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RADIATION BALANCE AND MICROCLIMATIC FEATURES OF MARSH IN THE SANJIANG PLAIN

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ABSTRACT: Radiation balance, soil temperature and the temperature and humidity of air were measured in marshes and reclaimed farmlands of the Sanjing Plain. Soil–heat flux was calculated with two different methods. Through the analysis of a lot of data, the daily variations and the law of vertical distribution of microclimate factors on marsh surface was obtained. It is found that after marshes are reclaimed, radiation balance increases, both soil temperature at different depths and air temperature of various height near ground layer rise, and air humidity decreases obviously. Therefore, one should take the establishment of artificial ecosystem of growing paddy and reed and breeding fish as the main development direction of marshes, at the same time, protect some marshes in order to prevent the environment from getting dry, and maintain regional ecological balance.

KEY WORDS: marsh, radiation balance, microclimate, soil–heat flux

The Sanjiang Plain is located in northeast China. It includes the low plain formed by the alluviation of the Songhua River and the Wusuli River to the north of the Wanda Mountain, and the plain formed by alluviation and lacustrine action of the Wusuli River and Xingkai Lake and some hilly lands to the south of Wanda Mountain. It covers an area of 163,330,00 mu (1 mu = 1/ 15 ha). It is the important commodity grain base. But within this region many marshes are formed and spread all over the low–lying lands which are on the flood land, the lake side and the terrace because of low and flat topography, sticky and heavy soil, impeded drainage, and much rainfall in summer and autumn. There are now 167,890,000 mu of marshes altogether in this region according to the multi–spectrum satellite image analysis and the practical investigations. It is the largest region filled with marshes in China.

Since 1983 we successively made a series of continuous microclimate observations day and night on the reclaimed farmland and the typical marsh land (thickness of peat layer was 40cm, *Carex lasiocarpa, Deyeuxia angustifolia* and *Equisetum heleocharis* grew, the height of grass 60 cm, the cover degree was 90% and the soil was over wet) near the Raoli River—the Wusuli River branch three times in order to use and protect marshes better and learn about the change pattern of natural environment after marsh reclamation. Finally we got many valuable data, on the basis of these data, radiation of marsh land, soil climate and the basic characteristics of air temperature and air humidity near ground layer were analyzed and the proposals relevant to the development and utilization of marshes were put forward.

I. RADIATION ON MARSH SURFACE

Radiation balance (B) is the difference between the solar short wave radiation on ground surface and effective radiation; namely,

$$B = Q(1 - A) - F \qquad (1)$$

where, Q is the total radiation, A is the reflectivity of ground surface.

Radiation balance is the basic element that determines the change of air layer near ground layer, soil climate and land productive potentialities. There have not been any practical observation materials of the radiation balance of marsh surface in China. In order to learn about the change pattern we use net radiation meter and reflectometer in the observations.

As a result, in the marsh land covered with dense *Carex lasiocarpa* and *Deyeuxia angustifolia* vegetaion the radiation balance has an obviously daily variation, which is as the same as the other layers (Table 1). During the day time, the solar radiation volume absorbed by the marsh surface was more than the effective radiation and the radiation

Table 1 Radiation balance of marsh and reclaimed farmland [$J/(cm^2 \cdot min)$]

Observation date	Weather	Peat marsh land							Soybean land and ploughed farm land						
		2^h	5^h	8^h	11^h	14^h	17^h	20^h	2^h	5^h	8^h	11^h	14^h	17^h	20^h
June 18–19	Sunny	−0.12	0.26	2.77	3.60	3.28		−0.31	−0.13		2.57	3.80	2.97	0.22	−0.38
Sept. 3–8	Sunny, Sometimes doudy	−0.26	−0.22	1.43	2.82	2.24	0.07	−0.27	−0.35	−0.24	1.51	2.96	2.52	0.00	−0.35

balance was a positive value. Because the increasing speed of the radiation as the height of the sun rose was far more than the effective radiation, the radiation balance value got larger as the height of the sun rose; during the night time, the marsh surface lost its heat owing to the effective radiation, so the radiation balance was a negative value. The radiation balance value around the high noon was generally several or even ten more times bigger than the absolute value of the negative radiation balance at night. And the radiation balance was through zero within one day time, namely: $Q(1-A)=F$, it only appeared within the day time when short wave radiation was received. It generally happened within one hour after the sun rising and within or around one hour before the sun set.

