THE CHARACTERS OF ENERGY BUDGET ON THE GOBI AND DESERT SURFACE IN HEXI REGION *

Hu Yinqiao (胡隐樵), *Yang Xuanli* (杨选利), *Zhang Qiang*(张 强) and *Zuo Hongchao* (左洪超)

Lanzhou Institute of Plateau Atmospheric Physics, Academia Sinica, Lanzhou

Received January 3, 1991

ABSTRACT

In the paper, the characters of surface energy budget on Huayin (Gobi) and the desert surface during the period from 26 June to 31 August 1990 in the HEIFE have been analyzed, then have been compared with the observed results during 4—19 September 1988 in the Pilot Observation Period of the HEIFE. The results show that the atmosphere is in superadiabatic unstable state and there is a phenomenon of inverse humidity to form negative water vapour flux. The sensible heat flux on the surface energy budget is in majority, but the latent heat flux may be neglected over the Gobi and desert surface in the cloudless daytime in the summer.

Key words: surface layer, energy budget, arid region, inverse humidity

I. INTRODUCTION

It is an important link to study the land processes in order to improve the climate model and the atmospheric circulational model, so that the World Climate Research Program (WCRP) has organized a series of land surface process field observational experiments (WMO, 1987), e.g.,the Hydrologic Atmospheric Pilot Experiment (HAPEX) (Andre et al., 1986) in France and the First ISLSCP Field Experiment (FIFE) in U.S.A. These experiments were in the moist area in the southwest of France and the semi–arid area in Kansas Prairle of U.S.A. separately. But the HEIFE is a larger program of the field observational experiment for the land surface processes after HAPEX and FIFE. The experiment site is at Heihe River Basin in Gansu Province, and is situated in the arid region in hinterland of Asia.

It is predicated that characters of the processes, through which matter and energy are exchanged between atmosphere and land surface, are different between arid and moist regions. The latent heat and the water vapour flux are important in moist region, but in arid region the sensible heat flux is more important than the latent flux.

In the paper, the energy budget and turbulent flux over the Gobi (station 004) and desert (station 006) during the period from 26 June to 31 September 1990 are analysed. It presents the essential features of the energy budget in arid region of Hexi in Gansu Province in the summer.

* This paper is one of the results of HEIFE subject which is supported by the National Natural Science Foundation of China.

II. MEASUREMENT SITES AND INSTRUMENTS

The experiment area of the HEIFE is situated at Heihe River Basin as shown in Fig.1. The southwest of the experiment area is to the Qilian Mountain, the north is to the Badain Juran Desert, and the Gobi is between the mountain and the desert. The Heihe River with oasis on both

Table 1. The Model and Functions of Various Sensors

Sensor	Nation	Factory	Model	Specifications
Wind Direction	China	Tianjin Factory of Meteor. Inst.	FXI	
Wind Speed	U.S.A.	BELFORT	1022S	wind range: 0.2 — 13 — 22 — 51m / s precision: 0.11 0.22 0.55 m / s
Air Temp.	U.K.	Mathey Electronic	Thermafilm 100W30	platinum resistance sensitivity: 0.38Ω / ℃ response time: 0.1s precision: ± 0.05—0.08Ω at 0 ℃
Air Temp. Gradient	China	made of ourselves		temperature precision: 0.1℃ gradient precision: 0.05℃ (Platinum resistance 100W30 are connected as an arm of an electronic bridge)
Humidity	Finland	VAISALA	HMP35A	precision: ± 2% RH (0—99% RH, ± 20℃) ± 3% RH (90—100% RH, ± 20℃)
Soil Temp.	China		Pt100 / A	platinum resistance
Soil Heat Flux	Japan	EKO	CN—81	thermal conductivity $\lambda = 0.23 W^{-1}$ ℃$^{-1}$
Shortwave Radiation	Japan	EKO	MR—21	precision: ± 3%
Longwave Radiation	U.S.A.	Eppley	PIR	precision: ± 1%
Net Radiation	Japan	EKO	CN—11	precision: ± 5%

sides, flows throug the Gobi region. In the experiment area, five formal stations have been set separately at Zhangye (001), Linze (002), Pingchuan (003), Huayin (004) and desert (005). Stations 001 and 002 are located in oasis, but 004 in Gobi, 005 in desert, 003 in oasis–desert border. They represent four different characters of the underlying surface. The HEIFE is a Sino–Japanese cooperational subject. The Lanzhou Institute of Plateau Atmospheric Physics (LIPAP), Academia Sinica, China is responsible for stations 002, 003 and 004, and the Disaster Prevention Research Institute (DPRT), Kyoto University, Japan, is responsible for other stations. The field observational experiment started on 26 June 1990. The mobile station 006, for which LIPAP is responsible, was set in desert to substitute station 005 before 28 September 1990, because the instruments at station 005 have not been installed in the period.

