Applied Mathematics and Mechanics
(English Edition, Vol 25, No 5, May 2004)

Published by Shanghai University,
Shanghai, China

©Editorial Committee of Appl. Math. Mech., ISSN 0253-4827

Article ID: 0253-4827(2004)05-0488-11

OBSERVATION AND MODELING FOR TERRESTRIAL PROCESSES IN ALPINE MEADOW*

YAO De-liang (姚德良)[1], ZHANG Qiang (张 强)[1], LI Jia-chun (李家春)[1],
XIE Zheng-tong (谢正桐)[1], SHEN Zhen-xi (沈振西)[2]

(1. Institute of Mechanics, CAS, Beijing 100080, P.R.China;
2. Northwest Plateau Institute of Biology,
CAS, Xining 810001, P.R.China)

(Contributed by LI Jia-chun)

Abstract: *The water-heat transfer process between land and atmosphere in Haibei alpine meadow area has been systematically observed. A multi-layer coupling model for land-atmosphere interaction was presented with special attention paid to the moisture transfer in leaf stomata under unsaturated condition. A profound investigation on the physical process of turbulent transfer inside the vegetation has been performed with a revised formula of water absorption for root system. The present model facilitates the study of vertically distributed physical variables in detail. Numerical simulation was conducted according to the transfer process of Kinesia humility meadow in the area of Haibei Alpine Meadow Ecosystem Station, CAS. The calculated results agree well with observation.*

Key words: alpine meadow; land-atmosphere coupling model; turbulence transfer; numerical simulation; field obervation

Chinese Library Classification: P463.23 **Document code**: A
2000 Mathematics Subject Classification: 76F25;76F40;80A20

Introduction

Rapid expansion of population, persistent damage of ecological environment, shortage in food and crisis of energy are the main issues perplexing human beings nowadays. The damage of ecological environment results in sharp reduction of biotic resources, deterioration of climate and soil to such a degree that they have threatened mankind's life. Take the degeneration of grassland as an example, the grassland occupies 30% of total area of China, the abnormal and out-of-date management gives rise to low economic efficiency, serious waste of resources and deterioration of

* **Received date**: 2002-10-16; **Revised date**: 2003-12-26

Foundation items: the National Natural Science Foundation of China (10332050, 40071007, 19832060); Chinese Academy of Sciences Knowledge Innovation Program (KJCX2-SW-L1)

Biographies: YAO De-liang (1943 ~), Professor (Tel: + 86-10-62554124; Fax: + 86-10-62561284; E-mail: yaodl@imech.ac.cn); LI Jia-chun (1940 ~), Professor, Academician of Chinese Academy of Science

ecological environment of grassland. It is reported that there exists degeneracy to varied degree in 1/3 of total grassland all over China. Another example, the percentage of forest coverage dropped from 12.7% to 8.9% due to deforestation. Still another example is that desertification, i.e. the total area of desert reaches 2.626 million km^2, more than 27% of total area of China. The majority of these environmental disasters are caused by the flow near the ground. Therefore, the study on terrestrial process model and observation may yield great social and economic benefit.

The characteristics of Qinghai-Tibet Plateau influence not only the distribution pattern of vegetation in our country, but also that in Eurasia. They include high sea level elevation, abundance of sunshine, intense radiation, low atmosphere temperature, large diurnal variation in temperature, low air pressure. The generated "Qinghai-Tibet High Pressure" forces the atmosphere to form west wind circulation and flow north and south respectively. Meanwhile, Qinghai-Tibet Plateau is a sensitive zone to global change, a window to observe how mankind's activities affect the environmental change. The Alpine Meadow Station[1] lies at 101°19′E, 37°37′N, at the south foot of Lenglong Hill, east part of Qilian Mountains in the northeast of Qinghai-Tibet Plateau, with mean altitude of 3 200 m. The station area has apparent plateau-continental climate characteristics. There are no four clearly demarcated seasons but only two of them. One is called the cold season, long and chill; the other is the warm season, short and mild. The mean annual temperature is −2 ℃. The diurnal range of temperature is higher (14.4 ℃), the annual range lower (24.2 ℃). The sunshine time is long and amounts to 2 672.6 h annually. The solar radiation is intense, and amounts to $5.86 \times 10^6 - 6.70 \times 10^6$ kJ/m^2 annually. Annual precipitation is 498 mm, unevenly distributed in seasons with 88% in warm season. It is windy all year round with annual mean wind velocity 2.6 m/s. The region is covered with high mountain meadow soil, high mountain shrub meadow soil or marshy soil. Relatively the first one spreads most widely. The vegetation is alpine meadow and alpine shrub with *Kinesia humility* Meadow overwhelming there. The area, where fodder grass grows heavily, is an ideal grazing region but endangered by over-grazing, low temperature and wind erosion. The study of land-surface processes in the alpine meadow area is meaningful in understanding global climate change. In addition, an optimal utilization program suitable for alpine environment can be worked out, enabling us to properly explore meadow resources, to protect them from threat of low temperature and wind erosion to maintain the dynamic balance of meadow ecosystem and to further promote the regional economic development.

