thus to construct daily rainfall scenarios for 1970-1979, 2030-2039 and 2090-2099.

First, however, the original conditional weather generator used in Chapter 3 is modified to provide a new conditional weather generator in which the occurrence of rainfall is dependent on the circulation type and on whether the previous day was wet or dry, and the amount of rainfall on a wet day is dependent on the circulation type. The reasons for modifying the original weather generator and the characteristics of the new model are described in Section 6.1.1.

For the purposes of the original conditional weather generator (CWG) sensitivity experiments described in Chapter 3, only the number of rain days was simulated. In the new conditional weather generator (NCWG) simulations, rainfall amount is also simulated. Thus two sets of rainfall parameters are required for each station and each season. The first set is made up of rainfall probabilities, which describe the rainfall occurrence process depending on the circulation type and on whether the previous day was wet or dry. Then, a gamma distribution is used to describe the distribution of daily rainfall. Thus the second set of parameters consists of shape and scale parameters for the gamma distribution. The estimation of parameters for the NCWG is described in Section 6.2.

Two groups of simulations were performed with the NCWG in order to, first, evaluate model performance and, second, to construct climate-change scenarios. The rationale for these two groups of simulations is described in Section 6.1.2, together with their main characteristics.

6.1.1 Characteristics of the new conditional weather generator

In the original CWG applied to UKTR model output in Chapter 3, the probability of rain is dependent only on the circulation type of each day. The persistence of wet and dry day spells was underestimated by the CWG. In subsequent analyses, therefore, it was decided to make the occurrence of precipitation conditional both on the circulation type of each day, and on whether the previous day was wet or dry, in an attempt to increase persistence (see Section 4.4).

In the CWG simulations in Chapter 3, the transition from one circulation type to another was modelled as a first-order Markov Chain process (conditional on the circulation type of the previous day), giving a different daily sequence of circulation types for each of the 100 30-year sequences making up each simulation set. This approach was used, rather than taking the circulation-type sequences directly from the UKTR model, in order to introduce a greater probabilistic element to scenario construction and to provide longer time series (only 10 years of GCM data were available from the perturbed run). It was, however, concluded that, since the circulation–type sequences from the CWG simply reflect the errors in the underlying GCM, modelling the circulation types as a Markov Chain process has little benefit and, moreover, complicates interpretation of the results (see Section 4.4). In subsequent analyses, therefore, it was decided to take the daily succession of circulation types directly from the GCM. This has the substantial advantage of making it much easier to construct self-consistent scenarios for multiple stations and/or climate variables. In order to further increase the stochastic element of the simulations, it was also decided to increase the number of runs in each simulation set from 100 to 1000 (see Section 4.4).

Analysing the output for several stations when each simulation set consists of 1000 runs would be very time consuming. It was, therefore, decided to perform weather generator simulations for a single baseline station in each region. Methods by which the baseline scenarios can be used to construct scenarios which are consistent throughout a group of stations in the region, or for other variables such as daily maximum/minimum temperature, are discussed in Chapter 7. Alcantarilla (Figure 3.1) was selected as the baseline station in the Guadalentin because it has more rain days per year than the other stations (Table 3.1), thus providing the largest possible, although still relatively small, sample sizes for parameter estimation. Missanello was selected for the Agri because it is centrally located in the basin (Figure 5.3) and has a long record (Table 5.1) with very few missing values. It is advantageous to use a centrally-located station for the Agri because stations at the western and eastern ends of the basin tend to have somewhat different circulation-type/rainfall relationships (see Section 5.5.2).

6.1.2 The new conditional weather generator simulations and terminology

Ideally, empirical model parameters should be calculated using a sub-set of the observed data (the calibration period), leaving the remainder for independent validation. Conventionally, the observed data are divided into two, giving calibration and validation periods of equal length. In this study, however, the relatively infrequent occurrence of rainfall, particularly in the Guadalentin, means that sample sizes would be too small if the data were partitioned by calibration/validation period, season and circulation type. Thus, in order to evaluate model performance, a cross-validation approach was adopted, in which all the available observed data except that for the year being simulated are used to calculate the rainfall occurrence and amount parameters. The retained year is used for validation. The group of simulations employing this approach is referred to as the CV (cross-validation) group. Two sets of CV simulation runs (each consisting of 1000 runs) were performed for Alcantarilla and Missanello (see Table 6.1).

In the first set of CV simulations (referred to as CVOBS), daily circulation-type sequences were taken from the observations, while the second set (referred to as CVHAD) use circulation-type sequences derived from HadCM2 output. In both sets of simulations, all the available observed data (except that for the year being simulated) are used to calculate the rainfall occurrence and amount parameters (i.e. 1958-1987 for Alcantarilla and 1956-1988 for Missanello) and observed or simulated circulation-type sequences for the same periods are used. Thus simulated time series of 30 and 33 years were produced for Alcantarilla and Missanello respectively. The cross-validation group of simulations is described in Section 6.3.

While the first group of NCWG simulations (the cross-validation group) was designed to evaluate model performance, the second group (the scenario group) was designed for the construction of daily rainfall scenarios. Thus this group of runs takes the daily circulation-type sequences from HadCM2SUL output for 1970-1979, 2030-2039 and 2090-2099 (these runs are referred to as HAD1970, HAD2030 and HAD2090 respectively; see Table 6.1). Validation is not possible for future time periods, so in this group of simulations the rainfall occurrence and amount parameters are calculated using all the available observed data in order to maximise sample size (i.e. 1958-1987 for Alcantarilla and 1956-1988 for Missanello). In order to determine whether any errors identified in the cross-validation runs are also evident in the scenario runs, a fourth simulation set was completed in which the circulation-type sequences were taken from the observed data for 1970-1979 (referred to as OBS1970; see Table 6.1). Each simulation set in the scenario group consists of 1000 runs, each of 10 years length. The scenario runs are described in Section 6.4 and the scenarios are evaluated in Section 6.5.

The NCWG results described in Sections 6.3 and 6.4 are analysed by season, focusing initially on the number of rain days (NRD) and rainfall amount (AMT). A number of abbreviations are used in the text and tables for the diagnostic statistics used to summarise the model output (see Table 6.1b). Mean values calculated over each of the 1000 runs making up each simulation set (i.e. the means of 30, 33 or 10 seasonal values) are referred to as NRD_m (mean number of rain days per season) or AMT_m (mean rainfall amount per season). Mean values calculated over a simulation set (i.e. the means of 1000 values) are referred to as $\overline{NRD}_m$ or $\overline{AMT}_m$. Year-to-year standard deviations are indicated by the subscript $_{sd}$ rather than $_m$. Other diagnostic statistics relate to the persistence of wet and dry spells and the occurrence of extreme events. The length in days of the longest wet and longest dry spells is referred to as LW and LD respectively (with $\overline{LW}$ and $\overline{LD}$ being the mean calculated over a simulation set). Annual daily rainfall maxima with return periods of 5, 10, 20 and 50 years, referred to as T5, T10, T20 and T50, were also calculated.

6.2 PARAMETER ESTIMATION

6.2.1 Introduction

For the scenario runs discussed in Section 6.4, the NCWG parameters were calculated using all available days during the common data periods (1958-1987 for Alcantarilla and 1956-1988 for Missanello) for which both precipitation and SLP data were available. It was decided to use all the available data in order to maximise the sample size (see Section 6.1.2). This was considered particularly important because the data had to be partitioned by circulation type and according to whether the day was wet or dry. The rainfall occurrence parameters are discussed in Section 6.2.2, while the rainfall amount parameters are discussed in Section 6.2.3. The parameters used in the cross-validation runs are discussed in Section 6.3.4., focusing on their variability and how they compare with the parameters described in the next two sections.

6.2.2 Rainfall occurrence parameters

The first set of parameters required by the NCWG are the rainfall probabilities, calculated for each circulation type, i.e. the probability of a wet day following a wet day (P_{ww}) and of a dry day following a wet day (P_{wd}); and the probability of a wet day following a dry day (P_{dw}) or a dry day following a dry day (P_{dd}). However, because some of the circulation types were found to have both similar underlying pressure patterns (Section 5.4) and similar rainfall characteristics (Section 5.5), it was decided to combine some of the circulation types before calculating the parameters. This had the additional advantage of increasing the sample sizes.

The following types were found to have similar pressure patterns and rainfall characteristics in the Guadalentin (see Sections 5.4.2 and 5.5.1):

- C and HYC;
- A and HYA;
- E and SE;
- S and SW; and,
- W and NW.

For the Agri, the following types were found to have similar circulation and rainfall characteristics (see Sections 5.4.3 and 5.5.2):

- C and HYC;
- A and HYA;
- E and SE; and,
- SW and W.

Thus five circulation-type pairs were combined in order to estimate rainfall probabilities in the Guadalentin (for Alcantarilla), giving 9 circulation-type groups. Four pairs were combined in the Agri (for Missanello), giving 10 circulation-type groups. Probabilities were calculated for each season and for each group for Alcantarilla (Table 6.2) and Missanello (Table 6.3). The tables also indicate the total number of days available for calculating the probabilities for each circulation-type group.

There is considerable variation in sample size between the different circulation-type groups, particularly in summer when the greatest range in sample size occurs. For Alcantarilla in summer, sample size ranges from 38 S/SW-type days to 942 UC-type days. For Missanello in summer, it ranges from only four E/SE-type days to 839 UA-type days.

The rainfall occurrence parameters shown in Tables 6.2 and 6.3 reflect the circulation/rainfall relationships identified in Section 5.5. At Alcantarilla, for example, the highest probability of a wet day following a wet day (P_{ww} = 0.84) occurs for the E/SE-type group in winter. Both these types are identified as high-rainfall types in Table 5.9. Table 5.9 also identifies the A and HYA-types as low-rainfall types. In summer, both P_{ww} and P_{dw} for the A/HYA-type group are equal to zero, meaning that it can never rain on a simulated A/HYA-type day in summer. For Missanello, the highest P_{ww} values (P_{ww} = 0.75) occur on C/HYC-type days in spring and on SW/W-type days in summer. In Table 5.10, the C and HYC-types are identified as high-rainfall types in spring and the SW-type as a high-rainfall type in summer.

Since P_{ww} and P_{wd} sum to one, as do P_{dw} and P_{dd}, the NCWG actually only requires two of the parameters: P_{ww} and P_{dw} are used. On each day, a random number is selected from a uniform distribution, and used to determine whether the day is wet or dry. If the day being simulated is a winter C/HYC-type day at Missanello and the previous day was wet, for example, P_{ww} = 0.68 (Table 6.3). Thus if a random number of 0.71 is selected, the current day is dry, whereas if a random number of 0.44 is selected, the current day is wet. At the start of each simulation set, the random number generator is seeded using the PC clock, giving a different sequence of random numbers each time the NCWG is run.

6.2.3 Rainfall amount parameters

Identification of rainfall amount categories

The sample sizes shown in Tables 6.2 and 6.3 are for all circulation-type days, wet and dry. Some of the sample sizes are already quite small and would be reduced dramatically if only wet days were included (on average, 13% of days are wet at Alcantarilla and 24% at Missanello). Small sample size may affect the reliability of some of the rainfall occurrence parameters, but this is likely to be even more of a problem when attempting to fit a theoretical distribution to daily rainfall amount. Rather than using the 9 or 10 circulation-type groups used to calculate the occurrence parameters, it was, therefore, decided to fit distributions for three rainfall amount categories. The identification of these categories is based on the circulation-type/rainfall relationships for the Guadalentin and the Agri summarised in Tables 5.9 and 5.10 respectively. From these tables, circulation types were assigned to a *high* or *low* rainfall amount category. Circulation types not assigned to either of these two categories were assigned to the *moderate* category. Inevitably this assignment involves a large element of subjective judgement. The categorisation could have been made using mean rain per rain day values, but subjective judgement would still have been required to identify appropriate threshold values for the three categories.

The rainfall categories identified for Alcantarilla and Missanello are shown in Tables 6.4 and 6.5 respectively. Whereas the same 9 or 10 circulation-type groups are used in all seasons, the rainfall categories are allowed to vary between seasons. The E/SE-type group for Alcantarilla, for example, is assigned to the *high* rainfall category in winter, spring and autumn, as is the NE-type in winter and autumn. In summer, however, the E/SE-type group is assigned to the *moderate* rainfall category and the NE-type to the *low* category. The C/HYC and S/SW-types appear in the *high* rainfall category in summer. The E/SE-type group for Missanello is also assigned to the *high* rainfall category in winter, spring and autumn (as are the C, HYC, S and NW types depending on season), but again a very different set of circulation types (UC, A, NE and NW) are assigned to this category in summer.

The gamma distribution

Having identified the three rainfall amount categories, the next step was to fit the two parameter gamma distribution to each category for each season and each station. The gamma distribution was selected because it is a common choice for precipitation data (Gregory *et al.*, 1993; Schubert, 1994; Wilks, 1995; Semenov *et al.*, 1998; Corte-Real *et al.*, 1999a; Wilks and Wilby, 1999), which tends to be right skewed, and because the gamma probability distribution function (PDF) can have a wide variety of shapes depending on the value of the shape parameter (Wilks, 1995).

The gamma distribution is defined by the PDF

$$f(x) = \frac{(x/\beta)^{\alpha-1}\exp(-x/\beta)}{\beta\,\Gamma(\alpha)}, \qquad x, \alpha, \beta > 0. \qquad \text{(Equation 6.1)}$$

where the two parameters of the distribution are α, the shape parameter; and β, the scale parameter. The quantity $\Gamma(\alpha)$ is the value of the standard mathematical gamma function, defined by the integral

$$\Gamma(\alpha) = \int_0^\infty t^{\alpha-1} e^{-t}\, dt. \qquad \text{(Equation 6.2)}$$

The mean of the gamma distribution is given by the product $\alpha\beta$, and the variance is $\alpha\beta^2$. From these expressions, the shape and scale parameters can be estimated using the moments estimators

$$\hat{\alpha} = \frac{\bar{x}^2}{s^2} \qquad \text{(Equation 6.3)}$$

and

$$\hat{\beta} = \frac{s^2}{\bar{x}} \qquad \text{(Equation 6.4)}$$

where $\bar{x}$ is the sample mean and *s* is the sample standard deviation.

The moments estimators (Equations 6.3 and 6.4) were used to fit gamma distributions to the rainfall categories shown in Tables 6.4 and 6.5. The goodness-of-fit of the distributions was tested using the Kolmogorov-Smirnov test and the χ^2 test, which is less sensitive to discrepancies in the extreme tails of the distributions than the Kolmogorov-Smirnov statistic (Wilks, 1995).

Shape and scale parameter values

The shape and scale parameters for Alcantarilla and Missanello are shown in Tables 6.6 and 6.7 respectively. The tables also show the number of observed values available to calculate each set of distribution parameters. The final column of each table indicates cases where the gamma distribution is rejected at the 5% level using either the Kolmogorov-Smirnov or χ^2 test. Observed and theoretical distribution functions for each rainfall category and each season are shown in Figures 6.1 to 6.4 for Alcantarilla and in Figures 6.5 to 6.8 for Missanello.

For Alcantarilla, the number of available observations ranges from 24 for the *moderate* rainfall category in summer to 269 for the *moderate* category in spring (Table 6.6). The *high* category contains the fewest number of observations in winter and spring, while, except in summer, the *moderate* category contains the greatest number of observations. Alcantarilla has an average of 48 rain days per annum (Table 3.1), compared with 88 at Missanello (Table 5.1). Thus a greater number of observations are available for Missanello, ranging from 54 for the *moderate* category in autumn to 388 for the *high* category in autumn (Table 6.7). Mean annual rainfall at Missanello is 804 mm (giving an annual mean of 9.1 mm per rain day) compared with only 289 mm at Alcantarilla (giving an annual mean of only 6.0 mm per rain day). Thus, for Missanello, the *high* category always contains the greatest number of observations. Except in summer, the *moderate* category contains the fewest.

In 6 out of 12 cases the gamma distribution is rejected for Alcantarilla (Table 6.6). There is, however, only one case, the *low* rainfall category in winter, where the gamma distribution is rejected by both the Kolmogorov-Smirnov and χ^2 tests. Inspection of the distribution functions for this case (Figure 6.1b) shows that the fitted gamma distribution overestimates the probability of smaller rainfall amounts and underestimates the probability of higher (> ~1.5 mm) amounts. For Missanello, there are three cases where the gamma distribution is rejected by one of the statistical tests (Table 6.7). In the case of the *high* rainfall category in winter, for example, the probability of smaller (< ~8 mm) rainfall amounts is overestimated while the probability of higher amounts (up to ~ 47 mm) is underestimated (Figure 6.5a).

Generally, however, the gamma distribution is considered to provide a reasonable fit and is able to reflect the variations in distribution shape which occur. The highest value of the shape parameter (α = 2.03) occurs for the *moderate* rainfall category at Missanello in autumn. In this case (Figure 6.8c), the frequency distribution function begins at the origin and the distribution is less skewed and shifted to the right compared with other cases. The shape of the gamma distribution in winter for the *moderate* rainfall category at Missanello is a special case (α = 1.0), i.e. an exponential distribution (Figure 6.5c). In the majority of cases, however, α is less than 1.0, indicating distributions which are strongly skewed to the right (Wilks, 1995).

For Alcantarilla the minimum and maximum α values are both less than 1.0. The minimum value (α = 0.20) occurs in summer for the *low* rainfall category. This distribution has a high percentage of very low intensity rainfall days but a long tail (Figure 6.3b). The maximum value (α = 0.79) also occurs for the *low* rainfall category, but in spring. This distribution also has a high percentage of very low intensity rainfall days but a short tail (Figure 6.2b). For Missanello, the minimum α value (α = 0.51) occurs for the *high* rainfall category in winter. This distribution has a relatively high percentage of low intensity events and a very long tail (Figure 6.5a), in contrast to that of the *moderate* rainfall category in autumn (α = 2.03; Figure 6.8c) which has relatively few very low intensity events and a short tail. In general, the distributions with the longest tails tend to be associated with the *high* rainfall category at both stations.

For Alcantarilla, the scale parameter (β) ranges from 2.2 (the *low* rainfall category in spring) to 24.3 (the *high* rainfall category in autumn). For Missanello, β ranges from 4.5 (the *low* rainfall category in spring) to 24.0 (the *high* rainfall category in winter). With the exceptions of Alcantarilla in summer and Missanello in autumn, the value of the scale parameter in each season is lowest for the *low* rainfall category and highest for the *high* rainfall category, while the *moderate* category has an intermediate value. In summer, the highest β value for Alcantarilla actually occurs for the *low* rainfall category (β = 19.2). The observed distribution is not very smooth for this case and the probabilities of higher rainfall events are consistently overestimated by the gamma distribution (Figure 6.3b), which is rejected by the Kolmogorov-Smirnov test (Table 6.6). The exception of Missanello in autumn is of less concern because, although the *low* rainfall category does not have the lowest β value, the *high* rainfall category still has the highest β value.

The values of the scale parameters for Alcantarilla and Missanello are broadly similar in winter and spring. In summer and autumn, the values for Alcantarilla are higher than for Missanello. The highest β values for Alcantarilla occur in autumn when rainfall reaches a maximum and heavy rainfall events are most likely to occur (see

Chapter 3 and Section 5.5.1). For Missanello, highest β values occur in winter, coinciding with the season of maximum rainfall (Figure 5.12).

In general, the distributions of the three rainfall categories appear distinctive and the variations in parameter values between different categories/seasons/stations appear to reflect the different circulation-type/rainfall relationships identified in Chapters 3 and 5. The gamma distribution is considered adequate for the majority of cases considered here. However, there are some cases where it does not provide a good fit and some other distribution, such as the mixed exponential distribution (Wilks, 1998; 1999a; 1999b), might provide a better fit. Alternative methods of fitting the parameters, such as the method of maximum likelihood, might also give better results (Wilks, 1995).

Even with combining the circulation types into a fewer number of groups to estimate the rainfall occurrence parameters (Section 6.2.2) and using only three rainfall categories to estimate the rainfall amount parameters, some of the sample sizes used for parameter estimation are still very small. This affects the variability which can occur within each circulation-type group and may also make it more difficult to fit distributions. In summer, for example, the rainfall occurrence parameters are such that it can never rain at Alcantarilla on an A/HYA-type day and an E/SE-type day following a wet day will always be wet (Table 6.2). At Missanello, however, an E/SE-type day in summer following a wet day will always be dry (Table 6.3). Some of the observed rainfall amount frequency distributions are not very smooth (see, for example, Figure 6.2a), although they tend to be smoother for Missanello than for Alcantarilla because of the larger sample sizes.

These problems would be exacerbated if the data were divided into separate calibration and validation periods (see Section 6.1.2). All the available data were, therefore, used to calculate the NCWG parameters used in the final scenario runs (Section 6.4), but independent validation runs using a 'leave-one-out' cross-validation approach were also carried out (Section 6.3). The latter runs also allow exploration of how the parameters vary over time.

6.3 CROSS-VALIDATION RUNS

In the cross-validation runs described in this section, the rainfall occurrence and amount parameters are calculated using all available data except that for the year being simulated. This 'leave-one-out' approach allows independent validation of the NCWG performance using the retained data. In the first set of simulations ($CVOBS_{Alc}$ and $CVOBS_{Mis}$; see Section 6.3.1) the observed sequences of circulation types are used. In the second set of simulations ($CVHAD_{Alc}$ and $CVHAD_{Mis}$; see Section 6.3.2) the circulation-type sequences are derived from HadCM2SUL output. The simulated time series for Alcantarilla are 30 years long (1958-1987), and those for Missanello, 33 years (1956-1988).

6.3.1 The $CVOBS_{Alc}$ and $CVOBS_{Mis}$ simulation sets

Seasonal means and totals

The results for Alcantarilla and Missanello are summarised in Tables 6.8 and 6.9 respectively. Seasonal totals and means only are shown in these tables. Standard deviations are shown in Tables 6.10 and 6.11 which are discussed at the end of this section, together with the occurrence of extreme events.

