Observation and modeling of land-surface fluxes in HUBEX

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1. Overview

The clarification of land-atmosphere interaction and the quantitative evaluation of diurnal and seasonal variation of energy and water vapour fluxes are the common theme of the GEWEX/GAME. Most characteristic feature of this region is that the land surface is patches of paddy field, farmland, forest, water body, etc. and that most part of this basin is shared by cultivated land. So not only the detailed observaton of heat/water vapour fluxes at each land-use but also the acquisition of information related to artificial operation and management of river water systems is very important in this region. Instead of the complicated physical processes such as snowmelt and permafrost, we must handle the cultivated land, which leads to the difficulty in the quantitative evaluation of land surface fluxes.

In the HUBEX, two kinds of intensified land surface fluxes observation are planned.

1. Moving observation of heat/water vapour fluxes by KU-AWS
2. Long-term monitoring of heat/water vapour fluxes by GAME-PAM

The followings are the reports of the strategy and activity of above items respectively.

2. Moving observation of heat/water vapour fluxes by KU-AWS

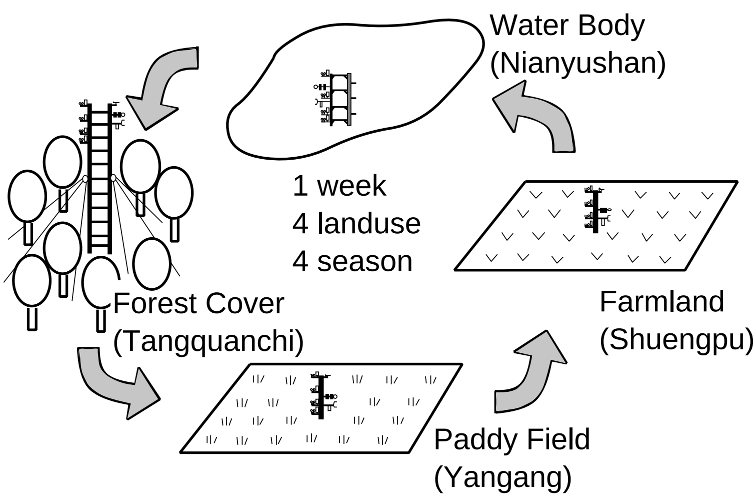


Figure 1: Moving observation in Shi-Guan Basin

We will have one station for long term flux monitoring at Shouxian. But it is only one station. And as mentioned above, the land surface condition of this region is composit of patches of different landuse. So additional observations are necessary to take this situation into account.

Intensified observation of land surface processes will be carried out in Shi-Guan Basin, the hydrological experimental basin in HUBEX (located in the south part of Huaihe River Basin), by using the flux observation system of Kyoto University(KU-AWS).

The objectives of intensified flux observation are :

1. To understand the diurnal, day-to-day, and seasonal variations of surface heat/water flux in the basin
2. To adjust the parameter set for each land-use used in land surface process model(SiBUC)
3. To collect the ground truth data for satellite remote sensing

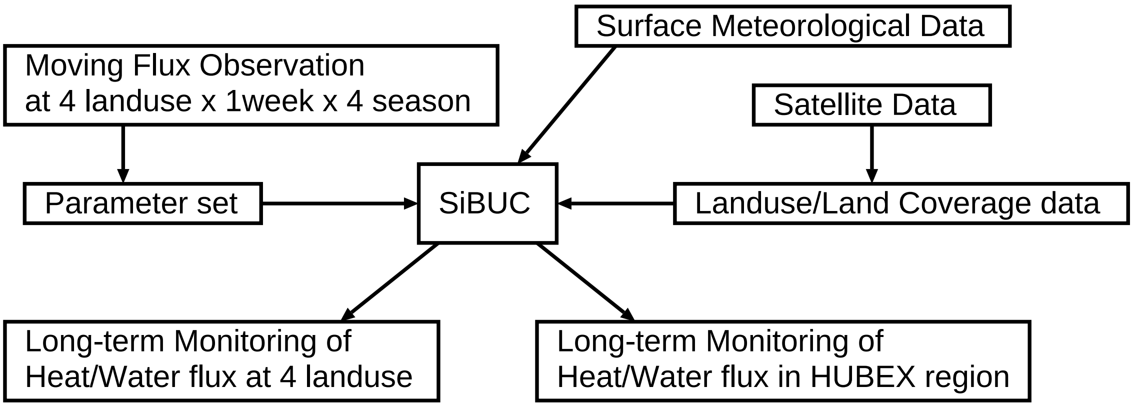


Figure 2: Role of moving flux observation

Many instruments are combined in KU-AWS system for comprehensive observation. Although the system is very sophisticated, we can prepare only one system for GAME-IOP. Then the system will be moved from place to place to meet the above objectives.

Considering the time for installment and transfer, at least one week is needed to get enough data for adjusting the model parameters at each site in each season.

Although the observation period is short(one week in each season), the observation items cover almost all components which are necessary to land surface process studies. And this observation will bring enough data for deciding and adjusting some parameters in the land surface process model(SiBUC). So it is worth saying that this moving observation is equivalent to having four flux monitoring stations in this basin.

In the HUBEX region, there are many surface meteorological stations, and among them almost 500 stations data are transfered through GTS. In addition, high resolution satellite remotely sensed data (NOAA-AVHHR, LANDSAT-TM, ADEOS-AVNIR, etc.) will be used to estimate the landuse/land coverage data.

So we can monitor the land surface flux of four landuse conditions from numerical simulation of SiBUC by using surface meteorological variables as forcing data. We can also apply the SiBUC model to the whole Huaihe River Basin and monitor the average and distribution of the diurnal/day to day/seasonal variations of land surface heat/water vapour fluxes.

These heat/water flux data will surely contribute to both research and practical aspect.

2.1 Observation site

In corporation with Huaihe River Commission(HRC) and Nianyushan Reservoir Administrative Bureau(NRAB), four observation sites of different land-use condition have been selected in the western part of Shi-Guan Basin.

The site for lake observation was selected in Nianyushan Reservoir, one of the two large reservoir in Shi-Guan Basin. The dum site is opened to northward.
The site for paddy field was selected in Yangang village. Yangang is well irrigated area, and most part of this area is rice paddy field.
The site for farmland was selected in Shengpu village. Shengpu is also well irrigated area. There are many kind of vegetables and crops in this region. Among these, the mulberry farmfield is most popular and shares large part.
The site for forest observation was selected in pine forest in Tanguanchi village. Tanguanchi is located in the mountaneous region, upstream of Nianyushan Reservoir.

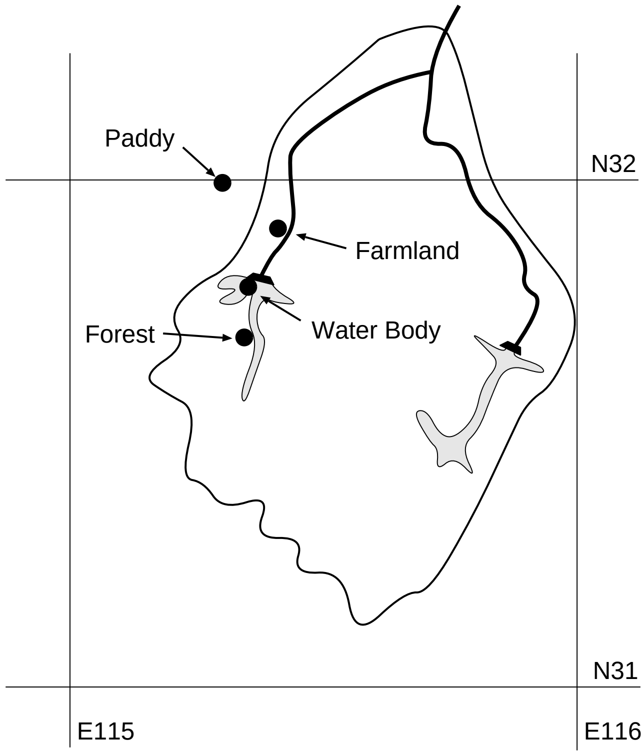


Figure 3: Four observation sites in Shi-Guan Basin

Table 1: Location of moving observation

Site	Land-use	Alt.	Lon.	Lat.
Nianyushan	Water Body	90m	E115.36	N31.79
Yangang	Paddy Field	90m	E115.31	N31.99
Shuengpu	Farmland	92m	E115.39	N31.91
Tangquanchi	Forest	120m	E115.36	N31.70

2.2 Preliminary flux observation in August 1997

Flux observation tower construction works were finished, and the preliminary flux observation was carried out in Shi-Guan Basin from 5th to 20th August 1997. The time schedule of this observation was as follows.

Table 2: Schedule of Preliminary flux observation

Day	From	To	Notes
8/5	Japan	Shanghai	airplane
	Shanghai	Bengbu	train, stay in Bengbu
8/6			stay in Bengbu
8/7	Bengbu	Shangcheng	transfer, stay in Shangcheng
8/8		Nianyushan	settting-up, stay in Shangcheng
8/9		(Water Body)	observation and checking, stay in Shangcheng
8/10		Nianyushan	removal and packing
		Yangang	settting-up, stay in Shangcheng
8/11		(Paddy Field)	observation and checking, stay in Shangcheng
8/12		Yangang	removal and packing
		Shuengpu	settting-up, stay in Shangcheng
8/13		(Farmland)	observation and checking, stay in Shangcheng
8/14		Shuengpu	removal and packing
		Tangquanchi	transfer, stay in Tangquanchi
8/15		mountain	setting-up, stay in Tangquanchi
8/16		(Forest)	observation and checking, stay in Tangquanchi
8/17		mountain	removal and packing
			(all instruments are stored in the house)
	Tangquanchi	Hefei	transfer, stay in Hefei
8/18	Hefei	Bengbu	stay in Bengbu
8/19		HRC	Report and Discussion
	Bengbu	Shanghai	midnight train
8/20	Shanghai	Japan	airplane

Although the schedule of this observation was very limited and tight one, and it was also the first trial to do this kind of observation in this Basin, we could really do almost perfectly, say, much better than expected. This successful result was brought by good cooperation with Japanese and Chinese side and also by fine weather condition.

The followings are the result of this preliminary observation at four sites. By processing the data, daily variations of heat budget, radiation budget, surface temperature, albedo, wind speed, wind direction, air temperature, relative humidity, air pressure are shown respectively.

2.2.1 Observation items and sensor heights in the Prelim. Obs.

Observation items and the way of installing the sensors are different from site to site depending on the situation. The observation items and sensor heights at four sites are summerized in the following table.

