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Incorporating spatial correlation into stochastic generation of solar radiation data

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Abstract

Spatial correlation of solar radiation (SCSR) has a significant impact on the overall data quality when generating radiation time series for multiple sites. Currently, there are no known methods for integration of SCSR into synthetic data by using reduced and easily available inputs. Based on a hypothesis that at long timescales general and simple characterization of SCSR is possible, this paper addresses the problem of modeling monthly and daily SCSR. A regression analysis of satellite-derived radiation data covering over 300,000 locations pairs in 4 US regions is firstly described and general mathematical expressions for SCSR estimation are presented. A procedure for incorporating spatial correlation into conventional stochastic solar radiation models is then introduced by applying the obtained SCSR formulae and the existing methods of linear algebra. Finally, the underlying hypothesis is validated and the effectiveness of the proposed technique for creating spatially correlated monthly and daily solar radiation values is demonstrated based on numerical simulations and analysis of historical data.
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Keywords: Regression analysis; Solar resource; Spatial correlation; Synthetic generation

1. Introduction

It is a common practice to use synthetic solar radiation data when meteorological measurements for a certain location or timescale are unavailable or unreliable. The synthetic data in this case can be generated by multivariate and univariate statistical models. The former, also known as the weather generator, creates the radiation time series at long timescales (usually on daily basis) together with other weather parameters (Wilks and Wilby, 1999). The univariate model generates only the values of solar radiation at various timescales based on simple inputs, typically comprising the long-term statistics for clearness index (Badescu, 2008; Meteonorm, 2013; Watgen, 1992). Despite high performance these stochastic algorithms traditionally have not incorporated spatial correlation of solar radiation (SCSR), which has a significant impact on the overall data quality when synthesizing the radiation time series for multiple sites.

The review of the recent literature indicates that there have not been any successful attempts to integrate SCSR into univariate solar radiation models. Yet, a number of methods for multivariate algorithms have been proposed. The effective and relatively simple approach in this case seems to be not to change the conventional single-site weather model, but to modify the input random number

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Nomenclature

A, B	sub- and superscripts referring to different locations
C	constant in the Haversine formula
C_r	correlation matrix for random number streams
d	intersite distance (km)
K_t	clearness index
$K_{t,M}$	long-term average of the monthly clearness index
n_p	polynomial degree
r, r_{corr}	uncorrelated and correlated random numbers
R^2	coefficient of determination
U	upper triangular matrix in the Cholesky factorization
x_j	mathematical indicator for intersite dependence (MIID)
y, y'	actual and predicted values of a given variable
ΔK_t	first difference (ramp rate) of clearness index series
λ	longitude
ϕ	latitude
v_i	constants in the functional relation between C_r and PCC
MAE	mean absolute error
MARE	mean absolute relative error
NSDD	normalized SDD
PCC	Pearson's correlation coefficient for ΔK_t^A and ΔK_t^B
RMSE	root mean square error
SDD	standard deviation of difference $\Delta K_t^A - \Delta K_t^B$

streams instead, for the given network of locations so that the resultant synthetic values of solar radiation (or other weather parameter) have realistic spatial correlations (Wilks, 1999; Khalili et al., 2009). Even though this technique allows adequate reproduction of SCSR, it still requires synchronized regional meteorological measurements for tuning the model coefficients, which, to some extent, defeats the purpose of using the synthetic data.

Apparently, there are no known methods for multisite generation of solar radiation data from reduced (easily available) inputs. This might be explained by the absence of general formal description of SCSR that could allow estimating the spatial correlation for any two locations based on simple predictor variables. Obviously, at short timescales, since local weather factors become significant, such a general characterization of SCSR is unrealistic. However, at long timescales the authors believe that this is possible. Interestingly, the literature reveals few research papers addressing this subject. For example, Aguado (1986) and Suckling (1995) estimate the coefficients of variability (the standard deviation of the intersite daily radiation differences divided by the mean values) for the selected station pairs by using directly the measured daily solar radiation values. And in recent studies, Hoff and Perez (2012) and Badosa et al. (2013) evaluate SCSR by Pearson's correlation coefficient and they represent the solar resource via ramp rates (deltas) of clear-sky index, which is more suitable for such analyses (Badescu, 2008). The paper by Hoff and Perez (2012) is of particular interest as it employs satellite-derived data covering over 70,000 pairs of points, though the considered timescales are only up to 4 h. The common shortcoming of the existing studies is that they try to relate SCSR to the intersite distance only, whereas the results clearly show that this dependence changes from one region to the other.

Taking into account the mentioned gaps in current research, the aims of this work are to: (a) determine general mathematical expressions relating solar radiation between two sites at monthly and daily timescales; and (b) incorporate SCSR into existing univariate algorithms for generating solar radiation data based on the obtained expressions. The given tasks are covered separately in Sections 2 and 3, respectively. In the end of the paper the concluding remarks are provided.

2. Characterization of the spatial correlation of solar radiation

2.1. Objectives

The authors hypothesize that at long timescales a general relation for SCSR can be derived based on simple (easily accessible) inputs. From various available parameters the clearness index K_t is selected to represent solar radiation, by taking into account: (a) its common use in climate research, particularly in the area of synthetic data generation; and (b) its straightforward calculation allowing exclusion of the local factors such as site altitude and turbidity levels required in the clear-sky index estimation. In order to remove non-stationarity (trend) in the K_t time series, differencing is applied, which means that the focus is not on the actual values of K_t, but on its ramp rates ΔK_t.

The final objective in this case is defined as to perform a regression analysis of historical meteorological data and to determine mathematical expressions that would allow quantifying SCSR for any two locations at monthly and daily timescales by using intersite distance and monthly statistics of K_t.

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