Analysis of Causes and Seasonal Prediction of the Severe Floods in Yangtze / Huaihe Basins during Summer 1991

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ABSTRACT

The present paper shows that a seasonal prediction for the large scale flooding and waterlogging of the mid-lower Yangtze / Huaihe River basins in the summer of 1991 made successfully in early April 1991. The seasonal forecasting method and some predictors are also introduced and analyzed herein. Because the extra extent of the abnormally early onset of the plum rain period in 1991 was unexpected, great efforts have been made to find out the causes of this abnormality. These causes are mainly associated with the large scale warming of SST surrounding the south and east part of Asia during the preceding winter, while the ENSO-like pattern of SSTA occurred in the North Pacific. In addition, the possible influence of strong solar proton events is analyzed. In order to improve the seasonal prediction the usage of the predicted SOI in following spring / summer is also introduced. The author believes that the regional climate anomaly can be correctly predicted for one season ahead only on the basis of physical understanding of the interactions of many preceding factors.

Key words: Summer flooding in the Yangtze / Huaihe River basins, Seasonal prediction, Causal analysis

I. INTRODUCTION

A large scale severe flooding and waterlogging occurred in the mid-lower Yangtze / Huaihe River basins in the summer of 1991, with the abnormally early onset of plum rains, earlier than normal by about one month. The amount of plum rains (Meiyu) in most areas of the Yangtze / Huaihe River basins as larger than normal by a factor of 1-3, more than one hundred million people were struck by this disaster. More than 13 million hectares farmlands were severely waterlogged. However, the occurrence of such disaster was not unexpected. According to the physical analysis of the forming process of the summer drought / flood in the Yangtze / Huaihe River basins and the studies of seasonal prediction (SP) for over thirty years (Xu, 1986; 1988a; 1990), the author had issued a summer prediction in early April 1991 as follows: "The onset of plum rains will be earlier, with large amount of rainfall and later ending date, hence a large scale summer flooding and waterlogging will occur in the mid-lower Yangtze River and the whole Huaihe River basin during following summer". Now this SP has been verified by the observations.

II. MAIN THINKING OF SEASONAL PREDICTION

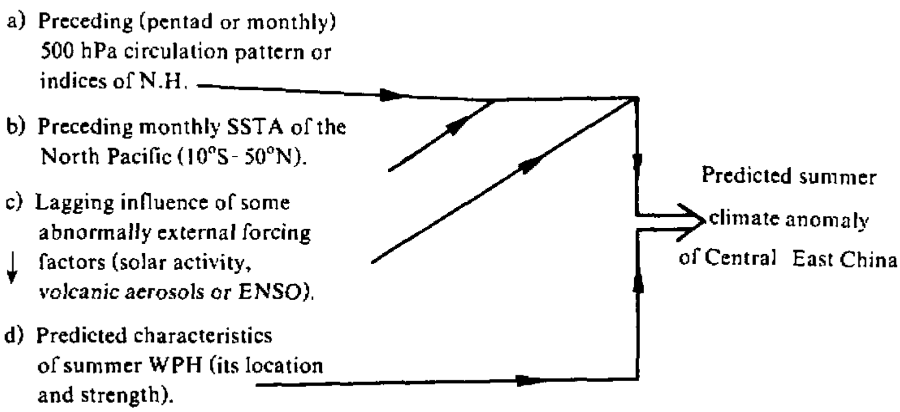
Seasonal prediction (SP) is an unsolved problem in the world, especially the SP of precipitation in temperate zone. Having been studying and making SP for summer rainy trend of the mid-lower Yangtze-Huaihe River basins for many years, the author has found a feasible way of SP of rainy trend for a definite time / space scale (Xu, 1988a). It is crucial to search seasonal predictors from the point of developing long-range weather process. Firstly, the

the mid–lower Yangtze–Huaihe River basins for many years, the author has found a feasible way of SP of rainy trend for a definite time / space scale (Xu, 1988a). It is crucial to search seasonal predictors from the point of developing long–range weather process. Firstly, the author has found a series of significant temporal–spatial teleconnection (TST), existing between the summer rainfall of Central–East China and the prevailing circulation pattern in preceding winter / spring; Next, it is notable that, these TSTs were broken in some years, whereas some external climatic factors (such as solar activity, volcanic aerosols and ENSO phenomena) might play dominant roles in these cases. However, none of the above predictors is always correct, for the forming factors of long–range weather process are changing in different periods. So we should find out the different sets of seasonal predictors from the view points of statistical analogy and physical analysis.