Table 3: Observation items and sensor heights

landuse	**paddy field**	**farmland**	**water body**	**forest**
site	Yangang	Shuengpu	Nianyushan	Tangquanchi
observation items				
4 components radiation	○	○	○	○
($S^{\downarrow}, S^{\uparrow}, L^{\downarrow}, L^{\uparrow}$)	156	205	229	840
wind speed	○	○	○	○
($u_1 \sim u_4$)	405,254,126,80	421,271,150,90	502,341,198,98	1050,720,475,270
air temperature	○	○	○	○
($Ta_1 \sim Ta_4$)	400,254,120,72	416,266,145,88	502,341,198,98	1040,720,486,269
air humidity	○	○	○	○
($RH_1 \sim RH_4$)	400,254,120,72	416,266,145,88	502,341,198,98	1040,720,486,269
surface temperature	(○)	(○)	(○)	(○)
(Ts by IRT)	water	canopy	water	canopy
soil temperature	○	○	×	○
($Tg_1 \sim Tg_3$)	1,10,20	1,10,20		1,10,20
soil heat flux	○	○	×	○
(G_1, G_2)	1,5	1,5		1,5
soil moisture	○	○	×	○
($W_1 \sim W_5$ by TDR)	15,30,45,60,90	15,30,45,60,90		5,20,50
water temperature	○	×	○	×
($Tw_1 \sim Tw_4$)	2		15,35,75,155	
Turbulent Flux	○	○	○	○
($\overline{u'w'}, \overline{T'w'}, \overline{q'w'}, \overline{c'w'}$)	200	210	147	825
wind direction	○	○	○	○
(WD)	338	350	450	1040
air pressure(Pa)	○	○	○	○

Infra-red thermometer (IRT) had some trouble in preliminary observation. Now we have changed this sensor to new one, and surface temperature will be monitored by IRT in IOP observaton.

Soil moisture is measured by TDR (Time-Domain Reflectometry) sensor. Average value of each 15 or 30cm soil layer can be measured.

Turbulent fluxes of momentum, sensible heat, latent heat, and CO_2 are measured by 3 dimensional sonic anemometer-thermometer(3D-SAT) and infra-red gas analyzer(IRGA) by using eddy corelation method. Sampling time is 10Hz and averaging time is 10 minutes.

The height of each sensor was actually measured value. So it will be slightly different in the IOP observation.

2.2.2 Observation in the Water Body (August 9th)

To do the observation in the reservoir, where the water level changes dynamically, the tower which is longer than water level variable range must be constructed.
As for observation tower in the lake, a concrete pole(length is 12m) was stuck in the lake bed, then a stainless steel pipe (length is 20m) was fixed to the concrete pole. The top of this steel pipe is higher than the maximum level of reservoir. The construction work was accomplished by NRAB and HRC, and the costs of this tower is 2000 US dollar in total, including material fee, transportation, and construction work (man power).
In the water body(lake surface), meteorological condition and heat budget characteristics is much different from other sites.
The observation site is located near the edge of the lake, so land and lake breeze is observed apparently (lake breeze in the daytime, land breeze in the night time).
Even in the night time, the humidy is less than 90 %, because the air temperature is relatively warm (28-29 ℃).
Albedo of water surface is very low (less than 10 %), and albedo shows daily variation depending on the solar radiation incident angle. Then the net radiation flux(Rn) is almost 800 W/m^2 near noon. The water surface temperature remains almost constant, so the upward longwave radiation flux(LRu) is almost constant (450W/m^2).

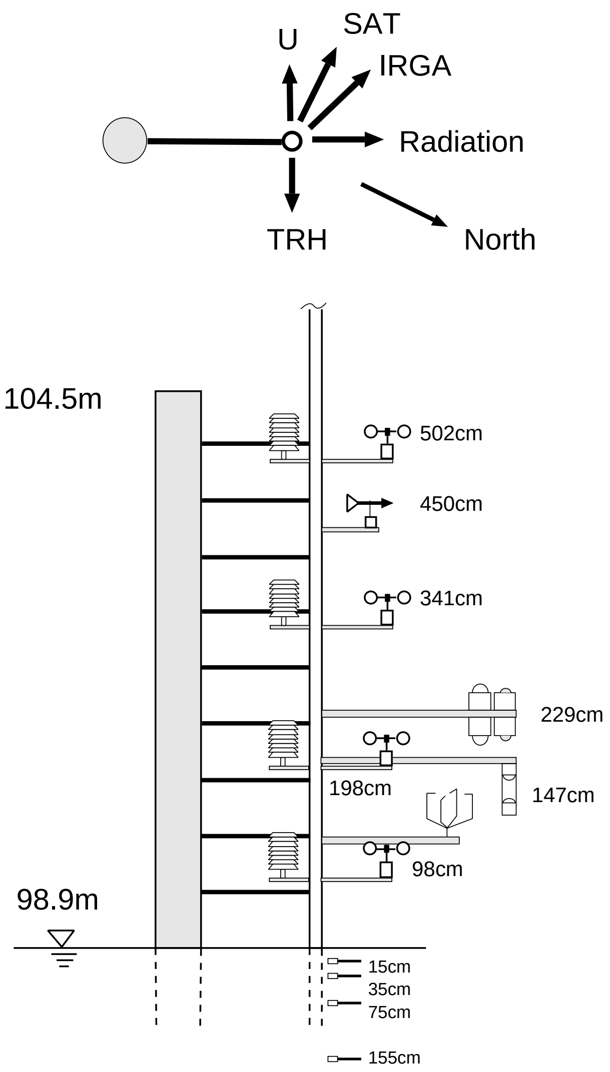


Figure 4: Sensor setting for lake observation

Most of the net radiation energy is stored in the water. So the most important thing in the water body observation is to estimate heat storage term(G).

By the way, water temperature change is too small at the deep lake, so it is very difficult to estimate heat storage term from observed temperature change. In addition, the change in water level make the observation more difficult.

Then, we calculate the sensible and latent heat flux from bulk method (bulk coefficient is 0.001), and the storage term is estimated from heat budget ($G = Rn - lE - H$).

Note that, logging interval of some items were set to 30 minutes(mistake!) in the moning.

2.2.3 Observation in the Paddy field (August 11th)

For the paddy field observation, a stainless steel pipe (length is 4.3m) was prepared for the observation tower. The height of rice canopy is almost 90cm from the soil surface, and the depth water is almost 5cm.

The wind is very calm, especially in the daytime, it is almost 1 (m/s). It is perfectly fine weather condition all day. In the night time, air temperature cools down to 24 ℃, then air humidity reaches to 100%.

In the paddy field, most of the net radiation flux(Rn) is released as latent heat flux(lE). Especialy the storage term(G), which is total of energy stored in the water (Gw) and conducted to soil ($G1$), plays important role in the diurnal variation of heat budget. Because the water temperature changes dynamically(26 ℃-33 ℃), we can estimate the (Gw) term from the water temperature data. Gw is estimated from temperature change multiplied by water depth. So water depth and water temperature are necessary to observe the actual heat budget in the paddy field.

The latent and sensible heat flux is estimated from Bowen ratio method, because we can estimate the heat storage term from the observation.

Figure 5: Soil Moisture Content (%) by TDR

		8/11 11:50	8/12 9:30
Ch1	0-15	68.0	63.7
Ch2	15-30	42.5	42.8
Ch3	30-45	43.5	43.3
Ch4	45-60	42.6	42.0
Ch5	60-90	48.3	45.9

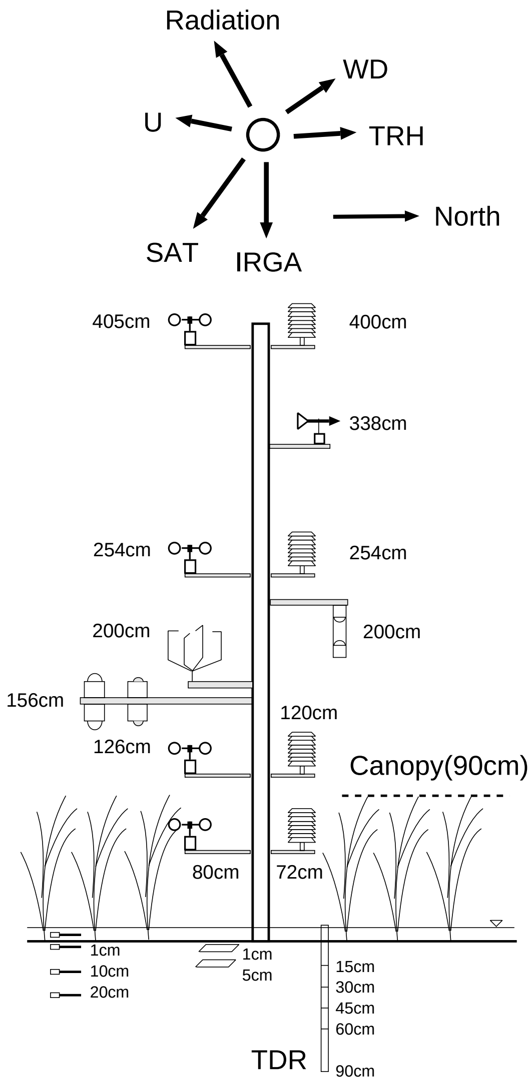


Figure 6: Sensor setting for paddy field observation

In the morning and near noon, significant part of Rn is stored in water and soil. In the evening, the energy released from water is used as vaporization of water (latent heat). This reads to the excess of latent heat to net radiation (minus value of storage term).

Albedo shows the daily variation like lake surface(higher in the morning and evening). This is deeply dependent upon the geometrical feature of rice canopy(almost flat), in another words, horizontal distribution of canopy leaves makes the albedo sensitive to the incident solar beam angle (see also the mulberry farmland data).

2.2.4 Observation in the Farmland (August 13th)

For the farmland observation, a stainless steel pipe (length is 4.3m) was prepared for the observation tower. The height of mulberry canopy is almost 150cm in average from the soil surface. And canopy coverage fraction is about 70%.
The wind is active (about 4 m/s) in the daytime, and calm (less than 1 m/s) in the night time.
It is partly cloudy in the morning then perfectly fine in the afternoon.
In the night time, air temperature cools down to 24 ℃, then air humidity reaches to 100%.
In the mulberry farmland, albedo is almost constant (25%). This feature is different from that for paddy field. Mulberry canopy leaves distribute hemispherically so that even lower layer leaves(located at the bottom of canopy) can absorb PAR flux effectively. in another words, hemispherical distribution of canopy leaves makes the albedo insensitive to the incident solar beam angle(see also the paddy field data).

