DOI: 10.1007/s11430-006-8273-7

Study of a model for correcting the effects of horizontal advection on surface fluxes measurement based on remote sensing

TIAN Jing[1,2], ZHANG Renhua[1], SUN Xiaomin[1], ZHU Zhilin[1] & ZHOU Yanlian[1,2]

1. Key Laboratory of Ecosystem Network Observation and Modeling, Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing 100101, China;
2. Graduate University of the Chinese Academy of Sciences, Beijing 100049, China

Correspondence should be addressed to Zhang Renhua (email: zhangrh@igsnrr.ac.cn)

Received October 27, 2005; accepted March 10, 2006

Abstract As well known, the methods of remote sensing and Bowen Ratio for retrieving surface flux are based on energy balance closure; however, in most cases, surface energy observed in experiment is lack of closure. There are two main causes for this: one is from the errors of the observation devices and the differences of their observational scale; the other lies in the effect of horizontal advection on the surface flux measurement. Therefore, it is very important to estimate the effects of horizontal advection quantitatively. Based on the local advection theory and the surface experiment, a model has been proposed for correcting the effect of horizontal advection on surface flux measurement, in which the relationship between the fetch of the measurement and pixel size for remote sensed data was considered. By means of numerical simulations, the sensitivities of the main parameters in the model and the scaling problems of horizontal advection were analyzed. At last, by using the observational data acquired in agricultural field with relatively homogeneous surface, the model was validated.

Keywords: fetch, horizontal advection, energy balance, pixel size, ChinaFLUX.

As well known, it needs continuous and regional quantitative data for studying net surface exchange between surface and atmosphere; however, at present, most of methods of measuring surface flux and other surface parameters only can be applied on local scale. Therefore, with these methods, spatial variation of surface parameters cannot be obtained, especially on heterogeneous surface, while depending on its consistent and frequent observation of the land surface on micro- and macro- scale, remote sensing provides a means of overcoming these problems. In recent 20 years, lots of algorithms to estimate surface flux by means of remote sensing were developed, but they were all built on the hypothesis energy balance closure on pixel scale. If this condition cannot be satisfied, great errors would be induced. In addition, techniques as to how to calibrate predicted turbulent energy fluxes remain an unresolved issue, which has close relationship with the accuracy of surface observed data and the scaling problem. Hence, it is very important to obtain accurate observational data and is necessary to analyze the relationship between the fetch of the measurement and pixel size. In a word, there are three problems as to retrieving precise regional surface flux by remote sensing: (1) energy balance closure on pixel scale; (2) veracity of the observed surface data; (3) scale transformation. It is obvious that the former two problems have close relationship with the horizontal advection.

At present, there are three main universal methods to measure surface flux: Bowen Ratio Energy Balance method (BREB); Eddy Covariance method (EC); Large Aperture Scintillometers method (LAS). They depend on different observational mechanisms and have different measurement source areas. Provided that the exchange coefficients of heat flux (k_h) equals to that of latent heat flux (k_w), BREB can estimate heat flux (*H*) and latent heat flux (*LE*) by means of partitioning available energy. Because of its convenience and simplicity, it is used widely; however, lots of historical evidences have indicated that[1−4], in most of cases, k_h is not equal to k_w for the sake of horizontal advection. When this happened, BREB is inapplicable. EC is a technique of directly measuring CO_2 flux, *H* and *LE* by calculating covariance between instantaneous fluctuations in vertical wind speed, air temperature, and water vapor density at high frequency above the canopy. It is considered as the best method of observing surface flux[5]. Nevertheless, this method is also affected by horizontal advection because advection has great influence on the energy exchange. Compared with the above two methods, LAS can measure *LE* in larger distance (1−5 km) by means of measuring electric frequency caused by laser bean that is refracted by heat turbulent and establishing the relationship between it and *H*[6], but two problems limit its application. One is that the measurement needs to be calibrated with corresponding eddy covariance data, that is to say, LAS and EC must be used at one time. The other is that its observation must be performed in large experimental field with homogeneous surface that is difficult to be found, especially in China. Besides these measurement principles, issues relating to their measurement scales are also of major difference. Usually, the ratio of fetch to observational height is 100:1 for BREB and EC; for LAS, the scale is determined by the distance between the transmitter and the receiver. In their applications, BREB and EC are often used to calibrate surface flux retrieved by remote sensed data with high resolution, such as TM, and LAS is used for calibrating the results obtained by remote sensed data with low resolution, such as MODIS. Because BREB and EC are affected by horizontal advection greatly, there exist some uncertainties for calibrated results. Furthermore, horizontal advection is a primary parameter affecting surface energy balance closure that is the foundation for retrieving accurate fluxes by remote sensing, therefore, how to correct the effects of advection on surface flux measurement, what is the relationship between advection's influences and pixel size, and how to make surface energy closed are the focuses in recent study.

