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THE CCA BETWEEN 500 hPa GEOPOTENTIAL HEIGHT FIELDS OVER NORTHERN HEMISPHERE AND RAINFALL OF CHINA IN MAY

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ABSTRACT: Based on the theory of Canonical Correlation Analysis (CCA), the correlation between 500 hPa geopotential height (H) fields over the Northern Hemisphere (NH) and a 15-region rainfall (R) field of China in May is studied. The results indicate that: (1) there is a strong relationship between the H fields in January / May and the R field in China, (2) the variation of the general circulation over the whole NH (especially the 500 hPa H field over Europe and Asia) can affect the R in China, (3) in January and February the atmospheric general circulation can affect the R mainly by means of planetary waves, while in April and May the main control mechanism can be due to some teleconnections, and (4) the characteristic vectors for R in May and H from January to May have wave train structure, alternating sign from south to north.

Key words: rainfall in dex;geopotential height fields;canonical correlation analysis

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1 INTRODUCTION

May is the month of transition when the general circulation changes from the winter pattern to the summer pattern in NH and the dry season shifts to wet season in China. The amount of precipitation over the period affects to some degree the harvest of summer crop and sowing of autumn crop and closely relates to national economy and everyday life. Among the various factors that affect climate anomalies, general circulation anomaly is one of the immediate causes. It is therefore positive for medium- and longer-term weather forecast and mitigation of meteorological destruction to study the correlation between general circulation anomalies and large-scale precipitation in late spring in China and to find out how the former affects the latter. At present, there are a number of works on the effect of regional general circulation on precipitation in some parts of the country. Large-scale circulation anomalies are studied in details for the valleys of the Changjiang and Yellow Rivers, with the emphasis on the effect of winter and summer monsoon location and intensity anomalies[1]. In their study on the effect and forecast of general circulation changes on May precipitation in Yunnan, Yan et al. point out that the wetness in May in the province results from persistent anomalies over large spatial and temporal scales of the general circulation[2]. Wang stresses the role of spring anomalies of the general circulation at mid- and higher- latitudes over the Euroasian continent in the anomalies of circulation and precipitation in the summer of East Asia[3]. Analyzing the relationship between precipitation patterns from June to August in the summer of East China and preceding 500-hPa

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Biography: YAN Hua-sheng (1955 -), male, native from Yunnan province, professor, mainly undertaking the analysis and prediction of climate changes.

circulation anomalies in the Northern Hemisphere, Chen points out seasonal changes in the general circulation in various latitudes and their interactions may be one of the important factors for the distribution of rain zones across East China[4]. Yang puts forward a framework in which precipitation patterns are forecast for May in China after his study on the correlation between the monthly mean 500-hPa anomalous fields in May together with their geopotential values in the East Asia region and the precipitation in the current and preceding April in China[5]. With the characteristics known of the general circulation for various patterns of precipitation preceding to the early summer (June), Chen shows that there is some correlation between the winter (DJF) 500-hPa circulation in North Pacific and the general circulation and precipitation patterns in China in early summer and introduces to a forecasting model for precipitation patterns over the period on the basis of statistic analysis[6]. Ju et al. have similar study that shows large correlation between the general circulation situation in preceding winters and summer precipitation in the eastern part of China and large effect of deepening / weakening of troughs / ridges at 500 hPa in winter on the distribution of rain zones[7]. From the viewpoint of atmospheric remote correlation, Huang finds that teleconnection resulted from the general circulation anomalies in East Asia in response to changes in the intensity of convection around the Philippine region is posing large impact on the precipitation in the eastern part of the country[8]. Peng and Zhang also show that the characteristic indexes for five of the atmospheric teleconnection patterns in the Northern Hemisphere correlate well with the summer precipitation in China. They discuss in-depth the ways with which it is forecast. Apart from the work above, Zhu reveals a close relationship between the wavetrains of the Eurasian (EU), Huang He / East Asia (HEA) and East Asia / Pacific (EAP) patterns and the wetness in China, with the latter two having greater impact on the precipitation in East China[10]. Of much work on the correlation between the general circulation and precipitation in China, most use the technique of single-point correlation analysis. It is not particularly good at revealing the general characteristics of relevant structure between two fields and yields results that have limited meanings inevitably. In contrast, few addresses the evolution of general circulation in the Northern Hemisphere and the correlation between May precipitation fields. In view of it, the current work uses the Canonical Correlation Analysis (CCA) to study the correlation between national precipitation fields in May and monthly mean 500-hPa geopotential height fields in the Northern Hemisphere in periods preceding to and concurrent of the month. The aim is to probe into how spatial and temporal changes in large-scale upper circulation affect precipitation across the country so that we could have a better idea of the effect of temporal and spatial evolution of the general circulation on precipitation in May, where and how it is shown.