Soil Moisture Content (%) by TDR

		8/12 15:50	8/13 9:20	8/13 10:15	8/14 8:35
Ch1	0-15	12.5	12.5	12.0	12.1
Ch2	15-30	13.9	14.3	14.1	13.9
Ch3	30-45	20.8	21.0	21.0	20.3
Ch4	45-60	18.2	17.2	16.7	18.0
Ch5	60-90	26.2	27.1	18.0	26.7

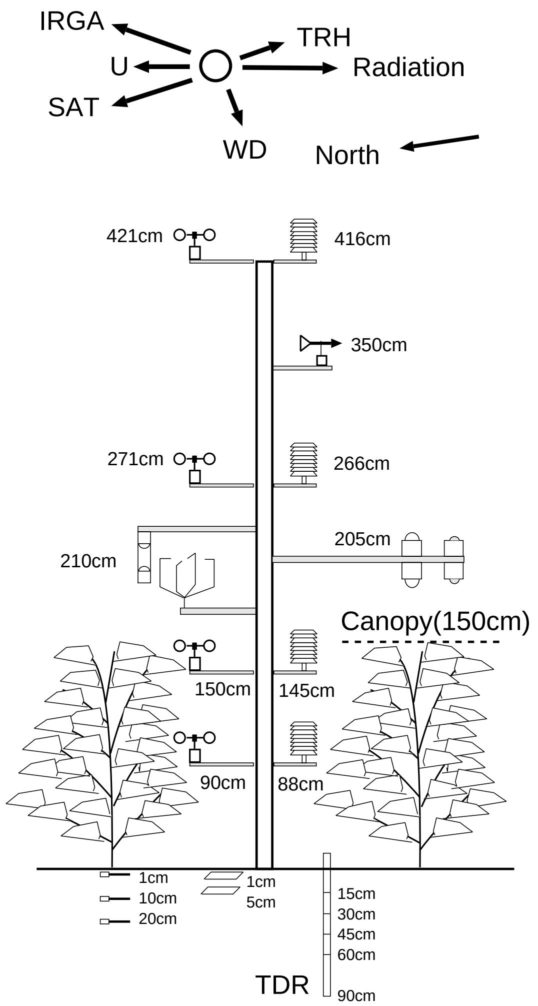


Figure 7: Sensor setting for farmland observation

In the farmland, most of the net radiation flux(Rn) is released as latent heat flux(lE) and sensible heat flux(H). The ratio of these two terms (Bowen ratio) is largely dependent upon the amount of soil moisture and vegetation(vegetation coverage). In addition to soil moisture, leaf temperature and other environmental variable can regulate the activity of leaf stomata.

In this case, soil moisture in the root zone is relatively high (14-20%), and mulberry canopy is relatively dense. So latent heat flux is larger than sensible heat flux.

Note that this result owes to the irrigation facilities (1997 summer was very dry). So when we drive the model for a long period, the data related to irrigation is neccessary to calculate the soil moisture realistically (see the later section).

2.2.5 Observation in the Forest (August 16th)

The observation should be above and inside the forest canopy, which means that the observation tower which can connect the sensors above the canopy is needed in the forest observation.
For the forest observation, the tower of 12m height was constructed by connecting three steel pipes(triangular tower). The top of this tower is about 4 m above the forest canopy. This tower is very strong one and two people can work on the top of the tower. The construction work was accomplished by Nianyushan Reservoir Administrative Bureau(NRAB) and Huaihe River Commission(HRC). The costs of this tower is 2500 US dollar in total, including material fee, transportation, and construction work (man power).
The observation tower was constructed in the pine forest. The top and bottom of pine canopy is about 710cm and 3m in average from the soil surface. And canopy coverage fraction is about 80%.
The wind is active (about 4-5 m/s) in the daytime, and calm (about 1 m/s) in the night time. It is almost cloudy and sometimes shine all day. In the daytime, air humidity is relatively high (more than 60%). In the night time, air temperature cools down to 23 ℃, then air humidity reaches to 100%.
Although solar radiation shows much variation, albedo remains almost constant (15%). In the late afternoon, albedo becomes slightly large. We could get only one day data, so it is difficult to say the feature of pine forest albedo is likely as mulberry farmland or paddy field.

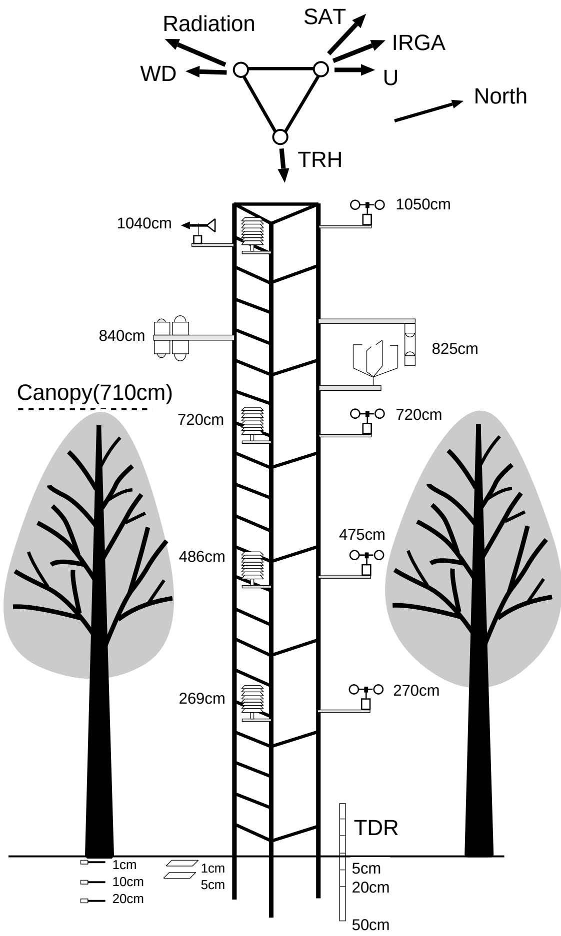


Figure 8: Sensor setting for forest observation

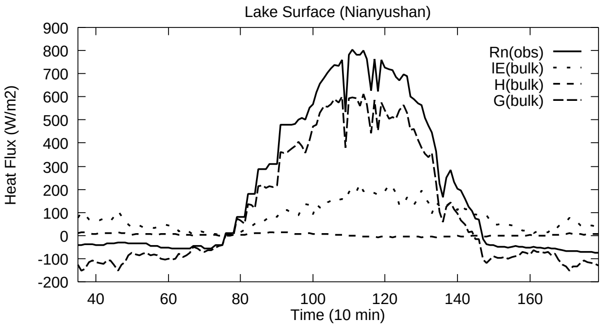
Soil Moisture Content (%) by TDR

		8/15 17:45	8/16 8:35	8/16 17:26	8/17 7:50
Ch4	5-20	9.7	10.1	8.6	11.3
Ch5	20-50	27.1	26.9	26.8	26.6

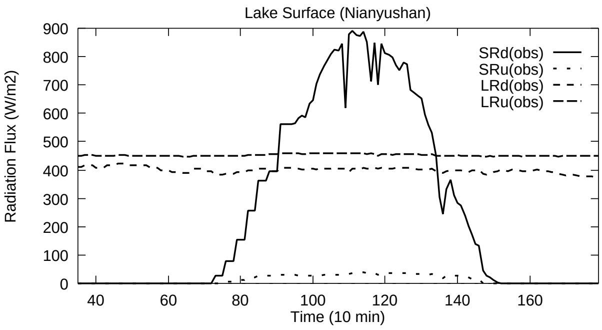
In the forest, most of the net radiation flux(Rn) is released as latent heat flux(lE) and sensible heat flux(H). The ratio of these two terms (Bowen ratio) is largely dependent upon the amount of soil moisture and vegetation(vegetation coverage). In addition to soil moisture, leaf temperature and other environmental variable can regulate the activity of leaf stomata.

Soil depth was very shallow around the site, and we could not drive in the TDR sensor perfectly. Then the soil moisture data is only for Ch4(5-20cm) and Ch5(20-50cm). In this case, soil moisture in the root zone is not enough for pine trees, then latent heat flux is almost same as sensible heat flux.

