Evaluation of Simulator of Missing Weather Data (SMWD) Required in simulation of agro hydrological modelling in the catchment and basin level: case of the PARCHED-THIRST and Marksim Model [1]

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Abstract

Problem of availability of quality and quantity of weather data in running most of agro hydrological models, numerous simulators of missing climate data have been produced as component of comprehensive model or as a stand alone model. The rainwater harvesting simulation PARCHED-THIRST (PT) model has an inbuilt module capable of simulating missing climatic data (PTSMCD) within the existing data series of the same site using the statistical properties of the other data at the same site or from other climatically similar site. MarkSim is an example of standalone simulators, with capability of simulating spatial data given site location and altitude. The results presented in this paper provide an evaluation of the performance on the two simulators of missing climate data for three stations namely, Same, Mwanga and Morogoro representing three different growing season. This was achieved by comparing observed and simulated by both models, daily, and derivatives of daily data (annual rainfall, long term mean monthly rainfall, monthly number of rainy days and long term standard deviation of monthly rainfall). The results shows that PTSMCD can not reproduce the daily rainfall records of a particular year with low R^2 ranged from 0.01 to 0.04. The same problem was observed for total annual rainfall, D-Index ranged from 0.24 to 0.44 and 0.37 to 0.50 for PTSMCD and MarkSim, respectively. PTSMCD produced much better results on number of rainy days and long term mean monthly rainfall(R^2 ranges from 0.98 – 99 for both), while for MarkSim (R^2 ranged 0.75 to 0.80 for number of rainy days and from 0.64 to 0.91 for long-term mean monthly rainfall). In PTSMCD had a good performance than MarkSim. It was also found that the Minimum data required to run the PTSMCD is between 10 to 15 years of historical data.

Keywords; agro hydrological modeling, rainfall, simulator of missing climate data, semi arid areas

Introduction

Rainfall is highly variable in the semi-arid and sub humid crop growing regions of Southern Africa. Because of this, short term field experiments designed to test water management such as conservation production techniques can give unreliable results. Long-term results are highly desirable. However long term results and facts can not be attained through experimental testing as these will be limited to resources. Also It needs to be kept in mind that the results of field experiments are ecotope specific. These two facts provide the opportunity for simulation models to make a very valuable contribution towards the aim of maximizing precipitation utilization. However, the use of the model requires long term weather data to simulate long-term yields for any ecotope that has been characterized efficiently, or for different production techniques on a particular ecotope.

[1] *Paper to be presented*

Rainfall is the most fundamental data input for most of the Simulation models. However, one of the major constraints of process-based models is the difficulty of obtaining required data sets, both in terms of format, quantity and quality. Though this problem is rather universal, it is often serious in many parts of developing countries especially Sub Saharan Africa (SSA). With the advent of computer technologies, simulations models are usually supplied with tools for creating the input files or data sets required by the model referred to here as simulator of missing climate data.

Three basic types of simulators of climate data models are reported in the literature (Young, 2002). First type is spatial-temporal model; these can simulate weather variables in both time and space .They range from simple based on small catchment to those, which can model climate of district, regional, country or the whole planet. The simulated results are very course depending on the scale. The second commonly found type is the point source model These can simulate the temporal variation of climate data on a particular given station, hence may not be suitable for large catchment. However, when combined with averaging methods like Krigings can be used in simulating climate for different stations. Third type are those based on known physical laws governing climate, these are referred to as Physical climate models.

Perhaps in basin modeling, the spatial-temporal models could be of interest. However in semi arid areas, where recording station are few on doesn't not exist, point source models can be of interest .In a review carried out by Young, 2002 on the point source models, several weather generation process were identified, with particular attention to rainfall generation. Discrete rainfall occurrences models were found to be important in semi arid areas. The two types are those based upon alternating renew process and those based on Markov chains.

The alternating renew process simulates the length of dry and wet spells on assumption that they are independent. However, it was found that the drawback of this process is when simulation long dry spell associated with dry seasons. Alternating renew process also requires hourly data; this is another limitation to semi arid areas where even daily data cannot be available in most of the stations. Markov chain (Jones and Thornton, 1992), is the most common used approach to generate a sequence of dry and wet days. Markov chains relate the occurrence of an event to the previous event or events. Markov chain of different order has been reported being used in many models (Zucchini et al, 1992)

This paper intends therefore to evaluate the performance of two simulator of missing data based on the Markov chain process which are: PARCHED-THIRST Simulator of Missing Climatic Data (PTSMCD) model, this is a point source model and MarkSim model which is a spatial temporal model. Interpolation and extrapolation of the data will be evaluated. The extrapolation will look on the capability of model in generating the rainfall depending on the length of the available data. Aim being to come out with recommendations of how long is long enough for the climate data simulator is reliable to be used in water management in catchment or basin level.

