Spacial Distribution of Actual Evapotranspiration Rate in Northeast Thailand during the Dry Season

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Introduction

The major part of Northeast Thailand is located in the climatic zone of 23–30°C in annual mean temperature, and 1,200–1,400 mm in annual precipitation. The most important agrometeorological problem is that the precipitation is concentrated mainly in the rainy season from mid May to early October and the rest of the year has only a few rainfall. Floods and droughts frequently occur as a result of erratic rainfall. Serious water deficit often appears in the dry season. Such water balance conditions limit the crop season and make the production unstable in Northeast Thailand.

To achieve efficient and stable agricultural production in that region, it is basically important to clarify the geographical distribution of water balance over complex terrain with diverse land uses, and to develop suitable cropping systems.

In order to estimate a reliable actual evapotranspiration rate, a modified Penman model was proposed recently by Kotoda (1986)[1]. By making use of the basic structure of that model, the present study was carried out. In this paper, the methodology, procedures of data analysis for estimating the actual evapotranspiration rate over complex surface condition, and some results obtained in the dry season of Northeast Thailand will be shown.

Basic formula

Penman (1948, 1956)[2,3] proposed the combination of a heat balance equation and an aerodynamic equation to estimate evaporation from shallow open-water of a well-saturated bare soil surface. Arranging his equation, for a well-saturated land surface covered by vegetation, the following equations are usually used:

$$E_p = \frac{\Delta}{\Delta+\gamma} Q_n + \frac{\gamma}{\Delta+\gamma} f(u)(e_s - e), \quad \text{......(1)}$$

$$Q_n = \frac{R_n - G}{aL}, \quad \text{......(2)}$$

$$f(u) = 0.13 + 0.14u, \quad \text{......(3)}$$

where E_p: the potential evaporation rate,
Q_n: the available energy for vegetative land surface,
R_n: the net radiation flux,
G: the soil heat flux,
a: the conversion coefficient from energy units to equivalent rate of evaporation,
$f(u)$: the wind function,
e_s: the saturated vapor pressure at the temperature of the air,
e: the vapor pressure of the air,
Δ: the slope of the saturation water vapor pressure curve at the air temperature,
γ: the psychrometric constant.

To calculate Δ and L, we can use the empirical equation with the daily mean air temperature.

Radiation fluxes are remarkably influenced by the nature of the surface. But net radiation data are usually not available. Then the determination of value of the albedo is exceptionally important for radiation regime. If duration of sunshine, air temperature and vapor pressure are available and albedo is given independently, R_n and G can be estimated by use of the following equations:

$$R_s = [K1 + K2(n/N)]R_0, \quad \text{......(4)}$$

$$R_{ln} = \sigma T_a^4 (0.34 - 0.044\sqrt{e})\,[0.1 + 0.9(n/N)], \quad \text{......(5)}$$

$$R_n = (1-A)R_s - R_{ln}, \quad \text{......(6)}$$

$$G = K3 R_n, \quad \text{......(7)}$$

where A: the albedo,
R_s: the short-wave radiation,
R_{ln}: the net long-wave radiation,
n: the duration of sunshine,
N: the possible duration of sunshine,
R_0: the extraterrestrial radiation,
σ: the Stefan-Boltzman constant per day,
$K1$–$K3$: the empirical constants fixed by the preliminary observations.

Values of N and R_0 can be calculated with latitude and sun-inclination at a reference location.

The first and the second terms in Eq. (1) are represented as E_e (equilibrium evaporation rate) and E_v (aerodynamic term in Penman's equation) respectively. In consequence, the following relation is derived:

$$E_{ac} = f_0 E_p = f_0(E_e + E_v), \quad \text{......(8)}$$

where E_{ac}: the actual evapotranspiration rate (mm/day),
f_0: the conversion factor from potential to actual evapotranspiration.

Kotoda (1986) mentioned the role of conversion factor and suggested that the value is decided by means of a multiple regression analysis.

Study area and observation method

The map of the study area is shown in Fig. 1. The study area is about 4,700 km^2. In order to operate the present procedures, a square-grid map with mesh size of $1' \times 1'$ (2.84 km in N–S axis $\times$ 2.75 km in E–W axis) was prepared as shown in Fig. 2.

The mean elevations of each grid-square are obtained from the topographic map of 1:250,000. The values of the mean elevation are useful for the calculations of air temperature and relative humidity at every meshed area. It is found that about 87% of the total area is located within the geographic altitude of 150–200 m.

