Numerical Experiments for the influence of the Transition Zone Migration on Summer Climate in North China①

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ABSTRACT

As the position of the transition zone changes obviously, that is, as the transition zone migrates to the north or the south from present position, it affects water or heat balance between the land and the atmosphere in a considerable degree and has a profound influence on climate in North China. The experiment results in this paper indicate whether in the dry case or in the wet case of the large-scale climatological background field, the surface air temperature in a wide range of the transition zone migration and its surrounding decreases as the transition zone migrates northward. Moreover, the net upward fluxes of the surface long wave radiation and the sensible heat decrease, and the evaporation to the atmosphere increases. As the transition zone migrates southward, the results are opposite. This kind of significant thermal forcing between the land and the atmosphere can excite secondary circulation or circulation cells, which interact with the large-scale circulation systems, changing the atmospheric motion, affecting the water vapor transportation and consequently having an effect on the precipitation.

Key words: Transition zone migration, Water and heat balance, Climate in North China, Numerical simulation

1. Introduction

Many observations show that North China, especially the Plain of North China, is one of the most severe drought areas in China. The drought disasters occur with a high frequency and a wide range, and sustain a long time. Moreover, the high temperature usually accompanies the drought in the corresponding period. The summer rainfall in 1997 is less than half of normal. It is the most severe drought disaster during recent decades. The regional climate anomalies are no doubt influenced by the global climate change. However, many recent observations and numerical studies reveal that the change in the land surface process has an important effect on general circulation and climate (Ye and Chen 1992; Charney 1975; Yan and Anthes 1988; Yu and Luo 1996; Sun et al. 1996). It demonstrates that the variations of surface albedo, roughness, soil temperature, soil moisture, vegetation, etc., can change the transfers of the fluxes between the land surface and the atmosphere as well as the balance of atmospheric energy and water in a considerable degree. It is one of the most important factors affecting general circulation and climate. Particularly, the influence of vegetation becomes more and more notable (Ye 1995). It not only has influence on surface albedo, sensible heat

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and latent heat fluxes, radiation budget and water conservation and so on, but also has a significant effect on transpiration. Besides, the another important effect can connect the ground water and the atmosphere. The distribution of vegetation in North China obviously shows the regional characteristics. The demarcation lines of forest, grassland and desert are very distinct. The most important and the greatest transition zone in China starts from the east of Inner Mongolia and extends southwest to the southeastern part of the Tibetan Plateau (Ye, 1992). It represents the transitional zone of grassland and forest, also the transitional zone from the inner arid and semi–arid climate to the southeast humid and semi–humid monsoon climate. The observation analyses indicate that the vegetation in the transition zone is weak and fragile, significantly changing with variations of mankind activities or the natural environment, further causing changes of the other environmental factors. Li et al. (1992) analyzed the change of the western sector of the transition zone and found that its position moved southward about one and a half latitudes as compared with that of 6800–3900 years ago.

Therefore, in this paper we study impacts of obvious migration of the transition zone by using the numerical model. How does its northward or southward migration have an effect on the water and heat balance between the land surface and the atmosphere in some degree and consequently affect the climate in North China?

2. Numerical model and experiment design

The model used in this paper is a second–generation regional climate model (RegCM2) developed by Giorgi et al. (1993a, 1993b) at the National Center for Atmosphere Research (NCAR). The model uses a σ–coordinate in the vertical direction, $\sigma=(p-p_t)/(p_s-p_t)$, where p_s is the prognostic surface pressure and p_t is the pressure specified to be the model top. We choose a domain of 3000 km × 3600 km size centered in North China at 41°N and 116°E with a horizontal grid–point spacing of 60 km (Fig. 1). The nonuniform vertical structure in the model is taken with ten levels with the model top at 100 hPa. Its physical processes include the detailed radiative transfer package, the Biosphere–Atmosphere Transfer Scheme (BATS) and so on. A Kuo–type cumulus parameterization is used in the RegCM2, along with a simple scheme for resolvable scale precipitation, whereby all water in excess of saturation at a given grid point instantaneously precipitates. The model incorporates the split–explicit time integration technique so that it runs more efficiently.

