METERIALS AND METHODS

Materials and Equipments

1. The Automatic Weather Station (AWS)

AWS was installed in the studied sites. The instruments and the system for measuring the Bowen ratio and evapotranspiration consist of followings :

1) dry and wet bulb thermometer for measure relative humidity (RH)
2) anemometer for measure wind speed and direction (WS and WD)
3) infrared thermometer for measure surface temperature (IRT)
4) net radiometer for measure net radiation (R_n)
5) pyrheliometer for measure solar radiation (R_s)
6) soil heat flux meters for measure heat storaged in soil (G_s)
7) tensiometers for measure soil moisture tension (pF)
8) thermistors for measure soil temperature (T_s)
9) 1.2 m diameter evaporation pan for measure evaporation (E_{pan}) for paddy field only
10) water level meter for measure water depth (WL) for paddy field only
11) 16 channel data logger for data storage
12) mobile phone with modem for transmit data
13) PC with DENWA software modified by Aoki *et al*. (1997) for data collection
14) DC generator for power source

2. Remote sensing materials

2.1 One set of personal computer and printer

2.2 Computer program calculation

2.2.1 Spreed sheet

2.2.2 Geographic Information (GIS)

2.2.3 Image processing (RS)

3. Data requirement

3.1 Remote sensing data

NOAA-AVHRR satellite image data during 2002-2004, from internet downloads of Yasuoka Laboratory, Institute of Industrial Science, University of Tokyo, JAPAN at website : http://webpanda.iis.u-tokyo.ac.jp/WebPaNDA/ , that website can evaluated data online (online data processing) abd send the satellite information through internet network. The data that collected at this website was belong to Asia Institute of Technology (AIT), Pathum Thani, Province.

3.2 Land use map data from Land Development Department (LDD), 2004 year

3.3 Meteorological data from Thai Meteorological Department (TMD) during 2002-2004.

3.4 Digital elevation model (DEM) data from internet download at http://ngdc.noaa.gov/ngdc.html of National Oceanic and Atmospheric Administration, (NOAA) U.S.A.

Methodology

Two steps of calculation were applied in this study, (1) estimating evapotranspiration based on bowen ratio method, and (2) analysing evapotranspiration and Remote Sensing parameters reflecting evapotranspiration, i.e., NDVI, Land Surface Temperature and others using stepwise regression

1. Estimating evapotranspiration based on bowen ratio method

1.1 Site Selection

According to GAME-T project under corporative Thai and Japan there are 2 automatic weather station (AWS) installed in paddy field and teak plantation established since 1997

The following sites were selected for instrumentation and measurement :

1.1.1 Paddy field at Amphoe Muang, Changwat Sukhothai.

1.1.2 Teak plantation at Amphoe Mae Moh, Changwat Lampang.

1.2 Equipment Installation

1.2.1 Paddy field

The permanent site located at paddy field of Amphoe Muang, Changwat Sukhothai was a representative of lowland area. The instruments have been carried out since May 1997 by AWS. The detail shown in Figure 5 and the level of sensors were described in Table 1.

1.2.2 Teak plantation

Teak plantation at Amphoe Mae Moh, Changwat Lampang were selected for the representatives of forest land use. The instruments have been carried out since July 1999 by AWS. The detail and level shown in Figure 6.

