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Full Length Article

Assessment of the methods for determining net radiation at different time-scales of meteorological variables

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A B S T R A C T

When modeling the soil/atmosphere interaction, it is of paramount importance to determine the net radiation flux. There are two common calculation methods for this purpose. Method 1 relies on use of air temperature, while Method 2 relies on use of both air and soil temperatures. Nowadays, there has been no consensus on the application of these two methods. In this study, the half-hourly data of solar radiation recorded at an experimental embankment are used to calculate the net radiation and long-wave radiation at different time-scales (half-hourly, hourly, and daily) using the two methods. The results show that, compared with Method 2 which has been widely adopted in agronomical, geotechnical and geo-environmental applications, Method 1 is more feasible for its simplicity and accuracy at shorter time-scale. Moreover, in case of longer time-scale, daily for instance, less variations of net radiation and long-wave radiation are obtained, suggesting that no detailed soil temperature variations can be obtained. In other words, shorter time-scales are preferred in determining net radiation flux.

1. Introduction

Estimation of net radiation is essential for analyzing the soil-vegetation-atmosphere interactions in the fields of agronomy, soil science, environmental engineering, geotechnical engineering, etc. It represents the effective energy provided by sun to heat soil and air as well as to evaporate soil surface water.

Net radiation is the sum of short-wave radiation and long-wave radiation. It can be determined either by direct measurement or by calculation. For the direct measurement, net radiometer is usually used after calibration. The calibration allows the definition of a parameter termed as "net radiometer sensitivity". This parameter is strongly dependent on wind speed and light incidence angle. Thereby, it changes over time continuously and the measurements can have a high uncertainty. Indeed, Evett et al. (2011) stated that even new radiometers can have an error as high as 10%. Halldin and Lindroth (1992) performed comparative measurements using six different types of net radiometers, and they compared the measurement by each net radiometer with that by a four-component net radiometer which was taken as a reference. They observed a difference between 6% and 20%. Kustas et al. (1989) mentioned that a difference up to 25% between 9 different net radiometers from 7 different manufacturers was identified by Hodges and Smith (1997) and Smith et al. (1997) in high radiation conditions. Furthermore, in a standard weather station, only total solar radiation is monitored and the measurement of net radiation is conducted only in some specific circumstances. This limits the wide use of standard meteorological data for investigating soil-atmosphere interactions, and this also explains the high interest of researchers for the development of calculation methods for the purpose of net radiation determination from standard meteorological data.

There are many formulae proposed, which can be summarized as two methods. Method 1 relies merely on air temperature (Wright and Jensen, 1972; Brutsaert, 1975; Doorenbos and Pruitt, 1977; Weiss, 1982; Jensen et al., 1990), while Method 2 involves both air and soil surface temperatures (Brutsaert, 1982; Ortega-Farias et al., 2000; Bisht et al., 2005; Saito et al., 2006; Cui et al., 2010; Hemmati et al., 2012). For Method 1, Jensen et al. (1990) pointed out that the formulae of Wright and Jensen (1972) and Wright (1982) show high consistence with the measurement data in Copenhagen, Denmark and Davis, California. Later, Allen et al. (1998) applied Method 1 to computing net radiation in the evaluation of crop water demands. In Method 2, it is essential to well

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calculate the air emissivity. Different models were developed for this purpose (Brunt, 1932; Idso, 1981; Brutsaert, 1982). Comparison between these models showed that all of them can provide good predictions in clear sky conditions, but they underestimate the air emissivity in cloudy conditions and during nighttime (Hatfield et al., 1983; Howell et al., 1993; Choi et al., 2008). Furthermore, the model of Idso (1981) showed the highest performance due to its consideration of both vapor pressure and air temperature.

Even though both Methods 1 and 2 have been widely studied, to the authors' knowledge, there has been no comparison done between these two methods, and there is no consensus on the methods to be used in estimating net radiation. Moreover, the calculations done previously were mostly at a daily or monthly scale (Irmak et al., 2003; Bisht et al., 2005; Samani et al., 2007; Choi et al., 2008; Long et al., 2010; Jin et al., 2011; Hou et al., 2014), and a few calculations were considered at shorter time-scales (Nielsen et al., 1981; Ortega-Farias et al., 2000; Alados et al., 2003). In this study, the net radiation is calculated by the two methods at three different time-scales, i.e. half-hourly, hourly and daily, based on the meteorological data recorded on an embankment. Emphasis is put on the comparison between the two methods in determining the long-wave and net radiations, as well as the comparison between different time-scales.

