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Spatial patterns of seasonal scale trends in extreme hourly precipitation in South Africa

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ABSTRACT

Hourly precipitation data from 1998 to 2007 spread across 102 stations in South Africa were analyzed for trends in extreme hourly precipitation events. The analyses were conducted at the seasonal scale for summer and winter for nine different variables. The results of our analysis showed predominantly positive trends during summer, with the strongest trends concentrated in the coastal areas in the southeast. The spatial variations in the trends were reversed during the winter season, with negative trends observed in the coastal areas and positive trends occurring in the interior. The summer patterns also overlap with areas experiencing overall increasing trends in annual extreme precipitation as well as a stronger diurnal cycle identified in recently published literature.

Introduction

Extreme weather events have emerged as one of the major manifestations of climate change in several regions of the world. Extreme events are usually defined by unusually high or low values in the total range of observations (IPCC, 2012). Given the extensive impacts of extreme weather events, there have been increasing concerns about the rising trends in the occurrence of extreme weather events around the world, such as extreme heavy precipitation. For instance, one of the earlier studies examining the widespread increasing trends in the occurrence of intense heavy precipitation events in the mid-latitudes was by Groisman et al. (2005). This was followed by a global level study by Alexander et al. (2006), who reported a significant increase in precipitation extremes, with fewer spatially coherent patterns compared with trends in extreme temperatures. These widespread increases in extreme precipitation events have been attributed to augmented levels of atmospheric water vapor as a result of warmer oceans, particularly in low-latitude regions (Trenberth et al., 2007). This has been further validated by increasing trends in specific humidity at the global level since 1970 (Dai, 2006; Willett, Jones, Gillett, & Thorne, 2008). Furthermore, Frich et al. (2002) found a decreasing trend in the number of consecutive dry days. Such positive trends in the occurrence of extreme precipitation events has resulted in widespread impacts in the form of floods and landslides, leading to long-term increases in economic losses in different regions of the world including northern Europe and North America (Easterling et al., 2000; Lamb, 2001).

However, there are substantial variations among spatial patterns of extreme heavy rainfall events. The frequency of heavy precipitation has specifically increased in the higher latitudes, tropics, and during winter season in the northern mid-latitudes. For instance, analysis of trends in heavy precipitation events in the United States revealed an overlap of areas that experienced excessive wetness with areas experiencing increasing trends in the frequency of days exceeding 50.8 mm of precipitation (Karl, Knight, Easterling, & Quayle, 1996). Several subsequent studies showed a rising trend in the occurrence of extreme daily precipitation events in the US (Easterling et al., 2000; Karl & Knight, 1998). More recently, Groisman, Knight, and Karl (2012) examined changes in intense precipitation events across central United States, and found significant increase in very heavy rainfall events (the daily rain events above 76.2 mm) and extreme precipitation events (defined as daily and multiday rain events with totals above 154.9 mm or 6 inch). Furthermore, a detailed analysis of extreme precipitation events associated with extratropical cyclone near a front and near a center of low over the conterminous United States showed significant increasing trends (Kunkel et al., 2012). The trends significantly positive in Northeast and east north central United States for extratropical cyclone near a center of low. Similar significant positive trends in extreme precipitation intensity were also observed in continental Europe (Brunetti, Buffoni, Maugeri, & Nanni, 2000; Frei &

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Schar, 2001), the UK (Lamb, 2001; Osborn, Hulme, Jones, & Basnett, 2000), and Japan (Iwashima & Yamamoto, 1993). Substantial variation in the magnitude of different extreme precipitation parameters, including both negative and positive trends, were observed in India (Goswami, Venugopal, Sengupta, Madhusoodanan, & Xavier, 2006; Sen Roy & Balling, 2004) and China (Wang & Zhou, 2005). In case of Australia, an increase in the proportion of total area under extreme wet conditions was found by Plummer et al. (1999). In a recent study by Toreti et al. (2010), examining extreme winter precipitation patterns in Mediterranean coastal cities revealed a significant role of large scale atmospheric circulation at the upper, mid and low troposphere such as the alignment of the subtropical jet stream axis with African coastline.

All of the above mentioned studies involved the analysis of station-level or gridded daily precipitation data for analyzing the trends in extreme intense precipitation events. However, a majority of the extreme intense precipitation events usually occur on shorter time scales, in the span of less than hour to a few hours. Therefore, the analyses of trends in extreme precipitation events at finer temporal resolution can better reveal the trends at the local level (Kanae, Oki, & Kashida, 2004). This is particularly applicable to regions with substantial seasonal-scale variability and undulating topography, adding to the complexity of immediate impacts of heavy precipitation events, such as in South Africa. Hourly scale data were used to examine trends in extreme precipitation events in the case of Tokyo (Fujibe, Yamazaki, Katsuyama, & Kobayashi, 2005; Sato & Takahashi, 2000). A detailed analysis of hourly precipitation data revealed a positive relationship between the amplitude and the intensity of precipitation events in the central and eastern United States (Winkler, Skeeter, & Yamamoto, 1988). Furthermore, spatial patterns of extreme hourly precipitation events were analyzed over the Indian subcontinent, which discovered trends in the frequency of events above the 90th percentile, 97.5th percentile, largest hourly seasonal precipitation, largest 3-hour and 5-hour precipitation events (Sen Roy, 2009). Therefore, in the present study, we have analyzed trends in station-level, extreme hourly precipitation events in South Africa between 1998 and 2007.

