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HELICITY ANALYSIS FOR HIGH-WIND AND UNCOMMON RAINSTORM PROCESSES OVER YUNNAN IN EARLY SUMMER

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ABSTRACT: Helicity was applied to analyze several high-wind and rainstorm processes, which occurred from May to June, 2001 over Yunnan in early summer. The results of diagnostic analyses show that the rainstorm occurs in the area in which h_p is positive at 700 hPa and energy is unstable. The change of helicity can reflect the movement and development of synoptic system and the position and intensity of the rainstorm. The value of h_p is a negative center at the upper level and a positive at the lower level over the rainstorm position; moreover it can reflect the characteristics of vertical distribution and rotational motion.

Key words: rainstorm; helicity; diagnostic analyses

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1 INTRODUCTION

Helicity is the physical parameter that describes the rotation and motion of airflow in the direction of the movement in the wind field. It reflects the characteristics of the atmospheric motion by good description of the nature and characteristics[1]. Tudurf and Ramis[2] give the relationship between helicity and temperature advection —relative surface helicity is generally viewed as a measure of the temperature advection induced by the geostrophic wind. At present, the application of helicity in severe convection and heavy rain weather draws much attention and becomes a very important physical quantity in the analysis and forecast of weather in recent years. Yang et al. [2] make a helicity analysis of the heavy rain with the Mei-yu front and obtain some indicative results: As a new diagnostic quantity, the helicity is useful in heavy rain research. Defining the vertical helicity in the *p*-coordinates with the concept put forward by Davies-Jones et al., Wang et al. calculate it for both upper and lower levels and establish the relationship between the coupling area of helicity from both levels and the regional heavy rain. With the helicity theory in conjunction with the humidity and instability condition, Tan et al. study a usually heavy rain in August 1999 in Shandong province, discovering that the changes in helicity are a good indicator to some extent of the movement, development of synoptic systems and intensity of heavy rains. Working on a process of thunderstorm and hailstorm in southern Yunnan in the lower half of March 1997, Li points out that helicity as a physical parameter for dynamic conditions is also a thermodynamic factor. All of the above work shows that as a diagnostic physical quantity, helicity is a helpful indicator in the forecast of heavy rain and severe convection weather.

In the early summer of 2001, an unusual sustained process of rain occurred in Yunnan province subject to on-coming cold air mass and warm and humid airflow for the southwest. Rains, on heavy and usually heavy levels, occurred one after another across the province. The rain between May 30th and June 2nd was the strongest of them, which lasted for three successive

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days and broke historical records of rainfall for early summer by large margins. Using the helicity theory to study the heavy rain weather in early summer in Yunnan in 2001, the work discusses how the relation between helicity and heavy rain performs over Yunnan, a low-latitude plateau region.

2 EXPRESSIONS OF HELICITY

For the strictest definition, helicity is expressed as the ratio of volume between the wind velocity and the dot product of vorticity[2]

$$H = \iiint_t \vec{V} \cdot (\nabla \wedge \vec{V})\,\mathrm{d}\,t$$

From the expression above, we know that the magnitude of helicity reflects the intensity of rotation and motion in the direction of the rotating axis. $h = \vec{V} \cdot (\nabla \wedge \vec{V})$ is the density of helicity, called helicity in short. In the *p*-coordinates we have

$$h = (¶w/¶y - ¶v/¶p)\,u + (¶u/¶p - ¶w/¶x)\,v - (¶v/¶x - ¶u/¶y)\,w$$
$$= x \times u + h \times v - w \times z$$

expanded. The three terms on the right of the expression differ in physical meaning, which connect with wind velocity and vorticity components *x*, *h*, *z* in the *x*, *y* and *p* directions, respectively, and they are called helicity *x*, *y* and *p*, and denoted h_x, h_y and h_p, respectively.