Taking the daily variations of radiation balance in a sunny day (Sept.4, 1983) (Fig.1) for example, the radiation balance was changed from negative to positive through zero within 50 minutes after the sun rising in the morning. In the morning because

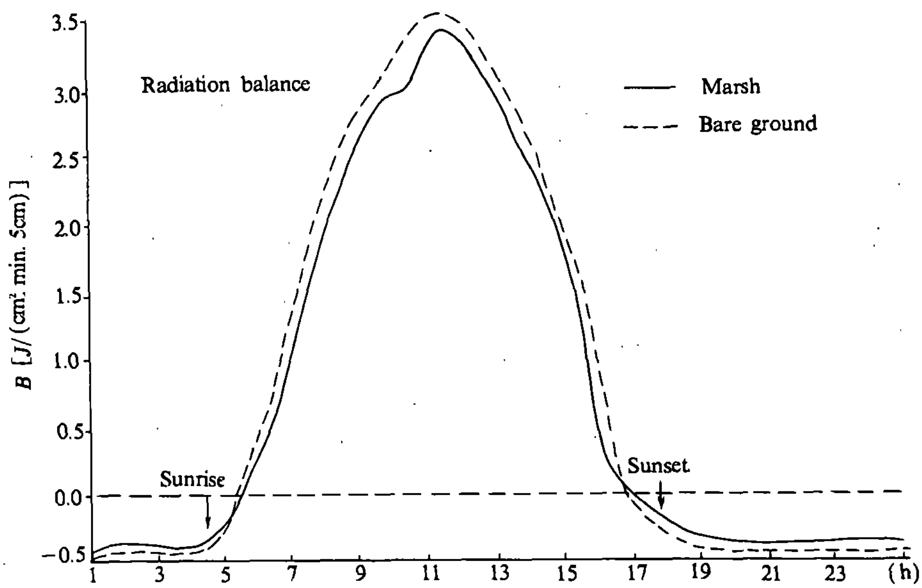

Fig.1 Daily variations of radiation balance of marsh and bare ground in a sunny day

$(1-A)\theta_F/\theta_t$ was larger than θ_F/θ_t, the radiation balance was gradually getting large, up to 11:25, the radiation balance value was the largest, that of marsh was $3.43J/cm^2 \cdot min$, the farmland $3.50\ J/cm^2 \cdot min$. The intensity of short wave radiation was the largest at noon time, the effective radiation was still getting larger with the rise of the ground temperature because the radiation input was no longer increasing, so the radiation balance had been falling. In the afternoon the total radiation intensity was weakened gradually as the height of the sun dropped, the radiation balance decreased progressively and the process of the progressive decrease was getting quicker and quicker, when it was up to 51 minutes before the sun set, the radiation balance changed from positive to negative, through zero; the lowest value of the radiation balance appeared at dusk and just at this time the radiation balance was near or equal to zero. The effective radiation was still maintaining a large numerical value because the ground temperature was still high. So the radiation balance value was the lowest. The variations of radiation balance were very small after 8 o'clock in the evening to before the sun rising. The effective radiation was reduced and the absolute value of negative radiation balance was also reduced at cloudy nights. For example, the night on Sept. 5, 1983, it had thin cirrostratus (C_5) and the negative radiation balance value was only 1 / 2 of that at clear night.

There is a great difference in the radiation balance above the vegetation layer of marshes (150 cm above ground surface) and in the vegetation layer (20 cm above ground surface). As seen from Table 2 the radiation balance reduces progressively from the upper vegetation of marsh to the bottom because the vegetation weakens the short wave radiation during the day time, when it is up to the height of 20 cm, the radiation balance is equal to only one half to one third of that above the vegetation layer; during the night time, the effective radiation reduces because of the blocking of the vegetation, the radiation balance increases progressively from the upper surface of the vegetation downwards the bottom (i.e. absolute value reduces). This is one of the important reasons why marsh soil temperature is lower than bare farmland and the daily change range is small.

