RELATION BETWEEN LONG-DISTANCE MIGRATION OF ORIENTAL ARMYWORMS AND SEASONAL VARIATION OF GENERAL CIRCULATION OVER EAST ASIA

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ABSTRACT

China is situated in the region of the prevailing East Asian monsoon, which has obvious seasonal variation. There exists a close relation between the long-distance northward and southward movement of armyworms and the seasonal variation of the general circulation in the lower atmosphere over East Asia. So according to the data of moths and the notes of meteorological observation, we put emphasis on analysing the problems of the transmigration direction, height, limits, ascending and descending condition of armyworms and moths base in this country, and then draw the transmigration route diagram.

I. RELATIONSHIP AMONG GROUND CLIMATIC FRONTAL ZONE, ADVANCE AND RETREAT OF 500 hPa CHARACTERISTIC CONTOUR, AND NORTHWARD AND SOUTHWARD MOVEMENT OF ARMYWORMS

Ground climatic frontal zone and the advance and the retreat of 500 hPa characteristic contour can show the situation of seasonal variation in the lower atmospheric circulation.

According to the time sequence of the incidence of armyworms in China, we divide the territory into the following five major incidence area[1-4]: the first-time incidence area (nearly the south of 27°N), including mainly Fujian, Guangdong, Guangxi and Taiwan; the second-time incidence area (about 33—36°N), including mainly the middle and southern parts of Henan, the northern part of Jiangsu and Anhui, the south of Shandong and the northwest of Hubei; the third-time incidence area (nearly the north of 39°N), including mainly the Northeast China, Inner Mongolia, Beijing, Hebei, Shanxi, Shaanxi, Gansu, the western part of Guizhou, Sichuan and Yunnan; the fourth-time incidence area (about 36—39°N), including mainly Shandong, Hebei, Henan and east Shanxi; and the fifth-time incidence area (nearly the south of 33°N), including mainly Fujian, south Jiangxi, south Hunan, Guangdong, Guangxi, Jiangxi, Zhejiang and south Jiangsu and Anhui. There are two processes of migration from south to north (west) in the first half year. In the second half year there are also two processes of migration but from north to south. Whenever armyworms migrate into a new region, they breed a generation within about 60 days and then continue the migration. We recognize that the phenomenon of long-distance northward and southward movement of armyworms has close relation to the seasonal variation of lower atmospheric circulation in East Asia.

Shown in Figs. 1 and 2 are the locations of ground climatological frontal zone of February, April, June, August and October and 500 hPa characteristic contour, and the sketch of northward and southward movement of armyworms. From Fig. 1, we can see that the region of the northward movement of armyworms varies as the seasonal position of the 500

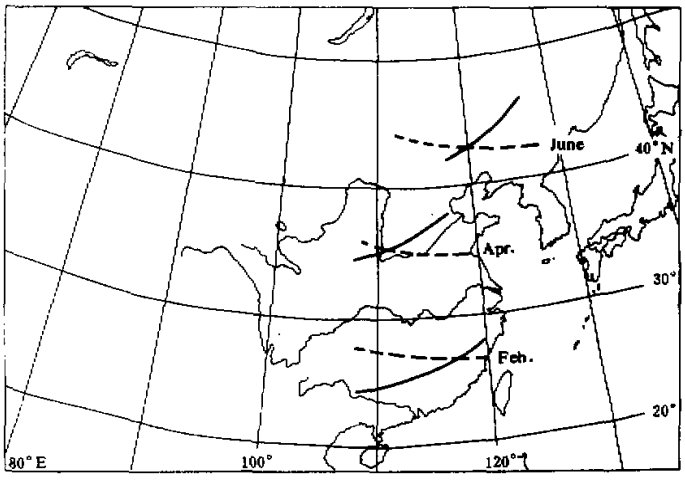

Fig. 1. The locations of the ground climatological frontal zone of February, April and June and 500 hPa characteristic contour, and the sketch of northward movement of armyworms.
---- 572 line; —— ground climatological frontal zone.