For each season, the first line of Tables 6.8 and 6.9 shows the observed mean for the number of rain days (NRD) and rainfall amount (AMT). The overall mean of each simulation set ($\overline{NRD}_m$ and $\overline{AMT}_m$) is also shown in the tables, together with maximum and minimum values (of NRD_m and AMT_m) and the range across 1000 runs. Time series of seasonal totals from each run (i.e. 30 or 33 values per run) were compared with the observed time series using the *t*-test. The number of runs for which the simulated mean values were found to be significantly higher or lower than the observed means (at the 5% level) is shown in the tables, together with the number of runs where the observed and simulated mean seasonal totals are not significantly different. The final diagnostic statistics shown in the tables concern correlation analyses performed using the observed and simulated time series of seasonal totals (i.e. 30 or 33 values per run). The mean of the correlation coefficients averaged over all 1000 runs is shown, together with the highest positive and negative values obtained in any one of the 1000 runs.

Seasonal means and totals: Alcantarilla ($CVOBS_{Alc}$, Table 6.8)

- For the number of rain days, the percentage of runs where there are no significant differences between observed and simulated values is high, ranging from 99.8% in spring to 95.5% in summer.
- The observed mean number of rain days falls within the simulated range of mean values in all seasons, though this range is large, varying from 5.6/5.8 days in winter/spring to 11.3/11.4 days in summer/autumn.
- However, the number of rain days tends to be underestimated in winter and, to a lesser extent, in spring and autumn. ($\overline{NRD}_m$ is lower than the observed mean. NRD_m is significantly underestimated in a number of runs (33 out of 1000 in the case of winter) but never overestimated.)

- The number of rain days is well simulated in summer. ($\overline{NRD}_m$ is very similar to the observed mean. NRD_m is significantly overestimated in 23 runs and underestimated in 22 runs.)
- For rainfall amount, the percentage of runs where there are no significant differences between observed and simulated values is high, ranging from 99.7% in spring to 95.7%/95.6% in summer/autumn.
- The observed mean rainfall amount falls within the simulated range of mean values in all seasons, though this range is large, varying from ~68 mm in winter/spring to 118 mm in autumn.
- However, the amount of rain tends to be overestimated in all seasons (most frequently in summer, 43 out of 1000 runs).

Overall, the number of rain days and rainfall amount are reasonably well simulated. However, in summer, although the simulated time series have approximately the right number of rain days, these days tend to be too wet. In other seasons, the simulated time series tend to have too few rain days, with too much rainfall on each. These errors are more severe in winter than spring or autumn.

Seasonal means and total: Missanello ($CVOBS_{Mis}$, Table 6.9)

- For the number of rain days, the percentage of simulated means which are not significantly different from the observed value is high, ranging from 94.6% in autumn to 99.9% in spring.
- The observed mean number of rain days falls within the simulated range of mean values in all seasons, though this range is large, varying from 6.9 days in spring to 14.5 days in summer.
- Although the number of rain days is well simulated in spring, it tends to be underestimated in other seasons, most frequently in winter (4.0% of runs) and autumn (5.4% of runs).
- In summer, $\overline{NRD}_m$ is slightly lower than the observed mean, but NRD_m is more frequently significantly overestimated (2.0% of runs) than underestimated (0.5% of runs).
- For rainfall amount, the percentage of simulated means which are not significantly different from the observed values is high, ranging from 96.9% in autumn to 98.8% in spring. In every season except spring, this percentage is somewhat greater for rainfall amount than for the number of rain days.

- The observed mean rainfall amount falls within the simulated range of mean values in all seasons, though this range is large, varying from about 114 mm in winter and spring to 185 mm in autumn.
- However, rainfall amount tends to be overestimated, most frequently in winter (2.5% of runs) and summer (1.7% of runs). In autumn, $\overline{AMT}_m$ is slightly higher than the observed mean, but AMT_m is more frequently underestimated (2.5% of runs) than overestimated (0.6% of runs).

Comparison of Alcantarilla and Missanello

- A tendency to underestimate the number of rain days and to overestimate rainfall amount is evident at both stations.
- The percentage of simulated means which are not significantly different from the observed value is similar for Missanello and Alcantarilla in winter, and higher for Missanello in summer, i.e. the NCWG tends to perform better in summer at Missanello than at Alcantarilla.
- In spring, the number of rain days is very well simulated at both stations, but rainfall amount is slightly better simulated at Alcantarilla.
- In autumn, the number of rain days is simulated better at Alcantarilla than Missanello, while rainfall amount is simulated better at Missanello.
- At both stations, the observed mean values lie within the range of simulated values. However, as might be expected, the range of simulated values is greater for Missanello, which is markedly wetter.

Correlation coefficients

Mean correlation coefficients between the simulated and observed time series of seasonal totals tend to be very low for both stations (only correlation coefficients greater than 0.31 for Alcantarilla and greater than 0.28 for Missanello are statistically significant at the 5% level) and are close to zero in a number cases.

Correlation coefficients: Alcantarilla ($CVOBS_{Alc}$, Table 6.8)

- Mean correlation coefficients range from -0.02 in summer to +0.33 in winter (the only statistically significant mean value) for the number of rain days and from -0.04 in summer to +0.22 in spring for rainfall amount.
- Correlations tend to be higher in winter and spring (when mean correlations for the number of rain days are higher than for rainfall amount) than in summer and autumn.
- Maximum positive correlations range from +0.65/+0.58 in summer to

+0.79/+0.78 in winter.

- Some quite high negative correlations do, however, occur. In summer, for example, the maximum negative correlation of -0.65 for the number of rain days is equal in absolute terms to the maximum positive correlation of +0.65.

Correlation coefficients: Missanello ($CVOBS_{Mis}$, Table 6.9)

- Correlation coefficients for Missanello are lower than for Alcantarilla.
- For the number of rain days, mean correlations range from almost zero in summer and autumn to only +0.13 in spring.
- The mean correlations for rainfall amount are almost zero in every season.
- The maximum positive correlation occurs for rainfall amount in spring (+0.75), but generally the maximum positive correlations are fairly low.
- Some fairly high negative correlations occur. The latter are never greater in absolute terms than the positive correlations although the two can be quite similar. For rainfall amount in autumn, for example, the maximum positive correlation is +0.58 compared with a maximum negative correlation of -0.57.

Correlation coefficients: discussion

It is perhaps not surprising that correlations are lower for rainfall amount, which is dependent on the value of two random numbers, than for the number of rain days, which is dependent on the value of only one random number. In part, however, the poorer reproduction of observed rainfall amount may be related to problems with the identification of rainfall amount categories and distribution fitting.

The extent to which high correlations between the observed and simulated time series should be expected is, however, open to debate given that the NCWG is a probabilistic model. Separating out inherent problems with the weather generator and the inherent variability of weather (which occurs even if the model is a perfect representation of the real climate) is difficult (Hayhoe, 2000). If it were assumed that the NCWG is fully reliable, how many times would it have to be run before it might be expected to reproduce the observed series exactly? Ideally, the model should be validated using 1000 observed data series which would allow comparison of the range of variability across both the observed and simulated time series. Such series could be created by random sampling from the station series to give 1000 new series, but variability across these sampled series will be similar to that of the original series. In the absence of sufficiently long observed series to investigate natural variability, the extent to which the finding that the observed means always fall within the simulated range of mean values can provide a meaningful indicator of performance is unclear.

Seasonal totals and means: a summary

Despite the uncertainties discussed above in the interpretation of the results, it is nonetheless concluded that the NCWG output contains some systematic biases in the seasonal totals and means. In both regions, with the exception of Alcantarilla in summer, the number of rain days tends to be underestimated and rainfall amount overestimated, i.e. there tend to be too few, too wet, rain days. Generally, however, the percentage of runs in which the mean values are not significantly different from observed values is high, indicating that the NCWG performs reasonably well. It is perhaps surprising that, with the exceptions of Alcantarilla in autumn and Missanello in spring, this percentage is somewhat higher for rainfall amount than for the number of rain days. The additional probabilistic element in simulating rainfall amount, together with any shortcomings in the underlying rainfall amount categories and their representation by the gamma distribution (see Section 6.2.3), might be expected to result in a worse performance for rainfall amount than for the number of rain days. The apparently better simulation of rainfall amount may, however, be a reflection of the fact that observed rainfall amount tends to be more variable than the number of rain days (see Tables 6.10 and 6.11).

Standard deviations

The ability to reproduce observed seasonal totals and mean values is only one aspect of model performance. The ability of the weather generator to reproduce the observed year-to-year variability is also important. Standard deviation results for Alcantarilla and Missanello are summarised in Tables 6.10 and 6.11, using the same diagnostic statistics used for seasonal totals and means (with the exception that correlation coefficients were not calculated). The only differences are that the *F*-test rather than the *t*-test was used to test the individual time series and a significance level of 10% rather than 5%.

Standard deviations: Alcantarilla ($CVOBS_{Alc}$, Table 6.10)

- Standard deviations for the number of rain days are underestimated in winter, spring and autumn.
- In summer (when the observed variance is considerably lower than in other seasons), the rain day standard deviations tend to be overestimated.
- For the number of rain days, the percentage of simulated standard deviations which are not significantly different from observed ranges from 42.0% in winter to 62.9% in summer.

- A similar pattern of error occurs for rainfall amount (standard deviations are overestimated in summer, but underestimated in other seasons).
- For rainfall amount, a higher percentage of simulated standard deviations are not significantly different from the observed values than for the number of rain days. For rainfall amount, this percentage ranges from 76.4% in autumn to 89.5% in winter.

Standard deviations: Missanello ($CVOBS_{Mis}$, Table 6.11)

- Observed standard deviations are higher than for Alcantarilla in all seasons except autumn (and for the number of rain days in winter) and the simulated standard deviations are too low in every season.
- In winter and autumn, the percentages of standard deviations for the number of rain days and rainfall amount which are not significantly different from the observed value are higher than for Alcantarilla.
- In spring, the percentages are lower than for Alcantarilla.
- In summer, the percentage is lower at Missanello for rain day standard deviations and similar at both stations for rainfall amount.
- For Missanello rain day standard deviations, this percentage ranges from 32.8% in summer to 95.2% in autumn. For rainfall amount standard deviations, it ranges from 51.7% in spring to 95.1% in winter.
- Overall, Missanello standard deviations are simulated better in winter and autumn than in spring and summer when the tendency to underestimate the observed variability is strongest.

Standard deviations: a summary

At both Alcantarilla and Missanello, the observed standard deviations fall within the simulated range in all seasons, although the extent to which this provides a useful guide to performance is uncertain. At both stations, however, the percentage of simulated standard deviations which are not significantly different from observed is higher for rainfall amount than for the number of rain days, with the exception of Missanello in autumn. This suggests that the additional probabilistic element (the dependence on a second random number and sampling from a distribution) may increase the variance in the simulated rainfall amount series. In part, however, it is likely to reflect the fact that rainfall amount tends to be overestimated while the number of rain days tends to be underestimated by the NCWG. The extent to which variability is better simulated by the NCWG or by the original CWG is considered in Section 6.3.3.

Length of the longest wet/dry day spell

The ability of the weather generator to reproduce the observed persistence of wet and dry spells can be evaluated using the LW (length of the longest wet day spell) and LD (length of the longest dry day spell) parameters. Results for the $CVOBS_{Alc}$ and $CVOBS_{Mis}$ simulation sets are summarised in Tables 6.12 and 6.13. Observed values are shown in the tables, together with the mean, maxima, minima and range of the simulated values. The number of runs where the simulated LW/LD values are longer or shorter than, or the same as, the observed values is also shown.

Length of the longest wet/dry day spell: Alcantarilla ($CVOBS_{Alc}$, Table 6.12)

- With the exception of LW in summer, the persistence of wet days and dry days is underestimated, particularly in winter and spring.
- Observed LD is very much longer than observed LW, reflecting the strong persistence of dry day spells in this region of Spain.
- In all cases, the number of runs where the simulated LD is shorter than the observed LD is greater than the number of runs where the simulated LW is shorter than the observed LW.
- The observed LW and LD values always fall within the simulated range, but the minimum simulated values tend to be very low, i.e. about half of the observed value in a number of cases.

Length of the longest wet/dry day spell: Missanello ($CVOBS_{Mis}$, Table 6.13)

- Wet-day and dry-day persistence is underestimated at Missanello in winter, spring and summer.
- In autumn, LW tends to be overestimated, while LD is reasonably well simulated, being longer or shorter than the observed value in approximately the same number of runs.
- The observed values always fall within the range of the simulated values, although only just in the case of LD in summer, and the minimum values again tend to be very low in comparison to the observed values.

Extreme event analysis

Classical extreme value theory has been used to evaluate the ability of the NCWG to reproduce extreme events (i.e. annual maximum daily rainfall). It is assumed that the extremes fit the Gumbel (Generalized Extreme Value (GEV) Type I) distribution (see Palutikof *et al*. (1999) for a concise review of extreme value theory). The method of moments (Stedinger *et al*., 1993) is used to calculate the parameters of the distribution and hence the return period extremes.

According to classical extreme value theory, the maxima of samples of size *n*, for large *n*, can be fitted to one of three basic families, provided that sufficiently long sequences of independent and identically distributed random variables are available. These three families can be considered as a single distribution, the GEV distribution, which has the cumulative distribution function

$$\begin{aligned} F(x) &= \exp[-(1-ky)^{1/k}] \qquad k \neq 0, \\ &= \exp[-\exp(-y)] \qquad k = 0 \end{aligned} \qquad \text{(Equation 6.5)}$$

where *k* is a shape parameter which determines the type of extreme value distribution. The case for k = 0 is known as the GEV Type I or Gumbel distribution. It is the most commonly used of the theoretical extreme value distributions (Wilks, 1995) and is used here. Gumbel (1958) argued that, in the case of floods, each year of record constitutes a sample of 365 cases, and that the annual extreme flood is the maximum value of the sample. Thus the GEV distributions can be fitted to a set of annual maxima. This is the basis of all classical extreme value theory. The aim is to define the form of the limiting distribution and estimate the parameters, so that values of the quantile X_T can be calculated, where X_T is the maximum value which is exceeded, on average, once every *T* years, i.e. the return period. Here, a program written by Tom Holt and Jean Palutikof in the Climatic Research Unit is used to estimate annual daily rainfall maxima with return periods of 5, 10, 20 and 50 years (i.e. T5, T10, T20 and T50 events) using input time series of 30 (Alcantarilla) or 33 (Missanello) years.

Results from the extreme value analysis are summarised for Alcantarilla and Missanello in Tables 6.14 and 6.15. Observed values are shown in the tables, together with the mean, maxima, minima and range of the simulated values. The number of runs where the simulated events are larger or smaller than the observed events is also shown.

Extreme event analysis: Alcantarilla ($CVOBS_{Alc}$, Table 6.14)

For Alcantarilla, the simulated return period events are systematically larger than the observed events (Table 6.14). This reflects the fact that mean seasonal rainfall totals are overestimated in every season in the NCWG (Table 6.8). Moreover, rainfall amount is more frequently overestimated in summer and autumn, when the majority (67%) of the annual daily rainfall maxima occur, than in other seasons. However, the percentage of runs in which the magnitude of simulated return period events is smaller than observed increases with increasing return period length, from 8.9% of runs for T5 to 16.4% of runs for T50, i.e. there is a tendency for the NCWG to underestimate the intensity of extreme rainfall events with longer return periods more frequently than those with shorter return periods.

Extreme event analysis: Missanello ($CVOBS_{Mis}$, Table 6.15)

For Missanello, the mean simulated return period events are similar in magnitude to the observed events (Table 6.15). However, for return periods of 10 years or more, the simulated events are somewhat more frequently smaller, rather than larger, than the observed values. About 85% of the annual daily rainfall maxima occur in winter or autumn. Mean seasonal rainfall totals are overestimated by the NCWG in winter (and in spring and summer), but are more frequently underestimated rather than overestimated in autumn (Table 6.9). As for Alcantarilla, there is a tendency for the percentage of runs in which the simulated events are smaller than observed to increase with increasing return period length, from 49.3% for T5 to 59.5% for T50, i.e. there is a tendency for the intensity of extreme rainfall events with longer return periods to be more severely underestimated than those with shorter return periods.

Variability and persistence – a summary

In part, the ability of the NCWG to reproduce the observed variance and persistence of rainfall, and the intensity of extreme rainfall events, reflects the extent to which mean seasonal totals (number of rain days and rainfall amount) are well reproduced. However, this weather generator is clearly susceptible to the inherent tendency of Markov Chain weather generators to underestimate variance and persistence and to be less successful at reproducing the magnitude of extreme events than mean values (Wilks, 1999a; Wilks and Wilby, 1999; see also discussion in Section 4.4 and Chapter 7).

6.3.2 The $CVHAD_{Alc}$ and $CVHAD_{Mis}$ simulation sets

Seasonal totals and means

The results for Alcantarilla and Missanello are summarised in Tables 6.16 and 6.17 respectively. The same diagnostic statistics are used as for the CVOBS simulation sets (see Section 6.3.1), although correlation coefficients are not shown. Seasonal totals and means only are shown in Tables 6.16 and 6.17. Standard deviations are shown in Tables 6.18 and 6.19 and are discussed at the end of this section, together with the occurrence of extreme events.

Seasonal totals and means: Alcantarilla ($CVHAD_{Alc}$, Table 6.16)

- The number of rain days is underestimated in winter, spring and autumn. This error is most severe in spring, when 96.8% of the simulated means are significantly lower than the observed mean. In summer, a slightly higher percentage of means are significantly underestimated (3.4%) than overestimated (1.8%).

- Compared with the $CVOBS_{Alc}$ simulation set, in all seasons, a smaller percentage of simulated rain-day means are not significantly different to the observed values, i.e. the NCWG performs less well in every season. This percentage ranges from only 3.2% in spring to 97.8% in autumn.
- For rainfall amount the percentage of means which are not significantly different from observed ranges from 29.0% in spring to 98.6/98.4% in winter/summer.
- Except in autumn, rainfall amount tends to be better simulated than the number of rain days and the deterioration in performance between the $CVOBS_{Alc}$ and $CVHAD_{Alc}$ simulation sets is not as marked as for the number of rain days.
- In spring, however, the number of rain days and rainfall amount are both severely underestimated. This is the one season where both observed means lie outside the range of simulated means.
- In winter, despite the tendency to underestimate the number of rain days, rainfall amount is reasonably well simulated.
- In summer and autumn, rainfall amount tends to be overestimated.

Seasonal means and totals: Missanello ($CVHAD_{Mis}$, Table 6.17)

- The number of rain days, and to a lesser extent rainfall amount, are underestimated in all seasons.
- The worst results are in winter, when the mean number of rain days is significantly underestimated in 97.4% of runs, and mean rainfall amount in 39.3% of runs. In summer, the number of rain days and rainfall amount are occasionally significantly overestimated rather than underestimated.
- The percentage of rain-day mean values which are not significantly different from observed ranges from only 2.6% in winter to 98% in spring. For rainfall amount, this percentage ranges from 60.7% in winter to 100% in spring. In all seasons, the percentage of non-significant differences is higher for rainfall amount than for the number of rain days.
- The percentage of non-significant differences for the number of rain days and rainfall amount is lower for the $CVHAD_{Mis}$ simulation set than for the $CVOBS_{Mis}$ set, with the exception of rainfall amount in spring, i.e. the NCWG performs less well when the circulation-type sequences are derived

from HadCM2SUL output.

Discussion of the $CVHAD_{Alc}$ and $CVHAD_{Mis}$ results

How do the errors identified in the $CVHAD_{Alc}$ and $CVHAD_{Mis}$ simulation sets relate to the GCM errors in circulation-type frequency described in Section 5.6 (see Tables 5.11 and 5.12; Figure 5.21)? The main problem with the HadCM2SUL circulation-type frequencies is that over the year as a whole, in both study regions, there are too many anticyclonic (A and HYA) days and too few cyclonic (C and HYC) days. The A and HYA-types are low-rainfall types and the C and HYC-types are high-rainfall types (Tables 5.9 and 5.10). Thus the GCM circulation-type errors are consistent with the general tendency for the NCWG to underestimate the occurrence of rainfall in the $CVHAD_{Alc}$ and $CVHAD_{Mis}$ simulation sets.

Overall, HadCM2SUL simulates the observed circulation types rather less well in the Guadalentin than in the Agri (Section 5.6). Thus the poorer results for the $CVHAD_{Mis}$ simulation set compared with $CVHAD_{Alc}$ are unexpected, particularly as the results for $CVOBS_{Mis}$ and $CVOBS_{Alc}$ are broadly comparable (Section 6.3.1). In winter, however, the frequencies of the C, E and SE-types in the Agri (all high-rainfall types, Table 5.10) are significantly underestimated (by a total of 13.7 days on average, Table 5.12), while most of the low-rainfall types (A, HYA, UA, N and NW) are significantly overestimated (by a total of 17 days on average). This particular combination of errors is likely to account for the particularly severe underestimation of the number of rain days at Missanello in winter (Table 6.17). The best $CVHAD_{Mis}$ results occur in spring, when there are fewer statistically significant differences in observed and simulated circulation-type frequency than in other seasons (Table 5.12).

At both stations, the HadCM2SUL errors in circulation-type frequency appear to reinforce the rain-day errors in the NCWG evident in the CVOBS simulation sets, i.e. the number of rain days is more severely and more frequently underestimated in the CVHAD simulation sets than in the CVOBS simulation sets. In the case of rainfall amount, at Missanello, the HadCM2SUL errors appear to more than compensate for the errors inherent in the NCWG, i.e. rainfall amount is underestimated in all seasons except spring (when it is well simulated) in the $CVHAD_{Mis}$ simulation set whereas it is consistently overestimated in the $CVOBS_{Mis}$ simulation set. Rainfall amount is also underestimated in winter and spring in the $CVHAD_{Alc}$ simulation set and overestimated in the $CVOBS_{Alc}$ simulation set, again suggesting that the HadCM2SUL errors more than compensate for the inherent NCWG errors. Rainfall amount is, however, still overestimated in summer (though less so than in the $CVOBS_{Alc}$ simulation set) and in autumn (more so than in the $CVOBS_{Alc}$ simulation set, indicating that the HadCM2SUL errors reinforce the inherent NCWG errors in this case).