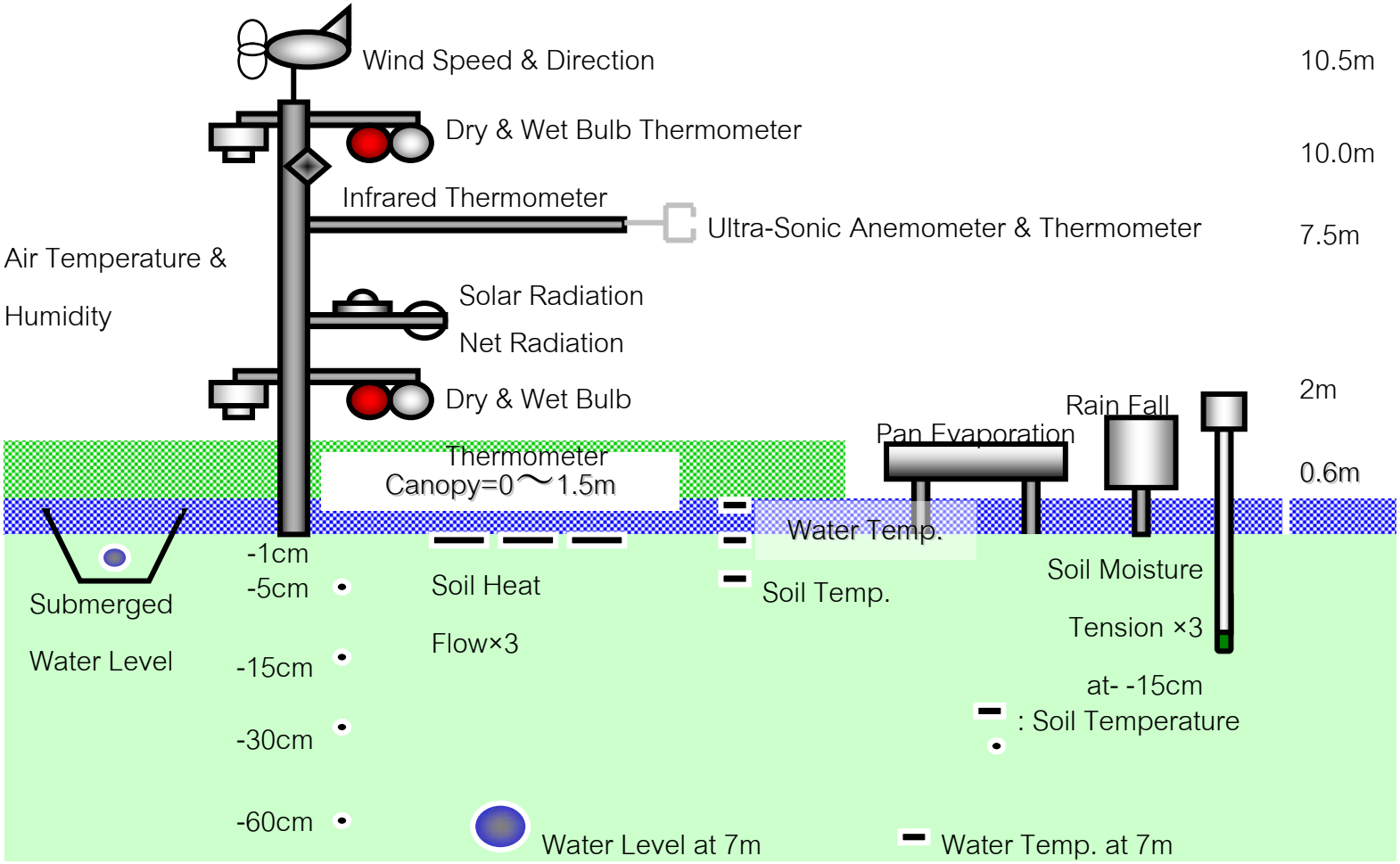

Figure 5 Schematic of instruments (Automatic Weather Station : AWS) installed at paddy field, Amphoe Muang, Changwat Sukhothai

