PART II
Application of Equilibrium Evaporation Model to Estimate Evapotranspiration by Remote Sensing Technique

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INTRODUCTION

In the process of evapotranspiration, there are three things required to occur: (1) energy for the change of phase of the water; (2) a source of the water; (3) a sink for the water. Remote sensing can contribute information to the first two of these conditions by providing estimates of solar insolution, surface albedo, surface temperature, vegetation cover, and soil moisture content (Schmugge and Gurney, 1982). Many methods for estimating of evapotranspiration have been studied (Rosema et al., 1978; Soer, 1980; Carlson et al., 1981; Elkington and Hogg, 1981; Gurney and Camillo, 1982), which are reviewed by Schmugge and Gurney (1982).

In a humid region like Japan, it seems that radiation term in energy balance equation plays an important role for evapotranspiration rather than vapor pressure difference between the surface and lower atmospheric boundary layer. For this reason, the present study adopted a Priestley-Taylor type of equation which is called in this paper an ''Equilibrium Evaporation Model'' to estimate evapotranspiration. This method acquires the data of net radiation, soil heat flux and surface temperature, but not necessary to get the data of vapor pressure and wind speed. Carlson et al. (1981), Thomas and Kanemasu (1981) and Kanemasu (1982) used the GOES data to estimate daily solar radiation. However, in the present study, such data were not available, and we used only temperature data obtained by remotely sensed techniques.

LAND USE AND VEGETATION

Compared with continental countries, the land use of Japan is very minute and tremendously complicated. Topography around the test area can be divided into two parts, one is diluvial upland (altitude 25-30 m) and the other is alluvial lowland (altitude 10-15 m). The most part of the alluvial lowland is occupied mostly by rice field. Therefore, the vegetation of lowland is fairly monotonous and landscape is relatively simple. On the contrary, diluvial upland is a complex of farms, residential quarters, forest, orchards and others. Most parts of the upland are occupied by farms (mainly vegetable fields), residential quarters and towns, red pine forests and grass land.

A test study was carried out at the Tsukuba Academic New Town on 21st and 22nd Jan., 1983 during which field survey provided ground truth data for comparison with satellite (LANDSAT) imagery and airborne sensing information. In the present study, however, the satellite image from LANDSAT was inadequate for identifying the land use and vegetation categories required. This is due to the facts that one is cloud cover when LANDSAT flew over the test area on 21st Jan. and the other is due to the spectral resolution which could not provide inadequate intervegetation differentiation.

Fig. 2-1 shows an example of the actual vegetation map of Tsukuba Academic New Town and its surrounding districts (Nakamura et al., 1980) obtained by field survey.

RADIATION REGIME AND SURFACE TEMPERATURE

Surface temperature was measured every two minutes by a Barnes Infrared Thermometer (model PRT-5) from 0800h to 1600h for the purpose of ground truth of surface temperature.

As shown in Fig. 3-1, it was fine on January 22nd, when the flight was done. However, there existed fluctuations in incoming short-wave radiation (Rs↓) and net radiation (Rn) from 1150h to 1430h (Fig. 3-2). The fluctuations were caused by scattered cloud which shaded sunshine for a short time interval.

Surface temperature (Ts) showed fluctuations in response to those of Rs (Fig. 3-3). Before 1100h, Ts showed a smooth increase and the fluctuations of Ts were within 2 °C. After that, it became partly cloudy by the traveling of scattered cloud. As a result, Ts changed rapidly and greatly. The maximum change of Ts was about 9 °C in two minutes. These large and rapid fluctuations were true in the case of 10-min average Ts (Fig. 3-3).

In contrast to this, fluctuations in air temperature (Ta) were very small and responded slowly to the changes in Rs↓.

SURFACE TEMPERATURE MEASUREMENTS BY REMOTE SENSING

Remotely sensed measurements of surface temperature were made from two types of platforms: One was a satellite, i.e. LANDSAT, the other was an aircraft. The LANDSAT offers large coverage but suffers from reduced spatial resolution compared to aircraft. The aircraft platform was primarily used for experimental studies because of the greater control and resolution possible.

Airborne remote sensing was conducted over the Tsukuba Academic New Town at 8:52, 12:02 and 15:09 JST on 22nd Jan., 1983. Fig. 4-1 shows a flight course and coverage area. The flight height was about 2000 m, and the ground resolution (one pixel) was an area of 15 m x 15 m. Fig. 4-2 shows synoptic conditions on 22nd. The day was clear, and the wind was northwesterly at 1 to 4 m/s at the height of 1.6 m from the ground surface. The clearing sky provided moderately favorable conditions for the remote sensing.

Airborne MSS information was used to estimate the surface temperatures and to give maps of them. The surface temperatures were estimated from measurements at thermal infrared wavelengths, i.e. the 8.0 to 14.0 micron meters, of the emitted radiant flux, and were calibrated by the ground truth. Fig. 4-3 shows distributions of the surface temperatures at 8:52, 12:02 and 15:09 JST on the 22nd.

