GiST: A model for spatio-temporal downscaling of climate forecasts

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Justification

Weather generators are tools developed to create synthetic daily weather data over long periods of time. These tools have also been used for downscaling monthly to seasonal forecasts, produced by global and regional circulation models, to daily values in order to provide inputs for crop and other environmental models. One main limitation of weather generators is that they do not take into account the spatial structure of weather and climate in a given region or watershed. This spatial correlation is important when one spatially aggregates, for example, simulated crop yields or water resources in a watershed or region.

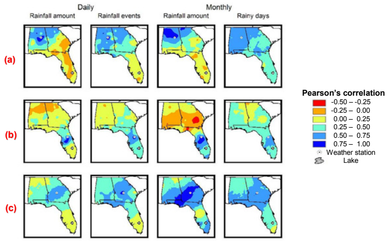


Fig. 1: Correlation's spatial variability of daily rainfall amount, daily frequency or rainfall events, monthly rainfall amount and monthly number of rainy days for the month of January (1990-2004). (a) Sylacauga, (b) Mountain Lake, and (c) Hawkville (Baigorria et al., 2007)

Objective

The objective of this study was to design a simple rainfall event and rainfall amount, and maximum and minimum temperature weather generator capable of reproducing both the daily spatial correlation among weather stations as well as the monthly statistics of each individual weather station

GeoSpatio-Temporal weather generator

The methodology presented in this research is based on the assumption of spatial-temporal covariance stationarity, which implies that the mean and autocovariance functions of the data series as well as the spatial correlation among the data series do not change through time for the time period under consideration. From a temporal point of view, this allows one to characterize a time series of a given variable, like rainfall, as a probability distribution at each weather station. From the spatial point of view, this allows one to characterize the spatial relationship between pairs of weather stations with a Pearson's correlation and among all the weather stations in a selected area with Pearson's correlation matrix.

Rainfall event generation:

a. Parameterization and initial conditions

- Calculation of the Pearson's correlation matrix among all locations
- Calculation of the Euclidean N-correlational distance for each location
- Calculation of the two-state Orthogonal Markov transitional probabilities
- Generation of spatially correlated total number of monthly rainfall events at each location

b. Data generation

- Generation rainfall events for the two closest Euclidean N-correlational locations
- Nearest Euclidean 3-correlational neighbor assimilation

Rainfall amount generation:

a. Parameterization and initial conditions

- Calculation of the Pearson's correlation matrix among all locations
- Parameterization of the 2-parameter gamma distribution for each location

b. Data generation

- Generation of a vector of correlated random numbers following Uniform distributions based on the Toeplitz-Choleski factorization matrix or the Eigen decomposition matrix
- Transformation of the vector of correlated random number to a Gamma distribution using inverse cumulative probability functions
- Shaping and scaling of each random number to rainfall amount values

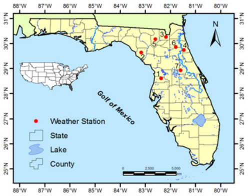
Maximum and minimum temperatures:

- Generation of a vector of correlated random numbers following Uniform distributions based on the Toeplitz-Choleski factorization matrix or the Eigen decomposition matrix
- Transformation of the vector of correlated random number to a Gaussian distribution using inverse cumulative probability functions
- Locating and scaling each random number to temperature values

Study case

Data:

Daily rainfall data from the seven weather stations (Fig. 1) from 1974 to 2004 were obtained from the NOAA/NWS/National Climate Data Center (http://nndc.noaa.gov/?home.shtml). A 30-year period was selected to avoid the effects of temporal climatic shifts detected over time in the study area (Baigorria et al., 2007).



(1) Brooksville – Hernando
(2) Cross City – Dixie
(3) Glen – Baker
(4) Hasting – St. Johns
(5) Lake City – Columbia
(6) Lisbon – Lake
(7) Mountain Lake – Polk.

Fig. 1: Map of the study area and location of the weather stations

Methods:

- To generate a thousand years of daily synthetic data of rainfall, and maximum and minimum temperatures using GiST
- To compare the results to the same type of generated data using the standard WGEN (Richardson and Wright, 1984) and the most advanced weather generator (Schoof et al., 2005)

Results and discussion

As expected, the point-based weather generator did not reproduce any observed spatial correlation of rainfall events between pairs of locations. GiST generator reproduced the monthly observed correlations of rainfall events and amounts with an statistical significance of α=0.01

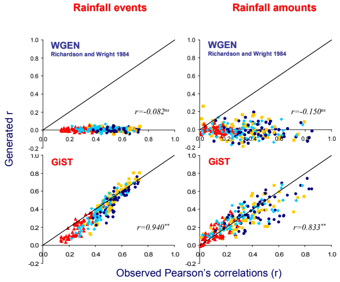
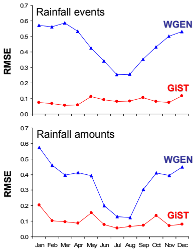


Fig. 3: Comparison between observed and generated daily Pearson's correlation of rainfall events and mounts for each month among all weather stations.



Comparisons of the two-state first-order Markov transitional probabilities (P_{01} and P_{11}) from observed and generated daily rainfall events showed P_{01} calculated from WGEN was 0.979, whereas for GiST, was 0.972. Meanwhile, P_{11} calculated from WGEN was 0.883, whereas for GiST was 0.760.

Fig. 4: Comparison of the monthly variation of the root mean square error between methodologies

Same results were obtained for the generation of maximum and minimum temperatures. Maximum temperatures showed a wider dispersion of points compared to minimum temperatures. Hypothetically, the covariance between rainfall events and maximum temperatures, that was included during the generation, was responsible of this dispersion.

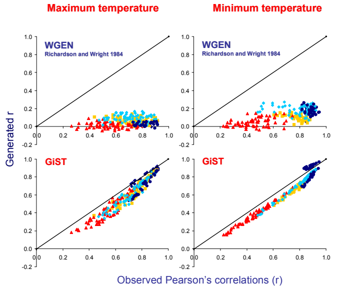


Fig. 5: Comparison between observed and generated daily Pearson's correlation of maximum and minimum temperature for each month among all weather stations.

Implications of using point and multipoint weather generators:

The region-wide accumulated rainfall generated by the point-site weather generator showed a linear trend (Fig. 5a), since every day is rainy in at least one location at the time (Fig. 5b).

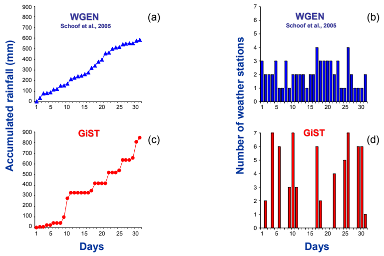


Fig. 5: Aggregated effect of using (a) and (b) point-specific generator and (c) and (d) spatio-temporal weather generator over regional dry and wet spell distributions

Using GiST, the region-wide accumulated synthetic rainfall (Fig. 5c) showed a stair-shaped trend, since dry and wet spells are well-defined in the daily sequence (Fig. 5d). Hydrologists studying floods and soil scientists studying soil erosion, for example, should be interested in the shifts in watershed accumulated rainfalls; alternatively, agronomists studying the regional effects of droughts over crops would be interested in the regional dry spell lengths.

Conclusions

The proposed algorithms reproduce the main statistics of the observed historical record of each individual weather station as well as the spatial correlation between pairs of weather stations. Pearson's correlations between observed and generated pairs of weather stations were statistically significant at the probability level of 0.01. The proposed methodology reproduced the two-state first-order Markov transitional probabilities with statistical significance as well as the regional-wide number of days without rainfall at any location.

Reference

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