CLIGEN WEATHER GENERATOR PREDICTIONS OF SEASONAL WET AND DRY SPELLS IN UGANDA

C. D. Arnold, W. J. Elliot

ABSTRACT. *Daily precipitation from 20 years of record from highland and central plains sites of Uganda were used to analyze the ability of the CL1GEN weather generator to predict seasonal wet and dry spell lengths. Results indicate that the predicted wet and dry spell probability density functions were not significantly different (P = 0.05) from the observed data for the central plains, lower elevation site. CLIGEN-predicted distributions were found to be significantly different (P = 0.05) for 50% of the probability density functions estimated for the high-elevation site. The monthly precipitation totals and probability estimates were not significantly different (P = 0.05), but CLIGEN appears to have a problem in predicting the precipitation pattern within a month for the high-frequency, low-intensity site.*
Keywords. Climate assessment, Model validation.

Over the past decade, the USDA-Agricultural Research Service has developed a climate generator program (CLIGEN) capable of producing synthetic climate records for use in the EPIC (Williams et al., 1984), GLEAMS (Leonard et al., 1987), and WEPP (Laflen et al., 1991) soil erosion and water quality models (Nicks, *1985;* Nicks et al., *1995).* CLIGEN can generate a weather record of any length— from one storm to any number of years. The precipitation outputs include rainfall amount, storm duration, maximum intensity, and time to peak intensity.

CLIGEN generates the occurrence of precipitation on each day with a two-state, first order Markov chain. The Markov chain method is based on two conditional probabilities: the probability of a wet day following a dry day, P(W/D), and the probability of a wet day following a wet day, P(W/W) (Nicks et al., 1995).

Twenty years of daily precipitation values from Uganda were analyzed, including monthly and annual totals, and number of events per year. The wet and dry probabilities of a synthetic record were compared to the observed record. Table 1 summarizes the observed and generated means. Another study found that the number of wet days and the amount of daily precipitation generated by CLIGEN was not different from the observed values (Elliot and Arnold, 1996). The CLIGEN-generated statistics are based on 10 sets of 20 years each. The statistics of the values generated by CLIGEN closely approximate those observed, indicating the integrity of the CLIGEN code in matching the observed statistics.

An alternative method to the Markov chain is to define probability density functions for the length of both wet and dry spells within a season (Bowles et al., 1994). These functions are then used to generate the daily probability of a precipitation event. The wet and dry spells method can predict a potentially more accurate representation of seasonal effects, and it requires less input data than the Markov chain method. Such a reduction in input data, however, may adversely impact the estimated distribution if the generating statistics are based on a reduced sample size. The identification of the seasonal time limits (or bandwidths) and the development of the wet- and dry-spell length probability density functions can also be difficult. Another problem with the wet- and dry-spell model is that the shorter the season, the shorter the potential longest spell. A spell can never be longer than the length of the season. This limitation has a confounding effect on all seasonal spell-length research.

This study compares seasonal precipitation pattern data generated by CLIGEN ver. 3.1 by the Markov chain method to probability density functions of wet- and dry-spell length developed from strongly seasonal observed data from Uganda.

EXPERIMENTAL PROCEDURES

Uganda straddles the equator and is situated on a high plateau between two mountainous regions, Mount Elgon on the east and the Ruwenzori Mountains on the west. Twenty years of daily precipitation data collected at two sites in Uganda were used for the CLIGEN validation (Arnold, 1993). The first site, Kabanyolo, is located near Lake Victoria, 60 km from the equator at an elevation of 697 m. The second site, Buginyanya is located on the slopes of Mount Elgon at an elevation of 2 030 m. Kabanyolo is representative of the central "lowland" rainfall found in much of Uganda. Buginyanya is representative of the rainfall patterns found in the mountainous borders of Uganda (fig. 1). The data were of similar quality for both

Table 1. CLIGEN-generated precipitation statistics compared to precipitation observations at Kabanyolo and Buginyanya, Uganda