Fig. 2. The locations of the ground climatological frontal zone of August, October and 500 hPa characteristic contour, and the sketch of southward movement of armyworms.
---- 584 line; —— ground climatological frontal zone.

hPa characteristic contour (572 geopotential dkm contour, called 572 line) and ground climatological frontal zone move northward. In February, the subtropical high of the West Pacific is weaker and the position is to the east of the normal, the average position of 572

line is near 27°N on 500 hPa chart. According to the surface map, there is a climatological frontal zone from northeast to southwest along the Nanling Mountains. On the north side of frontal zone, northwest air current is usually prevailing and on the south side of the frontal zone, southwest air current is usually prevailing, thus the climate in Guangdong, Guangxi and Fujian being warm and wet. This is suitable for armyworms to cause disaster. In early spring, the strength of cold air is gradually getting weaker, while southwest air current getting stronger and pushing to the north. On 500 hPa chart in the case that 572 line moves to near 35°N and that the ground climatological frontal zone moves to the southern part of North China, armyworms get over the Nanling Mountains with the southwest air current, entering into the second-time incidence area, accomplishing the first transmigration. In June, the southwest air current continues to push towards the north. In the case that 572 line jumps to near 43°N on 500 hPa chart and that the climatological frontal zone moves along the line of Harbin–Siping–Chifeng–Zhangjiakou, on surface map armyworms transmigrate to the third-time incidence area, accomplishing the second transmigration.

The region of southward movement of armyworms also varies with the average position of ground climatological frontal zone and 500 hPa characteristic contour. From Fig. 2 we can see that when 584 geopotential dkm characteristic contour at August 500 hPa is situated near 38°N and the ground climatological front zone goes back to the Baoding–Xingtai–Linfen line, armyworms transmigrate to the fourth-time incidence area, thus accomplishing the third transmigration. In October, the subtropical high over the West Pacific already fails and the winter monsoon influences the south region of the Changjiang River while 584 line moves to the south near 26°N on 500 hPa chart and the ground climatological frontal zone moves to the Nanling Mountains. In this case, armyworms transmigrate to the south with northwest air currents, accomplishing the fourth transmigration.

Because the situation of active cold or warm air is different each year, the occurrence time of the transmigration of armyworms is also different. For example, in the warm spring of 1978, the position of the subtropical high moved to the north steadily, and the 572 line of 500 hPa also moved to the north with it. The variation of position of 500 hPa 572 line at 120°E is as follows. It moved to 30.8°N in March, 1978, to 32.2°N in April, and to 39°N in May. The transmigration time of a new generation of adult armyworms from the second-time incidence area to the third-time one is from the end of May to the beginning of June. Since it was a severe cold spring in 1979, the subtropical high could not move to the north all along, thus the position of 120°E 500 hPa 572 line moved only to 28.3°N in March, 32.8°N (nearly the same as in 1978) in April, and 35.6°N in May, which is 3.4 degrees of latitude more southward than that of 1978. The air temperature was obviously lower. Therefore the transmigration time of a new generation of adult armyworms to the second-time incidence area was deferred until the beginning of June.

II. WEATHER SYSTEM AND ARMYWORMS' ASCENDING OR DESCENDING

1. *Weather System and Armyworms' Ascending*

It has been pointed out that updrafts are of great advantage to armyworms' ascending, but downdrafts are not[5]. Based on this conclusion we analyse the weather system in Xuzhou area during the period of transmigration of a new generation of adult armyworms, 1978 (see Fig. 3). Here we only take a short period from 30 May to June as an example. It can be seen from Fig. 3 that Xuzhou was situated before trough and behind ridge from

31 May to 2 June, and remained behind ridge during 5—10 June, thus southeast and southwest winds prevailed. During about 75 % of this period, often occurring in these weather systems were updrafts which are of great advantage to armyworms' ascending. On the contrary, the weather situation was unfavorable for armyworms' ascending when Xuzhou was situated before ridge on 30 May or before ridge and behind trough during 3—4 June, because of the northeast and northwest winds causing downdraft very often.

