CHANGES IN EXTREME RAINFALL EVENTS IN SOUTH AFRICA

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Abstract. Extreme rainfall events can have severe impacts on society, so possible long-term changes in the intensity of extreme events are of concern. Testing for long-term changes in the intensity of extreme events is complicated by data inhomogeneities resulting from site and instrumentation changes. Using rainfall data from stations in South Africa that have not involved site relocations, but which have not been tested for inhomogeneities resulting from changes in instrumentation, a method of testing for changes in the intensity of extreme events is adopted. Significant increases in the intensity of extreme rainfall events between 1931–1960 and 1961–1990 are identified over about 70% of the country. The intensity of the 10-year high rainfall events has increased by over 10% over large areas of the country, except in parts of the north-east, north-west and in the winter rainfall region of the south-west. Percentage increases in the intensity of high rainfall events are largest for the most extreme events. While some inhomogeneities remain in the data used, the observed changes in the intensity of extreme rainfall events over South Africa are thought to be at least partly real.

1. Introduction

Although much of southern Africa lies within arid to semi-arid climatic regions, extreme rainfall events in the region are relatively frequent (Lindesay and Jury, 1991; Mason and Jury, 1997). The long-term implications of increases in the magnitude and frequency of high rainfall events for flood impacts is of serious concern. For example, the possibility of collapses of small dams and reservoirs is likely to increase and there are up to 100 000 people in South Africa that have settled on floodplains which could be inundated (Alexander, 1993). The impacts of extreme climate and weather events on agriculture and insurance are considerable (Fosse and Changnon, 1993; Changnon et al., 1997).

A number of theoretical, modelling and empirical analyses have suggested that noticeable changes in the frequency and intensity of extreme events, including floods, may occur when there are only small changes in climate (Mearns et al., 1984; Wigley, 1985; Rind et al., 1989; Katz and Brown, 1992; Katz and Acero, 1994; Wagner, 1996). It has therefore been suggested that tests for climatic change should focus on changes in extreme events rather than on changes in climatic means (von Storch and Zwiers, 1988). Sensitivity tests using the CSIRO (Commonwealth Scientific and Industrial Research Organisation, Australia) 9-level general

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circulation model linked to a simple mixed-layer ocean have been performed to test for simulated equilibrium climate changes under doubled concentrations of atmospheric carbon dioxide. Increases in extreme rainfall events were simulated over Australia (Whetton et al., 1993; Suppiah, 1994) and southern Africa (Mason and Joubert, 1997), even in areas where simulated mean annual rainfall decreased (cf. Yu and Neil, 1993). Observational evidence indicates that increases in extreme rainfall events have been observed in many areas (Changnon, 1983, 1985; Huff and Changnon, 1987; Iwashima and Yamamoto, 1993; Yu and Neil, 1993; Rakhechka and Soman, 1994; Karl et al., 1995, 1997; Suppiah and Hennessy, 1996; Hopkins and Holland, 1997). In this note, evidence for changes in the intensity of extreme daily rainfall events over South Africa during the last 60 years is assessed.

2. Data and Methods

Daily rainfall data from stations throughout South Africa were obtained for the 60-year period 1931–1990. Stations were selected on the basis of completeness of records and were chosen only if at least 50 years of complete daily records were available. Stations that involved site relocations were not included, but inhomogeneities resulting from changes in instrumentation have not been tested for because of a lack of metadata. Consequently, the results should be approached with caution. A large number of the selected stations opened in the early 1930s and so to avoid a large decrease in the number of stations, earlier data, where available, were not used. The locations of the 316 selected sites are shown in Figure 1. Annual maxima were extracted from the daily records at each of the stations. A missing value was given in the series if the year's records were not complete.