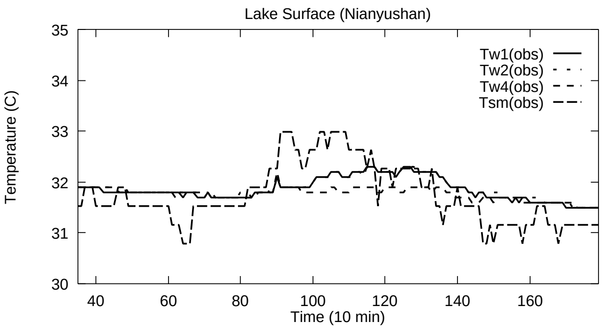
Result of Lake Observation



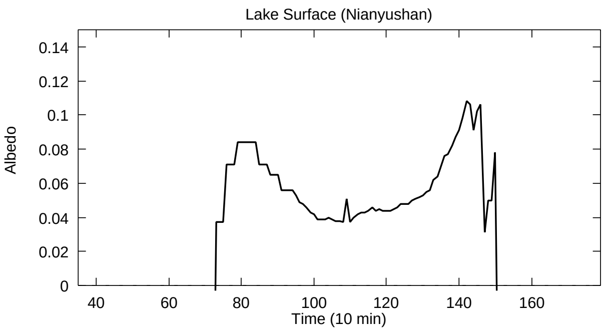
heat budget



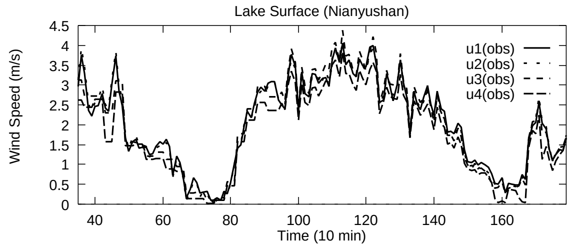
radiation budget



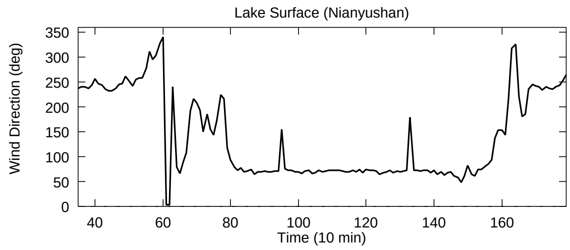
water temperature



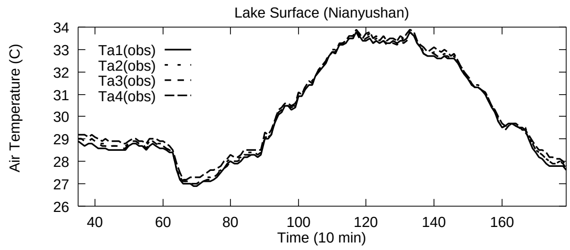
albedo



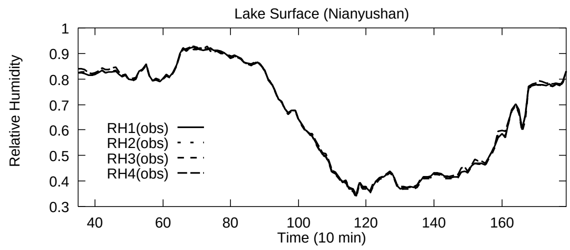
wind speed



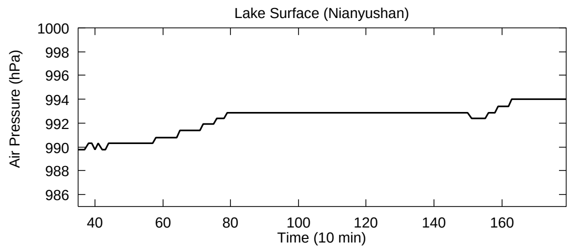
wind direction



air temperature

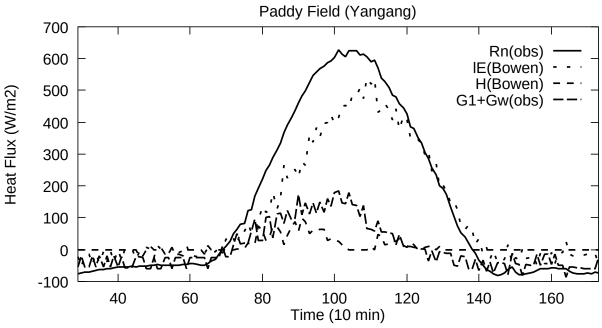


relative humidity

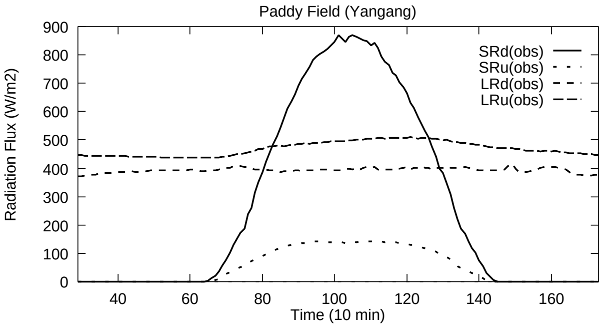


air pressure

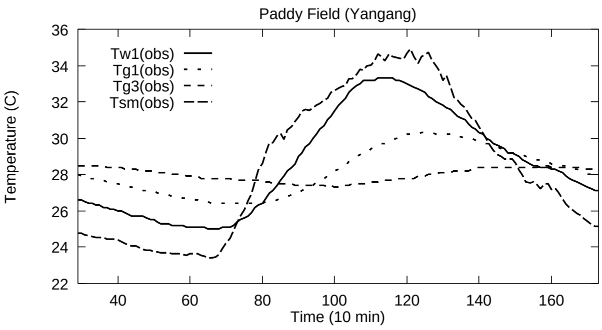
Result of Paddy Field Observation



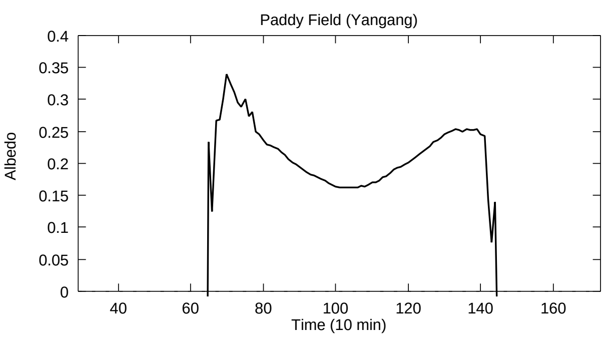
heat budget



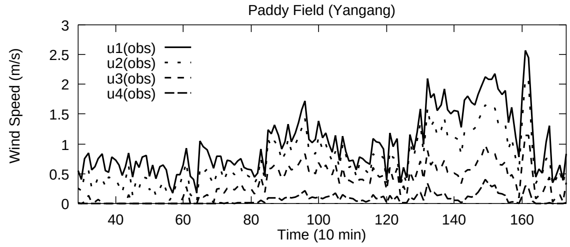
radiation budget



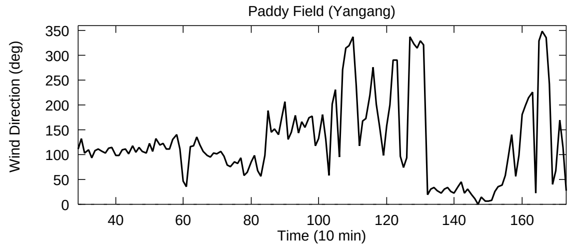
water temperature



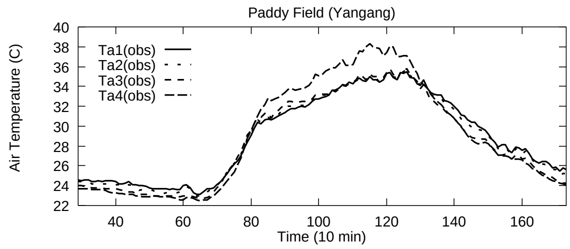
albedo



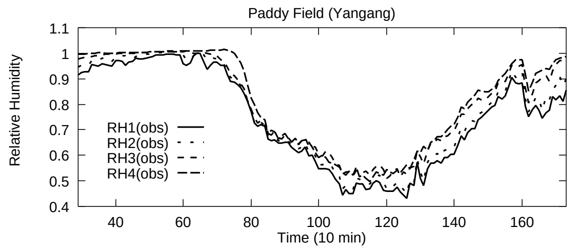
wind speed



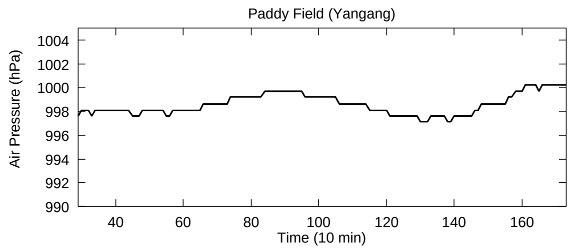
wind direction



air temperature

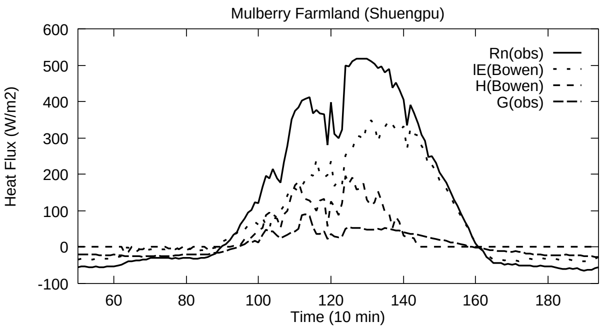


relative humidity

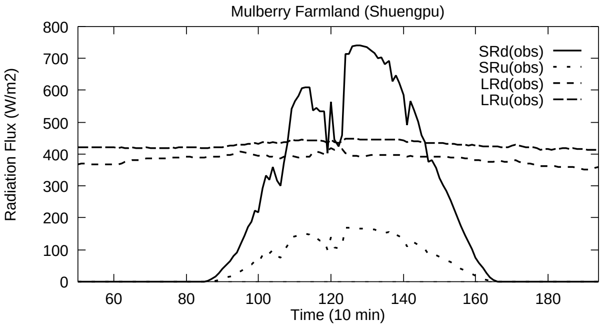


air pressure

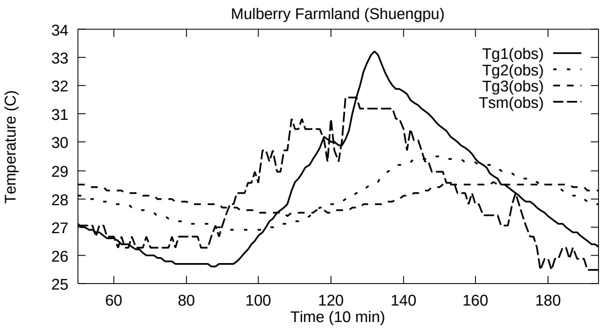
Result of Mulberry Farmland Observation



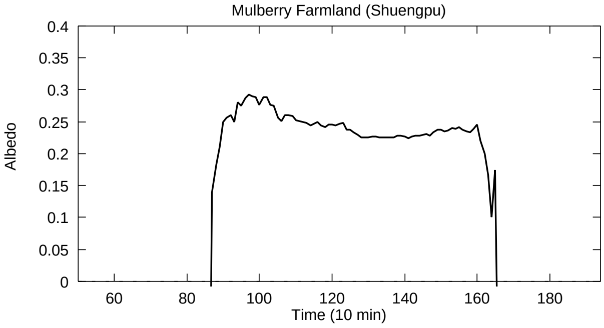
heat budget



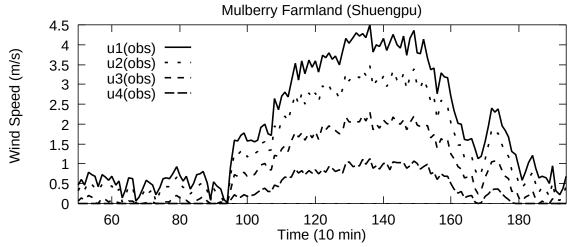
radiation budget



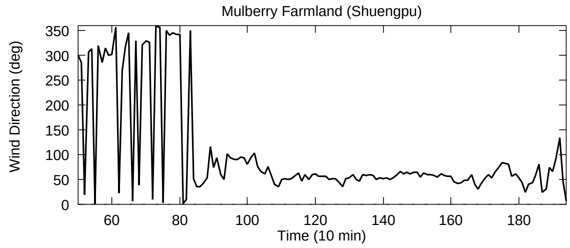
water temperature



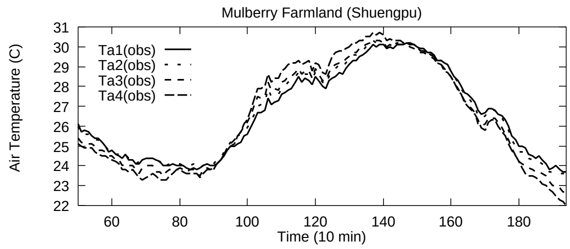
albedo



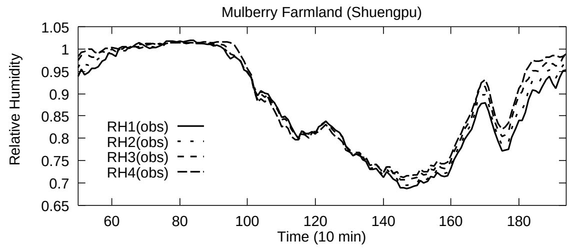
wind speed



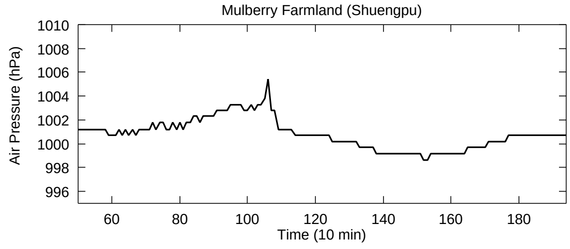
wind direction



air temperature

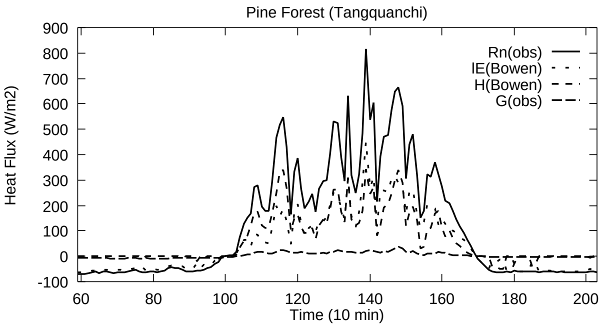


relative humidity

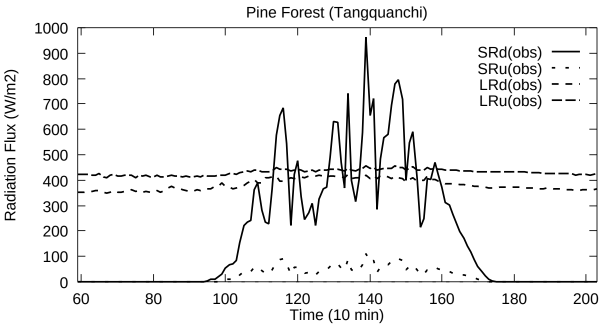


air pressure

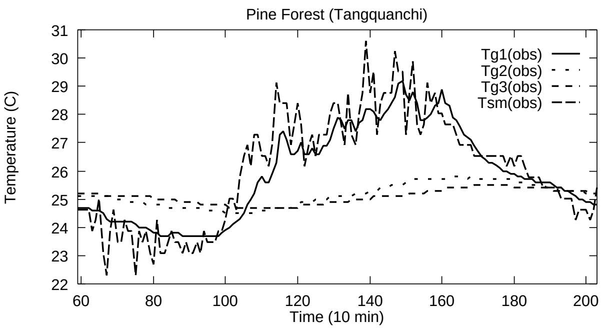
Result of Pine Forest Observation



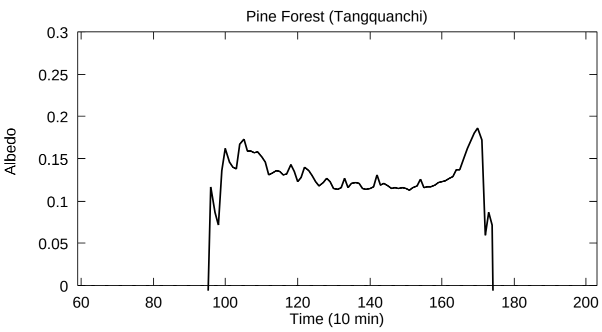
heat budget



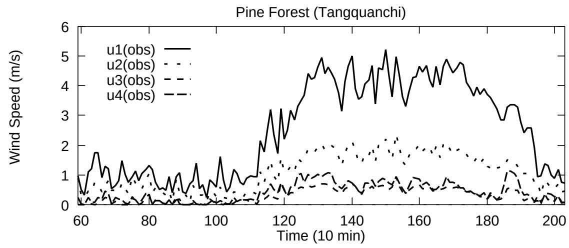
radiation budget



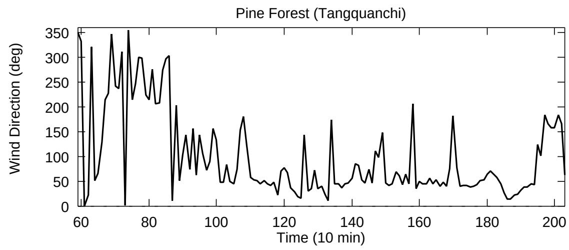
water temperature



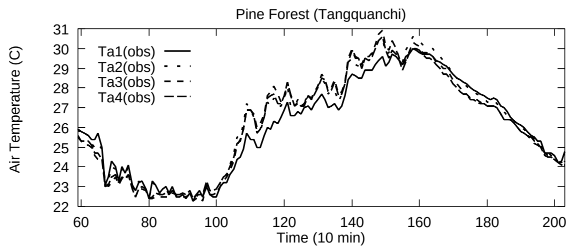
albedo



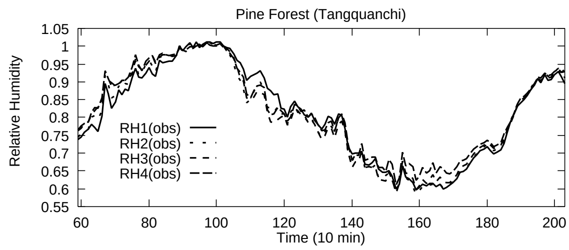
wind speed



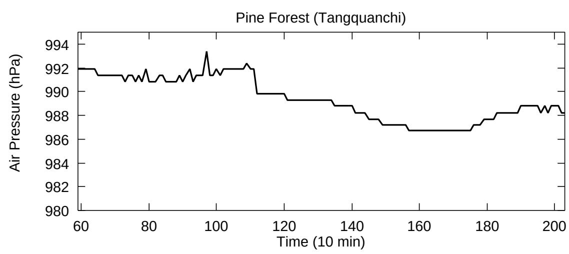
wind direction



air temperature



relative humidity



air pressure

2.3 Flux observation plan in IOP

Now the preparation of observation hardware and data processing software have finished, and we are ready for IOP observation.

Table 4: Schedule of the moving observation in IOP in one season

Day	From	To	Notes
1	Japan	Shanghai	airplane
	Shanghai	Bengbu	train, stay in Bengbu
2	Bengbu	Shangcheng	transfer, stay in Shangcheng
3		Yangang	settting-up, stay in Shangcheng
4-8		(Paddy Field)	observation and checking, stay in Shangcheng
9		Yangang	removal and packing
		Shuengpu	settting-up, stay in Shangcheng
10-14		(Farmland)	observation and checking, stay in Shangcheng
15		Shuengpu	removal and packing
		Nianyushan	settting-up, stay in Shangcheng
16-20		(Water Body)	observation and checking, stay in Shangcheng
21		Nianyushan	removal and packing
		Tangquanchi	transfer, stay in Tangquanchi
22		mountain	setting-up, stay in Tangquanchi
23-27		(Forest)	observation and checking, stay in Tangquanchi
28		mountain	removal and packing
			(all instruments are stored in the house)
	Tangquanchi	Ryuan	stay in Ryuan
29	Ryuan	Bengbu	Report and Discussion
	Bengbu	Shanghai	midnight train
30	Shanghai	Japan	airplane