METHOD OF ANALYSIS

As described in Part I of this paper, evaporation equation can be expressed as

$$E = \frac{\alpha}{\lambda} \left(\frac{\Delta}{\Delta + \gamma} \right) (Rn\text{-}G) \qquad (1)$$

where Δ is the slope of the saturation water vapor pressure curve, and γ is the psychrometric constant. Using the data of temperature, the values of Δ and γ can be estimated as follows:

$$\Delta = 0.4476 + (0.030669 + 0.000493T + 0.000023T^2)T \quad (mb \cdot {}^\circ C^{-1}) \qquad (2)$$

$$\gamma = \frac{Cp\ P}{0.622\lambda} \qquad (mb \cdot {}^\circ C^{-1}) \qquad (3)$$

$$\lambda = (2501 - 2.37T) \times 10^3 \qquad (JKg^{-1}) \qquad (4)$$

where T (°C) is the surface temperature obtained by remote sensing, c_p is the specific heat of air (=1005 $Jkg^{-1}{}^\circ C^{-1}$), P is the atmospheric pressure (=1013 mb), and λ is the latent heat of vaporization.

The net radiation flux, the result of incoming and outgoing radiation fluxes, is given as

$$Rn + (1 - a_s)R_s + \epsilon(L\downarrow - \sigma T^4) \qquad (5)$$

where Rs is the incoming total short-wave radiation flux, a_s is the albedo, $L\downarrow$ is the downward long-wave radiation flux, T is the surface temperature, ϵ is the emission coefficient of the surface (=0.98) and σ is the Stefan-Boltzmann constant [(5.67 × 10^{-8}) $Wm^{-2}K^{-4}$].

The heat flux into the soil is proportional to the temperature gradient and the heat conductivity in the soil depending on the soil moisture content. In this study, the following relationship was used.

$$G = a_r Rn \qquad (6)$$

where a_r is the proportional constant depend on the soil conditions. The values of a_s and a_r vary with surface condition and time of day. In this study daily mean values are used to estimate the evapotranspiration. So, it is necessary to convert the momentary evapotranspiration data into 24-hr estimates of evapotranspiration. For the practical purpose, if we know the relationships momentary data and daily mean data, it may be estimated from the daily mean evapotranspiration.

In order to avoid the complexity of calculation, land use / land cover are classified in 8 categories. Using the data of Rs = 180 Wm^{-2}, $L\downarrow$ = 403 Wm^{-2} which are the typical summer climatological conditions at Tsukuba, and assuming T = 20 °C, α = 1.0, evapotranspiration from various surface covers can be calculated (Table 5-1). It seems that the results are reasonable compared with the lysimeter data obtained in August, 1979 (Kotoda, 1980) and the data of lake evaporation obtained at Lake Kasumigaura in August and September 1981 (Takeda et al., 1982).

CONCLUDING REMARKS

Using the surface temperature obtained by airborne remote sensing and other necessary data measured at experimental field at ERC, University of Tsukuba (Kotoda et al., 1983), evapotranspiration from various surfaces were calculated. The result (point A) is shown in Fig. 6-1 with other data of evapotranspiration from grass land which were measured by lysimeter at ERC. Calculated daily mean evapotranspiration on 22nd Jan., 1983 is approximately 0.4 mm/day, however the differences of evapotranspiration with the vegetation types were not detectable, because the magnitude of evapotranspiration is very little in winter.

The future subject of remote sensing techniques to the estimate of evapotranspiration will depend on establishing correlations between land surface reflectance and hydrometeorological parameters related to heat balance terms, such as Rn, H or G. As a satellite monitoring, more frequent operational satellite, like a geostationary satellite is desired, because the present LANDSAT can operate nothing but one or two days measurement per month.

