Numerical Study of Ural Blocking High's Effect Upon Asian Summer Monsoon Circulation and East China Flood and Drought①

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ABSTRACT

In terms of Kuo–Qian *p*–sigma incorporated coordinate five–level primitive equation spheric band (70°N–30°S) model with the Ural high's effect introduced into it as initial and boundary conditions, study is made of the high's influence on Asian summer monsoon circulation and dryness / wetness of eastern China based on case contrast and control experiments. Rusults show that as an excitation source, the blocking high produces a SE–NW stationary wavetrain with its upper–air atnicyclonic divergent circulation (just over a lower–level trough zone) precisely over the middle to lower reaches of the Changjiang River, enhancing East Asian westerly jet, a situation that contributes to perturbation growth, causing an additional secondary meridional circulation at the jet entrance, which intensifies the updraft in the monsoon area. As such, the high's presence and its excited steady wavetrain represent the large–scale key factors and acting mechanisms for the rainstorm over the Changjiang–Huaihe River catchment in the eastern part of the land.

Key words: Ural blocking high, Asian summer monsoon circulation, East China flood and drought

I. INTRODUCTION

The eastern China dryness / wetness are no doubt linked to eastern Asian summer monsoon anomaly and its seasonal northward march. Needless to say, the establishment of the eastern Meiyu precipitation situation is directly related to the June sudden change in the atmospheric circulation pattern (Yeh; Tao and Li, 1958; He et al, 1991). However, the extratropical blocking situation has been the focus in the meteorological context because of its effect on the eastern dryness / wetness. Chen (1957) and Tao et al. (1962) showed that the genesis / maintenance of the Okhotsk blocking high give rise to the East Asian southern–leg jet immediately to the north of the Changjiang River if the high is located in an appropriate place, a situation that is likely to induce disturbance to develop over the river catchment, leading to Meiyu rainstorm. Subsequently, Tao et al. (1980) indicated that the emerging Ural high brings about an extensive trough zone around Lake Baikal with a more zonal westerly flow about 35–40°N. This arrangement favors cold air concentrated inside the Baikal trough, which runs equatorward from the bottom and meets SW current travelling poleward along the west side of the subtropical high in the Changjiang River basin, thereby resulting in persistent rainstorm. Ding (1991) asserted that extratropic circulation systems such as the Ural

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high are responsible for sustained anomaly of westerly circulation systems that influences the summer monsoon system, leading to the eastern rainfall anomaly. In brief, the extratropic blocking is undoubtedly of great significance to the summer precipitation regime in eastern China. However, how it acts on the East Asian monsoon and as the eastern–China dryness / wetness mechanism remains a problem to be explored.

It is known that the 1991 Meiyu–period exceptional rain gush inflicted heavy loss on Anhui, Jiangsu, Zhejiang and Shanghai with other 18 provinces (inclusive of Taiwan) suffering the flood to different extent. Synoptic analysis indicates that, of the features of the atmospheric circulation abnormality in that season, the most prominent is the presence / long–lived maintenance of the blocking situation at extratropics. In contrast to the summer of 1991, the 1985 saw a large–scale drought south of the Yellow River with severe dryness over the Changjiang–Huaihe River basins (CHB), rainfall deficit to the south of the Changjiang River as compared to richer precipitation north of the Yellow River. And the 1985 extratropic circulation pattern displayed stronger variability, leading to lowered probability of the blocking highs with little or no persistent steadiness nor greater vigor. The case contrast demonstrates that the extratropic blocking is of importance to the eastern dryness / wetness.

Zhao et al. (1987) reported the numerical simulation of the short–lived effects of a midlatitude bi–blocking situation (one high situated between the Black and Caspian Seas westward of the Urals and the other from Lake Baikal to Heilongjiang of China) upon all the monsoon systems during early–summer monsoon establishment in the context of the 1979 MONEX data. Results show that in the presence of the blocking, Indian monsoon develops slowly and attains feeble vigor with rainfall deficit in Central India and the monsoon trough there hardly discernible, and v.v. (only with the conditions close to long–term averages). However, they did not seem to address the problem of East–Asian monsoon circulation anomaly. The present study investigates the physical mechanism for the East–China dryness / wetness due to the Ural high's influence on the Asian summer monsoon circulation with the aim to provide a useful basis for medium– and long –term forecasting through case contrast and control experiments based on the 1991 CHB flood event.