Standard deviations

Year-to-year standard deviation results for Alcantarilla and Missanello are summarised in Tables 6.18 and 6.19 respectively. HadCM2SUL standard deviations for circulation-type frequency are discussed in Section 5.6 (see Tables 5.18 and 5.19). Overall, the GCM overestimates rather than underestimates standard deviations for the majority of circulation types but, for the statistically significant differences only, the model underestimates standard deviations in more cases.

Standard deviations: Alcantarilla ($CVHAD_{Alc}$, Table 6.18)

- The pattern of error in the number of rain day and rainfall amount standard deviations is the same in this simulation set as in the $CVOBS_{Alc}$ simulation set, i.e. standard deviations are underestimated in all seasons except summer when they are overestimated.
- The percentage errors are again higher for the number of rain days than for rainfall amount.
- There does not appear to be a very clear pattern in terms of whether errors are better or worse in the $CVOBS_{Alc}$ or $CVHAD_{Alc}$ simulation set.
- The worst deterioration in performance, however, occurs in spring. In the $CVHAD_{Alc}$ simulation set, 84.4% of rain day standard deviations and 68.9% of rainfall amount standard deviations are significantly underestimated (compared with 38.0% and 18.8% in the $CVOBS_{Alc}$ simulation set). It is noted that the standard deviations for five circulation types are significantly underestimated in spring (Table 5.17).

Standard deviations: Missanello ($CVHAD_{Mis}$, Table 6.19)

- The pattern of error is similar in the $CVOBS_{Mis}$ and $CVHAD_{Mis}$ simulation sets, i.e. rain day and rainfall amount standard deviations are too low in every season.
- In winter and spring, there are fewer significant differences in the $CVHAD_{Mis}$ simulation set than in the $CVOBS_{Mis}$ set, while there are more in summer, and similar numbers in autumn.
- The worst $CVHAD_{Mis}$ errors are in summer, when 71% of rain day standard deviations and 31.4% of rainfall amount standard deviations are underestimated.

Standard deviations: a summary

The simulated variance tends to be too low in all the cross-validation runs at both stations. Overall, however, there does not appear to be any systematic loss of variance when the circulation-type sequences are derived from HadCM2SUL output rather than from the observed data, i.e. performance is broadly similar for the CVOBS and CVHAD simulation sets.

Length of the longest wet/dry day spell (Tables 6.20 and 6.21)

LW and LD parameters for the $CVHAD_{Alc}$ and $CVHAD_{Mis}$ simulation sets are summarised in Tables 6.20 and 6.21. As in the CVOBS simulation sets, there is a general tendency for the persistence of wet and dry day spells to be underestimated. In the CVHAD simulation sets, the major exceptions to this general tendency are for LW in summer at Alcantarilla and, to a lesser extent, for LW and LD in autumn at Missanello when persistence tends to be overestimated. With these exceptions (which do not appear to be related to the errors in mean seasonal totals, see Tables 6.16 and 6.17), the number of runs in which simulated LW is smaller than observed tends to be greater for the CVHAD simulation sets than for the CVOBS simulation sets, while for LD fewer runs tend to have significantly smaller values. This reflects the general tendency of the NCWG to underestimate rainfall occurrence when the circulation-type sequences are derived from HadCM2SUL output rather than from observed SLP.

Extreme event analysis

The results of the extreme event analysis for the $CVHAD_{Alc}$ and $CVHAD_{Mis}$ simulation sets are summarised in Tables 6.22 and 6.23.

Extreme event analysis: Alcantarilla ($CVHAD_{Alc}$, Table 6.22)

Observed annual daily rainfall maxima occur more frequently in summer and autumn than in other seasons. For the $CVHAD_{Alc}$ simulation set, seasonal rainfall totals are underestimated in winter and spring but overestimated in summer and autumn (Table 6.16). Thus the magnitudes of the return period events are overestimated in $CVHAD_{Alc}$ (Table 6.22). With the exception of the T5 event, the number of runs in which the simulated extreme events are larger than observed is greater in the $CVHAD_{Alc}$ simulation set than in the $CVOBS_{Alc}$ simulation set. In both simulation sets, this percentage decreases with increasing return period length, from 90.2% for T5 to 85.8% for T50 in the $CVHAD_{Alc}$ simulation set.

Extreme event analysis: Missanello ($CVHAD_{Mis}$, Table 6.23)

The majority of observed annual daily rainfall maxima occur in winter and autumn. In the $CVHAD_{Mis}$ simulation set, mean rainfall totals tend to be underestimated in all seasons except spring (Table 6.17). As in the $CVOBS_{Mis}$ simulation set, the magnitude of return period events is systematically underestimated in the $CVHAD_{Mis}$ simulation set (Table 6.23). In the latter set, however, the percentage of runs in which simulated values are smaller than observed is greater, and similar (~74%) for all return periods.

6.3.3 Comparison of the performance of the original and new conditional weather generators

$CVOBS_{Alc}$ vs the original CWG

The performance of the $CVOBS_{Alc}$ simulation set (Table 6.8) can be compared with that of the original CWG simulation set for Alcantarilla using circulation-type sequences derived from the observations (see the $M_{g(NRD)}$ values in Table 3.6). In spring, summer and autumn, $\overline{NRD}_m$ values are slightly lower (by 0.2-0.5 days) than mean $M_{g(NRD)}$ values. In winter, $\overline{NRD}_m$ is 0.8 days lower. Thus mean values tend to be somewhat less well simulated in the NCWG. However, it should be remembered that all available data were used to calculate the model parameters for the original CWG and thus independent validation of this model is not possible. The range of simulated mean values is much higher in the NCWG than in the original CWG, particularly in summer and autumn. This is expected because the NCWG was run 1000 times for each simulation set, compared with 100 times for the original CWG.

In terms of standard deviations, the NCWG performs much better than the original model. $\overline{NRD}_{sd}$ values (Table 6.10) are consistently higher than the mean $\sigma_{g(NRD)}$ values in all seasons except summer (Table 3.6). In terms of range, the minimum standard deviation values are similar in both simulation sets, but the $\overline{NRD}_{sd}$ maximum values are considerably higher. This indicates that the better results obtained from the NCWG are not just an artefact of the greater number of runs (1000 rather than 100). The greatest improvements are in spring (when the percentage of values which are significantly underestimated decreases from 96% to 38%) and autumn (when the percentage of values which are significantly underestimated decreases from 100% to 50%).

The NCWG also performs better in terms of the persistence of wet and dry day spells. The mean LW and LD values from Table 6.12 are consistently higher than the LW_g and LD_g values in Table 3.6. More importantly, the minimum values in Table 6.12 are very similar to the LW_g values in Table 3.6 while the maximum values are very much higher. This also tends to be the case for LD, although the minimum values in

Table 6.12 tend to be somewhat lower than the LD_g values.

$CVHAD_{Alc}$ vs UKTR

The performance of the $CVHAD_{Alc}$ simulation set (Table 6.16) can be compared with that of the original CWG using circulation types derived from UKTR output (see the $M_{c(NRD)}$ values in Table 3.6). In winter, $CVHAD_{Alc}$ has a stronger tendency to underestimate the number of rain days than the original CWG. This could be related to a new error in HadCM2SUL compared with UKTR, i.e. the tendency for simulated SLP to be too high over the Mediterranean in winter (see Section 5.3.1), but may also be an inherent feature of the NCWG because the number of rain days is also underestimated in $CVOBS_{Alc}$. The NCWG also tends to be somewhat drier in spring and autumn, but performs slightly better in summer than the original CWG. In terms of mean number of rain days and rainfall amount, $CVHAD_{Alc}$ does not appear to perform as well as the original CWG. This might be expected given the poorer reproduction (except in winter) of circulation-type frequency by HadCM2SUL compared with UKTR (see Section 5.6). However, standard deviations are consistently higher for NCWG output (Table 6.18) than for the original CWG (see $\sigma_{c(NRD)}$ values in Table 3.6) and the persistence of wet and dry day spells is greater for the NCWG (Table 6.20) than for the original CWG (see LW_c and LD_c values in Table 3.6).

6.3.4 Variability of the parameters in the cross-validation simulation sets

Mean values of the rainfall occurrence parameters (P_{ww} and P_{dw}) and the rainfall amount parameters (α and β) used in the cross-validation simulation sets are shown in Tables 6.24 and 6.25 for Alcantarilla and Missanello respectively. The maximum and minimum values are also shown, together with the range.

In all cases, the mean parameter values from the cross-validation runs are very similar to those used in the scenario runs (i.e. the values given in Tables 6.2, 6.3, 6.6 and 6.7). P_{ww} and P_{dw} values for Alcantarilla (Table 6.24) fall within ± 0.01 of the values in Table 6.2, while those for Missanello (Table 6.25) fall within ± 0.02 of the values in Table 6.3. The α values for Alcantarilla fall within ± 0.03 of those in Table 6.6, β values within ± 0.8. For Missanello, α values fall within ± 0.02 of those in Table 6.7, β values within ± 0.2.

Tables 6.24 and 6.25 indicate that the values of all the parameters vary from year-to-year over the cross-validation simulation sets. The maximum range for P_{ww} at Alcantarilla is ± 0.18 for the S/SW-type group in winter. For Missanello, the maximum is 1.0 for the infrequent A/HYA-type group in summer. With this exception, the P_{ww}

parameters tend to be less variable for Missanello than Alcantarilla. The P_{dw} parameters are less variable than the P_{ww} parameters at both stations (a maximum range of 0.08 for the E/SE-type group at Alcantarilla in winter and spring and 0.07 for the N-type at Missanello in autumn).

In terms of absolute range, the shape and scale parameters of the gamma distribution for Alcantarilla vary less from year-to-year than those for Missanello in summer and autumn, and vary more in winter and spring. When expressed in terms of percentage of the mean value, however, the range of variability is consistently greater for Alcantarilla. The highest percentage variability occurs at Alcantarilla in winter for the *low* rainfall amount category (178% for α and 80% for β). The highest percentage variability for Missanello occurs in summer for the *high* rainfall category (36% for α and 34% for β). In summer, year-to-year parameter variability is also high at Alcantarilla for the *low* rainfall category. For Missanello, percentage variability is lower in winter and autumn than other seasons, whereas for Alcantarilla it is lower in spring and autumn than other seasons.

Some relationships between variability and sample size can be identified. At Alcantarilla, for example, except in summer, the shape and scale parameters tend to vary more for rainfall categories with smaller, though not necessarily the smallest, sample size. At Missanello, except in summer, the greatest variability of the shape parameter is associated with the smallest sample size. In winter and summer, the greatest variability of the scale parameter is associated with the largest sample size.

Inspection of the individual parameter values for each year (not shown) indicates that, although the shape and scale parameters vary in value, the relationships between the three rainfall amount categories are maintained from year-to-year. In winter at Alcantarilla, for example, the scale parameter is consistently highest for the *high* rainfall category and lowest for the *low* rainfall category, with the single exception of 1980, when the scale parameter for the *moderate* category (7.4) is slightly lower than that for the *low* rainfall category (7.6). At Missanello in winter, there are no exceptions to the expected relationships.

Tables 6.24 and 6.25 indicate that, even leaving out just one year in 30 (for Alcantarilla) or 33 (for Missanello) causes the NCWG parameter values to vary from year-to-year. Figures 5.50 and 5.51 demonstrate, for Missanello, the variability over time of the probability of rain and the amount of rain per rain day. Different parameter values would be expected if they were calculated over, say, 1979-1988 rather than 1956-1968 or 1969-1978. But which of these sub-periods would be most appropriate for application in future scenario runs, i.e. which is most representative of expected future conditions? Such a decision would not be easy to make. It might, however, be possible to incorporate some of the uncertainty about parameter variability by sampling from a distribution of parameter values rather than using single values. Such a distribution could be constructed by using overlapping decades say, or n-sets of n-randomly selected years. Given the tendency of the parameter values to be sensitive to sampling period and sample size, however, the approach adopted here for the scenario runs (i.e. to use all available data) is considered better than using a shorter time period for parameter estimation.

6.4 SCENARIO RUNS

In the scenario runs, circulation-type sequences are derived from observed data for 1970-1979 and from HadCM2SUL output for 1970-1979, 2030-2039 and 2090-2099 (see Table 6.1 and Section 6.1.2). The NCWG rainfall parameters are calculated using all available data for 1958-1987 (Alcantarilla) or 1956-1988 (Missanello) (see Section 6.2). The results from the four scenario-run simulation sets are summarised in Tables 6.26 to 6.29, focusing on mean seasonal totals for the number of rain days (NRD_m) and rainfall amount (AMT_m).

The mean values from each simulation set, together with the maxima, minima and range across the simulation set, are shown in Tables 6.26 and 6.27 for Alcantarilla and Missanello respectively. The first column of each table shows the observed means for 1970-1979 and the maximum and minimum observed decadal values. Mean values from the OBS1970 and HAD1970 simulation sets which fall outside the observed decadal range are indicated by an asterisk in columns 2 and 3. Mean values from the HAD2030 and HAD2090 simulation sets which fall outside the range of HAD1970 values are indicated by an asterisk in columns 4 and 5.

Tables 6.28 and 6.29 show, for Alcantarilla and Missanello respectively, the number of runs where the mean seasonal totals from the OBS1970 and HAD1970 simulation sets are significantly greater than (Sig. +), smaller than (Sig. -), or not different to (No. diff.), the observed values (calculated for the two sets of ten annual values using the *t*-test and a significance level of 5%) (columns 1 and 2). The tables also show (in columns 3 and 4) the number of runs where HAD2030 and HAD2090 values are significantly greater than, smaller than, or no different to, HAD1970 values and, finally (column 5), HAD2090 and HAD2030 values are compared. These numbers were calculated using the *t*-test (5% significance level) to compare the ten annual values from unranked pairs of runs, e.g. run 1 from the $HAD2030_{Alc}$ simulation set was compared with run 1 from the $HAD1970_{Alc}$ simulation set, run 2 from the $HAD2030_{Alc}$ simulation set was compared with run 2 from the $HAD1970_{Alc}$ simulation set, and so on.

6.4.1 The OBS1970 and HAD1970 simulation sets

The first comparisons made here are between the OBS1970 and HAD1970 simulation sets and the observed values in order to determine whether the NCWG biases and errors identified in the cross-validation runs (Section 6.3) are also evident in the scenario runs. It should be noted that the scenario runs are shorter than the cross-validation runs (10 rather than 30 or 33 years) and independent validation is not possible for the scenario runs because all available data were used to calculate the NCWG parameters. Comparison of the results from the OBS1970 and CVOBS runs also allows investigation of whether or not the NCWG is able to reproduce the particular rainfall characteristics of the decade 1970-1979.

Alcantarilla (Tables 6.26 and 6.28)

Comparison of the observed values in Tables 6.26 and 6.8 indicates that, compared with the period 1958-1987, the observed time series for Alcantarilla for the decade 1970-1979 are characterised by:

- higher number of rain days but lower rainfall amount in winter;
- higher number of rain days and higher rainfall amount in spring and summer; and,
- same number of rain days, but higher rainfall amount in autumn.

Comparison of the $OBS1970_{Alc}$ values in Table 6.26 with the $CVOBS_{Alc}$ values in Table 6.8 indicates that, compared with the simulations for 1958-1987, the simulated time series for Alcantarilla for 1970-1979 are characterised by:

- similar $\overline{NRD}_m$, but lower $\overline{AMT}_m$ in winter;
- higher $\overline{NRD}_m$ and higher $\overline{AMT}_m$ in spring;
- very similar $\overline{NRD}_m$ and $\overline{AMT}_m$ in summer; and,
- slightly higher $\overline{NRD}_m$ and higher $\overline{AMT}_m$ in autumn.

Thus, except in summer, the NCWG has some success in picking up the qualitative differences between the two periods.

Comparison of the $OBS1970_{Alc}$ values with the observed values in Table 6.26 indicates that, compared with the observations for 1970-1979, the simulated time series for Alcantarilla for 1970-1979 are characterised by:

- lower $\overline{NRD}_m$ and higher $\overline{AMT}_m$ in winter;
- similar $\overline{NRD}_m$ and slightly lower $\overline{AMT}_m$ in spring;
- lower $\overline{NRD}_m$ and similar $\overline{AMT}_m$ in summer; and,
- similar $\overline{NRD}_m$ and very much higher $\overline{AMT}_m$ (outside the observed decadal range) in winter.

Except in summer, the percentage of runs in which the mean number of rain days is not significantly different from the observed mean tends to be slightly higher for the $OBS1970_{Alc}$ simulation set (Table 6.28) than for the $CVOBS_{Alc}$ simulation set (Table 6.8), or similar. Both simulation sets share the general tendency of having too few rain days in all seasons except summer. However, the percentage of non-significant differences tends to be higher for the $OBS1970_{Alc}$ simulation set because 1970-1979 has a higher frequency of rain days than the period 1958-1987. For rainfall amount, the percentage of non-significant differences is higher for $OBS1970_{Alc}$ than for $CVOBS_{Alc}$ in all seasons except winter. Rainfall amount is lower in winter during 1970-1979 than 1958-1987 and thus the tendency to overestimate rainfall amount is stronger in the $OBS1970_{Alc}$ simulation set in winter.

Comparison of the $HAD1970_{Alc}$ values with the observed values in Table 6.26 indicates that, compared with the observations for 1970-1979, the simulated time series for Alcantarilla for 1970-1979 are characterised by:

- lower $\overline{NRD}_m$ and similar $\overline{AMT}_m$ in winter;
- very much lower $\overline{NRD}_m$ and $\overline{AMT}_m$ (both outside the observed decadal range) in spring;
- lower $\overline{NRD}_m$ and slightly higher $\overline{AMT}_m$ in summer; and,
- slightly lower $\overline{NRD}_m$ and very much higher $\overline{AMT}_m$ (outside the observed decadal range) in autumn.

These errors are in the same direction as those identified for the $CVHAD_{Alc}$ simulation set (Table 6.16), as expected given the similarity of the errors in simulated circulation-type frequency over the full data period and 1970-1979 (compare Tables 5.11 and 5.14). The percentage of non-significant differences for the number of rain days and rainfall amount is, however, higher for $OBS1970_{Alc}$ (Table 6.28) than for $CVHAD_{Alc}$ (Table 6.16), but the same for rainfall amount in winter. Again this reflects the fact that 1970-1979 (with the exception of rainfall amount in winter) is wetter than the period 1958-1987.

Thus, for Alcantarilla, the biases and errors are generally similar and in the same direction in the $CVOBS_{Alc}$ and $OBS1970_{Alc}$ simulation sets and in the $CVHAD_{Alc}$ and $HAD1970_{Alc}$ simulation sets. In terms of the percentage of non-significant differences compared to the observations, however, performance appears slightly better for the scenario runs than for the cross-validation runs because the decade 1970-1979 is generally wetter than the period 1958-1987 (a characteristic which the $OBS1970_{Alc}$ simulation set has some success in reproducing).

Missanello (Tables 6.27 and 6.29)

Comparison of the observed values in Tables 6.27 and 6.9 indicates that, compared with the period 1956-1988, the observed time series for Missanello for the decade 1970-1979 are characterised by:

- lower number of rain days and higher rainfall amount in winter, spring and summer; and,
- lower number of rain days and slightly lower rainfall amount in autumn.

Comparison of the $OBS1970_{Mis}$ values in Table 6.27 with the $CVOBS_{Mis}$ values in Table 6.9 indicates that, compared with the simulations for 1956-1988, the simulated time series for Missanello for 1970-1979 are characterised by:

- lower $\overline{NRD}_m$ and lower $\overline{AMT}_m$ in winter;
- same $\overline{NRD}_m$ and slightly lower $\overline{AMT}_m$ in spring;
- similar $\overline{NRD}_m$ and slightly higher $\overline{AMT}_m$ in summer; and,
- similar $\overline{NRD}_m$ and $\overline{AMT}_m$ in autumn.

Thus the $OBS1970_{Mis}$ simulation set reproduces the observed fall in the number of winter rain days during 1970-1979 relative to 1956-1988 but does not reproduce any of the other observed differences between the two periods.

Comparison of the $OBS1970_{Mis}$ values with the observed values in Table 6.27 indicates that, compared with the observations for 1970-1979, the simulated time series for Missanello for 1970-1979 are characterised by:

- very much lower $\overline{NRD}_m$ (outside the observed decadal range) and lower $\overline{AMT}_m$ in winter;
- slightly higher $\overline{NRD}_m$ and $\overline{AMT}_m$ in spring;
- slightly higher $\overline{NRD}_m$ and slightly lower $\overline{AMT}_m$ in summer; and,
- slightly higher $\overline{NRD}_m$ and slightly higher $\overline{AMT}_m$ in autumn.

The percentage of runs in which the number of rain days and rainfall amount are not significantly different from observed is consistently higher for the $OBS1970_{Mis}$ simulation set (Table 6.29) than for the $CVOBS_{Mis}$ simulation set (Table 6.9). The latter simulation set tends to have too few rain days, with too much rain on each. These inherent biases in the NCWG are less evident for the decade 1970-1979 than the period 1956-1988 because this particular decade is characterised by fewer rain days with more rainfall on each compared with the full data period.

Comparison of the $HAD1970_{Mis}$ values with the observed values in Table 6.27 indicates that, compared with the observations for 1970-1979, the simulated time series for Missanello for 1970-1979 are characterised by:

- very much lower $\overline{NRD}_m$ (outside the observed decadal range) and lower $\overline{AMT}_m$ in winter and spring; and,
- lower $\overline{NRD}_m$ and lower $\overline{AMT}_m$ in summer and autumn.