The analysis data of the National Meteorological Center in China are used as the initial and lateral boundary conditions necessary to drive the model runs. The driving data have a resolution of 1.875° × 1.875° in the horizontal, are distributed on eight pressure levels from 1000 hPa to 100 hPa, and are available at intervals of 12 hours. The bilinear technique is employed to interpolate horizontally wind components, geopotential height, temperature and relative humidity to the model grid. Vertical interpolation is linear in pressure for wind and relative humidity, and linear in the logarithm of pressure for temperature. The time–dependent boundary condition is obtained by the linear interpolation of data at intervals of 12 hours and a standard relaxation procedure involving a Newtonian and a diffusion term is applied. The model topography and land–use distribution are obtained by the interpolation of NCAR topography and land–use with a resolution of 0.5° × 0.5°.

In order to consider the influence of the transition zone migration on the regional climate under different cases of the large–scale climatological background field, we choose two typical experiment cases. One is a severe drought case of summer in 1997 and represents a dry case. The other is a case of summer in 1996 in which the rainfall is much more than normal

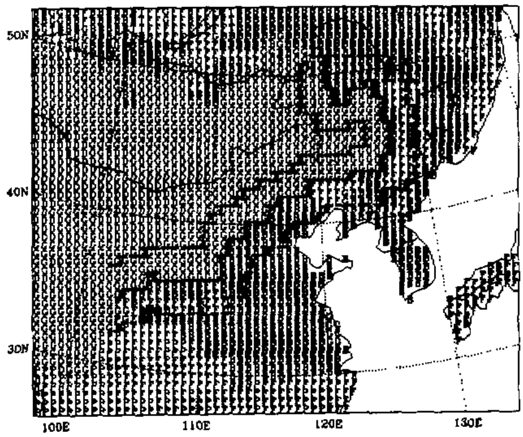

Fig. 1. Model land–use distribution in the domain. Land–use types are G–grassland, B–deciduous forest, F–coniferous forest, D–desert, T–tundra, and P–tropical or subtropical forest. The solid line denotes the present position of the transition zone, the dotted line the position of its northward migration and the dashed line the position of its southward migration.

and represents a wet case. As to the northward migration of the transition zone (NMTZ), we suppose that the influence of mankind activities, e.g., planting, results in grassland being replaced by forest within the scope of 1.5–2 latitudes or longitudes from its current position to the north. In contrast, its southward migration is supposed that forest is destroyed and replaced by grassland in the similar scope from the current position to the south, as shown in Fig. 1. Therefore, we design two groups of numerical experiments. One is for a dry case, the other for a wet case. Numerical experiments of the northward or southward migration of the transition zone (SMTZ) are carried out under the two cases, respectively. The model runs from 00 GMT, June 1 to 00 GMT, August 31 and the period of simulation is 91 days in total for each case. The model outputs of the whole summer are averaged for the following analyses.

3. Variations of the flux transfers and water budget between the land surface and the atmosphere

For the NMTZ experiment, grassland is replaced by forest in the range of the transition zone migration. As to the whole underlying surface, the absorbed solar radiation increases because the albedo of forest is smaller than that of grassland. However, since the forest transpiration significantly increases and the solar radiation incident on the ground is resisted and absorbed by forest, surface air temperature and surface temperature decrease, which can obviously shown from the numerical results of the two cases. From the variation of surface air temperature in the summer of 1997 (dry case), for example, it can be found that in the area of the transition zone migration and its surrounding, the surface air temperature decreases considerably, with the maximum decreasing up to over 1.5°C (see Fig. 2a). Figures 2b–2d also give the anomalies of the net fluxes of long–wave radiation, sensible heat and evaporation from the surface to the atmosphere for the dry case. Because the surface air temperature and

