ANALYSES OF IMPACT OF THE COLD AIR ON MOVING OFF THE TIBETAN PLATEAU OF THE PLATEAU LOW VORTEX

YU Shuhua [1] XIAO Yuhua [2] GAO Wenliang [1]
[1] The Institute of Plateau Meteorology, CMA, Chengdu, 610072
[2] Sichuan Provincial Meteorological Observatory, CMA, Chengdu, 610072
E-mail: shuhuayu@mail.sc.cninfo.net

Abstract: Cyclonic vortexes often emerge in the Tibetan Plateau in summer, some of which move out of the Plateau and cause heavy rain and even extensive damage in the area to the east of the Plateau. Investigation on the activities of the Tibetan Plateau Vortexes that last longer time after leaving the Plateau during 1998-2004 and detailed diagnostics of baroclinity and temperature advection as well as numerical experiments are undertaken in this study to elucidate the effect of the cold air. The conclusions are as follows: 1.If a Plateau vortex is affected by the cold air around its leaving the Plateau, its lifespan off the Plateau will be longer than 36 hours. 2.The Tuole Vortex's moving out of the Plateau is closely related to the strong baroclinity associated with the cold air at 500hPa, especially one extending into the vortex from northeast. 3. The cold advection takes an important role in Tuole Vortex movement. When the advection to the west of the Tuole Vortex is stronger than that to the east, Tuole Vortex moves out of the Plateau; when dominated largely by cold advection the vortex moves less. 4. The numerical experiments on the effect of the cold air display that in the absence of the cold air in vortex area or cold temperature trough in the northeastern China, the Plateau vortexes go eastward slowly with weaker intensity and smaller maximum velocity; the cold trough in the northeastern China is more essential to Plateau vortexes' movement; Without the cold trough, Plateau vortexes even go backward.

Keywords: Plateau vortex,the cold air effect, diagnostics of baroclinity, numerical experiment

1. INTRODUCTION

Tibetan Plateau cyclonic vortexes (briefly as Plateau vortex) move eastward sometimes out of the Tibetan Plateau and cause heavy rains, or even severe heavy rains over a larger area of eastern China with a result of severe floods there.

Many meteorologists have paid great attention to the eastward movement of Plateau vortexes. Ye Duzheng and Gao Youxi pointed out in 1979 that with a favorable upper condition, a shallow system in the planetary boundary layer over the Plateau could develop and move out of the Plateau. Li Guoping said that certain steering conditions enabled the cyclonic vortexes to migrate out of the Plateau. Hideo Takahashi also found that the cold air posed a direct impact on development of the low pressure over the northern Plateau. Although these studies help us to understand the activities of Plateau vortexes, we are still lack of the knowledge of how the cold air to influence the movement of Plateau vortexes.

In this paper, we focus on understanding how the cold air affects the movement of Plateau vortexes by means of diagnostic analyses, numerical simulation and experiments, in addition to investigations on the Plateau vortexes causing severe heavy rains and floods around China.

2. METHOD AND DATASET

On the basis of investigation on the different performances of Plateau vortexes while moving eastward, we do some synoptic analyses of the vortex processes which bred heavy rains and floods over the different parts of China during 1998-2004.

The data we used in the study is the NCEP reanalysis data, four times a day with a resolution of $1^{\circ}\times1^{\circ}$, along with the upper observation data at the same time. Baroclinity and temperature advection are diagnosed and numerical simulations and experiments are performed on MM5 version 3.4, an American PSU/NCAR high-resolution mesoscale numerical forecast model.

The formulas used for diagnoses in this paper are as follows:

Diagnostics of baroclinity:

$$\vec{A} = -\nabla\alpha \times \nabla P \qquad (1)$$

Here, $\vec{A}$, a vector, is the baroclinity of the eddy column. The bigger the $\vec{A}$, the stronger the baroclinity.

The form of $\vec{A}$ in P-coordinates is like this:

$$Ax = \frac{g}{\alpha}\frac{\partial\alpha}{\partial y}, \quad Ay = -\frac{g}{\alpha}\frac{\partial\alpha}{\partial x}, \quad Az = 0 \qquad (2)$$

Diagnostics of Temperature advection:

$$B= - \vec{V} \bullet \nabla T = - \left(u \frac{\partial T}{\partial X} \right) - \left(v \frac{\partial T}{\partial y} \right) \qquad (3)$$

Positive B, temperature advection means warm advection. Otherwise, cold advection.