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
						Precipitation (mm)						
Kab*	53.3	81.0	143.0	174.8	128.8	80.5	59.4	94.0	113.8	131.1	168.7	82.3
CLI†	58.2	83.3	140.0	180.3	140.2	75.4	62.0	95.8	115.6	115.8	164.1	76.5
Bug‡	47.8	69.9	134.4	210.8	234.4	178.8	200.9	263.9	199.6	194.6	135.6	31.0
CLI	47.0	66.8	143.0	229.9	250.7	188.7	207.3	291.8	215.9	208.8	140.2	29.7
						Probability (W/W)						
Kab	0.41	0.46	0.54	0.66	0.54	0.44	0.46	0.47	0.58	0.60	0.64	0.49
CLI	0.41	0.46	0.53	0.66	0.54	0.43	0.45	0.47	0.59	0.59	0.63	0.48
Bug	0.52	0.61	0.62	0.69	0.81	0.72	0.74	0.79	0.79	0.79	0.70	0.48
CLI	0.48	0.60	0.61	0.69	0.80	0.72	0.75	0.79	0.79	0.79	0.71	0.49
						Probability (W/D)						
Kab	0.22	0.29	0.42	0.54	0.50	0.29	0.29	0.40	0.46	0.49	0.51	0.28
CLI	0.23	0.29	0.44	0.54	0.48	0.29	0.29	0.40	0.46	0.49	0.51	0.27
Bug	0.14	0.17	0.22	0.37	0.42	0.50	0.60	0.64	0.48	0.42	0.30	0.14
CLI	0.15	0.17	0.22	0.37	0.43	0.51	0.61	0.65	0.45	0.40	0.30	0.14

* Kab = Kabanyolo 20-year mean.
† CLI = Mean of 10, 20-year means generated by CLIGEN.
‡ Bug = Buginyanya 20-year mean.

sites, with data sets chosen that represented 20 continuous years for each site.

The number of wet days following a wet day divided by the number of days in the period, P(W/W), and the number of a wet days following a dry day divided by the number of days in the period, P(W/D) were determined for each 10-day period of the year. A plot of these probabilities with respect to the period of the year (fig. 2) determined the beginning of the wet and dry seasons for each site. Seasonal lengths similar to those reported by farmers in the area were estimated by considering the period of time when the value of P(W/W) was greater than 0.2 as a rainy season period. 1\vo wet seasons per year were identified for Kabanyolo: 1 March to 15 June and 15 August to 15 December. One long wet season per year was identified for Buginyanya: 1 April to 25 November.

Within each determined season, the probability density function of the length of a wet or dry spell was estimated. The spell lengths ranged from 1 to 28 days with the majority of the spells 13 days or less in length. We divided the number of spells of each spell length by the total number of spells recorded for the entire season to determine the frequency of spell length in the season. A plot of the frequency of the spell length versus the spell length illustrates the probability density function for the season. Figure 3 shows the wet and dry probability density functions for both wet seasons at Kabanyolo, using the 20-year mean values.

The shape of the curves in figure 3 suggested an inverse relationship between spell length and the probability of the spell occurring. Subsequent analysis of the density functions for both the wet and dry seasons at the two sites revealed that equation 1 exhibited high coefficients of determination for the observed 20-year mean values.

$$1/(SL) = A + B(Fr) \tag{1}$$

where
- SL = length of consecutive wet/dry days during the specified season
- A = regression constant
- B = coefficient of regression

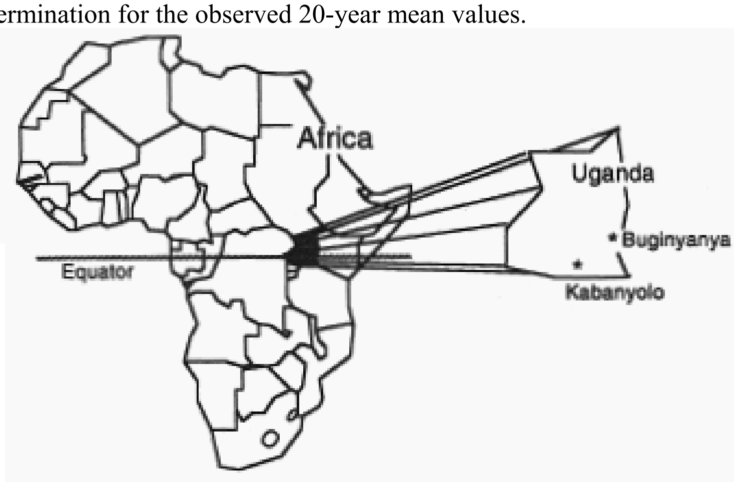

Figure 1–Location of climate observations in Uganda.