SIMULATOR OF MISSSING WEATHER DATA

Most of the other agrohydrological model requires daily climate data to run. However, in many sites in the SSA, there is no consistent of the data records. Data may be existing for the short periods and contains large number of the missing data. In many stations if data exist will be for only few parameters common being rainfalls, other climate variable are not commonly collected. Other problems leading to poor records of climate data are such as instruments breakdown, running out of consumable or even destruction of the paper records by vermin (Kihupi, 1990). In this case, models which require long term series of data and more than one climate variables to make meaningful simulation are difficult to use. Efforts have therefore been employed to establish simulator of missing climate data Young, 2002, Jones et al., 2002).

Most of simulator of the missing climate data are designed with two fold purposes. The first purpose was to generate long series of synthetic weather data with the same statistical properties of the existing short term climatic data. The second was to "fill in" the missing meteorological variables using the statistical properties of the same site or from other climatically similar sites. However, the second purpose is not available in some of the simulator. Being designed to extract statistical properties of the existing data to generate and fill in gaps, the simulator of climate data are not intended to be used as forecast tool or generating the climatic copy writes series of the long term records. This paper evaluate two simulators of missing data, one is the data pre processor within the PARCHED- THIRST model Young et al, 2002), agrohydrological model for simulation of rainwater harvesting and rainfed systems and the MarkSim model which is a computer tool that generated the simulated weather data for crop mcdelling and risk assessment. Both model are based on the Markov chain at the different order which is the most common approach to generating sequences of dray and wet days (Jones and Thornton, 1992).

Markov chain are used to relate the occurrence of an event to an antecedent event and events. The order of Markov chain describes the number of antecedent events which are considered. For example first order Markov chain the state of the system X at the time t depends upon its state at time t – 1 and it is independent of the its value at time t – 2, t- 3, ... t = 0.

Thus the system X is represented as occurring in one of the number of states, C_n. A probability matrix P(t) of the size C_n * C_n (equation 2) is constructed which describes the probability (p_{ij}) of occurrence of state C_j at time t given state C_i at time t – 1 (equation 1).

$$P_{ij}(t) = prob\{X(t) = C_j \mid X(t-1) = C_i\}. \quad (1)$$

$$P(t) = \begin{bmatrix} P_{11} & P_{12} & P_{1..} & P_{1n} \\ P_{21} & P_{22} & P_{2..} & P_{2n} \\ P_{..1} & P_{..2} & P_{....} & P_{..n} \\ P_{n1} & P_{n2} & P_{n..} & P_{nn} \end{bmatrix} \quad (2)$$

In rainfall studies the only two and three states are generally considered. First order Markov chains which consider the state of preceding day are widely used (Zucchini, 1992) however, it has been observed by some authors (e.g. Chin, 1977, Mimikou, 1983) that they do not adequately describe the persistence of wet and dry periods. Higher orders which takes into account large numbers of preceding days are expected to simulate better the persistence. Deciding upon which order is better performing that depends on location and season. For example Chin (1977) observed that in 100 stations in US, summer rainfall required only first order while winter rainfall required a second order Markov chain.

The advantage observed using Markov chain approach is the relative low data requirements for parameterization. This is enhanced more by the availability of parameterization methods which require even less data (Young, 2002).

The Parched Thirst Simulator of Missing Climate Data (PTSMCD)