II. MODEL, DATA AND EXPERIMENTAL SCHEMES

The simulation is based upon the Kuo–Qian p–σ coordinate 5–level primitive equation spheric band (70°N–30°S) model with top 2 (the remaining 3) levels in $p(\sigma)$ coordinates and an important coupling layer included below the ground or sea level for examining earth–air interaction. Included therein is a fuller range of diabatic heatings, e. g., solar (air–earth–system) short (long) wave radiation, large–scale condensation, cumulus convection and underlying surface sensible / latent heatings. Moreover, adopted in this model are real terrains with fixed walls as the southern and northern boundary conditions. For details see Kuo and Qian (1987).

The schemes used for experiments include case contrast and control experimental scenarios, designated Categories A and B, respectively.

Category A is designed to verify the ability for the model to simulate the wetness / dryness regime over the Changjiang River basis in central / eastern China. As stated earlier, this area had a dry (wet) summer in 1985 (1991). So the initial fields are represented by the pentad mean typical of the June characteristic with the first pentad pattern for 1991 and the pentad field of incipient Meiyu rainfall for 1985, the differences lying in that: 1) the 1991 Ural high was quite strong and steady on a persistent basis; the 1985 blocking was feeble with an unstable situation in the main at extratropics; 2) the 1991 westerly (easterly) jetstream was intense (faint), making the South–Asian high's ridge line southward of its mean position as opposed to the 1985 case; 3) the 1991 (1985) subtropical high was located southward (northward); 4) the cross–equatorial flow at 45 and 90°E (110, 125 and 145°E) was weaker (stronger) in 1991 than in 1985. It stands to reason that these differences could all be the major factors of the 1991 flood and 1985 drought in eastern China. The runs were conducted with the above initial fields fed into the model. Because the model involves in itself diurnal variation of solar radiation the integration on day 5 is enough to yield quasi–steady solutions (Kuo and Qian) with the daily mean rainfall over the 5 days as that of the June's model. To get rid of the systematic deviation of precipitation from modelling the distribution is characterized by model rainfall departure percentage as the criterion to evaluate the capability to reproduce the flood and drought of the research region.

Category B is developed to explore the role of the Ural high responsible for the eastern dryness / wetness. A pair of control experiments with and without the high involved is laid out based on the first pentad mean of June 1991. Note that the initial field with the Ural high present is the June first pentad mean pattern for the run with the blocking kept northward of 45 ° N through the boundary conditions during integration and for the no–high run the initial field is formed based on the pentad mean treated by multi–smoothing adjustment north of 45°N to change the high–available pattern to a no–blocking one that causes the extratropical circulation situation to resemble the June's pattern from long–term average. Evidently, the discrepanies in the initial field and boundary conditions for both runs depend largely on the presence of the blocking in Ural. Note that such smoothing has some influence on the pre–ridge trough and the connection around 45 ° N. It is clear that the different integration results from both runs can be assumed to be related to the effects of the Ural high.

The initial data come from 100–, 300–, 500–, 700– and 1000–hPa height and 300–, 500–, 700– and 850–hPa humidity; the extratropical windfield takes the form of geostrophic wind balance and the 5°N–5°S wind pattern is found in virtue of simplified equilibrium equations; the initial temperature field comes from the height data with the aid of the static balance relation; the surface temperature field at initial time is the climatological mean and determined by the surface energy balance equation, in the course of integration. After initialization, the standard isobaric data are interpolated onto the model levels for operation. The 5–day run has led the flow field to reach a quasi–steady state.

