Nordic Hydrology, 7, 1976, 135-144

The Variability of the Net Radiation Ratio

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Prediction equations for estimating evaporation from bodies of water, often require values of net radiation. Solar radiation data are usually more accurate and more readily available than measurements of net radiation. Measured solar radiation and the mean ratio of net radiation to solar radiation have been used to estimate the net radiation levels required to predict evaporation rates. However, although the average net radiation ratio is relatively stable from year to year the effect of daily variation in the net radiation ratio on evaporation estimates has not been investigated. An empirical energy balance and measurements of pan evaporation and meteorological factors are used to examine the effect of the average daily variation on evaporation rates computed with the mean net radiation ratio. The results indicate that the average daily variation from the mean net radiation ratio may produce an error of approximately 13 per cent in an estimate of daily evaporation when the mean net radiation ratio is used. However, daily variability in the net radiation ratio has little influence on the regeneration of a large number of evaporation estimates. Estimated values of the net radiation ratio and its variability are compared with observed values from polar climates.

Introduction

Net radiation represents the portion of the total energy that is potentially available for evaporation when advection is insignificant. Penman (1948, 1956) used net radiation and other meteorological factors to estimate evaporation rates. If estimates of net radiation are to be used for estimating evaporation rates then the net radiation estimates must be of acceptable accuracy.

Estimates of net radiation can be obtained by direct field observations or through empirical relationships with other meteorological factors. However, field observations of net radiation are rarely available. Furthermore, a recent study (Holmes and Watson 1967) indicated that net radiation measurements from radiometers exposed side by side can differ by as much as 10 per cent. Thus, it appears that field measurements of net radiation, when available, may be unreliable for estimating evaporation rates.

Observations of the total flux of short wave radiation, which may be within less than 5 per cent of the true value, contain considerably less observational error than measurements of net radiation. This has led to the development of numerous empirical relationships between net radiation $R_{\bar{n}}$ and the total flux of short wave radiation R. Linear regression relationships of $R_{\bar{n}}$ on R have provided correlation coefficients greater than 0.9 (Davies 1967; Monteith and Szeicz 1961; Polavarapu 1970; Shaw 1956). But the variation among the empirically derived regression coefficients prohibits their use at other locations without prior verification of the constants. Data required for properly verifying the coefficients are rarely available. Furthermore, these regression equations were derived, for the most part, from observations of R_n and R collected during periods of similar meteorological conditions; their use is then questionable for periods involving meteorological conditions different from that when the data was collected for calibrating the prediction equations. In summary, it appears that the empirical linear regression relationships are not transferable to other locations and thus an alternate means of estimating net radiation needs to be developed.

From observations of net radiation and total short-wave radiation, Monteith and Szeicz (1962) in England and Stanhill et al. (1966) in Israel obtained values of the net radiation ratio (R_n/R) of 53 and 58 per cent, respectively, for small water bodies. In Indiana, Newman (1969) reported a net radiation ratio of 0.582 for weekly data observed above a grass covered soil surface. The apparent stability in the mean ratio for different latitudes in non-polar climates suggests that a mean ratio could be used for estimating net radiation from observations of total short-wave radiation when observations of R_n are not available or when an empirical relationship between R_n and R has not been verified for a specific location. However, the feasibility of using the net radiation ratio for estimating evaporation rates depends on the consistency of the ratio under varying meteorological conditions. Thus, the consistency of the net radiation ratio needs to be examined.

A simplified energy balance is used herein to estimate the net radiation ratio R_n/R and to examine the feasibility of using the net radiation ratio for estimating R_n from observations of R. The computed mean ratio is compared with values derived from observations of R_n and R at other locations. The reliability of a mean R_n/R ratio for estimating evaporation rates at a specific location depends in part on the daily variability of the ratio. Specifically, a high daily variability about the mean ratio would suggest that it is impractical to use a mean net radiation ratio. Although a study by Newman (1969) examined the range of the net radiation ratio for different synoptic air masses previous investigations have not indicated the degree of daily variation from the mean net radiation ratio or the effect of daily variation on estimates of evaporation. An indirect energy balance approach is also used herein to estimate the expected daily variation of the ratio. The computed daily variability is used by the authors to estimate the error in computed evaporation rates resulting from daily variation of the R_n/R ratio from the mean value.