PARCHED-THIRST stands for **P**redict **A**rable **R**esources **C**apture in **H**ostile **E**nvironments **D**uring the Harvesting of **I**ncidental **R**ainfall in **S**emi arid **T**ropics. Parched –Thirst is a process- based distributed model, capable of simulating catchment hydrology with growth and yield of a crop by combining several sub models in one platform (Young et al., 2002). Runoff sub model, which simulates the rainfall – runoff process. The amount of runoff generated is the infiltration excess based on the modified Green and Ampt equation (1911). The runoff amount depends on the depression storage and the soil surface characteristics. Soil water sub model, which simulates the soil water movement, is an important element accounting for excess runoff generated and the crop growth. Crop sub models which simulates crop growth and yield of different crop cultivars depending on the daily climate data. Currently it consist of two crop sub model which are PARCH (Bradely and Crout, 1994) and ORYZA –W (Wopereis et al.,1996). The Parched –Thirst also includes data pre – processors, designed to minimise data requirements. With exception of crop cultivars, all other parameters used by the model are measurable, in case, where this data are not available, the data pre-processors are used to obtain minimum set of these data required to run the model. The three data pre-processors includes simulator of missing climate data (SMCD), Pedotransfer functions (PTFs) and rainfall disaggregator. Rainfall disaggregator is used to generate 5 min rainfall intensities, which are required in the runoff component of the model. Pedotransfer functions are used to estimates soil hydraulic properties which are difficult to measure from easily measurable soil physical properties such as texture and bulk density. Simulator of Missing Climate Data which is of importance in this paper is primarily used to generate long term climate data from statistical properties of available short term data; it can also be used to fill in gaps in the existing climate data series.

Simulator of Missing Climate data in the PT model is based on the point process model which is capable of simulating the temporal variation of climate at a point. The simulator is based on the statistical behaviour of the historical data and random number to stochastically generated novel sequence of weather data (Young 2002). PT climate generator is capable of simulating seven weather variables which are:

- Rainfall, which is generated in two stage process where by wet or dry day of rainfall occurrence is based upon two-state first order Markov chain and the rainfall amount is sampled from Gamma distribution. The transitional probability if given by:

$$P(t) = \begin{bmatrix} P_{DD} & P_{DW} \\ P_{WD} & P_{WW} \end{bmatrix} \tag{3}$$

Where: P_{DD} = conditional probability that a dry day is followed by a dry day
P_{DW} = conditional probability that a wet day is followed by a dry day
P_{WD} = conditional probability that a dry day is followed by a wet day
P_{DW} = conditional probability that a wet day is followed by a wet day
Transitional probability can be calculated from historical data, by the following equation

$$P_{WD}(i) = \frac{\sum_{p=1}^{p=n} \{X(i+1) = W \mid X(i) = D\}}{\sum_{p=1}^{p=n} \{X(i) = D\}} \tag{4}$$

$$P_{WW}(i) = \frac{\sum_{p=1}^{p=n} \{X(i+1) = W \mid X(i) = W\}}{\sum_{p=1}^{p=n} \{X(i) = W\}} \tag{5}$$

And by definition the other two probability can be calculated as:

$$P_{DD}(i) = (1 - P_{WD}(i) \quad (6)$$

and

$$P_{DW}(i) = (1 - P_{WW}(i) \quad (7)$$

- Maximum and Minimum Temperatures and radiation this are generated based on multivariate process, which involves the generation of long term residual means, it also depends upon the wet and dry status of the day.
- Relative humidity is simulated from the one or two gamma distribution, also depending on the status of the day weather wet or dry.
- Wind speed is simulated from the gamma distribution, however does not depend on wet or dry status of the day.

MarkSim Model

MarkSim developed CIAT is a computer tool that generate simulated data for crop modelling and risk assessment (Jones at al., 2002) as compared to PTSMCD, MarkSim is a stand alone model with two basic parts. Part one is stochastic rainfall generator, which drives the weather simulation model. The second part pf MarkSim is a set of surface parameters that can sampled by users, this part gives the MarkSim spatial dimension (Jones et al.2002). The MarkSim model is capable of simulating four weather parameters, these are radiation, maximum temperature, minimum temperature and rainfall.

- Rainfall in the MarkSim model is modelled based on the two-stage third order Markov chain. The first stage is basically transitional probability to determine whether any particular day is wet, since it is third order Markov chain this wet day will depend on whether there was any rainfall in the previous three days. The second stage of the MarkSim is to determine the amount of rainfall.

Probability of day I being wet is defined as:

$$P(W \mid D_1 D_2 D_{3)} = \phi^{-1}(b_i + a_{i-1}d_1 + a_{i-2}d_2 + a_{i-3}d_3 \quad (8)$$

Where: Φ^{-1} is the inverse normal probability function (probit)
b_i is the monthly baseline probit of a wet day following three consecutive dry days
a_m are binary coefficient of rain(1) or no rain (0) on a day
d_m are lag constants

To determine rainfall amount on those days that rainfall is experienced, MarkSim uses censored gamma distribution restricted below 1 mm (Stern and Coe, 1982). The method of maximum likelihood is used to estimate the mean and shape parameters of the distribution for each month. In generating rainfall records, the monthly baseline probabilities are interpolated to daily probabilities by using 12 – points Fourier transform as described by Jones (1987).