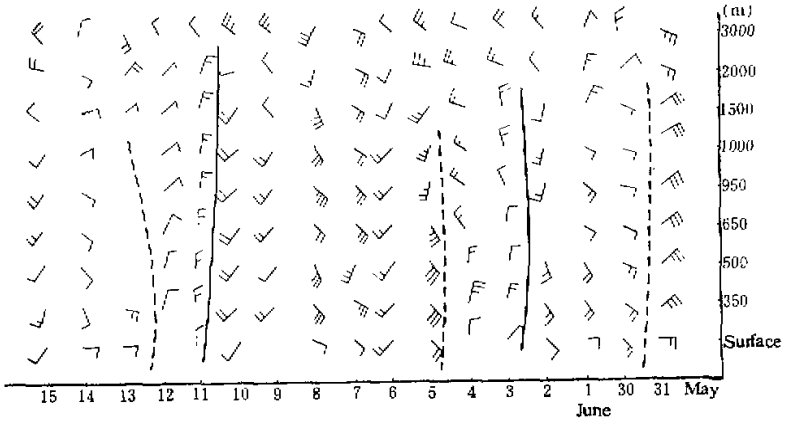

Fig. 3. Time-height cross section during the period of transmigration for the first generation of adult armyworms in Xuzhou area from 30 May to 10 June, 1978.
——— trough line; - - - - - ridge line.

2. *Weather System and Armyworms' Descending*

Selecting three examples in different seasons and regions, i. e. the adult armyworms transmigrated from the first-time incidence area into Xuzhou during 15 March—22 April, 1978, those transmigrated from the second-time incidence area into Shenyang during 21 May—12 June 1978, and those transmigrated from the third-time incidence area into Dezhou during 16 July—20 August, 1979, we have drawn a picture of time-space cross section of upper wind during the period of transmigration (figure not shown), and statistically analyzed the influence of various weather system on armyworms' descending. Listed in Table 1 are the results calculated. From this it can be seen that:

(1) Even in the same weather system, the numbers of moths reaching different places are also different because of the different seasons and places of transmigration, as well as the different activities of weather system. For instance, the ratio of the number of descending moths to the total, when it is before ridge and behind trough, is 34.8 % for Shenyang, 51.2% for Xuzhou, and 64.7 % for Dezhou.

(2) Of 94 descending days for northward migration and southward returning of armyworms, 3 days are situated before trough, 2 behind trough, 41 behind trough and before ridge, 43 behind ridge and before trough, 2 before ridge, and 3 behind ridge. The corresponding ratios of descending moths to the total are 0.4, 0.9, 51.6, 46.0, 0.4 and 0.7 %, respectively. Therefore, armyworms can descend in all the weather systems mentioned

Table 1. The Relationship between Armyworms Descending and Weather System*

Place (Time)	Before T			Behind T			Behind T & Before R			Behind R & Before T		
	No. of Moths	%	D	No. of Moths	%	D	No. of Moths	%	D	No. of Moths	%	D
Xuzhou (1978)	3	0.1	1	—	—	—	1081	51.2	19	1018	48.1	18
Shenyang (1978)	13	1.4	2	38	4.3	2	310	34.8	6	531	59.5	9
Dezhou (1979)	—	—	—	—	—	—	787	64.7	16	396	32.6	16
Total	16	0.4	3	38	0.9	2	2178	51.6	41	1945	46.0	43

Place (Time)	Before R			Behind R			Total	
	No. of Moths	%	D	No. of Moths	%	D	No. of Moths	D
Xuzhou(1978)	—	—	—	13	0.6	1	2115	39
Shenyang(1978)	—	—	—	—	—	—	892	19
Dezhou(1979)	15	1.2	2	18	1.5	2	1216	36
Total	15	0.4	2	31	0.7	3	4223	94

*T: trough, R: ridge and D: days.

above and the numbers of descending moths are somewhat larger in the weather situations, such as before ridge and behind trough, behind trough, and before ridge (52.9%). These weather systems are favorable for the descending of armyworms, which is consistent with the previous results obtained[5,6].

