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A semi-parametric model for stochastic generation of multi-site daily rainfall exhibiting low-frequency variability

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Longer-term aggregated variables

Summary A semi-parametric stochastic modeling framework for generation of daily rainfall at multiple locations is presented. The proposed framework represents longer-term variability and low-frequency features such as drought, while still simulating other daily key distributional and dependence attributes present in the observed rainfall record with sufficient spatial coherency. The rainfall occurrences at individual sites are simulated using a two-state, first-order Markov model. The transition probabilities of the Markov model are modified by using ''aggregate'' predictor variables that are indicative of how wet it has been over a period of time. The rainfall amounts on the simulated wet days are generated using a nonparametric kernel density estimation approach. Multisite spatial correlations in the rainfall occurrences and amounts series are represented by driving the single-site models with spatially correlated random numbers. The model is applied on a network of 30 raingauge stations around Sydney in eastern Australia. The analyses of results show that the model is capable of reproducing daily and higher time-scale key spatial and temporal characteristics of rainfall desired in most hydrologic applications.
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Introduction

Simultaneous simulation of weather variables at multiple point locations is often desired in many hydrological and agricultural applications. However, observed records of these variables providing sufficient temporal and spatial coverage are rarely available. To overcome this, stochastic models are commonly used to generate synthetic sequences of weather variables that are statistically consistent with the observed record. Point rainfall at a daily time scale usually forms one of the key variables in these applications. Rainfall at individual point locations is often generated by assuming low-order Markovian dependence (Wilks, 1999c; Wilks and Wilby, 1999) and therefore cannot satisfactorily reproduce the low-frequency variability that is observed (Gregory

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et al., 1993; Jones and Thornton, 1993; Katz and Parlange, 1993, 1998; Wilks, 1999a,c) and cannot be generalized to represent spatial dependence across multiple point locations. Another drawback often observed is under-simulation of extended drought frequencies (Buishand, 1978; Guttorp, 1995; Racsko et al., 1991; Semenov and Porter, 1995), suggesting their use in catchment management studies can lead to improper evaluation of the hydrological or agricultural behavior of a region, and to suboptimal policies for system management.

Some of the above mentioned limitations are illustrated in Fig. 1 wherein plots of a few rainfall attributes of observed and first-order Markov model simulated rainfall occurrences are presented (more background on the study region and data used are provided in later sections). As can be seen from these plots, the first-order Markov model while reproduces satisfactorily the average number of wet days in a year (plot a), underestimates, the interannual variability of wet days (plot b) and provides poor distribution of number of wet days and rainfall totals at annual time scale at a station (plots c and d). Also, while maximum wet spells are simulated quite well (plot e), maximum dry spells are under simulated at majority of stations (plot f). Results of second-order Markov model also follow similar trends (results not presented).

Results of earlier studies suggest that the day to day as well as low-frequency variations in the rainfall primarily govern the observed interannual variability and use of higher-order Markov models of rainfall occurrences and more complex models of rainfall amounts can explain only a part of the unexplained variance associated with day to day variations in the rainfall (Katz and Parlange, 1998; Wilks, 1999c, and the references therein). Other researchers have inferred this unexplained variance (often referred to as ''overdispersion'') as the portion of the interannual variance associated with climatic nonstationarity, and/or longer time scale variations in the rainfall (Madden et al., 1999; Shea and Madden, 1990; Singh and Kripalani, 1986; Harrold et al., 2003a,b). It is suggested that the simple stationary models of daily rainfall cannot effectively reproduce the