Many tests for changes in the intensity of extreme rainfall events involve a time-weighting in the calculation of return periods (e.g., Smith, 1989; Davison and Smith, 1990). Such tests assume a linear increase or decrease in intensity and their power can be severely restricted if the assumption of linearity is not valid. An alternative method is to calculate the probability of observing all the n most extreme events within a given, usually the most recent, sub-period (e.g., Wigley and Jones, 1987), however the results can be sensitive to the a priori definition of the sub-period and to the value of n. A re-sampling method that is free from distributional assumptions was used for testing the significance of changes in the intensity of extreme rainfall events over South Africa. The 60 years of data from each station were divided into two successive periods of 30 years each (1931–1960 and 1961–1990) and beta-κ and beta-P distributions were fitted to the annual rainfall maxima for each of the two periods. Maximum likelihood estimates of the beta-κ and beta-P parameters (Mielke and Johnson, 1974) provide the most accurate estimates of rainfall probabilities in the right and left tails, respectively. For each station, the intensities of 5-, 10-, 20-, 30- and 50-year large and small annual maxima were then obtained from the relevant fitted distribution for the 30-

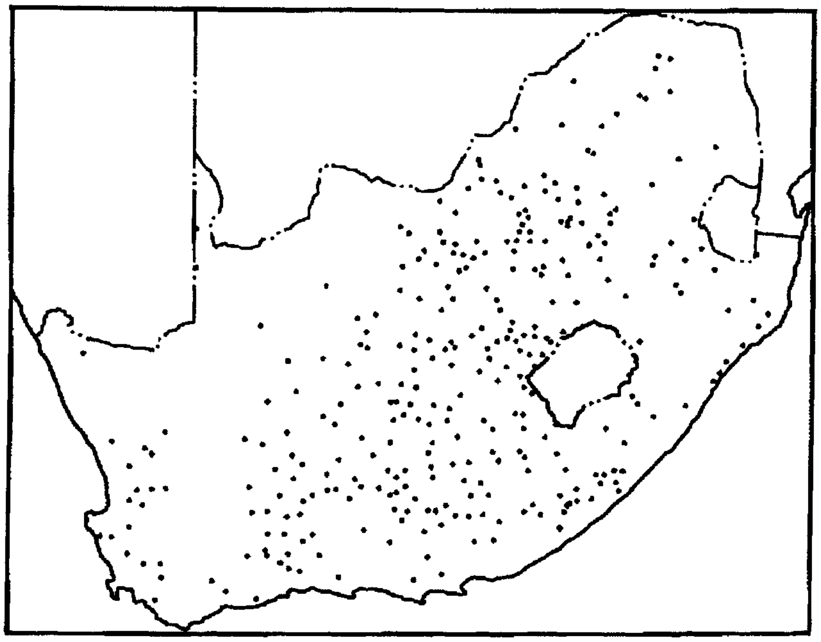

Figure 1. Location of 314 rainfall stations in South Africa with at least 50 complete years of daily rainfall records during the 60-year period 1931–1990.

year periods and the difference in the intensities in the two periods was calculated. The significance of changes in rainfall extremes was then assessed by comparing the difference in the intensity of high rainfall events with the difference expected under the null hypothesis. (The null hypothesis is that there is no difference in the intensity of high rainfall events between 1931–1960 and 1961–1990.) The empirical distribution of the differences expected under the null hypothesis was obtained by randomly dividing the 60 years of data into two 30-year periods. For each station, 1000 random divisions were performed, beta-κ and beta-P distributions were refitted each time and differences in high-rainfall intensities were calculated. The significance of the observed change was then obtained by comparison with the randomly generated differences. The procedure was repeated, but focusing on changes in the intensity of the annual rainfall maxima in the left hand tail, which was fitted using the beta-P distribution. A change in the left tail indicates a change in the intensity of the smallest annual rainfall maxima.