III. RESULT ANALYSIS

1. *Analysis of Results from Category A*

The rainfall departure percentage patterns from the June 1991 and 1985 model findings are presented in Figs.1a, b, separately, illustrating that the 1991 precipitation is 1 – 2 times more south of the Changjiang River, over the CHB and the central / eastern parts of the land with the rainfall center in the latter segments, an outcome in good concord with the actual happening; the same is true of precipitation 1–2 times increased from Hainan province to the Indochina Peninsula, with deficit in western China. This shows that the simulation is a good reproduction of the basic features of the eastern 1991 rainstorm. From these figures we see in addition abundant (deficient) rainfall in South (North) India with the northern limit of the precipitation anomaly shifted equatorward, a result that agrees roughly with observation. In sharp contrast to the 1991 simulation, the 1985 model rainfall departure percentage for South China and south of the Changjiang River is lowered, indicating basically these parts under the control of drought as opposed to the lower Yellow River basins to Korea Peninsula. Also, the

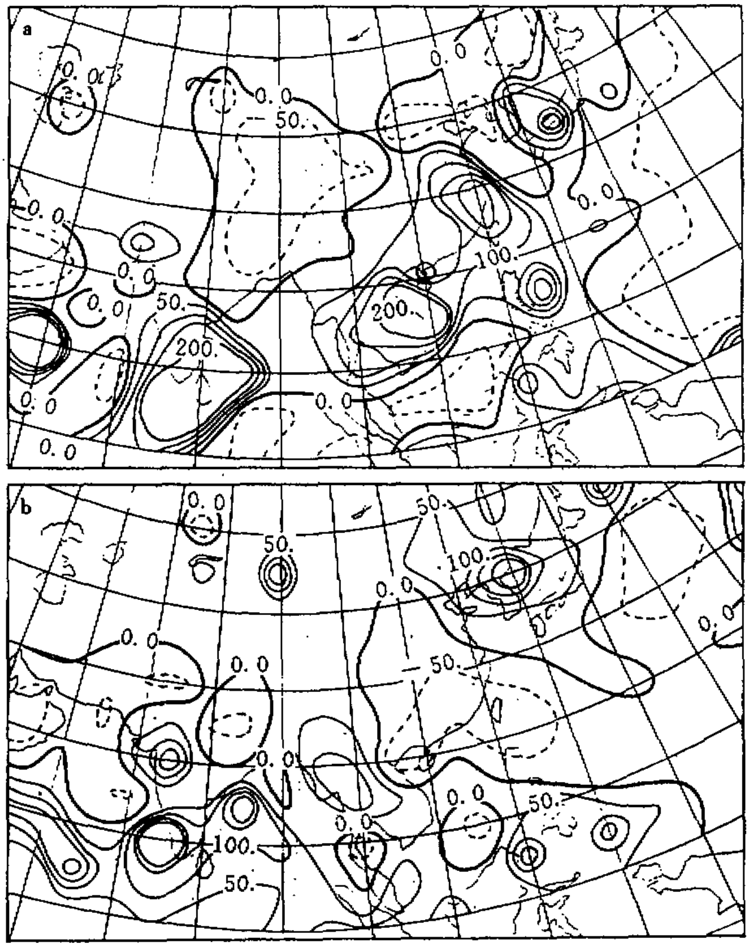

Fig. 1. Model rainfall departure percentage patterns for June of 1991 (a) and 1985 (b).

percentage pattern reveals a certain relation of India summer monsoon precipitation anomaly to East Asia rainfall, i.e., they are, to some extent, in antiphase: with intense rainfall of India monsoon reaching its northern (southern) position as shown in the record, the eastern part of China receives deficient (excessive) precipitation (Chen and Luo, 1979; Zhu, He and Wang, 1986).