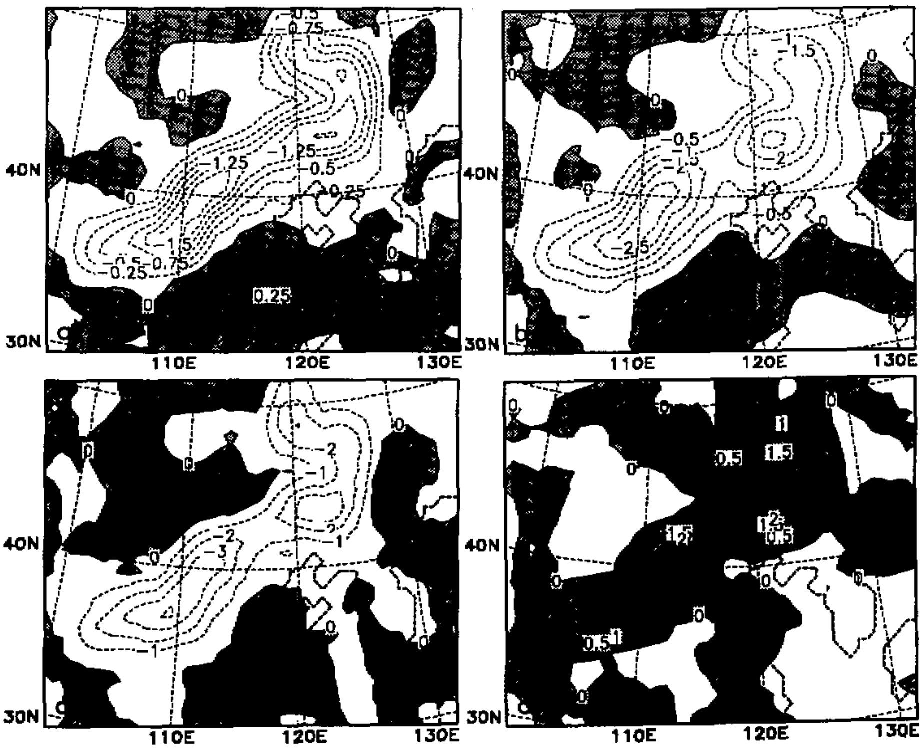

Fig. 2. Anomalies of the average surface air temperature (a), net long–wave radiation flux from the surface to the atmosphere (b), the sensible heat flux (c), and the evaporation (d) in the summer of 1997 for the NMTZ experiment. The contour interval is 0.25°C in (a), 0.5×100 W / m^2 in (b), 1.0×100 W / m^2 in (c) and 1.0×10^{-4} mm / day in (d).

the surface temperature decrease, and forest absorbs much surface long–wave radiation, the net flux of long–wave radiation to the atmosphere significantly decreases and the sensible heat flux also obviously reduces. Conversely, the evaporation from the surface to the atmosphere increases. Those results demonstrate that as forest replaces grassland, the soil moisture increases, forest intercepts much atmospheric precipitation and reduces the surface water loss and the soil moisture loss. Its effect of transpiration can increase the water transportation to the atmosphere. Moreover, it also shows from Fig. 2 that the area of the maximum drop in surface air temperature has the maximum reduction of the long–wave radiation flux and the sensible heat flux as well as the maximum increase of the evaporation.

As to the SMTZ experiment, forest is replaced by grassland, and the results are shown in Fig. 3. Within the scope of the transition zone migration and its surrounding, surface air temperature increases. The maximum increase range can reach 1.25°C which is close to the maximum decrease one in the NMTZ experiment. Moreover, the net long–wave radiation flux from the surface to the atmosphere and the sensible heat flux increase, while the evaporation decreases, showing results contrary to that of the NMTZ experiment.