For further improving the SP level of summer rainy trend of Central–East China, it is more suitable to predict a weather system of planetary scale– the West Pacific high (WPH), for both its location and strength exert dominant effects on the spatial distribution of the summer monsoon rainfall of East China. Owing to the potentially higher predictability of planetary scale systems than that of a local rainfall, it is suitable to cooperate the SPs of both the former and latter for improving the SP of summer rainy trend of Central–East China (Xu, 1988a).

The above thinking may be summed up by a diagram. We generally make SP by using some TSTs (predictors a and b). But if some preceding external factors c appear abnormally, their signal for the summer climate is contradicting with the above TST, then we should prefer using predictors c and d to TST; this means that, above TST has been overwhelmed by the effects of some abnormally external factors.

A Diagram for SP



Using the above method, the author has reached moderate success in the SPs of the summer rainy trend in the mid–lower Yangtze River basin for the recent 20 years (1968–1987) (Xu, 1986; 1990). The skill–scores (SC) of SPs are significantly higher than climatic probability (Table 1).

Table 1. The SC of SPs for Summer Rainy Trend of the Mid–Lower Yangtze River Basin during the Recent 20 Years

SC	M	M_{JJ}	M_{JJA}
SP	+0.25	+0.40	+0.32
CP	+0.47	+0.48	+0.40

Here, the CP is the corrected prediction issued at least one month ahead of the predictand; M is the amounts of plum rains, M_{JJ} and M_{JJA} are the averaged rainfall of 10 stations evenly distributed in the mid–lower Yangtze River basin during June–July and summer season respectively. It is notable that, the years with severest summer flooding / waterlogging or drought in these 20 years (such as 1969, 1970, 1978, 1980, 1983 and 1987) have been all successfully predicted by the SP or CP, in spite of some failures had occurred in other years. The forecasted results are generally better, when the TSTs (a) and (b) coinciding well with external factors (c) and (d), the SP of summer 1991 is a good example of this kind.

III. THE SP FOR SUMMER 1991

In making the SP for summer 1991, following predictors as TSTs have been considered.

1) Positive winter (Dec.–Jan.) anomalies of the SST in the regions of the Kuroshio current and South China Sea, while the SOI is in normal state (Xu, 1988b). This combination of SSTA in the North Pacific during the preceding winter is of benefit to the north–westward extension of the west ridge of WPH (at 500 hPa level) in June (Xu, 1988b), which means that the WPH tends to stretch over the warmer regions of SSTA (such as the Kuroshio current and South China Sea), causing a stronger south–west warm moist airstream over the Yangtze–Huaihe River basins from the source in the Bay of Bengal; hence the onset of plum rains will be earlier.

2) Warming took place in China during winter 1990–1991 followed by cold March in 1991. This temporal distribution of temperature anomalies during the preceding winter and early spring benefits more frequent invasions of cold air from Siberia in the following summer (Xu, 1990).

3) Higher intensity of WPH in the regions of the West Pacific and the South China Sea during February–March 1991. This regional positive anomaly of 500 hPa height tends to persist in following June, favoring the strengthening of warm–moist air from the Bay of Bengal, hence in phase with the predictor 1.

4) The SOI has changed to a significant negative value in March 1991, which means that a stronger Hadley circulation will tend to appear in the following months, with the enhanced cloud clusters rising over the equatorial mid–Pacific; the stronger Hadley cell also benefits the strengthening of WPH, with its west ridge extending more westward in June, showing a lagging influence also in phase with the predictors 1 and 3.

5) Most distributions of telecorrelations between summer rainfall of the Yangtze / Huaihe River basins and the preceding monthly 500 hPa height fields indicate that, copious rainfall would occur in the forthcoming summer due to the frequent invasions of cold air from north.

The above predictors of TST indicate the possibility of early onset of plum rains. According to the predictors 2 and 5, more frequent invasions of cold air from the north will be expected in the summer of 1991; whereas from the predictors 1, 3 and 4, a strengthened summer

WPH will appear, with its west ridge extending more westward, thus the warm moist airstream over Central–East China from the Bay of Bengal will be intensified. Hence both the cold and warm moist air from opposite directions will enhance, confronting each other over the Yangtze / Huaihe River basins during the summer of 1991.