In this paper, as a primary result, a model for correcting the effect of horizontal advection on the measurement of surface flux was proposed. According to the numerical simulations, effects of input variables on the modeled results, such as surface available energy, surface water content, wind speed, and vertical gradient of air temperature, were analyzed. Here, surface available energy is the difference of net radiation and soil heat flux. In addition, the issue of advection's effects at different pixel resolutions was discussed. At last, based on the surface experiments, the model was validated. This study is of great significance for improving the accuracy of measured surface flux by EC method and for acquiring accurate regional surface fluxes by remote sensing.

1 Method for correcting the effects of horizontal advection on surface flux measurement

Spatial variations in surface temperature, surface humidity and available energy are the drives of horizontal advection; wind speed, wind direction and exchange coefficients of *H* and *LE* are the controls of surface energy transport. They determine horizontal advection together. Water vapor and heat move horizontally under the drive of wind, at the same time, move vertically via molecule diffusion and heat conduction, in this way, horizontal advection influences the measurement. According to this mechanism and making use of BREB method, we put forward the following equations to estimate ΔH and ΔLE:

$$\Delta LE = \frac{\Delta N}{1+\beta'}, \quad \Delta H = \frac{\Delta N \cdot \beta'}{1+\beta'}, \quad \beta' = \beta + \Delta\beta, \tag{1}$$

where ΔLE and ΔH are latent heat flux and sensible heat flux induced by horizontal advection, respectively; ΔN is the difference of measured turbulent energy fluxes (sensible and latent heat) and available energy and quantitatively expresses the closure extent of measured energy, β and $\Delta\beta$ all represent, yet the former is calculated by measured turbulent energy fluxes and the latter is the variance of Bowen ratio caused by advection. It is obvious that horizontal advection can be corrected if ΔN, β and $\Delta\beta$ are all known. Because β can be obtained in experiment, the key problem is how to acquire ΔN and $\Delta\beta$.

For illustrating the relationship between horizontal advection and pixel size, here, the surface was regarded as the combination of pixels with some resolution. Thus, each pixel only was given a value for specific parameter; dN and $d\beta$ are defined as the variance of energy and water content caused by horizontal advection, respectively; ΔN is the sum of dN, and $\Delta\beta$ is the sum of $d\beta$. Because Bowen ratio has close relationship with surface water content[7], $d\beta$ can be used to quantitatively express the effect of advection on water content. At the same time, because surface water content can be expressed by differential thermal inertia (*DTI*) more accurately than apparent thermal inertia (*ATI*, eq.(2)), *DTI* was adopted in the paper, then the function between $d\beta$ and *DTI* was established by means of water content. Generally, the difference between *ATI* in the morning and *ATI* at midday approximates to the time integral of differential thermal inertia[7]. Hence, on the assumption that apparent thermal inertia in the morning is similar in the footprint, the difference between *ATI* of effective pixel and *ATI* of the pixel at which EC equipment is located could indicate the difference of water content. Besides that, in terms of local advection's theory and the previous studies[8−11], another four parameters, pixel size, distance, wind speed and vertical gradient of air temperature, were included (eq. (3)). In the paper, the pixels in the fetch were called as effective pixels, namely pixels that have effects on flux measurement.

