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The Stochastic Two-State Cloud Cover Model STSCCM

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Abstract

A stochastic model is presented that simulates cloud cover. Implementations reaching from the simple simulation of the steady state probability distribution of cloud cover up to the generation of cloud cover as a function of time are shown. In the model, the steady state probability distribution of cloud cover is invariant to the observation area over a wide range. Simulation results are discussed and compared with real world data. Particularly, the steady state probability distributions compare well with the real world.

Keywords: Climatology; Cloud cover; Meteorology; Solar energy; Stochastic modeling; Vertical visibility

1. Introduction

The understanding of the dynamics of solar irradiance is important for the design and analysis of solar energy systems. Many of these systems are nonlinear. Consider for example a solar water heater. It switches its circulation pump on when there is collectable energy falling onto the solar collectors, and will cut the circulation if there is no energy to harvest. The analysis of such systems can hardly be achieved in any other way than by simulations in the time domain. Thus, time sequences of solar irradiance must be available as input for simulation runs. Up to what frequency such time sequences must properly reflect reality depends on the problem at hand. Solar water heaters have time constants in the order of minutes. Photovoltaic systems react to irradiation changes within milliseconds. For detailed systems design and reasonable load matching of photovoltaic systems in the UK, Craggs et al. (2000) came to the conclusion that at least 10 min average irradiance readings are needed. For the design of command and control systems of large solar thermal plants solar irradiance input with a sampling interval of less than one second is used (Gall et al., 2010).

A model that takes higher frequencies of solar irradiation into account, particularly those caused by the interference of clouds, was first proposed in Robinson (1966) by W. Schüepp. It was then refined by Biga and Rosa (1980). The model supposes three types of irradiation:

(1) Beam irradiation, only present when the sun is shining.
(2) Diffuse irradiation emanating from the clear part of the sky.
(3) Diffuse irradiation emanating from the covered part of the sky.

In Morf (1998) we presented the Stochastic Two-State Solar Irradiance Model – STSIM that is based on the ideas of Biga and Rosa. For this purpose, we implemented the Stochastic Insolation Function – SIF, a function that divides time into insolated periods and periods when the sun is hidden behind clouds, into a model for average instantaneous solar irradiance by Suehrcke and McCormick (1989). The model, simple and fast in its execution, proved to be a valuable tool for the dynamic simulation of solar water heaters. However, as we mention in the conclusion of Morf

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Nomenclature

Capital letters

A	area (m^2)
A	generic variable
B	area (m^2)
B	generic variable
N	number of clusters (–)
P	probability (–)
R	autocorrelation
T	time in the sense of duration (s)
W	steady state probability (–)

Small letters

cc	cloud cover (–, oktas, tenths)
d	differential element (–)
f	probability function (–)
f	probability density function
i	daily relative vertical visibility (–)
i	daily relative sunshine duration (–)
n	generic counter (–)
n	number of grid points (–)
t	time (s)
v	generic counter (–)
vv	vertical visibility (–)
w	probability density function of the steady state
x	generic free variable
y	generic dependent variable

Greek letters

Δ	small element, difference
μ	mean, expectation
σ^2	variance
τ	time shift (s)

Special characters

[ ]	transition matrix
| |	absolute value
$\bar{}$	mean, expectation
$\cap$	intersection
|	condition

Indices

0	where the view is obstructed by clouds (cc)
0	part of the sky that is clear (vv)
1	part of the sky that is covered by clouds (vv)
1	where the view is clear (cc)
cc	cloud cover
d	daytime (the time span between sunrise and sunset)
D	one day (= 24 h)
f	when overflying the cloud field
i	row number of a matrix
j	column number of a matrix
obs	observed

(1998): “It is evident that there are still other fluctuations than those considered by the STSIM, most likely due to varying cloud cover”.

Therefore, we set out to find a stochastic function that simulates cloud cover as a function of time. The researches lead to climatologists and meteorologists who were principally interested in the parameterization of the probability distribution of cloud cover. Over the years, a considerable selection of mathematical functions as well as methods for storage and presentation of this distribution has been proposed and used (Henderson-Sellers and McGuffie, 1991). Despite an intensive literature review, the necessary stochastic function could not be found. However, in Burger (1985) the “Burger model” implements a probability distribution for cloud cover that is the fit to the results of a saw tooth cloud simulation model (Burger and Gringorten, 1984). Burger (1985) reports rms errors[1] from 0.9% to 2.6 % between probability functions constructed with his model and others constructed with samples collected in the real world. Henderson-Sellers and McGuffie (1991) undertook a profound analysis of the Burger model. They confirm the excellent fit of the Burger model to the real world.

What drew our attention was the striking resemblance of probability bar charts of relative daily sunshine duration generated with the Stochastic Insolation Function – SIF (Morf, 1998), and the probability bar charts of cloud cover generated with the Burger model shown in Fig. 11 on page 23 in Burger (1985).[2] This resemblance is insofar remarkable as sunshine is a function of time whereas cloud cover expands over an area. This gave rise to hope for finding a stochastic model for cloud cover expanding over time and area.

We finally succeeded to formulate such a model, which we call the Stochastic Two-State Cloud Cover Model – STSCCM. Simulated key elements of the model are vertical visibility – vv and cloud cover – cc. Vertical visibility describes the state (covered or clear) of a single point in the sky. Cloud cover is the fraction of the sky that is covered by clouds. To adjust the model to the real world mean and variance of cloud cover and vertical visibility, or a time sequence of cloud cover need to be known.

[1] Given two probability functions $f_a(x_1, x_2, \ldots x_n)$ and $f_b(x_1, x_2, \ldots x_n)$, where $P_a(x_1) = a_1$, $P_a(x_2) = a_2, \ldots P_a(x_n) = a_n$ and $P_b(x_1) = b_1$, $P_b(x_2) = b_2, \ldots P_b(x_n) = b_n$, then the rms error is given by $\sqrt{\frac{\sum_{i=1}^{n}(a_i - b_i)^2}{n}}$.

[2] As an orientation on the kind of probability bar charts in discussion here, the reader may refer to Fig. 1.