These errors are in the same direction as those identified for the $CVHAD_{Mis}$ simulation set (Table 6.17), i.e. both simulation sets tend to be too dry. This is expected given the similarity of the errors in simulating circulation-type frequencies over the full data period and 1970-1979 (compare Tables 5.12 and 5.15). The percentage of non-significant differences for the number of rain days and rainfall amount in the $OBS1970_{Mis}$ simulation set (Table 6.29) is generally higher than (particularly for the number of rain days), or similar to, the percentages for $CVHAD_{Mis}$ (Table 6.17). The greatest difference is for the number of rain days in winter: in the $CVHAD_{Mis}$ simulation set 97% of simulated values are significantly lower than observed in winter, compared with only 1% in $HAD1970_{Mis}$. This reflects the fact that the frequency of rain days is lower in 1970-1979 than over the period 1958-1987. Thus at Missanello, as at Alcantarilla, the NCWG biases are offset, in part, by the particular characteristics of the decade 1970-1979.

As in the case of the UKTR model (Section 3.5), errors in the GCM simulation of the observed circulation types can be traced through to the weather generator results for Alcantarilla and Missanello. Thus the HAD1970 simulation sets, rather than the observed data, are used to provide a baseline for the climate-change scenarios, on the (un-testable) assumption that the errors are consistent throughout the HadCM2SUL run.

6.4.2 The HAD1970, HAD2030 and HAD2090 simulation sets

Alcantarilla (Tables 6.26 and 6.28)

At Alcantarilla, there is a clear trend towards wetter conditions in winter and autumn in 2030-2039 and 2090-2099, i.e. towards higher $\overline{NRD}_m$ and $\overline{AMT}_m$ in the $HAD2030_{Alc}$ and $HAD2090_{Alc}$ simulations sets compared with $HAD1970_{Alc}$ (Table 6.26). The largest change is for the number of rain days in winter 2090-2099 when

$\overline{\text{NRD}}_m$ is higher than the maximum simulated value for 1970-1979 (Table 6.26), and NRD_m is significantly higher than the simulated values for 1970-1979 in 73% of runs (Table 6.28). Spring and summer are somewhat drier in 2030-2039, i.e. $\overline{\text{NRD}}_m$ and $\overline{\text{AMT}}_m$ are lower in the $\text{HAD2030}_{\text{Alc}}$ simulation set than in $\text{HAD1970}_{\text{Alc}}$, and somewhat higher in 2090-2099 (Table 6.26). The percentage of significant differences in mean values is, however, generally low, less than 10% in all seasons except winter (Table 6.28). The only cases where the percentage of significant negative differences is greater than the percentage of significant positive differences are for the number of rain days and rainfall amount in spring and summer 2030-2039. Thus while the general tendency is towards wetter conditions in the two future decades, the changes are relatively small, with differences in the pattern of change in winter and autumn compared with spring and summer. The *t*-test was, however, used to compare the distributions of 1000 NRD_m and AMT_m values from the three simulation sets (results not shown). The only case where significant differences (at the 5% level) were not found was for rainfall amount in autumn in 2090-2099 compared with 2030-2039.

Missanello (Tables 6.27 and 6.29)

At Missanello, the opposite trend to that which occurs at Alcantarilla is found in winter and autumn, i.e. a trend towards lower $\overline{\text{NRD}}_m$ and $\overline{\text{AMT}}_m$ in 2030-2039 and 2090-2099 compared with 1970-1979 (Table 6.27). In spring, $\overline{\text{NRD}}_m$ and $\overline{\text{AMT}}_m$ are somewhat higher in 2030-2039 compared with 1970-1979. In 2090-2099 they are lower than in 2030-2039 but still higher than in 1970-1979. In summer, there are weak trends towards higher $\overline{\text{NRD}}_m$ and $\overline{\text{AMT}}_m$ in 2030-2039 and 2090-2099. None of the $\overline{\text{NRD}}_m$ or $\overline{\text{AMT}}_m$ values for 2030-2039 or 2090-2099 lie outside the simulated range for 1970-1979, although the values in winter 2090-2099 lie very close to the bottom of the range. The percentages of significant differences in NRD_m and AMT_m are generally lower than for Alcantarilla, but do exceed 10% in the following cases: for NRD_m and AMT_m in winter 2030-2039 and 2090-2099 and in autumn 2090-2099 (Table 6.29). As for Alcantarilla, the *t*-test was used to compare the distributions of 1000 NRD_m and AMT_m values from the three simulation sets (results not shown). The only cases where significant differences (at the 5% level) were not found were for the number of rain days and rainfall amount in summer in 2030-2039 compared with 1970-1979 and for rainfall amount in summer in 2090-2099 compared with 2030-2039. In general, however, the changes at Missanello are relatively small. As at Alcantarilla, they are larger in winter and autumn than spring and summer, but are in the opposite direction, i.e. the trend at Missanello is towards drier conditions in winter and autumn whereas the trend at Alcantarilla is towards wetter conditions in the latter seasons.

The daily rainfall scenarios for Alcantarilla and Missanello provided by the HAD1970, HAD2030 and HAD2090 simulations sets are discussed in further detail in Section 6.5.

6.5 EVALUATION OF THE SCENARIOS

6.5.1 Graphical presentation of the scenarios

So far, output from the NCWG has been summarised in table form. Output can also be usefully summarised in the form of frequency distributions. Frequency (i.e. the percentage of 1000 runs) distributions for the scenario runs are shown in Figures 6.9 and 6.10 for Alcantarilla and Missanello respectively. A number of different parameters are shown: NRD_m, NRD_{sd}, AMT_m, AMT_{sd}, rain per rain day, LW and LD (see Table 6.1b). The larger changes identified in Section 6.4.2 can be readily seen in these frequency distributions, i.e. a shift to the right in the NRD_m and AMT_m distributions in winter, and to a lesser extent in autumn, for the $HAD2030_{Alc}$ and $HAD2090_{Alc}$ simulation sets compared with $HAD1970_{Alc}$ (Figure 6.9) and a shift to the left in the NRD_m and AMT_m distributions in winter and autumn for the $HAD2030_{Mis}$ and $HAD2090_{Mis}$ simulation sets compared with $HAD1970_{Mis}$ (Figure 6.10). For the NRD_m and AMT_m distributions, the only case where the HAD2030 and HAD2090 distributions are not significantly different from the HAD1970 distribution is summer, 2030-2039 at Missanello (see Section 6.4.2).

6.5.2 Representation of uncertainty

There is growing interest in the treatment of uncertainty in climate-change scenarios and impact assessments (see Carter *et al*. (1999) for a recent assessment of these issues in the context of European impact assessments). The range of possible future climate changes indicated by the HAD1970, HAD2030 and HAD2090 simulation sets was calculated in the following way. First, the runs making up each simulation set were ranked on the basis of their mean annual number of rain days from 1 (fewest rain days) to 1000 (most rain days). Seasonal differences between the mean number of rain days and mean rainfall amount were calculated for each ranked pair for HAD2030 minus HAD1970 to give the 2030-2039 minus 1970-1979 change, and for HAD2090 minus HAD1970 to give the 2090-2099 minus 1970-1979 change. For each set of differences, the 0.1, 0.25, 0.5, 0.75 and 0.9 quantile values were calculated and are shown in Tables 6.30 and 6.31 for Alcantarilla and Missanello respectively.

Alcantarilla (Table 6.30)

For Alcantarilla, the largest changes are indicated in winter when the mean number of rain days and mean rainfall amount increase, by 3.3 days (27%) and 25 mm (30%) respectively for 2030-2039 at the 0.5 quantile level and by 6 days (50%) and 28 mm (34%) for 2090-2099. Smaller increases are indicated in autumn, 1.4 days (11%) and 7 mm (5%) for 2090-2099 at the 0.5 quantile level. In spring and summer, small decreases are indicated at the 0.5 quantile level for 2030-2039 (6-15%), with smaller (in absolute terms) increases for 2090-2099 (4-10%). The quantile changes illustrate the wide range of uncertainty associated with these scenarios. The 0.1 and 0.9 quantile values have the same sign (positive) in winter only. In all other seasons they have the opposite sign, indicating that there is uncertainty about the direction as well as the magnitude of change.

Missanello (Table 6.31)

For Missanello, the largest changes are also indicated in winter when the mean number of rain days and mean rainfall amount decrease by 4.7 days (19%) and 51 mm (22%) respectively at the 0.5 quantile level for 2030-2039 and by 5.9 days (24%) and 71 mm (31%) for 2090-2099. Smaller decreases are indicated in autumn, -3 days (14%) and -40 mm (19%) for 2090-2099. Small (2-7%) increases in the number of rain days and rainfall amount are indicated in spring and summer at the 0.5 quantile level. As for Alcantarilla, there is a wide range of uncertainty associated with the magnitude and direction of change. The 0.1 and 0.9 quantile values are only of the same sign (negative) in winter 2039-2039 and 2090-2099 and autumn 2090-2099.

6.5.3 Scenario selection

Running the NCWG 1000 times increases the Monte Carlo or probabilistic element compared with the original CWG which was only run 100 times. Uncertainties, reflecting the spread of results obtained, can be represented using frequency distributions (Section 6.5.1) or quantile changes (Section 6.5.2). For most impact assessments it is not practical to evaluate 1000 climate-change scenarios. There are, however, a number of different ways in which a smaller number of scenarios can legitimately be sampled from the larger population of simulation sets.

One possibility is to use ranked pairs selected on the ability of the HAD1970 runs to reproduce observed rainfall, thus taking some account of systematic errors in the NCWG and the underlying GCM. The procedure is to take the ranked pairs (ranked on the basis of the annual total number of rain days, see Section 6.5.2) and to identify all the HAD1970 runs for which the mean number of rain days, or both the mean number of rain days and rainfall amount, for each season fall within the observed decadal range (these ranges are shown in Tables 6.26 and 6.27). For Alcantarilla, 63 runs meet the rain day only criterion and 11 meet the rain day and rainfall amount criteria. The majority of the selected runs lie within the top 25% of the ranked runs (and all lie within the upper 50%), reflecting the tendency for the $HAD1970_{Alc}$ simulation set to underestimate rainfall (see Section 6.4.1). For Missanello, 33 runs meet the rain day only criterion and 20 meet the rain day and rainfall amount criteria. All these runs lie within the top 20% of the ranked runs, reflecting the same tendency for the $HAD1970_{Mis}$ simulation set to underestimate rainfall (see Section 6.4.1). A second possibility exists in the case where only one reference scenario is required. Then, one HAD1970 run can be selected at random from all those meeting the desired criteria. Say the randomly selected HAD1970 run for Alcantarilla is ranked 989th on the basis of mean annual number of rain days, then the HAD2030 and HAD2090 runs ranked 989th are selected to complete the reference scenario.

Based on the assumptions that the HadCM2SUL errors are consistent throughout the GCM run and that the NCWG errors are also consistent across all three simulation sets, the methods of selecting scenarios described above are considered superior to randomly selecting unranked pairs of runs. For the purposes of some climate-impact sensitivity studies, however, it may be advantageous to adopt a third approach in which non-ranked pairs of runs are selected from the distribution tails in order to maximise the change in a particular season. If, say, the aim is to explore the impacts of future wetter winters on riverflow in the Guadalentin Basin, an extreme scenario could be constructed by selecting a run from the $HAD1970_{Alc}$ simulation set with winter mean rainfall amount close to the mean value for this simulation set (i.e. 57 mm, Table 6.26) and then selecting the runs from the $HAD2030_{Alc}$ and $HAD2090_{Alc}$ simulation sets with the maximum winter rainfall amount (i.e. 127 mm and 142 mm respectively).

6.5.4 Changes in persistence and extreme events

Length of wet/dry day spells (Tables 6.32 and 6.33)

LW (length of the longest wet day spell) and LD (length of the longest dry day spell) parameters for the HAD1970, HAD2030 and HAD2090 simulation sets are summarised for each season in Tables 6.32 and 6.33 for Alcantarilla and Missanello respectively. The mean value for each simulation set is shown, together with the maximum, minimum and range. The NCWG has a general tendency to underestimate the persistence of wet and dry day spells (Section 6.3) so the tables can only be used as a guide to the trends in persistence. It should also be noted that the LW and LD values are smaller than those obtained from the CVHAD simulation sets (Tables 6.20 and 6.21) because they are calculated over 10 years rather than 30 or 33 years.

As expected, the changes in LW and LD largely reflect the changes in the number of rain days (Tables 6.30 and 6.31), i.e. LW increases and LD decreases with higher number of rain days. Thus at both stations, the largest changes occur in winter and the changes in spring and summer are small. At Alcantarilla in winter (where the 0.5 quantile change in the number of rain days at 2090-2099 is +6 days, Table 6.30), mean LW increases from 5.4 days in 1970-1979 to 6.6 days in 2090-2099 and mean LD decreases from 44 to 33 days (the maximum LW value increases from 11 to 16 days, while the maximum LD value decreases from 90 to 61 days). At Missanello in winter (where the 0.5 quantile change in the number of rain days is -4.7 days at 2030-2039 and -5.9 days at 2090-2099, Table 6.31), mean LW decreases from 7.8 days in 1970-1979 to 6.4 days in 2090-2099. LD increases, but the mean, maximum and minimum LD values are all slightly higher in 2030-2039 than in 2090-2099.

Extreme event analysis

Results of an extreme event analysis (see Section 6.3.1 for details of the method) for the HAD1970, HAD2030 and HAD2090 simulation sets are summarised in Tables 6.34 and 6.35 for Alcantarilla and Missanello respectively. The mean, maximum and minimum values and range are shown for annual daily rainfall maxima events with return periods of 5, 10, 20 and 50 years (T5, T10, T20 and T50). The ability of the NCWG to reproduce the observed extreme events is considered in Sections 6.3.1 and 6.3.2. Further caution is needed here, because only 10 years of data are available to fit the GEV distributions and additional extrapolation is needed to estimate the magnitude of the T20 and T50 events.

Alcantarilla (Tables 6.34 and 6.36)

At Alcantarilla, there are small increases in the magnitude of the return period events between 1970-1979 and 2030-2039 (up to 2 mm for the mean T50 event or 17 mm for the maximum T50 event), with little further change at 2090-2099. These changes appear small relative to the largest changes in rainfall amount which occur (Table 6.30). However, the time of year at which the annual maxima tend to occur needs to be considered. Table 6.36 shows the percentage of all annual maxima (i.e. the percentage of 10,000 values (10 years x 1000 runs)) which occur in each season for the

$HAD1970_{Alc}$, $HAD2030_{Alc}$ and $HAD2090_{Alc}$ simulation sets, and for the observed data (1958-1987). In comparison to the observations, the NCWG overestimates the percentage of annual maxima which occur in autumn and underestimates the percentage in summer. In all three simulation sets, however, about 75% of the annual maxima occur in summer and autumn, both seasons in which there is uncertainty about the direction and magnitude of change (Table 6.30). There is a small increase in the percentage of annual maxima which occur in winter during the future decades, reflecting the larger increases in rainfall amount which occur in this season.

Missanello (Tables 6.35 and 6.37)

At Missanello, there are small decreases in the magnitude of the return period events (up to -7 mm for the mean T50 event). An interesting feature of these results is that, although the magnitude of the return period events decreases, the range of values increases, i.e. the maximum values are largest at 2090-2099 and the minimum values smallest (giving an increase of 18 mm in the magnitude of the maximum T50 event between 1970-1979 and 2090-2099). The seasons in which annual maxima occur are indicated in Table 6.37. About 84% of observed values occur in winter and autumn, this percentage is somewhat lower (72%) in the $HAD1970_{Mis}$ simulation set. Rainfall amount decreases in winter, and to a lesser extent in autumn (Table 6.31), hence decreases in the magnitude of extreme events are expected. The percentage of annual maxima which occurs in autumn is similar in all three simulation sets, but the percentage of events which occurs in winter decreases from 43% in 1970-1979 to 35% in 2030-2039 and to 33% in 2090-2099. This is compensated for by increases in the percentage of events which occur in spring (from 18% in 1970-1979 to 24% in 2090-2099), and to a lesser extent in summer (from 10% in 1970-1979 to 14% in 2090-2099).

6.5.5 Links between changes in rainfall and circulation-type frequency

Mean seasonal changes in the frequency of the circulation types between 1970-1979 and 2030-2039/2090-2099 are summarised in Tables 5.24 and 5.25 for the Guadalentin (Alcantarilla) and the Agri (Missanello) respectively. Changes in the mean seasonal cycles are shown in Figures 5.59 and 5.60. How do these changes in circulation-type frequency relate to the changes in rainfall indicated by the NCWG?

In terms of statistically significant changes in circulation-type frequency, the changes are greater at 2090-2099 than at 2030-2039 and greater in the Guadalentin than in the Agri (Section 5.7.2). There is also a strong contrast in the pattern of change in winter in the two regions. At 2090-2099, for example, there are significant increases in the frequency of the C, HYC and UC circulation types in the Guadalentin (Table 5.24), together with non-significant decreases in the frequency of the A and HYA-types, while in the Agri there are significant decreases in the frequency of the C and HYC-types and significant increases in the A and HYA-types (Table 5.25). The different patterns of circulation-type change in the two regions reflect the different pattern of change in SLP in winter (see Section 5.7.1 and Figures 5.57 and 5.58). SLP falls over the Northeast Atlantic and over the Iberian Peninsula in winter, but increases over the Mediterranean, reflecting the decreased land-sea temperature contrast (Mitchell and Johns, 1997). There is a broadly similar pattern of change in SLP, and hence in circulation-type frequency, in autumn, although the changes are weaker in autumn than in winter (Sections 5.7.1 and 5.7.2).

In Section 5.7.2 it was concluded that the changes in the frequency of the cyclonic (high-rainfall) and anticyclonic (low-rainfall) circulation types are expected to contribute to increased rainfall in the Guadalentin and to decreased rainfall in the Agri during winter, with larger changes in 2090-2099 than in 2030-2039 and a similar, but weaker, pattern of change in autumn. These expected changes are in agreement with the changes indicated by the HAD1970, HAD2030 and HAD2090 simulation sets (Tables 6.30 and 6.31). At Alcantarilla in winter, the changes in the cyclonic and anticyclonic types are reinforced by significant increases in the high-rainfall (Table 5.9) E, SE, S and SW circulation types (Table 5.24). In autumn, there are non-significant increases in the E, SE and S high-rainfall types. At Missanello in winter, there is a significant increase in the high-rainfall (Table 5.10) SE-type in 2090-2099, but this change is relatively small in comparison to the changes in cyclonic and anticyclonic circulation types (Table 5.25).

More significant and consistent changes in circulation-type frequency occur in winter, and to a lesser extent in autumn, than in spring and summer. In Section 5.7.2 it was concluded that it is not possible to identify the expected pattern of rainfall change in spring and summer from the circulation-type changes. At Alcantarilla, spring and summer tend to be slightly drier at 2030-2039 than at 1970-1979, and slightly wetter at 2090-2099 (Table 6.30). In these seasons, the C, HYC, E and SE-types are identified as high-rainfall types (Table 5.9). The changes in these types are not consistent (i.e. they do not all decrease or increase in frequency), but the balance of change in these types is consistent with the pattern of rainfall change: in 2030-2039 the total change in these types is -1.9 days in spring and -3.6 days in summer (suggesting drier conditions), compared with +0.5 days in spring and +2.0 days in summer in 2090-2099 (suggesting wetter conditions). The C, HYC, E and SE-types are also identified as high-rainfall types for Missanello in spring (Table 5.10). The balance of change in these types is +1.4 days in 2030-2039 and +1.5 days in 2090-2099, consistent with the small increase in spring rainfall (Table 6.31). In summer, however, the balance of change (+0.1 days at 2030-2039 and -1.7 days at 2090-2099) in the high-rainfall types (see Table 5.10) is not consistent with the rainfall changes at Missanello (i.e. drier in 2030-2039 and wetter in 2090-2099).

Thus the largest changes in rainfall (i.e. those associated with the greatest certainty, see Tables 6.30 and 6.31), can be linked with the largest and most consistent changes in circulation-type frequency identified in Section 5.7.2. The rainfall changes do not appear to be driven by a change in any one particular circulation type, but rather by a combination of changes. Thus in winter, the increased frequency of the high-rainfall cyclonic types in the Guadalentin is reinforced by the increased frequency of the high-rainfall E, SE, S and SW-types and the decreased frequency of the low-rainfall anticyclonic types, resulting in a trend towards wetter winter conditions. In the Agri, in contrast, the decreased frequency of the high-rainfall cyclonic types in winter is reinforced by the increased frequency of the low-rainfall anticyclonic types, resulting in a trend towards drier winter conditions. There are fewer significant or consistent changes in circulation-type frequency in spring and summer than in winter and autumn. This is reflected in the greater uncertainty about the magnitude and direction of change in rainfall in spring and summer.

6.5.6 Comparison of the UKTR and HadCM2SUL rain day scenarios

The changes in the number of rain days at Alcantarilla indicated by the NCWG and HadCM2SUL output (Table 6.30) can be compared with the mean changes indicated by the original CWG and UKTR output (Tables 3.6 and 3.7). The UKTR perturbed results are for the final decade of the perturbed run (Years 66-75) during which the atmospheric CO_2 concentration doubles with respect to the pre-industrial value of 323 ppmv. In the HadCM2SUL experiment, the equivalent atmospheric CO_2 forcing evolves as follows (Mitchell and Johns, 1997):

1765 - 323 ppmv
1860 - 341 ppmv
1960 - 386 ppmv
1990 - 473 ppmv
2025 - 670 ppmv

2050 - 859 ppmv

2100 - 1414 ppmv.