Station 004 (Hu et al., 1990) is located at a site in the Gobi desert about 5 km southwest of Linze County. The nearest oasis is about 2.5 km in the due north to the station and the Qilian

Mountain is about 15 km in the southwestern to the station. The terrain of the site is even, with a slope 0.05% of south–high–north–low. The location of station 006 is at desert to the north of Pingchuan village of Linze County. In fact, the desert is a tongue belt as a consequence of that the Badain Juran Desert encroaches on northern region of Gansu Province. The belt is about 70 km long and 8 km wide. Both sides of the belt are Gobi desert. The station is located on a desert ridge. The nearest oasis is about 2 km apart from the station.

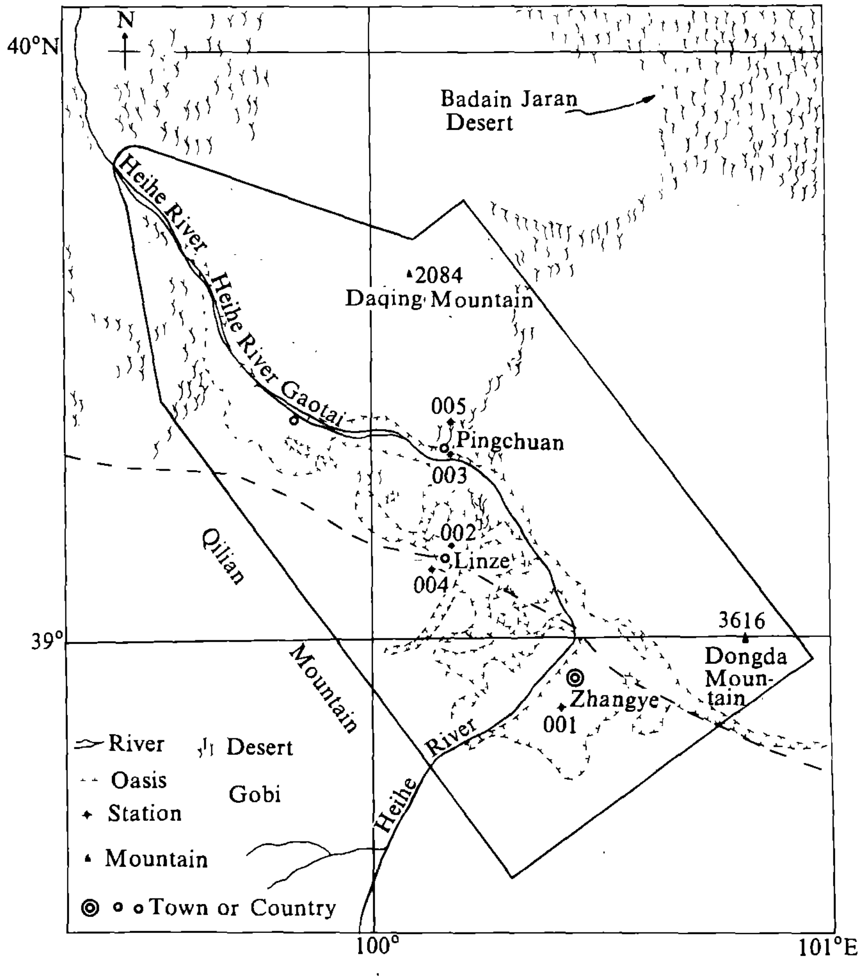

Fig. 1. The experiment area of the HEIFE and formal stations.