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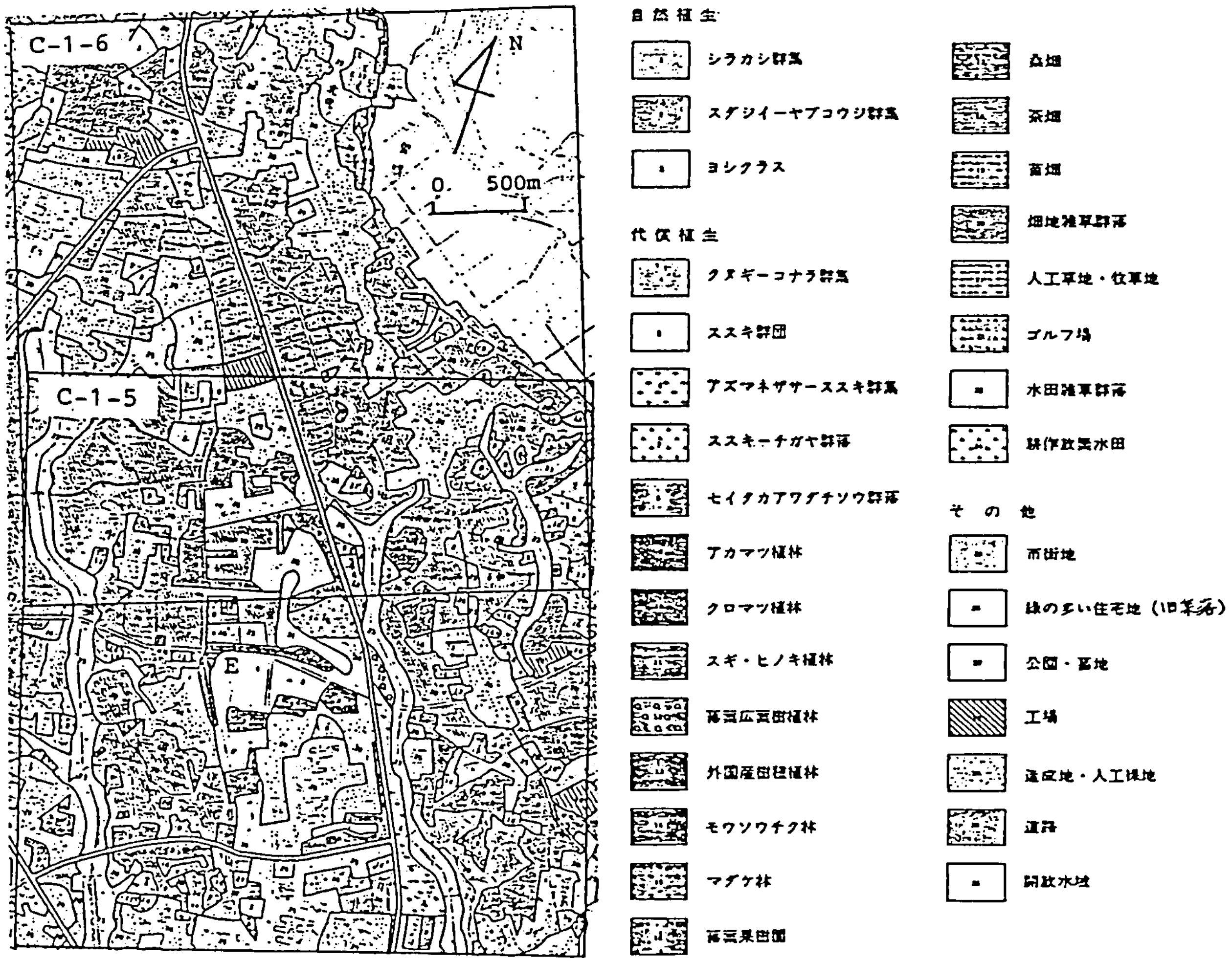


Figure 2-1. An example of the actual vegetation map of Tsukuba academic New town and its surrounding districts. E : ERC

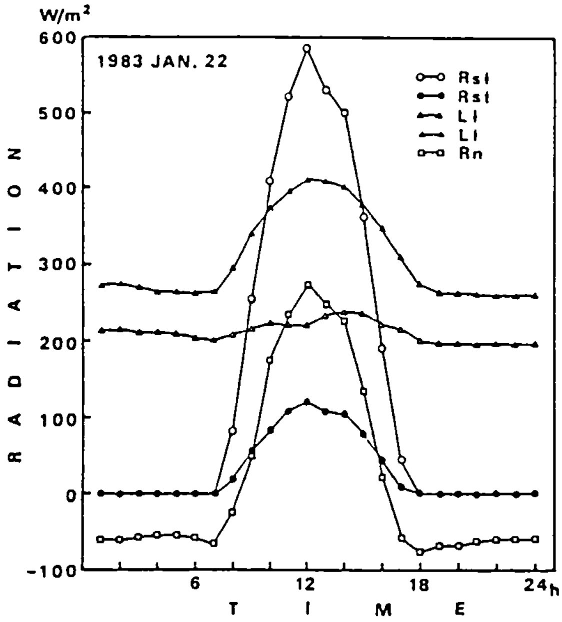


Figure 3-1. Diurnal variations of radiation balance components observed at the Aerological Observatory, Tateno.

Rs↓ : incoming short-wave radiation
Rs↑ : reflected short-wave radiation
L↓ : downward long-wave radiation
L↑ : upward long-wave radiation
Rn : net radiation

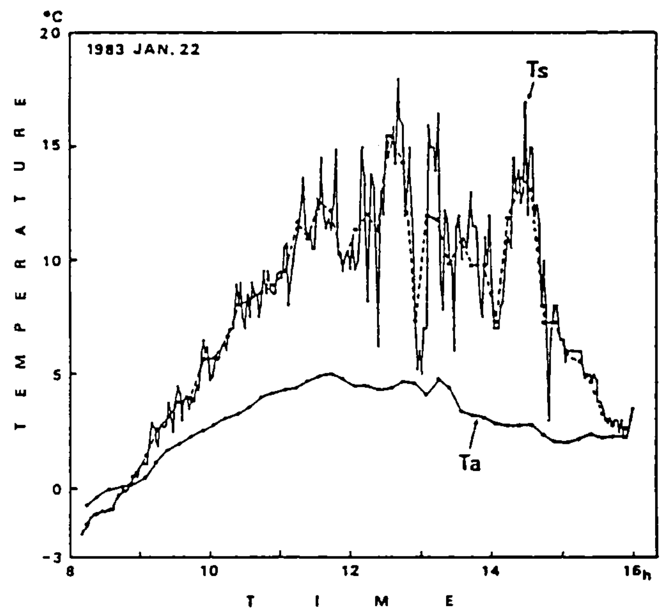


Figure 3-2. Hourly variations of surface temperature (Ts) and air temperature (Ta) at ERC. Broken line in Ts and Ta are 10-min averaged values. Ta was observed at a height of 1.6 m.