According to the cost of preliminary observation, and through discussion with HRC and NRAB, we can estimate the cost for IOP flux observation in the next year.

If the observation period for each site is five days, total period will be 30days. We are planning to do this moving observation in four season.

Table 5: Observation period for IOP

Season	Date
Spring	1998 May
Summer	1998 August
Autumn	1998 October ~ November
Winter	1999 January ~ February

Depending on the amount of financial support, we are forced to give up doing all of the planned schedule - cut-off the period or cut-off the number of site.

If chinese side can operate and maintain the system, KU-AWS will be installed in the north part of Huaihe River Basin during the 'off-season' of the moving observation. In this case, the system should be fixed in the most representative field in that area, and the Eddy correration flux observation system will be removed from the system.

3. Long-term Flux Observation by GAME-PAM

3.1 Development of Flux-PAM station

The Atmospheric Technology Division (ATD) at NCAR has completed development of the third generation of its Portable Automated Mesonet(PAM) field observing facility. PAM is a network of portable surface meteorological stations designed to support observational field research projects.

Flux-PAM has been designed not only to meet the need for a traditional mesonet that provides measurements of standard meteorological variables such as wind, temperature, humidity, pressure, solar radiation, and precipitation but also to measure fluxes of momentum, sensible heat, water vapor, net radiation, and soil heat flux. User-provided sensors also can be interfaced to a Flux-PAM station.

Flux-PAM has been designed for **maximum sitting flexibility** and therefore relies principally on solar-charged-battery power and real-time data transmission through the GOES satellite. However Flux-PAM data system has been designed with broad capabilities so that stations can also be enhanced for such options as on-site data recording or direct, line-of-site data transmission to a central field base.

3.2 Collaboration with GAME

GEWEX has been initiated as a major component of the WCRP with the goal of understanding the energy fluxes and hydrological cycle and their variability in the global climate system. Since the surface energy budget is a fundamental forcing of the climate system, GAME plans include the deployment of an Asian Automated Weather Station(AWS) Network (AAN) for **long-term monitoring of directly-measured energy fluxes**.

Flux-PAM is used as surface meteorological station of AAN program. Several enhancements are being made to the NCAR Flux-PAM design to meet the needs of GAME. These include development of a serial interface for the TDR system to enable accurate measurement of soil moisture at multiple locations, development of the capability to **transmit data through the Japanese GMS satellite**, and expansion of the capacity for local data storage on the station through the use of removable PCMCIA flash memory cards.

Other sensors to be added to the GAME-PAM include an infrared thermometer (IRT) for the measurement of surface temperature, a 4-component radiation system, and a second hygrothermometer(TRH) for the measurement of vertical temperature and humidity gradients.