$$ATI = \frac{R_{\text{rei}}}{(T - T_{\min})\sqrt{\Delta t}}, \tag{2}$$

$$dN_i = A \cdot \eta \cdot \frac{[(R_{ni} - G_i) - (R_{n0} - G_0)]}{R_{n0} - G_0} \cdot (\omega / x_i^2) \cdot e^{(-\frac{1}{u^2} - \frac{1}{dT_i^2})},$$
$$d\beta_i = A \cdot \eta \cdot \left[\frac{(T_i - T_{\min}) \cdot \sqrt{\Delta t} / R_{ni} - (T_0 - T_{\min}) \cdot \sqrt{\Delta t} / R_{n0}}{(T_0 - T_{\min}) \cdot \sqrt{\Delta t} / R_{n0}} \right] \cdot (\omega / x_i^2) \cdot e^{(-\frac{1}{u^2} - \frac{1}{dT_i^2})}, \tag{3}$$

where R_{rei}, T, $T_{\min}$ and Δt are energy density, surface temperature at midday, lowest surface temperature in a day and time difference between the time when T and $T_{\min}$ are observed, respectively. Obviously, dN and $d\beta$ are relative values. Because, besides advection effects, the three factors, sampling errors associated with different measurement source areas for the terms in energy balance equation, systematic bias in instrumentation and neglected energy sinks, also play important role in energy balance, but it is very difficult to estimate them, η is designed to correct for them and only can be obtained by experiments. The subscript o indicates the pixel at which eddy covariance equipment is located, and subscript i indicates pixel-i. A is a weight coefficient evaluating pixel size effect, for example, if A is set at 1 for the resolution of 30 m, A equals to 4 for 120 m. R_n, G, x, u and dT_i are net radiation, soil heat flux, true surface distance between the center of pixel-i and the center of the pixel-o, wind speed, vertical gradient of air temperature, respectively. ω is a coefficient for dimensional conversion.

Approximately, flux footprint of measurement area (fetch) is as 100 times as the height of sensors. When surface area covered by one pixel is smaller than flux footprint, advection in upwind direction would influence every corner of the pixel; on the contrary, when surface area covered by one pixel is larger than flux footprint, only the edge of the pixel as the same range as footprint would be affected directly, then under the function of energy averaging and mixing, the whole pixel is influenced. In this case, the effects on flux measurement are reduced greatly. In the paper, ratio of footprint to resolution of remote sensed data was adopted to correct for this (eq. (4)).

$$\begin{cases} \Delta N = \sum_{i=1}^{n} \frac{100 \cdot h}{p} \cdot dN_i \cdot (R_{n0} - G_0) \\ \Delta \beta = \sum_{i=1}^{n} \frac{100 \cdot h}{p} \cdot d\beta_i \cdot [(T_0 - T_{\min}) \cdot \sqrt{\Delta t} / R_{n0}] \end{cases}, p > 100 \cdot h,$$

$$\begin{cases} \Delta N = \sum_{i=1}^{n} dN \cdot (R_{n0} - G_0) \\ \Delta \beta = \sum_{i=1}^{n} d\beta \cdot [(T_0 - T_{\min}) \cdot \sqrt{\Delta t} / R_{n0}] \end{cases}, \quad p < 100 \cdot h, \tag{4}$$

where h is the height of sensor, $100h$ is fetch length, p is the resolution of remote sensed data, the meanings of other variables are the same as the above.

From eqs. (1)—(4), we can see that parameters in the model, except for wind speed and the gradient of air temperature, all can be retrieved by means of remote sensing. As long as η is acquired in experiments, the effects of advection would be corrected successfully, which is very useful for achieving more accurate surface flux data and calibrating remote sensed data more precisely.

2 Numerical simulations of horizontal advection's effects under different conditions

2.1 Effects of spatial variations in available energy, water content, wind speed and vertical gradient of air temperature on modeled results

In the model, there are four major parameters controlling the advection: available energy, water content, wind speed and vertical gradient of air temperature. Different combinations of these four variables can represent many types of surface and microclimate conditions. By means of simulative analysis, the effects of horizontal advection under different conditions were completed.