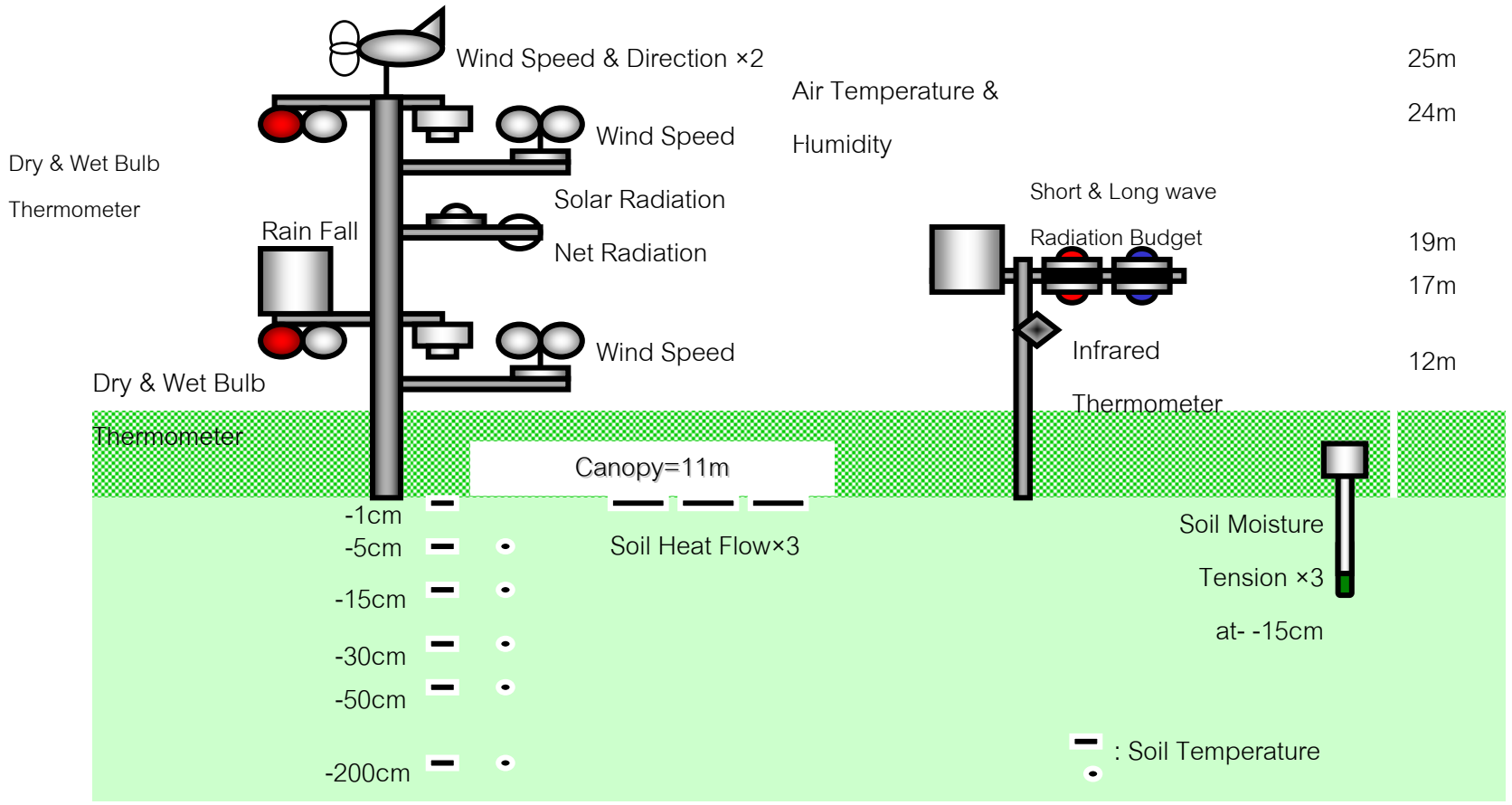

Figure 6 Schematic of instruments (Automatic Weather Station : AWS) installed at Teak plantation, Amphoe Mae-Moh, Changwat Lampang

Table 1 Site location and the level of sensors in flux measurement.

Location and instrument	Measurement sites	
	1	2
1. Location in topographic map		
1.1 Sheet number	4943 III	4945 III
1.2 Latitude (N)	17°04'16"	18°25'18"
1.3 Longtitude (E)	99°42'18"	99°43'28"
2. Elevation (m MSL)	50	380
3. The level of sensors (m above ground)		
Anemometer (WS, WD)	11	25
Upper psychometer (T_a, T_w, RH)	9.5	24
Infared thermometer (IRT)	10	24.5
Pyrheliometer and net radiometer (R_s, R_n)	7.5	21.8
Lower psychometer (T_a, T_w, RH)	2	17
4. The level of sensors (m depth in soil)		
Thermistor at 1 cm (T_s-1 cm)	1	1
Thermistor at 15 cm (T_s-15 cm)	15	15
Soil heat flux meter (G_s)	1	1
Tensiometer (pF)	15	15

Remark : 1 = paddy field at Amphoe Muang, Changwat Sukhothai

2 = teak plantation at Amphoe Mae Moh, Changwat Lampang

1.3 Data Collection

A 32 channel data recorder was developed to collect and transmit data measured by difference sensors. Their instantaneous data of every one minute is collected by data logger to obtain ten minutes average. The data logger has a function to allow storage of data for approximately 11 days.

1.4 Data Transmitting

At experiment site, measured data was transmitted from measurement site to the office at Kasetsart University by a system consisting of data logger, modem and mobile telephone. In other way, the measured data was transmitted directly form data logger to the personal computer.

1.5 Data Calculation

Data calculation consists of 4 steps, they are :

Step I – Raw data collection from data logger were transmitted into floppy diskette by PC (DENWA software program) with an average of every ten minute's data (DAILYPRO software program).

Step II – Every measured data in each time in unit of millivolt was minus by error from noise sensor or DC power. The average ten minute's data was then changed in to the average 30 minutes data.