Thus the equivalent atmospheric CO_2 concentration has more than doubled from the pre-industrial level of 323 ppmv by 2030-2039. The net radiative forcing from 1860 to 2100 is, however, reduced due to the negative contribution from the direct effects of sulphate aerosols (Mitchell and Johns, 1997). This contribution is -1.14 W m^{-2} at 2025 (giving a total net radiative forcing of +2.52 W m^{-2}) and -1.45 W m^{-2} at 2100 (giving a total net radiative forcing of +5.95 W m^{-2}). The baseline for the CWG rain-day changes is taken from the UKTR control run in which the equivalent atmospheric CO_2 concentration is only 323 ppmv, whereas the baseline for the NCWG/HadCM2SUL rain-day changes is the model period 1970-1979, when the atmospheric CO_2 concentration is considerably higher than the pre-industrial concentration (although offset to some extent by sulphate forcing – the net radiative forcing is +0.45 W m^{-2} in 1960 and +1.27 W m^{-2} in 1990 (Mitchell and Johns, 1997)). Thus the results from the two weather generators are not directly comparable. Nonetheless, it is interesting to compare the pattern of change in the two models.

In both the NCWG (Table 6.30) and CWG (Table 3.7) simulations, the direction of change is the same in winter and autumn (an increase in the number of rain days), although even at 2030-2039 the 0.5 quantile NCWG changes are larger than the mean CWG changes. In the NCWG simulations, the largest rain-day changes occur in winter (and to a lesser extent in autumn), reflecting the larger changes in SLP and circulation-type frequency which occur in this season in the HadCM2SUL model (see Section 6.5.5). In the UKTR model, the largest changes in circulation-type frequency occur in summer (Section 2.5), which is when the largest rain-day changes occur in the CWG simulations (Section 3.5). The CWG change in the number of summer rain days (a positive change) is in the opposite direction to the 0.5 quantile NCWG change in 2030-2039 but in the same direction as the 2090-2099 change. In spring, the CWG rain-day change is the same as the 0.5 quantile NCWG change for 2030-2039 (-0.7 days), but in the opposite direction to the 2090-2099 change.

Thus there are clear differences in the pattern of rain-day changes indicated by the NCWG and CWG generators, reflecting the different forcing and patterns of SLP change in the two GCMs and hence in circulation-type change (see Sections 5.7.1 and 5.7.2 for a discussion of these differences).

6.5.7 Comparison of the downscaled scenarios and raw model changes

The raw HadCM2SUL changes in mean seasonal rainfall for two grid boxes closest to the study areas are shown in Tables 6.38 (the Guadalentin) and 6.39 (the Agri). Both study areas are located within a sea grid box, but changes for the nearest land grid box are also shown in the tables. The changes for 2030-2039 and 2090-2099 are expressed as a percentage of the grid box mean for 1970-1979. This mean is shown, together with the observed station mean for 1970-1979 and the HAD1970 simulation-set mean (taken from Tables 6.26 and 6.27) for Alcantarilla and Missanello.

The HadCM2SUL grid box changes are not very consistent between seasons, land and sea grid boxes, or time period. The only changes which are consistent across both grid boxes and both time periods, are increases in spring rainfall and decreases in autumn rainfall in both regions.

In winter, the grid box values indicate an increase in rainfall for the Guadalentin (except for the land box in 2030-2039), which is in agreement with the downscaled pattern of change for Alcantarilla (Table 6.30). For the Agri, the grid box values indicate a decrease in rainfall (except for the land box in 2030-2039), which is also in agreement with the downscaled pattern of change for Missanello (Table 6.31). In autumn, however, all grid box values for both regions indicate a decrease in rainfall, which is consistent with the downscaled scenario for Missanello, but not for Alcantarilla (where rainfall increases in autumn). In spring, all grid box values for both regions indicate an increase in rainfall. This is consistent with the 0.5 quantile changes in the downscaled scenarios, except for Alcantarilla in 2030-2039. In summer, the patterns of change in HadCM2SUL and the downscaled scenarios are more complex. Changes are, however, in the same direction in 2030-2039 in both regions (i.e. positive in the Agri and negative in the Guadalentin) and, for the sea box only, in the Guadalentin in 2090-2099 (positive).

In total, there are eight cases out of 16 (i.e. 4 seasons x 2 grid boxes x 2 time periods) in the Guadalentin, and three cases out of 16 in the Agri, where the raw HadCM2SUL and 0.5 quantile changes in the downscaled scenarios are in the opposite direction. The strongest disagreement (i.e. all four cases) occurs in autumn for the Guadalentin. Inconsistencies were also found between the raw UKTR rain-day changes and the original CWG rain-day scenarios for the Guadalentin (Section 4.5). In the discussion in Section 4.5, it is noted that it is not unusual for empirical downscaling methods to produce changes which are of the opposite sign to the raw GCM changes (see also Semenov and Barrow, 1997; Wilby *et al*., 1998b; Busuioc *et al*., 1999; Giorgi and Mearns, 1999; Mearns *et al*., 1999). It is noted that other studies have also found that precipitation changes indicated by circulation-based downscaled scenarios are smaller in magnitude than the raw GCM changes, and are also small in comparison to the observed variability and errors in the underlying predictor variables (Wilby and Wigley, 1997; Schnur and Lettenmaier, 1998; Wilby *et al*., 1998a; Buishand and Brandsma, 1999; Wilby *et al*., 1999; Zorita and von Storch, 1999). The downscaled scenarios constructed using the NCWG and HadCM2SUL output indicate larger changes than those from the scenarios constructed using the CWG and UKTR output (Section 6.5.6), but these changes are generally smaller in percentage terms than the raw GCM changes (compare the 0.5 quantile values in Tables 6.30 and 6.31 with the raw GCM values in Tables 6.38 and 6.39). These issues are discussed further in Chapter 7.

Comparison of the mean seasonal rainfall totals calculated from raw HadCM2SUL output with the observed station values for 1970-1979 very clearly shows that the raw GCM values do not provide an adequate representation of the station data (Tables 6.38 and 6.39). The land box values are somewhat closer to observed values than the sea box values (as might be expected, although both study areas are actually located in the sea boxes), but all grid box values are consistently much too low for both regions. In comparison, the HAD1970 values shown in Tables 6.38 and 6.39 are much closer to the observed values. The autumn rainfall maximum in the Guadalentin, for example, is successfully reproduced by the downscaled values but not by the raw GCM values. Thus the downscaled series are considered to provide more plausible scenarios for Alcantarilla and Missanello than the raw GCM changes.

A circulation-based approach to downscaling has been successfully used here to construct daily rainfall scenarios for two Mediterranean stations. A number of issues are, however, raised by the results presented in Chapters 5 and 6. These are discussed further in Chapter 7, together with ways in which the methodology might be further refined and developed.

6.6 SUMMARY OF CONCLUSIONS

- A new conditional weather generator (NCWG) is developed in which rainfall occurrence is dependent on the circulation type of each day and on whether the previous day was wet or dry. Rainfall amount is dependent on the circulation type of each day. Circulation-type sequences are taken directly from the observations or GCM output. In each simulation set, the NCWG is run 1000 times.

- In the cross-validation runs, mean rainfall is well simulated when circulation-type sequences are taken from the observations, but variance and persistence are underestimated. Systematic errors occur when the circulation-type sequences are taken from HadCM2SUL output. In particular, simulated rainfall tends to be too low in the Guadalentin and Agri. This bias can be traced back to the underestimation of the frequency of the cyclonic circulation types and the overestimation of the frequency of the anticyclonic types by HadCM2SUL. There is, however, no additional loss of variance or persistence when circulation-type sequences are taken from the GCM.
- The NCWG is used to construct daily rainfall scenarios for the Guadalentin and Agri for 1970-1979, 2030-2039 and 2090-2099. A number of different ways of presenting and evaluating the scenarios are discussed, including ranges, quantiles, frequency distributions and ranked/unranked pairs. It is possible to distinguish between changes in which confidence is higher (i.e. increased rainfall in the Guadalentin in winter and autumn and decreased rainfall in the Agri in these seasons) and changes in which confidence is low (i.e. the changes in spring and summer in both regions).

Table 6.1a: Summary of the new conditional weather generator simulation runs.

Scenario set	*Parameters*	*Circulation-type sequences*
$CVOBS_{Alc}$	Calculated from observations, 1958-1987, using all available data except that for the year being simulated	Derived from observations, 1958-1987
$CVHAD_{Alc}$	Calculated from observations, 1958-1987, using all available data except that for the year being simulated	Derived from observations, 1958-1987
$OBS1970_{Alc}$	Calculated from observations, 1958-1987	Derived from observations, 1970-1979
$HAD1970_{Alc}$	Calculated from observations, 1958-1987	Derived from HadCM2SUL output, 1970-1979
$HAD2030_{Alc}$	Calculated from observations, 1958-1987	Derived from HadCM2SUL output, 2030-2039
$HAD2090_{Alc}$	Calculated from observations, 1958-1987	Derived from HadCM2SUL output, 2090-2099
$CVOBS_{Mis}$	Calculated from observations, 1956-1988, using all available data except that for the year being simulated	Derived from observations, 1956-1988
$CVHAD_{Mis}$	Calculated from observations, 1956-1988, using all available data except that for the year being simulated	Derived from observations, 1956-1988
$OBS1970_{Mis}$	Calculated from observations, 1956-1988	Derived from observations, 1970-1979
$HAD1970_{Mis}$	Calculated from observations, 1956-1988	Derived from HadCM2SUL output, 1970-1979
$HAD2030_{Mis}$	Calculated from observations, 1956-1988	Derived from HadCM2SUL output, 2030-2039
$HAD2090_{Mis}$	Calculated from observations, 1956-1988	Derived from HadCM2SUL output, 2090-2099

Table 6.1b: Summary of the diagnostic statistics used to summarise output from the new conditional weather generator.

Abbreviation	*Description*
NRD_m	Mean number of rain days calculated over one run (i.e. over 30, 33 or 10 years)
AMT_m	Mean rainfall amount (mm) calculated over one run (i.e. over 30, 33 or 10 years)
$\overline{NRD}_m$	Mean number of rain days calculated over one simulation set (i.e. the mean of 1000 values)
$\overline{AMT}_m$	Mean rainfall amount (mm) calculated over one simulation set (i.e. the mean of 1000 values)
NRD_{sd}	Year-to-year standard deviation for the number of rain days calculated over one run (i.e. over 30, 33 or 10 years)
AMT_{sd}	Year-to-year standard deviation for rainfall amount calculated over one run (i.e. over 30, 33 or 10 years)
$\overline{NRD}_{sd}$	Mean year-to-year standard deviation for the number of rain days calculated over one simulation set (i.e. the mean of 1000 values)
$\overline{AMT}_{sd}$	Mean year-to-year standard deviation for rainfall amount calculated over one simulation set (i.e. the mean of 1000 values)
LW	Length in days of the longest wet day spell
LD	Length in days of the longest dry day spell
$\overline{LW}$	Mean length in days of the longest wet day spell calculated over one simulation set (i.e. the mean of 1000 values)
$\overline{LD}$	Mean length in days of the longest dry day spell calculated over one simulation set (i.e. the mean of 1000 values)
T5, T10, T20, T50	Annual daily rainfall maxima with return periods of 5, 10, 20 and 50 years

Table 6.2: Total number of circulation-type days (No. CTs.) and rainfall occurrence parameters (P_{ww}, P_{wd}, P_{dw} and P_{dd}) for the new conditional weather generator calculated for Alcantarilla, 1958-1987.

	C/HYC	*UC*	*A/HYA*	*UA*	*N*	*NE*	*E/SE*	*S/SW*	*W/NW*
Winter									
No. CTs.	185	85	571	241	361	153	62	137	352
P_{ww}	.56	.56	.29	.29	.22	.26	.84	.53	.23
P_{wd}	.44	.44	.71	.71	.78	.74	.16	.47	.77
P_{dw}	.39	.15	.05	.09	.05	.10	.46	.24	.09
P_{dd}	.61	.85	.95	.91	.95	.90	.54	.76	.91
Spring									
No. CTs.	413	378	259	403	244	112	83	131	228
P_{ww}	.64	.29	.08	.17	.04	.34	.75	.21	.21
P_{wd}	.36	.71	.92	.82	.96	.66	.25	.79	.79
P_{dw}	.29	.13	.02	.05	.07	.11	.33	.16	.07
P_{dd}	.71	.87	.98	.95	.93	.89	.67	.84	.93
Summer									
No. CTs.	587	942	55	413	56	49	52	38	48
P_{ww}	.28	.28	.00	.24	.00	.00	1.0	.00	.00
P_{wd}	.72	.72	1.0	.76	1.0	1.0	.00	.00	1.0
P_{dw}	.08	.03	.00	.02	.02	.08	.11	.03	.00
P_{dd}	.92	.97	1.0	.98	.98	.92	.89	.97	1.0
Autumn									
No. CTs.	240	445	410	452	204	79	83	115	166
P_{ww}	.51	.48	.23	.34	.16	.50	.65	.37	.32
P_{wd}	.49	.52	.77	.66	.84	.50	.35	.63	.68
P_{dw}	.28	.12	.04	.07	.03	.14	.35	.13	.03
P_{dd}	.72	.88	.96	.93	.97	.86	.65	.87	.97

Table 6.3: The total number of circulation-type days (No. CTs.) and rainfall occurrence parameters (P_{ww}, P_{wd}, P_{dw} and P_{dd}) for the new conditional weather generator calculated for Missanello, 1956-1988.

	C/HYC	*UC*	*A/HYA*	*UA*	*N*	*NE*	*E/SE*	*S*	*SW/W*	*NW*
Winter										
No. CTs.	754	265	117	268	95	142	285	234	204	54
P_{ww}	.68	.42	.26	.32	.17	.33	.54	.39	.39	.38
P_{wd}	.32	.58	.74	.68	.83	.67	.46	.61	.61	.62
P_{dw}	.46	.08	.06	.07	.12	.14	.27	.23	.22	.10
P_{dd}	.54	.92	.94	.93	.88	.86	.73	.77	.78	.90
Spring										
No. CTs.	515	421	226	539	162	71	122	195	177	96
P_{ww}	.75	.53	.21	.36	.41	.33	.57	.31	.48	.40
P_{wd}	.25	.47	.79	.64	.59	.67	.43	.69	.52	.60
P_{dw}	.44	.17	.09	.06	.16	.21	.30	.12	.20	.16
P_{dd}	.56	.83	.91	.94	.84	.79	.70	.88	.80	.84
Summer										
No. CTs.	301	800	96	839	278	70	4	22	28	73
P_{ww}	.56	.51	.25	.25	.37	.57	.00	.00	.75	.14
P_{wd}	.44	.49	.75	.75	.63	.43	1.0	1.0	.25	.86
P_{dw}	.15	.10	.02	.07	.11	.11	.50	.05	.04	.09
P_{dd}	.85	.90	.98	.93	.89	.89	.50	.95	.96	.91
Autumn										
No. CTs.	465	492	146	661	68	84	223	156	135	18
P_{ww}	.68	.41	.11	.22	.41	.33	.67	.65	.51	.50
P_{wd}	.32	.59	.89	.78	.59	.67	.33	.35	.49	.50
P_{dw}	.41	.12	.03	.05	.17	.22	.23	.18	.33	.27
P_{dd}	.59	.88	.97	.95	.83	.78	.77	.82	.67	.73

Table 6.4: The three rainfall amount categories identified for Alcantarilla.

Category	*Winter*	*Spring*	*Summer*	*Autumn*
High	NE, E/SE	E/SE	C/HYC, S/SW	NE, E/SE
Low	S/SW, W/NW	A/HYA, N, S/SW, W/NW	UC, A/HYA, N, NE, W/NW	N, S/SW, W/NW
Moderate	C/HYC, UC, A/HYA, UA, N	C/HYC, UC, UA, NE	UA, E/SE	C/HYC, UC, A/HYA, UA

Table 6.5: The three rainfall amount categories identified for Missanello.

Category	*Winter*	*Spring*	*Summer*	*Autumn*
High	HYC, E/SE	C/HYC, E/SE	UC, A, NE, NW	C/HYC, E/SE, S, NW
Low	UC, A/HYA, UA, N, NE, S, SW/W, NW	A/HYA, UA, N, NE, S, W, NW	HYC, HYA, N, E/SE, S, SW/W	UC, A/HYA, UA, N, NE
Moderate	C	UC, SW	C, UA	SW/W

Table 6.6: Shape (α) and scale (β) parameters for the gamma distribution calculated for the three rainfall amount categories at Alcantarilla. The final column indicates cases where the gamma distribution is rejected at the 5% level using the Kolmogorov-Smirnov test (*) or the χ^2 test (+).

	Shape (α) parameter	*Scale (β) parameter*	*Number of Observations*	*Distribution Testing*
Winter				
High	0.52	20.0	59	
Low	0.28	7.4	78	* +
Moderate	0.48	9.0	208	*
Spring				
High	0.77	13.9	33	
Low	0.79	2.2	65	
Moderate	0.67	9.6	269	+
Summer				
High	0.64	16.3	52	
Low	0.20	19.2	53	*
Moderate	0.45	17.0	24	
Autumn				
High	0.61	24.3	59	
Low	0.32	8.2	40	*
Moderate	0.32	22.0	225	*

Table 6.7: Shape (α) and scale (β) parameters for the gamma distribution calculated for the three rainfall amount categories at Missanello. The final column indicates cases where the gamma distribution is rejected at the 5% level using the Kolmogorov-Smirnov test (*) or the χ^2 test (+).

	Shape (α) parameter	*Scale (β) parameter*	*Number of Observations*	*Distribution Testing*
Winter				
High	0.51	24.0	296	*
Low	0.83	7.4	267	
Moderate	1.00	9.1	238	+
Spring				
High	0.81	13.3	340	
Low	1.23	4.5	230	
Moderate	0.79	9.0	138	
Summer				
High	0.79	13.7	146	
Low	0.92	6.7	78	
Moderate	0.96	9.2	113	
Autumn				
High	0.93	13.0	388	+
Low	0.81	8.4	191	
Moderate	2.03	4.8	54	

Table 6.8: Summary of results for the $CVOBS_{Alc}$ (Alcantarilla) simulation set. NRD = number of rain days. AMT = total seasonal rainfall (mm).

6.8a: Winter	*NRD*	*AMT*
Observed mean, 1958-1987	14.8	65.3
Simulation-set mean: $\overline{NRD}_m$ / $\overline{AMT}_m$	13.3	75.1
Maximum simulated mean: Max(NRD_m) / Max(AMT_m)	16.0	122.0
Minimum simulated mean: Min(NRD_m) / Min(AMT_m)	10.4	53.5
Range of simulated means: Range(NRD_m) / Range(AMT_m)	5.6	68.5
Number of runs where the simulated mean (NRD_m / AMT_m) is significantly higher than the observed mean	0	27
Number of runs where the simulated mean (NRD_m / AMT_m) is significantly lower than the observed mean	33	0
Number of runs where the simulated mean (NRD_m / AMT_m) is not significantly different to the observed mean	967	973
Mean correlation between observed/simulated time series of seasonal totals	+0.33	+0.18
Highest positive correlation between observed/simulated time series of seasonal totals	+0.79	+0.78
Highest negative correlation between observed/simulated time series of seasonal totals	-0.37	-0.44

6.8b: Spring	*NRD*	*AMT*
Observed mean, 1958-1987	14.7	87.0
Simulation-set mean: $\overline{NRD}_m$ / $\overline{AMT}_m$	14.4	91.6
Maximum simulated mean: Max(NRD_m) / Max(AMT_m)	16.7	119.0
Minimum simulated mean: Min(NRD_m) / Min(AMT_m)	10.9	51.5
Range of simulated means: Range(NRD_m) / Range(AMT_m)	5.8	67.5
Number of runs where the simulated mean (NRD_m / AMT_m) is significantly higher than the observed mean	0	1
Number of runs where the simulated mean (NRD_m / AMT_m) is significantly lower than the observed mean	2	2
Number of runs where the simulated mean (NRD_m / AMT_m) is not significantly different to the observed mean	998	997
Mean correlation between observed/simulated time series of seasonal totals	+0.28	+0.22
Highest positive correlation between observed/simulated time series of seasonal totals	+0.73	+0.73
Highest negative correlation between observed/simulated time series of seasonal totals	-0.20	-0.35

6.8c: Summer	*NRD*	*AMT*
Observed mean, 1958-1987	5.2	36.9
Simulation-set mean: $\overline{NRD}_m$ / $\overline{AMT}_m$	5.1	43.3
Maximum simulated mean: Max(NRD_m) / Max(AMT_m)	14.8	98.2
Minimum simulated mean: Min(NRD_m) / Min(AMT_m)	3.4	26.3
Range of simulated means: Range(NRD_m) / Range(AMT_m)	11.3	71.9
Number of runs where the simulated mean (NRD_m / AMT_m) is significantly higher than the observed mean	23	43
Number of runs where the simulated mean (NRD_m / AMT_m) is significantly lower than the observed mean	22	0
Number of runs where the simulated mean (NRD_m / AMT_m) is not significantly different to the observed mean	955	957
Mean correlation between observed/simulated time series of seasonal totals	-0.02	-0.04
Highest positive correlation between observed/simulated time series of seasonal totals	+0.65	+0.58
Highest negative correlation between observed/simulated time series of seasonal totals	-0.65	-0.56

6.8d: Autumn	*NRD*	*AMT*
Observed mean, 1958-1987	13.3	100.2
Simulation-set mean: $\overline{NRD}_m$ / $\overline{AMT}_m$	13.0	119.4
Maximum simulated mean: Max(NRD_m) / Max(AMT_m)	16.4	163.1
Minimum simulated mean: Min(NRD_m) / Min(AMT_m)	5.0	44.7
Range of simulated means: Range(NRD_m) / Range(AMT_m)	11.4	118.4
Number of runs where the simulated mean (NRD_m / AMT_m) is significantly higher than the observed mean	0	35
Number of runs where the simulated mean (NRD_m / AMT_m) is significantly lower than the observed mean	18	9
Number of runs where the simulated mean (NRD_m / AMT_m) is not significantly different to the observed mean	982	956
Mean correlation between observed/simulated time series of seasonal totals	+0.12	+0.14
Highest positive correlation between observed/simulated time series of seasonal totals	+0.64	+0.68
Highest negative correlation between observed/simulated time series of seasonal totals	-0.55	-0.49

Table 6.9: Summary of results for the $CVOBS_{Mis}$ (Missanello) simulation set. NRD = number of rain days. AMT = total seasonal rainfall (mm).

