ENERGETIC DIAGNOSIS FOR TWO KINDS OF LOW LEVEL JETS

Wang Zhongxing (汪钟兴)

1. *Department of Earth and Space Sciences, University of Science and Technology of China, Hefei,* 230026

2. *Advanced Center for Earth Sciences and Astronomy, University of Science and Technology of China, Third World Academy of Science, Hefei,* 230026

and Jiao Meiyan (矫梅燕)

Anhui Meteorological Institute, Hefei, 230026

Received 6 June 1994, accepted 28 November 1994

ABSTRACT

On the basis of the budget equations for K_R and K_D, this paper presents the horizontal pattern of budget terms for two kinds of low level jets (LLJ) with and without heavy rain. The results show that the mechanisms for generating and maintaining LLJ are different, and especially, the direction of energy conversion is opposite. A positive conversion from K_D to K_R appears to be a necessary but not sufficient condition in the lower troposphere near the heavy rain area. The intensity and direction of energy conversion depends not only on the relative position of vorticity and divergence field, but also on the vertical profile of the jets directly.

Key words: low-level jet, heavy rain, energetic diagnosis

Ⅰ. INTRODUCTION

Subsynoptic-scale low level jet is commonly associated with heavy rain and the correlation coefficient reaches 80%. Thus, some people proposed to establish the conceptual model of heavy rain forecasting in China with LLJ as a clue. But LLJ is complicated. Sometimes it is not associated with heavy rain, and forecasters call it an "empty" jet. They want to know what features and what mechanisms are behind the generating and maintaining of LLJ. Comparatively speaking, this aspect is lacking in understanding. The purpose of this paper is to examine the evolution and conversion of kinetic energy for divergent (K_D) and rotational (K_R) wind components from the viewpoint of energetics and to discuss the dynamical processes and the relationship with heavy rain for two kinds of LLJ with and without heavy rain. It will undoubtedly provide reference basis for operational forecasting of heavy rain.

Ⅱ. THE BUDGET EQUATIONS FOR K_R and K_D

In the study of meso-scale analysis and tropical meteorology, one finds that the divergent wind plays a very important role in the evolution of circulation and development of the weather systems as it is related to ageostrophic and nonlinear processes. According to Helmholtz's theorem, the horizontal wind was separated into its the divergent (V_D) and rotational (V_R) wind components. Because the magnitude of V_R is generally much larger than that of V_D, the total kinetic energy can be replaced by K_R. Coupling the budget equations for K_R and K_D, we will discuss the mechanism of maintenance and development of LLJ.

The budget equations for K_R and K_D proposed by Buechler and Fuelberg (1986) are formulated for a fixed, limited volume in the isobaric coordinate system.

$$\underset{DKR}{\frac{\partial K_R}{\partial t}} = \underset{INTR}{\iint -V_R \cdot \frac{\partial V_D}{\partial t}} + \Big[\underset{C1}{\iint -f(v_R u_D - u_R v_D)} + \underset{C2}{\iint -\zeta(v_R u_D - u_R v_D)} + \underset{C3}{\iint -\omega \frac{\partial K_R}{\partial p}} + \underset{C4}{\iint -\omega V_R \cdot \frac{\partial V_D}{\partial p}} \Big] + \underset{GR}{\iint -V_R \cdot \nabla \phi} + \underset{HFR}{\iint -\nabla \cdot k V_R} + \underset{DR}{\iint V_R \cdot F}, \tag{1}$$

$$\underset{DKD}{\frac{\partial K_D}{\partial t}} = \underset{INTD}{\iint -V_D \cdot \frac{\partial V_R}{\partial t}} - \Big[\underset{C1}{\iint -f(v_R u_D - u_R v_D)} + \underset{C2}{\iint -\zeta(v_R u_D - u_R v_D)} + \underset{C3}{\iint -\omega \frac{\partial K_R}{\partial p}} + \underset{C4}{\iint -\omega V_R \cdot \frac{\partial V_D}{\partial p}} \Big] + \underset{GD}{\iint -V_D \cdot \nabla \phi} + \underset{HFD}{\iint -\nabla \cdot k V_D} + \underset{VF}{\iint -\frac{\partial \omega k}{\partial p}} + \underset{DD}{\iint V_D \cdot F}, \tag{2}$$