Information of the distribution of surface conditions provides a principal part for the estimation of the actual evapotranspiration rate to be presented in this paper. Classification sources of the land use distribution can be obtained mainly from an analysis of the surface moisture content map by remotely

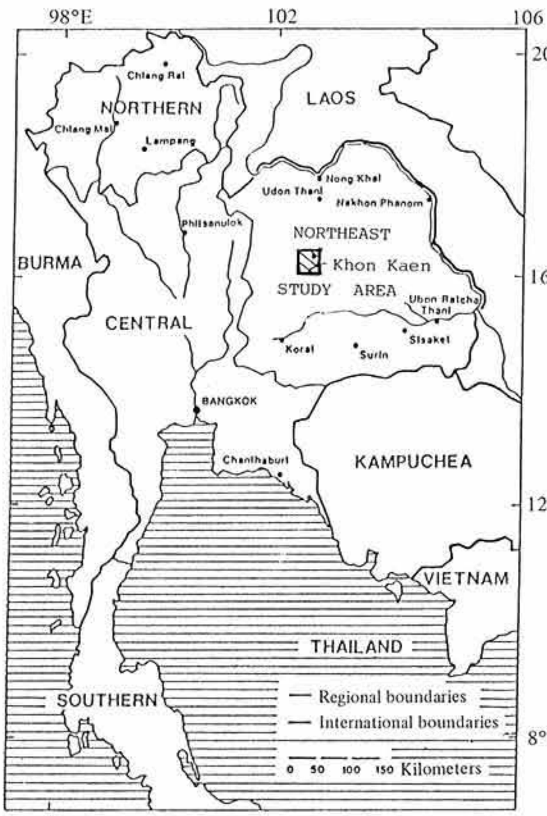

Fig. 1. Location of Northeast Thailand and the study area

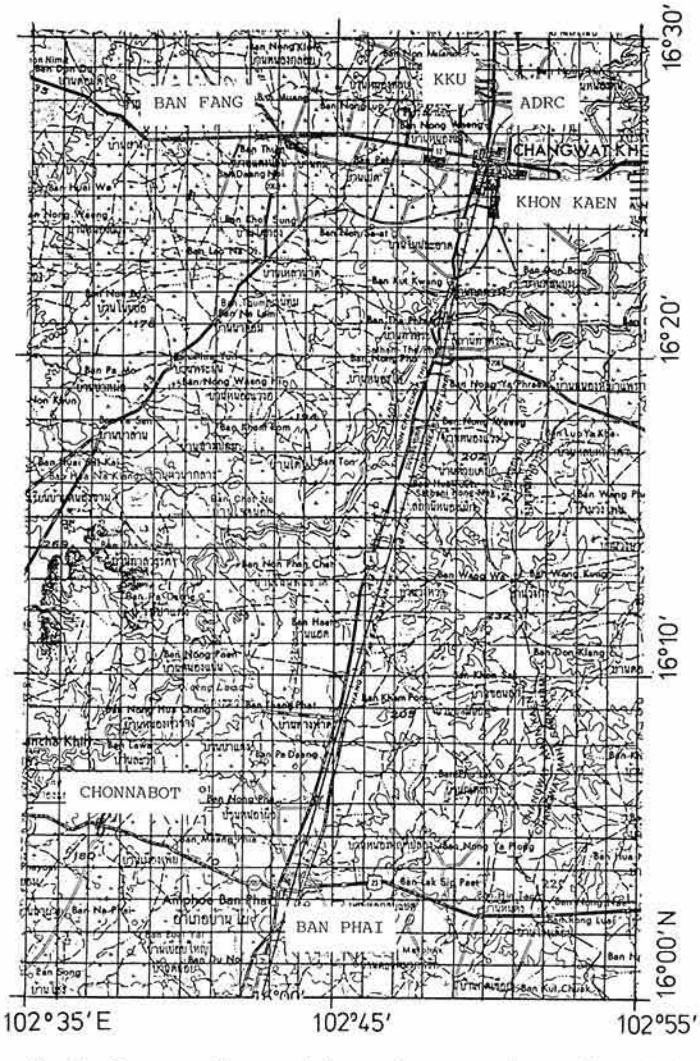

Fig 2. Square-grid map of the study area and some important points quoted in the present study

sensed satellite data (presented by courtesy of Dr. Mongkolsawat, Khon Kaen University). On the other hand, surface soil classification maps have been published by Land Development Department. Combining these two sets of information, a digitized square-grid map of the surface properties was made. Fig. 3 shows the map of distribution of the surface properties. According to the statistical treatment of the classification of the surface properties, the plowed bare field (code 2) which consists mainly of rice fields in the wet season is about 44% of the total area. The second largest area is the cassava field (code 3) which occupies about 39% of the total.