Great improvement has been achieved in understanding land-atmosphere interaction and parameterization scheme since 1970s, from defining the potential temperature of land surface to the "bucket model"[2] by using the conservation law. Since 1980s, biophysical and physiological processes of vegetation for water and heat cycling have been extensively studied. A few models for Soil-Plant-Atmosphere Continuous SPAC system, such as Biosphere and Atmosphere Transfer System BATS model (Dickinson[3] 1986) and Simple Biosphere SiB model (Seller[4] 1986) have been proposed with results agreeing well with observation. However, BATS and SiB models depend on too many observational parameters. It is also too complicated to use in reality. At the same time, the land-atmosphere interaction coupling model was developed with the aid of new turbulence models. In 1989, Naot *et al.*[5] took advantage of 2-order turbulent closure model to simulate the micro-climate environment over cotton and bare soil in Nahal-Oz and Gilgal, Israel.

In 1990, the soil-atmosphere coupling model (SALSA)[6] which reflects the water-heat exchange of the bare soil and the lower atmosphere was established by Ten Berge *et al*.

The domestic research on land-atmosphere process started with field observation in Qinghai-Tibet Plateau in 1980s. In 1994, Hu *et al*.[7] carried out field experiment on land-atmosphere interaction in Heihe area. In 1999, Ji[8] made the experiment on energy input and output in Qinghai-Tibet Plateau. However, there's still little research on land-atmosphere in alpine meadow. Yao De-liang *et al*.[9] (1966) studied an interaction model to predict fodder grass output in Qinghai-Tibet Plateau and showed how the soil water content and evapor-transpiration affect grass growth. Yao De-liang *et al*.[10] (2002) developed a land biosphere model in alpine meadow ecosystem and analyzed the influence of vegetation on soil water-heat transfer. Based on the previous work[11~14] and focused on the land-atmosphere water-heat transfer process in Haibel Alpine Meadow Ecosystem Station CAS, a multi-level land-atmosphere interaction coupling model is presented in this paper. With special attention paid to the moisture transfer in leaf stomata under unsaturated condition, a profound investigation is made on the physical process of the turbulent transfer inside the vegetation. A revised water-absorption formula for root system is utilized. The influence of the wilting and field moisture capacities is included. Meanwhile, we introduce the condition of climate and field observation. Numerical simulation is conducted according to the transfer process of *Kinesia humility* meadow in the area of Haibei Alpine Meadow Ecosystem Station, CAS. The results agree well with the experiment. The model is proved to successfully simulate the land-atmosphere interaction process and may serve as scientific foundation for the optimal use of local water-heat resources.

1 Field Observation

In June 2001, we carried out the ovservations in Haibei Alpine Meadow Ecosystem Station, CAS. The water and heat parameters of atmosphere, soil and vegetation pertaining to *Kinesia humility* meadow were recorded. The following items were measured: atmosphere temperature, humidity, wind speed, land surface temperature, soil temperature, soil moisture, soil heat flux, net radiation. MAOS-I micro-climate automatic observation system was used, composing of many kinds of meteorological radiation sensor, data-acquiring case, power unit case, notebook computer, sensor support *etc*. The atmospheric humidity was measured through HTF-2 sensor. The measurements were arranged at the height of 0.5, 1, 2, 4 m. Taking into account that the inter-plant wind speed in micro-climate system is small, VF-1, a tpye of magnetic-shaft-bearing breeze sensor with small threshold was employed to capture as small wind speed as 0.2 m/s. There were four sensors of this type in the system to measure wind speed at four different heights. EC9-1B, a type of wind direction sensor with high dynamic response, was used to decrease the dynamic error caused by ordinary sensor with low dynamic response. These sensors were installed at the top of the system. Considering that the representation of the land surface temperature measurement was poor, three land surface temperature sensors in this system were arranged at different positions to obtain average value of land surface temperature in order to improve the resolution. Seven platinum resistance temperature sensors were distributed at different soil layers of depth 5, 10, 15, 20, 40, 60, 70 cm under the ground to measure the soil temperature. The soil heat flux was measured by sensor of model HF-1 and net radiation by sensor of model

TBB-1. In addition, the soil water content was measured through soil-sampling-drying-weighing method. The sampling depths were 10, 20, 30, 40, 50, 60 cm. Three points at each depth were measured to yield averaged ones.