III. TEMPERATURE FIELD IN THE LOWER ATMOSPHERE AND ARMYWORMS' TRANSMIGRATION

1. *The Height of the Armyworms' Transmigration*

It is suggested that[7,8] the suitable temperature for the long distance transmigration of armyworms is within the range of 17—20°C with the lowest limit of temperature being 10°. Because we can not capture armyworms at various altitudes so far, an alternative is to replace the height of armyworms' transmigration by the height at which the atmospheric temperature is within the range mentioned above.

According to the above criteria of temperature, the average heights of 10°C and 17—20°C isotherms are given at 10 places in this country, listed in Table 2. From the table we can see the variation of flying heights with seasons and latitudes. From spring to summer, the height of armyworms' transmigration increases month by month, the area of their transmigration

extends gradually. However, from summer to autumn, the suitable height of transmigration decreases month by month, and the area of their transmigration gradually shrinks back from the north to the south. Since the temperature in spring is lower than that in autumn at the same altitude, the south–north transmigrating height of armyworms in spring is also lower than the north–south transmigrating one in autumn.

In March, only the temperature in Haikou is higher and the suitable flying height ranges 620—1120 m. However, the upper air temperature in other places is rather lower, which is unsuitable for flying and thus there is no significant transmigration. In April, the temperature in the inland area increases rapidly, and so does the height of 10°C and 17—20°C isotherm. The suitable flying area of armyworms extends from coast to inland, and the suitable flying height along the coast is higher than that of inland. For example, the suitable transmigratng height over Haikou is as high as 1300 m, but that for Enshi decreases

Table 2. Average Heights (in m) of Isotherms (10°C, 17—20°C)

North Latitude		43°54′	41°49′	36°04′	39°48′	36°41′	34°43′	34°17′	23°24′	30°16′	20°02′
Place		Changchun	Shenyang	Qingdao	Beijing	Jinan	Zhengzhou	Xuzhou	Shantou	Enshi	Haikou
March	10℃								2170	750	2900
	17—20℃										1120—620
April	10℃			810	700	920	850	1050	2890	1590	3140
	17—20℃								960—460	450	1850—1350
May	10℃	1310	1450	1980	1920	1880	1680	2190	3190	2390	3300
	17—20℃				880—380	970—470	850—350	890—390	1600—1100	1140—640	2000—1500
June	10℃	1870	2020	2480	2570	2590	2800	2600	3350	3000	3340
	17—20℃	840—340	860—360	1300—800	1670—1170	1610—1110	1830—1330	1600—1100	1900—1400	1780—1280	1990—1490
July	10℃	2560	2720	3000	2930	3210	3350	3400	3460	3300	3400
	17—20℃	1330—830	1440—940	1950—1450	1800—1300	1970—1470	1820—1320	2080—1580	2050—1550	2100—1600	2080—1580
Aug	10℃	2400	2640	3120	2800	3120	3250	3280	3380	3320	3370
	17—20℃	1200—700	1360—860	1840—1340	1620—1120	1770—1270	1950—1450	1950—1450	2000—1500	2090—1590	2000—1500
Sept	10℃	1300	1530	2170	1920	2120	2320	2300	3290	2940	3300
	17—20℃			850—350	830—300	1130—630	1030—530	1050—550	1810—1310	1510—1010	1850—1350
Oct	10℃			1050	910	970	1390	1270	2950	1740	3300
	17—20℃								1130—630	560—60	1420—920
Nov	10℃								2250	870	2800
	17—20℃								410		950—450

down to 450 m or less. In May and June, the suitable flying area gradually extends northward and reaches its northernmost part in June. At this time, the difference of suitable flying heights between the north and south reduces, e. g. that in Xuzhou is about 1110—1600 m, but 360—860 m in Shenyang and 340—840 m in Changchun. In July such height reaches its maximum, then starts decreasing from August and reduces obviously in September and October. Finally, the 17—20°C isothermal surface disappears over most of areas except the coastal ones with higher temperatures.