Simulations were performed on the assumptions that: (1) the height of sensor was 2 m; (2) fetch length was 250 m; (3) resolution of remote sensed data was 30 m. Soil heat flux was calculated by eq. (5)[12]:

$$G = 0.3(1 - 0.9f)R_n, \tag{5}$$

where f is vegetation fractional cover. According to the validation, this equation is applicable.

For quantifying energy balance closure, another variable, ratio of energy variance ζ, was defined (eq. (6)). When energy loses, ζ is a positive value, otherwise, ζ is a negative value.

$$\zeta = \frac{Rn - G - (H + LE)}{Rn - G}. \tag{6}$$

Taking agricultural field as an example, we fulfilled the analyses. Usually, surface exhibits homogeneous for agricultural field (except for the common boundary between irrigated area and unirrigated area), so the following simulative data were adopted. Rn_0 is 500 w/m^2; T is 312 K; $T_{\min}$ is 288 K; η is 0.8; R_n of effective pixels varies from 410 w/m^2 to 490 w/m^2; T of effective pixels vary from 298 K to 308 K. Fig. 1(a)—(d) show the results. Obviously, the greater the distance between pixel-o and pixel-i is, the weaker the effect is. From Fig. 1(a) and (b), we can see that the closer the values of available energy and values of surface temperature between pixel-o and pixel-i are, the weaker the effect is. Fig. 1(c) and (d) show the effects of wind speed and the gradient of air temperature. The influence of horizontal advection increases with the increase of wind speed and the gradient of air temperature. In addition, from eq. (3), we found that when the reciprocals of available energy and ATI of pixel-i are smaller than that of pixel-o, ζ is positive; contrarily, ζ is negative.

2.2 Effect of spatial resolution of remote sensed data on modeled results

At present, TM, NOAA and MODIS are often used to retrieve regional surface parameters; however, lots of investigations have proved that the resolution of remote sensed data has significant effects on the retrieval results. Without exception, at different pixel sizes, horizontal advection also has different effects on fluxes measurement. Therefore, in this section, the effects of horizontal advection across different levels of pixel resolution were discussed, which will provide the foundation for our model's application to different remote sensed data.

In the computation, η is still set at 0.8. For other parameters, such as R_n, G, the aggregated data calculated by linearly averaging the high resolution data is adopted as the value on larger scale. The results are given in Table 1. Evidently, with the increase of the pixel size, the effect of advection becomes decreasing.