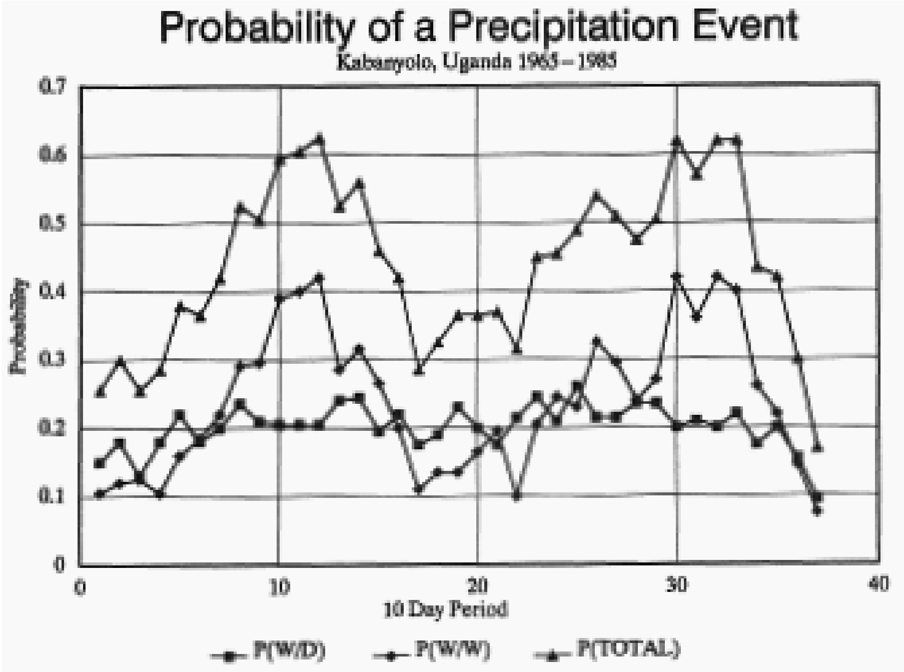

Figure 2–Precipitation event probabilities in Kabanyolo.

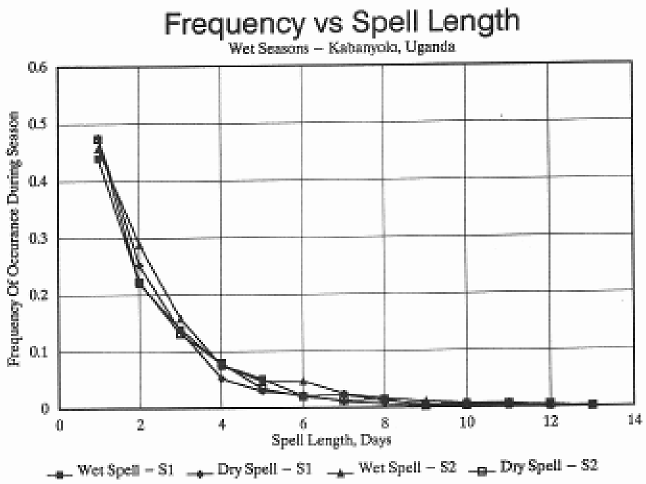

Figure 3–Frequency vs. spell length for the two wet seasons in Kabanyolo.

Table 2. Probability density function coefficients for Kabanyolo for observed and CLIGEN-generated values

	Observed Data			CLIGEN Values		
Season	A	B	r^2	A	B	r^2
Dry Season 1						
Wet spell	0.1205	1.6129	0.983	0.0945	1.7072	0.963
Std. error	0.0351	0.0641		0.0422	0.0238	
Dry spell	0.0417	2.655	0.966	0.0403	2.7956	0.851
Std. error	0.0497	0.1509		0.0844	0.083	
Wet Season 1						
Wet spell	0.0897	2.016	0.994	0.079	2.0177	0.976
Std. error	0.2138	0.0486		0.034	0.0225	
Dry spell	0.1052	1.8157	0.984	0.0863	1.8711	0.978
Std. error	0.0336	0.0691		0.0328	0.0201	
Dry Season 2						
Wet spell	0.1382	1.426*	0.954	0.0965	1.6684	0.964
Std. error	0.0579	0.0949		0.0419	0.0231	
Dry spell	0.0419	2.6474	0.924	0.0542	2.5148	0.925
Std. error	0.0739	0.2284		0.06	0.0509	
Wet Season 2						
Wet spell	0.0834	1.837*	0.971	0.0759	2.0795	0.976
Std. error	0.0456	0.0953		0.0342	0.0234	
Dry spell	0.0997	1.8856	0.994	0.0856	1.885	0.977
Std. error	0.0205	0.0435		0.0335	0.0208	

* Modeled significantly different from observed (P = 0.05).

Fr = Number of spells of a given spell length divided by the total number of wet/dry events in the season

Two hundred years of daily precipitation values were generated for each Ugandan site using the CLIGEN ver. 3.1 program. This record was divided into 10 sets of 20 years for comparison to the observed 20-year records from Uganda. The wet and dry spell frequencies for each spell length in each season, using the seasonal dates determined above, were estimated for each year of generated record. The mean values of the spell frequency per spell length over the 200-year record were used to estimate the coefficients for equation 1 for each wet or dry probability function in each season for both sites.

RESULTS AND DISCUSSION

Regression coefficients, with equation 1 as the model, were determined for the observed 20-year mean values and the CLIGEN 200-year mean values. Tables 2 and 3 give the values of *A* and *B,* the standard error of *A* and *B,* and the coefficients of determination corresponding to each wet and dry probability density function for all seasons of observed and generated precipitation records for the two Ugandan sites.