6.9a: Winter	*NRD*	*AMT*
Observed mean, 1956-1988	29.2	257.9
Simulation-set mean: $\overline{NRD}_m$ / $\overline{AMT}_m$	27.9	272.0
Maximum simulated mean: Max(NRD_m) / Max(AMT_m)	31.2	324.0
Minimum simulated mean: Min(NRD_m) / Min(AMT_m)	20.4	209.2
Range of simulated means: Range(NRD_m) / Range(AMT_m)	10.8	114.8
Number of runs where the simulated mean (NRD_m / AMT_m) is significantly higher than the observed mean	0	25
Number of runs where the simulated mean (NRD_m / AMT_m) is significantly lower than the observed mean	40	0
Number of runs where the simulated mean (NRD_m / AMT_m) is not significantly different to the observed mean	960	975
Mean correlation between observed/simulated time series of seasonal totals	+0.11	+0.09
Highest positive correlation between observed/simulated time series of seasonal totals	+0.59	+0.66
Highest negative correlation between observed/simulated time series of seasonal totals	-0.43	-0.51

6.9b: Spring	*NRD*	*AMT*
Observed mean, 1956-1988	25.7	203.8
Simulation-set mean: $\overline{NRD}_m$ / $\overline{AMT}_m$	25.2	217.2
Maximum simulated mean: Max(NRD_m) / Max(AMT_m)	28.8	291.3
Minimum simulated mean: Min(NRD_m) / Min(AMT_m)	21.9	177.4
Range of simulated means: Range(NRD_m) / Range(AMT_m)	6.9	114.0
Number of runs where the simulated mean (NRD_m / AMT_m) is significantly higher than the observed mean	0	12
Number of runs where the simulated mean (NRD_m / AMT_m) is significantly lower than the observed mean	1	0
Number of runs where the simulated mean (NRD_m / AMT_m) is not significantly different to the observed mean	999	988
Mean correlation between observed/simulated time series of seasonal totals	+0.13	+0.07
Highest positive correlation between observed/simulated time series of seasonal totals	+0.68	+0.75
Highest negative correlation between observed/simulated time series of seasonal totals	-0.55	-0.44

6.9c: Summer	*NRD*	*AMT*
Observed mean, 1956-1988	12.8	113.1
Simulation-set mean: $\overline{NRD}_m$ / $\overline{AMT}_m$	12.4	113.6
Maximum simulated mean: Max(NRD_m) / Max(AMT_m)	23.8	221.4
Minimum simulated mean: Min(NRD_m) / Min(AMT_m)	9.3	82.6
Range of simulated means: Range(NRD_m) / Range(AMT_m)	14.5	138.8
Number of runs where the simulated mean (NRD_m / AMT_m) is significantly higher than the observed mean	20	17
Number of runs where the simulated mean (NRD_m / AMT_m) is significantly lower than the observed mean	5	2
Number of runs where the simulated mean (NRD_m / AMT_m) is not significantly different to the observed mean	975	981
Mean correlation between observed/simulated time series of seasonal totals	+0.07	+0.04
Highest positive correlation between observed/simulated time series of seasonal totals	+0.57	+0.63
Highest negative correlation between observed/simulated time series of seasonal totals	-0.47	-0.49

6.9d: Autumn	*NRD*	*AMT*
Observed mean, 1956-1988	23.3	231.0
Simulation-set mean: $\overline{NRD}_m$ / $\overline{AMT}_m$	22.3	233.8
Maximum simulated mean: Max(NRD_m) / Max(AMT_m)	25.2	292.2
Minimum simulated mean: Min(NRD_m) / Min(AMT_m)	12.0	107.7
Range of simulated means: Range(NRD_m) / Range(AMT_m)	13.2	184.5
Number of runs where the simulated mean (NRD_m / AMT_m) is significantly higher than the observed mean	0	6
Number of runs where the simulated mean (NRD_m / AMT_m) is significantly lower than the observed mean	54	25
Number of runs where the simulated mean (NRD_m / AMT_m) is not significantly different to the observed mean	946	969
Mean correlation between observed/simulated time series of seasonal totals	+0.04	-0.01
Highest positive correlation between observed/simulated time series of seasonal totals	+0.62	+0.58
Highest negative correlation between observed/simulated time series of seasonal totals	-0.49	-0.57

Table 6.10: Summary of standard deviation (SD) results for the $CVOBS_{Alc}$ (Alcantarilla) simulation set. NRD = number of rain days. AMT = total seasonal rainfall (mm).

6.10a: Winter	*NRD*	*AMT*
Observed SD, 1958-1987	6.5	42.1
Simulation-set mean SD: $\overline{NRD}_{sd}$ / $\overline{AMT}_{sd}$	4.5	41.3
Maximum simulated SD: Max(NRD_{sd}) / Max(AMT_{sd})	7.0	95.3
Minimum simulated SD: Min(NRD_{sd}) / Min(AMT_{sd})	2.2	20.0
Range of simulated SDs: Range(NRD_{sd}) / Range(AMT_{sd})	4.8	75.4
Number of runs where the simulated SD (NRD_{sd} / AMT_{sd}) is significantly higher than the observed SD	0	37
Number of runs where the simulated SD (NRD_{sd} / AMT_{sd}) is significantly lower than the observed SD	580	68
Number of runs where the simulated SD (NRD_{sd} / AMT_{sd}) is not significantly different to the observed SD	420	895

6.10b: Spring	*NRD*	*AMT*
Observed SD, 1958-1987	6.1	52.3
Simulation-set mean SD: $\overline{NRD}_{sd}$ / $\overline{AMT}_{sd}$	4.6	44.2
Maximum simulated SD: Max(NRD_{sd}) / Max(AMT_{sd})	6.9	71.9
Minimum simulated SD: Min(NRD_{sd}) / Min(AMT_{sd})	2.5	21.6
Range of simulated SDs: Range(NRD_{sd}) / Range(AMT_{sd})	4.4	50.2
Number of runs where the simulated SD (NRD_{sd} / AMT_{sd}) is significantly higher than the observed SD	0	0
Number of runs where the simulated SD (NRD_{sd} / AMT_{sd}) is significantly lower than the observed SD	380	188
Number of runs where the simulated SD (NRD_{sd} / AMT_{sd}) is not significantly different to the observed SD	620	812

6.10c: Summer	*NRD*	*AMT*
Observed SD, 1958-1987	2.1	33.0
Simulation-set mean SD: $\overline{\text{NRD}}_{sd}$ / $\overline{\text{AMT}}_{sd}$	2.9	35.2
Maximum simulated SD: Max(NRD_{sd}) / Max(AMT_{sd})	8.7	70.8
Minimum simulated SD: Min($_c NRD_{sd}$) / Min(AMT_{sd})	1.6	19.1
Range of simulated SDs: Range(NRD_{sd}) / Range(AMT_{sd})	7.1	51.7
Number of runs where the simulated SD (NRD_{sd} / AMT_{sd}) is significantly higher than the observed SD	371	108
Number of runs where the simulated SD (NRD_{sd} / AMT_{sd}) is significantly lower than the observed SD	0	41
Number of runs where the simulated SD (NRD_{sd} / AMT_{sd}) is not significantly different to the observed SD	629	851

6.10d: Autumn	*NRD*	*AMT*
Observed SD, 1958-1987	6.4	83.1
Simulation-set mean SD: $\overline{\text{NRD}}_{sd}$ / $\overline{\text{AMT}}_{sd}$	4.6	69.0
Maximum simulated SD: Max(NRD_{sd}) / Max(AMT_{sd})	7.0	125.5
Minimum simulated SD: Min(NRD_{sd}) / Min(AMT_{sd})	2.7	37.4
Range of simulated SDs: Range(NRD_{sd}) / Range(AMT_{sd})	4.3	88.0
Number of runs where the simulated SD (NRD_{sd} / AMT_{sd}) is significantly higher than the observed SD	0	3
Number of runs where the simulated SD (NRD_{sd} / AMT_{sd}) is significantly lower than the observed SD	498	233
Number of runs where the simulated SD (NRD_{sd} / AMT_{sd}) is not significantly different to the observed SD	502	764

Table 6.11: Summary of standard deviation (SD) results for the $CVOBS_{Mis}$ (Missanello) simulation set. NRD = number of rain days. AMT = total seasonal rainfall (mm).

6.11a: Winter	*NRD*	*AMT*
Observed SD, 1956-1988	6.4	88.5
Simulation-set mean SD: $\overline{NRD}_{sd}$ / $\overline{AMT}_{sd}$	5.9	87.4
Maximum simulated SD: $Max(NRD_{sd})$ / $Max(AMT_{sd})$	10.5	142.5
Minimum simulated SD: $Min(NRD_{sd})$ / $Min(AMT_{sd})$	3.7	53.0
Range of simulated SDs: $Range(NRD_{sd})$ / $Range(AMT_{sd})$	6.8	89.4
Number of runs where the simulated SD (NRD_{sd} / AMT_{sd}) is significantly higher than the observed SD	18	12
Number of runs where the simulated SD (NRD_{sd} / AMT_{sd}) is significantly lower than the observed SD	66	37
Number of runs where the simulated SD (NRD_{sd} / AMT_{sd}) is not significantly different to the observed SD	916	951

6.11b: Spring	*NRD*	*AMT*
Observed SD, 1956-1988	8.1	96.8
Simulation-set mean SD: $\overline{NRD}_{sd}$ / $\overline{AMT}_{sd}$	5.9	71.9
Maximum simulated SD: $Max(NRD_{sd})$ / $Max(AMT_{sd})$	9.3	138.6
Minimum simulated SD: $Min(NRD_{sd})$ / $Min(AMT_{sd})$	3.7	43.5
Range of simulated SDs: $Range(NRD_{sd})$ / $Range(AMT_{sd})$	5.7	95.1
Number of runs where the simulated SD (NRD_{sd} / AMT_{sd}) is significantly higher than the observed SD	0	1
Number of runs where the simulated SD (NRD_{sd} / AMT_{sd}) is significantly lower than the observed SD	546	482
Number of runs where the simulated SD (NRD_{sd} / AMT_{sd}) is not significantly different to the observed SD	454	517

6.11c: Summer	*NRD*	*AMT*
Observed SD, 1956-1988	6.5	62.7
Simulation-set mean SD: $\overline{NRD}_{sd}$ / $\overline{AMT}_{sd}$	4.6	55.1
Maximum simulated SD: Max(NRD_{sd}) / Max(AMT_{sd})	10.0	95.9
Minimum simulated SD: Min(NRD_{sd}) / Min(AMT_{sd})	2.6	29.5
Range of simulated SDs: Range(NRD_{sd}) / Range(AMT_{sd})	7.4	66.4
Number of runs where the simulated SD (NRD_{sd} / AMT_{sd}) is significantly higher than the observed SD	12	8
Number of runs where the simulated SD (NRD_{sd} / AMT_{sd}) is significantly lower than the observed SD	660	140
Number of runs where the simulated SD (NRD_{sd} / AMT_{sd}) is not significantly different to the observed SD	328	852

6.11d: Autumn	*NRD*	*AMT*
Observed SD, 1956-1988	5.4	82.4
Simulation-set mean SD: $\overline{NRD}_{sd}$ / $\overline{AMT}_{sd}$	5.3	77.1
Maximum simulated SD: Max(NRD_{sd}) / Max(AMT_{sd})	8.7	137.8
Minimum simulated SD: Min(NRD_{sd}) / Min(AMT_{sd})	3.4	44.5
Range of simulated SDs: Range(NRD_{sd}) / Range(AMT_{sd})	5.2	93.3
Number of runs where the simulated SD (NRD_{sd} / AMT_{sd}) is significantly higher than the observed SD	16	7
Number of runs where the simulated SD (NRD_{sd} / AMT_{sd}) is significantly lower than the observed SD	32	63
Number of runs where the simulated SD (NRD_{sd} / AMT_{sd}) is not significantly different to the observed SD	952	930

Table 6.12: Summary of LW (longest wet day spell) and LD (longest dry day spell) results for the $CVOBS_{Alc}$ (Alcantarilla) simulation set.

6.12a: Winter	*LW*	*LD*
Observed LW/LD, 1958-1987	9	59
Simulation-set mean LW/LD: $\overline{LW}$ / $\overline{LD}$	6.4	46.0
Maximum simulated LW/LD	14	79
Minimum simulated LW/LD	4	29
Range of simulated LW/LD	10	50
Number of runs where the simulated LW/LD is longer than the observed value	29	80
Number of runs where the simulated LW/LD is shorter than the observed value	931	909
Number of runs where the simulated LW/LD is the same as the observed value	40	11

6.12b: Spring	*LW*	*LD*
Observed LW/LD, 1958-1987	9	59
Simulation-set mean LW/LD: $\overline{LW}$ / $\overline{LD}$	6.5	44.0
Maximum simulated LW/LD	16	91
Minimum simulated LW/LD	4	27
Range of simulated LW/LD	12	64
Number of runs where the simulated LW/LD is longer than the observed value	31	56
Number of runs where the simulated LW/LD is shorter than the observed value	922	936
Number of runs where the simulated LW/LD is the same as the observed value	47	8

6.12c: Summer	*LW*	*LD*
Observed LW/LD, 1958-1987	4	89
Simulation-set mean LW/LD: $\overline{LW}$ / $\overline{LD}$	4.5	82.8
Maximum simulated LW/LD	9	92
Minimum simulated LW/LD	2	44
Range of simulated LW/LD	7	48
Number of runs where the simulated LW/LD is longer than the observed value	435	416
Number of runs where the simulated LW/LD is shorter than the observed value	149	561
Number of runs where the simulated LW/LD is the same as the observed value	416	23

6.12d: Autumn	*LW*	*LD*
Observed LW/LD, 1958-1987	7	59
Simulation-set mean LW/LD: $\overline{LW}$ / $\overline{LD}$	6.8	49.5
Maximum simulated LW/LD	13	92
Minimum simulated LW/LD	3	30
Range of simulated LW/LD	10	62
Number of runs where the simulated LW/LD is longer than the observed value	263	158
Number of runs where the simulated LW/LD is shorter than the observed value	480	821
Number of runs where the simulated LW/LD is the same as the observed value	257	21

Table 6.13: Summary of LW (longest wet day spell) and LD (longest dry day spell) results for the $CVOBS_{Mis}$ (Missanello) simulation set.

6.13a: Winter	*LW*	*LD*
Observed LW/LD, 1956-1988	16	31
Simulation-set mean LW/LD: $\overline{LW}$ / $\overline{LD}$	9.8	25.3
Maximum simulated LW/LD	22	50
Minimum simulated LW/LD	6	15
Range of simulated LW/LD	16	35
Number of runs where the simulated LW/LD is longer than the observed value	7	104
Number of runs where the simulated LW/LD is shorter than the observed value	984	867
Number of runs where the simulated LW/LD is the same as the observed value	9	29

6.13b: Spring	*LW*	*LD*
Observed LW/LD, 1956-1988	10	39
Simulation-set mean LW/LD: $\overline{LW}$ / $\overline{LD}$	9.8	30.5
Maximum simulated LW/LD	19	62
Minimum simulated LW/LD	6	18
Range of simulated LW/LD	13	44
Number of runs where the simulated LW/LD is longer than the observed value	294	88
Number of runs where the simulated LW/LD is shorter than the observed value	514	899
Number of runs where the simulated LW/LD is the same as the observed value	192	13

6.13c: Summer	*LW*	*LD*
Observed LW/LD, 1956-1988	10	88
Simulation-set mean LW/LD: $\overline{LW}$ / $\overline{LD}$	6.9	53.3
Maximum simulated LW/LD	14	90
Minimum simulated LW/LD	4	27
Range of simulated LW/LD	10	63
Number of runs where the simulated LW/LD is longer than the observed value	27	1
Number of runs where the simulated LW/LD is shorter than the observed value	943	999
Number of runs where the simulated LW/LD is the same as the observed value	30	0

6.13d: Autumn	*LW*	*LD*
Observed LW/LD, 1956-1988	8	33
Simulation-set mean LW/LD: $\overline{LW}$ / $\overline{LD}$	9.3	33.6
Maximum simulated LW/LD	19	84
Minimum simulated LW/LD	5	20
Range of simulated LW/LD	14	64
Number of runs where the simulated LW/LD is longer than the observed value	652	446
Number of runs where the simulated LW/LD is shorter than the observed value	132	489
Number of runs where the simulated LW/LD is the same as the observed value	216	65

Table 6.14: Summary of the extreme value analysis of annual maximum daily rainfall (mm) for the $CVOBS_{Alc}$ (Alcantarilla) simulation set.

	T5	*T10*	*T20*	*T50*
Observed events	55.9	66.9	77.5	91.3
Simulated events - means	65.4	78.1	90.2	106.0
Maximum simulated events	89.2	112.2	134.3	162.9
Minimum simulated events	45.9	53.0	59.8	68.7
Range of simulated events	43.4	59.3	74.5	94.2
Number of runs where the simulated event is larger than the observed event	911	884	865	836
Number of runs where the simulated event is smaller than the observed event	89	116	135	164

Table 6.15: Summary of the extreme value analysis of annual maximum daily rainfall (mm) for the $CVOBS_{Mis}$ (Missanello) simulation set.

	T5	*T10*	*T20*	*T50*
Observed events	75.9	88.9	101.5	117.7
Simulated events - means	76.3	88.5	100.2	115.3
Maximum simulated events	98.3	116.2	134.7	158.8
Minimum simulated events	60.3	67.6	74.6	83.7
Range of simulated events	37.9	48.6	60.1	75.1
Number of runs where the simulated event is larger than the observed event	507	459	428	405
Number of runs where the simulated event is smaller than the observed event	493	541	572	595

Table 6.16: Summary of results for the $CVHAD_{Alc}$ (Alcantarilla) simulation set. NRD = number of rain days. AMT = total seasonal rainfall (mm).

6.16a: Winter	*NRD*	*AMT*
Observed mean, 1958-1987	14.8	65.3
Simulation-set mean: $\overline{NRD}_m$ / $\overline{AMT}_m$	12.4	58.9
Maximum simulated mean: Max(NRD_m) / Max(AMT_m)	15.6	134.0
Minimum simulated mean: Min(NRD_m) / Min(AMT_m)	9.7	28.7
Range of simulated means: Range(NRD_m) / Range(AMT_m)	5.9	105.3
Number of runs where the simulated mean (NRD_m / AMT_m) is significantly higher than the observed mean	0	6
Number of runs where the simulated mean (NRD_m / AMT_m) is significantly lower than the observed mean	121	8
Number of runs where the simulated mean (NRD_m / AMT_m) is not significantly different to the observed mean	879	986

6.16b: Spring	*NRD*	*AMT*
Observed mean, 1958-1987	14.7	87.0
Simulation-set mean: $\overline{NRD}_m$ / $\overline{AMT}_m$	10.4	58.4
Maximum simulated mean: Max(NRD_m) / Max(AMT_m)	12.9	77.6
Minimum simulated mean: Min(NRD_m) / Min(AMT_m)	8.2	37.2
Range of simulated means: Range(NRD_m) / Range(AMT_m)	4.6	40.4
Number of runs where the simulated mean (NRD_m / AMT_m) is significantly higher than the observed mean	0	0
Number of runs where the simulated mean (NRD_m / AMT_m) is significantly lower than the observed mean	968	710
Number of runs where the simulated mean (NRD_m / AMT_m) is not significantly different to the observed mean	32	290

6.16c: Summer	*NRD*	*AMT*
Observed mean, 1958-1987	5.2	36.9
Simulation-set mean: $\overline{NRD}_m$ / $\overline{AMT}_m$	5.1	41.8
Maximum simulated mean: Max(NRD_m) / Max(AMT_m)	10.4	63.9
Minimum simulated mean: Min(NRD_m) / Min(AMT_m)	3.3	22.4
Range of simulated means: Range(NRD_m) / Range(AMT_m)	7.1	41.6
Number of runs where the simulated mean (NRD_m / AMT_m) is significantly higher than the observed mean	18	16
Number of runs where the simulated mean (NRD_m / AMT_m) is significantly lower than the observed mean	34	0
Number of runs where the simulated mean (NRD_m / AMT_m) is not significantly different to the observed mean	948	984

6.16d: Autumn	*NRD*	*AMT*
Observed mean, 1958-1987	13.3	100.2
Simulation-set mean: $\overline{NRD}_m$ / $\overline{AMT}_m$	12.7	127.3
Maximum simulated mean: Max(NRD_m) / Max(AMT_m)	15.9	174.1
Minimum simulated mean: Min(NRD_m) / Min(AMT_m)	4.7	39.7
Range of simulated means: Range(NRD_m) / Range(AMT_m)	11.2	134.4
Number of runs where the simulated mean (NRD_m / AMT_m) is significantly higher than the observed mean	0	121
Number of runs where the simulated mean (NRD_m / AMT_m) is significantly lower than the observed mean	22	8
Number of runs where the simulated mean (NRD_m / AMT_m) is not significantly different to the observed mean	978	871

Table 6.17: Summary of results for the $CVHAD_{Mis}$ (Missanello) simulation set. NRD = number of rain days. AMT = total seasonal rainfall (mm).

