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Improved historical solar radiation gridded data for Australia

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ABSTRACT

An improved blended data method was developed for preparation and generation of solar radiation gridded datasets for SILO; Queensland Government database containing point and gridded daily climate data for Australia from 1890 till present designed for crop and pasture modelling. The new blended data method incorporates three sources of solar radiation data: radiometer measurements, sunshine duration, and cloud-cover observations. The new method converts all data sources to the percentage extra-terrestrial radiation using new conversion equations derived from the experimental data and thus the conversion tables previously used are now redundant. Comparison with satellite derived estimates shows that the blended data method has reduced bias compared to the previous method. The blended data method addresses the need for historical pre-satellite solar radiation gridded datasets for climate and agricultural modelling, model calibration, and computation of synthetic evaporation rates.

1. Introduction

This paper addresses the problem of estimating historical solar radiation data from heterogeneous sources. A reliable and accurate method for generating gridded datasets from ground based measurements is required for the pre-satellite era. It can also fill gaps in satellite record due to technical problems with satellite instruments, telemetry or navigation. The new blended data method provides consistent solar radiation estimates in the form of gridded datasets from 1889 onwards. The consistent methodology for computing solar radiation estimates allows more reliable calibration and operation of various agricultural and climate models over long periods of time. Satellite estimates provide a relatively short record from 1990 until current. Seasonal forecasting systems, based on historical analog years, require good quality input data prior to 1990, see Carter et al. (2003), Clothier et al. (1986), Guo and Trotter (2004), Jensen and Haise (1963), Li et al. (2011), and Potgieter et al. (2003).

The new blended data method for computing gridded datasets incorporates three sources of solar radiation data:

- radiometer measurements: most accurate but very few stations providing radiometer measurements,
- sunshine duration: reliable data source, more measurements available but insufficient number to create accurate gridded datasets based exclusively on sunshine duration,
- cloud-cover observations: most numerous observations available, least reliable and subject to human error. Observations are made by a human observer who estimates sky cloudiness using 0–8 scale (hence the cloud-cover observations are called 'cloud-oktas'), with '0' being clear sky conditions and '8' full cloud cover.

The gridded solar radiation datasets, generated using the new blended data method, were incorporated into the SILO climate database. SILO is a database system designed to provide users of biological and hydrological models 'ready-to-use' climate data. Plant growth models that rely on solar radiation data for estimating productivity should benefit from improved accuracy of new estimates. Solar radiation data are also used to compute the synthetic daily Class A pan evaporation rate as an alternative to evaporation gridded datasets computed directly from class A pan measurements but reliably available only from the mid-1970s, Rayner (2005).

The blended data method converts all data sources to the percentage extra-terrestrial radiation using conversion equations derived from the experimental data using *Eureqa* software, Schmidt and Lipson (2009). Thus the previously used conversion tables, as documented in Jeffrey et al. (2001), are made redundant. The conversion of point-data (station measurements) to percentage extra-terrestrial radiation removes the effects of location and time

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Notation

R_p	predicted short-wave (SW) solar radiation on flat surface [MJ/m^2]
R_a	extra-terrestrial solar radiation (top of atmosphere) [MJ/m^2]
R_m	measured solar radiation [MJ/m^2]
R_{sat}	satellite estimate of solar radiation [MJ/m^2]
R_{pet}	percentage extra-terrestrial solar radiation: R_m/R_a in 0.0–1.0 scale
h	station elevation [m]
φ, λ	latitude and longitude [rad]
J	number of the day in the year, between 1 and 365 or 366
δ	solar declination [rad]
ω	solar time angle [rad]
ω_s	sunset hour angle [rad]
ϕ	solar altitude angle [rad]
s_9, s_{15}	sine of solar altitude angle at 0900 and 1500
sh	sunshine duration [h]
dh	daylight hours [h]
okt_9, okt_{15}	cloud cover estimation in oktas (0–8 scale)
c_9, c_{15}	cloud cover estimation in 0.0–1.0 scale
e_s	mean daily saturation vapour pressure [kPa]
e_a	calculated vapour pressure [kPa]
P	atmospheric pressure [kPa]
P_{msl}	mean sea-level pressure [kPa]
W	precipitable water [mm]
L_w	path length precipitable water [mm]
New	results obtained using new blended data method
SILO	results obtained using previous SILO method
Sat	satellite gridded datasets

of year in the interpolated data. The interpolation of percentage extra-terrestrial values is performed on the uniform 0.05° grid between 10°S and 44°S latitude and between 112°E and 154°E longitude. The percentage extra-terrestrial grid values are then converted to the predicted solar radiation R_p for each grid-point and masked to land areas.