2. *Boundary of Armyworms' Landing*

It can be seen from Table 2 that the 10°C isotherm at the height of 800—1000 m in April is near 36°N. This explains why a great number of adult armyworms of overwintering generation migrate into the area south of 36°N. To the south of this line, the air temperature below 1000 m is above 10°C, and the armyworms are able to fly on their own. At that time the air temperature near the surface reaches 12—14°C already and wheat is thriving so that there are plenty of food and suitable ecological conditions for armyworms. In the north of this line, the air temperature below 1000 m is lower so that the ability of armyworms' flying on their own reduces obviously. Even though the air flow brings some armyworms to the Northeast area, the ecological conditions are unsuitable for them because of the lower temperatures. The ground temperature in the south part of Northeast is only 0°—2°C in March and 8°C in April. The temperature in other parts of Northeast is even lower and most crops are not sown or grown.

The second and third armyworms' transmigrations are not limited by temperature because of the higher temperature at that time. In September and October the temperature reduces obviously, the suitable flying area for armyworms is limited to the south of 33°N. At this time the millet, corn, Chinese sorghum, and rice in the fourth incidence area are to be harvested and the rice in South China grows so luxuriantly that the nutrition supply to armyworms is sufficient.

IV. HUMIDITY FIELD IN THE LOWER ATMOSPHERE AND THE LIMIT OF THE ARMYWORMS' TRANSMIGRATION

The research[9] indicates that the suitable range of the relative humidity required for the life of adult armyworms and their egg-producing is 50—70 %[9].

The analysis of temperature field shows that the 10°C isotherm at 800—1000 m in April is a good indicator. Therefore we take the humidity field of 900 hPa level, which is about 1000 m high in April, and choose the relative humidity of 50—70 % as a criterion to analyse. It can be seen from Table 3 that the relative humidity is higher than 50 % in the area south of 36°N in April and lower than 50 % in the area north of 36°N. So the isohume of 50% at the height of about 1000 m can also show why the overwintering adult armyworms mainly land on the area south of 36°N.

The second, third and fourth transmigrations are not limited by the humidity because of the higher relative humidity.

V. FLOW FIELDS IN THE LOWER ATMOSPHERE AND THE DIRECTION OF ARMYWORMS' TRANSMIGRATION

From the analysis of diagrams of 1500 m flow fields averaged for many years (Central Meteorological Service[10], 1974) we can see the following:

Table 3. The Relative Humidity on 900 hPa Isobaric Surface for an Average April

North Latitude	Place	Relative Humidity (%)	North Latitude	Place	Relative Humidity(%)
43°36′	Tongliao	40	39°41′	Beijing	36
41°39′	Shenyang	43	37°41′	Jinan	40
42°16′	Chifen	35	35°41′	Zhengzhou	51
38°54′	Luda	45	34°43′	Xuzhou	53
36°04′	Qingdao	50	34°17′	Hefei	65
33°46′	Sheyang	57	31°51′	Nanchang	74
32°00′	Nanjing	65	28°12′	Changsha	76
26°05′	Fuzhou	81	23°24′	Shantou	80

In March and April the west winds in this country begin weakening considerably, the westerlies move to the north and the anticyclonic circulations over the West Pacific strengthen. The southwest air currents in the northwest of the anticyclone enter the mainland in March, and expand continually to the north. They approach to Changjiang and Huaihe Rivers basin in April, the north limit they can reach is 35°N (see Fig. 4.). The southwest and north flows form an obvious shear line along the line of Kunming–Yichang–Linyi, on the southeast side of which the warm and wet southwest flows prevail, the armyworms migrate into the second incidence area with the air flow. The north limit reached by southwest flows is generally the limit landed by most armyworms. At this time the northwest flows still control the Northeast and North China, so only few armyworms are brought by south and southwest winds to the above-mentioned regions.