An observational mast with 6 levels of 0.5,1.0 2.0, 4.0, 8.0 and 16.0 m is set up at stations 004 and 006. The sensors of mean wind speed, temperature and humidity are mounted at each level and a sensor of wind direction at 10 m level, in addition, instruments for shortwave incoming radiation, shortwave reflected radiation, infrared incoming radiation, and infrared outgoing radiation are set up at 2.0 m level. The ground surface temperature is got by averaging over 4 thermometers mounted in various directions on the surface. The sensors of soil temperature are set at depth in 5, 10, 20, 40, 80 and 160cm and the sensors of soil heat flux at depth in 5, 10 cm.

In each station, all data are automatically collected by "Automatic Observational Network on the Micrometeorological Research" (Zhang et al., 1990; Wei et al.,1990). The data, which have been preliminarily processed, are transported to the central station (000)by radio transmission. Then the data are processed further by a personal computer to obtain utilizable results.

The precision of the sensors is higher to satisfy requirments for micrometeorological observation. The model and specifications of the sensors are shown in Table 1. The sensors have been calibrated before using. In general, the precision of the sensors after calibrating is within standards given by factory.

III. METHODS OF CALCULATING TURBULENT FLUXES AND SOIL HEAT FLUX

The underlying surface of the site is horizontally uniform basically, so that the condition to be claimed by the similarity theory of the surface layer is satisfied (Hu, 1990b). The combinatory method (Hu et al., 1991; Thom,et al., 1975) and the aerodynamic method have been used to calculate turbulent fluxes H_0, λE_0, u_{*0}, which are the sensible flux,the latent flux and the friction velocity and uncorrected by the stratification. They are defined as

$$H_0 = -\rho C_p k^2 Z^2 \frac{\partial u}{\partial Z} \frac{\partial \theta}{\partial Z}, \quad (1)$$

$$\lambda E_0 = -\rho \lambda k^2 Z^2 \frac{\partial u}{\partial Z} \frac{\partial q}{\partial Z}, \quad (2)$$

$$u_{*0} = kZ \frac{\partial u}{\partial Z}, \quad (3)$$

where u, θ, q, are the wind speed, the potential temperature and the specific humidity separately; Z is height; k is Karman constant; ρ, C_p and λ are the air density,the specific heat at constant pressure and the vaporization latent heat of water.

Monin–Obukhov universal functions are Φ_M, Φ_H, Φ_V separately for u, θ and q. It is supposed that transports of the sensible heat and the latent heat are similar, $\Phi_H = \Phi_V$. Here the stratification influence function F (Hu et al.,1990; Thom et al.,1975) is introduced:

$$F = (\phi_M \cdot \phi_H)^{-1} . \quad (4)$$

Consequently, the formular calculating turbulent fluxes can be got (Hu et al., 1991):

$$H = H_0 \cdot F , \quad (5)$$

$$\lambda E = \lambda E_0 \cdot F , \quad (6)$$

$$u_* = u_{*0} \sqrt{\frac{F}{\alpha}} , \quad (7)$$

$$\alpha = \phi_M / \phi_H . \quad (8)$$

It is the aerodynamic method that the turbulent fluxes can be calculated from (1)—(8) with observational data. F can be obtained from (4) when Φ_M and Φ_H have been given.

In the aerodynamic method, F is calculated from (4), but in the combinatory method F is calculated by the energy budget equation on the ground surface (Hu et al.,1991; Thom et al., 1975), i.e.

$$F = \frac{\Omega}{H_0 + \lambda E_0} \quad . \tag{9}$$

The utilizable energy on the ground surface is defined as

$$\Omega = R_n - G - S \ , \tag{10}$$

where, R_n, G and S are respectively net radiation, soil heat flux at a depth and heat stored by soil layer between the ground surface and δz depth measuring soil heat flux.

R_n and G can be measured. The stored heat can be calculated from the formula

$$S = C_w \frac{\partial T_s}{\partial t} \delta z \ , \tag{11}$$

where, T_s is surface temperature, C_w can be decided by either experience value or calculation of formula (11), and $S = G_1 - G_2$, in which G_1 and G_2 are observational values. In the paper, C_w is a statistic average about a lot of data (Hu et al.,1990).In practice, C_w equals $1.28 \times 10^6 \mathrm{J} \cdot \mathrm{m}^{-3} \mathrm{K}^{-1}$(Oke,1981).