2 DATA AND COMPUTATION TECHNIQUES

The CCA is a technique that works well at analyzing the correlation between any two fields or groups of variables because it extracts main relevant structures which are different from field to field and forecasts based on them. The method has been applied in the analysis and forecasting of meteorological elements fields and results have been good[10-12].

The paper uses the month to month 500-hPa geopotential height fields in the Northern Hemisphere (0° – 360°E, 10°N – 85°N, 36×16) over preceding and current periods (January - May) for a 50-year period (1951 – 2000) and precipitation indexes for 15 divisions in China in May. They are denoted as the predictors field X for the CCA (with the number of variables m = 576) and forecast field Y (with the number of variables p = 15). When typical CCA is used, however, it is required that the sample amount n be greater than the number of the two groups of variables combined or the number of spatial points m and p in the two fields of variables to ensure a reversible variance matrix, which keeps the computation going on. An EOF decomposition is first done of the 500-hPa geopotential height field to pick up main components with certain accumulated variance to be used as the latest predictors field X^* (the accumulated variance taken to be 92%). The number of main components $k1$ is given in Tab.1 as extracted from individual fields of predictors. With some small perturbation information removed and large-scale features of the original geopotential field retained, because of the EOF decomposition, the relationship between the predictors fields, made up of main components, and the precipitation fields, well reflects main correlated structures in the two fields.

Tab.1 Number of main components extracted from individual fields of predictors (with the accumulated variance of 92%)

month	Jan.	Feb.	Mar.	Apr.	May
number of main components extracted ($k1$)	14	16	17	20	20

Applying the EOF decomposition to the predictors field and multiplying $k1$ main components with characteristic vectors for canonical relevant loads passing the significance tests, we can infer the canonical relevant fields of the original geopotential fields in individual pairs of correlation coefficients. For detailed inference, see [15]. Each of the components determined for the vectors is dimensionless, indicating that the larger the weight coefficient, the more important the variables it reflects will be. Major influence predictors or key zones can then be isolated for study. On the other hand, analysis of individual canonicai relevant fields reveals comprehensively the interior workings of the predictors and forecast fields and their mutual interactions.

For the forecast field Y, the formula by the National Climate Center of China, $\gamma = \left(\frac{1}{n} \sum_{i=1}^{n} \frac{R_i}{\overline{R_i}} + \frac{n^+}{n} \right) 100\%$, is used to calculate the precipitation indexes for the 15 regions in China. R_i is the monthly amount of precipitation, $\overline{R_i}$ is the multi-year mean of rainfall, i is the number of stations within the region, n^+ is the serial number of selected stations in the region, which indicates the number of stations with monthly precipitation anomalies $\Delta R \geq 0$ among the n total. It is obvious that a larger precipitation index indicates more precipitation in the region[14].

3 ANALYSIS OF RESULTS

3.1 *Analysis of the correlation between preceding and current 500-hPa geopotential fields and rainfall fields in May*

The generalized correlation coefficient can be used to study the correlation between the predictors and objects fields on an individual basis. For a particular field of predictors, we can determine for how long ahead the maximum correlation can be found in which the former relates to the latter so as to summarize the law by which they work. Following [15], the maximum canonical correlation coefficient is defined to be $\rho_{xy} = \max_{1<i<r} \lambda_i$ for the variables in two fields, using the generalized correlation coefficient set for the work.

Fig.1 gives the generalized correlation coefficients for precipitation coefficients in May and 500-hPa geopotential height fields in the preceding and current periods over the 15 regions in China. It shows a general "V" pattern in the curve. In other words, the May precipitation field in China is better correlated with the geopotential height field in the preceding period of January, or, the field of general circulation in the period has a greater effect on the precipitation field, by a coefficient of 0.9501. The correlation is decreasing with time, dropping to its lowest point in

March before ascending again till the current period of May, which is a little larger than in January (0.9594). In his summary of long-term weather forecast, Wang points out that many of the circulation factors affecting the precipitation in summertime in China is correlating every other season, with the one for about six months the most dominant[6]. As shown in what is calculated in the work, correlation every other season is present.