- Maximum and minimum temperatures are other weather variables that can be generated by MarkSim. Maximum and minimum temperatures are simulated in MarkSim using the DSSAT weather generator (Pickering et al., 1994), based on routines of Richardson (1985) and Geng et al. (1988) while considering whether the day is wet or dry. Parameters for generating daily maximum and minimum temperatures are the long term monthly means.

• Solar radiation data are generated from the monthly mean values for daily solar radiation. MarkSim uses the routine in DSSAT weather generators also based on routines of Richardson (1985) and Geng et al. (1988). MarkSim calculates daily solar radiation at the earth surface as a product of potential radiation and an estimates of the atmospheric solar radiation transitivity coefficient.

Methodology

Since in both model important and sensitive weather variables for generation of weather variable is rainfall, evaluation was cantered on this weather variable. Also in running of the most agrohydrological models rainfall is the most important driving variable. Rainfall records of three station were collected from Tanzania Meteorological Agency (TMA). The criteria used to select three stations was based on ; one the station being located in semi arid areas and secondly the station to represent one of the type of growing season as defined by Gommes and Houssiau (1978). The selected stains are Same in Kilimanjaro Region falling under bimodal type of growing season, Dodoma station in Dodoma region falling under central type with unimodal rainfall regime and Morogoro stations in Morogoro region falling under transitional type which is intermediate between Central and Bimodal type. Data collected from these stations were of 30 years period, however, since consistent years data were not available, data from 1971 to 2001 were used form Morogoro and Same station, where as data from 1960 to 1990 were used from Dodoma station were used in this study and the gaps of the missing data are shown in Table 1.

Table 1: Rainfall data used showing the length of missing data

Name of station	Location	Altitude (masl)	Years available	Length of Missing data (months)
Morogoro	6° 50'S, 37° 42'E	920	1971 - 2001	9
Same	3° 36'S, 37° 36'E	870	1971 - 2001	30
Dodoma	5° 49'S, 35° 42'E	1,100	1960 - 1990	25

Data from all the station were entered into a computer in Excel package and exported into Instat + software for further analysis. Quality of the data were checked by using Instat + and the annual total rainfall was derived which was used in double mass curve to also confirm on the quality of the daily rainfall data.

PTSMCD requires data in the format of XXXXYY.DAT, where XXXX is a four letter station identifier (e.g. DODO) and YY is the year (e.g. 60 to represent 1960). Therefore data for all station were arranged files of the required format. The file were arranged as follows:
Null, Null, Rainfall(mm), PanEvap(mm), TempMax(oC), TempMin(oC), Null, Null, Null, SatDef, Radiation(MJ/m2), RelHum(%), WindSpeed(km/d)
Each row contained one complete day of data, missing data was presented by 9999, trace rainfall by 8888. A complete weather file must have 365 (or 366 in a leap year) days of data. Data within a row were separated by at least one space or a comma without no blanks or gaps within the data. Comments were allowed before the first row of data as long as they don't start with a number. For MarkSim, simulation requires MarkSim parameter file (CLX). This file is created by running the *clxgen* after specifying the station location (Longitude and latitude) and the elevation.

Series of 30 years of data were simulated for all the three stations using both PTSMCD and MarkSim. Quality of the simulated data were checked using double mass curve method .To asses the reliability of each simulator, simulated data were compared by the actual recorded data for all the stations.

Randomly one year data for each station of actual and corresponding simulated were picked. Correlation and descriptive statistics was done to compare the actual recorded and simulated. This analysis was aimed to check the reliability of the simulator on re-producing actual time series.

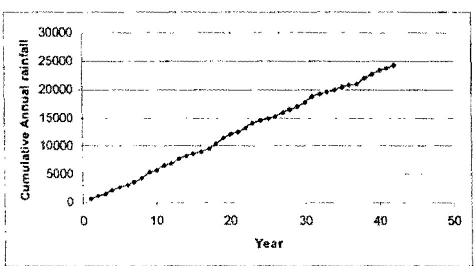
Further analysis was on the derivatives of daily data. These derivatives are annual total rainfall, number of rainy days in a month, long term mean monthly rainfall and standard deviation of long term mean monthly rainfall. All these variable are important in the most of agricultural planning and water management with exception of annual total rainfall. These derivatives were extracted from daily rainfall of both simulated and actual recorded data using INSTANT + software.