where the generation of kinetic energy due to cross-contour flow are represented by GR and GD respectively. Terms HFR and HFD denote horizontal flux divergence of total kinetic energy by V_R and V_D, while VF is vertical flux divergence of kinetic energy and is only affected in K_D since ω arises from V_D. Terms INTR and INTD are small in magnitude and called the terms of "interaction" because they arise from $V_R \cdot V_D$. Terms DR and DD are dissipation terms representing frictional processes as well as transfer of energy between resolvable and unresolvable scales of motion. The four terms enclosed by brackets in(1) and (2)represent conversion between K_R and K_D since they appear in both equations with opposite signs. $C1$ and $C2$ depend on relative orientations and magnitudes of V_R and V_D. The maximum value occur where angles between V_R and V_D are equal to 90°. Term $C3$ describes the vertical exchange of K_R, while term $C4$ means vertical distribution of V_D and relative orientation with V_R. The K_D converts to K_R if the sum of the four components is positive. Conversely, the conversion is opposite.

If rotational wind V_R is replaced by the geostrophic wind V_g which is substituted into C1, then

$$C1 = -\iint (K \wedge \nabla \phi) \cdot (K \wedge V_D) = \iint -V_D \cdot \nabla \phi. \tag{3}$$

Thus, signs of $C1$ and GD will agree in area where directions of V_g and V_R are similar, but it is not necessarily equal in magnitude.

An iterative scheme by Endlich (1967) was used to separate the total wind into its divergent and rotational components. Comparing to the solution of Poisson equation, the method requires no need to calculate stream function and velocity potential or to assume boundary condition, and the accuracy can also be estimated.

Ⅲ. CASES AND THE RESULTS FOR DIAGNOSIS

Two cases for two kinds of LLJ were chosen: (1) LLJ with heavy rain over Jiang-Hui basin during 12~13 June 1982. The highest speed of LLJ at 850 hPa reached 20 ms^{-1}. It was located at the entrance region of upper level jet (ULJ) at 200 hPa. The center speed of ULJ inclining to the north side was approximately 30 ms^{-1} and the distance between the jets was 7 latitudes. The heavy rain area was located at the northern flank of the LLJ and associated with two centers of ascending motion. (2) LLJ without heavy rain during 8～9 May 1979. The maximum speed was 24 ms^{-1} at 700 hPa and also located at the entrance region of ULJ in which the strongest speed reaches 60 ms^{-1} at 200 hPa. The distance between the jets was 3 latitides. But there were only scattered showers ahead of LLJ. Both cases show that the precipitation intensity is not related to that of both jets.

The objective of this study is to illustrate the major energetic processes for maintaining two kinds of LLJ, but not the calculation of complete energy budgets. So we present the horizontal pattern for each term at low and upper level jets according to Eqs. (1) and (2).

Case 1. The horizontal pattern of term *GR* at 850 hPa reveals that the cross-contour V_R creates K_R upstream of LLJ and destroys K_R downstream, so K_R transfers toward downstream of LLJ. Fig. 1a shows the horizontal pattern of term *GD*. Although the positive maxima axis of term *GD* is located at the southern flank of LLJ axis, it produces K_D and especially two positive centers nearly coincide in heavy rainfall area. It indicates that kinetic energy produced by V_D plays an important role during precipitation.