The simulation meridional circulation in relation to the seasonal rainfall of 1991 and 1985 is presented in Figs. 2a, b. One can see that a strong meridional circulation exists at 120°E on the 1991 panel, with intense updraft over 20–30°N (obviously in association with heavy rain in the CHB and south of the Changjiang River) and downdraft between 4–20°S in connection with subsidence on the west side of the Australian high. This circulation is usually referred to as East Asian monsoon meridional circulation (EAMMC). Unlike the 1991 EAMMC, the 1985 counterpart is substantially weaker. Although the lower–level deeper

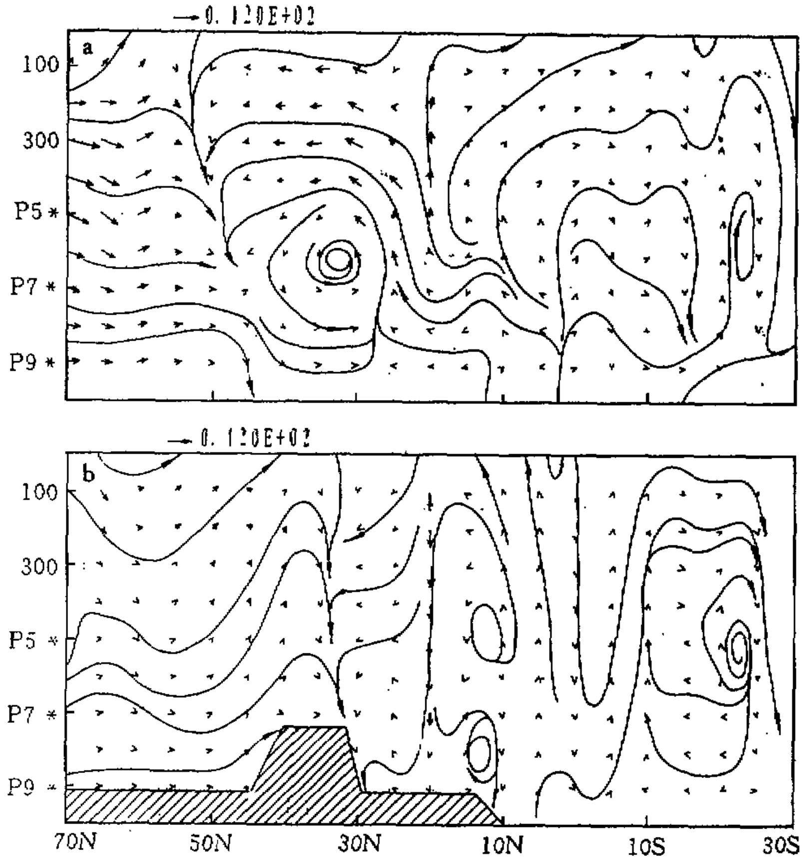

Fig. 2. Model–produced 120 ° E meridional circulation for June of 1991 (a) and 1985 (b).

south wind reaches high latitudes, two small–scale monsoon circulation cells are observed, one at low latitudes and the other around 30 ° N, with faint updraft in between and downdraft over 25–30°N, instead, leading to drought in the Changjiang River catchment and to the south with the rising zone moved poleward of 35°N, causing wetness in the lower Yellow River basin. More detailed inspection will lead to i) the EAMMC is more northward markedly in 1985 than in 1991 with ascending / descending moved 5–10 degrees of latitude poleward; ii) the northern–leg air (from extratropics) is stronger in 1991 than in 1985 with its confluence with the southern–leg current 5–10 degrees of latitude more equatorward in 1991. This may be the important cause for the 1991 eastern great flood relative to the stronger northern leg obstructive to the southern one.

2. *Analysis of Results from Category B*

From the findings of Category A one sees that the model works well in reproducing the dryness / wetness features over the research area, and particularly the simulated intense rainfall centered in the mid–lower reaches of the Changjiang River is in surprisingly good