Table 2 Radiation balance of marsh surface at different height [J / (cm^2 • min)]

Height	Sept.5			Sept.6		
	8^h	14^h	20^h	2^h	8^h	14^h
150cm	1.88	2.12	−0.21	−0.17	1.29	1.56
20cm	0.70	0.92	−0.10	−0.07	0.44	0.65

The reflectance of the marsh surface obtained through the practical observations is 0.15—0.20 around the high noon and the reflectance also has a little difference owing to the different type of marsh. For example, the reflectance of *Glyceria spiculosa* marsh is a little larger than that of *Carex pseudocuraica* marsh, the reflectance of *Deyeuxia angustifolia* after the heading period is a little larger than that before the earing period. When the height of the sun is under 30° , the reflectance of the marsh increases from 0.2—0.3[1]. Since the reclaimed bare farm land (dry farming land) has relatively dark colour owing to rich organic matter in the upper layer of soil, the reflectance around the high noon is from 0.07 to 0.15[2]. Therefore, the farmland surface can absorb much more short wave radiation during the day time, and the value of radiation balance is a little larger than that of the marsh surface. During the night time, the output of the effective radiation is a little smaller than that of the reclaimed farmland. This is because that the marsh is covered with vegetation and the air humid is large.

II. THE HEAT FLUX IN MARSH SOIL

The heat exchanging between soil surface and deep layer is the important component part of the heat balance on the ground surface. The variation of temperature in soil is determined by the quantity of the heat exchange.

There are many kinds of methods to calculate the heat flux in soil[3], we adopt the standard method of heat balance station and the heat content method of earth column. The theoretical basis of the standard method of the heat balance station was put forward by Д. Л.Лайхтмаи. Since it was introduced into China from the late 1950s, it has been used until now.

The calculating formula is:

$$Qs = \frac{C_m}{t_2 - t_1}(S_1 - \frac{K}{10}S_2) \tag{2}$$

where, Q_s is the heat flux in soil, C_m is the heat capacity of volume, K is the thermal conductivity, S_l means the temperature changing part of the earth column, if H takes 20 cm, $S_l \cdot C_m / t_2 - t_l$ means the variations of mean heat content in 0–20 cm layer within $t_2 - t_l$ time section. $S_2 = \int_{t_1}^{t_2} [\theta(H \cdot t) - \theta(h \cdot t)]dt$ so $- 1/ t_2 - t_1 CmKS_2 / 10$ means the average heat flux through 20 cm.

The heat content method of earth column is a kind of calculating method which set up on the basis of the changing rate that the mean heat flux of earth surface flowing into or out of earth column is equal to the heat content in this earth column within a certain time section. The formula is:

$$\triangle Q_s = \frac{1}{t_2 - t_1}\int_{Z_1}^{Z_2} C_m [\theta(Z,t_2) - \theta(Z,t_1)]dZ \tag{3}$$

where, $\theta(Z,t)$ means the ground temperature at the depth of Z and the time of t. If we let the average heat capacity of the whole soil layer substitute the heat capacity of volume (C_m) in every layer, the formula is:

$$\triangle Q_s = \frac{1}{t_2 - t_1} C_m \int_{Z_1}^{Z_2} [\theta(Z,t_2) - \theta(Z,t_1)]dZ \tag{4}$$

Since the vertical distribution curve of soil temperature can be expressed by straight line connection approximately (except for the place near the sunrise and sunset), generally we can calculate approximately the heat flux in every layer by trapezoid formula[4]. The soil heat flux of marsh and reclaimed farmland calculated with the two methods is shown in

Table 3.

Table 3 Calculated soil heat flux of marsh and ploughed farmland [$J/(cm^2 \cdot min)$](Sept.3–6, 1983)

Type	Method	Time section					
		1:40–7:40	7:40–10:40	10:40–13:40	13:40–16:40	16:40–19:40	19:40–1:40
Marsh	1	0.017	0.557	0.314	−0.113	−0.410	−0.356
	2	−0.025	0.599	0.343	−0.151	−0.456	−0.344
Ploughed	1	0.100	0.682	0.389	0.314	−0.402	−0.289
farmland	2	0.121	0.666	0.281	0.368	−0.498	−0

1: The heat content method of earth column; 2: The standard method of heat balance station.