There are horizontal flux divergence (convergence) of kinetic energy near upstream (downstream) of LLJ as show in term *HFR*. The positive value areas of term *HFD* (Fig. 1b) are situated near the LLJ and heavy rain area, which is another source for ki-

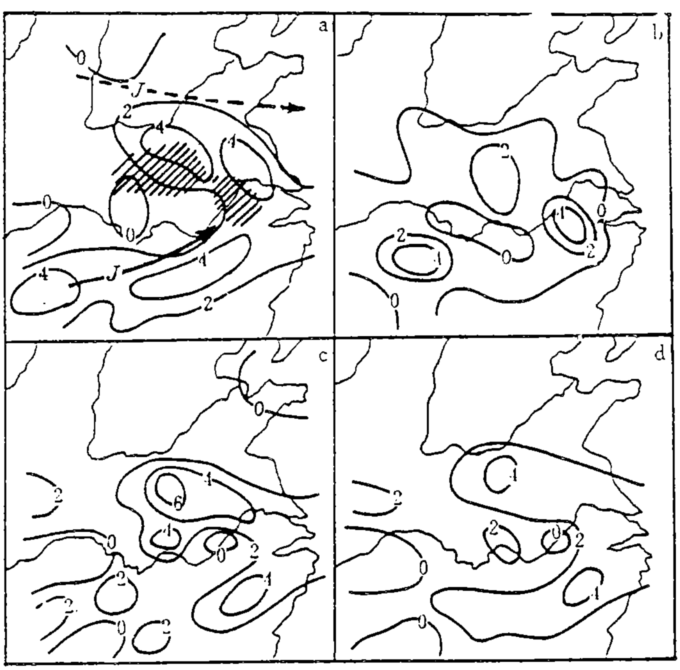

Fig. 1. The horizontal patterns of *GD* (a)、*HFD* (b)、energy conversion (c) and *C*1 (d) for the 850 hPa at 00 UTC 13 June 1984 (The shaded area denotes rainfall of more than 50 mm for 12 hours and the solid and dashed arrows show the low and upper level jets. Units: ($10^{-3}m^2/s^3$).

netic energy import. Comparing Fig. 1a and 1c, the horizontal pattern of term *GD* is similar to that of energy conversion term and the magnitude nearly approach each other. The fact shows that the kinetic energy K_D caused by term GD mostly transport to K_R in good time and the greatest positive conversion is located near heavy rain area which exhibits intense interaction between vorticity and divergence field. Analysing the four conversion terms, *C*1 is the leading term (Fig. 1d) whose horizontal pattern almost determines that of total conversion. There are maximum positive values near heavy rain area because the sign of term *C*1 is agreeable with term *C*2, but the signs of both terms are opposite near LLJ and in its southern part. In addition, the similarity of horizontal pattern in Figs. 1a and 1d reflects that the ageostrophic characteristics are mainly divergent wind while the vorticity field satisfies quasi-geostrophic approximation within LLJ and heavy rain area.

Terms *HFR* and *HFD* are energy sinks (horizontal energy export) near ULJ at 200 hPa. The ULJ axis accords with the axis of maximum positive value of *GD* and the zone of positive energy conversion, which results in available potential energy converting into K_D and then K_R. It becomes the major dynamical processes to form and maintain the ULJ. It should be pointed out that negative energy conversion term in the upper level of LLJ and heavy rain area indicates that K_R converts to K_D to strenghthen divergent wind, but negative conversion in the upper level of heavy rain area and LLJ depend on terms *C*3 and *C*1 respectively. These features are consistent with the results obtained by the author (Wang, 1992 and 1993).

Case 2. The horizontal pattern of term *GR* (Fig. 2a) is similar to that of *GD*. The