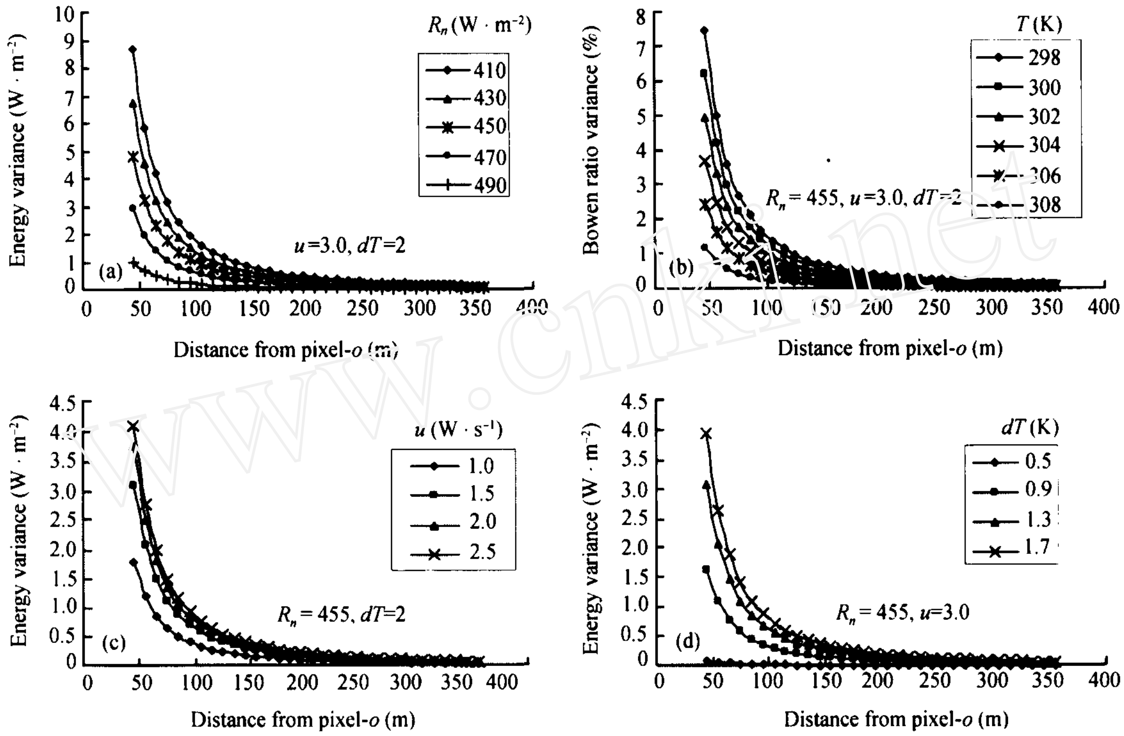

Fig. 1. Effects of spatial variations in available energy on modeled results . (a) Net radiation; (b) water content; (c) wind speed; (d) vertical gradient of air temperature.

Table 1 Effects of horizontal advection at different resolutions

Resolution (m)	ΔN (%)	$\Delta\beta$ (%)	ΔLE (W. m^{-2})	ΔH (W.m^{-2})
30	5.25	22.1	6.52	3.98
120	2.1	4.73	2.75	1.44
250	0.82	2.64	1.08	0.55
500	0.51	1.44	0.34	0.17
1000	0.21	0.44	0.069	0.035

That is to say, when TM and MODIS are used to retrieve surface flux, mutual effects between adjacent pixels for TM are much greater than that for MODIS data because of the averaging effect.

3 Validation of the model

In order to validate the model, surface experiments were performed at Xiaotangshan of Beijing in June, 2004 and May, 2005. The ground data set consist of half-hourly surface fluxes, meteorological data at eddy covariance stations and surface temperature across the footprint. Surface fluxes were measured by the eddy covariance method.

3.1 *The experiments*

Xiaotangshan (40.17°N, 116.44°E) is located in Changping district of Beijing. The experimental field was 1000 m long from north to south and 300 m wide from east to west, and was divided into two parts by a road, named north area and south area. During the experiment, the field was dominated by agricultural land-use. Using the data obtained in south area, we fulfilled the following analyses.

The eddy covariance equipment and automatic meteorological devices were mounted in the center of the south area and at height of 2 m above the surface, so the fetch length of the measurement area was 250 m. Fluxes of sensible heat, water vapor and carbon dioxide were measured by eddy covariance equipment with a sampling rate of 10 Hz. Average of the fluxes in 30 minutes was used in the calculation. Other ground data set included air temperature, air humidity, infrared temperature, soil heat flux, horizontal wind speed, wind direction, downwelling short wave radiation and long wave radiation, upwelling short wave radiation and long wave radiation, etc. We adopted two different methods to measure surface temperature in 2004 and

2005: line circuit method and area circuit method. In 2004, surface temperature was observed by infrared thermal radiometer. Two lines from south to north were symmetrically set on east side and west side of eddy covariance equipment, and the vertical distance between eddy covariance equipment and each line was 25m. Two persons walked along the two lines at one time and recorded a temperature data at 2m interval. The measurements were done two times. First was done from south to north and second was done from north to south. In this way, two temperatures were recorded at one 'point'. The average of them is used as the true temperature of this 'point', then the distribution of the temperature in the fetch was achieved by means of taking 'point' data as 'area' data, which would result in some errors unavoidably. This circuit method has the advantage of reducing the errors caused by observational time difference. Similar to the above procedures, in 2005, we still adopted circuit method. The differences were that thermal camera replaced thermal radiometer to observe surface temperature, which can record temperature data with high spatial resolution. One thermal image was recorded at 20m interval and is of 240×320 pixels. Here, for clear illustration, the direction facing the eddy covariance devices is positive, and the reverse is negative; one thermal image was regarded as two parts: near part and far part. Influenced by view angle, certain errors were induced for the far part, thus by selecting the corresponding two images in the opposite directions and using the near part of negative image to replace the far part of positive image, we overcame the problem and obtained the effective data of surface temperature. In addition, sky temperature, surface albedo and surface emissivity were also measured in the experiment. According to the experience, the sky temperature with 53° of zenith angle approximates to the average of hemispherical sky temperature[13]. Thus, four sky temperatures with 0°, 90°, 180°, 270° azimuth and 53° of zenith angle were observed by thermal radiometer. The average of them was used as the true value. Surface albedo was measured by ASD; surface emissivity was observed by portable emissivity instrument developed by Institute of Geographical Sciences and Natural Resources Research, CAS. Because of the large amount of work, the above measurements were only performed in north field of south area, which means that only when north wind blew, data could be used.