In addition, the following two external forcing factors are also important:

6) The significant low value of direct solar radiation of clear skies (S), which was detected from the data of 5 stations in East China during the winter of 1990–1991; S was lower than the normal by about 14% (base period: 1959–1986), reflecting a denser aerosol layer over East China. Although no significant volcanic eruptions occurring in this winter, the increasing trend of anthropogenic aerosols over East China was notable. It is shown that, when the S decreases sharply, the decreased heating of the land surface in Asian continent will lead to a southerly shift of WPH in high summer, with its northern monsoon rainy belt located steadily in the mid-lower Yangtze / Huaihe River basins (Xu, 1990).

7) Solar activities were very strong during 1989–early 1991. According to the works of Xu (1984, 1986), preceding strong solar activity will lead to strong WPH, with its west ridge extending more westward, benefiting an early onset of plum rains.

Based on the above thinking, the SP of summer 1991 was formed and issued by the author in April 2, 1991.

IV. CAUSAL ANALYSIS AFTER SUMMER 1991

The above main thinking concerning the SP is basically correct, even as we review and analyze it later on. However, the extent of abnormally early onset of plum rains was unexpected, in spite of the SP was "early". Practically, it appeared earlier (on 18 May) than normal for about one month. Therefore it is essential to find out the causes of such abnormality.

1. *Circulation Anomaly of East Asia in Late May 1991*

From a synoptic point of view, the abnormally early onset of plum rains was caused by the abnormally intense west–south airstream from the Bay of Bengal since late May, which may be seen clearly from Fig.1. The 500 hPa height anomalies show an outstanding feature that, the wave 2 prevailed in the extratropics of the Eastern Hemisphere: large positive anomaly appeared at Korea / Japan (35–40°N, 130–150°E) and the east side of Mt.Ural, while negative centers were located in East Europe and Lake Baikal, respectively (Fig.2). This distribution of height anomalies shows an abnormally weakening and retreating of the coastal trough in East Asia, which is normally located in the temperate zone of 130°E, favoring the strengthening of both a warm moist west–south airstream from the Bay of Bengal and a north–westward extension of WPH. The monsoon rainy belt on the west–north side of WPH was thus located steadily in the north of 30°N (east of 110°E) since late May 1991.

2. *Preceding Factors Dominating the Occurrence of Abnormal Circulation in East Asia during Late May 1991*

The characteristics of 500 hPa circulation over Asia in late May may be defined by the following two parameters.

A: Averaged anomaly of 500 hPa height in the east section of Asian temperat zone (35–40°N, 120–140°E). As A is positive (negative), it reflects a significantly weakening (strengthening) and retreating northward(extending southward) of the coastal trough over East Asia.

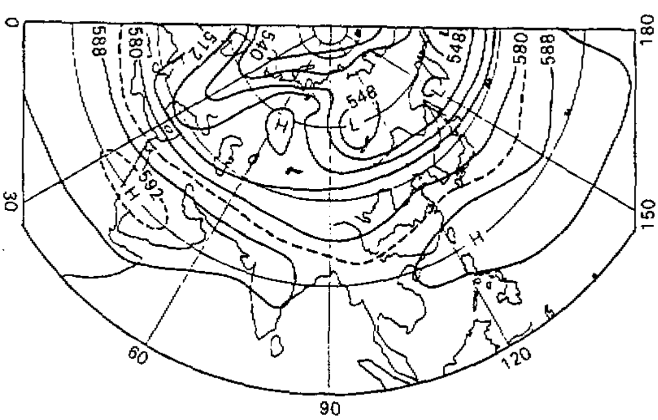


Fig. 1. Averaged 500 hPa height circulation during the last ten days of May 1991, the unit is dam.

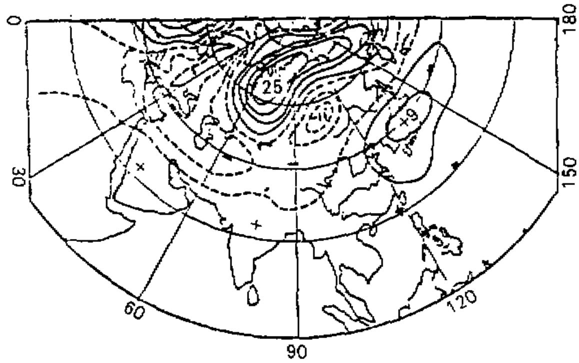


Fig. 2. Distribution of 500 hPa height anomalies during the last ten days of May 1991 (base period: 1971–1990), the unit is dam.

C: Difference of the averaged anomaly of 500 hPa height between the east (value A) and west section (35–40°N, 60–90°E) of Asian temperate zone; as C is positive (negative), which shows a measure of the west–south (west–north) airstream, prevailing over the mid–lower Yangtze / Huaihe River basins.