The data in the table show that the results calculated with the two methods are fairly same. The heat flux of the marsh transmitting from the soil surface to the deepest layer is smaller than that of the reclaimed farmland during the day time. And it is similar at night. The daily changing curve of the heat flux in marsh soil of every layer (Fig.2) approximates to a sine wave and the amplitude is reduced as the increase of the depth. The maximum value of the heat flux in the surface layer appears 9 to 10 o'clock in the morning. It is 3 to 4 hours earlier than the highest temperature on ground. The lowest value appears 5 to 6 o'clock in the afternoon.

Because of the small thermal conductivity of the marsh layer, the daily variations of the heat flux have been very small when it is up to the depth between 15 and 20 cm. The daily amplitude is only 0.021 $J/cm^2 \cdot min \cdot 5cm$.

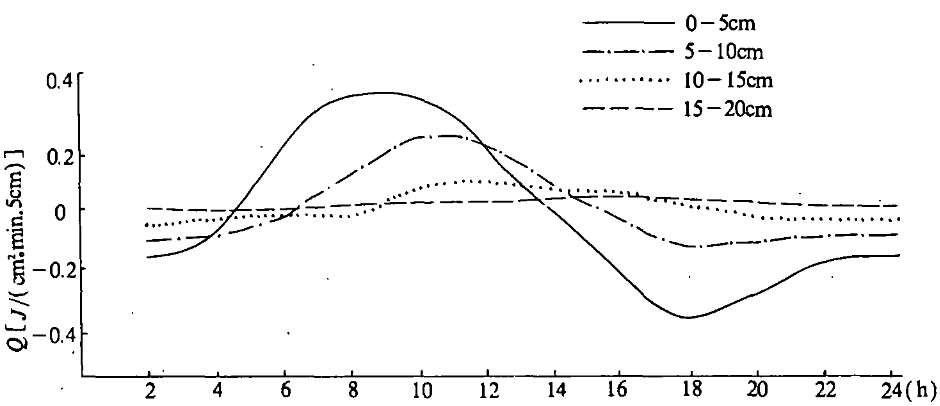

Fig.2 Daily variation curves of heat flux of marsh soil lay of 5cm thickness

III. TEMPERATURE IN MARSH SOIL

The variations of soil temperature have a close relation with radiation balance, soil thermal properties and soil heat flux. The thermal properties of peat marsh soil have clear differences as the soil humidity changes. The natural water content in the marsh soil reached 309.4% and the average bulk density in the marsh layer was 10,225g / cm^3 during the observation period. According to the method by C.A. Сапонеников а [5], the calculated thermal capacity of volume is 3.56 J/ (cm^3 • ℃), the daily average *temperature conductivity* is 7.8×10^{-4}cm^2/ s. The water contents of soil in ploughed farmland are respectively 39.1% at the depth of 0–10 cm and 43.8% at the depth of 10–20 cm, the bulk density of soil is 0.71g / cm^3, through calculation, the thermal capacity of volume is 1.8 J (cm^3 • ℃), the daily mean is 2.8×10^{-3}cm / s. Obviously, the thermal capacity of over wet marsh land is larger than that of the reclaimed farmland, but the *temperature conductivity* is smaller than that of the reclaimed farmland[6].

The variations of soil temperature in different depths of peat marsh have the following characteristics:

1. The daily variation amplitude of soil temperature of marsh is smaller than the bare ground. Taking the ground temperature for example, when the daily variation amplitude of bare ground is 23.4℃ in sunny days, the marsh surface is only 12.9℃. When the daily variation amplitude of the soil temperature of bare ground at the depth of 10 cm is 5.7℃, that of the marsh land is only 3℃ (Fig.3). This is the reason why the daily variation amplitude of the radiation balance on the marsh surface is smaller and why the heat capacity is larger. The range of the fluctuation of soil temperature is reduced according to the geometric progression with the increasing of depth, and the *temperature conductivity* of marsh soil is also smaller, it's generally within 40 cm. Because the thermal capacity of the drained marsh reduces, but the temperature conductivity increases, the daily variation amplitude of the drained marsh is larger than that of the stagnant water marsh.