3.3 PAM maintenance

The followings are **one month interval** maintenance items

- replacement of PCMCIA card and sending to Japan.
- check radiation sensors(including replacement of Q7 dome, if needed)
- check soil probes
- TRH comparison with carry on standard
- pressure comparison with carry on standard
- propeller vane visual check
- Gill sonic spiking errors → replacement of transducer
- hardware check (stay wire), cables, power stand, batteries
- replacement of silicagel(TRH, Q7, electric boxes)

The followings are **one year interval** maintenance items

- calibrate TRH probes (maybe more often)
- calibrate barometer (maybe 2 or 3 years interval)
- propeller bearings replacement
- check battery voltage. 11V is bad sign → replace batteries
- properor vane visual check
- Gill sonic spiking errors, replacement of transducer
- hardware check (stay wire), cables, power stand, batteries
- replacement of silicagel(TRH, Q7, electric boxes)

3.4 GAME-PAM designed for HUBEX

GAME-PAM for HUBEX area will be installed at Anhui Province Shouxian Meteorological Bureau(E116.77, N32.58). The maintenance work for the Shouxian station will be carried out by the staff of Anhui Meteorological Bureau. Contact persons are Mr. Wang Xiangwen and Mrs. Xu Guifang.

HUBEX-GAME-PAM is specially designed for installing in the flood plain. The past record indicates that the site has been the target of flooded water, and typical depth of flood is around 2m in 1991.

To be prepared against this possible flood, the length of the legs of tripod of tower mast and radiation stand will be elevated by 1 to 1.5m.
The capacity of PCMCIA card will be expanded to 80MB so that up to 3 months of data can be stored.
In this area, there is almost no snow cover. So snow depth sensor is removed and ETI rain gauge(weighing type) will be replaced with a regular tipping bucket type.
The location of the PAM station will be very near from the radiation station where precise radiation component measurements will be carried out. Thus only the upward components are needed for this station.
In addition, the water depth and water temperature in the paddy field are being planned.

Specification of HUBEX-GAME-PAM

component	note
Tower Mast Tripod	1.5m extension
3-legged Stand	1m Taller Stand
Logger	Campbell CR10X (1)
	AM416 Multiplexer (1)
Charge Controller	3
PCMCIA Storage Capacity	40MB (2)
GMS Communication	1
Prop/Vane Anemometer	1
Hygrothermometer(TRH)	2
Barometer	1
Precip. Gauge	Tipping Bucket
Eddy Flux Sonic	Gill (1)
BPH(Band-Pass Humid.)	1
Soil Temp.	REBs (4)
Soil Heat Flux	REBs HFT (2)
Soil Moisture	CS615 (4)
Surface IRT	Everest 4004.GL (1)
Net Radiometer	REBs Q7 (1)
Pyranometer	Kipp & Zonnen (1)
Pyrgeometer	Eppley (1)
Water Depth/Temp.	Potential

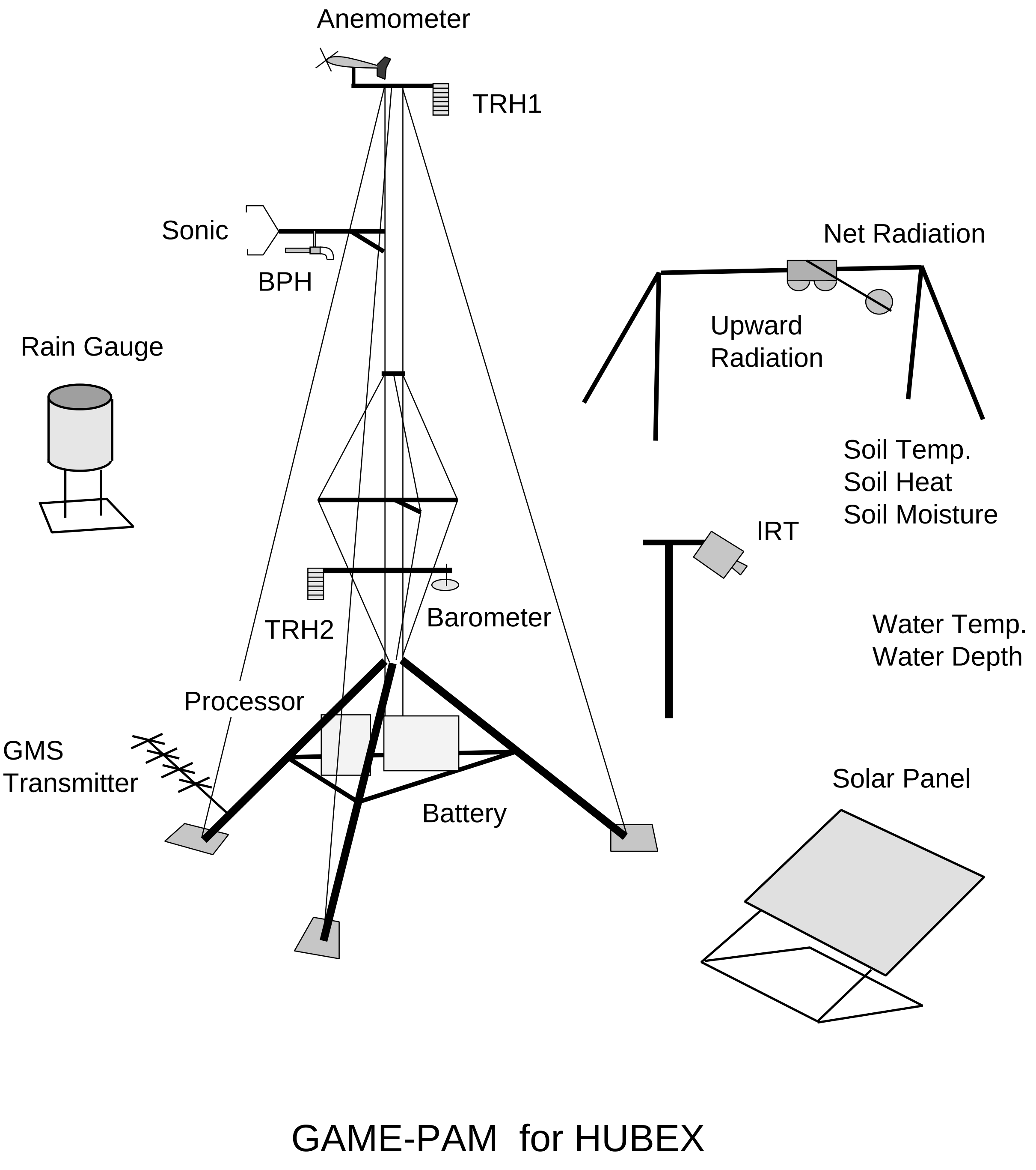


Figure 9: GAME-PAM hardware and sensors for HUBEX

4. Brief description of SiBUC model

The heat budget characteristics for water surface and urban area are quite different from that for both vegetation cover and bare soil surface. We expand the SiB of Sellers et al.(1986) to the form including urban area and water surface, because their effects are large on a basin-scale. We call this model 'SiBUC'. This model can describe basin-scale land surface processes more realisticaly than existing models.

4.1 Surface Elements and Fractional Area

In the SiBUC model, the surface of each grid area is divided into three landuse categories and six components:

1. Green Area (vegetation canopy(c), ground(g))
2. Urban Area (building roof(br), building wall(bw), urban ground(ug))
3. Water Body (wb)

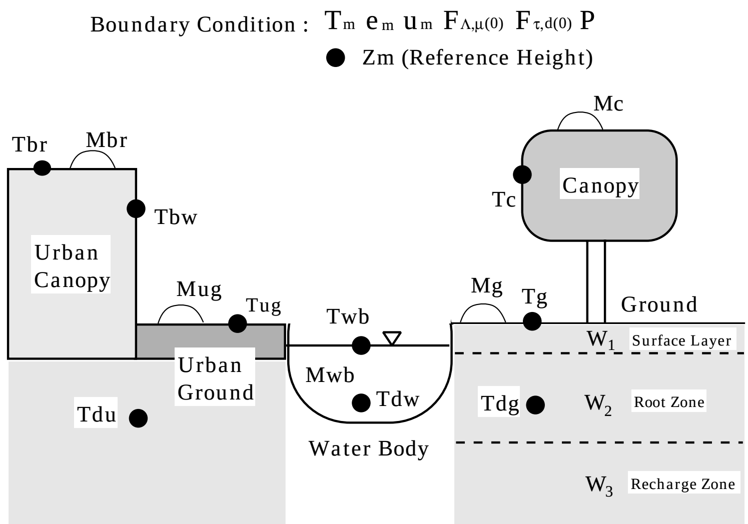


Figure 10: Atmosphreric boundary conditions and prognostic variables in SiBUC

In order to estimate the total energy and water fluxes of complex landuse grid area accurately, we should treat at least these three landuses since the micrometeorological characteristics of these landuses are much different each other. The fractional areas of these landuses (V_{ga}, V_{ua}, V_{wb}) and canopy fraction within each landuse (V_c, V_{uc}) are assigned to each grid.

Although the surface of real basin is a mixture of much more constituents, all surface elements must be classified into either of them. All the surface elements that are included in the same category are lumped and treated as 'unit element'. Of course the number of landuse categories depend on the objective (needed accuracy) of the model and available data.

The models for the green area are much the same as in SiB. In the urban area, each roughness element is expressed by a square prism. All prisms are assumed to have the same width and to be evenly spaced, while they have their own roof heights. This description of urban canopy is used in the models for radiative transfer and turbulent transfer in the urban area.

4.2 Prognostic variables and their governing equations

SiBUC has additional prognostic variables for urban area and water body (see 10).

(1) 6 surface temperature : $T_c, T_g, T_{br}, T_{bw}, T_{ug}, T_{wb}$

(2) 3 deep layer temperature : T_{dg}, T_{du}, T_{dw}

(3) 4 interception water store on surface : M_c, M_g, M_{br}, M_{ug}

(4) 3 soil moisture stores : W_1, W_2, W_3

Notice that the deep layer temperature is defined as daily mean temperature of each landuse that varies seasonally.

The governing equations for the temperature and soil moisture in green area are the same as in SiB. Soil moisture stores under urban area are assumed to be constant. This means that no water can infiltrate into or evaporate from the soil layer because of the artifitial impermeable cover. At this moment, SiBUC treats the vertical movement of soil moisture, and the exchange of soil moisture between green area and urban area is omitted. The horizontal movement of water is allowed only through river channel, and it is calcurated by coupling the runoff routing model. The weakness in soil model must be improved in future.