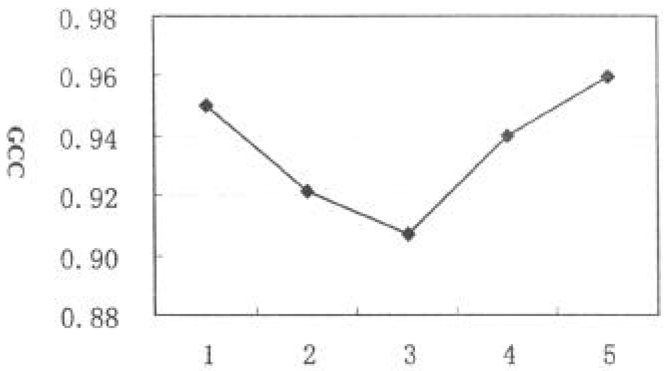

Fig.1 The generalized correlation coefficients for precipitation coefficients in May and 500-hPa geopotential height fields in the preceding and current periods over the 15 regions in China.

The canonical correlation coefficients are tested for significance[15] and the results are shown in Tab.2. It shows they are all above 0.9 for individual months and correlation is obvious except in March. For the canonical characteristic vectors for the maximum canonical correlation coefficient in individual months, they are graphically described for more analysis of the correlation between the May precipitation fields and circulation fields in the preceding January, February and April and current May.

Tab.2 Results of tests on the significance of correlation between rainfall fields in May and 500-hPa geopotential height fields in preceding and current periods

Month	Jan.	Feb.	Mar.	Apr.	May
Number of coefficients passing the significance tests (*k*2)	1	1	0	1	1
Coefficients passing the significance tests	0.9501	0.9216	0.9073	0.9379	0.9594

3.2 *Analysis of the correlation between May rainfall and January geopotenital height field*

Fig.2 gives the distribution of the first couple of characteristic vectors for canonical loads of the May rainfall field in China and the 500-hPa geopotential height field in the preceding January in the Northern Hemisphere. From Fig.2a, large regions of correlation centers, both positive and negative, appear in the whole hemispheric geopotential height field. Extending zonally, they are mostly within the planetary jet stream zones in mid- and higher- latitudes in an obvious alternative 3-wave structure along the zonal circle. Three negative correlation centers are located in the east coast of Asia, eastern Canada and eastern Europe, which happen to be the mean positions three ultra-long troughs at 500 hPa in winter. In other words, the general circulation in the preceding January is affecting the precipitation anomalies in May in China mainly via the changes in the ultra-long wave. Similar results are obtained in the analysis of precipitation for

June – August[7]. With calculation, Zhang points out that the contribution by long-term processes above 1 month contribute little due to rapidly decaying shortwave and longwave in the initial field while the ultra-long wave with 1 – 3 wavenumbers becomes the dominating system for long-term weather processes. It is also noted that the largest couple positive and negative centers do not appear over China but over northeastern Pacific Ocean and eastern Canada, respectively, with some characteristics of teleconnection. It is similar to the results achieved by Chen with charts of composite anomalies[7]. Besides, it is not hard to find that the elongated correlation zone over the east coast of Asia and eastern Canada is right over the major paths of storms in the Northern Hemisphere. It is then used to infer that there may be links between precipitation anomalies in May and changes in storm track at 500 hPa in the hemisphere. A couple of meridional positive and negative centers are clearly existent over western Atlantic Ocean, which may reflect strong WA atmospheric teleconnection patterns.