Measurements were carried out at a meteorological observation station in Khon Kaen University (KKU) and at a plowed bare field in Agricultural Development Research Center (ADRC) in Khon Kaen. The data were collected in the dry season of 1988, i.e., from Jan. 26 to Feb. 2 and from Feb. 6 to 14. In addition, the short period observation was

16°30'N

3	5	3	3	5	3	3	3	3	3	3	5	3	3	2	3	5	5	3	3
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2	2	2	4	4	2	1	2	4	4	2	2	2	2	2	2	2	2	2	3

16°15'N

16°00'N

102°35'E 102°45'E 102°55'E

Fig. 3. Distribution map of surface properties
Code 1: Short grass field, 2: Plowed bare field,
3: Cassava field, 4: Very dry or saline field,
5: Forest, 6: City, 7: Settlement,
8: Water surface.

made at the cassava field in ADRC and the saline field near Ban Phai. All the outputs from those sensors were fed to a digital printer. In the present study, daily mean values or daily accumulated values are considered.

Determination of constants

From the linear regression between observed short-wave radiation flux (R_s) and relative duration of sunshine (n/N) in Eq. (4), we can decide the values of parameter $K1$ and $K2$ by use of routinely observed data at ADRC weather station. The relation is shown in Fig. 4 and as:

$$R_s/R_0 = 0.075 + 0.5(n/N). \quad \text{(9)}$$

Then we got the values of $K1=0.075$ and $K2=0.5$.

The values of albedo were also represented in the previous study for various surfaces. Adding the results observed here, Fig. 5 shows their half-hourly variations for various surfaces defined in the present study area. The plowed bare field will represent the surface of rice fields during the dry season of Northeast Thailand. And the saline field represents an area of the lowest content of soil moisture. The daily mean values of albedo and the constant $K3$ adopted to the present model are tabulated in Table 1.

In general the surface air temperature decreases with the elevation of the topography and its lapse rate has been known as similar as the free atmosphere's one. Using this relation, the horizontal distributions of daily mean air temperature and relative humidity were estimated from the mean elevation of the reference mesh area. It will be feasible

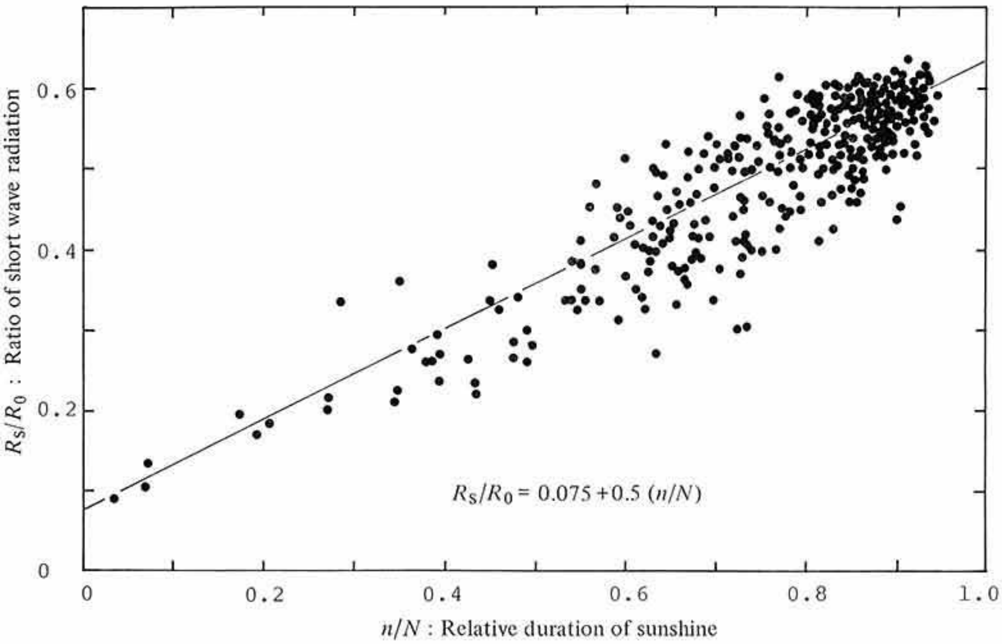

Fig. 4. Relation between normalized short wave radiation flux (R_s/R_0) and normalized sunshine duration (n/N)

Table 1. Daily mean values of albedo and constant $K3$ used in the present model

Code	Surface	Albedo	$K3$
1	Short grass f. (KKU)	0.251	0.127
2	Plowed bare f. (ADRC)	0.229	0.098
3	Cassava f. (ADRC)	0.262*	0.140
4	Saline f. (near Ban Phai)	0.415*	0.100
5	Forest	0.15	0.04
6	City	0.30	0.40
7	Settlement	0.25	0.30
8	Water	0.60	0.20

The values for code 5 to 8 are quoted from Kotoda (1986)[1].
* Calculated from the data during 11 : 00—13 : 00.

that the lapse rates change seasonably rather than being constants throughout the year. In the present study, for the dry season, lapse rates of air temperature and relative humidity were fixed as 0.52°C/100 m and 1.07%/100 m, respectively. For the determination of the lapse rates, monthly vertical profiles at Ubon Ratchathani (15°15′N, 104°53′E, 123 m in elevation) were processed.