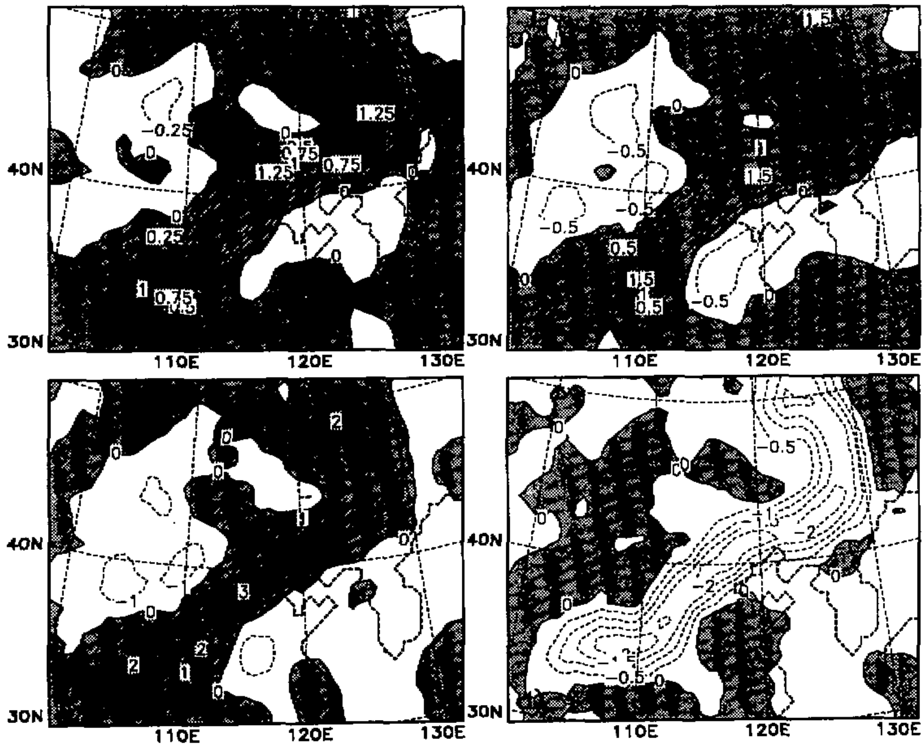

Fig. 3. The same as in Fig. 2, but for the NMTZ experiment.

Similarly, we analyze the wet case and find that the thermal effects in the two cases have no difference for the transition zone migration. The results demonstrate that the migration changes the transfers of the fluxes between the land surface and the atmosphere, with the same characteristics on the thermodynamic process, although the large–scale climatological background fields are different. This kind of regional forcing no doubt has a profound influence on the atmospheric circulation. Next we analyze the variation of the atmospheric circulation.

4. Excited secondary circulation and its characteristics

The climatological background field in the summer of North China is primarily the Northwest Pacific High and the long–wave trough in the northern westerlies. The Northwest Pacific High in the summer of 1997 is unusually strong and its position is northward of the normal, controlling almost the whole North China, with its north boundary at 44°N (on the model level of $\sigma = 0.80$, about 820 hPa, not shown). In the summer of 1996, however, the Northwest Pacific High is weaker and its north boundary is around 40°N. Therefore, the climatological background fields for those two cases are quite different. For the dry case, the Northwest Pacific High is stronger, its position is northward of the normal and the long–wave trough in the westerlies is weaker. For the wet case, however, the Northwest Pacific High is weaker, its position is southword of the normal and the long–wave trough is

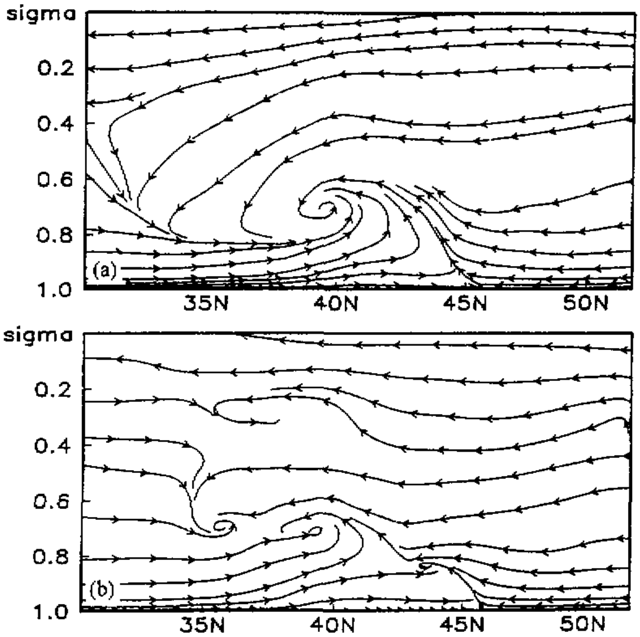

Fig. 4. Meridional circulation along 115°E. (a) The dry case, (b) The wet case.