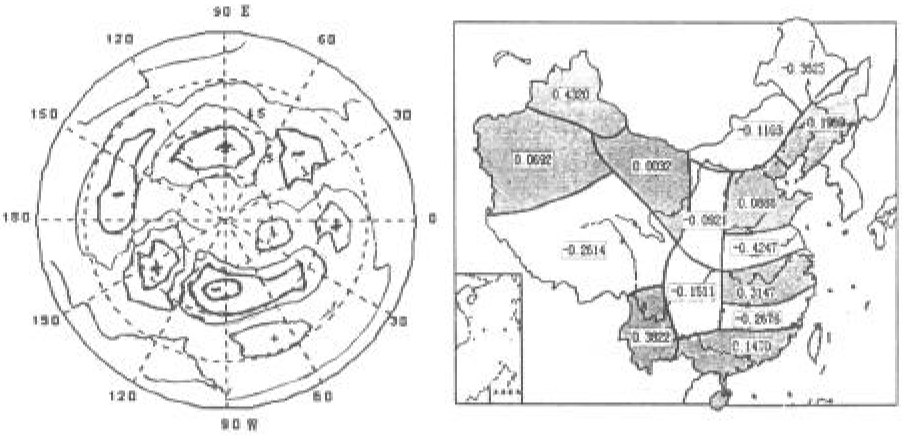

Fig.2 The distribution of the first couple of characteristic vectors for canonical loads of the May rainfall field in China and the 500-hPa geopotential height field in the preceding January in the Northern Hemisphere. b. The shaded parts are for positive correlation, the same below.

For the precipitation field, basic climatological characteristics were drawn for May and annual variability was found to be large in all parts of China over the month, with the north and west more obvious than the south and east[5, 14, 18]. From Fig.2b, we know that the values of canonical characteristic vectors in eastern China distribute from north to south in wavetrains that are positive and negative in alternation. Across the nation, positive correlation regions also alternate with the negative ones from east to west, with the positive correlation centers over northern Xinjiang and Yunnan and the negative ones over the Huai He R. and northeastern Inner Mongolia. In comparison with Fig.2a, we can see that the intensity of the upper-level ridges over Siberia, North America, western Pacific and western Europe are positively correlated with the southern coast of China, Yunnan, the Changjiang R. and its neighboring areas, southeastern part of Northeast China and Northwest China but negatively correlated with the rest. The positive correlation is most evidently seen in northern Xinjiang and Yunnan while the negative one in the Huai He R. and area west of Heilongjiang. In other words, when ridges intensify over the Ural

Mts. and North Pacific and the North America trough deepens in January, precipitation will increase in northern Xinjiang and Yunnan in May while decreasing in the valley of the Huai He R.

3.3 *Analysis of the correlation between May rainfall and February geopotenital height field*

From Fig.3a, we know that longwave is still the main structure in the distribution of positive and negative correlation centers in the Northern Hemisphere in February, though with the 3-wave feature more transitory than that in January. Firstly, the number of wavenumber increases and the whole system tends to move east and expands south, with the range of change being about 10 degrees in both zonal and meridional extensions. It may be related with the eastward propagation of low-frequency atmospheric oscillation and seasonal changes in longwave troughs and ridges. For the maximum correlation area, the low-value part begins weakening in January in eastern Canada while the high-value part is relatively stable over the Pacific Ocean and a new area of positive correlation appears over the European region. Judging from the case of precipitation, we know that the positive and negative correlation centers distribute differently from January (Fig.2b), as the high-correlation areas over East China move about 10 latitudes to the south while the rest stays over northern Xinjiang, areas west of Heilongjiang and Yunnan. Besides, the signs of correlation change in ways that are the same as in Fig.2b in all parts of the country except for part of the southern provinces.

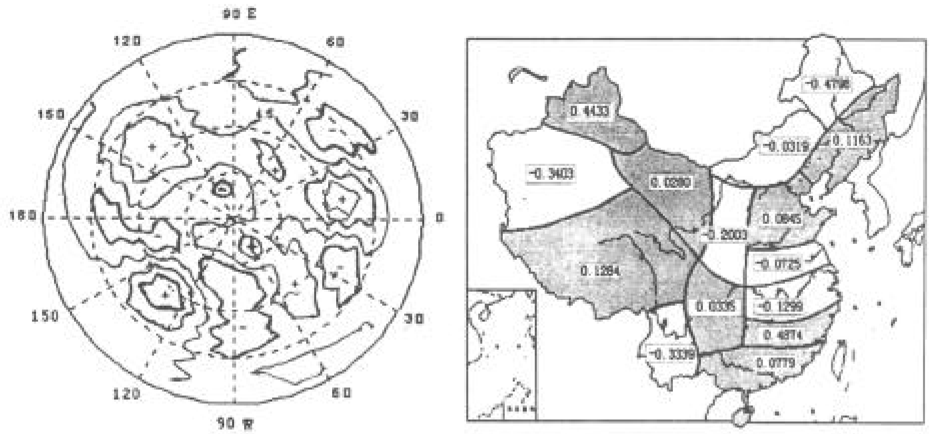

Fig.3 The first couple of canonical correlation field for precipitation index in May (a) and 500-hPa geopotential field in preceding February (b). The captions are the same as Fig.2.