2 Coupling Model

In this paper, we pay special attention to the effect on the land-atmosphere interaction of atmosphere and vegetation. The vegetation layer is regarded as the location where distribute sources or sinks of momentum, heat and moisture. The vegetation is also divided into multi-layers. The equations and the couple process of atmosphere boundary layer (ABL), plant layer and soil layer are discussed as follows.

2.1 Atmosphere turbulence movement in ABL

Generally speaking, the flows in ABL can be separated into two layers: the surface layer and the Ekman layer, and their dynamic properties are not the same. In ABL, the momentum and heat flux through the ground have intensive impacts on the atmosphere, and the meteorological elements vary drastically as altitude changes, therefore the Coriolis force is ignored for small scale movements there.

All the physical variables in the turbulent ABL including horizontal velocities u, v, pressure p, potential temperature T and the specific humidity q can be divided into the summation of mean value (indicated by "-" above the letters) and fluctuation (indicated by the superscript "′"). If the vertical pressure is almost fixed in the ABL, the horizontal pressure gradient can also be represented by the geostrophic wind u_g and v_g. The governing equations for a horizontally homogeneous flow are written as

$$\frac{\partial \bar{u}}{\partial t} = f(\bar{v} - v_g) - \frac{\partial \overline{u'w'}}{\partial z} - C_d A(z)\bar{u} \mid \bar{u} \mid, \tag{1}$$

$$\frac{\partial \bar{v}}{\partial t} = - f(\bar{u} - u_g) - \frac{\partial \overline{v'w'}}{\partial z} - C_d A(z)\bar{v} \mid \bar{v} \mid, \tag{2}$$

$$\frac{\partial \bar{T}}{\partial t} = - \frac{\partial \overline{w'T'}}{\partial z} + 2A(z)(T_l - \bar{T})/r_b(z), \tag{3}$$

$$\frac{\partial \bar{q}}{\partial t} = - \frac{\partial \overline{w'q'}}{\partial z} + 2A(z)(q_l - \bar{q})/(r_s(z) + r_b(z)), \tag{4}$$

where $\bar{u}$, $\bar{v}$ are the averaged velocities in x-, y-directions. $\bar{T}$ and $\bar{q}$ are the mean potential temperature and specific humidity. T_l, q_l are the temperature and humidity at the leaf. t stands for time, z is the vertical coordinate. $f = 2\Omega\sin\phi$ is the Coriolis parameter. $\Omega = 7.27 \times 10^{-5}$/s, ϕ is the local latitude. $A(z)$ is the leaf distribution density of vegetation. Eqs. (1) ~ (4) are also suitable for the situation of bare soil or over vegetation canopy if $A(z)$ is taken to be zero. C_d is the drag coefficient. The last term in Eqs. (3) and (4) are called heat source (sensible heat flux into or out of leaves) and vapor source (water transpired or condensed), respectively. Inspired by the single layer model, we assume that there exists a kind of resistance hindering heat from fluxing into or out of the leaves and a kind of resistance hindering water from being transpired or condensed in canopy. r_b, r_s are the leaf boundary layer resistance and stomata resistance to the diffusion of water vapor, respectively.