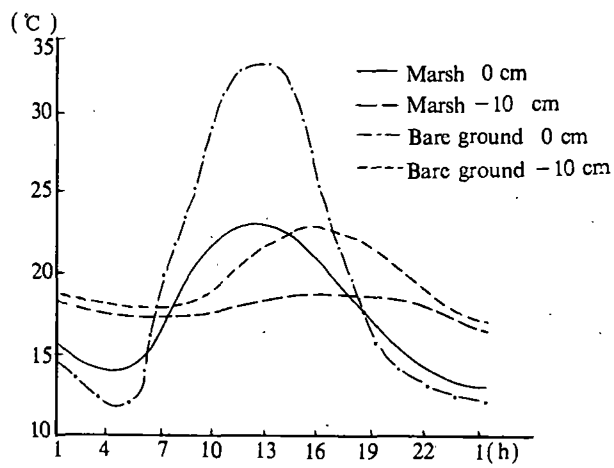

Fig.3 Daily variation of soil temperature of marsh and bare ground at different depths (Sept. 4), 1983, a sunny day)

2. The phase delay of soil temperature of marsh is larger than that of the reclaimed farmland. In theory, the phase delay is increased linear with the depth. But the quickness

and slowness of the delaying just becomes an inverse ration with the square root of the temperature conductivity and of harmonic volume. The temperature conductivity and thermal conductivity are both small. The temperature wave transmits slowly. So the phase delay is large.

3. Many observations from June to September proved that the soil temperatures of different depths in marsh land were all lower than the reclaimed farmland (Table 4) except that the lowest temperature on ground surface before the sunrise was sometimes higher than the bare ground. In the late spring and the early autumn, the average daily temperature on the ground surface of marsh is generally 3—5℃ lower than the reclaimed farmland. The highest ground temperature is 6—12℃ lower than the farmland; with the comparison of the average daily soil temperature at the depth of 5—20 cm, the temperature increasing of marsh was slow in spring, it was 5—10℃ lower than the farmland, there was a thin layer of water on the marsh land in summer, it was 8—12℃ lower than the ploughed farmland; the temperature of marsh decreased slowly in autumn, it was only 1—3℃ lower than the farmland. So we can see from this fact that the thermal regime of soil in marsh land was not good, due to stagnant water, vegetation coverage and small temperature conductivity, but it could be improved obviously after reclamation.

Table 4 Comparison of soil temperature between marsh and bare farmland (℃)

Obseration date	Average daily soil temperature					Highest temperature of ground	Lowest temperature of ground
	0cm	5cm	10cm	15cm	20cm		
June 18	−2.8	−5.1	−7.0	−8.6	−10.3	−8.7	−0.5
Aug. 14	−13.3		−10.3		−10.3	−20.1	−3.3
Sept. 3	−3.3	−1.4	−0.9	−2.3	−2.7	−6.3	+0.5
Sept. 4	−3.0	−1.5	−1.7	−2.1	−2.7	−9.1	+0.5
Sept. 5	−4.9	−2.1	−2.6	−1.6	−2.8	−11.8	+0.8

4. The vertical distribution of soil temperature (Fig.4). Because of the daily variations by different elements of radiation balance, the vertical distribution of soil temperature in

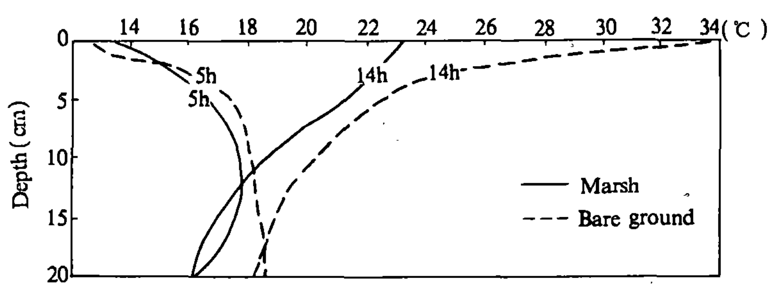

Fig.4 The vertical distribution of soil temperature of marsh and bare ground (Sept. 4, 1983)

marsh land can be divided into the insolation pattern in daytime, the radiation pattern at night and the transitional pattern at dawn and dusk, but the vertical gradient is not larger than the reclaimed farmland, and the pattern transformation is also slower than the farmland.