With the 1°×1° objective analysis data for May and June, 2001, the work calculates h_p on mandatory pressure levels within 15°N – 45°N, 80°E – 120°E. As there is deep updraft over the area of heavy rain (ω<0) , positive vorticity (ζ>0) is with positive h_p and negative vorticity is with negative h_p. To highlight the point for the heavy rain region, a rule that $h_p = 0$ if $\omega > 0$ in the computation. In other words, helicity h_p is calculated only when there is ascending motion of air. The mean wind velocity for the layer is a arithmetic mean over isobaric surfaces between the upper and lower layers. The h_x and h_y are determined for individual isobaric surfaces. According to the number of daily heavy rain records from stations over the concurrent period in the province and the operational standard of the Yunnan Meteorological Services, a day of heavy rain is defined to occur if nine or more of the province' s stations report measurements of heavy rainfall.

3 ANALYSIS OF CIRCULATION PATTERNS

The South Asia high was anomalously stronger in early summer 2001. The anti-cyclonic circulation appeared at 500 hPa as early as mid-May with intensity at a rare 588 dagpm at the center. From the figure (omitted) of 500-hPa geopotential height anomalies, we know that there is a higher-than-normal, positively anomalous geopotential height field over the Qinghai-Tibet Plateau. It shows that high-pressure circulation appears repeatedly there. A positive anomalous area is found over the southern tip of the Indochina Peninsula, indicating that the subtropical high is more southward and stronger than normal. An area of negative anomalies appears from the southeastern edge of the plateau to Yunnan, showing that the region from the eastern plateau to Yunnan is under the control of low-value convergence zone. In the early summer of 2001, a synoptic situation very similar to what is presented above appeared. A high-pressure circulation maintains at 500 hPa over the plateau and the west Pacific subtropical high was more southward with the line of ridge near 20°N, exposing the eastern part of the plateau to a low-value convergence zone that is flanked by two high pressures. During the heavy rain, southwest jet streams kept traveling north over the Indochina Peninsula and the Bay of Bengal from the outer rim of the subtropical high, which was accompanied by the formation of shears or low vortexes at 700 hPa. At the surface, cold fronts moved into Yunnan to add to the working. May 27th, 30th –

31st, June 1st an 29th are the times when days of heavy rain are thought to happen in Yunnan. The heavy rain concentrated in the central, western and southern parts of the province.

4 ANALYSIS OF HELICITY

4.1 *Relationship between helicity h_p and the number of heavy rain stations*

Fig.1 (a & b) gives the number of stations with records of heavy rain and the time evolution of 700-hPa helicity h_p for gridpoint values averaged over the province (22°N – 26°N, 97°E – 104°E). It shows that when a heavy rain day appears (with the number of stations reporting it being over nine), h_p is in the positive territory and the value increases when the number of the stations grows. When h_p is well in the negative zone, there is no heavy rain across the province, showing that the low-level h_p evolves so that it indicates the onset of heavy rain with some reliability.