The turbulent kinetic energy (TKE; $e = 0.5(u'^2 + v'^2 + w'^2)$ equation is writtten as

$$\frac{\partial e}{\partial t}=\frac{\overline{u'w'}}{\rho}\frac{\partial \bar{u}}{\partial z}+\frac{\overline{v'w'}}{\rho}\frac{\partial \bar{v}}{\partial z}+\frac{g}{T}\frac{\partial\,\overline{T'w'}}{\rho C_p}+\frac{\partial}{\partial z}\left(K_M\frac{\partial e}{\partial z}\right)-\frac{(Ce)^{3/2}}{l_M}+C_dA(z)(|\bar{u}|^3+|\bar{v}|^3), \tag{5}$$

where ρ is the density of atmosphere, C_p is the heat capacity, g is the acceleration due to gravity, K_M is the total transfer coefficient. The first, second and third term at the right hand side are turbulent kinetic energy produced by shear and heat respectively. The fourth and fifth terms are the radiation of kinetic energy and dissipation. The last term indicates the effect of canopy effect. If $A(z)=0$, the turbulent kinetic energy equation is applied for the bare soil or over vegetation canopy. Reynolds-average procedure results in Reynolds stresses—$\overline{u'w'}$, $\overline{v'w'}$, and sensible heat—$\rho C_p\,\overline{T'w'}$, latent heat—$\rho\lambda_v\,\overline{q'w'}$. For atmospheric turbulent flows, we prefer k model to close the equation system[13].

The conditions at the upper boundary of the system are defined as below

$$\overline{u'w'}=\overline{v'w'}=\overline{w'T'}=\overline{w'q'}=0, \tag{6}$$

$$\frac{\partial e}{\partial z}=0. \tag{7}$$

2.2 Water and heat transfer in the soil

The one-dimensional equation for heat in the soil can be written as

$$\frac{\partial(CT)}{\partial t}=\frac{\partial}{\partial z}\left(\lambda\frac{\partial T}{\partial z}\right), \tag{8}$$

where T is the soil temperature, C is the soil heat capacity, λ is the thermal conductivity.

The general moisture equation for one-dimensional transport of liquid water in the soil is written as

$$\rho_1\frac{\partial\theta}{\partial t}=\frac{\partial}{\partial z}\left(K(\theta,T)\frac{\partial p(\theta,t)}{\partial z}\right)-\rho_1 g\frac{\partial}{\partial z}K(\theta,T)-S(z,t), \tag{9}$$

where ρ_1 is the density of liquid water, θ is the soil moisture, K is the hydraulic conductivity, p is the pressure potential, g is the gravity acceleration.

The plant root water absorption function $S(z,t)$ has different kinds of expressions[15]. In the paper, the $S(z,t)$ is written as

$$S(z,t)=\frac{E_c(t)L(z)f(\theta)}{\int_0^{L_r}L(z)f(\theta)\mathrm{d}z}, \tag{10}$$

$$f(\theta)=\begin{cases}0 & (0\leqslant\theta<\theta_w),\\ \dfrac{\theta(\theta-\theta_w)}{\theta_j(\theta_j-\theta_w)} & (\theta_w\leqslant\theta<\theta_j),\\ 1 & (\theta_j\leqslant\theta),\end{cases} \tag{11}$$

where $E_c(t)$ is the flux of transpiration, $L(z)$ is the root distribution function, $f(\theta)$ is a function related to water absorption resistance of root, θ_w is the volumetric moisture content at the wilting point, θ_j is the field capacity, L_r is the maximum depth of the root. The model is applied to alpine meadow, therefore, the parameters in the formula by measurement are chosen as

$$\theta_w=0.1\,796,\ \theta_j=0.7\,713,\ L(z)=\exp(3.30-3.60z)\quad(0\ \mathrm{m}\leqslant d\leqslant 0.2\ \mathrm{m}), \tag{12}$$

$$\theta_w=0.2\,232,\ \theta_j=0.6\,742,\ L(z)=\exp(3.30-3.60z)\quad(0.2\ \mathrm{m}\leqslant d\leqslant 0.6\ \mathrm{m}), \tag{13}$$

where $z=d/\mathrm{m}$. The root water absorption model implies that the plant root water absorption rate is proportional to the rate of transpiration and also related to volumetric moisture content at the wilting point and field capacity.

The conditions at the lower boundary of this system are assumed as follows:

$$\frac{\partial T}{\partial z} = \frac{\partial \theta}{\partial z} = 0. \tag{14}$$