Satellite based estimates of solar radiation were used to validate gridded datasets of R_p as the best independent solar radiation reference, BoM (2009a, 2009b). However, satellite data are not always a reliable reference as satellite data suffer from missing measurements and calibration problems, as indicated in Section 7. Bias of the new blended data method relative to the radiometer and satellite data was investigated as merging different data series for modelling purposes is often required. Comparison between the previous and new interpolation methods shows an improvement in the range of interpolated solar radiation values. Furthermore, a better correlation with satellite estimates is achieved with the new blended data method potentially allowing for future blending of terrestrial and satellite data.

This methodology can be seen as part of wider effort in modelling community to address difficulties in generation of consistent long-term climate related data-series. Often, methodologies for such data-series generation use estimation of climate variables based on the related climate measurements. A comprehensive approach to computation of climate data-series can be found in the Twentieth Century Reanalysis (20CR) project, Compo et al. (2011), Allan et al. (2011). Some examples of generation of long-term rainfall data-series can be found in Rosenberg et al. (2004) and Piantadosi et al. (2007). Other examples can be found in Donatelli et al. (2006) for solar radiation estimation; Pogson et al. (2012) for crop growth models based on alternative datasets; Romero et al. (2012) for soil profiles; and Wang et al. (2012) for temporal and spatial data infilling of global soil moisture derived from satellite images.

2. Related work

There are a number of papers and books dealing with the conversion of observational data to solar radiation. In particular, the conversion of sunshine duration to solar radiation has a relatively large bibliography. The SILO database and spatial interpolation of Australian climate data are comprehensively described in Jeffrey et al. (2001). Some useful remarks about oktas-derived solar radiation estimates can be found in a paper by Rayner (2007). Much research for the conversion of sunshine duration to solar radiation estimates revolves around the equation recommended by FAO (Food and Agriculture Organization of the United Nations), see Allen et al. (1998) and based on the Angstrom formula, see Angstrom (1924):

$$R_p = (a + b \cdot sh/dh) \cdot R_a \tag{1}$$

The constant coefficients a and b are usually adjusted to the local conditions using experimental data; see for example: Ahmed et al. (2009), Almorox and Hontoria (2004), Ampratwum and Dorvlo (1999), Andretta et al. (1982), El-Sebaii and Trabea (2005), Mellit et al. (2007), Weymouth and Le Marshall (2001), and Yang and Tsukamoto (2009). This linear equation is a good approximation of the experimental data especially for the mid-range sunshine duration hours but does not match well the measurements for low and very high values of sunshine duration hours. For low and very high sunshine duration, a nonlinear relation between sunshine duration and R_{pet} is required. Often, as in Ahmed et al. (2009), the constants a and b are computed as a function of latitude and sh/dh. Test results for the Angstrom formula in Nigerian conditions can be found in Chukwuemeka and Nnabuchi (2009). The locally fitted (Port Harcourt, Nigeria) parameters were verified with observed daily solar radiation measurements achieving good error statistics of RMSE = 0.5861 [MJ/m^2] and $R^2 = 0.852$. The results show clear linear correlation between the sunshine hours and measured solar radiation.

Iziomon and Mayer (2002) presented results in their parameterisation of conversion equations for a lowland and a mountain site in Germany. Simple conversion equations were used to convert both cloud-cover and sunshine duration to solar radiation. Equation parameters were computed on a relatively small sample of data from two station locations: Bremgarten (Upper Rhine lowland) and Feldberg (Black Forest, South Germany).

Rivington et al. (2005) investigated three methods of solar radiation estimation; one based on sunshine duration data and two air temperature based models. The two air temperature methods can be used at meteorological stations that record air temperatures but not any solar radiation related observations (such as radiometer, sunshine duration or cloud-cover). The sunshine duration based model provided the best estimate of solar radiation.

Santamouris et al. (1999) presented three methods for estimating solar radiation: an atmospheric deterministic model and two data-driven intelligent methods that rely on Neural Network (NN) and Fuzzy Logic (FL) techniques. The methods were developed specifically for Athens. In the FL approach (as well as in the NN approach) the method uses air temperature, relative humidity, sunshine duration, and extra-terrestrial radiation to determine the