The conversion factor was defined empirically as:

$$f_0 = 0.18 + 0.022\ T_a - 0.024\ u.$$

Here, T_a and u are daily mean values.

The preliminary check of the model

Fig. 6 shows the comparison between the observed actual evapotranspiration rates by the evaporation pan (E_{acpan}) and the estimated one by the present model (E_{ac}) on the basis of the daily mean. Although there is some scattering, it can be seen that the following relation may be applicable for the dry season in Northeast Thailand:

$$E_{ac} = 0.72\ E_{acpan} + 1.24. \quad \text{(10)}$$

Here we will find an acceptable reliability of the model with the correlation coefficient of 0.848.

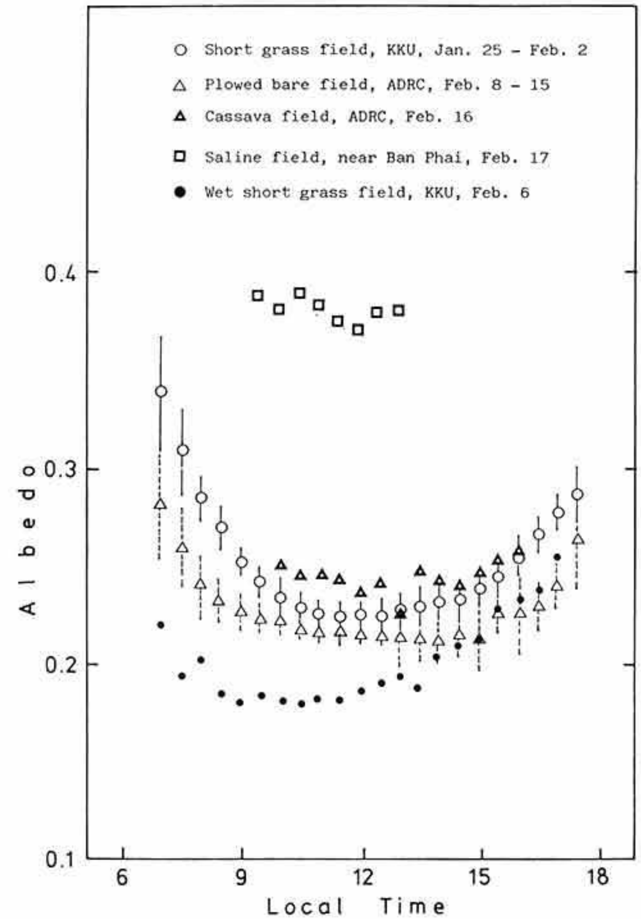

Fig. 5. Diurnal variations of albedo for several surface conditions
Bars represent the standard deviations.

Distribution of estimated actual evapotranspiration rates

The estimated daily actual evapotranspiration rates E_{ac} over the present study area are shown in Plate 1(a) for a clear day and Plate 1(b) for a cloudy day. Variables at a standard point in ADRC are set as follows:

$RH=60\%$, $T_a=27°C$, $u=2$ m/s, $n=11$ hr for a clear day,
$RH=80\%$, $T_a=22°C$, $u=5$ m/s, $n=5$ hr for a cloudy day.

The distribution maps of the estimated values are well described by the surface properties shown in Fig. 3. The distribution under clear weather shows that the minimum value of $E_{ac}=3.0$–3.1 mm/day is found at the city and the saline field. On the other hand, the large value of $E_{ac}=4.6$–4.7 mm/day appeared at the forest area. Over the plowed bare field and the cassava field, their values lie almost 4.0 mm/day.

Under the cloudy weather conditions, the values of E_{ac} reduced under 2 mm/day for the city or the saline field and about 2.5 mm/day for the plowed bare or the cassava field.