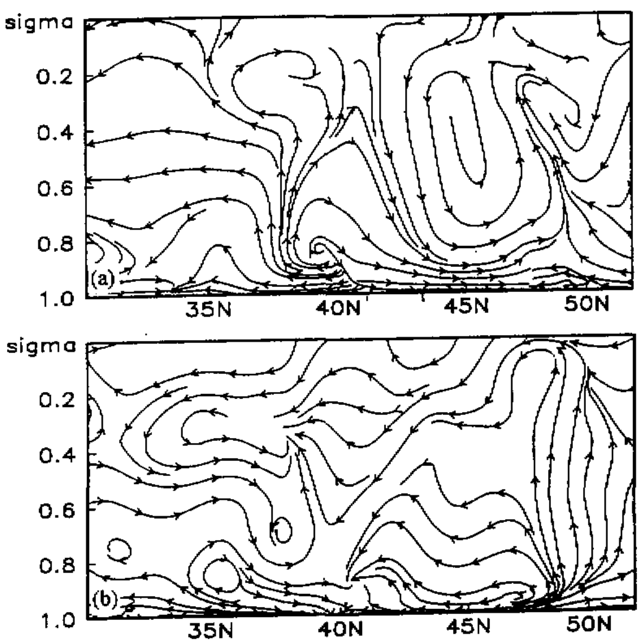

Fig. 5. Secondary circulation along 115°E for the NMTZ experiment. (a) The dry case, (b) The wet case.

stronger. The meridional circulation can obviously show those characteristics on the climatological background fields. Fig. 4 is a cross–section of meridional circulation along 115°E for the two cases. As to the dry case the meridional circulation is simple. Basically, flow by north appears in the upper troposphere, but in the lower troposphere flow by south appears to the south of 45°N and flow by north to the north. There exists downdraft to the south of 40°N. An obvious cell appears and its center is located around 40°N. This kind of meridional circulation is a mid–latitude indirect circulation (that is, Ferrel cell). However, the Ferrel cell in the wet case is less obvious. It is weaker and its center splits up into several. The two main centers are located around 36°N and 39°N, respectively. As mentioned above, in the NMTZ experiment the surface air temperature decreases in the transition zone and the sensible heat flux reduces, exciting the sinking motion as a result. Fig. 5a shows differences of the meridional circulation between the control experiment and the NMTZ experiment for the dry case along 115°E. The uniform downdraft appears in the area of the transition zone migration. One anticlockwise circulation cell appears in the north, another clockwise circulation cell in the south. Almost the unanimous ascending motion occurs in the range from 35°N to 40°N (that is, the southern part of North China). It shows by a comparison with Fig. 4a that the secondary circulation excited is opposite to the Ferrel cell, consequently weakening the Ferrel cell. The ascending motion in the range from 35°N to 40°N offsets a part of the downdraft of the Northwest Pacific High. The downdraft in the area of the transition zone migration and its surrounding offsets a part of the ascending motion arisen from the convergence between the warm–wet air from the Northwest Pacific High and the cold air carried by the long–wave trough of the westerlies. The influence for the wet case is less obvious than that of the dry case (Fig. 5b). However, the downdraft also appears in the area of the transition zone migration. The clockwise secondary circulation cell to the south of the transition zone is weaker, with its position of the center being southward up to 34°N. Although the characteristics on the thermodynamic influence in the NMTZ experiment are consistent under different climatological background fields, the responses of the atmospheric circulation are somewhat different.

The characteristics on thermodynamic influence for the SMTZ experiment are just opposite to those for the NMTZ experiment. Hence, the response of atmospheric circulation should have notable differences as compared with that for the NMTZ experiment. Similarly, we cut a cross–section of the differences of the meridional circulation along 115°E (Fig. 6). The results of the two cases all show that there appears ascending motion around the transition zone, especially for the wet case. Its ascending motion for the wet case is stronger, approaching the upper troposphere. Convergence obviously occurs in the boundary layer. The secondary circulation cells are aroused on both sides, respectively. Their centers are located in the middle troposphere. The ascending motion for the dry case approaches only the middle troposphere. The secondary circulation on both sides also appears in the lower troposphere. Therefore, it indicates by a comparison with Fig. 4 that the secondary circulation excited in the SMTZ coincides with the Ferrel cell, consequently strengthening the Ferrel cell.