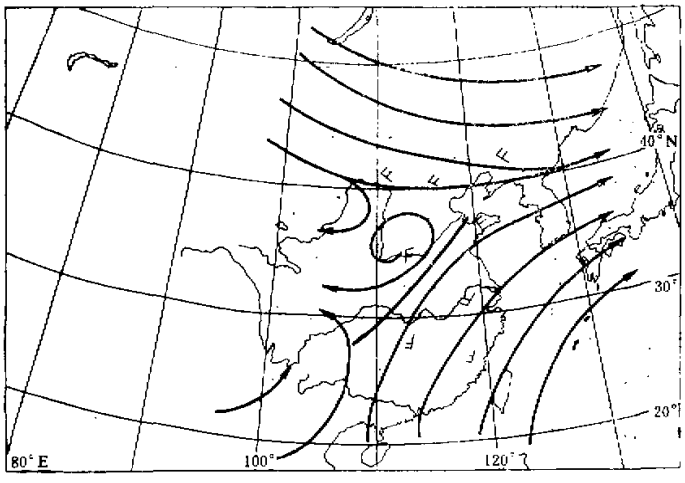

Fig. 4. The flow field at 1500 m for an average April.
(The direction of arrows shows that of air currents)

The westerlies weaken again and remove to the north in May and June. The westerly trough locates at about 120°E and its base about 38°N. The warm cyclone of the continent

develops and the subtropical anticyclone over the west Pacific strengthens, removes northwards and spreads westwards, while the southwest air currents continue to spread northwards. Most of the eastern areas in this country are controlled by southwest air currents. There is a branch of the east air current at about 35°N(see Fig. 5), flowing to the west. Fol-

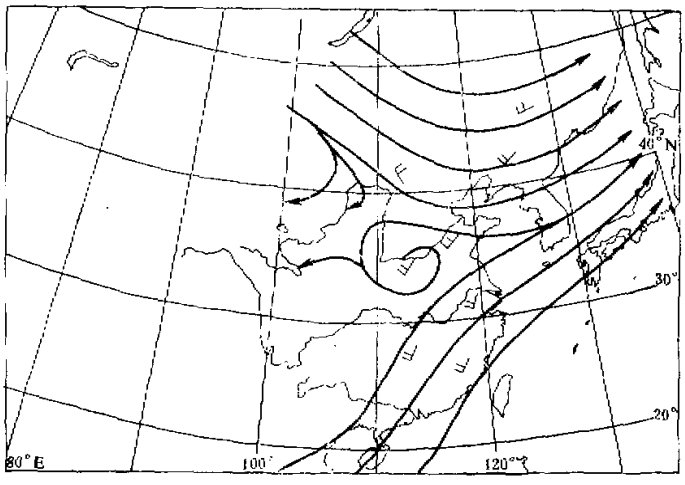

Fig. 5. As in Fig. 4, except for June.

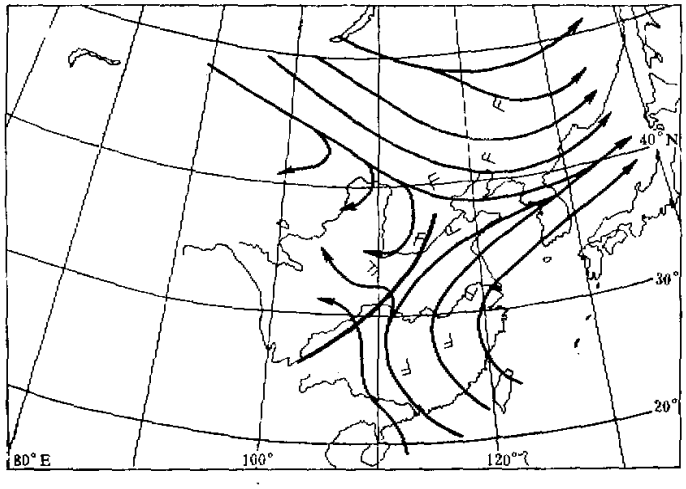

Fig. 6. As in Fig. 4, except for August.

lowing the southwest air currents, the first generation of armyworms in the second incidence area lands in the northeast region and other places, or following the east air currents lands in the southwest and northwest regions. In June, the north limit influenced by southwest air currents is about 49°N, which can be regarded as the north limit of the transmigration.