2. Methods for net radiation calculation

2.1. Energy balance

Solar radiation consists of direct and diffuse radiations. Direct radiation is the part of solar radiation which spreads out without striking any obstacle and finally reaches the Earth's surface. The solar radiation, which is diffused on its way through the atmosphere by clouds, water and dust particles, and finally reaches the Earth's surface, is termed as diffuse radiation. Both direct and diffuse radiations are short-wave radiation. Besides, the Earth's surface and atmosphere emit long-wave radiation. Net radiation includes the absorption and refelction of short-wave radiation, as well as the outgoing and incoming long-wave radiations, and can be expressed as follows:

$$R_n = (1-\alpha)R_{si} - L\uparrow + L\downarrow \tag{1}$$

where R_n is the net radiation (W m^{-2}), R_{si} is the solar radiation (W m^{-2}), α is the soil surface albedo ($\alpha = 0-1$), $L\uparrow$ is the long-wave radiation (W m^{-2}) from the Earth's surface, and $L\downarrow$ is the long-wave radiation (W m^{-2}) from the sky.

The energy balance at the Earth's surface is expressed as

$$R_n = G + L_E + H \tag{2}$$

where G is the soil heat flux, L_E is the latent heat flux which is the product of the evaporative flux E and the latent heat of vaporization λ, and H is the sensible heat flux.

When analyzing the impact of atmosphere on soil behavior, it is essential to determine the soil heat flux G because it is set as the main boundary condition at the interface of atmosphere and soil. Obviously, the calculation accuracy of G is conditioned by the calculation accuracy of R_n. In the following sections, the two methods commonly used in practice for calculating R_n are presented and assessed.

2.2. Method 1

Normally, a standard weather station provides parameters as R_{si} (solar radiation), T_a (air temperature), wind speed and relative humidity. Using these data, Allen et al. (1994a,b) proposed the following equation for calculating the daily net radiation:

$$R_n = (1-\alpha)R_{si} - \left[a_c\left(\frac{R_{si}}{R_{so}}\right) + b_c\right]\left(a_1 + b_1 e_d^{0.5}\right)\sigma\left(\frac{T_m^4 + T_n^4}{2}\right) \tag{3}$$

where σ is the Stefan–Boltzmann constant, $\sigma = 5.67 \times 10^{-8}$ W/(m^2 K^4); T_m and T_n represent the maximum and minimum air temperatures (°C) in one day, respectively; a_c and b_c are the cloud factors, equal to 1.35 and −0.35, respectively; a_1 and b_1 are the emissivity factors, equal to 0.35 and −0.14, respectively, as suggested by Evett et al. (2011); α is the soil surface albedo as indicated in Eq. (1), depending on the soil water content, color and texture as well as the organic matter content and surface roughness. The suggested values for α are listed in Table 1. Based on the suggestion of Rosenberg et al. (1983) for bare fields, a value of 0.23 is taken as the soil surface albedo for the studied embankment. R_{si}/R_{so} is the relative short-wave radiation, which is used to express the cloudiness of the atmosphere. When the sky is cloudier, its value is smaller. It varies in the range from 0.33 (dense cloud cover) to 1 (clear sky) (Allen et al., 1998). Specifically, its value is 0.7 for nighttime (Evett et al., 2011).

Besides, e_d is calculated from the mean daily dew point temperature T_d (°C):

$$e_d = 0.611 \exp\left(\frac{17.27T_d}{T_d + 237.3}\right) \tag{4}$$

In Eq. (3), the solar radiation in case of clear sky, R_{so}, is expressed as

$$R_{so} = (0.75 + 0.00002EL_{msl})R_{sa} \tag{5}$$

where EL_{msl} is the elevation (m) above the mean sea level; and R_{sa} is the extraterrestrial solar radiation, which can be calculated by (Evett et al., 2011):

$$R_{sa} = \left[\frac{24(60)}{\pi}\right]G_{sc}d_r(\cos\phi\cos\delta\sin\omega_s + \omega_s\sin\phi\sin\delta) \tag{6}$$

$$d_r = 1 + 0.033\cos\left(\frac{2\pi J}{365}\right) \tag{7}$$

$$\omega_s = \cos^{-1}(-\tan\phi\tan\delta) \tag{8}$$

where the term $24(60)/\pi$ is the inverse angle of rotation in daily; G_{sc} is the solar constant (−0.08202 MJ m^{-2} min^{-1}); d_r is the relative distance between the Earth and the sun (m); J is the day of year; ω_s is the sunset time angle (rad), the angle from solar noon to sunset; ϕ is the latitude; and δ is the solar declination.

Table 1
Soil albedo values for various soil surfaces.

Soil surface	Albedo	Source
Soils, dark, wet to light, dry	0.05–0.5	Oke (1987)
Dry sandy soil	0.25–0.45	Rosenberg et al. (1983)
Sand, wet	0.09	Van Wijk and Scholte Ubing (1963)
Sand, dry	0.18	Van Wijk and Scholte Ubing (1963)
Dark clay, wet	0.02–0.08	Van Wijk and Scholte Ubing (1963)
Dark clay, dry	0.16	Van Wijk and Scholte Ubing (1963)
Fields, bare	0.12–0.25	Van Wijk and Scholte Ubing (1963)
Grass, green	0.16–0.27	Van Wijk and Scholte Ubing (1963)