3.4 *Analysis of the correlation between May rainfall and April geopotential height field*

On the figure showing the correlation between the May precipitation and April geopotential height field (Fig.4a), we observe that large changes have taken place in the distribution of correlation centers in the Northern Hemisphere as compared to the winter —wavetrains are less obvious for the distribution of general troughs and ridges other than a few set of well-defined teleconnection patterns, with more obvious effect from the mid- and lower- latitudes. It is interesting to find that a set of meridionally distributed zone of positive and negative correlation over the North Pacific is very similar to the WP pattern (teleconnection for western Pacific) at 500 hPa. Correspondingly, the high precipitation correlation area is largely over the upper and middle reaches of the Yellow River with the highest weight coefficient being 0.5502. It differs much with the distribution of correlation as shown in Fig.2b and Fig.3b. The distribution of simultaneous correlation coefficients using the WP pattern characteristic indexes and June precipitation fields in China are close to the results as given in Fib.4b[10]. The same literature points out that it is synoptically right to think that the high correlation distribution as shown in the figure is caused by increased north-south gradient in the geopotential height field and strengthened westerly frontal zone, together with possible convergence between the southeasterly from the rear portion of an anomalously elongated high pressure and the northwesterly from the north over the middle and upper reaches of the Yellow R., as a result of a developing western Pacific subtropical high and a deepening Aleutian low. We can then infer that precipitation will increase over the upper and middle reaches of the Yellow R. if the WP teleconnection is anomalously stronger in the preceding April. Besides, two centers of high correlation appear over the North Pacific and Canadian region, which match well with negative centers in both zonal and meridional directions. They are in effect similar to the patterns of Northern Oscillation (NO) and western Atlantic (WA) teleconnection.

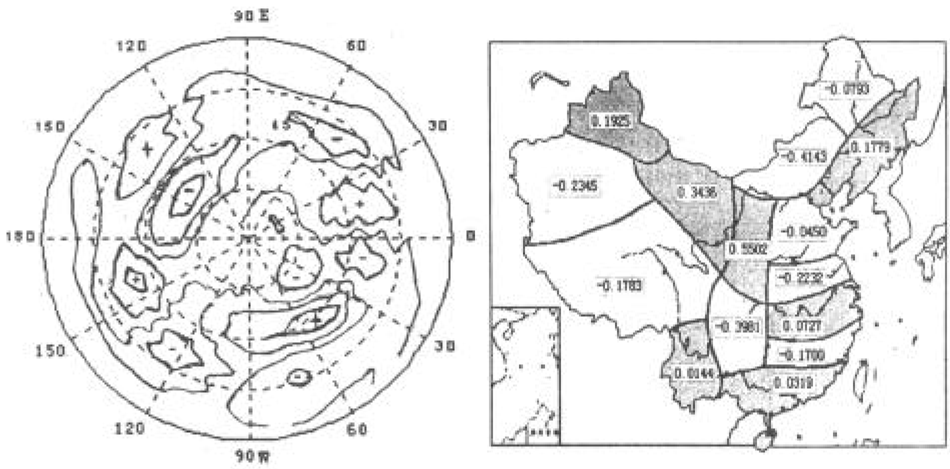

Fig.4 The first couple of canonical correlation field for precipitation index in May (a) and 500-hPa geopotential field in preceding April (b). The captions are the same as Fig.2.