It is the combinatory method that the turbulent fluxes are calculated by (5)—(7) when F has been calculated by (9)—(11). But α must be given to calculate u_*. Under the condition of the stable stratification, $\alpha = 1.2$ based on the results of Bussinger (Bussinger et al., 1971), but α is variational with the stability parameter z / L, if the stratification is unstable. For the convenience of the calculation, a Bussinger–Dyer approximation is used (Bussinger,1988):

$$Z / L \approx R_i \ , \tag{12}$$

where L is Monin–Obukhov length

$$L = -\frac{u_*^3}{K \frac{g}{T} \frac{H}{\rho C_p}} \ , \tag{13}$$

R_i is the Richardson number to be defined

$$R_i = \frac{g}{T} \frac{\partial \theta}{\partial Z} \Big/ \left(\frac{\partial u}{\partial Z} \right)^2 \ . \tag{14}$$

The formula of calculation u_* can be induced from (12)—(14):

$$u_* = \left[-k \frac{g}{T} \frac{H_0 F}{\rho c_p} \frac{\overline{Z}}{R_i} \right]^{1/3} \ . \tag{15}$$

If using (1),(3) and (14),then

$$u_* = u_{*0} F^{1/3} \ . \tag{16}$$

Consequently u_* can be calculated from (3), (9) and (16) in unstable states.

Then the turbulent fluxes H, λE(or E) and u_*, S,R_n and G can be directly calculated with observational data.

IV.THE CHARACTERS OF TURBULENT FLUXES AND ENERGY BUDGET

The observational data for three months have been analysed systematically to get the characteristics about the surface budget and the turbulent fluxes,which include the sensible heat, the latent heat, the water vapour and momentum flux. The results show that the characteristics are considerably consistent for each day. For the convenience of analyses and explanation, daily variations of the turbulent fluxes and the energy budget at stations 004 and 006 are given only on 30 August 1990 as an illustration. The day is cloudless. The statistical results about three months will be given in another paper. Fig.2a is diurnal variations about the energy budget at Gobi station 004 (upper part of the figure) and the water flux, the friction velocity, but the corresponding results at desert station 006 are shown in Fig.2b. The specific humidity displays a positive gradient, i.e. inverse humidity, in the cloudless daytime. It means negative vapour flux, that is to say little evaporation. But the soil temperature on the ground surface is considerably high and relative humidity is considerably low (under 40% in general), so that the condensation can not appear. Consequently,the negative vapour flux means $\lambda E=0$, as shown in the figures.

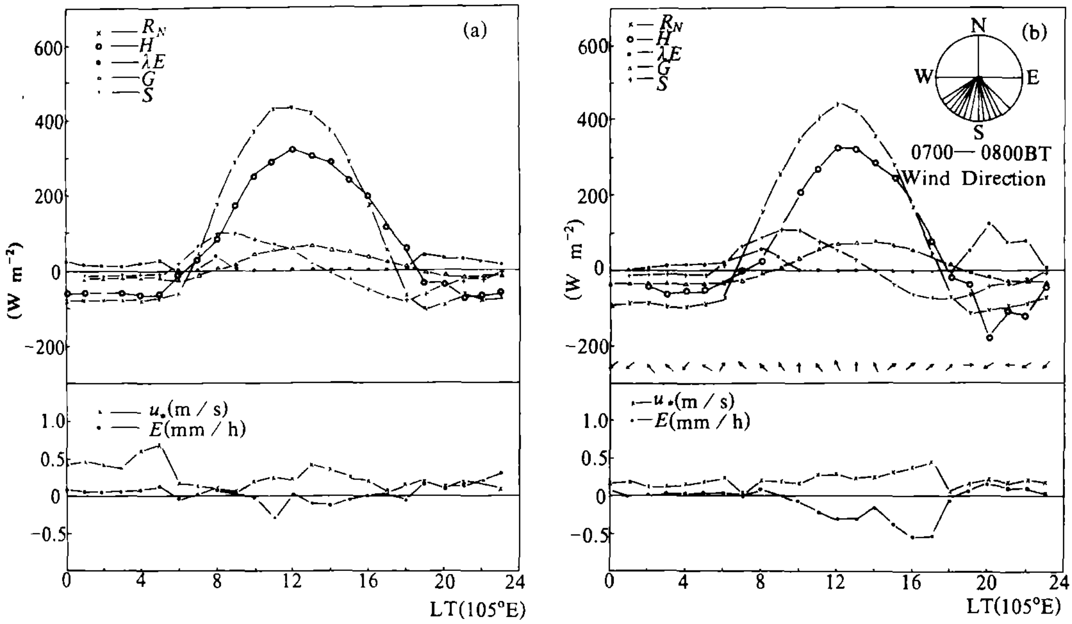

Fig.2. The energy budget and the turbulent fluxes at the Gobi station (a) and the desert station (b) on 30 August 1990.