2.3 Energy-budget equation

The energy-budget equation within the vegetation layers is

$$R_n(z) + H_p(z) + E_p(z) = 0. \tag{15}$$

The evaluation of net radiation distribution function is based on Ref. [16]. The calculation method of sensible and latent heat fluxes is referred to Ref. [13] and written as

$$H_p(z) = -2\rho_a C_p A(z)(\bar{T}_a(z) - T_1(z))/r_b(z), \tag{16}$$

$$r_b(z) = C_b(D/\bar{u}(z))^{1/2}, \tag{17}$$

$$E_p(E) = -2\rho_a LAI(z)(\bar{q}(z) - q_1(z))/(r_b(z) + r_s(z)). \tag{18}$$

In this paper, the model of canopy resistance $r_s(z)$ is defined as

$$r_s(z) = (r_{\min}/LAI) \times (F_1 \times F_2 \times F_3 \times F_4)^{-1}, \tag{19}$$

where

$$\begin{cases} F_1 = (r_{\min}/r_{\max} + f)/(1 + f), \; f = 0.55Q_t/Q_{cri} \times 2/LAI, \\ F_2 = (\theta - \theta_w)/(\theta_j - \theta_w), \; F_3 = 1 - \beta(e_{sat}T_a - e_a), \\ F_4 = 1 - 1.6(T_0 - T_a)^2/10^3, \end{cases} \tag{20}$$

in which $\bar{T}_a(z)$, $T_l(z)$, $q_l(z)$ are the mean temperature of atmosphere, the mean temperature of the leaf surface and the mean humidity of the leaf surface, respectively. The present model may account for unsaturated condition in leaf stomata. C_b is set to be 200 ($S^{1/2}/m$), D is the average diameter of the leaves, $r_{\min}$ and $r_{\max}$ are the minimal and maximum vapor resistance, respectively. $\beta = 0.06$, LAI is the leaf area index of the whole canopy, T_o is the reference leaf temperature and set to be 298 K, T_a is the temperature of atmosphere, Q_t is the solar short wave radiation that reaches the top of the canopy, Q_{cri} is the critical radiation and set to be 100 W/m^2.

The energy-budget equation of the soil surface is defined as

$$R_n + H_s + E_s + G = 0, \tag{21}$$

where R_n, H_s, E_s, G are the net radiation, sensible, latent and soil heat flux, respectively. The foregoing equation implies that the surface itself has no heat capacity, namely, no energy can be stored there.

The index attenuation model is applicable to low and concentrated plant vegetation.

2.4 Numerical method

Equations (1) ~ (5), (8) ~ (9) are numerically integrated by a finite-difference scheme, which are discretized in space by staggered grid control volume method with forward time step. 1 500-meter-high ABL is divided into 11 layers in which 2 layers are within vegetation layer, and special cells are non-uniform with dense grid nearby the ground. 60-centimeter-deep soil is divided into 12 layers. Nonlinear equations (15) and (21) are solved by the Newton iteration. Initial profiles of mean wind speed, mean air temperature and humidity, soil temperature and moisture are given in advance.

The mean wind speed, mean specific humidity, mean atmosphere temperature, soil temperature, soil moisture and turbulence fluctuations are specified as the initial condition. Based on the assumption that the production term and the dissipation term in Eq. (5) balance each other at the befinning, the initial kinetic energy of turbulent fluctuations can be obtained.

3 Comparison Between Computational and Experimental Results

By the method mentioned above, we have performed the numerical simulation using water and heat parameters of atmosphere, soil and vegetation pertaining to low grass meadow in Haibei Alpine Meadow Ecosystem Station recorded from June 3rd to June 10th, 2001. The comparison between simulations and experiment is shown in Fig. 1 to Fig. 6, where symbols stand for experimental values and curves for simulations.

3.1 Characteristics of net radiation in plateau area

Figure 1 shows the numerical results of temporal variation of total and net radiations. It can be seen that both the total and net radiation are high, which is attributed to the high sea level elevation there. Haibei Alpine Meadow lies in the northeast of Qinghai-Tibet Plateau with mean altitude of 3 200 m. For this reason, the atmosphere is rarefied with lower air density. The transparency of atmosphere increases with decreasing of atmospheric impurity such as water content and dust. As a result, the solar radiation is highly abundant and amount to $5.86 \times 10^6 \sim 6.70 \times 10^6$ kJ/m^2 annually. There are a lot of sunny days and sunshine time is long and amounts to 2 672.6 h annually. In growing season, mean daily sunshine time is 7.2 ~ 8.5 h, and sunshine rate reaches 60%. The proportion of shortwave light (blue light and violet light) is high in favor of the protein synthesis in plants, resulting in prolific nutritional ingredients in fodder grass. Compared with the case in plain area, the solar radiation in plateau area differs: on the one hand of input, scattered radiation decreases with increasing of sea level elevation, while the direct radiation and the total radiation increase. On the other hand of output, reflective radiation is greater than that in plain area, and increases as sea level elevation increases owing to much more ice and snow in Qinghai-Tibet Plateau.