5. Influence of the transition zone migration on precipitation

It can be known from the analyses mentioned above that the transition zone migration has an influence on transfers of the fluxes between the land surface and the atmosphere in a considerable degree and excites the secondary circulation. Then interaction between the

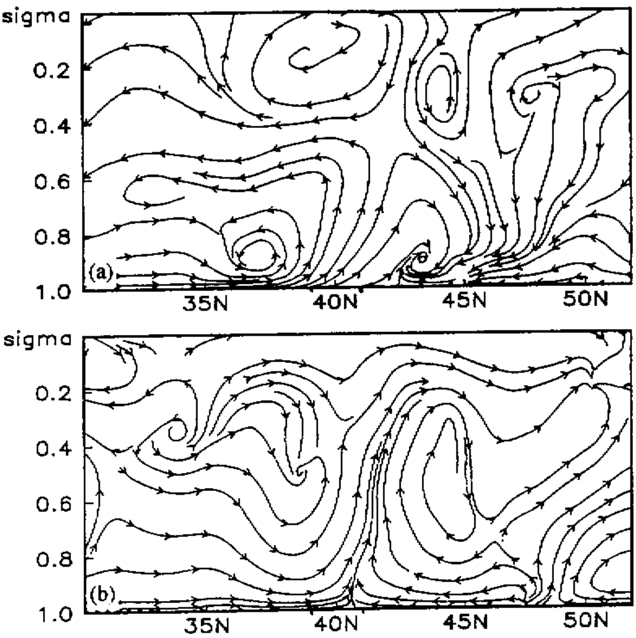

Fig. 6. Secondary circulation along 115°E for the SMTZ experiment. (a) The dry case, (b) The wet case.

secondary circulation and the large-scale circulation systems can change the atmospheric circulation, affect the water vapor transport and thus certainly have an effect on the precipitation. Just as indicated by many studies, the variations of drought and flood in North China are complicated and flood disasters usually arise from several times of heavy rain. Therefore, it is particularly difficult to catch the variations of drought and flood in the climate models. Moreover, the precipitation anomaly is not only determined by the circulation but also greatly related to the atmospheric stratification, moisture and so on. As a result, the influence of the transition zone migration on precipitation is very complicated. Figure 7 shows the anomalies of the summer accumulated rainfall and the vertical velocity ω on the model level of $\sigma=0.525$ (about 573 hPa) at a cross-section of 115°E. It indicates from Fig. 7a that the rainfall decreases in the range of the transition zone (41–43°N) and the Changjiang–Huaihe River Valley (31–33°N) in the NMTZ experiment, obviously increases in the Huanghe River Valley (33–41°N) and most northern North China (43–50°N). Comparison with Fig. 5a shows that the areas where the rainfall increases have the ascending motion of the secondary circulation, while the areas where the rainfall decreases have the downdraft motion. Although the evaporation obviously rises from the surface to the atmosphere in the area of the transition zone migration, the divergence of the secondary circulation transports moisture outward. Thus the atmospheric moisture in its surrounding increases and the result is in favor of precipitation there. As to the SMTZ experiment (Fig. 7b), the notable variation of precipitation appears to the south of 41°N. The rainfall decreases in the Changjiang–Huaihe River Valley, increases in the Huanghe River Valley and decreases somewhat in the north of the transition zone migration. Similarly, this kind of variation of the rainfall is related to the secondary circulation.

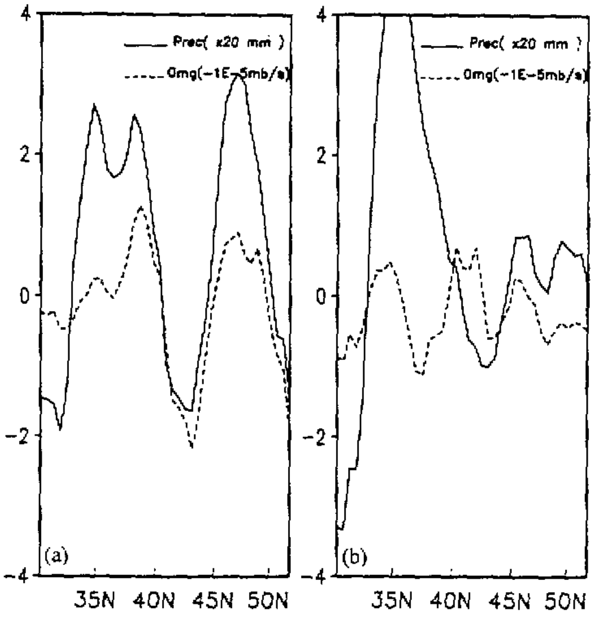

Fig. 7. For the dry case, anomalies of summer accumulated rainfall and vertical velocity ω on $\sigma=0.525$ model level as a function of latitude along 115°E. (a) The NMTZ experiment, (b) The SMTZ experiment.