Comparing Fig.2a to Fig.2b shows that basical characters about the energy budget and the turbulent transport over Gobi and desert are similar. They are:

(1) In cloudless daytime, the temperature stratification is in superadiabatic unstable state, but the specific humidity displays a positive gradient, i.e. inverse humidity, implying negative water vapour flux, so that the sensible heat is dominant in the energy budget on the surface, but the latent heat can be neglected.The soil heat flux on the ground surface $G_s= G + S$, occupies about 25% in the net radiation.

(2) It can be easily understood that the time to show peak value of the soil heat flux at

depth 5 cm lags about 4 hours compared with the heat stored by the soil, because the sunshine heats surface soil greatly at the first and then the heat is transported downward into deeper soil layer.

(3) As opposed to daytime, the atmosphere is in stable inverse stratification in cloudless night, resulting in negative sensible heat flux, but the vapour indicates weakly negative or positive gradient, as a consequence of a little vapour flux. In some time, there is faint evaporation. Energy, which is consumed by the effective radiation , is supplied by the sensible heat and the soil heat flux in the energy budget on the ground surface in night.

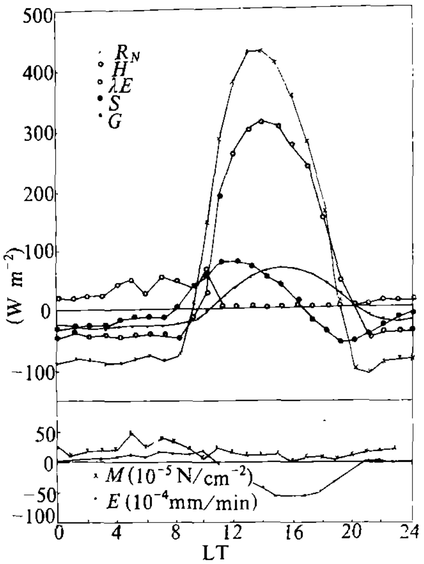

Fig.3. The energy budget on the ground surface, and the vapour flux and the momentum flux on September, 1988.

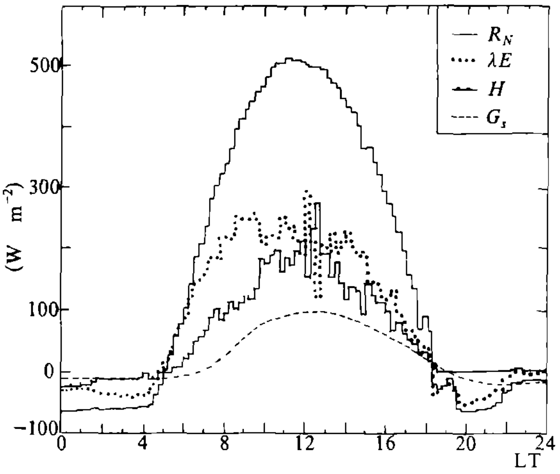

Fig.4. A classic surfase energy budget in the HAPAX on 16 June 1986.

Above characters are consistent with results obtained in observations of the energy budget in the Pilot Observation Period (POP) in 1988 (Hu et al.,1990). Much the same results have been obtained by the eddy correlation method (Wang, et al., 1990) for observing the sensible heat flux, the water vapour flux and friction velocity directly at station 004 in August 1990 and in POP in September 1988. The energy budget and the vapour flux, the momentum flux (M) at Huayin station (Gobi) on 10 September 1988 are shown in Fig.3. Compared with Fig.2a, Fig.3 shows the basically consistent featuers.