Radiation Balance

Neglecting advective energy, the available net-radiation can be expressed as:

$$R_n = (1-\alpha)(R_i+r_i) + R_1 - r_1 \quad (1)$$

where R_i and r_i are the direct incoming and diffuse short-wave solar radiation, respectively, α is the mean albedo of the surface, and R_1 and r_1 are the incoming and outgoing long-wave thermal radiation, respectively. Since most available instruments are designed to measure the total incoming shortwave radiation $R = R_i + r_i$, and net long-wave radiation $R_{n1} = R_1 - r_1$, *Eq. (1)* reduces to:

$$R_n = (1-\alpha)R + R_{n1} \quad (2)$$

Net radiation has been estimated by the empirical relationship:

$$R_n = aR - b \quad (3)$$

where a and b are linear regression coefficients. Eqs. (2) and (3) suggest that the regression coefficient a depends particularly on the albedo of the surface and coefficient b on the degree of cloudiness. The necessity of including the albedo in a relationship used to estimate net radiation has been questioned by Fritschen (1967), Idso (1968), and Davies and Buttimor (1969). Fritschen (1967) showed that the inclusion of the albedo term did not improve the estimate of net radiation and thus, concluded that it is not worth the additional effort. Davies and Buttimor (1969) demonstrated that the regression coefficient a was insensitive to changes in the albedo caused by variation in surface and plant factors and variation in solar elevation.

The results of previous studies (Monteith and Szeicz 1962; Penman 1948; Stanhill et al. 1966) have demonstrated that Eq. (3) is capable of providing correlation coefficients greater than 0.90. Linacre (1968) indicated that decreases in the mean number of hours of bright sunshine n in a day - length of N hours are accompanied by an increase in the value of b. The mean annual ratio of n/N, for most parts of the United States is between 0.4 and 0.7 (Dept. of Commerce 1966). For such values of

n/N, the regression coefficient b is approximately zero. With b equal to zero, Eq. (3) reduces to:

$$R_n \equiv aR \qquad (4)$$

Thus, Eq. (4) represents an aproximation of the energy balance of Eq. (1). Factors such as cloud cover and surface emissivity, which are not used in the calculation of the net radiation ratio, will affect the actual value of R_n / R. The usefulness of an approximation such as Eq. (4) is dependent upon the effect on computed evaporation rates of variation in factors such as cloud cover and emissivity.

To estimate evaporation rates, Penman (1948, 1956) equated the net radiant heat flux density to the sum of the latent heat of evaporation and the flux density of sensible heat. The Penman equation has been used extensively for estimating evaporation rates E_o from shallow, open water surfaces in which heat storage and advected energy losses were considered negligible (Stephens and Stewart 1963):

$$E_o = \frac{(\Delta R_n + \gamma E_{ao})}{(\Delta + \gamma)} \qquad (5)$$

where Δ is the slope of the saturation vapor pressure versus temperature curve at air temperature and γ is the psychrometric constant. E_{ao} is an empirical function having the form of Dalton's mass transfer equation:

$$E_{ao} = 0.35(0.5 + \frac{V}{100})e_d \qquad (6)$$

where V is the wind speed in miles per day and e_d is the vapor pressure deficit. Solving Eq. (5) for R_n gives:

$$R_n = E_o(1. + B) - BE_{ao} \qquad (7)$$

where $B = \gamma/\Delta$.

Mean Value of the Net Radiation Ratio

Over a three-year period, 392 daily values of incoming short-wave radiation, humidity, air temperature, and air speed were observed at the Georgia Coastal Plain Experiment Station (GCPES) at Tifton, Georgia. Daily evaporation rates from a Standard Class A floating pan were observed at Walker Pond which is located 5.4 miles southwest of the GCPES. Daily values of net radiation were estimated using Eq. (7) and necessary meteorological and pan evaporation data. A least squares fit of Eq. (3) in which R was the observed incoming radiation and R_n was computed from Eq. (7), resulted in a standard error of 0.1050 and the regression coefficients of Eq. (8):

$$R_n = 0.47073 R + 0.02653 \qquad (8)$$

A least squares fit of Eq. (4) resulted in a standard error of 0.1054 and a net radiation ratio of 0.5563:

$$R_n = 0.5563\,R \tag{9}$$

The resulting standard error suggests that Eq. (4) is a reasonable approximation of Eq. (3). The close agreement of the computed net radiation ratio with the previously mentioned values of 0.53 and 0.58 suggests that the ratio is fairly stable and that the computed standard error of the net radiation ratio can be accepted as representative of the variability of the ratio. The validity of using an energy balance involving empirically derived coefficients will be discussed later.