3.2 Budget of energy

Figure 2 shows the numerical result of diurnal variation of net radiation (R_n), sensible (H), latent heat (E) and soil heat (G) flux. The net radiation is the source of sensible, latent and soil heat flux. The factors that influence the net radiation are solar altitude angle, transparency of atmosphere, cloudiness, cloud shape, reflectivity and temperature of the earth's surface, temperature and humidity of atmosphere *etc*.[1] It is seen from the figure that there is clear variation in the net radiation in sunny days: generally positive during days, negative during nights, the maximum appears at noon, the minimum after the sunset. Take June 9th as example, the maximum is 572 W/m^2 at 14:00, the minimum is -25 W/m^2 at 22:00. The latent heat is the heat absorbed during evaporation or released during condensation. The transfer of latent heat flux is determined by the moisture exchange process between the underlying surface and the atmosphere. The sensible heat flux is mainly due to the turbulent transfer near the ground. The soil heat flux is the heat transfer between the ground and soil, linked to the heat conductivity of soil. From the figure, we may see that the sensible heat flux occupies the largest fraction, the latent heat follows and the soil heat flux is the least.

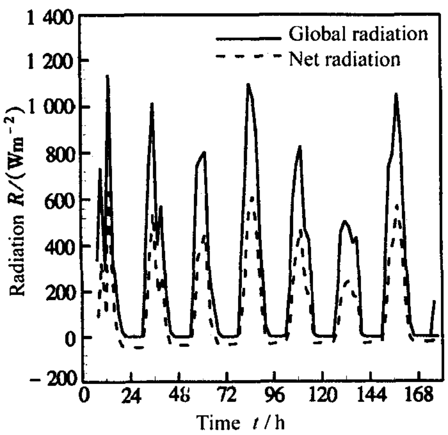

Fig.1 Diurnal variation of global and net radiation with time

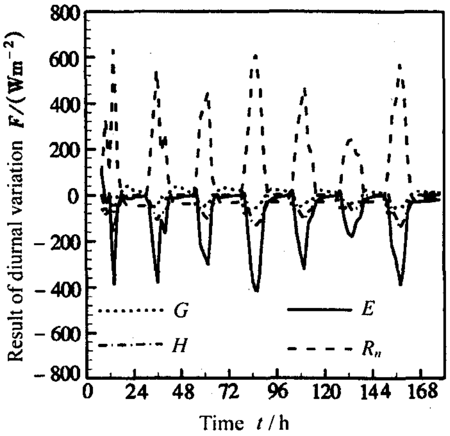

Fig.2 Diurnal variation of net radiation (R_n) , latent heat (E), sensible heat (H) and soil heat flux (G) with time

3.3 Diurnal variation of land surface temperature

Figure 3 shows the numerical result of diurnal variation of land surface temperature. Comparisons are made with the measured data. The land surface temperature varies cyclically in the period of a day. This is caused by the diurnal variation of the solar radiation reaching the land surface and its effective radiation. The alpine meadow area locates in the hinterland of Eurasia, far away from oceans. There is little oceanic influence on heat accumulation. The heat conducts slowly, concentrates on the top layer of the land and results in intense increase in the land temperature. During the night, the effective radiation of the land surface increases. Because of atmospheric rareness, little cloud, small water content in atmosphere, the insulation of atmosphere is weak. So the heat radiates quickly from the land surface, and in turn, the land cools down quickly. As a consequence, the land temperature varies greatly in a diurnal cycle. For instance, the maximum land temperature is 42.4 ℃ at 14:00, the minimum is - 6.1 ℃ at 6:00 on June 7th.

3.4 Soil moisture

Figure 4 depicts the profile of the soil moisture. From the figure, we may see that there is good agreement between the numerical simulation and the measurement data. The soil moisture decreases with depth. There are stones under the depth of 60 cm preventing the groundwater to supplement upward, while there is fog and rain as supplement on the top layer. So, more moisture stays on the top layer. From the figure, it is seen that the moisture on June 3rd is more than that on June 8th since a light rain occurred on June 2nd.