The coefficients of determination range from *0.775* to 0.994, with a mean value of 0.968 for the observed values, and 0.9342 for the CLIGEN-generated values. Although no pattern of low coefficients was found across all seasons, the lowest values occurred with respect to the CLIGEN generated dry spell functions. These high coefficients indicate that equation 1 is generally adequate for relating probability of spell length to number of spells. They do not necessarily indicate the adequacy of CLIGEN to describe the respective climates.

The coefficients *A* and *B* compared favorably between the observed and CLIGEN-generated values, with *A* values 37.4% and *B* values *15.8%* different from each other on the average. The standard errors for the observed values are on the order of 0.66 times greater for the *A* coefficients and 2.4 times greater for the *B* coefficients than the standard errors for the CLIGEN-generated values. This would be expected since the CLIGEN values are from 200 years of data, whereas the observed values are from only 20 years of data. Also, variations in modeled data are generally less than in observed data in natural resource modeling because the model does not include all the natural sources of variation.

A t-test tested for the significant differences *(P = 0.05)* between the observed sample of 20 years and the sample of 200 years generated by CLIGEN (Haan, 1979). Only four *B* coefficients and no *A* coefficients, were significantly different (tables 2 and 3). The differences noted were for two wet-spell functions at the Kabanyolo site and two dry spell functions at the Buginyanya site.

The significantly different coefficients for the Kabanyolo site show a difference of 14.5 and 11.7% between the observed values and CLIGEN values, and may possibly be accounted for by the increased variation expected in a small sample of 20 years. The significantly different coefficients for the Buginyanya site, however, show a difference of 47.9 and 86.9%, respectively between the observed and CLIGEN values, and a value of $r^2 = 0.775$ for one of the CLIGEN-generated functions. This seems to indicate that there is a problem in generating the appropriate dry-spell functions for high-elevation areas.

Both sites are strongly seasonal in their rainfall patterns. The CLIGEN values resulting from the Markov chain method appear to adequately model the lower elevation site, Kabanyolo, but there is some difficulty in modeling the longer dry-spell rainfall patterns of the high-altitude Buginyanya site. One explanation for this may be that high-elevation precipitation tends to come in low-intensity rains, occurring over a large number of days, thus producing greater P(W/W) and a longer season length. Conversely, lower elevation precipitation tends to come in high-intensity rains, occurring over a smaller number of days, thus producing lower P(W/W) values and a second dry season during the months of July and August.

Table 1 indicates no significant differences between the observed and CLIGEN-generated mean monthly total precipitation for either site. Table 1 shows that CLIGEN is able to predict the correct number of rainy days within the month. The results from tables 2 and 3 indicate, however, that CLIGEN is not successfully modeling the pattern of events within the month for the high-frequency, low-intensity site, Buginyanya.

Table 3. Probability density function coefficients for Buginyanya for observed and CLIGEN-generated values

	Observed Values			CLIGEN Values		
	A	B	r^2	A	B	r^2
Dry Season						
Wet spell	0.0992	1.8978	0.976	0.0804	1.99	0.968
Std. error	0.0412	0.0889		0.0394	0.0259	
Dry spell	0.017	5.919*	0.944	–0.0137	4.002	0.775
Std. error	0.0637	0.4357		0.1039	0.1533	
Wet Season						
Wet spell	0.0302	2.9238	0.943	0.0261	3.089	0.886
Std. error	0.0643	0.2174		0.074	0.0789	
Dry spell	0.1071	3.567*	0.986	0.0845	1.9086	0.982
Std. error	0.0318	0.1284		0.029	0.0182	

* Modeled significantly different from observed (P = 0.05).

CONCLUSIONS

CLIGEN-predicted monthly precipitation totals and wet and dry probabilities are not significantly different *(P = 0.05)* compared to the observed data for the two sites. In testing for seasonal effects, the Markov chain was successful in modeling six out of eight probability density functions developed from the lower altitude Kabanyolo site. But the Markov chain model could only generate rainfall patterns similar to two out of four density functions for the high altitude, Buginyanya site.

Although CLIGEN is successful in reproducing the monthly probabilities of a wet or dry event, CLIGEN appears to have some difficulty in predicting seasonal frequencies at the high-elevation site where the rainfall pattern consists of high-frequency, low-intensity events. CLIGEN appears to be predicting the correct number of rainy days, yet it is not predicting the correct pattern of days within the month for the high-frequency, low-intensity site. This may lead to errors in predicting antecedent soil water content and related soil properties within natural resource models for high-altitude sites.

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Moscow Forestry Sciences Laboratory
Rocky Mountain Research Station
USDA Forest Service
1221 South Main Street
Moscow, ID 83843