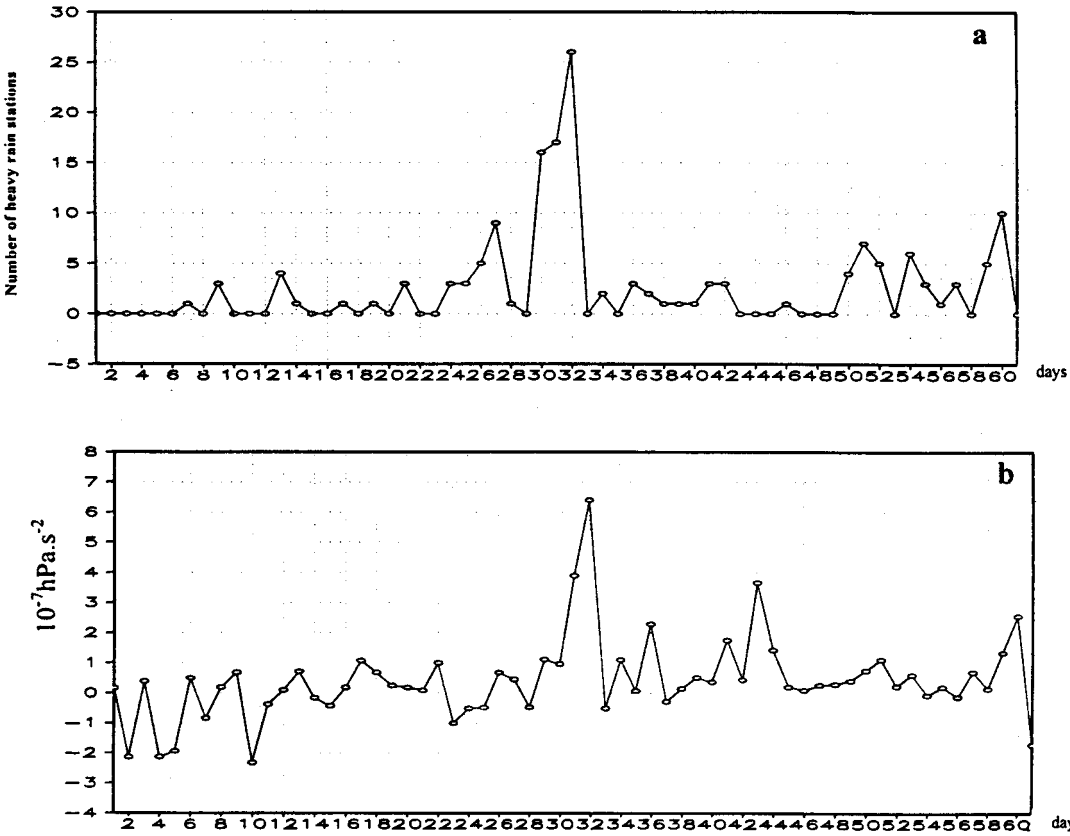

Fig.1 Number of stations reporting heavy rain in May and June (a); time evolution of helicity averaged over gridpoints (22° N – 26°N, 97°E – 104°E) at 700 hPa (b).

4.2 *Relationship between the horizontal helicity h_p and the hyetal region of heavy rain*

Studying the horizontal distribution of low-level h_p, we find that the 700-hPa helicity well correlates with synoptic systems —during the heavy rain process, the longer axis of positive h_p always goes in parallel with the shear convergence line at 700 hPa. Of the five processes studied, three occurred around the large positive center of h_p (May 27th, 30th and June 29th) and two within the area of secondary positive centers. It shows that heavy rain is likely to occur in the largest or secondary positive centers of helicity. The study also finds that the positive centers of h_p are not necessarily in company of heavy rain. The distribution of an unstable area of $\Delta\theta_{se500\text{-}850}$ is analyzed. It is found that the weather takes place in a region where positive helicity superposes with unstable energy. Let's look at the case of May 30th through June 2nd. Fig.2 gives the distribution of the 700-hPa helicity over the period and the hyetal region of the heavy rain in the following 12 hours. It is seen that there is large-value center of positive 4×10^{-7} hPa/s^2 inside the unstable region ($\Delta\theta_{se500\text{-}850}<-4$ ℃) at 08:00 May 30th and heavy rain is just in the approximate neighborhood. There are two positive centers of helicity on May 31st and June 1st,