3.5 Atmosphere specific humidity

Figure 5 shows the specific humidity of atmosphere at different heights, different time in *Kinesia humility* area. The specific humidity ratio, the ratio between the mass of moisture m_v and the mass of moist air $m_v + m_a$ [17], is another expression of atmosphere humidity. The condition of atmosphere humidity is determined by a number of important weather factors such as cloud, fog, precipitation. They are also the main factors influencing the evaporation of water in soil and the transpiration of plants. We may see in Fig.5 that, the specific humidity near the land surface is at its largest value at noon (14:00), larger at night (20:00), smallest in the morning (8:00) in a diurnal cycle.

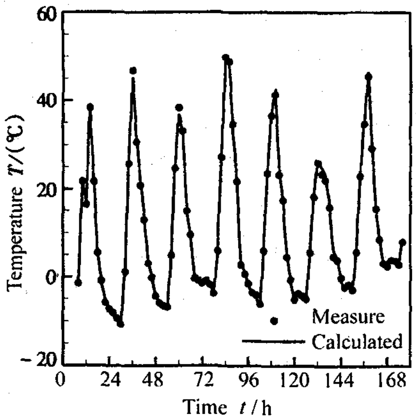

Fig.3 Diurnal variation of temperature of soil surface with time

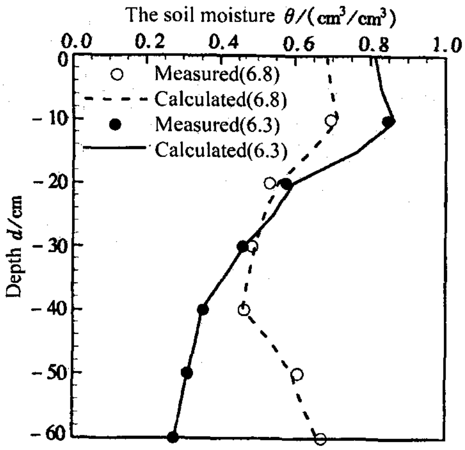

Fig.4 Variation of soil moisture with depth

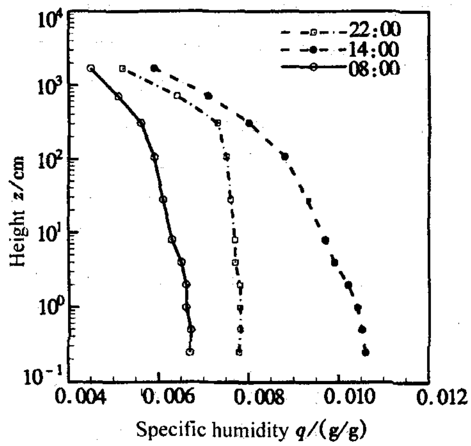

Fig.5 Variation of specific humidity with height

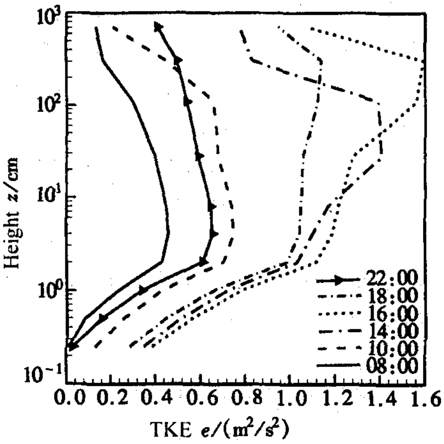

Fig.6 Variation of turbulent kinetic energy with height

3.6 Atmosphere turbulence

The variation of the turbulent kinetic energy (TKE) with altitude is described in Fig.6, in which, TKE reaches its peak near the top of vegetation. Influenced by the vegetation, the turbulent fluctuation is suppressed greatly near the land surface. The turbulent intensity increases in daytime, reaches its maximum between 14:00 to 18:00, and then decreases. The numerical result shows that TKE reaches the maximum at 16:00 or so, becomes smaller at 10:00 and 22:00, and reaches the minimum at 8:00.

4 Conclusions

1) Haibei Alpine Meadow lies in the northeast of Qinghai-Tibet Plateau with mean altitude of 3 200 m. As a result, the atmosphere is rarefied. Because of high visibility, plentiful sunny days and long sunshine time, the solar radiation is highly abundant and totally amount to $5.86 \times 10^6 \sim 6.70 \times 10^6$ kJ/m^2 annually.