3. Significance of Changes in the Intensity of High Rainfall Events over South Africa

Percentage changes in the intensities of 10-year high rainfall events between 1931–1960 and 1961–1990 are illustrated in Figure 2. Increases in the intensities of the

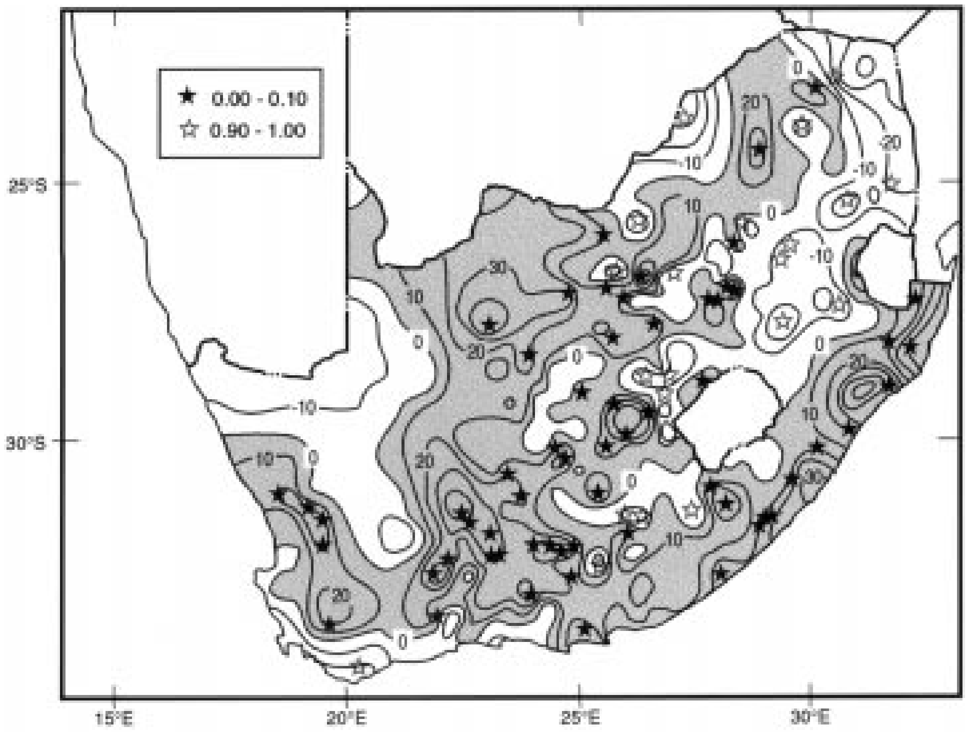

Figure 2. Percentage changes in the intensity of 10-year high rainfall events over South Africa between 1931–1960 and 1961–1990. Areas in which the intensity of 10-year rainfall events increased are shaded. Solid and hollow stars indicate stations where increases and decreases, respectively, in intensity are significant at the 90% level.

high annual maxima are evident over a large part of central South Africa and along the east coast. Over the eastern part of the country in a band down to Lesotho, in the north-west and over the winter rainfall region of the south-west, decreases in intensities of high rainfall have been experienced. The north-eastern part of South Africa has experienced a decrease in annual rainfall totals since the late-1970s (Mason, 1996), which is reflected in the decrease in extreme rainfall events in the area. Along the east coast, increases of over 50% in the intensity of 10-year high rainfall events have been experienced. The large increases here are partly a reflection of the impact of cyclone Demoina in January 1984 (Jury et al., 1993a), which precipitated more than 800 mm north of Durban in one day. However, the increases along the east coast are statistically significant at a large number of the rainfall stations and increases in the intensity of high rainfall events have occurred in the last 30-year period apart from 1984. Areas of significant change have experienced increases or decreases in intensity in more than one year. Similar spatial patterns of change are evident for the different return periods analysed, but the percentage changes are even larger for the more extreme rainfall events.