6.17a: Winter	*NRD*	*AMT*
Observed mean, 1956-1988	29.2	257.9
Simulation-set mean: $\overline{NRD}_m$ / $\overline{AMT}_m$	23.1	213.0
Maximum simulated mean: Max(NRD_m) / Max(AMT_m)	26.6	281.4
Minimum simulated mean: Min(NRD_m) / Min(AMT_m)	18.3	170.7
Range of simulated means: Range(NRD_m) / Range(AMT_m)	8.3	110.7
Number of runs where the simulated mean (NRD_m / AMT_m) is significantly higher than the observed mean	0	0
Number of runs where the simulated mean (NRD_m / AMT_m) is significantly lower than the observed mean	974	393
Number of runs where the simulated mean (NRD_m / AMT_m) is not significantly different to the observed mean	26	607

6.17b: Spring	*NRD*	*AMT*
Observed mean, 1956-1988	25.7	203.8
Simulation-set mean: $\overline{NRD}_m$ / $\overline{AMT}_m$	24.0	204.9
Maximum simulated mean: Max(NRD_m) / Max(AMT_m)	27.8	251.2
Minimum simulated mean: Min(NRD_m) / Min(AMT_m)	20.3	165.3
Range of simulated means: Range(NRD_m) / Range(AMT_m)	7.5	85.9
Number of runs where the simulated mean (NRD_m / AMT_m) is significantly higher than the observed mean	0	0
Number of runs where the simulated mean (NRD_m / AMT_m) is significantly lower than the observed mean	20	0
Number of runs where the simulated mean (NRD_m / AMT_m) is not significantly different to the observed mean	980	1000

6.17c: Summer	*NRD*	*AMT*
Observed mean, 1956-1988	12.8	113.1
Simulation-set mean: $\overline{NRD}_m$ / $\overline{AMT}_m$	10.6	93.7
Maximum simulated mean: Max(NRD_m) / Max(AMT_m)	21.5	190.2
Minimum simulated mean: Min(NRD_m) / Min(AMT_m)	7.8	60.5
Range of simulated means: Range(NRD_m) / Range(AMT_m)	13.8	129.7
Number of runs where the simulated mean (NRD_m / AMT_m) is significantly higher than the observed mean	11	9
Number of runs where the simulated mean (NRD_m / AMT_m) is significantly lower than the observed mean	181	154
Number of runs where the simulated mean (NRD_m / AMT_m) is not significantly different to the observed mean	808	837

6.17d: Autumn	*NRD*	*AMT*
Observed mean, 1956-1988	23.3	231.0
Simulation-set mean: $\overline{NRD}_m$ / $\overline{AMT}_m$	20.7	214.8
Maximum simulated mean: Max(NRD_m) / Max(AMT_m)	24.4	262.1
Minimum simulated mean: Min(NRD_m) / Min(AMT_m)	10.5	90.4
Range of simulated means: Range(NRD_m) / Range(AMT_m)	14.0	171.7
Number of runs where the simulated mean (NRD_m / AMT_m) is significantly higher than the observed mean	0	0
Number of runs where the simulated mean (NRD_m / AMT_m) is significantly lower than the observed mean	322	45
Number of runs where the simulated mean (NRD_m / AMT_m) is not significantly different to the observed mean	678	955

Table 6.18: Summary of standard deviation (SD) results for the $CVHAD_{Alc}$ (Alcantarilla) simulation set. NRD = number of rain days. AMT = total seasonal rainfall (mm).

6.18a: Winter	*NRD*	*AMT*
Observed SD, 1958-1987	6.5	42.1
Simulation-set mean SD: $\overline{NRD}_{sd}$ / $\overline{AMT}_{sd}$	4.6	33.0
Maximum simulated SD: Max(NRD_{sd}) / Max(AMT_{sd})	6.9	92.2
Minimum simulated SD: Min(NRD_{sd}) / Min(AMT_{sd})	2.1	13.8
Range of simulated SDs: Range(NRD_{sd}) / Range(AMT_{sd})	4.8	78.4
Number of runs where the simulated SD (NRD_{sd} / AMT_{sd}) is significantly higher than the observed SD	0	20
Number of runs where the simulated SD (NRD_{sd} / AMT_{sd}) is significantly lower than the observed SD	415	326
Number of runs where the simulated SD (NRD_{sd} / AMT_{sd}) is not significantly different to the observed SD	585	654

6.18b: Spring	*NRD*	*AMT*
Observed SD, 1958-1987	6.1	52.3
Simulation-set mean SD: $\overline{NRD}_{sd}$ / $\overline{AMT}_{sd}$	3.8	34.8
Maximum simulated SD: Max(NRD_{sd}) / Max(AMT_{sd})	6.7	57.6
Minimum simulated SD: Min(NRD_{sd}) / Min(AMT_{sd})	2.1	17.7
Range of simulated SDs: Range(NRD_{sd}) / Range(AMT_{sd})	4.6	39.9
Number of runs where the simulated SD (NRD_{sd} / AMT_{sd}) is significantly higher than the observed SD	0	0
Number of runs where the simulated SD (NRD_{sd} / AMT_{sd}) is significantly lower than the observed SD	844	689
Number of runs where the simulated SD (NRD_{sd} / AMT_{sd}) is not significantly different to the observed SD	156	311

6.18c: Summer	*NRD*	*AMT*
Observed SD, 1958-1987	2.1	33.0
Simulation-set mean SD: $\overline{NRD}_{sd}$ / $\overline{AMT}_{sd}$	3.3	36.9
Maximum simulated SD: Max(NRD_{sd}) / Max(AMT_{sd})	5.6	73.8
Minimum simulated SD: Min(NRD_{sd}) / Min(AMT_{sd})	1.7	11.9
Range of simulated SDs: Range(NRD_{sd}) / Range(AMT_{sd})	3.9	61.9
Number of runs where the simulated SD (NRD_{sd} / AMT_{sd}) is significantly higher than the observed SD	731	112
Number of runs where the simulated SD (NRD_{sd} / AMT_{sd}) is significantly lower than the observed SD	0	24
Number of runs where the simulated SD (NRD_{sd} / AMT_{sd}) is not significantly different to the observed SD	269	864

6.18d: Autumn	*NRD*	*AMT*
Observed SD, 1958-1987	6.4	83.1
Simulation-set mean SD: $\overline{NRD}_{sd}$ / $\overline{AMT}_{sd}$	4.7	71.8
Maximum simulated SD: Max(NRD_{sd}) / Max(AMT_{sd})	7.5	114.5
Minimum simulated SD: Min(NRD_{sd}) / Min(AMT_{sd})	2.7	31.2
Range of simulated SDs: Range(NRD_{sd}) / Range(AMT_{sd})	4.8	83.3
Number of runs where the simulated SD (NRD_{sd} / AMT_{sd}) is significantly higher than the observed SD	0	0
Number of runs where the simulated SD (NRD_{sd} / AMT_{sd}) is significantly lower than the observed SD	434	174
Number of runs where the simulated SD (NRD_{sd} / AMT_{sd}) is not significantly different to the observed SD	566	826

Table 6.19: Summary of standard deviation (SD) results for the $CVHAD_{Mis}$ (Missanello) simulation set. NRD = number of rain days. AMT = total seasonal rainfall (mm).

6.19a: Winter	*NRD*	*AMT*
Observed SD, 1956-1988	6.4	88.5
Simulation-set mean SD: $\overline{NRD}_{sd}$ / $\overline{AMT}_{sd}$	6.2	82.9
Maximum simulated SD: Max(NRD_{sd}) / Max(AMT_{sd})	10.7	139.7
Minimum simulated SD: Min(NRD_{sd}) / Min(AMT_{sd})	3.5	38.2
Range of simulated SDs: Range(NRD_{sd}) / Range(AMT_{sd})	7.2	101.5
Number of runs where the simulated SD (NRD_{sd} / AMT_{sd}) is significantly higher than the observed SD	16	5
Number of runs where the simulated SD (NRD_{sd} / AMT_{sd}) is significantly lower than the observed SD	26	51
Number of runs where the simulated SD (NRD_{sd} / AMT_{sd}) is not significantly different to the observed SD	958	944

6.19b: Spring	*NRD*	*AMT*
Observed SD, 1956-1988	8.1	96.8
Simulation-set mean SD: $\overline{NRD}_{sd}$ / $\overline{AMT}_{sd}$	6.0	72.2
Maximum simulated SD: Max(NRD_{sd}) / Max(AMT_{sd})	9.4	118.8
Minimum simulated SD: Min(NRD_{sd}) / Min(AMT_{sd})	3.2	42.7
Range of simulated SDs: Range(NRD_{sd}) / Range(AMT_{sd})	6.2	76.1
Number of runs where the simulated SD (NRD_{sd} / AMT_{sd}) is significantly higher than the observed SD	0	0
Number of runs where the simulated SD (NRD_{sd} / AMT_{sd}) is significantly lower than the observed SD	422	378
Number of runs where the simulated SD (NRD_{sd} / AMT_{sd}) is not significantly different to the observed SD	578	622

6.19c: Summer	*NRD*	*AMT*
Observed SD, 1956-1988	6.5	62.7
Simulation-set mean SD: $\overline{NRD}_{sd}$ / $\overline{AMT}_{sd}$	4.2	49.6
Maximum simulated SD: Max(NRD_{sd}) / Max(AMT_{sd})	10.7	110.2
Minimum simulated SD: Min(NRD_{sd}) / Min(AMT_{sd})	2.2	24.3
Range of simulated SDs: Range(NRD_{sd}) / Range(AMT_{sd})	8.5	85.9
Number of runs where the simulated SD (NRD_{sd} / AMT_{sd}) is significantly higher than the observed SD	7	8
Number of runs where the simulated SD (NRD_{sd} / AMT_{sd}) is significantly lower than the observed SD	710	314
Number of runs where the simulated SD (NRD_{sd} / AMT_{sd}) is not significantly different to the observed SD	283	678

6.19d: Autumn	*NRD*	*AMT*
Observed SD, 1956-1988	5.4	82.4
Simulation-set mean SD: $\overline{NRD}_{sd}$ / $\overline{AMT}_{sd}$	5.3	76.7
Maximum simulated SD: Max(NRD_{sd}) / Max(AMT_{sd})	9.0	135.6
Minimum simulated SD: Min(NRD_{sd}) / Min(AMT_{sd})	3.0	42.6
Range of simulated SDs: Range(NRD_{sd}) / Range(AMT_{sd})	5.9	93.0
Number of runs where the simulated SD (NRD_{sd} / AMT_{sd}) is significantly higher than the observed SD	19	7
Number of runs where the simulated SD (NRD_{sd} / AMT_{sd}) is significantly lower than the observed SD	29	62
Number of runs where the simulated SD (NRD_{sd} / AMT_{sd}) is not significantly different to the observed SD	952	931

Table 6.20: Summary of LW (longest wet day spell) and LD (longest dry day spell) results for the $CVHAD_{Alc}$ (Alcantarilla) simulation set.

6.20a: Winter	*LW*	*LD*
Observed LW/LD, 1958-1987	9	59
Simulation-set mean LW/LD: $\overline{LW}$ / $\overline{LD}$	6.0	48.5
Maximum simulated LW/LD	12	88
Minimum simulated LW/LD	3	29
Range of simulated LW/LD	9	59
Number of runs where the simulated LW/LD is longer than the observed value	16	142
Number of runs where the simulated LW/LD is shorter than the observed value	944	840
Number of runs where the simulated LW/LD is the same as the observed value	40	18

6.20b: Spring	*LW*	*LD*
Observed LW/LD, 1958-1987	9	59
Simulation-set mean LW/LD: $\overline{LW}$ / $\overline{LD}$	5.9	55.4
Maximum simulated LW/LD	11	90
Minimum simulated LW/LD	3	29
Range of simulated LW/LD	8	61
Number of runs where the simulated LW/LD is longer than the observed value	7	310
Number of runs where the simulated LW/LD is shorter than the observed value	956	658
Number of runs where the simulated LW/LD is the same as the observed value	37	32

6.20c: Summer	*LW*	*LD*
Observed LW/LD, 1958-1987	4	89
Simulation-set mean LW/LD: $\overline{LW}$ / $\overline{LD}$	6.6	86.0
Maximum simulated LW/LD	14	90
Minimum simulated LW/LD	3	45
Range of simulated LW/LD	11	45
Number of runs where the simulated LW/LD is longer than the observed value	942	618
Number of runs where the simulated LW/LD is shorter than the observed value	7	365
Number of runs where the simulated LW/LD is the same as the observed value	51	17

6.20d: Autumn	*LW*	*LD*
Observed LW/LD, 1958-1987	7	59
Simulation-set mean LW/LD: $\overline{LW}$ / $\overline{LD}$	7.1	53.5
Maximum simulated LW/LD	14	90
Minimum simulated LW/LD	4	31
Range of simulated LW/LD	10	59
Number of runs where the simulated LW/LD is longer than the observed value	332	240
Number of runs where the simulated LW/LD is shorter than the observed value	375	740
Number of runs where the simulated LW/LD is the same as the observed value	293	20

Table 6.21: Summary of LW (longest wet day spell) and LD (longest dry day spell) results for the $CVHAD_{Mis}$ (Missanello) simulation set.

6.21a: Winter	*LW*	*LD*
Observed LW/LD, 1956-1988	16	31
Simulation-set mean LW/LD: $\overline{LW}$ / $\overline{LD}$	8.4	29.1
Maximum simulated LW/LD	16	66
Minimum simulated LW/LD	5	17
Range of simulated LW/LD	11	49
Number of runs where the simulated LW/LD is longer than the observed value	0	274
Number of runs where the simulated LW/LD is shorter than the observed value	998	657
Number of runs where the simulated LW/LD is the same as the observed value	2	69

6.21b: Spring	*LW*	*LD*
Observed LW/LD, 1956-1988	10	39
Simulation-set mean LW/LD: $\overline{LW}$ / $\overline{LD}$	9.2	29.5
Maximum simulated LW/LD	20	59
Minimum simulated LW/LD	6	17
Range of simulated LW/LD	14	42
Number of runs where the simulated LW/LD is longer than the observed value	205	59
Number of runs where the simulated LW/LD is shorter than the observed value	638	926
Number of runs where the simulated LW/LD is the same as the observed value	157	15

6.21c: Summer	*LW*	*LD*
Observed LW/LD, 1956-1988	10	88
Simulation-set mean LW/LD: $\overline{LW}$ / $\overline{LD}$	6.3	58.3
Maximum simulated LW/LD	14	90
Minimum simulated LW/LD	4	24
Range of simulated LW/LD	10	66
Number of runs where the simulated LW/LD is longer than the observed value	15	10
Number of runs where the simulated LW/LD is shorter than the observed value	970	988
Number of runs where the simulated LW/LD is the same as the observed value	15	2

6.21d: Autumn	*LW*	*LD*
Observed LW/LD, 1956-1988	8	33
Simulation-set mean LW/LD: $\overline{LW}$ / $\overline{LD}$	9.0	35.2
Maximum simulated LW/LD	20	90
Minimum simulated LW/LD	5	21
Range of simulated LW/LD	15	69
Number of runs where the simulated LW/LD is longer than the observed value	544	523
Number of runs where the simulated LW/LD is shorter than the observed value	252	403
Number of runs where the simulated LW/LD is the same as the observed value	204	74

Table 6.22: Summary of the extreme value analysis of annual maximum daily rainfall (mm) for the $CVHAD_{Alc}$ (Alcantarilla) simulation set.

	T5	*T10*	*T20*	*T50*
Observed events	55.9	66.9	77.5	91.3
Simulated events - means	65.6	78.9	91.7	108.3
Maximum simulated events	97.5	123.5	148.4	180.7
Minimum simulated events	45.0	51.5	57.8	65.8
Range of simulated events	52.4	72.0	90.7	114.9
Number of runs where the simulated event is larger than the observed event	902	887	871	858
Number of runs where the simulated event is smaller than the observed event	98	113	129	142

Table 6.23: Summary of the extreme value analysis of annual maximum daily rainfall (mm) for the $CVHAD_{Mis}$ (Missanello) simulation set.

	T5	*T10*	*T20*	*T50*
Observed events	75.9	88.9	101.5	117.7
Simulated events - means	71.7	83.2	94.3	108.7
Maximum simulated events	101.9	126.6	150.2	180.8
Minimum simulated events	53.6	60.5	67.1	75.6
Range of simulated events	48.4	66.1	83.1	105.1
Number of runs where the simulated event is larger than the observed event	266	264	265	263
Number of runs where the simulated event is smaller than the observed event	734	736	735	737

Table 6.24: Values of the NCWG parameters in the cross-validation runs for Alcantarilla.
(a) Rainfall occurrence parameters, and (b) rainfall amount parameters.

6.24a	*C/HYC*	*UC*	*A/HYA*	*UA*	*N*	*NE*	*E/SE*	*S/SW*	*W/NW*
P_{ww}									
Winter									
Mean	.56	.56	.29	.29	.22	.26	.84	.53	.23
Max	.58	.60	.30	.32	.23	.29	.91	.60	.25
Min	.51	.50	.26	.27	.20	.14	.42	.42	.20
Range	.07	.10	.04	.05	.03	.15	.11	.18	.05
Spring									
Mean	.64	.29	.08	.17	.04	.34	.75	.21	.21
Max	.66	.31	.09	.19	.04	.37	.82	.25	.24
Min	.62	.22	.04	.15	.00	.30	.70	.15	.16
Range	.04	.09	.05	.04	.04	.07	.12	.10	.08
Summer									
Mean	.28	.28	.00	.24	.00	.00	1.00	.00	.00
Max	.30	.30	.00	.26	.00	.00	1.00	.00	.00
Min	.25	.26	.00	.17	.00	.00	1.00	.00	.00
Range	.05	.04	.00	.09	.00	.00	.00	.00	.00
Autumn									
Mean	.51	.48	.23	.34	.16	.50	.65	.37	.32
Max	.52	.50	.27	.38	.19	.52	.69	.44	.35
Min	.47	.44	.15	.31	.11	.39	.61	.33	.21
Range	.05	.06	.12	.07	.08	.13	.08	.11	.14
P_{dw}									
Winter									
Mean	.39	.15	.05	.10	.05	.11	.46	.24	.09
Max	.41	.16	.05	.10	.05	.11	.50	.25	.10
Min	.36	.14	.04	.08	.04	.10	.42	.21	.08
Range	.05	.02	.01	.02	.01	.01	.08	.04	.02
Spring									
Mean	.29	.13	.02	.05	.07	.11	.33	.16	.07
Max	.31	.13	.02	.05	.07	.12	.35	.17	.08
Min	.29	.12	.01	.04	.06	.09	.27	.14	.06
Range	.02	.01	.01	.01	.01	.03	.08	.03	.02
Summer									
Mean	.08	.03	.00	.02	.02	.08	.11	.03	.00
Max	.08	.04	.00	.02	.02	.09	.12	.03	.00
Min	.07	.03	.00	.01	.00	.06	.07	.03	.00
Range	.01	.01	.00	.01	.02	.03	.05	.00	.00
Autumn									
Mean	.28	.12	.04	.07	.03	.14	.35	.13	.03
Max	.29	.13	.04	.07	.04	.16	.43	.14	.04
Min	.26	.11	.03	.06	.02	.11	.33	.11	.02
Range	.03	.02	.01	.01	.02	.05	.10	.03	.02

6.24b	*High rainfall amount category*	*Low rainfall amount category*	*Moderate rainfall amount category*
Shape (α)			
Winter			
Mean	0.53	0.30	0.47
Max	0.59	0.80	0.54
Min	0.48	0.26	0.45
Range	0.10	0.54	0.09
Spring			
Mean	0.79	0.80	0.68
Max	0.95	0.87	0.70
Min	0.73	0.74	0.65
Range	0.22	0.13	0.05
Summer			
Mean	0.66	0.21	0.47
Max	0.81	0.40	0.52
Min	0.57	0.19	0.41
Range	0.24	0.21	0.12
Autumn			
Mean	0.62	0.33	0.32
Max	0.70	0.39	0.34
Min	0.54	0.27	0.29
Range	0.16	0.12	0.05
Scale (β)			
Winter			
Mean	19.7	7.3	9.0
Max	21.4	8.0	9.4
Min	16.0	2.1	7.4
Range	5.3	5.9	2.0
Spring			
Mean	13.4	2.2	9.6
Max	14.3	2.3	9.9
Min	11.4	1.9	8.9
Range	2.9	0.4	1.0
Summer			
Mean	15.9	18.7	16.2
Max	17.4	20.4	17.4
Min	11.3	7.5	12.3
Range	6.2	12.9	5.0
Autumn			
Mean	23.8	7.9	21.9
Max	25.6	9.3	23.0
Min	19.5	5.5	19.2
Range	6.2	3.7	3.8

Table 6.25: Values of the NCWG parameters in the cross-validation runs for Missanello.
(a) Rainfall occurrence parameters, and (b) rainfall amount parameters.