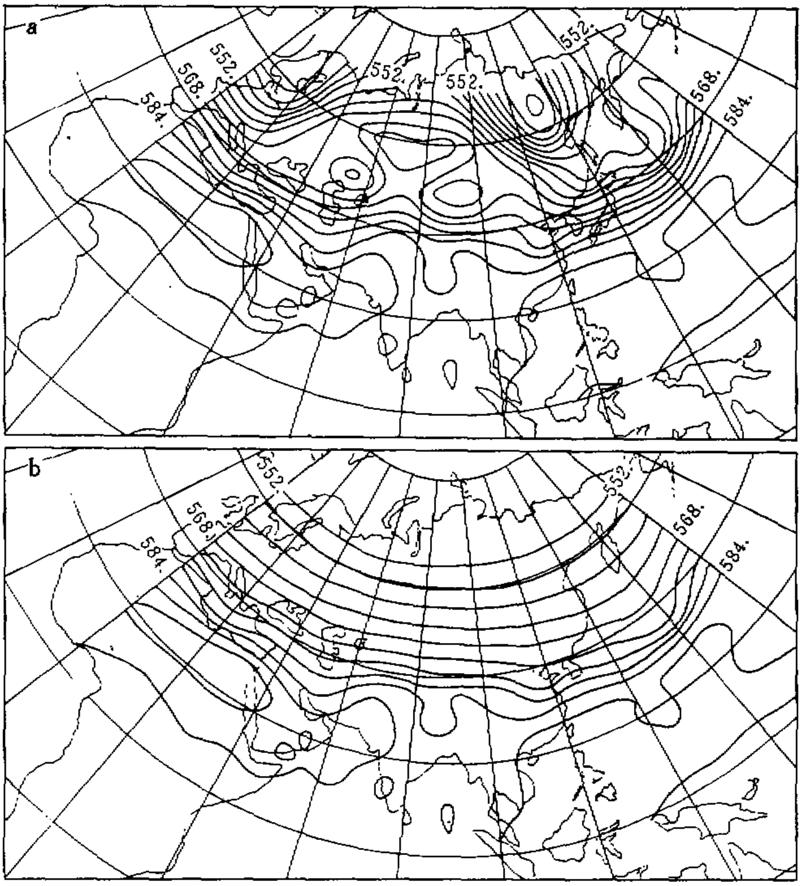

Fig.3. Initial 500–hPa height fields for UH91 and NH91, separately.

agreement with the record. Then the ensuing problem should be: What causes and mechanisms are for the rainfall core and the exceptional severe flood. As stated before, the presence of the Ural blocking is one of the characteristics of 1991 anomaly of atmospheric circulations. It is natural to develop a pair of control experiments with and without the high available (hereafter designated UH91 and NH91, respectively). Fig.3 depicts the initial 500–hPa height pattern for both the experiments, showing their complete analog southward of 45 ° N and the difference lying merely in the presence / absence of the Ural high to the north of the latitude.

Fig.4 illustrates the difference in daily mean rainfall between the two runs. Clearly a *strong difference–value core is at the mouth of the Changjiang River with the maximum in* excess of 10 mm / day, almost coinciding with the intense core in the 1991 record (Cf. Fig. 1a), indicating the unignorable role of the Ural high (UH91) in the formation of the great flood in eastern China. Alternatively, a negative difference–value belt runs from western China to northern / central India with South India in a positive area.

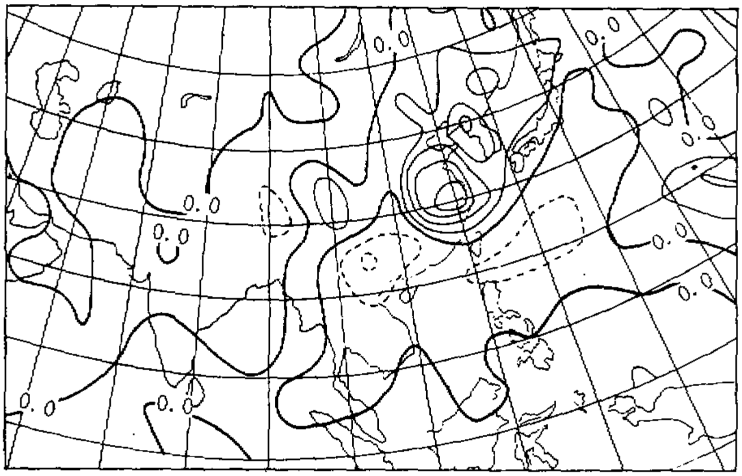

Fig.4. Difference Rainfall map (UH91 minus NH91).

