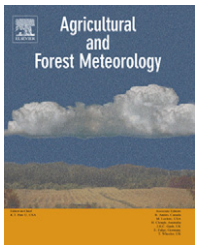
available at www.sciencedirect.com

ScienceDirect

journal homepage: www.elsevier.com/locate/agrformet



Estimation of monthly solar radiation from measured air temperature extremes

A. Bandyopadhyay [a,*], A. Bhadra [b], N.S. Raghuwanshi [c], R. Singh [c]

[a] Centre for Flood Management Studies (Brahmaputra Basin), National Institute of Hydrology, Sapta Swahid Path, G.S. Road, Dispur, Guwahati, Assam 781006, India

[b] Department of Agricultural Engineering, North Eastern Regional Institute of Science and Technology, Nirjuli, Itanagar, Arunachal Pradesh 791109, India

[c] Department of Agricultural and Food Engineering, Indian Institute of Technology Kharagpur, Kharagpur, West Bengal 721302, India

ARTICLE INFO

Article history:
Received 13 August 2007
Received in revised form
6 June 2008
Accepted 15 June 2008

Keywords:
Solar radiation
Air temperature
Sunshine hours
Meteorological data
Data substitution

ABSTRACT

Solar radiation (R_s), a very important variable in agricultural meteorology, is measured at a very limited number of meteorological stations worldwide. However, a number of methods are reported in the literature for estimating R_s from routinely measured air temperature extremes, the accuracy of which needs to be tested. R_s was thus estimated by different methods for 29 stations distributed throughout India. The methods compared were Hargreaves [Hargreaves, G.H., 1994. Simplified coefficients for estimating monthly solar radiation in North America and Europe. Dept. Paper, Dept. Biol. and Irrig. Eng., Utah State Univ., Logan, Utah], Annandale et al. [Annandale, J.G., Jovanovic, N.Z., Benadé, N., Allen, R.G., 2002. Software for missing data error analysis of Penman–Monteith reference evapotranspiration. Irrig. Sci. 21, 57–67], Allen [Allen, R.G., 1995. Evaluation of procedures for estimating mean monthly solar radiation from air temperature. Rep., Food and Agriculture Organization of the United Nations (FAO), Rome, Italy], Samani [Samani, Z., 2000. Estimating solar radiation and evapotranspiration using minimum climatological data. J. Irrig. Drain. Eng., ASCE, 126(4), 265–267], Allen [Allen, R.G., 1997. Self-calibrating method for estimating solar radiation from air temperature. J. Hydrol. Eng., ASCE, 2 (2), 56–67], and Bristow and Campbell [Bristow, K.L., Campbell, G.S., 1984. On the relationship between incoming solar radiation and daily maximum and minimum temperature. Agric. Forest Meteorol., 31, 159–166]. The estimated R_s values were then compared to measured R_s (or R_s estimated from measured sunshine hours with locally calibrated Ångström coefficients), to check the suitability of these methods under Indian conditions. Three statistical indicators were used for comparing the performances of different methods, namely, modelling efficiency (ME), coefficient of residual mass (CRM), and root mean squared error (RMSE) expressed as a percentage of the arithmetic mean of observed values. To understand the effect of R_s estimation on reference evapotranspiration, ET_0, the internationally accepted FAO-Irrigation and Drainage Paper 56 Penman–Monteith based method (Allen et al. [Allen, R.G., Pereira, L.S., Raes, D., Smith, M., 1998. Crop evapotranspiration—guidelines for computing crop water requirements. Irrig. and Drain. Paper 56, Food and Agriculture Organization of the United Nations (FAO), Rome, Italy]), employed using both measured R_s and estimated R_s, were also compared. The methods performed differently for different stations. In general, the original Hargreaves methods, both with [Annandale, J.G., Jovanovic, N.Z., Benadé, N., Allen, R.G., 2002. Software

* *Corresponding author*. Tel.: +91 3612331150; fax: +91 3612228823.
E-mail address: arnabbandyo@yahoo.co.in (A. Bandyopadhyay).
0168-1923/$ – see front matter
doi:10.1016/j.agrformet.2008.06.002