3.2 *Validation of the model*

According to the wind direction data of 2004, 6-day data sets were chosen to determine the coefficient η, then the model was validated by using 5-day data sets of 2005.

In the computation, fetch length is 250 m. In terms of the experimental results, surface emissivity is about 0.96. Given surface temperature, surface eimissivity, downwelling solar radiation and surface albedo, the following equation were used to calculate net radiation:

$$R_n = S - \rho S + \sigma\varepsilon_{\text{sky}} T_{\text{sky}}^4 - \sigma\varepsilon_{\text{s}} T_{\text{s}}^4, \tag{7}$$

where S is downwelling short wave radiation, ρ is surface albedo, σ is Bolzman costant, ε is emissivity, T surface temperature, the subscript of sky, s indicate sky and surface. Here, emissivity of sky is set at 1. Based on R_n, G can be estimated by eq.(5).

Table 2 showed 6-day data sets of eddy covariance and meteorological data. Mean of high resolution data were used as the values at coarse resolution. By using these data, coefficient η at different resolutions were obtained (Table 3). Obviously, with the decrease of resolution, η increased greatly. It is because that when ratio of energy variance ζ is a constant, the effects of advection at coarse resolution are greater than that at high resolution. In addition, Table 3 also shows that the coarser the resolution is, the more labile the η is and the higher the standard deviation is. Because of the limitation of the data, only primary results are listed in Table 3.

By using mean of η in Table 3 and 2005 data, ratio of energy variance ζ was estimated. Fig. 2 shows the relationship between estimated ζ and observed ζ. Obviously, there is good correlation between them. However, with the increase of the resolution, the correlative coefficient decreases. For further study, taking 30 m resolution as the example, using the above estimated ΔH and ΔLE to correct the measured H and LE, we obtained the results seen in Fig. 3. The x-axis is the difference of R_n and G, namely available energy; the y-axis is the sum of H and LE. Evidently, corrected

Table 2 6-day surface data sets in 2004

Date	Down-welling solar radiation (W·m^{-2})	Upwelling short wave radiation (W·m^{-2})	Sky temperature (℃)	Latent heat flux (W·m^{-2})	Sensible heat flux (W·m^{-2})	Net radiation (W·m^{-2})	Soil heat flux (W·m^{-2})	Surface temperature (℃)	Air temperature (℃)	Wind speed (W·s^{-1})	Ratio of energy variance (%)
2004-06-05	285.75	25.45	3.4	156.48	16.44	212.85	12.61	23.075	21.68	1.26	13.6
2004-06-08	724.5	104.25	–4.2	166.77	147.34	494.3	54.33	36.8	26.38	1.85	28.77
2004-06-10	744.5	111.1	–9.76	147.1	143.96	454.5	59.7	47.02	32.61	1.36	26.28
2004-06-14	279	46.72	6.8	76.86	39.86	166.85	6.53	31.26	[illegible]	1.94	27.15
2004-07-03	472.05	55.39	14.43	176.06	45.49	355.58	49.97	31.36	26.29	0.95	27.5
2004-07-05	880.25	97.93	–18.12	448.65	55.12	676.68	56.3	29.92	28.64	3.62	16.24

Table 3 Coefficient η at different resolutions

Resolution (m)	2004-06-05	2004-06-08	2004-06-10	2004-06-14	2004-07-03	2004-07-05	Mean	Standard deviation
2	0.13	0.11	0.09	0.18	0.14	0.12	0.128	0.031
30	0.75	0.65	0.54	0.57	0.68	0.67	0.64	0.077
120	3.0	2.35	1.9	2.0	3.0	2.7	2.49	0.484
250	7.3	5.9	4.4	4.4	7.0	6.2	5.87	1.245