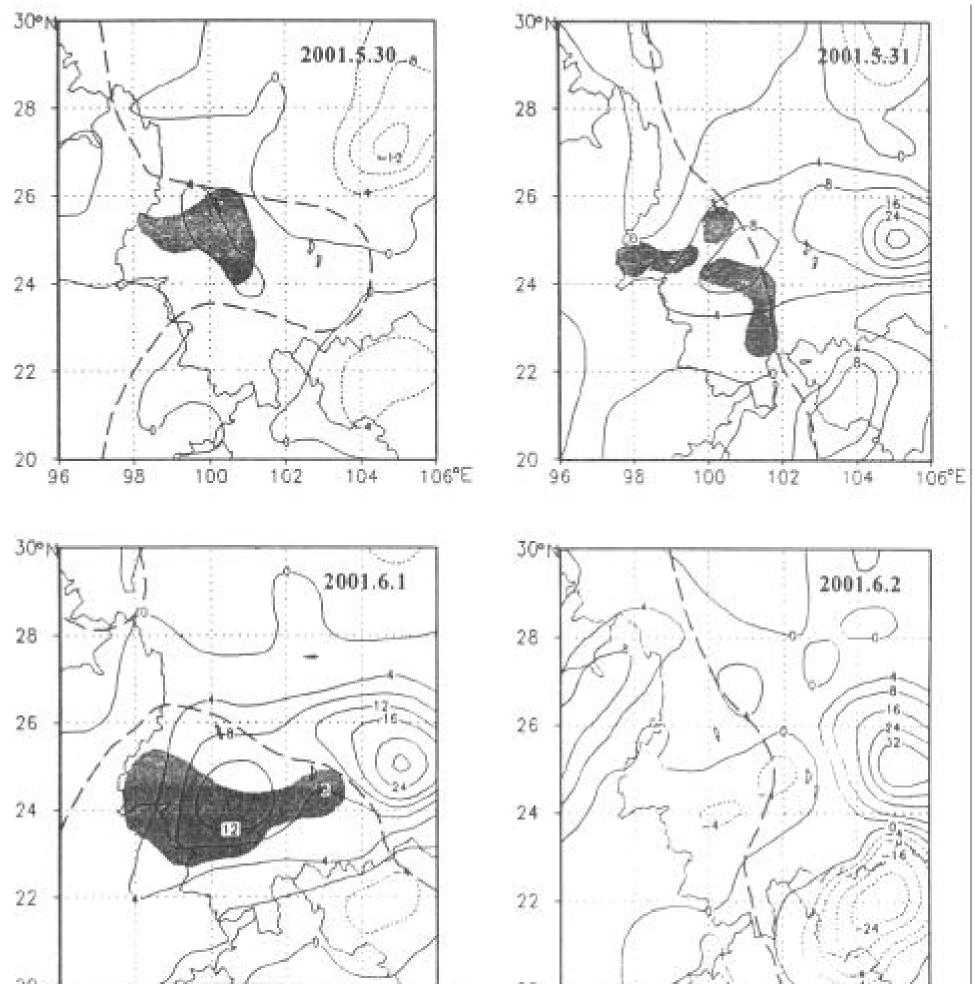

Fig.2 Distribution of helicity h_p at 700 hPa in unit of 10^{-7}hPa/s^2. The shaded area is the hyetal of heavy rain and the bold, long dashed line is $\Delta\theta_{se500\text{-}850} = -4$℃.

one over the central and southern Yunnan and the other over the eastern part of the province. The heavy rain occurs near the positive center in the unstable region. Although there is another strong positive center in the eastern part, the air layer is stable due to positive $\Delta\theta_{se500\text{-}850}$. Consequently, only moderate to heavy rain takes place there. The helicity value turns negative in the unstable region at 20:00 June 2nd, ending the heavy rain. Studying the intensity of the heavy rain, we also learn that sixteen stations report rain of the intensity from 20:00 May 30th to 20:00 May 31st, seventeen report it from 20:00 May 31st to 20:00 June 1st, 26 report it from 20:00 June 1st to 20:00 June 2nd. In comparison, the central value of helicity in the unstable area is 4×10^{-7} hPa/s^2, 8×10^{-7} hPa/s^2, 16×10^{-7} hPa/ s^2, from May 30th to June 1st. It is obvious that there is a close link between the increase of rainfall over the hyetal region and the helicity. From the 700-hPa situation figure (omitted), we know that the province has been under a shear convergence of wind field formed between the northeast flow in the front part of a westerly high pressure zone and the southwest flow at the periphery of the subtropical high, with the southwest flow only at 4 m/s to the south of the convergence. From May 31st to June 1st, the west Pacific subtropical high strengthens and moves west and the southwest flow increases to the south of the convergence, leading to the formation of southwest jet streams with cores of 12 m/s and 16 m/s, respectively. The maximum positive helicity appears in the front left of the jet axis. It shows that the jet streams are responsible for the increased helicity on May 31st and June 1st. As positive helicity is just near the shear convergence and there are cyclonic rotary and ascending motion of the air to cause cyclonic rotation around the vertical axis and in turn severe lifting motion, heavy rain is then provided with favorable condition for the generation and strengthening.