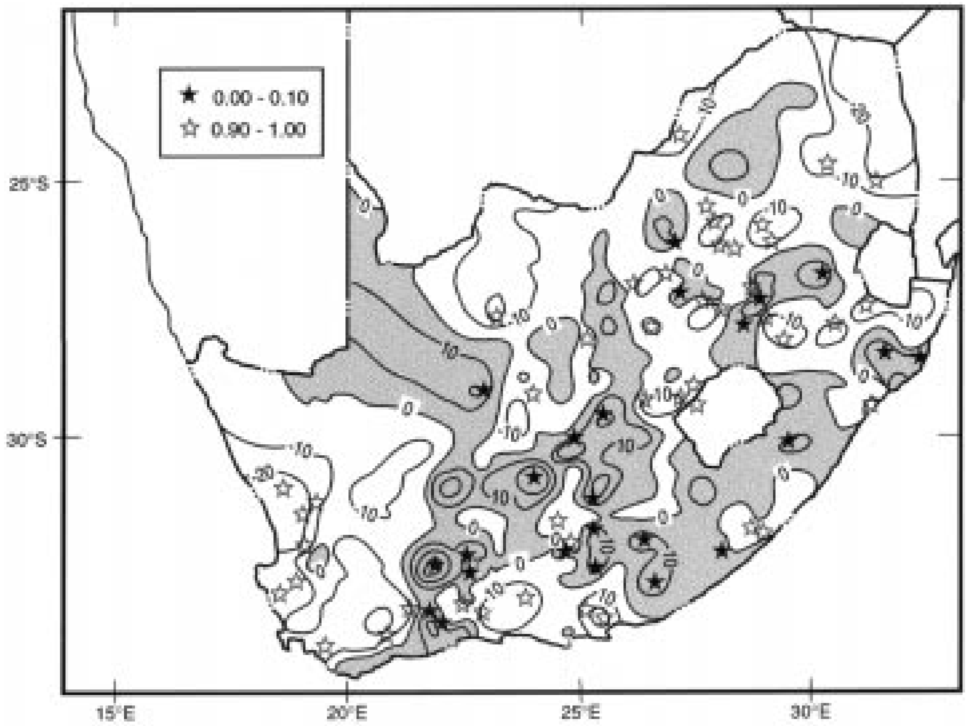

Figure 3. Percentage changes in the intensity of 10-year low annual rainfall maxima over South Africa between 1931–1960 and 1961–1990. Areas in which the intensity of the 10-year low annual rainfall maxima increased are shaded. Solid and hollow stars indicate stations where increases and decreases, respectively, in intensity are significant at the 90% level.

At the 90% confidence level, 65 stations have experienced increases in 10-year high rainfall intensities in the right tail between 1931–1960 and 1961–1990. Assuming independent tests, 31 of the 314 tests can be expected to erroneously indicate significant changes, and at least 43 significant changes would have to be detected in order to claim that changes in intensity have indeed occurred (Livezey and Chen, 1983). However, there is a degree of spatial dependence in the data: the first five principal components of the correlation matrix of annual rainfall maxima represent 25% of the total variance. Fraedrich et al. (1995) have proposed a method of calculating spatial degrees of freedom based on the eigenvalues of the correlation matrix, but the method involves strong distributional assumptions that are invalid in this context. Field significance levels were therefore not calculated.

In the left tail, changes in the intensity of low annual maxima are less spatially coherent (Figure 3). Over the west and south coasts and in the north-east, significant decreases have been observed at a number of stations, and there is a total of 46 stations countrywide where the low annual maxima have become significantly less intense. The decreases are, however, small and mostly less than 20%. At 24 stations increases in the intensity of low annual maxima have occurred. These sites are mainly located in the central and southern parts of the country. In areas such as the northern-central part of the country where an increase in the intensity of extreme 10-year rainfall events has occurred and the low 10-year events have decreased in intensity, an increase in the variance of the annual rainfall maxima is implied.