2) Based on the water-heat transfer process between land and atmosphere in the *Kinesia humility* meadow field in the area of Haibei Alpine Meadow Ecosystem Station, CAS, A multi-layer land-atmosphere interaction coupling model is presented in this paper. The present model, dividing soil, plant and atmosphere into multi-layers with detailed studies of the physical processes inside the vegetation, represents some facts in observations. As compared with the measurement, the model is proved to be able to simulate the land-atmosphere interaction process successfully and may serve as scientific foundation for the optimal use of local water-heat resources.

3) To extend this model, some revision and improvement have been made. An in-depth study on the physical process of turbulent transfer inside the vegetation is carried out with special consideration paid to the moisture transfer in leaf stomata under unsaturated condition, and a revised water-absorption formula for root system is utilized to enhance the forecasting capability of the land-atmosphere interaction coupling model presented in this paper.

References:

[1] XIA Wu-ping. *Alpine Meadow Ecosystem*[M]. Lanzhou: Gansu Publishing House of People, 1981. (in Chinese)

[2] Deardorff I W. Efficient prediction of ground surface temperature and moisture with inclusion of a layer vegetation[J]. *J Geophys Res*, 1978, **83**: 1889 - 1903.

[3] Dickinson R W. Biosphere-atmosphere transfer scheme (BATS) for NCAR community model[R]. NCAR, Boulder Co, TN-275 + STE, 1986.

[4] Seller P J, Mintz Y. A simple biosphere model (SiB) for use within general circulation models[J]. *J Atmos Sci*, 1986, **43**: 505 - 531.

[5] Naot O, Mahrer Y. Modelling microclimate environments: a verification study[J]. *Boundary Layer Meteorology*, 1989, **46**: 333 - 354.

[6] Ten Berge H F M. *Heat and Water Transfer in Bare Topsoil and the Lower Atmosphere*[M]. Netherlands: Pudoc Wageningen, 1990.

[7] HU Yin-qiao, Gao You-xi, WANG Jie-min, *et al*. Some results of Heihe field observation[J]. *Plateau Meteorology*, 1994, **13**(3): 225 - 236. (in Chinese)

[8] JI Guo-liang. Advanced in energy budget observation experiment over the Qinghai Xizang Plateau [J]. *Plateau Meteorology*, 1999, **18**(3): 333 - 340. (in Chinese)

[9] YAO De-liang, SHEN Wei-ming, XIE Zheng-tong, *et al*. Study on growth yield of forage grass in high cold meadow[J]. Acta Agrestia Sinica, 1996, **4**(4): 274 - 280. (in Chinese)

[10] YAO De-liang, SHEN Wei-main, ZHANG Qing, *et al*. A model of the land biosphere about alpine meadow ecosystem and its application[J]. *Plateau Meteorlogy*, 2002, **21**(4): 389 - 394. (in Chinese)

[11] XIE Zheng-tong, LI Jia-chun, Yao De-liang. A coupling model of the land-atmosphere interaction with canopy influence[J]. *Acta Mechanica Sinica*, 1998, **30**(3): 267 - 276. (in Chinese)

[12] LI Jia-chun, YAO De-liang, SHEN Wei-ming, *et al*. A coupling model for terrestrial processes in arid areas and its application[J]. *Applied Mathematics and Mechanics (English Edition)*, 1999, **20**(1): 1 - 11.

[13] YAO De-liang, XIE Zheng-tong, LI Jia-chun. Land-atmosphere interaction model and observation in Yucheng County[J]. *Acta Ecologica Sinica*, 2000, **20**(6): 1076 - 1082. (in Chinese)

[14] PAN Lin-lin, CHEN Jia-yi, ZHANG Hong-shen, *et al*. A one-dimensional coupling model for land-atmosphere interaction and its application in Inner Mongolia grassland[J]. *Atmosphere Sciences*, 1996, **20**(3): 267 - 277. (inChinese)

[15] Molz F J. Models of water transport in the soil-plant system: A review[J]. *Water Resour Res*, 1981, **17**(5): 1245 - 1260.

[16] KANG Shao-zhong, LIU Xiao-ming, XIONG Yun-zhang. *The Soil-Vegetation-Land-Atmosphere Countinuous Water Transfer Theory and Its Application* [M]. Beijing: Hydro-Electric Publishing House, 1994. (in Chinese)

[17] CHENG Qun-shu, FENG Xiu-zao, LIU Xiu-miao. *China Agriculture Encyclopedia*, *Volume of Agriculture Meteorology*[M]. Beijing: Agriculture Press, 1986. (in Chinese)