for missing data error analysis of Penman–Monteith reference evapotranspiration. Irrig. Sci. 21, 57–67] and without [Hargreaves, G.H., 1994. Simplified coefficients for estimating monthly solar radiation in North America and Europe. Dept. Paper, Dept. Biol. and Irrig. Eng., Utah State Univ., Logan, Utah] altitude correction, performed better. The choice of method to obtain R_s estimates was found to have a relatively small effect on the resulting ET_0 estimates. In conclusion, under Indian conditions where no R_s measurements are available, the R_s estimation methods from air temperature extremes were ranked as (in order of descending suitability): Hargreaves [Hargreaves, G.H., 1994. Simplified coefficients for estimating monthly solar radiation in North America and Europe. Dept. Paper, Dept. Biol. and Irrig. Eng., Utah State Univ., Logan, Utah] > Annandale et al. [Annandale, J.G., Jovanovic, N.Z., Benadé, N., Allen, R.G., 2002. Software for missing data error analysis of Penman–Monteith reference evapotranspiration. Irrig. Sci. 21, 57–67] > Samani [Samani, Z., 2000. Estimating solar radiation and evapotranspiration using minimum climatological data. J. Irrig. Drain. Eng., ASCE, 126(4), 265–267] > Allen [Allen, R.G., 1995. Evaluation of procedures for estimating mean monthly solar radiation from air temperature. Rep., Food and Agriculture Organization of the United Nations (FAO), Rome, Italy] > Allen [Allen, R.G., 1997. Self-calibrating method for estimating solar radiation from air temperature. J. Hydrol. Eng., ASCE, 2 (2), 56–67] > Bristow and Campbell [Bristow, K.L., Campbell, G.S. 1984. On the relationship between incoming solar radiation and daily maximum and minimum temperature. Agric. Forest Meteorol., 31, 159–166], for estimates of monthly means.

1. Introduction

Solar radiation (R_s), being the primary source of energy for biological and physical processes, is a very important and major input to many simulation studies, such as those related to climate change, hydrology, ecology, and agronomy (Rivington et al., 2005). In agricultural meteorology, having accurate R_s data is crucial for crop growth and yield simulation, and evaporation and evapotranspiration estimation, for example. Unfortunately, R_s, or alternatively, sunshine hours from which incident R_s can be estimated with sufficient accuracy, is measured at a very limited number of meteorological stations worldwide. In the United States and Britain, the percentage of stations measuring R_s is less than 1% and this is estimated to be worse globally (Thorton and Running, 1999; Rivington et al., 2002).

In India, India Meteorological Department (IMD) is the government organization responsible for meteorological observations and it is the main source of organized meteorological data. However, among 133 stations selected randomly from IMD's countrywide network, only 29 stations had either R_s or sunshine hours, or both, at monthly time steps for 32 years (1971–2002). Moreover, these data were not available for all months of all years. The details of data availability for these 29 stations (Fig. 1) are reported in Table 1. This fact clearly depicts the R_s and sunshine hours data measurement scenario in India. Indirect estimation of R_s from more commonly measured meteorological variables, therefore, becomes an important exercise in a country such as India.

Air temperatures, on the contrary, are routinely measured at most meteorological stations. A number of methods have been developed in the past for indirect estimation of R_s from difference between air temperature extremes. However, the accuracy of these estimates by different methods needs to be tested. The main goal of this paper is to compare the R_s estimation performance of different methods available in the literature. In addition, the impact of these estimates on reference evapotranspiration (ET_0), an important variable in agricultural meteorology that requires R_s data, has also been tested as an example.

2. Background

Hargreaves and Samani (1982) first suggested that R_s can be estimated from the difference between maximum and minimum air temperatures using a simple equation:

$$R_s = K_r(T_{max} - T_{min})^{0.5} R_a \quad (1)$$

where R_s is in MJ m^{-2} d^{-1}; T_{max} and T_{min} are mean daily maximum and minimum air temperatures, in °C, respectively; R_a is extraterrestrial radiation, in MJ m^{-2} d^{-1} which is a function of latitude and day of the year (Duffie and Beckman, 1991); and K_r is an empirical coefficient (unitless). Hargreaves (1994) recommended the value of K_r to be 0.16 for interior regions and 0.19 for coastal regions. Annandale et al. (2002) introduced a correction factor for K_r to account for effects of reduced atmospheric thickness on R_s as

$$K_r' = (1 + 2.7 \times 10^{-5} Z) K_r \quad (2)$$

where K_r' is the corrected K_r; and Z is the elevation, in m.

Allen (1995) also suggested estimating K_r as a function of elevation to account for effect of elevation on the volumetric heat capacity of the atmosphere by using:

$$K_r = K_{ra} \left(\frac{P}{P_0} \right)^{0.5} \quad (3)$$

where K_{ra} is an empirical coefficient having a value of 0.17 for interior regions and 0.20 for coastal regions; and P is the mean atmospheric pressure at the site, in kPa, which can be estimated