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Evaluation of CLIGEN for storm generation on the semiarid Loess Plateau in China

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Abstract

The Stochastic generation of storm patterns is often necessary for driving process-based hydrological and ecological models. CLIGEN is the only weather generator being able to generate internal storm patterns. Its goodness needs to be evaluated for its proper application. This paper aims to find the advantages and limitations of CLIGEN on semiarid areas and provide references for custom-built weather generators for the Loess Plateau. The daily rainfall time series (1957–2002) and breakpoint rainfall data (more than 20 years) on six stations on the Loess Plateau were used to estimate input parameters for CLIGEN and to compare with CLIGEN-generated 50 years of storm data. Precipitation occurrence (wet day and dry day sequence) is well-simulated without significant difference across months and sites. Errors of monthly average number of wet days range from −0.67 to 1.08 days, standard deviations range from −1.19 to 0.76 days, and the distributions of continuous number of wet and dry days on the semiarid Loess Plateau are adequately simulated. Daily rainfall amount is not simulated as well as precipitation occurrence. The relative errors of average daily rainfall range from −12.93% to 8.64% and those of standard deviations range from −21.35% to 27.46%. During the rain seasons (May–September), among 30 month–location combinations, all the Mann–Whitney tests for the means passed, 47% for squared ranks tests rejected the null hypothesis of equality of standard deviations, and 73% for K–S test suggested that the generated and measured distributions of daily rainfall were different at 0.01 level of significance Three variables to describe internal storm patterns in CLIGEN are storm duration, relative peak intensity, and time to peak. Storm duration was not well-reproduced because none of squared ranks tests and K–S test passed at the significance level of 0.01. The frequency of short duration storms (<300 min) was over-predicted while frequency of long duration storms (400–1200 min) was significantly under-predicted. The distribution of maximum 5 min rainfall intensity (ip_5) was well-simulated for four sites out of the six because all tests passed. However, generated maximum ip_5 for all six sites are around 190 mm/h, which are much larger than the measured (70 to 150 mm/h). Ip_{30} is simulated better than ip_5, suggesting that CLIGEN can reliably generate rainfall erosivity. Time to peak was well-simulated because all the tests passed with P values significantly greater than the significance level of $P=0.01$. Improvement for CLIGEN has to be made in terms of the daily rainfall simulation in rainfall-concentrated seasons and storm pattern generation in order to generate reliable rainfall time series on the Loess plateau.

Keywords: Weather generator; CLIGEN; Storm pattern; Loess Plateau

1. Introduction

The Stochastic generation of storm patterns is often necessary for driving process-based hydrological and ecological models when the measured weather data is insufficient. Among several commonly used weather generators, CLIGEN is the only one that generates internal storm patterns. Since it was officially released with WEPP (Water Erosion Projection Model) in 1995 (Flanagan et al., 1995), evaluations and improvements to CLIGEN have not stopped. Yu (2000) evaluated version 4.2, and suggested subsequent modifications to storm intensity calculations. In 2001, a "quality control" technique was introduced to guarantee the normality of random numbers (Flanagan et al., 2001). CLIGEN has been validated to adequately reproduce rainfall occurrence and annual and monthly precipitations in the U.S. (Johnson et al., 1996; Zhang and Garbrecht, 2003). However, the evaluation of a new version (v5.107) indicated the following: the daily precipitation distribution was not well-simulated, the storm duration

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required improvements, and the relative peak intensity was noticeably over-predicted (Zhang and Garbrecht, 2003).

The Loess Plateau, which has a semiarid climate with specific hydrological processes, is well-known for severe water erosion; therefore, extensive research has been conducted on process-based hydrological and erosion prediction models. Unfortunately, only a few studies were conducted on weather generators (Wu and Wang, 2000; Liao et al., 2004) in China, particularly on evaluating the ability of weather generators to simulate daily rainfall. Thus far, no detailed evaluations of storm pattern simulation have been reported.

By evaluating the applicability of CLIGEN for simulating rainfall patterns on the Loess Plateau, this paper aims to find its advantages and limitations in semiarid areas and provide references for custom-built weather generators for this area.