The Effect of Variation in R_n/R

The computed standard error of 0.1054 was used as a measure of the variation of the net radiation ratio about the mean value. The effect of daily variation in the net radiation ratio on computed evaporation rates was determined by incrementing the net radiation ratio by an amount equal to the standard error and computing the difference in evaporation. The results are given Table 1 for the daily averages of the meteorological factors at Tifton, Georgia, for four seasons. Table 1 shows that an increase in the net radiation ratio of one standard error results in an average error of 13.08 per cent in an individual estimate of evaporation.

Table 1 - Effect of variability of net-radiation ratio on evaporation rates

	Daily average				Net Radiation			
Period	Temp. (°F)	Wind (mpd)	Humidity (Percent)	Radiation (Lgy/Day)	R_{n1} = 0.556*R (Inches/ Day)	R_{n2} = 0.661*R (Inches/ (Day)	E_O	% Error***
Dec.-Feb.	52.2	216	72	270	.0990		.1002*	10.88
						.1180	.1111**	
Mar.-May	64.4	160	69	500	.1840		.1686	13.77
						.2185	.1918	
Jun.-Aug.	80.5	144	75	530	.1946		.1904	14.56
						.2310	.2181	
Sept.-Nov.	67.7	136	74	365	.1340		.1281	13.11
						.1591	.1451	

*E_{O1} Evaporation computed using Eq. 5 and R_{n1}

**E_{O2} Evaporation computed using Eq. 5 and R_{n2}

***$E_{O2} - E_{O1} / E_{O1}$

The observed total radiation values were multiplied by the mean net radiation ratio of 0.556. The resulting values of net radiation were used with the Penman Equation and the 392 daily observations of meteorological factors to generate daily estimates of evaporation. A comparion of the computed and observed evaporation rates provided a correlation coefficient of 0.627. Using the same procedure a net radiation ratio of 0.661 (0.556 plus one standard error) provided a correlation coefficient of 0.625. Thus, although a deviation of one standard error in the net radiation ratio caused an average difference of 13% in an individual estimate of evaporation, a difference of one standard error had a significantly less effect on the average reproduction of a series of computed evaporation rates.

Discussion and Conclusion

The derived net radiation ratio of 0.556 is not recommended for use except for estimating evaporation from shallow water bodies. Because of differences, such as surface reflectivity, the mean ratio for different agricultural surfaces varies considerably. Cole and Green (1963) found a net radiation ratio of 0.68 for rough grass, bracken heather, and moor woodland, while Stanhill et al. (1966), found a ratio of 0.25 for desert vegetation. But Davies and Buttimor (1969) indicated that single relationship having the form of Eq. (3) might be suitable for a specific crop. The possibility of using a mean ratio, Eq. (4), for a crop should be investigated.

Although Penman's equation (Eq. (5)), was formulated from a simplified energy balance, several of the coefficients were determined empirically. The effect of empiricism on net radiation values computed with Eq. (7) influences the validity of the computed mean net radiation ratio and the variability about the mean. Even though Eq. (5) has provided accurate estimates for evaporation, it does not necessarily follow that Eq. (7) will provide acceptable estimates of net radiation. Tanner and Pelton (1960) indicated that the net radiation term of Eq. (5) is considerably more important than the E_{ao} term. The E_{ao} term contains empirical coefficients for the wind function. The development of the vapor pressure deficit component of E_{ao} contains structural empiricism. However, Tanner and Pelton (1960) indicated that the empiricism in the components of E_{ao} resulted in compensating errors and that little error resulted in daily evaporation estimates from the empiricism of E_{ao}. If it can be assumed that the measurement error resulting from the data collection procedure is randomly distributed in the 392 observations reported herein, the effect of both empiricism and data error on net radiation computed by Eq. (7) will be minor.