The study above shows that helicity can dynamically triggers off unstable energy accumulated in the atmosphere to cause heavy rain. The change in helicity is indicative to some extent to the migration and evolution of synoptic systems and the hyetal region and intensity of the heavy rain.

4.3 *The temporal and spatial helicity h_p*

The helicity is also well-defined in the vertical. Fig.3 gives the temporal and spatial cross-section of helicity h_p averaged over gridpoints in the province (22°N – 26°N, 97°E – 104°E). It is found that on the heavy rain days there is a positive center at the lower level and a negative center at the upper level, of helicity, and the upper-level negative zone is larger or equal to the lower-level positive zone, with the center of large positive helicity mainly below 500 hPa.

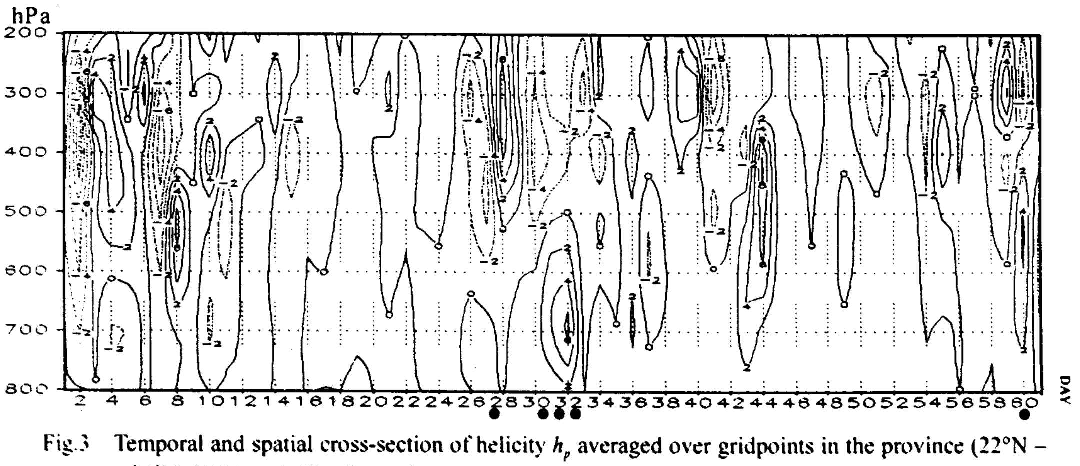

Fig.3 Temporal and spatial cross-section of helicity h_p averaged over gridpoints in the province (22°N – 26°N, 97°E – 104°E). The unit is 10^{-7} hPa/ s^2 and • indicate the day in which there is heavy rain.

The air is lifting throughout the whole layer over Yunnan on heavy rain days. According to the definition of helicity, $h_p = -\omega\times\zeta$, we know that the positive zone of h_p is right with the positive zone of h_p and the negative zone of h_p is right with the negative zone of h_p, over the region of heavy rain. It shows that the rain marks the time when there is cyclonic convergence of vorticity in the middle and lower layers but anti-cyclonic divergence of vorticity in the upper layers, of the troposphere. Such structure of helicity, that is the coupling between low-level positive center and high-level negative center, shows that a positive vorticity zone at low levels is with deep divergence and negative vorticity zone at high levels. It is apparent that it is favorable to the auto-evolution synoptic systems and the maintenance of heavy rain.