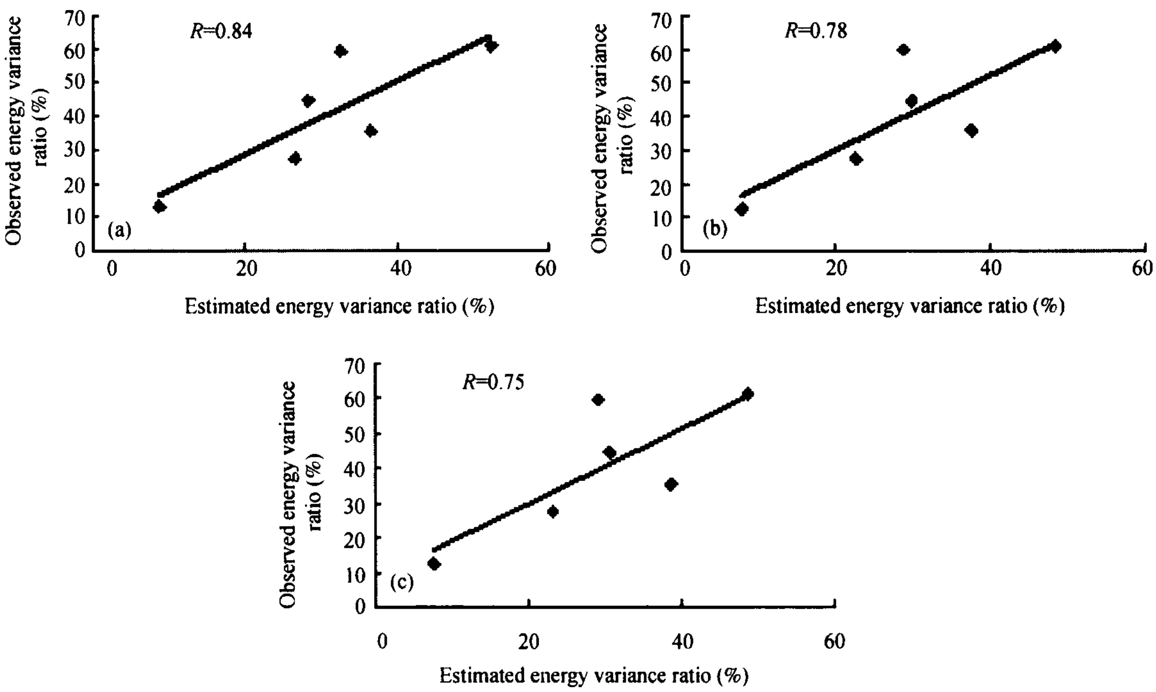

Fig. 2. The relationship between estimated energy variance ratio and the observed at 3 resolutions. (a) 30 m; (b)120 m; (c) 250 m.

results are better, which proves that the calculated η in Table 3 are applicable. If η at different surfaces can be determined by the experiments, the model would be applied more widely. In addition, it should be pointed out that the errors of input variables caused by systemic sampling and approximate estimation would bring some disturbances on the validation, yet at present, there is no way but to ignore them because the great difficulty to achieve the input parameters' true values.

4 Conclusions and discussion

In the present paper, a model for correcting the

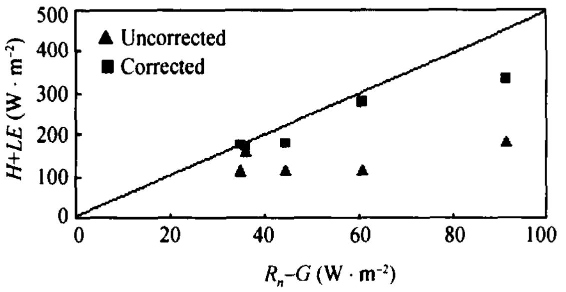

Fig. 3. The relationship between corrected energy balance closure and the uncorrected (30m).