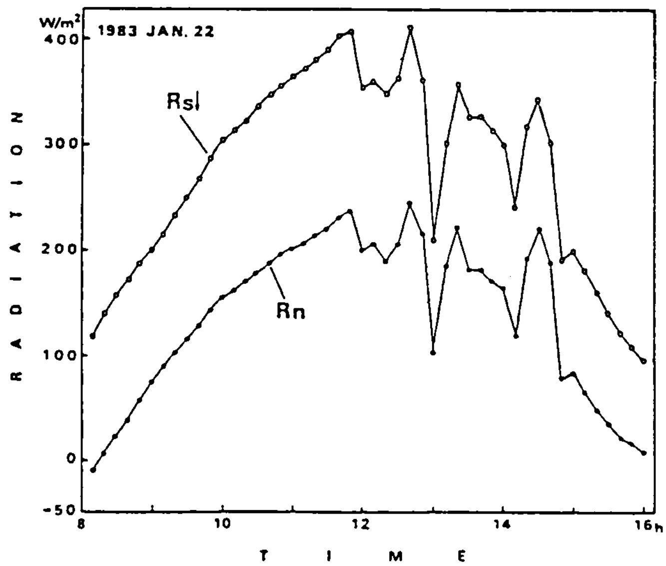


Figure 3-3. Hourly variations of incoming short-wave radiation (Rs↓) and net radiation (Rn) at ERC. Rs↓ and Rn are 10-min averaged values.

