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Original research article

Estimation of net surface radiation from eddy flux tower measurements using artificial neural network for cloudy skies

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A B S T R A C T

Accurate knowledge of net surface radiation (NSR) is required to understand the soil-vegetation-atmosphere feedbacks. However, NSR is seldom measured due to the technical and economical limitations associated with direct measurements. An artificial neural network (ANN) technique with Levenberg–Marquardt learning algorithm was used to estimate NSR for a tropical mangrove forest of Indian Sundarban with routinely measured meteorological variables. The root mean square error (RMSE), mean absolute error (MAE), modelling efficiency (ME), coefficient of residual mass (CRM) and coefficient of determination (R^2) between ANN estimated and measured NSR were 37 W m^{-2}, 26 W m^{-2}, 0.95, 0.017 and 0.97 respectively under all-weather conditions. Thus, the ANN estimated NSR values presented in this study are comparable to those reported in literature. Further, a detailed study on the estimated NSR for cloudy skies was also analysed. ANN estimated NSR values were compared with *in situ* measurements for cloudy days and non-cloudy days. The RMSE, MAE and CRM of the model decrease to half when considering the non-cloudy days. Thus, the results demonstrate that major source error in estimating NSR comes from the cloudy skies. Sensitivity of input variables to NSR was further analysed.

1. Introduction

Net surface radiation (NSR) is the main source of energy available at the Earth's surface that drives the process of evaporation, air and soil heating as well as other smaller energy-driven processes such as photosynthesis [1–4]. Since exchange of energy takes place between the Earth's surface and the atmosphere continuously, the accurate knowledge of NSR is essential in understanding the physical and biological processes of evapotranspiration, air and soil warming [5]. However, ground based net radiometers (direct measurements) are expensive, require frequent calibration and limited in availability. Therefore, various empirical [6–12], physical and neural network models have been developed by many researchers either with conventional meteorological parameters such as temperature, latitude, altitude, etc. or remote sensing platform [13–17] to estimate net radiation components. NSA represents the algebraic sum of downwelling (incoming ↓) and upwelling (outgoing ↑) components of short-wave in the wavelength range 0.3–4.0 μm [18] and long-wave (4–100 μm) fluxes respectively as shown in Eq. (1).

$$R_n = \left(R_s^{\downarrow} - R_s^{\uparrow}\right) + \left(R_l^{\downarrow} - R_l^{\uparrow}\right) \quad (1)$$

Where, the downward arrows (↓) and upward arrows (↑) indicate incoming and outgoing radiation components respectively. In Eq. (1), R_n is NSR, R_s is shortwave radiation and R_l is long-wave radiation at the Earth's surface. Several meteorologists have attempted to quantify the surface radiation budget with direct measurements. Downwelling R_s at the surface originated from the solar radiation during daytime is a function of scattering, emission, and absorption in the atmosphere, while R_l depends on the air temperature and air emissivity. Upwelling R_s can be estimated as the product of

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downwelling shortwave and surface albedo, while R_l depends on the land surface temperature and emissivity. The upward components of NSR are controlled by ground surface characteristics including snow/ice coverage, vegetation extent and soil moisture content. Knowledge of surface energy balance is an important parameter in advancing our understanding and ability to model land surface–atmosphere interactions, leading to more reliable weather forecasts. Further, it also assists us in forecasting local and large-scale effects of climate changes on rainfall and how it influences desertification and agricultural yield amongst other things.

In general, number of radiation measurements sites was limited as compared to sites where meteorological observations (air temperature, humidity, wind velocity, etc.) are recorded regularly. There are several surface radiation observational networks for providing long-term radiation budget. It is well understood that the flux tower data are the best but use is limited due to sparse network across the globe, especially in the country like India. The measurement of solar radiation is more prone to errors and often encounters more problems such as technical failure and operation related problems than other meteorological data. There have been few studies for NSR estimation using artificial neural network (ANN) technique based on remote sensing data and are restricted to clear sky conditions [19–22]. Therefore in this study, as a novelty, a detailed analysis on the estimated NSR using ANN approach for cloudy skies, clear skies respectively were analysed.