We have found that, both A and C correlated significantly with the SSTA of the North Pacific (10°S–50°N) during the preceding winter (data: 1971–1990). From Fig. 3, it is shown when the winter SSTAs in the equatorial mid–East Pacific and Kuroshio current (30°N) were significantly higher (lower), then a west–south (west–north) airstream might prevail over the mid–lower Yangtze–Huaihe River basins during late May.

In addition, when negative (positive) SSTA appears in the western tropical Pacific during the preceding winter, A tends to be positive (negative), favoring the weakening (strengthening) and retreating northward (extending southward) of the coastal trough in East Asia during late May. In sum, if El–Nino like SSTA appears in the tropical Pacific, accompanied by the negative SSTA in the western tropical Pacific during the preceding winter, while the SSTA of the Kuroshio current is also positive, then the meridional distribution (15–30°N) of SSTA

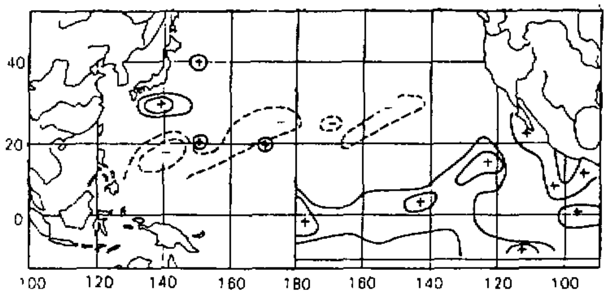


Fig. 3. Distribution of high correlations of SST field during the preceding winter with A (dashed line) and C (real line). Correlations in the outer and inner circle are significant at 95% and 99% level, respectively (data: 1971–1990Yr.).

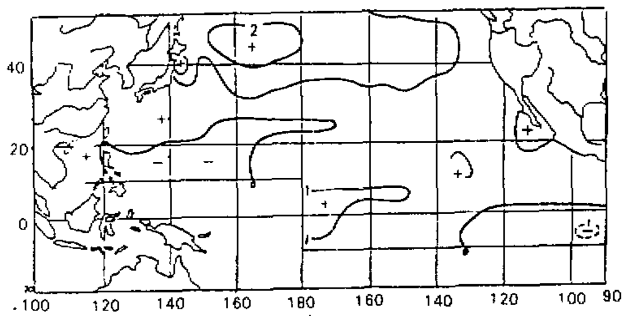


Fig. 4. Distribution of averaged anomaly (°C) of SST of the North Pacific during the winter of 1990–1991.

along 140°E is positive in the north and negative in the south. This means that, the isotherm ribbon of the western Pacific concentrating at 30°N (south of Japan) in the preceding winter will tend to persist in the following season, benefiting a corresponding change of the atmospheric circulation in East Asia during late May. The isopotential of the western tropical Pacific of 500 hPa in late May also concentrates at 30°N with a weakening of the coastal trough in East Asia, which also benefits a strengthening of warm moist west–south airstream prevailing over Central–East China during late May.

It is notable that, the distribution of SSTA in the North Pacific (Fig. 4) during the winter of 1990 (as an independent sample of Fig. 3) was analogous to Fig. 3, and thus a close relationship might exist between the former and the abnormal circulation pattern of East Asia in late May 1991, leading to an abnormally early onset of plum rains in central–East China.

V. INFLUENCE OF STRONG SOLAR PROTON EVENTS

From the view point of solar–terrestial relationship, the summer of 1991 was also characterized by its highest occurrences of strong solar proton events (SSPE) since 1976. The highly energetic proton flux may be a sole flux of solar activity, having the ability to penetrate deep into the troposphere. Thus it may have much influence on the tropospheric circulation. The author has calculated the lagging effect of SSPE on the 500 hPa circulation during first summer (May–June) using solar data from SESC (1976–1990). There were 10 cases of SSPE (peak proton flux reaching energy threshold of 20 pfu at greater than 10 MeV) in this season for the recent 15 years (1976–1990). Now we calculate the changes of the first, second and third pentad 500 hPa height anomaly field relative to the pentad just before the SSPE in the first summer separately, with the T–test on height change of each grid point in N.H.. It is notable that, a positive center, significant at 99% level, appears over the Yellow Sea (35°N,120–130°E) of the second pentad 500 hPa height change field after SSPE, which is just located in the region A (Fig.5). It is most interesting that a series of SSPEs occurred in the first summer of 1991, such as on 13 May, 1 June, 11 June and 15 June in sequence, all favoring a positive 500 hPa height anomaly persistently staying over region A through mid May– mid June 1991, which also benefits the strengthening of west–south warm moist airstream prevailing over central–East China since mid May, the abnormally early onset date of plum rains (18 May) just followed the first SSPE (13 May) be a lag of 5 days.