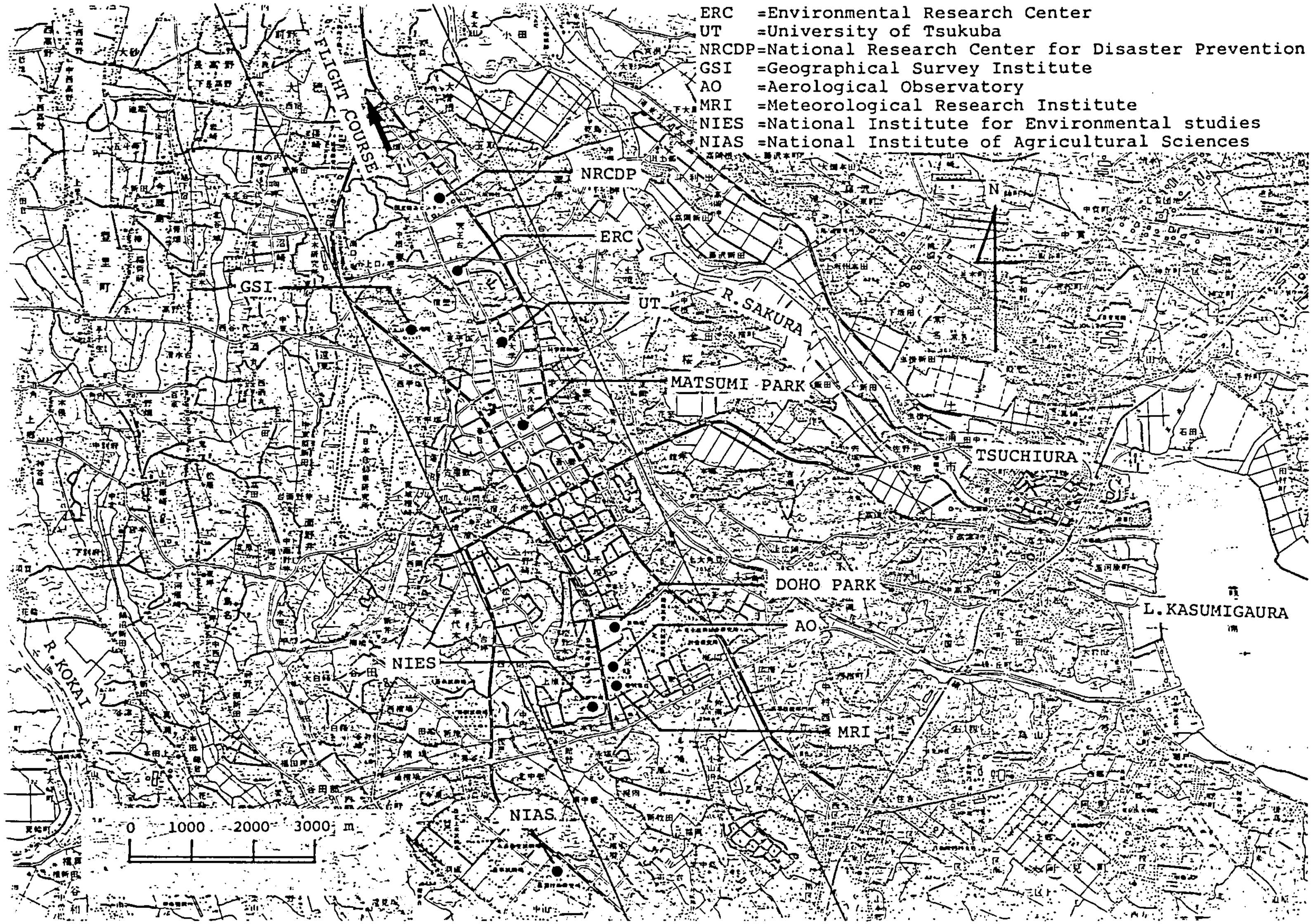
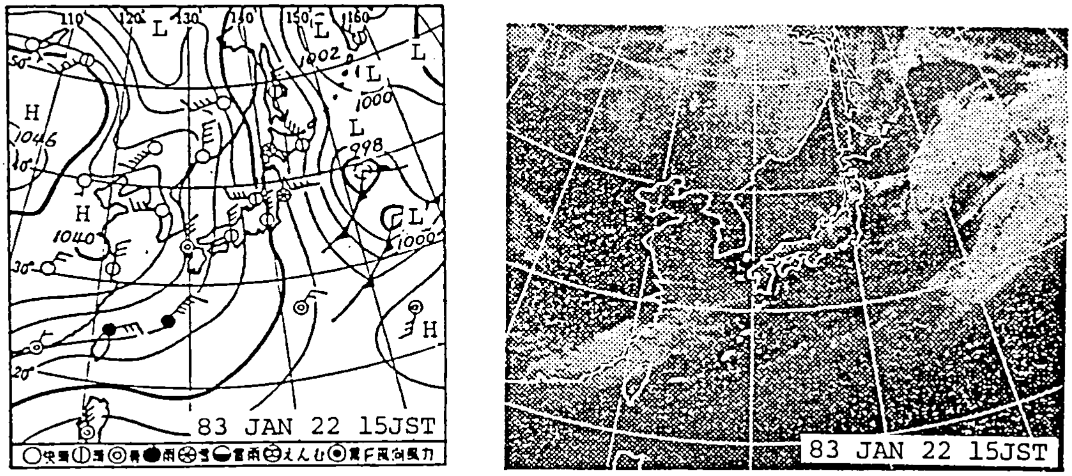