The characters of the energy budget on the ground surface over Gobi desert or sandy desert as compared with moist region are essentially distinct. For comparison, Fig.4 shows a classic surface energy budget, which has been observed over corn farmland in the HAPEX (Andre et al., 1988) on 16 June 1986. Fig.4 shows the latent heat is major fraction in the net radiation in cloudless daytime, the next is the sensible heat, and the soil heat flux accounts for about 25% .It is a classic character of the energy budget in moist region.

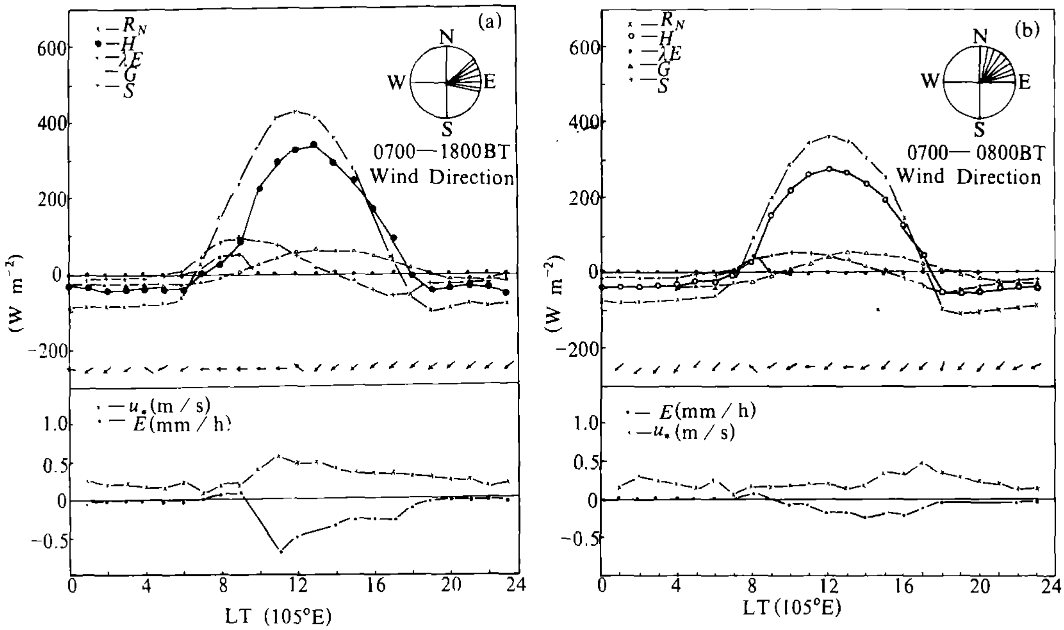

Fig.5. The energy budget and the turbulent fluxes over the sandy desert on 4 (a) and 29 (b) September 1990.

V. ABOUT NEGATIVE WATER VAPOUR FLUX

As stated in the above section, the water vapour flux is negative in cloudless daytime. For further explaining the problem of negative vapour flux, Figs.5a—b are given to show the energy budget and the turbulent fluxes over the desert station on 4 and 29 September 1990. These figures are compared with Fig.2b. We must note that the wind direction at 10 m level is marked in these figures, and the range of wind direction for 7— 18h on upper right corner. It is shown that the prevailing wind direction is south in daytime for 30 August and air flow is from oasis, but due east wind and east by north for 4 September and the air flow from the Gobi desert and a part of the oasis. Especially the prevailing wind direction is northeast in perpendicular to the oasis alignment for 29 September and the air flow is from Gobi desert and sandy desert. The features about the energy budget and the turbulent fluxes for the three days are basically similar and all show the negative vapour fluxes in the daytime.The daily integral values of the negative vapour flux for these days are shown in Table 2.

Table 2. The Daily Integral Values of the Negative Vapour Flux

Time	30 Aug. 1990	30 Aug. 1990	4 Sep. 1990	29 Sep. 1990	10 Sep. 1988
Site	Gobi	Desert	Desert	Desert	Gobi
Negative Vapour Flux (mm / d)	−0.5	−2.6	−3.1	−1.1	−2.5

It is very interesting that the negative vapour fluxes are not completely from the oasis. The fact seems to show that the negative vapour flux is not completely caused by the local advection effect near the oasis. A part of the reason may be that the vapour is transported over the station by the large–scale and mesoscale advection, and then it is transported downward within the atmospheric boundary layer by the turbulent process. Of course, the conclusion needs to be proved by observing the planetary boundary layer.