VI. WIDER BACKGROUND

As early as in 1970s, the winter SSTA in the northern Pacific had been analyzed and used for the SP of rainy season in China (The group of long–range weather forecast, 1978). Now we further stress the critical role played by the large scale warming of ocean currents in the preceding winter of 1991.

Two largest warm currents of N.H. (the Kuroshio current and the Gulf Stream) were stronger than normal during the winter of 1990–1991. Stronger warm currents transported more heat and moisture northward from the tropics. The author has found that, stronger

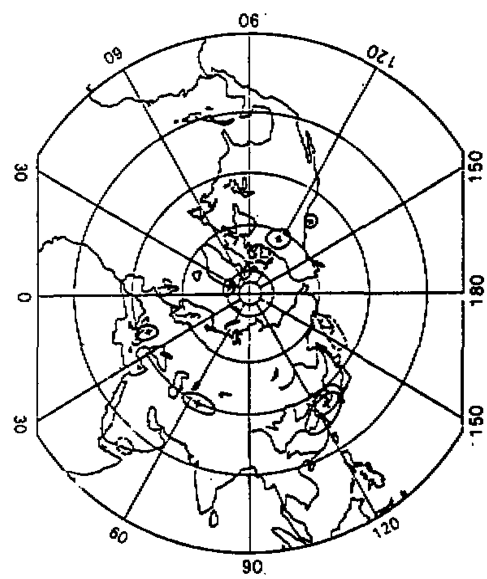


Fig. 5. Distribution of T–test for the change of second pentad 500 hPa height anomaly after the SSPE (relative to the pentad just before SSPE). The area in the outer and inner circle are significant at 95% and 99% level respectively.

winter Gulf Stream tends to be followed by increased summer rainfall in the Huaihe River basin (Xu, 1982). It has been found that, when the averaged SSTA of 7 grid points in the axis of the Gulf Stream (42.5°N, 67.5–52.5°W; 37.5°N, 72.5–62.5°W) in January $\geqslant +0.7$°C, while the averaged SSTA of 6 grid points in the axis of the Kuroshio current (35°N, 140–150°E; 30°N, 135–145°E) during January and last December $\geqslant +0.8$°C, the abnormally early onset of plum rains occurs in most (5 / 6) of the recent 42 years (1951–1992) possessing above two conditions (earlier than normal at least by 10 days); when the third condition (China is cold during March) also appears, consequently, the large scale flooding and waterlogging occurs in the mid–lower Yangtze–Huaihe River basins during following summers (3 / 3).

The strengthening phenomenon of warm currents in N.H. during the winter of 1990 was associated with a large scale warming of the sea surface from the tropic of the Indian Ocean to the North Pacific. It is shown in the SSTA of Jan. 1991 (omitted) that, a positive SSTA appeared in the 50°E of the western Indian Ocean, then expanded eastward across the South China Sea, via the Kuroshio current to the northern Pacific drift near 140°W. Going round the south and east part of Asia across about 170 longitudes, such large positive SSTA persisted from January through May 1991. Accordingly, a large scale positive height anomaly at 500 hPa level (starting from South India eastward, via the South China Sea to the western Pacific and Japan) also appeared steadily during the whole spring of 1991. This may be considered as a critical background for the abnormally strengthening of the west–south warm moist airstream from the Bay of Bengal since mid May and the successive occurrences of intense monsoon rainy belt over the mid–lower Yangtze–Huaihe River basins during the summer of 1991.

Indeed, the author noticed some parts of this phenomenon in making the SP of the summer of 1991 (predictors 1 and 3), but the actual lagging effects of this large scale warming of SST around Asia during the winter of 1990 still needs to be studied further.

VII. USE OF THE PREDICTED SOI IN SPRING / SUMMER FOR IMPROVING SUMMER SP

It should be further stressed here that SP is still an unsolved problem. Although the author has gained moderate success in SP for the past 20 years (1968–1987), the SPs for 1988 and 1990 had resulted in failure, some key predictors had failed for SP. The author has analyzed all 4 mistaken summer SPs (for years of 1973, 1981, 1988 and 1990) of the past 23 years (1968–1990). It is found that, they all appear in the changing phase of SOI during its course from the negative phase in January–March to the positive phase in April–July, which means that the developing trend of SOI in the forthcoming spring–summer may be a key factor dominating the success or failure of our SP. So a suitable way may improve SP by using the forecasted products of SOI form CAC of NOAA, though the latter is not always correct. It was very good for the year of 1991 due to following consistencies.