The observed changes in high rainfall intensities are noteworthy in the light of increases in the region expected with an enhanced-greenhouse effect, including in areas where total annual rainfall is expected to decrease (Brundrit and Shannon, 1989; Joubert and Hewitson, 1997; Mason and Joubert, 1997). Increases in atmospheric moisture content, that would occur as a direct effect of a warmer climate, are more likely to result in an increase in rain per rainday rather than in the number of raindays in many areas of the globe (Fowler and Hennessy, 1995). Over South Africa, increases in rain per rainday are expected to occur at the same time as decreases in the number of low rainfall days such that the net effect on annual rainfall totals is minimal (Joubert et al., 1996; Joubert and Hewitson, 1997). It is unknown whether there have been changes in atmospheric moisture or number of raindays over South Africa, but, contrary to expectations, decreases in atmospheric moisture have been observed further north (Hense et al., 1988) in areas where annual rainfall totals and the frequency of heavy rainfall events have also been decreasing (Hulme, 1996; Jury and Majodina, 1997; Mason and Jury, 1997). Over South Africa itself, there is little evidence of significant long-term trends in annual rainfall totals in the country, except possibly for a decrease in the far eastern part of the country (Mason, 1996; Jury and Majodina, 1997; Mason and Jury, 1997), where the intensity of extreme rainfall events has decreased also. The increases in the intensity of extreme rainfall events in other parts of the country are not inconsistent with the absence of any major changes in total annual rainfall: significant changes in extremes can occur with small changes in climate that may not be detectable in the annual totals.

It is not possible to attribute the observed changes in heavy rainfall intensities to changes in the frequency or intensity of any one particular rainfall-producing synoptic system. The influence of tropical cyclone Demoina over the east coast has been mentioned. Over the central interior and toward the south and east coasts, a number of heavy rainfall events in the last few decades have been attributed to intense cut-off lows (Tyson, 1986; Jury et al., 1993b; Mason and Jury, 1997), which are important contributors of mainly spring and autumn rainfall (Taljaard, 1986; Mason and Jury, 1997). Although cut-off lows are by definition cold-cored, mid-latitude circulation features, tropical moisture is believed to provide the main source for the rainfall associated with these systems (D'Abreton and Tyson, 1996). An observed warming trend in tropical Indian Ocean sea-surface temperatures (Graham, 1994) may therefore possibly have contributed to an intensification of rainfall produced by cut-off lows over South Africa. An increase in heavy rainfall events over South Africa, is not necessarily a manifestation of a warmer climate, however: there is evidence of palaeo-floods during the Little Ice Age that were much larger than anything recorded during the period of hydrographic records (Smith, 1991).

4. Summary

The impacts of heavy rainfall events on agriculture, engineering structures such as dams, water resource management, the insurance industry and human livelihood are considerable, and so the possibility of long-term changes in the intensity of extreme events are of concern. Data inhomogeneities resulting from site and instrumentation changes are most evident in the extreme values, and so testing for long-term changes in extreme events requires quality-controlled data. Using rainfall data from a large number of stations in South Africa that have not involved site relocations, but which have not been tested for inhomogeneities resulting from changes in instrumentation, a method of testing for changes in the intensity of extreme events is adopted. Over much of the country, there is significant evidence of increases in the intensity of high rainfall events between 1931–1960 and 1961–1990. Percentage increases in intensities are largest for the most extreme rainfall events. The intensity of 10-year high rainfall events has increased by over 50% along the east coast. The large increases here are partly a reflection of the impact of cyclone Demoina in January 1984, but other high rainfall events, frequently from cut-of lows, have occurred in the last 30-year period also. In parts of the north-east, north-west and in the winter rainfall region, decreases in extreme rainfall events have occurred and in the north-east are consistent with a decline in annual rainfall totals observed since the late-1970s. Changes in the intensity of low annual maxima are less spatially coherent and mostly of smaller magnitudes. While some inhomogeneities remain in the data used, the observed changes in the intensity of extreme rainfall events over South Africa are thought to be at least partly real.

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