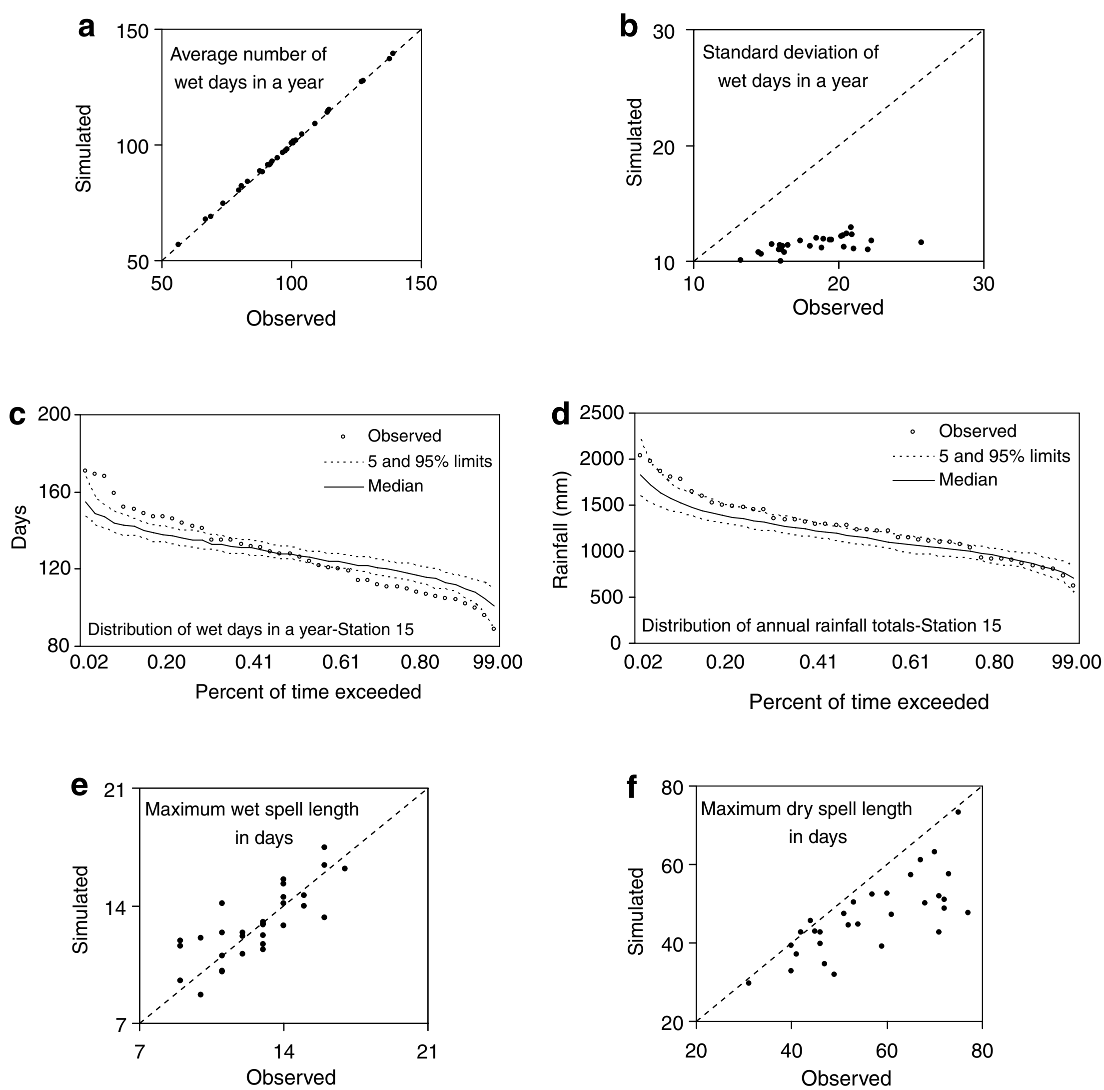

Figure 1 Scatter and distribution plots of (a) average number of wet days in a year, (b) standard deviation of annual wet days, (c) distribution of annual wet days at Station 15, (d) distribution of annual rainfall totals at Station 15, (e) maximum wet spell lengths, and (f) maximum dry spell lengths at all stations. Simulated statistics are obtained using first-order Markov model.

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