Simple graphic representation of the data, correlation analysis and Jack -Knife method referred to D- index (Willimott, 1983) were used to compared the agreement between the actual recorded and simulated derivatives of the daily rainfall data.

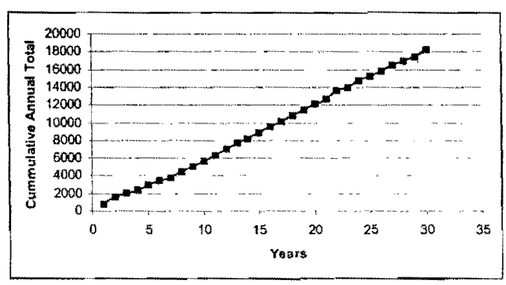
For the PTSMCD model further analysis was carried out on the length of input data which the simulator can be statistically reliable for simulation of missing data. For all stations 30 years of data was generated from 10, 15, 20, 25 years of existing historical record. Climate analysis package INSTAT was used to pull out the Long term mean monthly totals for 30 years of generated data. Graphical comparison was used to compare for the generated and the actual recorded data. The analysis was not carried out for the MarkSim model since its input file is a parametric one and not affected by the length of input data.

Results

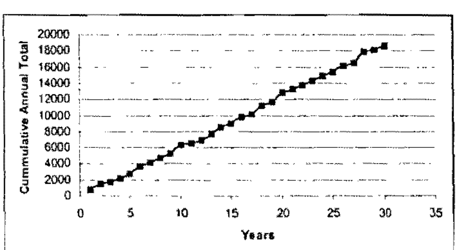
For all three stations the quality of data was satisfactory. Figure 1 shows the mass curve for actual recorded data, simulated data by PTSMCD and MarkSim for Same stations. The straight line shows the better quality of data.



a: actual recorded data



b: Generated bv PTSMCD



c: Generated by MarkSim

Figure 1: Cumulative rainfall for (a)actual recorded (b) Simulated by PTSMCD and (c) simulated by MarkSim – Same Stations

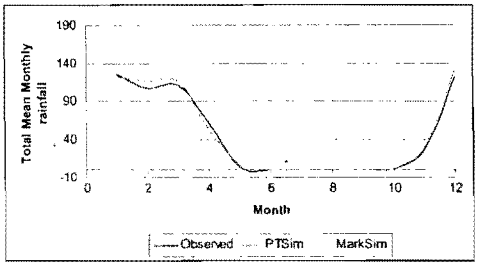
The mean monthly total rainfall generated by PTSMCD for all the three stations had no significant differences with the observed historical rainfall (**Figures 3**) Similar results were observed by Madapombe (1994). However, with exception of Morogoro station, the other two stations there is no close agreement between observed and simulated data by MarkSim. The results of Jack-Knife (D-index) and correlations are given in Table 3 and Table 4, respectively.

Table 3:D Index for extracts from daily measured data

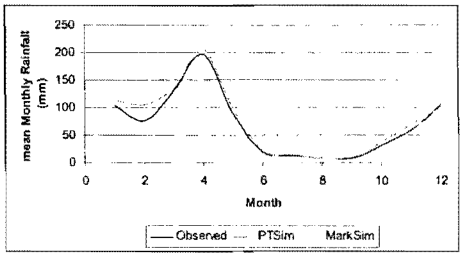
Station	Total Annual Rainfall		Mean monthly		Standard Deviation	
	PTSMCD	MarkSim	PTSMCD	MarkSim	PTSMCD	MarkSim
Same	0.36	0.39	1.0	0.8	0.8	0.6
Dodoma	0.44	0.37	1.0	1.0	1.0	0.9
Morogoro	0.24	0.50	1.0	0.9	0.9	0.8