3. OBSERVATION FACTS OF THE IMPACTS OF THE COLD AIR ON THE MOVEMENT OF PLATEAU VORTEXES

The investigation on the activities of Plateau vortexes during 1998-2004 (not shown) display that when the lifespan of a Plateau vortex is longer than 36 hours it almost certain that it will cause heavy rain or even torrential rain in its passage to the east. An eastward-moving Plateau vortex can influence not only regions near the Plateau but also the middle reach of Yangzi River and Huang-Huai area even far downstream to Korea peninsula. For this reason, five eastward-moving Plateau vortexes, occurred in 17-20 Aug. 1998, 2002 and 12-14 Jul. Jul. 2003, are picked out for detailed analysis. 14-16 Jul. 1999, 10-13 Jul. 2000, 12-20 Jul.

The facts are as follows:

At 1200GMT 17 Aug. 1998, a cyclonic vortex was formed near Shenzha, Tibet. This Shenzha Vortex moved off the Plateau two days later and reached finally to Mingwu with precipitations ranging from heavy rain to torrential rain in provinces of Gansu, Shanxi and Sichuan (not shown), causing the huge flood 7 in Yangzi River of year 1998.

Generated around Shiqu, Sichuan at 0000GMT 14 Jul. 1999, Shiqu Vortex had Sichuan Basin, Chongqing and the southern Hubei province hit by heavy rains (not shown), which led Mei Rain more intensive and flood more severe in the middle reach of Yangzi River.

At 0000GMT 10 Jul. 2000, Tuotuo Vortex emerged near Tuotuo River, Qinghai province, and moved out of the Plateau 24 hours later. The Tuotuo Vortex swept eastward four counties of two provinces, causing severe mudslide and landslide in Shanxi province and serious flooding in Helan province as the result of up to heavy rains in its track.

Originated at 0000GMT 12 Aug. 2002 in Tuole, Tibet, the Tuole Vortex migrated eastward across Jilantai, Tongxin, Huanxian, Tongchuan, Yangcheng and Tongchuang during the period 2000GMT 12-0000GMT 16 Aug 2002, then turned to the south at 1200GMT 16 and merged with a low pressure stretching from the northern South Sea. The movement of the Tuole Vortex led up to torrential rains over 6 provinces along its passage and posed a serious threat to the Yangzi River once.

Formed at 0000GMT 12 Jul. 2003 in Mongya, the Vortex left the Plateau at 1200GMT 12. Over the next 24 hours, it went across Hequ, Luoyang, Huhehaote and the middle Buo Sea Gulf with heavy rains or regional torrential rains in the southern Shanxi and Shandong and Henan province, bringing about continuous high level of water and serious flooding in Huai River.

the analysis of these five vortex processes through height and temperature at 500hPa (table is omitted) reveals a fact that in spite of the difference in environment, all five vortexes are affected by strong cold air before their leaving, and by slight colder (<-4^{o}C) or intensive cold air (<-10^{o}C) at the center of vortexes after leaving; Those along with strong cold air could last longer after leaving. In a word, the cold air can influence the movement of vortexes strongly.

4.DIAGNOSTICS OF IMPACTS OF THE COLD AIR ON THE MOVEMENT OF THE PLATEAU VORTEX

Baroclinity and thermal advection are diagnosed in this section to assess the role of the cold air in detail. (Other causes are beyond the scope of the current study and will be the focus of a subsequent investigation.). Now take Tuole Vortex (TLV, 12-14 Aug. 2002) as the case.

The synoptic situation during this vortex process can be described like this: at 0000GMT 12 Aug., except a ridge in Xingjiang accompanied with two troughs beside it in the north of 40^{o}N eastern Asia, In the presence of Subtropical High, this Mongolia high forms a shear stream field favorable for Tuole Vortex to generate. Noticeably, the vortex has been influenced by the cold air (-11^{o}C) at its beginning. By 1200GMT 12 Aug. (Figure is omitted), the shear stream field moves slightly eastward, which at last, drives the Tuole Vortex move out of the Plateau and arrive in Jitailan. But the effect of the cold air is still on because the temperature at TLV center has dropped to -13^{o}C by 0000GMT 13 Aug (table is omitted).

4.1 Diagnostics of baroclinity

The baroclinity is calculated in a column with the radius of 3 longitudes/latitudes over 600hPa and is diagnosed in four aspects: the baroclinity in the column, at 500hPa, its x-component and y-component.

The baroclinity in the column described above: points out that it is high baroclinity in the upper troposphere of TLV column that makes TLV move out of the Plateau; when TLV is acting to the east of the Plateau, the baroclinity in the middle-upper troposphere of the TLV column stays in a high level and increases in most of time; when a thermal upper front is heading for, the down transmission of the high baroclinity ends at 300hPa.