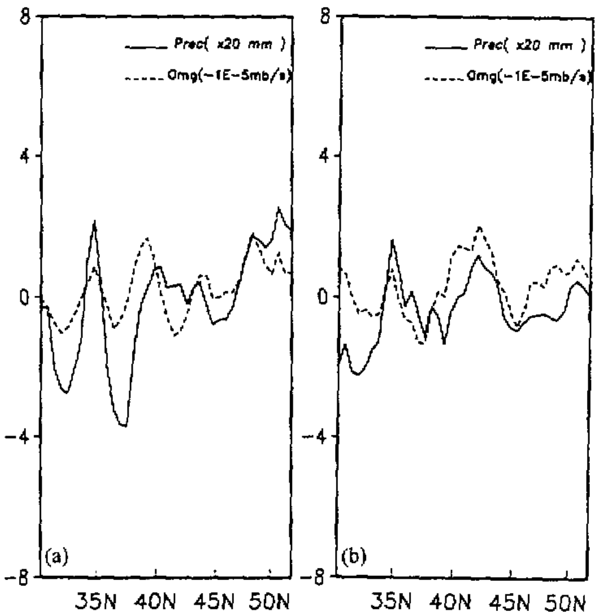

Fig. 8. The same as in Fig. 7, but for the wet case.

In the same way, we analyze the results of the wet case at a cross–section of 115°E (Fig. 8). Obviously, the variation of rainfall is somewhat different from that of the dry case. However, if comparing the variation of rainfall with the corresponding secondary circulation, we can also find that there exists the close relation between them, and the variation of the vertical velocity in the middle troposphere is quite consistent with that of the rainfall.

6. Conclusion and discussion

As mentioned above, although the transition zone migration occurs only in the narrow belt, its influence is not negligible. Within the wide range of the transition zone migration and its surrounding, transfers of the fluxes between the land surface and the atmosphere greatly change. Whether in the dry case or in the wet case of large scale climatological background field, the northward migration of the transition zone conduces to a decrease of the surface air temperature, reductions of the long–wave radiation flux and the sensible heat flux to the atmosphere, and an increase of evaporation. However, the results are opposite for its southward migration. This kind of obvious thermal forcing between the land surface and the atmosphere can excite the secondary circulation or the secondary circulation cell. It indicates from the two cases that the secondary circulation cell excited by the northward migration of the transition zone is basically opposite to the Ferrel cell and consequently weakens the Ferrel cell. While the secondary circulation cell excited by its southward migration is basically consistent with the Ferrel cell and thus strengthens the Ferrel cell. Although the influence of the transition zone migration shows the similar characteristics on thermal forcing in the dry case or in the wet case of climatological background fields, the response of the atmospheric circulation is somewhat different so that the secondary circulation excited is also somewhat different. It is much complicated that the interaction between the secondary circulation and the large scale systems changes the atmospheric motion, affects the moisture transport and finally has an effect on the precipitation. However, the variation of the precipitation is also related to many factors such as atmospheric stratification, moisture condition and so on. Thus, this needs to be investigated further in future.

Apart from the natural vegetation as shown in Fig. 1, the large–area cultivated vegetation is distributed over China, of which is primarily agricultural vegetation. Currently, the cultivated vegetation is characterized by large–scale areas and diversified crops, having become the same important as the natural vegetation (Ye and Chen, 1992). Particularly in the northern China, the historical change in the agricultural–pastoral transitional zone has coherence with that of the forest–grassland transition zone, but there exist great differences between them (Ye, 1992). It shows from the historical data that the long–term change of the position in the semi–arid zone or in the agricultural–pastoral transitional zone is related to the natural climate change and the mankind activities (Fu, 1996; Zhang et al., 1996). Thus, in discussing the influence of the transition zone migration it is necessary to consider the change in the agricultural–pastoral transitional zone further. In the experiment of the northward migration of the transition zone, for example, it may be reasonable that grassland is replaced by agriculture in the eastern sector of the transition zone. Besides, with the development of the remote sensing technique and more accurate vegetation data acquired, the relation of the climate change and the vegetation influence will be bound to be studied further.

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