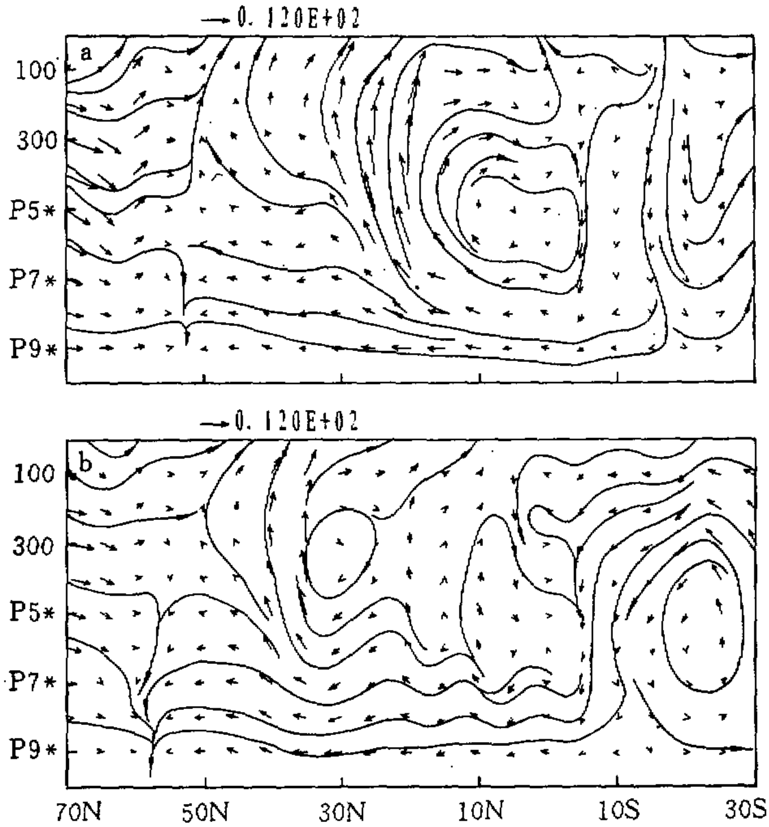

Fig.5. Difference (UH91–NH91) EAMMC at 120°E (a) and 75°E (b).

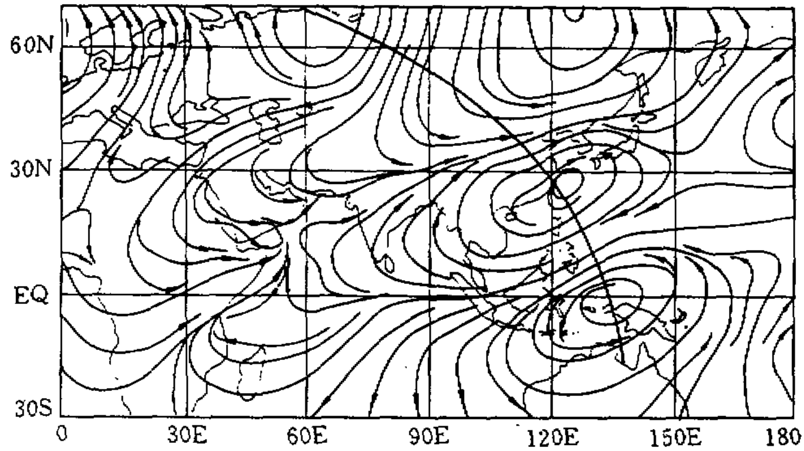

Fig.6. 100–hPa difference circulation (UH91 minus NH91).