VI. DISCUSSIONS

(1) The characters of the energy budget in arid region have remarkable differences from moist region. The sensible heat is dominant in arid region, but the latent heat is dominant in moist region. The conclusion is to be expected, consequently the results induced from the paper and the HAPEX is only an illustration.

(2) The results in the HEIFE experiment show that there is a clear phenomenon of the inverse humidity, i.e. the negative vapour flux, over the Gobi desert and the sandy desert. It means at least the advection effect can not be ignored. It must be proved by more data about planetary boundary layer observations that the advection is an influence of oasis on desert or a transport of the vapour due to macro–meso–scale advection. Sandy desert or the Gobi desert is in arid and hot state under the condition of cloudless daytime in summer, consequently the relative humidity is only about 20—40%, so that it can not be condensed on the ground surface. The vapour to be transported downward may be absorbed by the soil in gaseous state. This conclusion should be further proved by observational facts and an exacter physical mechanism should be studied.

(3) It is considerable that the integral values of negative vapour flux reach from −0.5 mm / d to −3.1 mm / d . But it must be noted that an assumption, $\Phi_H=\Phi_V$, has been used in the framework of calculation.It means the transports of heat and vapour are completely similar, i.e. the eddy coefficients are the same. It should be studied if the assumption is right under the condition of negative vapour flux. The negative vapour flux may be overestimated due to the assumption. We will study the method about calculation of the negative vapour flux.

REFERENCES

Andre,J.C., Goutorbe, P. and Perrier, A.(1986), HAPEX–MOBILHY, *Bull.Amer. Meteor.Soc.*, **67**:138—144.

Businger,J.A., Wyngaard,J.C., Izumi,Y. and Bradley,E.F.(1971), Flux profile relationship in the atmospheric surface layer, *J.Atmos.,Sci.*,**28**:181—198.

Businger, J.A. (1988), A note on the Businger–Dyer profile, *Bound–Layer Meteor.*,**42**:145—151.

Gao Youxi (1990), The Foreword on the Special Issue (1) for the HEIFE, *Plateau Meteor* .,**9(2)**,(in Chinese).

Hu Yinqiao, An atmosphere–land surface process experiment at Heihe River Basin (HEIFE), *Advance in Earth Science* ,(to be published in Chinese).

Hu Yinqiao (1990a), Comparison of errors in observing turbulent fluxes in surface layer,*Chinese J.Atmos.Sci.*, **14**:233—244.

Hu Yinqiao (1990b), On some aspects of observation of turbulent fluxes in surface layer,*Plateau Meteor.*,**9**:74—87 (in Chinese).

Hu Yinqiao, Qi Yuejin and Yang Xuanli (1990), Preliminary analyses about characteristics of microclimate and heat energy budget in Hexi Gobi (Huayin), *Plateau Meteor.*, **9**:113—119 (in Chinese).

Hu Yinqiao and Qi Yuejin (1991), The combinatory method to determine the turbulent fluxes and the universal functions in the surface layer, *Acta Meteor.Sinica* , **49**: 44—51 (in Chinese).

Oke, T.R. (1981), *Boundary Layer Climate*, published in USA by Methuen Co.,p.38.

Thom,A.S., Stewart,J.B.,Oliver,H.R. and Case,J.H.C. (1975), Comparison of aerodynamic and energy budget estimates of fluxes over a pine forest, *Quart.J. Roy. Met. Soc.*, **101**:93—105.

Wang, J. and Mitsuta,Y. (1990), Peculiar downward water vapour flux over Gobi desert in the daytime, *J.Meteor.Soc.Japan* , **68**:399—401.

Wei Guo'an et al.(1990),A data acquisition system for field near surface meteorological observation, *Plateau Meteor.*, **9**:183—189 (in Chinese).

WMO (1987), Report of the Third Session of the JSC Working Group on Land surface Processes and Climate (Manhathan, Kansas, 29 June—3 July 1987), WCRP–8, WMO / TD–NO.232.

Zhang Yongfeng et al.(1990), Automatic observational network on the micrometeorological reserch, *Plateau Meteor.*, **9**:177—182 (in Chinese).