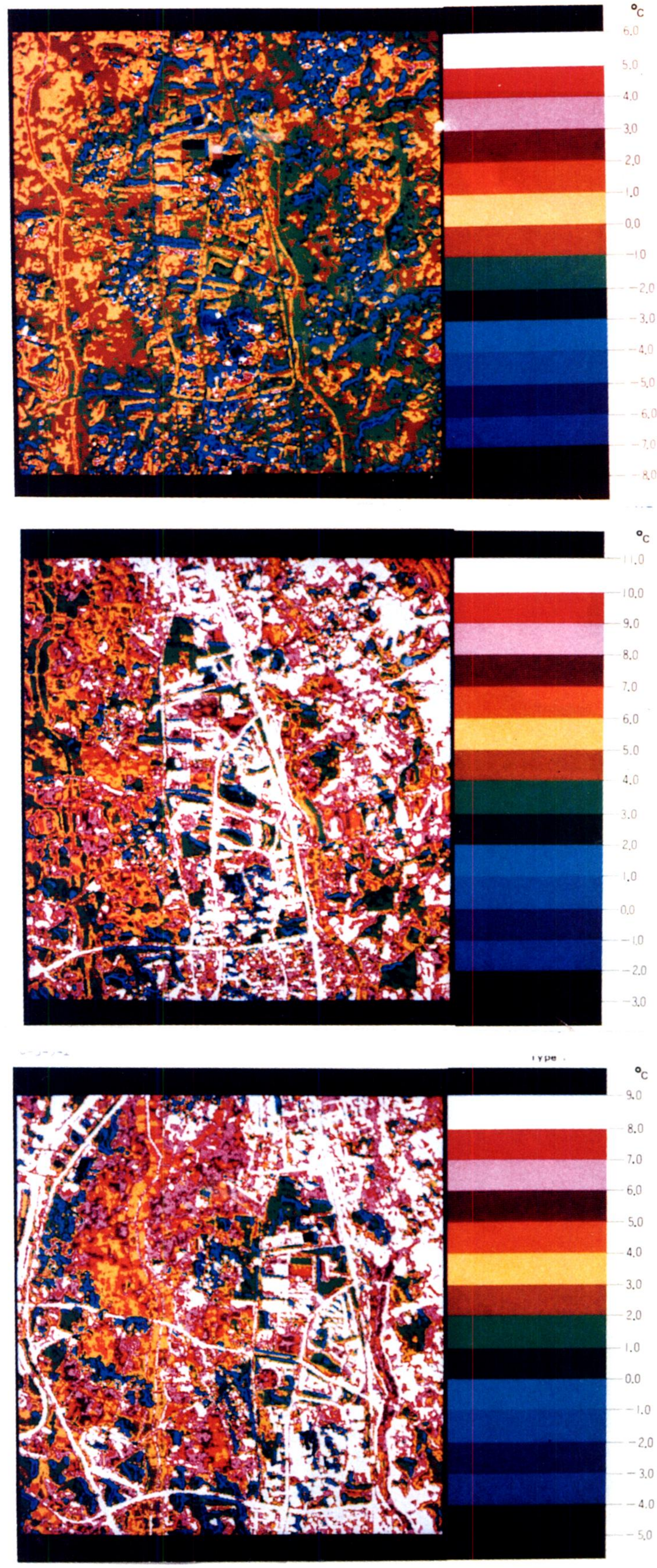


Figure 4-1. Flight course and coverage area.