Conclusion

The present study was intended to develop a method to estimate actual evapotranspiration from the wide area of the arid or semi-

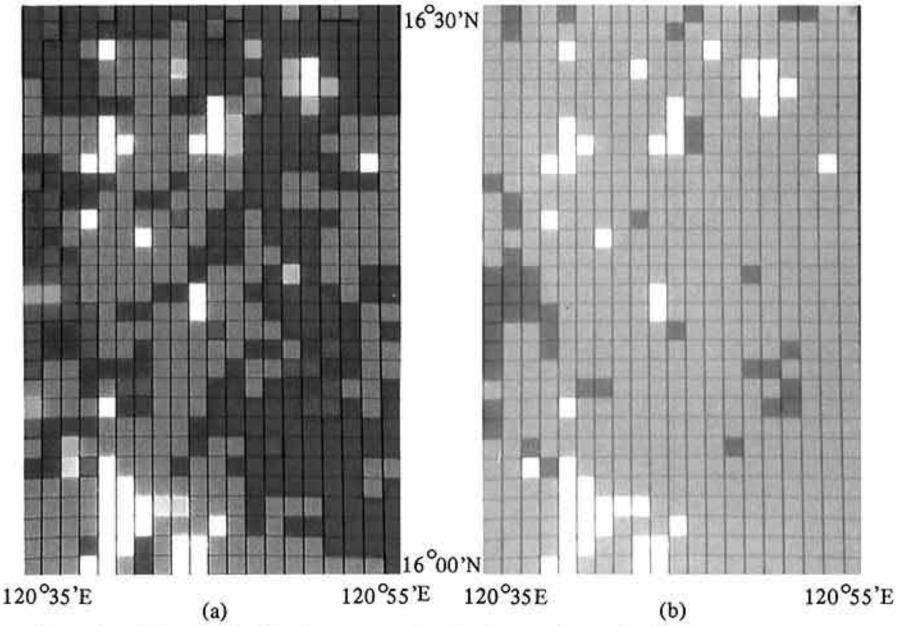

Plate 1. Colored distribution map of actual evapotranspiration rates calculated from the estimation model

(a): Under the condition of a clear day with $RH=60\%$, $T_a=27°C$, $u=2$ m/s and $n=11$ hr.

white:	—5.5	mm/day
yellow:	5.5—6.0	mm/day
red:	6.0—6.5	mm/day
purple:	6.5—7.0	mm/day
sky blue:	7.0—7.5	mm/day
dark blue:	7.5—	mm/day

(b): Under the condition of a cloudy day with $RH=80\%$, $T_a=22°C$, $u=5$ m/s and $n=5$ hr.

white:	—2.0	mm/day
sky blue:	2.0—2.5	mm/day
dark blue:	2.5—	mm/day

arid zone taking consideration into topography and complex land uses. The discussions were concentrated on the actual evapotranspiration rates in the dry season of Northeast Thailand.

In view of the fact that only a few information is available on the evapotranspiration rates in Northeast Thailand, we carried out the measurement of net radiation flux, soil heat flux, short-wave radiation flux, albedo, air temperature and soil temperature. Additionally, using the weather station data of ADRC and KKU, some constants were evaluated for the estimation of the evapotranspiration rate.

The procedure of the present method used for estimating the actual evapotranspiration rate was mainly based on the Kotoda's scheme (1986). However, we did not use the whole of the scheme. Because some additional factors specific to the tropics were requested to be taken into consideration for the present study area.

The driving parameters of the present model are air temperature, relative humidity, wind speed and sunshine duration. The estimated values of the actual evapotranspiration rates

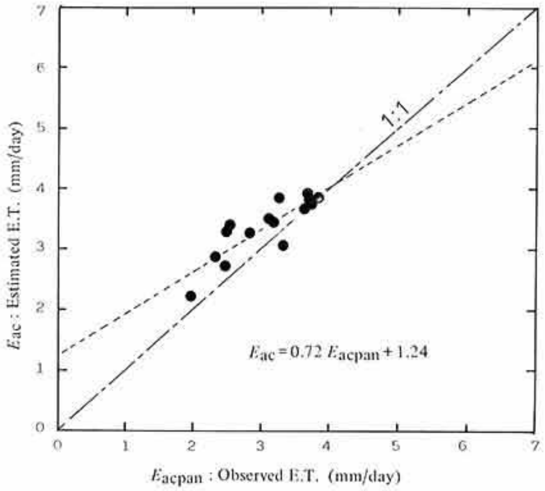

Fig. 6. Relation between observed actual evapotranspiration rates (E_{acpan}) and estimated ones (E_{ac})
Dotted line represents a first order approximation and broken line indicates 1 : 1 relation.

were almost the same as the observed ones. The spacial distribution of actual evapotranspiration will be useful for future agricultural planning and management.

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