In July and August, the main period of summer, the tropical pressure system intensely influences the mainland of China. The southwest air currents reach the northernmost in

July, but retreat southward to about 36°N with their weakening in August. At the same time west air currents strengthen and push to the south. For instance, the prevailing wind in Beijing is southwest in July and turns to the northwest in August (see Fig. 6). The second generation of armyworms in the northeast area withdraws with the southwest air currents, and transmigrates back to the fourth incidence area. The north limit of withdrawing of the southwest air currents is the same as the south limit of transmigration of armyworms.

In September and October, when autumn comes, the situation of flow fields changes greatly in the lower atmosphere. The subtropical anticyclone weakens. As a result, the prevailing southwest air currents disappear gradually in China. The northwest air currents control the Northeast and North China, and the northeast air currents the other areas (see Fig. 7). In this case armyworms remove back to the south of 33°N.

The above analysis shows that the direction of armyworms' transmigration is very similar to that of flow field in the lower atmosphere, and that the limits of armyworms' transmigration are also identical with those of push and retreat of the southwest air currents. Therefore, the armyworms' seasonal long-distance migration is closely related to the seasonal change of the flow fields in the lower atmosphere.

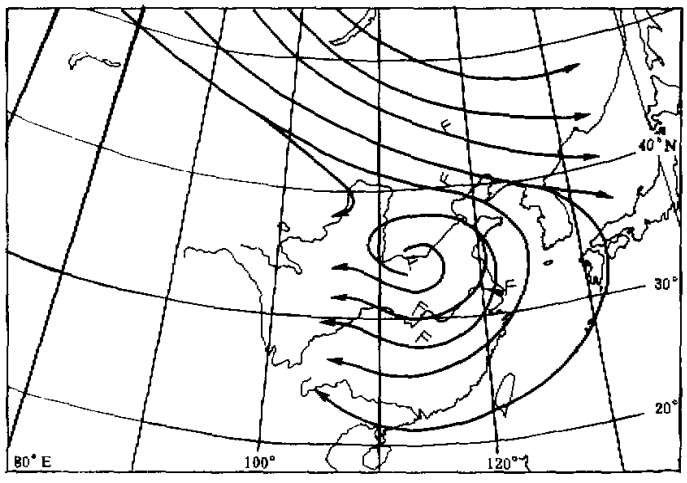

Fig. 7. As in Fig. 4, except for October.

VI. THE BASE OF ARMYWORMS' SOURCE AND THE STUDY OF TRANSMIGRANT ROUTE

According to the above analysis and previous works[3,11], using the prevailing wind direction of flow field at the height of 1500 m as that of armyworms' transmigration, using the locations of the 10°C isotherm, the isohume of 50% relative humidity pushing and withdrawing of the southwest air currents, and the average climatological frontal zone as the limits of transmigration, and using the base of armyworms in the period of the most moths as that of the taking-off armyworms, we draw the transmigrant routes of armyworms in Figs. 8 and 9. From these figures, the migration routes of armyworms can be described as follows:

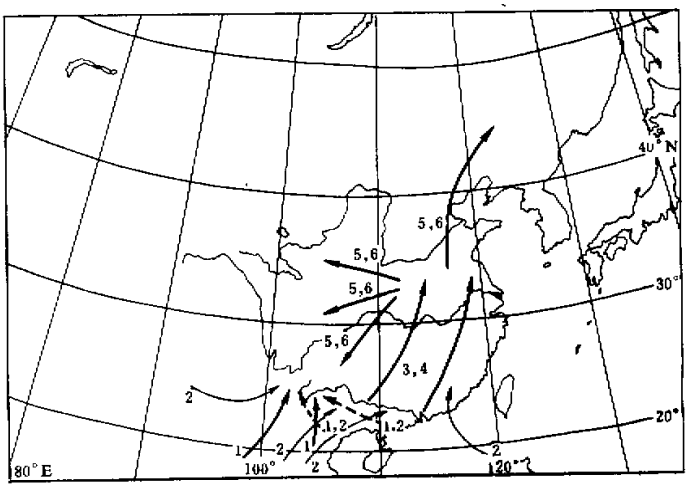

Fig. 8. Northward migrating routes of armyworms. The numbers represent the corresponding month.

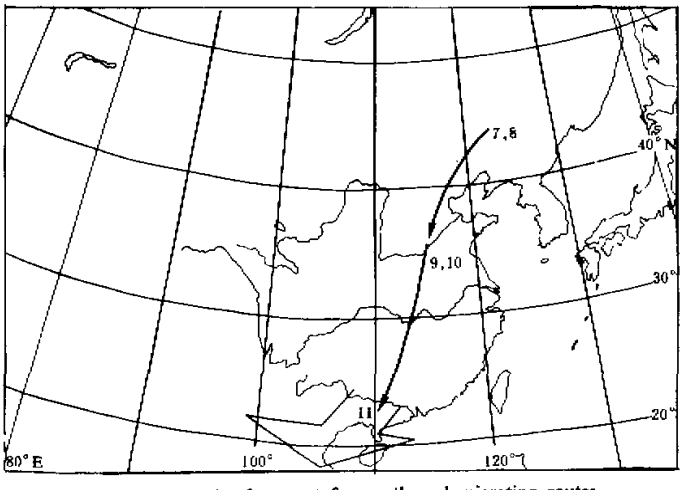

Fig. 9. As in Fig. 8, except for southward migrating routes.

In December, armyworms have two routes to remove with southerly air currents: one is from Guangxi and Vietnam mainly to Honghe and Wenshan Counties of Yunnan Province; the other is from Vietnam, Laos and Burma mainly to the areas of Dehong, Baoshan, Linchang, Xishuangbanna and Simao of Yunnan Province. In January, armyworms also have two routes to remove into China with the south air currents. One is from Vietnam, Laos and Thailand mainly to Honghe and Wenshan of Yunnan Province and to Guangxi; the other is from Thailand and Burma mainly to the areas of Dehong, Baoshan, Linchang, Xishuangbanna and Simao of Yunnan Province. In February, armyworms have three routes to remove into Guangdong, Guangxi, Fujian and Yunnan with the southwest air currents. The first is from Vietnam, Laos and Thailand mainly to the east of Guangxi and

Guangdong; the second from Kampuchea, Thailand, Veitnam and Laos to the west of Guangxi; and the third from Burma and India to Wenshan and Honghe of Yunnan Province. There is also a secondary route from Philippines to Guangdong and Fujian Provinces.

In March and April, with the southwest air currents the armyworms remove into the second incidence area, passing along two routes. The east route is from Guangdong, the east of Guangxi, Fujian, Hunan, the east of Hubei and the northwest of Jiangxi to Jiangsu and Anhui Provinces; the west route is from the west of Guangxi, Hunan and the west of Hubei to the mid-south of Henan, the south of Shandong and the northwest of Hubei.

There are two routes into the third incidence area in May and June. One is mainly from Jiangsu, Anhui and the south of Shandong to the Northeast, Inner Mongolia, Hebei and other places, removing northward with southwest air currents; the other is mainly from Henan to the Southwest and Northwest areas with east air currents.

In August, the southwest air currents withdraw, and armyworms transmigrate from the Northeast back to the fourth incidence area. In September and October armyworms transmigrate back to the area south of 33°N with the northeast air currents. In November, armyworms continue transmigrating to the sixth occurrence region (Southeast Asia).

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