(a) (b)

Figure 4-2. Synoptic conditions on 22nd January, 1983.
(a) Surface weather map at 15 JST 22 January, 1983
(b) GMS VIS imagery at 15 JST 22 January, 1983



(a) 8:52 JST

(b) 12:02 JST

(c) 15:02 JST

Figure 4-3. Surface temperature distributions at 8:52, 12:02 and 15:09 on 22nd, January, 1983

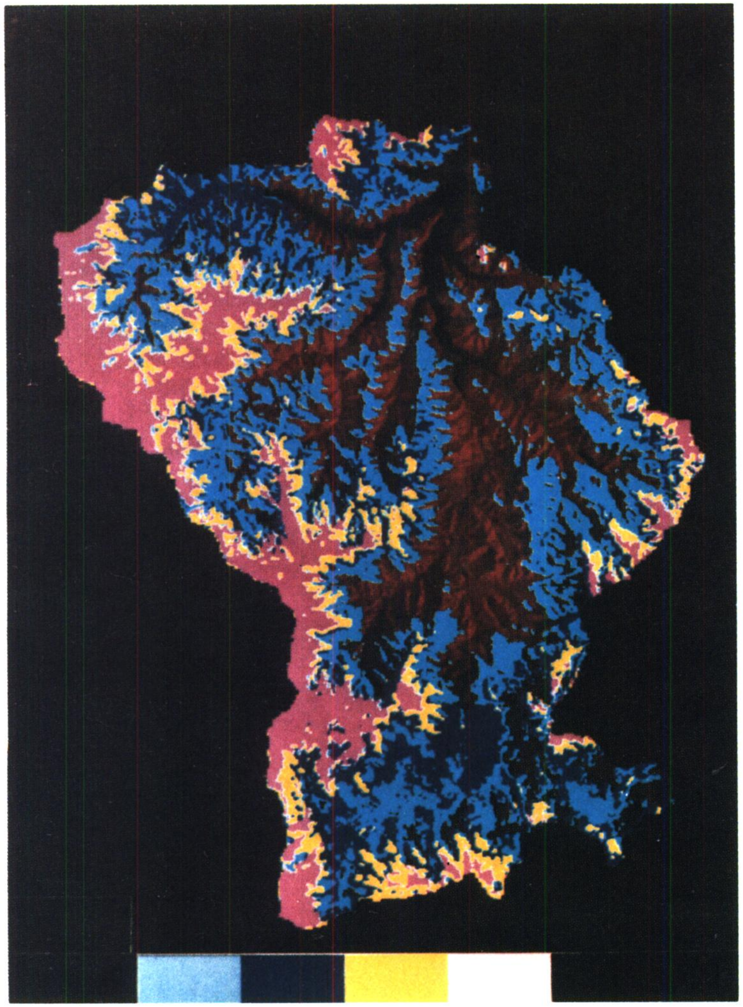


Photo 1. Superimposed Image of Snowcover Areas Extracted from Landsat Data

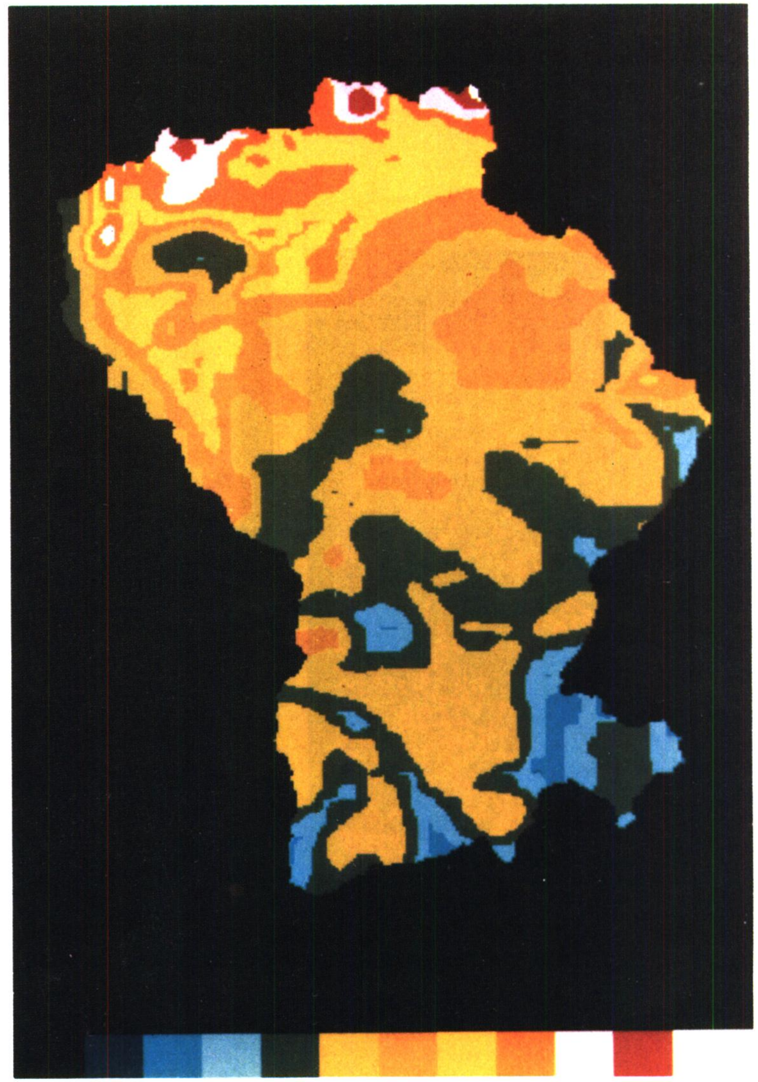


Photo 2. Maximum Snow Water Equivalent Map of Okutadami-gawa Bain in 1982

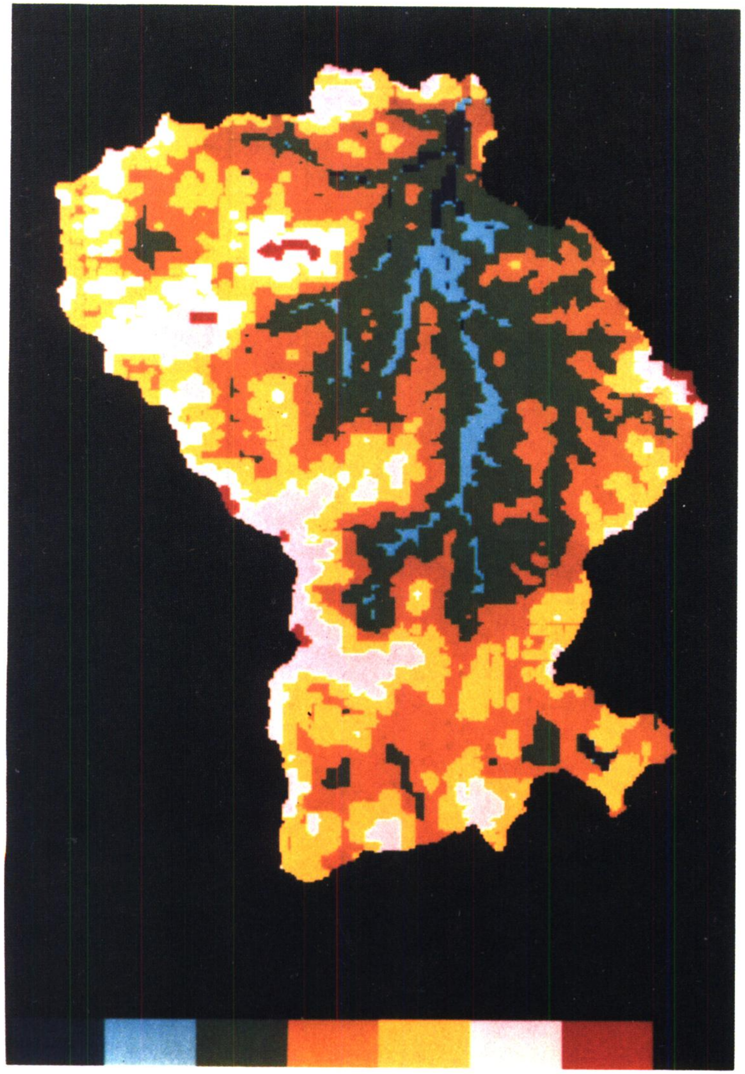


Photo 3. Snowcover Daily Variation Map Estimated From the Maximum Snow Water Equivalent Map Shown in Photo 2