2. Procedure

2.1. CLIGEN rainfall generation description

CLIGEN generates the daily precipitation, storm duration, time to peak, peak storm intensity, daily maximum and minimum temperature, mean daily solar radiation, mean daily dew point temperature, and mean daily wind direction and speed. The precipitation variables are independent of other weather variables. Owing to the fact that there are various storm patterns in nature, even during the same season over the same area, it is very difficult to reproduce internal storm patterns. Three assumptions were made in CLIGEN in order to simplify storm pattern simulation. First, there is only one storm event on a wet day, which implies that the storm duration is not longer than 24 h. Second, each storm process has only one peak. Third, all storm patterns can be described by a double-exponential function. CLIGEN begins by generating the occurrence of precipitation with the first-order and two-stage Markov chains following which a skewed normal distribution is used to generate the daily precipitation amount for each wet day. Next, three variables describing internal storm patterns are simulated, including storm duration, peak intensity and time to peak. The storm duration and peak intensity are both estimated using a log transformed gamma distribution, for which the maximum 0.5-h rainfall depth of each month is the only input parameter. The time to peak is estimated based on the accumulated distribution of 12 “time to peak” classes.

CLIGEN simulates the seasonal variation in weather variables by using input parameters to derive daily values for each month, and a interpolation/disaggregation scheme can be selected among three to provide more continuous daily values between the monthly ones.

The weather generating methods employed in CLIGEN were presented in the WEPP documentation (Flanagan et al., 1995). Zhang and Garbrecht (2003) described the newly revised algorithm in detail.

2.2. Materials and methods for CLIGEN evaluation

In order to drive CLIGEN v5.22564 (released on 2004-10-26, available at: http://horizon.nserl.purdue.edu/Cligen/), seven precipitation parameters as well as the temperature, radiation, and wind parameters for the simulated sites are required. Precipitation parameters including the probability of a wet day following a dry day and that of a wet day following a wet day, the mean, standard deviation and skewed coefficient of daily rainfall, and the average of the highest monthly maximum 0.5-h rainfall intensity should be prepared for each month. In addition, the accumulated distributions of 12 “time to peak” classes are required.

In order to estimate these parameters, not only the historical long-term daily precipitation data but also the intensity records within storms are required. Six stations with two resources of measured data on the Loess plateau were selected to evaluate the storm pattern simulation of CLIGEN. The daily rainfall time series (1957–2002) from the China Meteorological Administration (http://cdc.cma.gov.cn) were used to estimate five monthly input parameters (i.e., two types of rainfall occurrence probabilities, and the mean, standard deviation and skewed coefficient of daily rainfall) and to evaluate the simulated precipitation occurrence and daily rainfall amounts. Less than 1.3% of data were missing for the period of record at each station. The breakpoint rainfall data (more than 20 years) obtained from soil erosion experimental stations was used to estimate the other two input parameters (i.e., the average of the highest monthly maximum 0.5-h rainfall intensity and the accumulated distribution of 12 “time to peak” classes) and evaluate the storm pattern generation. Station information is listed in Table 1.

The Loess Plateau of China is well-known for the severe soil erosion caused by erosive rainfall. The annual precipitation varies from 316 to 512 mm across six sites selected to evaluate CLIGEN (Table 1); the coefficient of variation (CV-equals the standard deviation divided by the mean) of annual precipitation varies from 23.1 to 31.7%, and 75 to 85% of precipitation occurs between May and September.

Statistic tests, relative and absolute errors, and comparisons of historical and generated frequency distribution diagrams were employed to evaluate the reproducibility of CLIGEN. The site-to-site variation on the Loess plateau was hardly considered. CLIGEN was evaluated by the following steps: (a) build a database for historical precipitation data using Microsoft Access and develop a Visual Basic module to calculate the input parameters;

Table 1
Site location, period of record and other information of rainfall data

Station code	Station name	Lat. (°N)	Long. (°E)	Precipitation (mm/yr)	Period of daily data	Period of breakpoint rainfall data
52889	Lanzhou, Gansu	36.03	103.53	316	1957–2002	1952–1979 Jun–Oct
53487	Datong, Shanxi	40.06	113.20	376	1957–2002	1956–1980 May–Sep
53664	Xingxian, Shanxi	38.28	111.08	483	1957–2002	1966–1986 May–Sep
53673	Yuanping, Shanxi	38.44	112.43	429	1957–2002	1956–1980 May–Sep
53764	Lishi, Shanxi	37.30	111.06	475	1957–2002	1966–1986 May–Oct
57006	Tianshui, Gansu	34.35	105.45	512	1957–2002	1955–1979 May–Oct