IV. THE CHANGE OF TEMPERATURE AND HUMIDITY OF ATMOSPHERE NEAR GROUND LAYER OF MARSH LAND

The change of the air temperature near ground layer (below 2m) depends on radiation balance, ground temperature and turbulence exchange intensity. Because there is a thin layer of stagnant water or the soil is over wet in the marsh, as well as the vegetation weakens solar radiation, the temperature rising on the ground surface is very slow during the day time, so air the temperature near the ground layer is lower than the reclaimed bare farmland. Although the ground surface temperature of marsh is sometimes higher than the bare farmland at night, the air temperature is still lower than the reclaimed bare farmland owing to the influence of radiation cooling by the vegetation itself. It can be seen from Table 5 that when marsh is compared with the farmland, the largest temperature difference appears at the height of 20 cm and it is reduced gradually upwards. The largest difference appears from 1 to 5 o'clock in the afternoon within one day. In summer, the same result is achieved in the observations along the bank of the Qihulin River. But the temperature of the drained or dried marsh land in daytime is higher than the bare farmland, because the ground surface temperature rises strongly, and sometimes the weakening of the vegetation to turbulence exchange exceeds the weakening function to radiation.

Table 5 The differences in average daily temperature of marsh and bare farmland (℃)

Observation date	Height (cm)			
	20	50	150	200
June 18	−1.5	−1.2	−0.8	−0.4
Aug. 13	−2.6	−1.8	−1.1	
Sept. 3	−1.8	−1.4	−1.0	−0.9
Sept. 4	−2.5	−1.8	−1.3	−0.9
Sept. 5	−2.4	−1.7	−1.3	−1.0

The vertical distribution of the air temperature near the ground layer also can be divided into the insolation pattern, the radiation pattern and transitional pattern. But the vertical distribution of air temperature on the marsh land is regulated by the water body in marshes. Generally, the insolation pattern of air temperature with the decrease of height is not clear, even around the high noon, isotherm or inversion phenomenon often appears.

The variation of air humidity near ground layer mainly depends on hydrothermal regime of ground. On the over wet marsh land, the water source of evapotranspiration is abundant and the temperature is slightly low, so the relative humidity is larger than the reclaimed farmland. According to the observations in Sept. 3—6, 1983 and June 18—19, 1985 the average daily relative humidity of 20 cm height on marsh land was 6—16% higher than the reclaimed farmland, that of 150 cm height, was 5—9% higher than the bare ground. Within one day time, the greatest differences appeared in the afternoon (Fig.5). According to the observations on the bank of the Qihulin River in the middle August 1978, the average daily relative humidity of marsh land was 7—13% higher than the reclaimed farmland, the regulations obtained through the observations in spring, summer and autumn were completely the same.

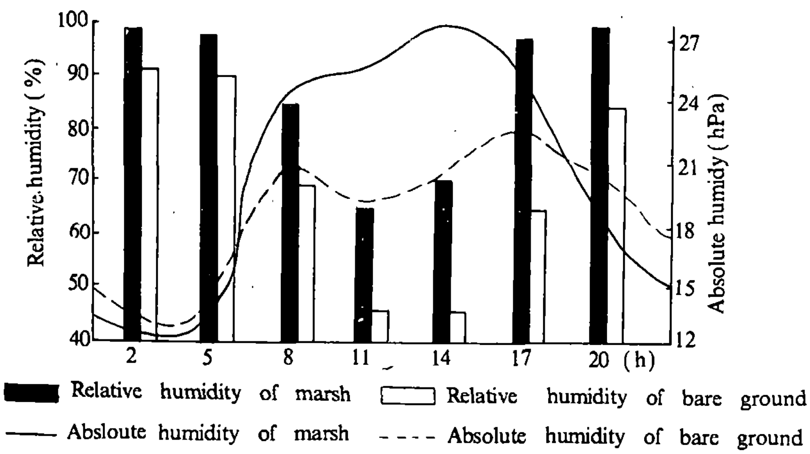

Fig.5 Comparison of air humidity of 20 cm above marsh and bare ground (Sept. 5, 1983)