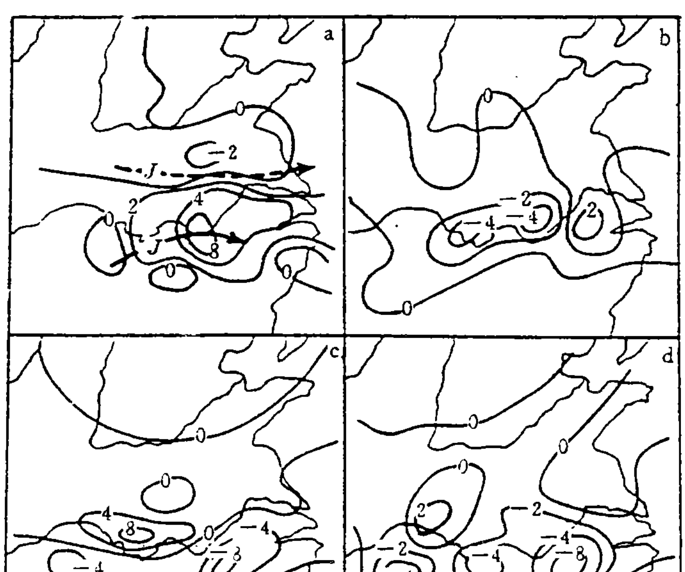

Fig. 2. The horizontal patterns of *GR* (a), *HFR* (b), energy conversion (c) and *C*3 (d) for 700 hPa at 12 UTC 8 May 1979 (other denotations are the same as Fig. 1).

positive value region located near LLJ and south of ULJ commonly produces kinetic energy. The intensity of negative conversion in Fig. 2c is determined by $C3$ (due to vertical difference of K_R) near LLJ, except for kinetic energy flux divergence for V_R (Fig. 2b) and V_D (including the vertical divergence $VF < 0$). The positive value area of energy conversion occurs in same sign as term $C1$ and $C2$, while in opposite sign in the southern flank. Thus, it appears that the horizontal and vertical distribution of K_R has immediate effect on evolution and conversion of kinetic energy.

The axis of ULJ at 200 is located south of positive maxima axis of GD and energy conversion term, where terms $C1$ and $C2$ are positive value and the magnitude are larger than that of Case 1. The horizontal pattern of term HFR is almost east-west direction, which exhibits the features of positive value alternating with negative one near ULJ and its southern part. But term HFD is a negative value, which decreases K_D due to flux divergence of K_D. The negative conversion regions are located at upper level of LLJ and the southern flank of ULJ axis which depends on term $C1$, but with opposite sign to term $C2$. Terms $C3$ and $C4$ are relatively small as compared with the other terms of energy conversion, so the magnitude of negative conversion is smaller than Case 1. For the whole troposphere, conversing K_R into K_D appears the energetic characteristics of LLJ without heavy rain.

Ⅳ. SUMMARY AND CONCLUSION

The main results are summarized as follows:

a. The energetic mechanisms are differnent for maintaining two kinds of LLJ, one kind of kinetic energy is generated by cross-contour divergent wind component and then converted into K_R; while another kind of kinetic energy is caused directly by rotational wind component. But K_D provides a major source to K_R for maintaining ULJ.

b. The intensity and direction of energy conversion depend not only on relative position between vorticity and divergence fields but also on vertical wind distribution of the low and upper level jets.

c. The positive conversion from K_D to K_R in the lower troposphere and negative conversion from K_R to K_D in the upper troposphere near heavy rain area suggest that they are necessary but not sufficient conditions for producing heavy rain.

d. Energy analysis of two cases show that the horizontal patterns and signs of term GD are very similar to those of $C1$, regardless of low or upper troposphere. Results imply that the vorticity field satisfies quasi-geostrophic relation and deviating wind is mainly divergent. Therefore, it is worthwhile to examine the horizontal pattern of term GD and energy conversion for forecasting heavy rain.

Further investigation to verify the results of this study is to be continued.

REFERENCES

Buechler D E, Fuelberg H E, 1986. Budget of divergent and rotational kinetic energy during two periods of intense convection. *Mon. Wea. Rev.*, **114**: 95-114.

Endlich R M, 1967. An interative method for altering the kinetic properties of wind field. *J. Appl. Met.*, **6**: 837-844.

Wang Zhongxing, 1992. The characteristics of budget for divergent and rotational component of kinetic energy in heavy rain processes. *J. China University of Sci. & Tech.*, **22**: 342-347 (in Chinese).

Wang Zhongxing, 1993. The characteristics of conversion between kinetic energies of divergent and rotational winds during heavy rain period. *Scientia Atmospherica Sinica*, **17**: 185-191 (in Chinese).