4.4 *Distribution of helicity* h_x and h_y

Studying the helicity h_x and h_y, we know that h_x is in better consistency with the hyetal region so that heavy rain is usually with positive h_x in the low level but negative h_x in the high level. h_y does not have corresponding relation with the hyetal region as good as h_x. The former is then used to discuss the distribution of vertical atmospheric motion over the heavy rain hyetal. Following the definition of helicity, $h_x = u\times\xi$, we find that $h_x>0$, $u>0$ in low-level hyetal, then $\xi>0$; air parcels rotate clockwise on the *y*-*p* plane. Now, the air rises in the relatively warm southern part but sinks in the relatively northern part, of the hyetal, forming a cell of vertical circulation in the advancing direction of the airflow. On the other hand, $h_x<0$, $u>0$ in high-level hyetal, then $\xi<0$; air parcels rotate counterclockwise on the *y*-*p* plane. Fig.4 gives the cross-section of vertical flow field for composite wind of *v* and *w* made through the center of heavy rain along 101°E for 08:00 May 30th. An well-defined cell of vertical circulation is indeed over the hyetal. The figure shows that a slanting southerly airflow over the hyetal is with a meridional vertical, clockwise circulation above low-level heavy rain region and a meridional vertical, counterclockwise circulation above 500 hPa south of the ascending airflow. Heavy rain appears in the slanting, lifting air between the low-level clockwise and high-level counterclockwise circulation. It is apparent that helicity also reflects the distribution of

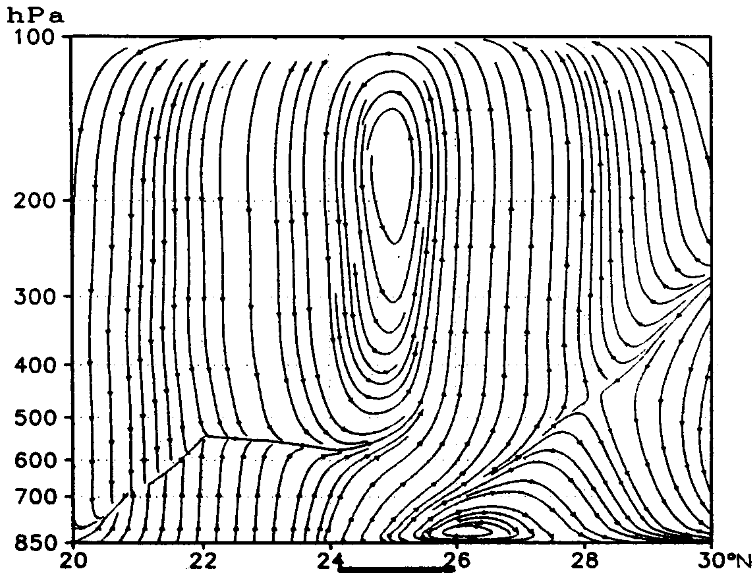

Fig.4 The cross-section of vertical flow field for composite flow field through the center of heavy rain along 101°E for 08:00 May 30th. The bar on the abscissa is the width of the hyetal region.

atmospheric vertical motion and rotation, which contain dynamic conditions for inducing heavy rain weather.

5 CONCLUDING REMARKS

a. It is found that the evolution of low-level 700-hPa helicity is indicative of the onset of heavy rain in the coming 12 hours.

b. In Yunnan province, heavy rains occur in a region that superimposes low-level positive helicity with unstable energy.

c. Over the heavy rain region, helicity distributes in such a way that there is a positive center at the low level and a negative center at the high level, with the area of positive value below 500 hPa.

d. Helicity reflects the distribution of atmospheric vertical motion and rotation.

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