The baroclinity in TLV area at 500hPa: The figures above illustrate that TLV moves off the Plateau under the condition of increasing baroclinity in the vortex area; the vortex continues to be active while off the Plateau if the baroclinity in the vortex area is still in a high level (Figure is omitted). The highest mode of baroclinity vector is in the first quadrant before the leaving and shifts to the second and third over the period hour 12-48 of after-leaving. By hour 48, the mode in the third and fourth has increased remarkably. Considering the activity of the cold air (table is omitted), it is easy to know that this is the result of continuing intrusion of the cold air. By hour 48 of after-leaving, the cold air (≤-9^{o}C) has dominated the whole vortex area.

X-component of the mode of vortex baroclinity vector in the column characterizes as follows: (1) the minus x-component exists below 200hPa, which indicates a cold-north and warm-south situation in the column between 600-200hPa. (2) x-component is -12.4*10^{-5}/s.s at 500hPa just before the leaving and remains minus after the leaving with the absolute value increasing 2-4 times. This phenomenon illustrates again that the vortex moves off the Plateau as the result of intrusion of the cold air, moreover, the position of cold-north and warm-south becomes more remarkable (Figure is omitted).

Y-component of baroclinity vector in TLV area at 500hPa is 3.5×10^{-5}/s.s just before the leaving. The positive value represents a pattern of cold-east and warm-west. At later four times of after-leaving, namely hour 12, 24, 36 and 48, the y-component are correspondingly -2.5×10^{-5}/s.s、3.2×10^{-5}/s.s、-3.2×10^{-5}/s.s、5.3×10^{-5}/s.s. The variation in sign of y-component means an alternation of two contrast positions (Figure is omitted), which is the result of an intermittent intrusion of the easterly cold air.

In short, the eastward movement of TLV is closely related to baroclinity associated with the cold air at 500hPa; among of the major contributors is the cold air from the northeast; the position of cold-north and warm-south is more evident after TLV's moving off.

4.2 Diagnostics of temperature advection

The temperature advection takes place in the area centered same as TLV with radius 3 longitudes/latitudes.

The temperature advection during TLV's moving eastward displays as follows: (1) just before leaving, TLV at 500hPa is largely dominated by cold advection (Figure is omitted), especially in its southwestern part where cold advection is stronger (<40*10^{-6} ^{o}c/s). Referring to synoptic chart (not shown), we understand that this situation results froma cold trough's stretching to the south of the vortex. By hour 12 of after-leaving, the area dominated by cold advection is wider than before with a little weak intensity (Figure is omitted). In the ensuing 36 hours, the most part of the vortex is controlled by cold advection but with the intensity varying like a seesaw as time goes on, from decreasing at hour 24 to increasing at hour 36 and decreasing again at hour 48. (Figure is omitted). Aligned with the synoptic chart, it is clear that TLV is located within a cold trough accompanied with a cold center coming and getting into the north and south of the vortex. In general, it is the cold advection at 500hPa that leads TLV to leave the Plateau finally; the vortex sustains when the cold advection controls the most part of the vortex. (2) Comparing the cold advection happening in the east of the vortex center to that in the west displays (table is omitted) that a stronger west cold advection enables TLV move out of the Plateau; at hour 12 of after-leaving, the cold advections on two sides of the vortex are roughly equal; during 24-48h of after-leaving, the western cold advection is obviously stronger than the eastern. The difference between the west- and the east-side cold advections can explain the activity of TLV: the stronger west-side cold advection makes the vortex not only move out of the Plateau but also more intensive after the leaving, otherwise, it weakens.

In all, the cold advection in the vortex area at 500hPa favors TLV's eastward movement; while stronger west-side cold advection is favorable for the development and sustaining of TLV.

5. NUMERICAL EXPERIMENTS

5.1 Design of the experimental scheme

As the analysis above, TLV's leaving and sustaining had a close relationship with the cold trough stretching from northeast to west. TLV moves out of the Plateau as a result of intensive baroclinity associated with the cold air and strong cold advection in the west of the vortex. This section is focused on understanding how the northeast cold trough and invading the cold air impact the vortex's movement through experiments runs on MM5-V3.4. Besides a control run, two experimental runs are performed, starting at 0000GMT 12 Aug. 2002 considering decrease of temperature in the southeastern TLV and the further south area. In test 1 the cold air is removed by increasing temperature 3^{o}C in vortex area as well as its neighborhood, say 32-40^{o}N、100-110^{o}E. In test 2 the northeast cold trough is deleted by increasing temperature 4^{o}C over 40-50^{o}N、110-120^{o}E. In this way, we tried to reveal how the cold air from different area influences the vortex movement.