4.2.1 temperature

In the urban area, the artificial heat Q_M is added to the temperature governing equations. The effect of this term is apparent in night time and winter since Q_M become large comparative to the net radiation. Now Q_M is assume to be city type dependent constant. Further study by urban climatologists will give the daily and seasonal variation of Q_M.

Most of the shortwave radiation absorbed by water body penetrate inside, and only little part of it can be absorbed by the upper skin surface layer. While the longwave radiation can be exchanged at the upper skin surface layer.

So the governing equations for temperatures in urban area and water body are slightly different from those in green area and expressed as follows.

Urban Area :

$$C_{br}\frac{\partial T_{br}}{\partial t} = Rn_{br} - H_{br} - \lambda E_{br} - \omega C_{br}(T_{br} - T_{bi}) + Q_M V_{uc} \quad (1)$$

$$C_{bw}\frac{\partial T_{bw}}{\partial t} = Rn_{bw} - H_{bw} - \lambda E_{bw} - \omega C_{bw}(T_{bw} - T_{bi}) + Q_M V_{uc} \quad (2)$$

$$C_{ug}\frac{\partial T_{ug}}{\partial t} = Rn_{ug} - H_{ug} - \lambda E_{ug} - \omega C_{ug}(T_{ug} - T_{du}) + Q_M(1 - V_{uc}) \quad (3)$$

$$C_{du}\frac{\partial T_{du}}{\partial t} = Rn_{ug} - H_{ug} - \lambda E_{ug} - \omega C_{bi}(T_d - T_{bi})/365 + Q_M(1 - V_{uc}) \quad (4)$$

$$(5)$$

Water Body :

$$C_{wb}\frac{\partial T_{wb}}{\partial t} = F_{wbtd} - H_{wb} - \lambda E_{wb} - \omega C_{wb}(T_{wb} - T_{dw}) \quad (6)$$

$$C_{dw}\frac{\partial T_{dw}}{\partial t} = Rn_{wb} - H_{wb} - \lambda E_{wb} \quad (7)$$

where

T_i = temperature (K), C_i = effective heat capacity (J m^{-2} K^{-1}), Rn_i = absorbed net radiation (W m^{-2}), H_i = sensible heat flux (W m^{-2}), E_i = evaporation rate (kg m^{-2} s^{-1}), λ = latent heat of vaporization (J kg^{-1}), Q_M = artificial heat source (W m^{-2}), F_{wbtd} = net longwave radiation absorbed by water body (W m^{-2}), ω = angular velocity for daily variation = 2π /86400 (s^{-1})

4.2.2 interception water stores

The governing equations for the four interception water stores are expressed in the same formula.

$$\frac{\partial M_i}{\partial t} = P_i - D_i - \frac{E_i}{\rho_w} \qquad \text{(i = ci, gi, uc, ug)} \tag{8}$$

where
M_i = water or snow-ice stored on surface, P_i = precipitation interception rate (m s^{-1}), D_i = water drainage rate (m s^{-1}), E_i = evaporation rate from interception stores (kg m^{-2}s^{-1}), ρ_w = density of water (kg m^{-3})

4.3 Atmospheric forcing variables

The atmospheric boundary conditions necessary to force SiBUC are same as those of SiB and listed in Table 8.

(1) Air temperature T_m, vapor pressure e_m, and wind speed u_m at a reference level, z_m, within the atmospheric boundary layer.

(2) Five components of the incident radiation $F_{\Lambda,\mu(0)}$ visible (direct and diffuse), near-infrared (direct and diffuse), and thermal (diffuse only).

(3) Precipitation rate P .

Table 6: Forcing variables of SiBUC

Symbol	Definition	Unit
T_m	atmospheric boundary-layer temperature	K
e_m	atmospheric boundary-layer vapor pressure	Pa
u_m	atmospheric boundary-layer wind speed	m s^{-1}
$F_{\Lambda,\mu(0)}$	incident solar radiation Λ= V(visible), N(near infrared), μ= b(beam), d(diffuse)	W m^{-2}
$F_{\tau,d(0)}$	incident thermal infrared radiation (diffuse only)	W m^{-2}
P	precipitation rate	mm

4.4 Resistances and Fluxes

The fluxes of sensible and latent heat from each surface are described by the electrical analogue form in which the fluxes are proportional to potential differences (in temperature or vapor pressure) and inversely proportional to resistances.

$$flux = \frac{potentialdifference}{resistance}$$

The transfer pathways for sensible heat and latent heat fluxes are shown schematically in Fig. 11 and 12.

The aerodynamic resistances are defined for each land-use.

- Grid Average
  r_a : between canopy air space and reference height

- Green Area
  r_b : between canopy leaves and canopy air space
  r_d : between ground (grass and soil) and canopy air space
- Urban Area
  r_{br} : between building roofs and canopy air space
  r_{bw} : between building walls and canopy air space
  r_{du} : between urban cover and canopy air space
- Water Body
  r_{dw} : between water surface and canopy air space

The surface resistances are the additional resistances imposed on the transfer of water vapor from leaves' stomata and soil pores. No surface resistances are imposed on the evaporation from the urban area and the water surface. So as for the surface resistances, there is no change from SiB.

r_c : bulk stomatal resistance of vegetation canopy
r_{soil} : bare soil surface resistance

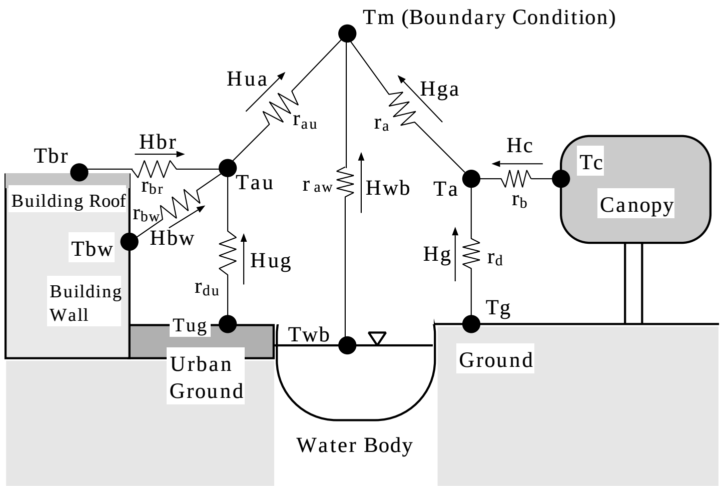


Figure 11: Sensible heat flux and resistances

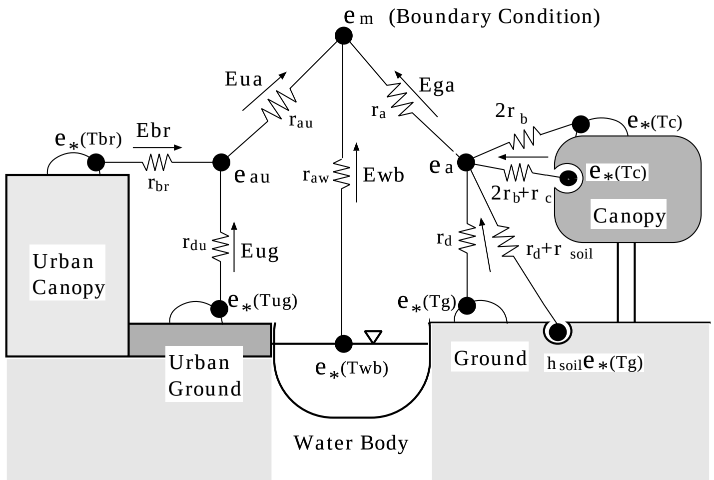


Figure 12: Latent heat flux and resistances

5. Parameter tuning from flux observation data

This model's output can be fitted to the observation data by adjusting some parameters in the model.

There are many parameters for the vegetation model(SiB), and these are roughly divided into three groups.

- morphological(geometrical) parameters
- optical parameters
- physiological parameters

Some of these parameters should be suitable to be tuned. Morphological(geometrical) parameters should be decided from real situation depending on age and season, because these are measurable in observation.

For example, the following parameters are well known to be tuned from sensitivity analysis in previous study.

- reflectance (α_V,α_N) and transmittance (δ_V,δ_N) of canopy leaves
- PAR dependent constant for stomatal resintance(a_2,c_2)

They are highly sensitive to the model's output and their influences are easily understood.

As the reflectance and transmittance become larger, the reflected short-wave radiation becomes larger, which lead to the reduction of upward shortwave radiation flux. From this nature, we can fit the simulated net radiation to the observed value.

As the PAR dependent constants become larger, stomatal resistance becomes larger, which lead to the reduction(increase) of latent(sensible) heat flux. From this nature, we can fit the simulated Bowen ratio to the observed value.

By setting some geometrical parameters properly and adjusting some optical and physiological parameters, heat budget characteristics of mulberry farmland, paddy field, pine forest are well simulated. The followings are the comparison of tuned model's output and observed value.