1. The most of predictors for the summer of 1991 are consistent with each other, especially between TST and external factors.

2. The predicted SOI issued by CAC (January 1991) had been considered, which showed a negative phase of SOI would be expected for the spring–summer of 1991. According to the work of Xu (1989), negative phase of SOI during April–June combined with a reduced solar radiation in China influenced by aerosols may lead to a more southerly position of WPH in high summer, with its northern monsoon rain belt located in the Yangtze–Huaihe River basins; this climate inference was also consistent with our SP of central–East China for the summer of 1991.

3. The last but important factor is the correctness of SP for SOI in the spring–summer of

1991, which further benefits the full success of our SP.

VIII. CONCLUSION AND DISCUSSION

1) According to the study of the SP for the summer rainy trend of central–East China, the author had issued a successful SP in early April 1991, predicting correctly the occurrence of large scale flooding and waterlogging in the mid–lower Yangtze–Huaihe River basins during the following summer.

2) Connecting with the significant skill scores of the present SP method for the recent 20 years, this way of SP is based on the TST between the preceding air–sea system and regional climate anomaly with the consideration of other physical factors. Therefore it is promising for the reduction and prevention of natural hazards.

3) From the view point of analysis after the event, there really exists a series of physical links between summer flooding of the Yangtze–Huaihe River basins and the seasonal predictors abovementioned. However, the extent of the abnormally early onset of plum rains in 1991 was unexpected. From preliminary estimation, the following preceding background is of critical importance – a large scale winter warming of SST had occurred from the tropic of the Indian Ocean, via the Kuroshio current to the North Pacific drift, across about 170 longitudes. Meanwhile the distribution of winter SSTA in the northern Pacific tended to be an ENSO–like pattern: negative SSTA in the western tropical Pacific was accompanied by a positive SSTA in the central equatorial Pacific and the Kuroshio current, the meridional thermal gradient of SST in 15–30°N along 140°E was thus reduced, with a northward shift of the thermal frontal zone, which also had much persistence, favoring the northward retreat of the coastal trough in East Asia during late May 1991. Hence it further benefited the strengthening of the warm moist west–south airstream over the mid–lower Yangtze–Huaihe River basins and the abnormally early onset of plum rains in 1991.

4) Imposing on the background of the above air–sea interaction, the frequent strong solar proton events starting on 13 May 1991 tended to stimulate a northward move of the coastal trough in East Asia during the early summer, further accelerating the abovementioned process. The abnormally early onset of plum rain in 1991 was thus caused by the coupled actions of many factors mentioned above.

5) The use of SP of spring–summer SOI is valuable. The consistency of phases between forthcoming spring–summer SOI and the SP of summer climate anomaly in central–East China will further confirm the occurrence of later; otherwise, we should reconsider our SP.

6) No significant influence on the present abnormality has been found either for the smoke clouds from the oil field or from the volcanic aerosols of the Mount Pinatubo. According to the results of two different numerical experiments on the Gulf's oil smoke rising in early 1991, a same conclusion from Browning et al. (1991) and Bakan et al. (1991) had been drawn as follows. Owing to the limited heights (less than 3–4 km) of the oil smoke, their climatic effects were not global, restricted only in some regional scale.

Although the volcanic eruption of the Mount Pinatubo (mid–June 1991) was very large with global influence lasting for several years, its dense aerosols floated south–westerly in the very beginning through July 1991, so there was less volcanic aerosols affecting east Asia–west Pacific (east of 100°E and north of 10°N) while the severest flooding occurred in central–East China; this result was obtained from the weekly charts of global aerosol optical thickness measured by the NOAA polar orbiting satellites (CAC, Sept. 1991).

7) We cannot expect an existence of several steady predictors of regional climate, lasting for several years (Kung, 1982). Hence regional climate prediction is more difficult than that

for planetary scale (such as the inter–annual change of global–hemispheric average temperature or ENSO phenomenon). However, owing to the closer association of the former with national–regional economy and people's life, it is urgent for us to develop the study of climate model for regional long–range prediction, based on the understanding of a series complex interactions from several different sets of preceding factors.

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