6.25a	*C/HYC*	*UC*	*A/HYA*	*UA*	*N*	*NE*	*E/SE*	*S*	*SW/W*	*NW*
P_{ww}										
Winter										
Mean	.68	.42	.26	.32	.17	.33	.54	.39	.39	.38
Max	.69	.44	.29	.34	.19	.35	.55	.41	.42	.42
Min	.67	.40	.21	.28	.13	.29	.52	.35	.37	.33
Range	.02	.04	.08	.06	.06	.06	.03	.06	.05	.09
Spring										
Mean	.75	.53	.21	.35	.41	.33	.59	.29	.48	.40
Max	.77	.54	.24	.36	.44	.36	.65	.32	.50	.44
Min	.73	.51	.18	.34	.37	.30	.56	.23	.45	.33
Range	.04	.03	.06	.02	.07	.06	.09	.09	.05	.11
Summer										
Mean	.55	.51	.34	.25	.38	.57	.00	.00	.75	.14
Max	.57	.52	1.0	.26	.42	.67	.00	.00	.75	.17
Min	.53	.49	.00	.24	.35	.50	.00	.00	.75	.00
Range	.04	.03	1.0	.02	.07	.17	.00	.00	.00	.17
Autumn										
Mean	.67	.40	.11	.22	.39	.33	.67	.65	.51	.50
Max	.69	.41	.12	.24	.43	.37	.68	.69	.55	.50
Min	.66	.38	.08	.20	.35	.29	.63	.62	.49	.50
Range	.03	.03	.04	.04	.08	.08	.05	.07	.06	.00
P_{dw}										
Winter										
Mean	.46	.09	.06	.07	.12	.14	.27	.23	.22	.10
Max	.47	.09	.07	.07	.13	.15	.28	.24	.24	.11
Min	.45	.07	.04	.06	.09	.13	.26	.21	.21	.07
Range	.02	.02	.03	.01	.04	.02	.02	.03	.03	.04
Spring										
Mean	.44	.18	.09	.06	.16	.20	.32	.12	.19	.16
Max	.45	.18	.10	.06	.17	.22	.33	.13	.20	.18
Min	.43	.16	.08	.05	.15	.18	.30	.10	.18	.14
Range	.02	.02	.02	.01	.02	.04	.03	.03	.02	.04
Summer										
Mean	.15	.10	.02	.07	.11	.10	.50	.05	.04	.09
Max	.15	.10	.03	.07	.11	.11	.50	.05	.04	.10
Min	.13	.09	.01	.06	.10	.07	.50	.05	.04	.06
Range	.02	.01	.02	.01	.01	.04	.00	.00	.00	.04
Autumn										
Mean	.41	.12	.03	.05	.19	.22	.23	.18	.33	.27
Max	.42	.13	.03	.05	.21	.25	.24	.19	.35	.27
Min	.40	.11	.02	.05	.14	.20	.22	.16	.31	.27
Range	.02	.02	.01	.00	.07	.05	.02	.03	.04	.00

6.25b	*High rainfall amount category*	*Low rainfall amount category*	*Moderate rainfall amount category*
Shape (α)			
Winter			
Mean	0.51	0.83	0.99
Max	0.60	0.92	1.11
Min	0.48	0.78	0.93
Range	0.11	0.13	0.18
Spring			
Mean	0.82	1.24	0.80
Max	0.88	1.32	0.96
Min	0.79	1.19	0.74
Range	0.10	0.14	0.22
Summer			
Mean	0.80	0.94	0.97
Max	1.04	1.04	1.14
Min	0.75	0.85	0.90
Range	0.29	0.19	0.24
Autumn			
Mean	0.94	0.82	2.07
Max	0.99	0.92	2.27
Min	0.91	0.79	1.92
Range	0.08	0.14	0.35
Scale (β)			
Winter			
Mean	24.0	7.4	9.1
Max	24.8	7.7	9.6
Min	20.5	6.2	8.0
Range	4.3	1.5	1.6
Spring			
Mean	13.3	4.5	8.9
Max	137	4.7	9.4
Min	12.1	4.2	7.1
Range	1.6	0.5	2.3
Summer			
Mean	13.5	6.6	9.1
Max	14.1	7.0	9.6
Min	9.5	5.6	7.3
Range	4.6	1.4	2.3
Autumn			
Mean	13.0	8.4	4.7
Max	13.2	8.6	4.9
Min	11.8	7.1	4.4
Range	1.4	1.5	0.5

Table 6.26: Summary of results for the Alcantarilla scenario runs: number of rain days (NRD_m) and total rainfall (AMT_m, mm).

	Observed 1970-1979	*OBS1970$_{Alc}$*	*HAD1970$_{Alc}$*	*HAD2030$_{Alc}$*	*HAD2090$_{Alc}$*
Winter:					
NRD					
Mean: $\overline{NRD}_m$	16.2	13.5	12.1	15.6	18.1*
Max(NRD_m)	16.8	17.8	16.9	20.7	23.7
Min(NRD_m)	12.0	9.3	8.7	11.7	13.0
Range(NRD_m)		8.5	8.2	9.0	10.7
AMT					
Mean: $\overline{AMT}_m$	56.3	73.5	56.8	82.7	85.4
Max(AMT_m)	76.0	117.1	90.9	127.3	141.9
Min(AMT_m)	55.2	39.6	28.8	49.0	54.6
Range(AMT_m)		77.4	62.1	78.3	87.3
Spring:					
NRD					
Mean: $\overline{NRD}_m$	15.4	15.6	11.3*	10.5	11.6
Max(NRD_m)	18.1	20.2	15.0	13.7	15.4
Min(NRD_m)	12.4	11.2	7.5	7.0	8.2
Range(NRD_m)		9.0	7.5	6.7	7.2
AMT					
Mean: $\overline{AMT}_m$	105.3	100.7	66.1*	57.7	71.0
Max(AMT_m)	115.0	163.7	102.7	93.1	107.0
Min(AMT_m)	69.8	65.0	38.8	31.5	39.5
Range(AMT_m)		98.6	63.9	61.6	67.5
Summer:					
NRD					
Mean: $\overline{NRD}_m$	6.2	5.1	5.4	4.7	5.9
Max(NRD_m)	6.9	8.4	9.6	7.7	9.2
Min(NRD_m)	4.4	2.5	3.0	1.9	3.0
Range(NRD_m)		5.9	6.6	5.8	6.2
AMT					
Mean: $\overline{AMT}_m$	43.3	43.4	46.3	40.4	50.4
Max(AMT_m)	53.0	91.1	103.3	80.0	105.9
Min(AMT_m)	24.0	13.1	15.9	14.8	16.6
Range(AMT_m)		78.0	87.5	65.1	89.4
Autumn:					
NRD					
Mean: $\overline{NRD}_m$	13.3	13.5	12.8	13.2	14.2
Max(NRD_m)	15.6	18.9	17.4	17.7	18.5
Min(NRD_m)	11.2	9.1	8.8	9.3	9.1
Range(NRD_m)		9.8	8.6	8.4	9.4
AMT					
Mean: $\overline{AMT}_m$	111.4	129.4*	130.3*	135.4	137.9
Max(AMT_m)	128.1	211.5	221.0	220.7	226.5
Min(AMT_m)	53.8	70.8	68.8	75.8	85.4
Range(AMT_m)		140.7	152.1	144.9	141.1

Table 6.27: Summary of results for the Missanello scenario runs: number of rain days (NRD_m) and total rainfall (AMT_m, mm).

	Observed 1970-1979	*OBS1970$_{Mis}$*	*HAD1970$_{Mis}$*	*HAD2030$_{Mis}$*	*HAD2090$_{Mis}$*
Winter:					
NRD					
Mean: $\overline{NRD}_m$	26.6	24.2*	24.7*	20.0	18.8
Max(NRD_m)	33.4	29.4	29.6	24.7	23.6
Min(NRD_m)	26.1	19.4	18.4	15.7	14.1
Range(NRD_m)		10.0	11.1	9.0	9.5
AMT					
Mean: $\overline{AMT}_m$	301.8	240.6	230.2	179.6	159.6
Max(AMT_m)	344.6	329.2	321.9	259.7	231.2
Min(AMT_m)	215.5	164.8	158.0	120.5	109.2
Range(AMT_m)		164.4	163.9	139.2	122.0
Spring:					
NRD					
Mean: $\overline{NRD}_m$	24.4	25.2	21.5*	22.9	22.3
Max(NRD_m)	32.1	30.6	27.9	27.6	26.8
Min(NRD_m)	22.1	19.8	16.3	18.1	17.7
Range(NRD_m)		10.8	11.6	9.5	9.1
AMT					
Mean: $\overline{AMT}_m$	215.9	216.3	175.5	190.1	185.1
Max(AMT_m)	239.3	296.2	244.9	259.0	244.2
Min(AMT_m)	152.5	160.5	124.4	143.0	127.9
Range(AMT_m)		135.7	120.5	116.0	116.3
Summer:					
NRD					
Mean: $\overline{NRD}_m$	12.0	12.6	11.1	11.2	11.6
Max(NRD_m)	16.8	18.2	15.8	15.4	15.8
Min(NRD_m)	10.3	8.7	6.5	7.0	7.5
Range(NRD_m)		9.6	9.3	8.4	8.3
AMT					
Mean: $\overline{AMT}_m$	119.7	116.5	97.7	100.3	102.9
Max(AMT_m)	140.8	178.2	168.8	166.4	166.9
Min(AMT_m)	97.2	66.9	55.8	52.3	56.9
Range(AMT_m)		111.4	113.0	114.1	110.0
Autumn:					
NRD					
Mean: $\overline{NRD}_m$	21.8	22.7	21.0	20.1	18.0
Max(NRD_m)	27.5	28.2	26.3	26.2	22.8
Min(NRD_m)	20.8	18.1	16.3	15.3	14.2
Range(NRD_m)		10.1	10.0	10.9	8.6
AMT					
Mean: $\overline{AMT}_m$	228.1	236.1	216.2	204.4	177.3
Max(AMT_m)	258.8	315.4	280.5	288.8	243.3
Min(AMT_m)	198.6	152.7	146.2	138.6	124.1
Range(AMT_m)		162.7	134.3	150.2	119.2

Table 6.28: Summary of significance testing for number of rain days (NRD_m) and total rainfall (AMT_m) at Alcantarilla. See text for explanation.

	$OBS1970_{Alc}$ vs Observed 1970-1979	*$HAD1970_{Alc}$ vs Observed 1970-1979*	*$HAD2030_{Alc}$* vs $HAD1970_{Alc}$	*$HAD2090_{Alc}$* vs $HAD1970_{Alc}$	*$HAD2090_{Alc}$* vs $HAD2030_{Alc}$
Winter NRD_m					
Sig. +	0	0	235	726	89
Sig. -	24	44	0	0	0
No diff.	976	956	765	274	911
Spring NRD_m					
Sig. +	0	0	6	23	60
Sig. -	1	374	56	8	2
No diff.	999	626	938	969	938
Summer NRD_m					
Sig. +	0	0	6	29	90
Sig. -	256	63	26	5	2
No diff.	744	937	968	966	908
Autumn NRD_m					
Sig. +	0	0	35	76	55
Sig. -	2	0	10	4	6
No diff.	998	1000	955	920	939
Winter AMT_m					
Sig. +	84	0	146	350	19
Sig. -	0	1	0	0	1
No diff.	916	999	854	650	980
Spring AMT_m					
Sig. +	2	0	8	29	52
Sig. -	0	216	55	9	1
No diff.	998	784	937	962	947
Summer AMT_m					
Sig. +	0	1	5	39	53
Sig. -	0	0	23	5	6
No diff.	1000	999	972	956	941
Autumn AMT_m					
Sig. +	1	2	32	39	27
Sig. -	0	0	14	15	14
No diff.	999	998	954	946	959

Table 6.29: Summary of significance testing for number of rain days (NRD_m) and total rainfall (AMT_m) at Missanello. See text for explanation.

	OBS1970$_{Mis}$ vs Observed 1970-1979	*HAD1970$_{Mis}$ vs Observed 1970-1979*	*HAD2030$_{Mis}$* vs HAD1970$_{Mis}$	*HAD2090$_{Mis}$* vs HAD1970$_{Mis}$	*HAD2090$_{Mis}$* vs HAD2030$_{Mis}$
Winter NRD_m					
Sig. +	0	0	0	0	4
Sig. -	4	9	332	538	35
No diff.	996	991	668	462	961
Spring NRD_m					
Sig. +	0	0	67	35	3
Sig. -	0	30	3	3	19
No diff.	1000	970	930	962	978
Summer NRD_m					
Sig. +	0	0	33	44	30
Sig. -	0	5	18	10	15
No diff.	1000	995	949	946	955
Autumn NRD_m					
Sig. +	0	0	1	1	0
Sig. -	2	16	44	179	63
No diff.	998	984	955	820	937
Winter AMT_m					
Sig. +	0	0	0	0	1
Sig. -	11	270	202	453	60
No diff.	989	730	798	547	939
Spring AMT_m					
Sig. +	0	0	45	37	8
Sig. -	0	47	3	6	15
No diff.	1000	953	952	957	977
Summer AMT_m					
Sig. +	0	0	27	40	31
Sig. -	11	76	19	17	15
No diff.	989	924	954	943	954
Autumn AMT_m					
Sig. +	3	0	5	0	1
Sig. -	1	7	30	153	65
No diff.	996	993	965	847	934

Table 6.30: Quantile changes in rain days (NRD_m) and rainfall amount (AMT_m, mm) for Alcantarilla. The .50 quantile changes are also shown in percentage terms.

		.10	*.25*	*.50*	*.75*	*.90*
HAD2030						
$HAD2030_{Alc}$ minus $HAD1970_{Alc}$						
NRD_m	Winter	+1.4	+2.4	+3.3 (+27%)	+4.6	+5.5
	Spring	-2.5	-1.6	-0.7 (-6%)	+0.2	+1.0
	Summer	-2.3	-1.5	-0.8 (-15%)	+0.1	+0.8
	Autumn	-1.5	-0.6	+0.4 (+3%)	+1.4	+2.3
AMT_m	Winter	+6	+16	+25 (+30%)	+36	+46
	Spring	-27	-18	-8 (-14%)	+2	+9
	Summer	-25	-17	-6 (-15%)	+5	+14
	Autumn	-32	-15	+5 (+4%)	+25	+43
$HAD2090_{Alc}$ minus $HAD1970_{Alc}$						
NRD_m	Winter	+3.9	+5.0	+6.0 (+50%)	+7.1	+8.0
	Spring	-1.4	-0.6	+0.4 (+4%)	+1.4	+2.2
	Summer	-1.1	-0.4	+0.5 (+9%)	+1.4	+2.1
	Autumn	-0.7	+0.3	+1.4 (+11%)	+2.5	+3.5
AMT_m	Winter	+10	+18	+28 (+34%)	+39	+48
	Spring	-15	-6	+5 (+9%)	+15	+24
	Summer	-18	-8	+4 (+10%)	+15	+25
	Autumn	-28	-13	+7 (+5%)	+28	+45

Table 6.31: Quantile changes in rain days (NRD_m) and rainfall amount (AMT_m, mm) for Missanello. The .50 quantile changes are also shown in percentage terms.

			.10	.25	.50	.75	.90
$HAD2030_{Mis}$ minus $HAD1970_{Mis}$							
	NRD_m	Winter	-7.0	-6.0	-4.7 (-19%)	-3.4	-2.3
		Spring	-1.1	+0.1	+1.5 (+7%)	+2.7	+3.8
		Summer	-2.0	-0.9	+0.2 (+2%)	+1.3	+2.4
		Autumn	-3.3	-2.3	-0.9 (-4%)	+0.2	+1.3
	AMT_m	Winter	-88	-72	-51 (-22%)	-30	-10
		Spring	-18	-2	+14 (+8%)	+31	+47
		Summer	-24	-12	+3 (+3%)	+17	+29
		Autumn	-49	-30	-12 (-6%)	+8	+27
$HAD2090_{Mis}$ minus $HAD1970_{Mis}$							
	NRD_m	Winter	-8.2	-7.2	-5.9 (-24%)	-4.6	-3.4
		Spring	-1.6	-0.4	+0.9 (+4%)	+2.1	+3.3
		Summer	-1.4	-0.5	+0.5 (+5%)	+1.6	+2.6
		Autumn	-5.3	-4.2	-3.0 (-14%)	-1.9	-0.9
	AMT_m	Winter	-110	-91	-71 (-31%)	-52	-33
		Spring	-23	-8	+10 (+6%)	+27	+42
		Summer	-21	-10	+4 (+4%)	+20	+33
		Autumn	-75	-58	-40 (-19%)	-20	-2

Table 6.32: Summary of LW (longest wet day spell) and LD (longest dry day spell) results for the Alcantarilla scenario runs.

	LW *$HAD1970_{Alc}$*	*LW* *$HAD2030_{Alc}$*	*LW* *$HAD2090_{Alc}$*	*LD* *$HAD1970_{Alc}$*	*LD* *$HAD2030_{Alc}$*	*LD* *$HAD2090_{Alc}$*
Winter						
Mean	5.4	6.5	6.6	44.1	38.1	33.0
Maximum	11	14	16	90	78	61
Minimum	3	4	3	24	20	17
Range	8	10	13	66	58	44
Spring						
Mean	5.4	4.2	5.1	44.1	44.0	44.6
Maximum	11	9	11	84	90	89
Minimum	3	2	3	24	25	24
Range	8	7	8	60	65	65
Summer						
Mean	5.7	4.9	5.9	78.5	78.7	72.6
Maximum	10	10	10	90	90	90
Minimum	2	2	2	47	44	42
Range	8	8	8	43	46	48
Autumn						
Mean	6.2	6.2	6.4	44.4	46.1	42.8
Maximum	16	15	14	90	85	87
Minimum	3	3	3	23	24	24
Range	13	12	11	67	61	63

Table 6.33: Summary of LW (longest wet day spell) and LD (longest dry day spell) results for the Missanello scenario runs.

	LW $HAD1970_{Mis}$	*LW $HAD2030_{Mis}$*	*LW $HAD2090_{Mis}$*	*LD $HAD1970_{Mis}$*	*LD $HAD2030_{Mis}$*	*LD $HAD2090_{Mis}$*
Winter						
Mean	7.8	6.8	6.4	24.9	32.9	30.2
Maximum	15	14	15	64	66	63
Minimum	5	4	3	15	17	16
Range	10	10	12	49	49	47
Spring						
Mean	7.4	7.8	7.8	28.7	27.3	27.7
Maximum	16	16	16	70	66	55
Minimum	4	5	4	16	16	17
Range	12	11	12	54	50	38
Summer						
Mean	5.8	5.9	5.8	50.5	49.2	46.4
Maximum	14	15	14	90	90	90
Minimum	3	3	3	28	29	24
Range	11	12	11	62	61	66
Autumn						
Mean	7.7	7.6	6.9	30.5	30.6	33.7
Maximum	15	17	14	70	63	74
Minimum	4	4	4	17	18	18
Range	11	13	10	53	45	56

Table 6.34: Summary of the extreme value analysis of annual maximum daily rainfall (mm) for the $HAD1970_{Alc}$, $HAD2030_{Alc}$ and $HAD2090_{Alc}$ simulation sets.

		$HAD1970_{Alc}$	*$HAD2030_{Alc}$*	*$HAD2090_{Alc}$*
T5				
	Mean	67.0	68.4	68.6
	Maximum	115.0	120.7	121.8
	Minimum	38.9	37.0	43.5
	Range	76.1	83.7	78.3
T10				
	Mean	80.4	82.0	82.0
	Maximum	145.7	155.3	155.8
	Minimum	42.6	40.9	47.9
	Range	103.1	114.4	107.9
T20				
	Mean	93.2	95.0	94.8
	Maximum	176.1	189.1	188.4
	Minimum	46.2	44.6	52.1
	Range	130.0	144.5	136.2
T50				
	Mean	109.7	111.8	111.5
	Maximum	215.6	232.8	230.6
	Minimum	50.8	49.4	57.6
	Range	164.8	183.4	172.9

Table 6.35: Summary of the extreme value analysis of annual maximum daily rainfall (mm) for the $HAD1970_{Mis}$, $HAD2030_{Mis}$ and $HAD2090_{Mis}$ simulation sets.

		$HAD1970_{Mis}$	*$HAD2030_{Mis}$*	*$HAD2090_{Mis}$*
T5				
	Mean	72.7	70.3	67.9
	Maximum	113.0	118.1	126.9
	Minimum	52.3	46.7	42.5
	Range	60.6	71.4	84.4
T10				
	Mean	84.6	81.8	79.1
	Maximum	142.3	147.9	157.6
	Minimum	57.8	50.7	46.1
	Range	84.5	97.2	111.5
T20				
	Mean	96.0	92.9	89.8
	Maximum	170.4	176.5	187.1
	Minimum	62.2	54.4	49.7
	Range	108.2	122.0	137.4
T50				
	Mean	110.7	107.2	103.6
	Maximum	206.9	213.5	225.2
	Minimum	67.1	59.3	54.2
	Range	139.8	154.1	171.0

Table 6.36: The percentage of annual maximum rainfall events which occur in each season at Alcantarilla.

	Observations 1958-1987	*HAD1970$_{Alc}$*	*HAD2030$_{Alc}$*	*HAD2090$_{Alc}$*
Winter	14	11	15	13
Spring	18	12	10	13
Summer	28	16	14	16
Autumn	39	61	61	58

Table 6.37: The percentage of annual maximum rainfall events which occur in each season at Missanello.

	Observations 1956-1988	*HAD1970$_{Mis}$*	*HAD2030$_{Mis}$*	*HAD2090$_{Mis}$*
Winter	47	43	35	33
Spring	10	18	23	24
Summer	6	10	12	14
Autumn	37	29	30	29

Table 6.38: Summary of HadCM2SUL changes in mean seasonal rainfall for the land and sea grid boxes closest to the Guadalentin.

	Winter	*Spring*	*Summer*	*Autumn*
Land box				
2030-2039 minus 1970-1979 (% change)	-0.6	+27.1	-7.8	-6.5
2090-2099 minus 1970-1979 (% change)	+43.4	+24.5	-21.5	-17.7
HadCM2SUL 1970-1979 mean (mm)	61.5	54.2	30.8	39.5
Sea box				
2030-2039 minus 1970-1979 (% change)	+25.7	+47.0	-36.8	-24.7
2090-2099 minus 1970-1979 (% change)	+20.1	+70.0	+25.4	-44.4
HadCM2SUL 1970-1979 mean (mm)	10.7	6.6	5.5	16.2
Observed mean, Alcantarilla, 1970-1979 (mm)	56.3	105.3	43.3	111.4
$HAD1970_{Alc}$ mean ($\overline{AMT_m}$) (mm)	56.8	66.1	46.3	130.3

Table 6.39: Summary of HadCM2SUL changes in mean seasonal rainfall for the land and sea grid boxes closest to the Agri.

	Winter	*Spring*	*Summer*	*Autumn*
Land box				
2030-2039 minus 1970-1979 (% change)	-13.6	+11.2	+20.3	-8.0
2090-2099 minus 1970-1979 (% change)	+15.4	+11.3	-16.8	-12.3
HadCM2SUL 1970-1979 mean (mm)	148.4	121.3	105.0	148.1
Sea box				
2030-2039 minus 1970-1979 (% change)	-16.4	+18.3	+29.5	-15.3
2090-2099 minus 1970-1979 (% change)	-20.5	+41.4	-14.6	-13.2
HadCM2SUL 1970-1979 mean (mm)	101.8	47.1	36.6	117.7
Observed mean, Missanello, 1970-1979 (mm)	301.8	215.9	119.7	228.1
$HAD1970_{Mis}$ mean ($\overline{AMT_m}$) (mm)	230.2	175.5	97.7	216.2