Step III – Every average 30 minutes data was calculated to the real value and the average daily data and daytime were calculated by DAILYPRO software program. The energy balance and Bowen ratio were used in estimating evapotranspiration. The method employed in this study can be simplified by the following equations :

$$R_n = H+G_s+G_w+LE \quad (52)$$

$$\beta = H/LE = (C_p.P/0.622L)(\Delta T/\Delta e) \quad (53)$$

$$=(1.0042*1{,}013/0.622L)(\Delta T/\Delta e)$$

Here, $$\beta = \frac{1.0042*1{,}013)*(\Delta T-0.006*\Delta Z)}{0.622*(2{,}500.8-2.3668T_a)]*(\Delta e)}$$

$$E = ET = (R_n-G_s-G_w)/L(1+\beta) \quad (55)$$

$$L = 2{,}500.8-2.3668*T_a \quad (56)$$

Step IV – The calculated daily data was shown in term of table and graph of Bowen ratio, heat balance and other climatic conditions

2. Analysing evapotranspiration and Remote Sensing parameters reflecting evapotranspiration

2.1 NDVI

The most common vegetation indices are the simple ratio of near-infrared to visible radiance. By AVHRR sensor, NOAA-14 collects data in range of near-infrared though channel 1 and in range of visible region though channel 2 NDVI index in equation 15 can be written as

$$NDVI = \frac{NIR - ViS}{VIS + NiR} \quad (57)$$

The principal problem associated with data acquisition over the study area involved in selecting relative cloud and haze free images at the appropriated time. For more precise positioning, the well known method of rectification is ground control points and second order transformation in polynomial rectification. For this study, 4 ground control points are used. The resulting rectified image is checked by displaying it and then overlaying in basins boundary map. The NDVI maps obtained from overlaying.

The differences in elevation and NDVI values related to the density of forest were found to be the important and appropriate parameters, which have strong

relationship with the evapotranspiration attributes. The transformation manages by selection the reliable data from clear cloud image in pixel scale.

2.2 Surface albedo

Albedo is the ratio of reflected to incident solar radiation at a surface and is computed as the ratio of outgoing short wave radiation to incoming short wave radiation. The reflectivity of a surface is wavelength-dependent, with a few natural surfaces being uniform reflectors across the portion of the electromagnetic spectrum of interest

The broadband albedo (α) is calculated as (Valiente *et al*. 1995)

$$\alpha = 0.545\rho_{ch1} + 0.32\rho_{ch2} + 0.035 \quad (58)$$

Where ρ_{ch1} is the spectral surface reflectance in channel 1

ρ_{ch2} is the spectral surface reflectance in channel 2

The solar energy reflectance might different from refecting of surface value and the calibration was shown as follow :

$$\alpha_0 = \frac{\alpha_p - \alpha_{path\_radiance}}{\tau_{sw}^2} \quad (59)$$

Where α_0 = surface albedo

α_p = broadband albedo

$\alpha_{path\_radiance}$ = reflectance from top of atmospheric through satellite

τ_{sw}^2 = one-way transmittance

2.3 Surface temperature (T_{surf})

Surface emissivity and radiance temperature in the thermal band are required to estimate surface temperature. Surface emissivity is a factor that describes how efficiently the surface radiates energy compare to blackbody (Lillesand and Kiefer, 2000). Normalized difference vegetation index (NDVI), one of the vegetation indices was used to estimate surface emissivity (ε_0) according to equation 60

$$\varepsilon_0 = 1.0094 - 0.0047 \ln(NDVI) \quad (60)$$

Where ε_0 = surface emissivity

NDVI = Normalized different index

Then surface temperature of NOAA-AVHRR can be described by split-window technique as follow :

$$T_s = a_o (T_4)^2 + a_1 (T_4) + a_2 (T_4 - T_5) + a_3 (T_5) + a_4 (T_5)^2 + offset \quad (61)$$

Where T_s = surface temperature (^0K)