2. Materials and methods

2.1. Study area and data used

The present work is based on the data measured from eddy covariance flux tower for the period of one year (April 2012 to March 2013) and is carried out as part of the National Carbon Project initiated by the Indian Space Research Organization. The footprint of the eddy-covariance flux tower (height of 15 m) is estimated to be about 200 m. The tower was located at the Bonnie camp location of Sundarban region (Fig. 1), India. The total area of Indian Sundarban mangrove forest is 9630 km^2 [23]. Net radiation and its components were measured using net radiometers consisting of a pyranometer pair with one facing upward, and the other facing downward (Kipp & Zonen CNR 4, Bohemia, NY, USA). In addition, air temperature, relative humidity, wind speed and wind direction data from eddy flux tower during the study period were used as input to the ANN. More information on the instruments and data quality is available in Ref. [24]. All the measurements were recorded every 10 min and reliability of observations from eddy-covariance technique is described by Twine et al. [25]. Since the performance of an ANN is influenced by the quality of the training datasets, values flagged as outliers or missing were removed from the dataset before the analysis and only the good quality data were used in this study.

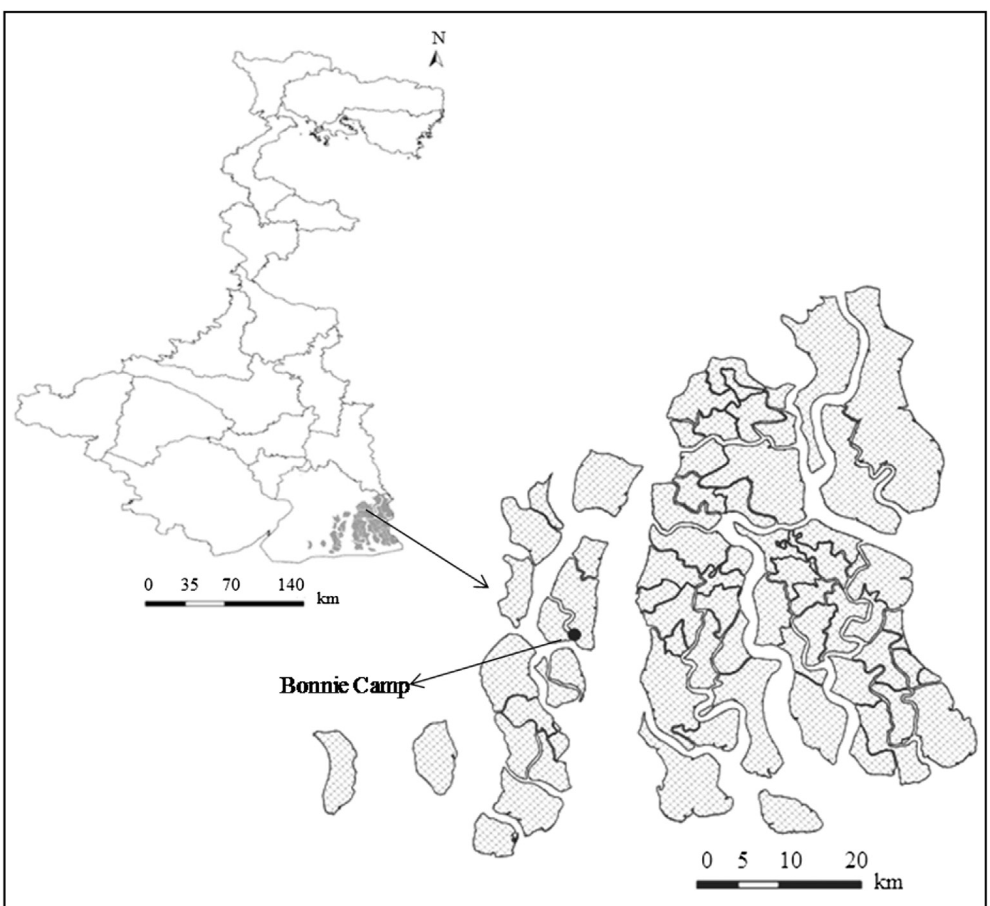

Fig. 1. Map of study area, black colour dot indicates the location of Eddy Covariance flux tower.