3.5 *Analysis of the correlation between May rainfall and May geopotential height field*

It is not hard to find that the anomalies of general circulation that affect China's precipitation in May are not global as they usually are but teleconnect with regions upstream, which reflects one of the most significant characteristics, as shown in Fig.5a: the high correlation area has reduced in size from the whole Northern Hemisphere to the Eurasian continent upstream of China. The centers of negative correlation between 60°N and 90°N, particularly, suggest that the intensity and routes of south-advancing cold air mass that affect China be the main cause for changes in the spatial distribution of precipitation in China, which in turn are directly governed by the evolution of general circulation and adjustment of longwave in upstream regions. It is then clear that it is of synoptical and climatological significance to find high correlation between the May precipitation in China and the general circulation over regions upstream. Zhang and Yu et al. emphasize the need to look at the influence of anomalous wavetrains at 500 hPa over the mid- and higher- latitudes in the Eurasian continent on precipitation in May and the whole summer in China and their results are also quite close to those presented above[19, 20].

3.6 *Discussions*

As shown in the analysis above, the general circulation differs much from in the ways it affects the May precipitation. From the viewpoint of influence coverage, circulation fields with longer time intervals have a global effect from places of high correlation that may be far away from China; for the circulation fields over the current period, the correlated region is no longer global and mostly locates in part the upstream region. From the viewpoint of governing system, the general circulation affects the anomalies of May precipitation in China mainly via the changes in ultra-longwave when its intervals are long but by means of atmospheric teleconnection patterns when they are short. The changes in and propagation of energy in the atmospheric system cause these phenomena. Some work has been devoted to describe the ultra-longwave. In Huang's opinion, the teleconnection is resulted from the transportation of quasi-stationary planetary waves in the spherical atmosphere[8]. He also concludes that it takes about a month for the teleconnection to travel from tropical Pacific to the Atlantic, which is a physical law governing short-term climatic changes.

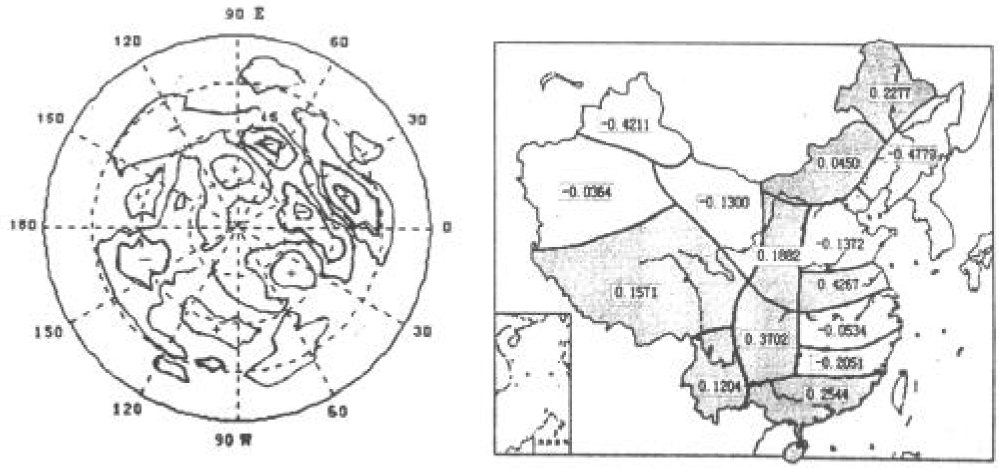

Fig.5 The first couple of canonical correlation field for precipitation index in May (a) and 500-hPa geopotential field in the current period (b). The captions are the same as Fig.2.

4 CONCLUDING REMARKS

a. An obvious every-other-season correlation is found between the May precipitation fields in 15 regions of China and 500-hPa circulation fields in periods preceding and concurrent to the month. The correlation is the best between the former and 500-hPa general circulation in preceding January and current May.

b. The preceding 500-hPa circulation field has a global effect on the precipitation in May, or, the forecast of the latter should include atmospheric changes on a global basis. Specifically, global atmospheric changes must be accounted for in the forecasting of precipitation in May using circulation fields for the preceding period. Specifically, atmospheric circulation over the preceding January and February is to be include the development of ultra-longwave in mid- and higher- latitudes while the WP and WA patterns should be the major atmospheric teleconnections for April, a time with shorter time intervals.

c. The teleconnection between 500-hPa circulation fields over current periods and precipitation in May is much more obviously shown in the changes in the circulation over the upstream Eurasian region than elsewhere.

d. For the distribution of canonical characteristic vectors in eastern China, it is a north-south wavetrain structure alternating with positive and negative anomalies; from east to west, positive and negative correlation centers also aligning alternatively.

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