Table 7: tuned parameters

	α_V	α_N	δ_V	δ_N	χ_L	a_2	c_2
mulberry farmland	0.20	0.50	0.20	0.45	0.0	10000	300
paddy field	0.15	0.50	0.20	0.45	0.2	3000	100
pine forest	0.07	0.30	0.07	0.40	0.0	10000	300

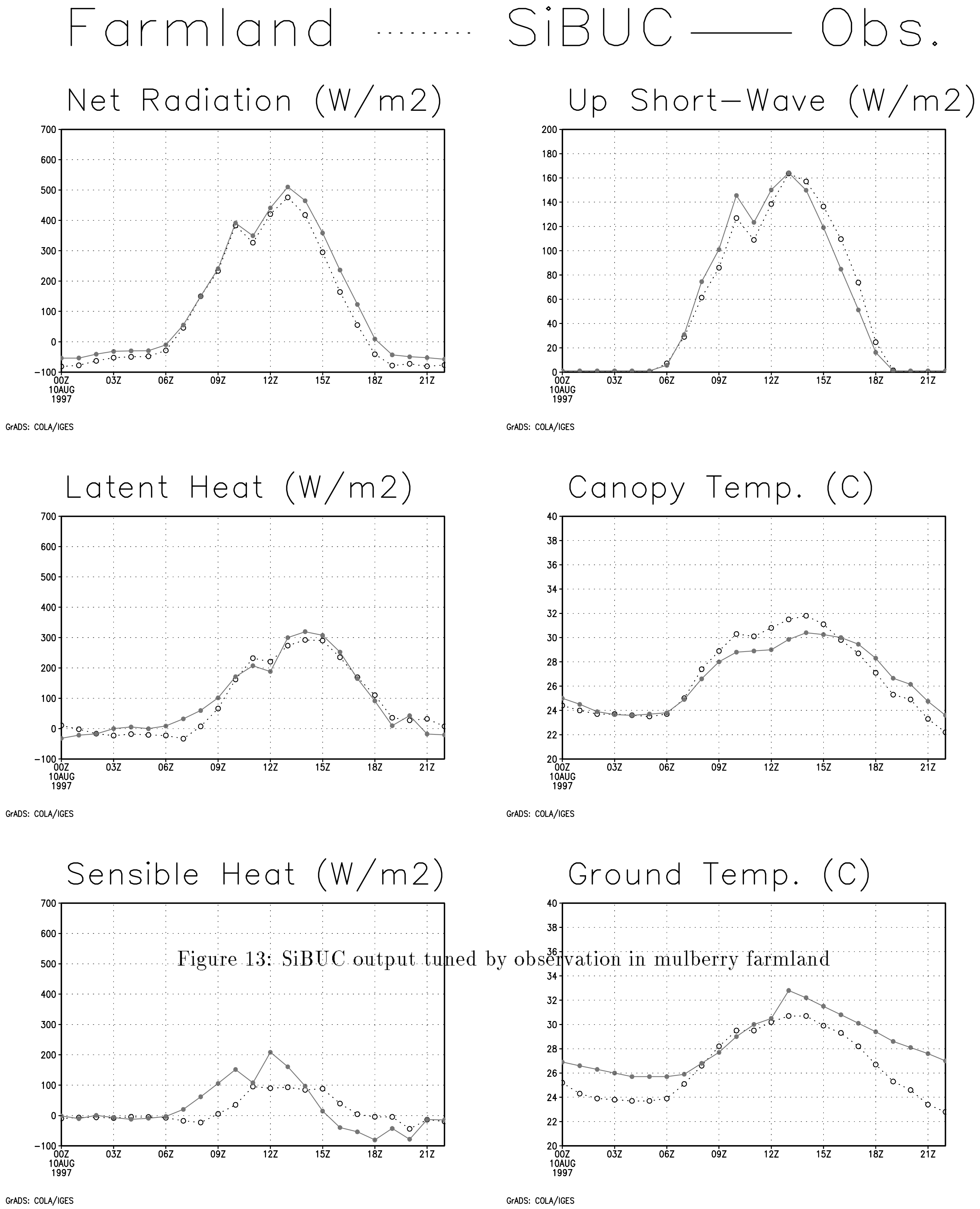


Figure 13: SiBUC output tuned by observation in mulberry farmland

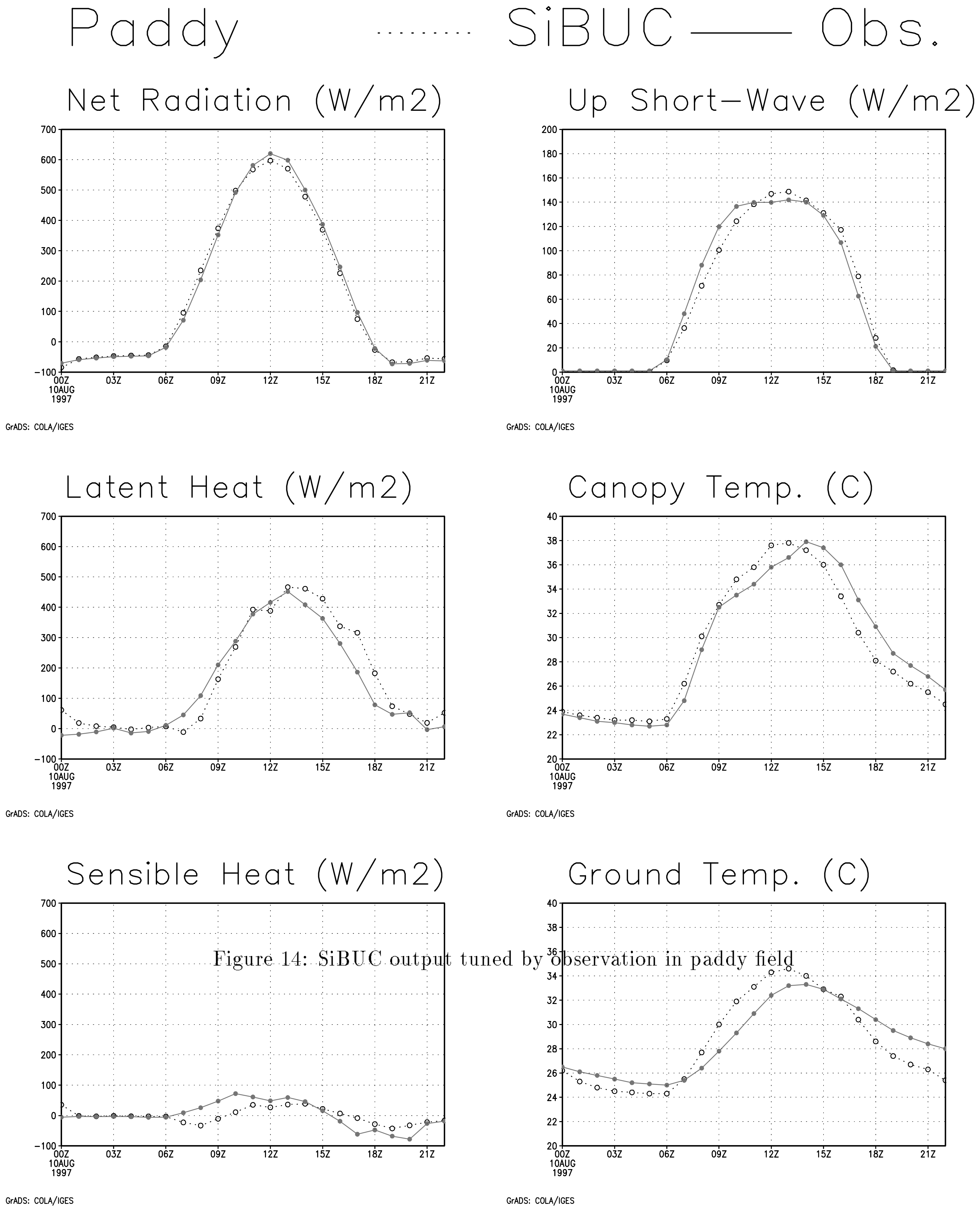


Figure 14: SiBUC output tuned by observation in paddy field

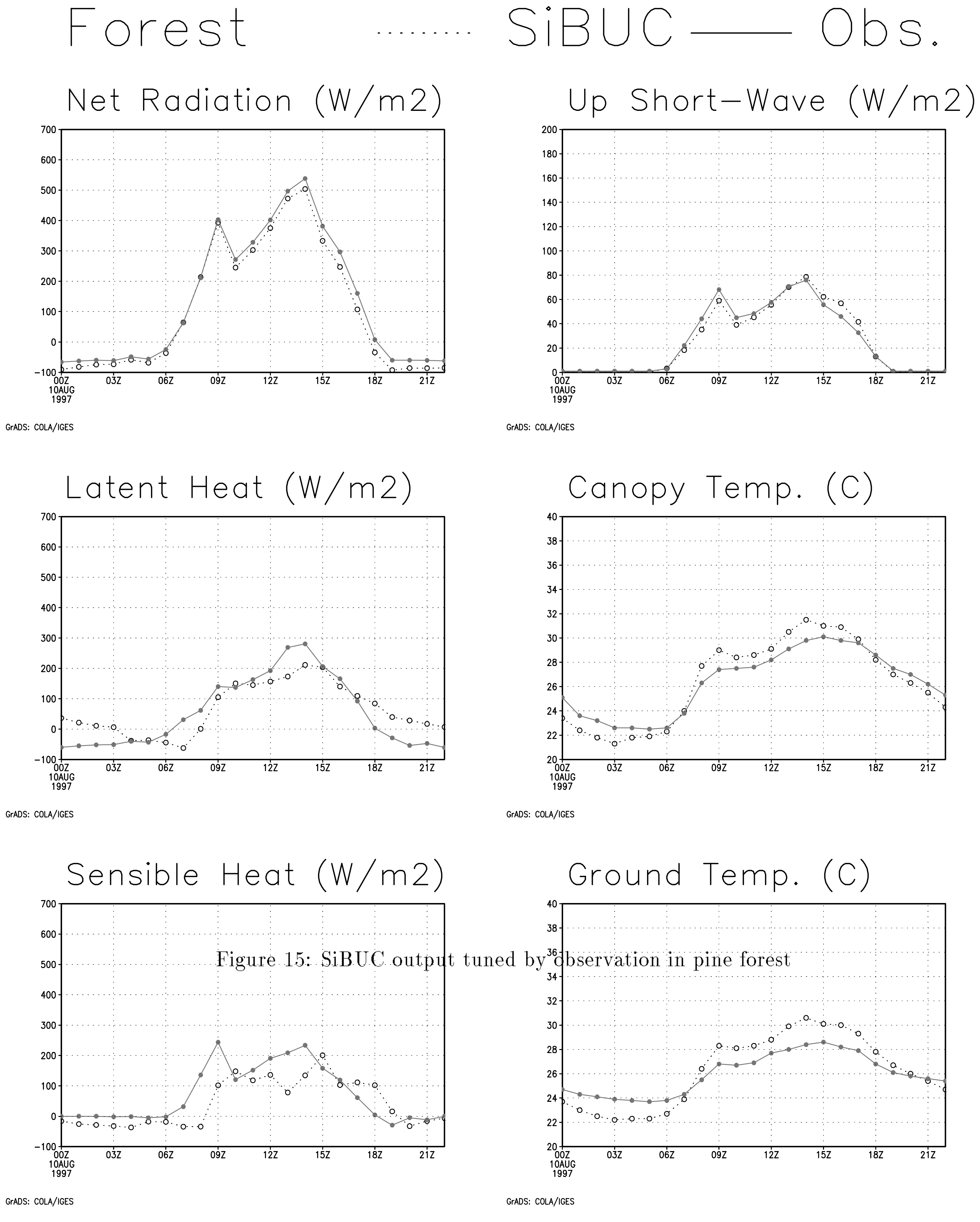


Figure 15: SiBUC output tuned by observation in pine forest