Table 4:Correlation (R^2) value of different derivatives from daily rainfall

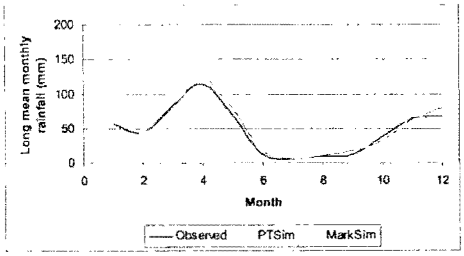
Station	No of rain days		Annual Rainfall(mm)		Mean monthly rainfall		Standard devia of monthly rainfal	
	PTSMCD	MarkSim	PTSMCD	MarkSim	PTSMCD	MarkSim	PTSMCD	Marks
Same	0.98	0.78	-0.99	- 0.95	0.98	0.64	0.86	0.31
Morogoro	0.98	0.80	-0.99	-0.99	0.98	0.91	0.87	0.59
Dodoma	0.99	0.75	-0.99	-0.63	0.99	0.67	0.92	0.73



Dodoma



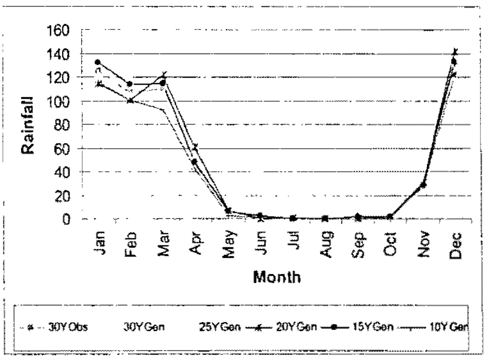
Morogoro



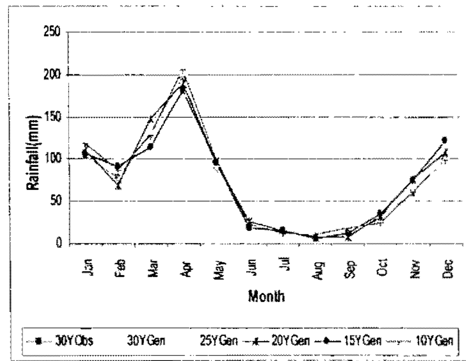
Same

Figure 3: Long term mean monthly rainfall from actual observed, PTSMCD and MarkSim data

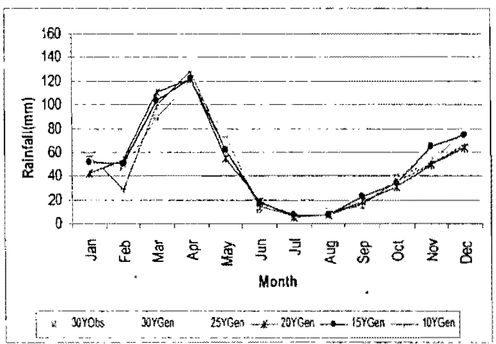
Long term mean monthly rainfall for all stations were extracted from the 30 years of simulated rainfall from input file of varying length from 10, 15, 20, 25 and 30 years of existing historical record. Figure 4 shows the long term mean monthly rainfall for all three stations. The length of input file does not affect the trend of the mean monthly rainfall and there is no significant changes on the amount of mean monthly rainfall between simulated and observed. However, the input file with 10 years of historical records under predicted mean monthly in months with high rainfall amount.



Dodoma



Morogoro



Same

Figure 4: Observed and generated long term mean monthly rainfall from 10, 15, 20, 25 and 30 years of input data

Discussion and Conclusions

Both PTSMCD and MarkSim have shown that they can well generated the rainfall. However, PTSMCD showed a close agreement between observed and simulated data than the MarkSim. Most decision making on agricultural water management can be extracted from the analysis of daily rainfall, For example, the result observed from this study on the mean rainfall prove that the PTSMCD can be used to simulate long term series data to be used in any model with confidence. The highly correlation observed between actual and generated mean monthly total and number of rainy day suggest that the PTSMCD can be used without any doubt as the mean have been extracted from daily data. With regards of how long is long enough the results have shown that, with more than 10 years data, the generated data and highly correlated to the actual observed. However, there are chances of over and under predicting. Therefore, it is recommended in area where this data are limited the minimum number of years to be used should be 15 years. The result also showed that the daily rainfall generated as not the reproduce of the actual data. Therefore, it should be understood that the PTSMCD is not a forecasting tool, rather it can reliably generate novel sequence of weather data with the same statistical properties as observed (input) climate data. PTSMCD proved to be a good simulator than the MarkSim, however, the relative advantage of using

MarkSim is that it does not require the users to assemble input data, what is needed is location and altitude.

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