T_4 = Brightness temperature from band 4 of NOAA-AVHRR

T_5 = Brightness temperature from band 5 of NOAA-AVHRR

2.4 Estimation evapotranspiration by remote sensing data

Evapotranspiration was estimated by using remotely sense data form the paddy field and teak plantation in form of the functional relation as :

$$ET = f(NDVI, SurTemp, Suralbedo) \quad (62)$$

$$ET = a + bNDVI + cSurTemp + dSuralbedo \quad (63)$$

3. Model formulation

3.1 Modelling between ET and meteorological data

Evapotranspiration was estimated using the observed data form the paddy field and teak plantation in form of the functional relation as :

$$ET = f(Ta, RH, pF, Ws) \quad (64)$$

$$ET = a + bTa + cRH + dpF + eWs \quad (65)$$

3.2 Relationship among ET , meteorological and Remote sensing data

Evapotranspiration was estimated using the observed data and remotely sense data form the paddy field and teak plantation in form of the functional relation as :

$$ET = f(Ta, RH, pF, Rn, Ws, NDVI, SurTemp, suralbedo) \quad (66)$$

$$ET = a + bTa + cRH + dpF + eRn + fWs + gNDVI + hSurTemp + isuralbedo) \quad (67)$$

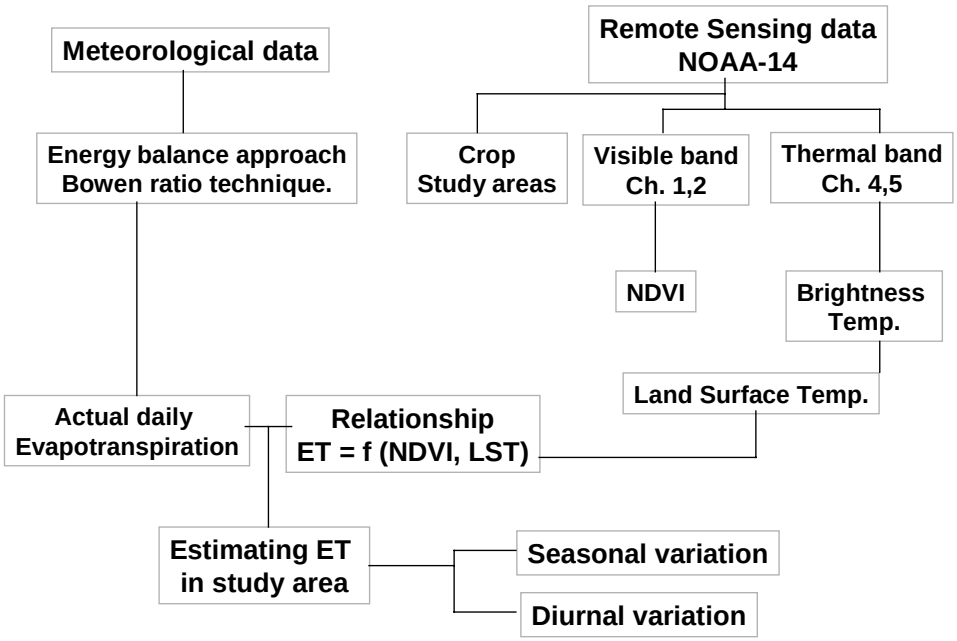

Figure 7 Data processing flowchart

Study areas

1. Study areas

1.1 Paddy Field.

Based on the topographic map scale 1:50000 of Royal Thai Survey Department sheet 4943 III, on 50 m MSL. Paddy field is located in Amphoe Muang,

Changwat Sukhothai at 17° 03' N and 99° 42' E. It is far from Bangkok about 460 km by highways. During 1997-1999, the annual average air temperature of Changwat Sukhothai was 28.3 °C. The average maximum air temperature was 30.4 °C in April and May while the average minimum air temperature was 24.9 °C in January. The maximum E_{pan} was in May, 6.7 mm day^{-1} and minimum was 3.6 mm day^{-1} in November with annual average 1,799 mm. The rainfall amount ranged between 916.4-1,078.8 mm $year^{-1}$ with annual average 981.9 mm. The maximum rainfall amount was in May, 205 mm $month^{-1}$ and it no rain in December (Si Samrong Agrometeorological Station, 1999).

The paddy field site is located in rainfed area and the crops are dependent on only rainfall. In generally, the farmers started planting in July-August and harvesting in November- December. After that, they will burn the paddy strubbles left after harvesting around the tower (Figure 7).

1.2 Teak Plantation.

The measurement site is located in Mae-Moh teak plantation of Forest Industry Organization (FIO), Changwat Lampang. It is in the topographic map scale 1:50,000 in sheet 4945 III. The Mae Moh teak plantation was established in 1968 with spacing 4x4 m, 32 years old and one time thinning. The average height of teak was about 17 m with average dbh of 21.4 cm.(Figure 8)

Figure 8 Automatic Weather Station, Sukhothai Paddy field.

Figure 9 Automatic Weather Station, Lampang Teak Plantation.