The validity of Eq. (4) as an approximation to Eq. (3) depends on the time period selected for use. Eq. (3) may be a valid approximation for periods as short as 1 day. However, for shorter periods its use is questionable. During the night net radiation is often negative. Thus, for such periods, the form of Eq. (3) may be preferable to the form of Eq. (4) because the negative intercept coefficient may provide negative net radiation estimates. However, it is still difficult to estimate the coefficients of Eq. (3).

The net radiation ratio and its variability were approximated using an energy balance technique and obervations of meteorological factors and the evaporation rates from a floating pan. Cooley and Idso (1971) successfully applied an energy balance technique for estimating atmospheric thermal radiation. The mean ratio of 0.556 computed herein agrees favorably with ratios determined from measurements of net radiation and total incoming radiation observed in England (Monteith and Szeicz 1962), Israel (Stanhill et al. 1966) and Indiana (Newman 1969). Ekern (1965a, 1965b) estimated a mean annual net radiation ratio of 0.65 from observations of pan evaporation rates and sunlight intensity in Hawaii. But the ratios computed for the summer months were affected by a strong positive advection of heat from a pineapple field located upwind from the pan. During the winter months when advective energy had no effect on the results, the average ratio was less than 0.60. Thus, the net radiation ratio appears stable for a variety of climates, even though Ekern's investigations indicated that an increase in the ratio was possible for tropical climates. The stability of the mean net radiation ratio with changes in latitude in non-polar climates might possibly result from a compensation of increases in temperature for a longer duration of bright sunshine with decreases in latitude. The apparent stability of the ratio for different locations suggests that a mean ratio can be used as an alternative to empirical relationships between net radiation and total incoming radiation which have not been verified for a particular location. However, in regions subjected to widely varying atmospheric conditions (i.e., continental polar air masses to tropical air masses) the mean ratio should be used with caution when estimating daily evaporation rates for short periods of time.

Although the mean net radiation ratio appears stable for non-polar regions the net radiation ratio is probably less in areas near the Arctic circle. Using approximately 12 years of data reported in a study at Palmer, Alaska (University of Alaska 1972), which is at a latitude of 61°36'N, a net radiation ratio of 0.32 was computed:

$$R_n = 0.32\,R \tag{10}$$

However, there is a considerable amount of variation throughout the year. From November 1 through January 30 the net radiation, and thus the net radiation ratio, is negative. During the periods of the year when the net radiation is positive the mean net radiation ratio was 0.43. From May 3 through August 1 a mean net radiation ratio of 0.535 was computed from the reported data.

In addition to the mean net radiation ratio of Eq. (10), a standard error of 0.17 was also computed from the Palmer, Alaska, data. The larger standard error reflects the greater variation in net radiation at higher latitudes. The relatively large standard error suggests that the net radiation ratio model of Eq. (4) may not be applicable to evaporation estimation in polar climates. The model containing the intercept coefficient, Eq. (3) may be a more realistic model for regions in which negative net radiation values are frequently observed.

The reliability of a constant net radiation ratio for estimating evaporation rates depends on the variability of the ratio. Largest deviations from the mean ratio will occur during periods of cold weather with cloudless skies or hot weather with a high cloud density (Linacre 1968; Newman 1969). An analysis of data indicated that the standard error of the mean ratio can be as much as twenty per cent of the mean ratio. However, the effect on computed evaporation rates of variation from the mean ratio is conservative because a deviation of one standard error from the mean produced a smaller percentage change in a computed evaporation rates. Furthermore, the data analysis indicated that the daily variation of the ratio would have little effect on the regeneration of a large number of observed evaporation rates.

Acknowledgments

The authors appreciate the computer programming assistance of Mr. Michael Shrader, Mr. Robert Menke, and Mr. David C. Curtis, University of Maryland. The computer time for this project was supported in full through the facilities of the Computer Science Center of the University of Maryland. Special thanks to Dr. Y. M. Sternberg, University of Maryland, for his comments on a draft of this paper.

Contribution from the Southern Region, Agricultural Research Service, U. S. Department of Agriculture, Tifton, Georgia, in cooperation with the University of Georgia College of Agriculture Experiment Stations, Georgia Institute of Technology, Atlanta, Georgia, and Middle South Georgia Soil Conservation District.

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Received: 10 October, 1973

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