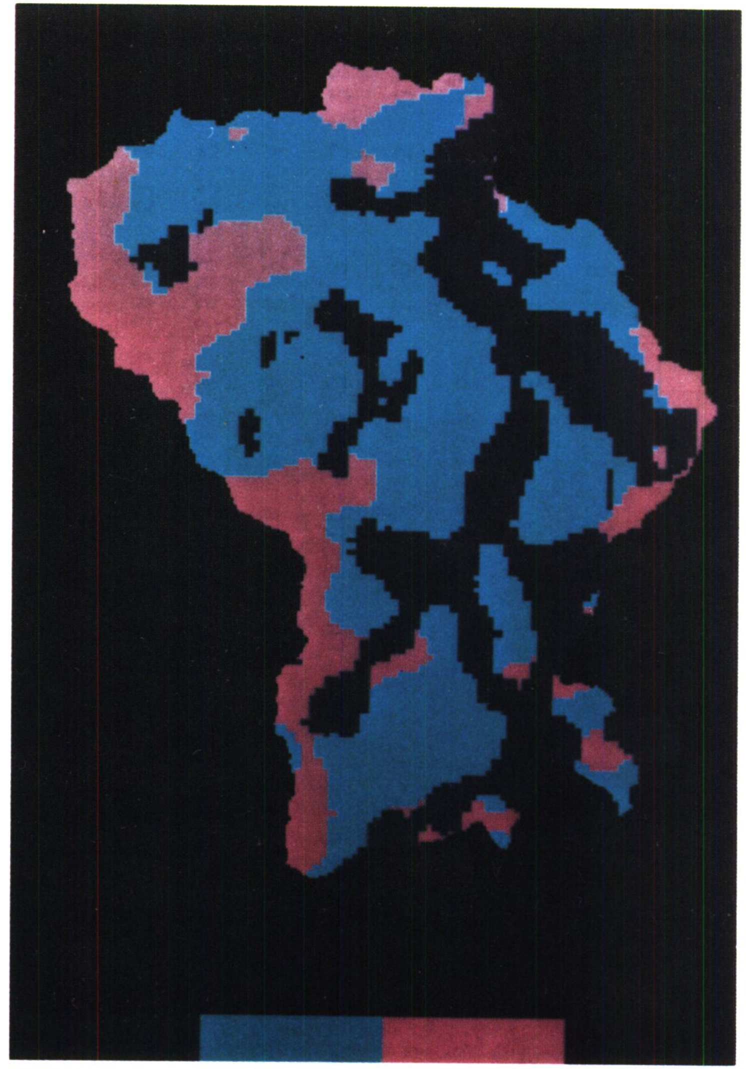


Photo 4. Snowcover Areas Extracted From NOAA-AVHRR Data

Table 5-1
Evaportranspiration from various surfaces

NO.	categories	a_s	a_r	Rn	G	λE	E
				Wm⁻²			mmd⁻¹
1	open water	0.06	0.20	153.8	30.8	84.1	2.96
2	urbanized area	0.30	0.30	110.6	33.2	52.9	0.47
3	tall vegetation (ever green)	0.15	0.08	137.6	11.0	86.5	3.05
4	tall vegetation (deciduous)	0.15	0.08	137.6	11.0	86.5	3.05
5	short vegetation (sparse)	0.18	0.10	132.2	13.2	81.3	2.86
6	short vegetation (dense)	0.15	0.05	137.6	6.9	89.4	3.15
7	bare soil(dry)	0.25	0.30	119.6	35.9	57.2	2.02
8	bare soil(wet)	0.20	0.30	128.6	38.6	61.5	2.17

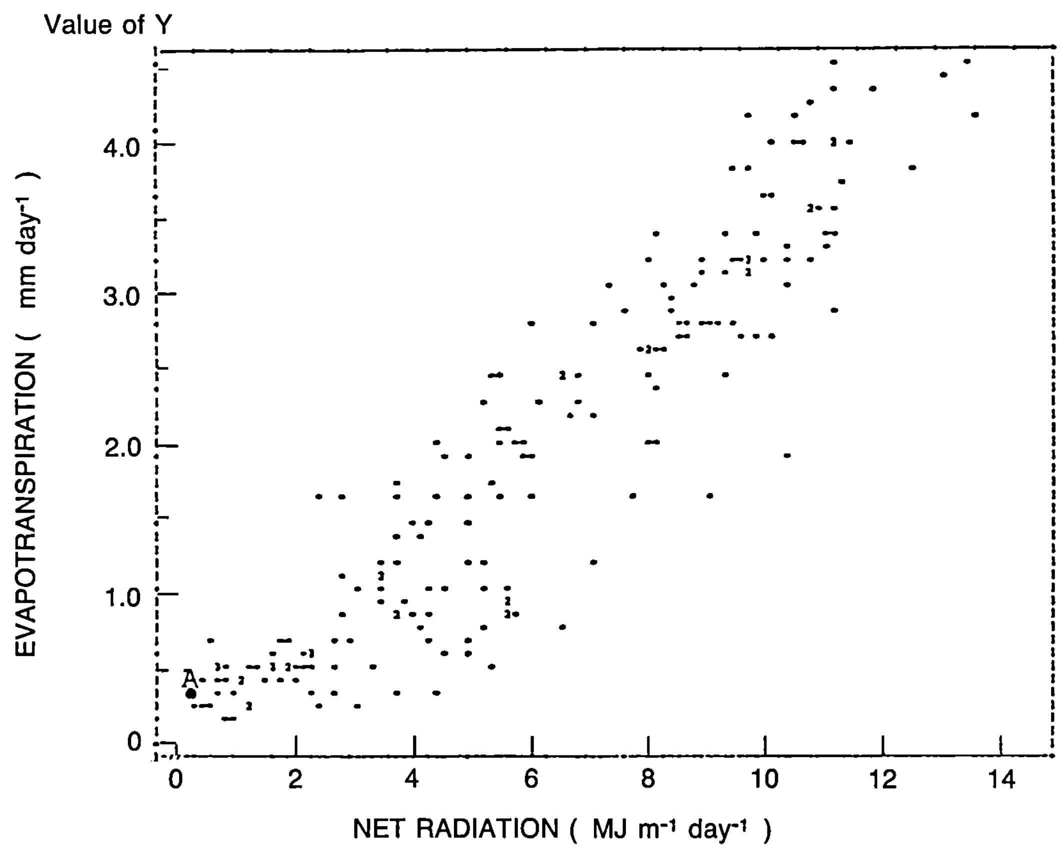


Figure 6-1. Relationship between evapotranspiration and net radiation. The value of point A is estimated evapotranspiration observed on 22nd, Jan., 1983 and the others are actual evapotranspiration obtained by lysimeter at ERC, Univ. of Tsukuba through the year of 1982 except rain day.

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