5.2 Analysis of the tests results

The model initial analysis of 500hPa height field (not shown) positions reasonably well the observed weather systems, like the observed 500hPa height field presented in section 4. Therefore, the objective analysis from the model is dependable.

By comparing the simulations to the reanalysis data of NCEP(not shown), it is showed that the locations of the vortexe, Subtropical High and the low number areas are similar, in addition to their activities. In all, the simulation is successful.

Table summarizes the characteristics of the vortex from three runs, control run and two test runs for 12h, 24h, 36h and 48h(table is omitted).

Test 1 differs from the control run in the location, the intensity of the vortex center and maximum speed. The former predicts the vortex center 0.4^o farther south and 0.4^o southwest for 12h, 24h, then little difference and 0.8^o farther northeast corresponding to 36h, 48h. The difference in location demonstrates that without the cold air around the vortex and its neighborhood, the vortex slow down in the first half of 48 hours but speed up in the second half; test 1 produces weaker intensity, particular for the last 12 hours, 13.6 geopotential meter lower than before; the maximum speed in the vortex in test 1 is smaller than control run from 24h to 48h, especially at hour 36, lowering 1.4m/s. the average cyclonic vorticity in test 1 is higher than control run by 18%, 12% and 4% at hour 12, hour 24, hour 36, but weaker by 7% at hour 48.

Test 2, on the other hand, has TLV to stay slightly to the west of the control run over the period hour 12-48 with the most at hour 24, 1.4^o more westerly, and 0.6^o backward according to hour 12. The result above suggests that in the absence of the cold trough in the northeastern China, TLV wanders along the edge of the Plateau in the first 24h, then moves eastward slowly; the intensity weakens after hour 12, even weaker than test 1, with the weakest 21.3 geopotential meter at hour 24. The maximum velocities are smaller over hour 12-48, with the smallest at hour 48, only 3.4m/s, smaller than test 1; the average vorticity decreases by 35% and 13% at hour 12 and 24 respectively, but increased slightly by 3% and 1% at hour 36 and 48.

The experimental results mentioned above illustrate that the cold air exerts an impact on the movement of vortexes. In the absence of the cold air in the vortex or cold trough in the northeastern China, the vortex moves slowly with weaker intensity and smaller maximum speed. The cold trough in northeastern China plays a more essential role in vortexes movement. Without the cold trough, the vortexes return westward instead of going eastward in the first 24 hours.

6. SUMMARY AND CONCLUSION

(1) If a vortex lasts longer (⩾36 hours), it mush have been affected by the cold air around its leaving the Plateau.

(2) The baroclinity connected with intrusion of the cold air, especially from the northeast, play an important role in the movement of the vortexes generated in the Plateau. After the vortex leaves the Plateau, the temperature in environment presents as the position of colder-north and warmer-south.

(3) The analysis of thermal advection reveals that Tuole Vortex moves out of the Plateau in the presence of a strong cold advection, particularly when the west cold advection of the vortex much bigger than the east. When controlled largely by cold advection the vortex is steady.

(4) The experimental runs on MM5 display that no cold air in the vortex or no cold trough makes the vortex migrate slowly with weaker intensity and smaller maximum speed. In the absence of the cold trough in the northwestern China, the vortex even goes in opposite direction.

In this paper, only the effect of the cold air is discussed. The other elements affecting the moving of the vortex will be studied later.

Acknowledgements: This work is financially Sponsored by the Chinese National Natural Science Foundation project (40475020) and the Chinese National science and technology ground work special project (2006FY220300).

REFERENCES

Zhang Shunli, Tao Shiyan, Zhang Qingyun, etc., 2001: Meteorological and hydrological characteristics of heavy rain and flood in summer of 1998 in China. Application Meteorological Transaction, **12**(4): 442-457. (In Chinese)

Ding Yihui, 1993: research on sustained severe torrential rain in the drainage area of Jang&Huai. Meteorological Press, 113-128. (In Chinese)

Ye Duzheng, Gao Youxi, etc., 1979: Meteorology of Tibetan Plateau. Science Press, 122-126, 145-146, 259-260. (In Chinese)

Li Guoping, 2002: Dynamical Meteorology of Tibetan Plateau. Meteorological Press, 22-23. (In Chinese)

Gao shouting, 2004: experimental study of the lee vortex forced by large-scale terrain, Science Aviso, **49**(23) , 2485-2494. (In Chinese)

Hideo Takahashi, 2003: observational study on the initial formation process of the Mei-yu frontal disturbance in the eastern foot of the Tibetan Plateau in middle-late June 1992, Journal of the Meteorological Society of Japan, **81**(6), 1303-1327.