In comparison of absolute humidity (vapour pressure) between the marsh land and the bare ground, the total evaporative quantity of the marsh land was fairly larger during the day time and the turbulence exchange was weakened. It is not easy to evaporate vapour on the ground surface and between the plants. So the absolute humidity of the marsh land was larger than that of the bare ground. Generally it was different from 3—5 hPa around the high noon. But it is quite different at night. Because the temperature of the marsh land at the height of 20 cm and 50 cm was often lower than that of the bare ground, the saturation vapour pressure was small, the unnecessary vapour was frozen into dew, so the absolute humidity was 1—3 hPa smaller than the bare ground. The daily variation of absolute humidity is generally two—peak type. The evaporating vapour was not reduced in the afternoon owing to the abundant water resource in marsh land and because the turbulence exchange was fairly weak in autumn, so the decrease of absolute humidity was unclear. It's close to the daily variation of one-peak type.

When there exists evaporation, The absolute humidity was progressively reduced with the height, and the gradient decreases with the increase of height, its distribution is damp type. Generally speaking, the damper the ground surface, the weaker the turbulence exchange, the more vigorous the evaporation, the larger the vertical gradient of absolute humidity, so the gradient of the absolute humidity in marsh land is larger than the bare ground. Taking 2 o'clock in the afternoon for example, the differences of moisture at the height of 150 cm and 20 cm averaged 4.6 hPa on the marsh land, but only 2.1 hPa on the bare ground. The practically observed vertical distribution shows no difference from the theoretical distribution, namely, the outline is a logarithmic model. During night time the freezing phenomenon often occurs on the marsh land surface and the vegetation surface, so the absolute humidity is increases with the height increasing. It assumed the dry type of distribution. No matter it's in day time or at night time, the relative humidity distribution is mostly damp type, and the vertical gradient is generally small except around the high noon.

V. CONCLUSIONS

1. The results of radiation balance firstly observed on the marsh land show that the radiation balance of the marsh surface in the Sanjiang Plain is a little smaller than the reclaimed bare farmland in the day time, and effective radiation output at night is also lower than that of the farmland. The maximum value of the positive radiation balance appears before the high noon within one day time. The change moment of the positive and negative radiation balance occurs about one hour after the sunrise and before the sunset. The absolute values of the positive radiation balance and the negative radiation balance at the height of 20 cm among plants is only equal to one half to one third of 150 cm height because of the effect of marsh vegetation.

2. The results of soil-heat flux calculated by the standard method of the heat balance station and the heat content method of earth column are nearly the same. The quantity of heat exchange between the surface and the deep layer of marsh is slightly smaller than the reclaimed farmland, the maximum value of the surface heat flux appears 9 to 10 o'clock in the morning. The heat flux reduces rapidly as the depth increases.

3. The mean daily soil temperature at various depths is all lower than the bare farmland because of the vegetation covering over marsh land, the large thermal capacity, the small temperature conductivity and the vigorous evaporation. Particularly, its highest temperature is several to more than 20℃ lower than the ploughed farmland, showing that the condition can be improved obviously after marsh land is drained and reclaimed.

4. The marsh is regulated by stagnant water and vegetation, air temperature below 2 m is lower than the bare ground, and the vertical distribution of air temperature mostly as-

sumes the isotherm or temperature inversion type. The insolation pattern is not clear.

5. After the reclamation of marsh land, the average daily relative humidity near ground layer is reduced by 5—16%, the absolute humidity is reduced 3 to 5 hPa around the high noon.

6. According to the microclimate environmental change before and after marsh reclamation, in particular, the change of air humidity, the proposals have been made that the development and utilization of marsh land should suit its low temperature condition, opening up paddy field, growing reed and fish breeding should be as the main ways. And some marshes should be as natural reserves, natural park, detention basin and the wide embankment drainage basin. One should not further reclaim marsh land into dry farmland for crops in order to prevent the environment from getting dry and to keep the regional ecological balance.

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