The difference (UH91–NH91) meridional circulation exhibits characteristics relative to the rainfall difference pattern as shown in Fig.5, where a complete difference circulation is displayed at 120°E between 35°and 50°N with extraordinarily strong updraft on the south side that greatly contributes to the EAMMC rising, making for the remarkable difference sector at the Changjiang River mouth as the most severe flood–hit area of the 1991 event. At 75°E, on the other hand, the Ural high gives rise to the difference value downdraft over northern / central India in contrast to updraft in the south, a result in agreement with the negative (positive) difference precipitation in the north (south). Zhao et al. (1987) showed that when a blocking high is present at midlatitudes India monsoon develops slowly and attains low strength only, thereby producing less rainfall over central India. Our result is analogous to theirs except that ours refers to a kind of climatic state.

The low–level difference (UH91 minus NH91) flow field (figure not shown) indicates a SW–NE difference trough zone in the eastern coastal region, which is evidently the result of the confluence of the NW flow from the high of Ural origin with SW current travelling northward from the west side of the subtropical high. This is especially noticeable in the mid to lower Changjiang River basins, a situation favorable for the development of the Meiyu trough and enhancement of the EAMMC. Thus, we come to the conclusion that the Ural blocking hinders the establishment / development of India monsoon but helps invigorate the EAMMC and western Pacific subtropical high.

3. *Analysis of Affecting Mechanisms of Ural High*

In the context of synoptic studies and the present simulation it has been shown that the Ural high has great impact on the eastern dryness / wetness and particularly the CHB Meiyu precipitation. There arises the problem: What are the affecting mechanisms for its regime?

Fig.6 is a plot of the 100 hPa difference flow field. Of interest is the distribution featured by a strong wavetrain with a SW–NE wave front travelling in the NW–SE orientation. In particular, the wavetrain's upper–air anticyclonic divergent circulation core is situated right over the Changjiang River's mouth, almost coinciding with rainfall difference value center of Fig.5 and intense precipitation core of Fig.1, suggesting that the upper–level divergence centre collated with the low–level trough zone resulted in the strong rainfall at the mouth. Moreover, the present of the difference circulation of the upper–air anticyclone at the mouth gave rise to the enhancement of East Asian westerly jet, which was conducive to disturbance growth over the region and to the induction of a secondary meridional circulation at the jet entrance (Cf. Fig.5), thereby amplifying the EAMMC's ascending leg that, in turn, intensified strong rainstorm over the mid to lower Changjiang River basins. From the foregoing discussion it follows that the anticyclonic divergence circulation inside the wavetrain relative to the existence of the Ural high acted as a key factor responsible for the 1991 great flood striking the study area.

Lu (1987) in his contribution reported the paths of stationary planetary–scale waves in moving over the spheric surface, indicating that the steady wavetrain travelling toward the southeast southward of jet at 45°N. As such, if an Ural high were assumed to be an excitation source, the resulting wavetrain would march southeastward. As shown in the present work, a stationary wavetrain of Ural origin advances toward the southeast, maintaining an upper–level anticyclonic divergent circulation at the Changjiang River's mouth and enhancing East Asian westerly jetstream, with a secondary meridional circulation induced at the jet entrance to strengthen updraft in the monsoon region, with which to sustain persistent heavy rainfall over the mid–lower Changjiang River catchment. Accordingly, the Ural high could act as the principal mechanism affecting dryness / wetness over East China, particularly the Meiyu precipitation of the CHB.

IV. CONCLUSIONS

The presence of the Ural high is an important factor contributing to the stability to the extratropic circulation pattern. This blocking affords ample supply of cold air in June to support the summer monsoon precipitation in the CHB, a result that has been borne out by multiple weather analyses and the present study. It should be emphasized that the SE–NW steady wavetrain of Ural origin has its upper anticyclonic divergent circulation (collocated with a low–level trough) precisely over the mid to lower reaches of the Changjiang River, which, in turn, intensifies East–Asian westerly jet (contributing to disturbance development) that induces an additional secondary circulation, enhancing monsoon updraft. As a consequence, the presence of the blocking high and the excited stationary wavetrain are the large scale critical factor and affecting mechanism for great flood over the CHB.

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