According to the fourth assessment report of the Intergovernmental Panel on Climate Change (IPCC), trends in overall rainfall patterns from 1900 to 2005 showed a decreasing pattern in southern Africa, specifically during the winter season. However, specific regional-level studies have indicated substantial regional and seasonal scale variations in long-term trends in South Africa (Engelbrecht, McGregor, & Engelbrecht, 2009; Tadross, Jack, & Hewitson, 2005). Moreover, increasing trends in the amount, intensity, and frequency of extreme precipitation events have been observed in places that have experienced an overall decrease in total precipitation amounts (Trenberth et al., 2007). It is also noted that there is a presence of a multi-decadal variability in the rainfall patterns, with abrupt changes in the occurrence of rainfall (Wang & Ding, 2006). However, there are limited numbers of studies that examine the spatial patterns in the longer term trends of occurrence of seasonal precipitation across South Africa. Specifically, Mason, Waylen, Mimmack, Rajaratnam, and Harrison (1999) analyzed daily rainfall data from 1931 to 1990, and reported increases in the intensity of extreme rainfall events for over 70% of the country. Additionally, a recently published study by Engelbrecht, Engelbrecht, and Dyson (2012), suggested a projected increase in extreme rainfall events over Southern Africa as a result of more intense convective rainfall events associated with tropical-temperate cloud bands. Given the role of localized systems leading to projected increases in extreme rainfall events and decadal variability in climate patterns, in this study of station-level hourly rainfall data is utilized to detect spatial patterns in trends of extreme rainfall events.

Datasets and methodology

Hourly rainfall data for 141 stations spread across South Africa were obtained from the South African Weather Service. The most common automated rain gauge used in collecting the data in these stations is usually of the tipping bucket. The rain gauge contains an open top which measures approximately 1 foot in a diameter that allows precipitation to fall into the upper portion, referred to as the collector. Collected water is funneled to the mechanical device (tipping bucket) which incrementally measures the accumulation and causes the momentary closures of switch for each increment. The tipping bucket is designed to measure in increments of 0.2 mm, 0.5 mm, 1.0 mm or 0.01 inch of rain. The South African Weather Service tipping bucket TB3 is set to measure in increments of 0.2 mm per tip. As water is collected, the tipping bucket fills to the point where it tips over. The information is recorded by the logger. Based on preliminary analysis of all the station-level data, 102 stations were used for the final analysis, which contained relatively complete data coverage from 1998 to 2007 (Fig. 1). Quality control methods included checking each station-level dataset for outliers or spurious values, and missing values (Table 1). In order to rule out the problems of clustering of data points, we conducted nearest neighbor analysis on the distribution of the station network. We obtained a ratio of 1.14, which is random to dispersed at the 0.01 level of statistical significance.

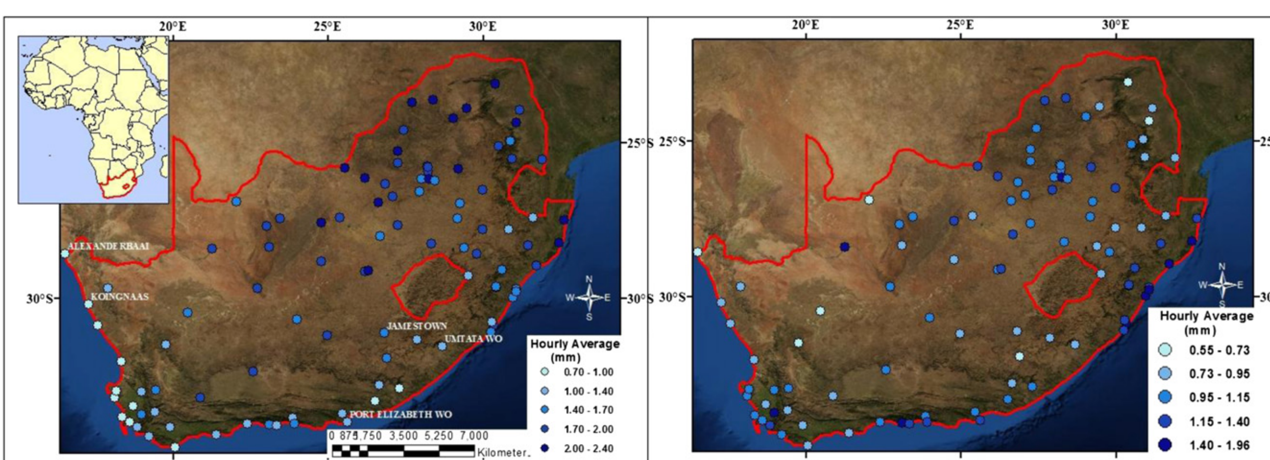

Fig. 1. Distribution of average hourly rainfall across 102 weather stations located in South Africa (a) Summer; (b) Winter.