effects of horizontal advection on surface flux measurements based on remote sensing has been proposed. On the basis of it, by means of numerical simulations, the effects of four central factors on surface flux measurements have been analyzed. In addition, the scaling problem of the effects of horizontal advection has been discussed. It is shown that with the decrease of the resolution, the farther the distance from observational location is, the weaker the advection effects are. For validating the model, firstly, coefficient η was determined by 2004 data. Then, by using 2005 data, the effects of horizontal advection were estimated. It is showed that there is a close relationship between estimated ratio of energy variance and measured ratio of energy variance, and the energy balance closure was improved, which is significant for promoting the precision of surface flux measurement.

The scheme presented in the paper is proved to be feasible, yet there are still some problems that must be pointed out:

(1) Only four parameters were preliminarily analyzed in this paper; more details about the transport process of horizontal advection should be investigated in both theory and practice and be used in the model.

(2) Because of the limitation of experimental data, the model was validated only in agricultural field. For other types of surface, such as wood land, grass land, etc, it is necessary to validate the model, too. Hence, more surface experiments should be done in future.

(3) In the application of the model, most of input parameters are usually obtained by remote sensing. Unavoidably, there exist some errors in themselves, of course, which would affect the precision of the model. Therefore, the model cannot be applied better until the accuracy of the input factors is improved, while the key problem of the improvement is how to retrieve their true values by remote sensing, which need more further study.

Acknowledgements This work was supported by the Key Project of the National Natural Science Foundation of China (Grant Nos. 40371089, 49890330), the Knowledge Innovation Program of Chinese Academy of Sciences (Grant Nos. KZCX1-SW-01-01A, CXIOG-E01-04, 04) and the National Basic Research Project (Grant No. 2000077900).

References

1 Raymond P M, Shashi B V, Norman J R. Exchange coefficients under sensible heat advection determined by eddy correlation. Agri Meteor, 1979, 20: 273—280
2 Shashi B V, Norman J R, Blaine L B. Turbulent exchange coefficients for sensible heat and water vapor under advective conditions. J Appl Meteor, 1978, 17: 330—338
3 Tilden P M, Steven E H. An assessment of storage terms in the surface energy balance of maize and soybean. Agri For Meteor, 2004, 125: 105—115
4 Hossein A, Pruitt W O, Paw K T, et al. Energy balance determinations close to the soil surface using a Micro-Bowen Ratio System. Agri Forest Meteor, 1989, 46: 259—274
5 Guo J X, Mei X R, Lu Z G, et al. Field evapotranspi ration measurement based on eddy covariance technology. Sci Agri Sin, 2004, 37(8): 1172—1176
6 Zhu Z L, Sun X M, Xu J P, et al. Using Large aperture scintillometer to validate pixel heat flux based on remote sensing models. Intern Geosci Remote Sensing Symposium (IGARSS), 2004. 3: 1984—1987
7 Zhang R H, Sun X M, Zhu Z L, et al. A remote sensing model for monitoring soil vaporation based on differential thermal inertia and its validation. Sci China Ser D-Earth Sci, 2003, 46(4): 342—355
8 Gash J H C. A note on estimating the effect of a limited fetch on micrometeorological evaporation measurements. Boundary- Layer Meteor, 1986, 35: 409—413
9 Schmid H P, Oke T R. A model to estimate the source area contribution to turbulent exchange in the surface layer over patchy terrain. Q J R Meteorol Soc, 1990, 116: 965—988
10 Rachel A S, Timothy R O, William P L. Advection and the surface energy balance across an irrigated urban park. Intern J Climat, 2000, 20: 1033—1047
11 Natasha N, Philip M. Local advection of sensible heat in the snowmelt landscape of Arctic tundra. Hydrol Processes, 1998, 12: 1547—1560
12 Zhang R H, Sun X M, Wang W M, et al. An operational two-layer remote sensing model to estimate surface flux in regional scale: Physical background. Sci China Ser D-Earth Sci, 2005, 48(Sup I): 225—244
13 Zhang R H. Experimental Remote Sensing Modeling and Surface Foundations. Beijing: Sciences Press. 1996