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MESO-SCALE DIAGNOSIS OF A TORRENTIAL RAINFALL CAUSED BY A TROPICAL DEPRESSION

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1. INTRODUCTION

On 5 August 2001, Shanghai was struck by a torrential rainfall coming together with a tropical depression. Xu-Jiahui station observed 275.2mm rainfall in 24 hours from 00UTC 5 August to 00UTC 6 August. The observed maximum rainfall intensity reached 75.4mm per hour, which was the maximum in recent 50 years. This extremely heavy rainfall caused huge economic losses and brought great trouble to people's daily life. In this paper, a set of meso-scale data is used to analyze the structure and evolution of moist potential vorticity and related elements. Theories of moist potential vorticity are used to understand possible mechanism of this rainfall.

2. BACKGROUND CIRCULATION

On 1 August, a tropical depression (TD) formed to the northwest of Guam. After its formation, this TD moved northwestward with intensity increasing only a little. Before its landfall, the TD began to weaken. It made landfall on the coast of Fujian province late on 3 August. Later, the TD kept on its northwestward movement with intensity almost unchanging. However, as it reached northeastern Jiangxi province, the subtropical high broke up and the TD suddenly turned toward east-northeastern guiding by the west-northwesterly in the northeast of the land high. Afterwards, being held up by the subtropical high over the sea, it slowed down a lot. The TD re-intensified just before it re-entered the sea. During this period, Shanghai was in the southeast of this TD. The convergence of warm and moist southwesterly and east-southeasterly in the lower atmosphere, and strong high level divergence provided a favorable background for the torrential rainfall.

3. MOIST POTENTIAL VORTICITY AND SLANTWISE VORTICITY DEVELOPMENT

Moist potential vorticity (MPV) is an integrated measurement of atmospheric dynamic, thermal-dynamic and moist characteristics. Based on primitive equations, Wu et al (1995, 1997) (referred to as WU later) proved that MPV of saturated moist air is conservative. They also pointed out that, if MPV conserves and the isentropic surfaces are slantwise, appropriate distribution of vertical stability, moist baroclinity and horizontal vorticity could cause explosive development of vertical vorticity. They named this as slantwise vorticity development (SVD), which provides a powerful tool for the diagnosis and prediction of explosive cyclonic vorticity development in low latitudes and lower troposphere (Liu and Zhang (1996), Yu and Wu (2001)). Please refer to WU for more details about MPV and SVD.

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4. PRIMARY RESULTS

The horizontal resolution of the data used is 27km×27km, with 19 vertical levels and 3 time levels (00UTC 4, 00UTC 5, and 00UTC 6).

4.1 MPV and the Equivalent Potential Temperature

At 00UTC on 5 August, MPV was negative in the lower atmosphere and positive on higher levels (approximately above 600hPa). That is to say, the lower atmosphere was moist symmetric unstable.

As to the distribution of equivalent potential temperature (θ_e) (Fig.1), the moist isentropic surfaces were steep in the lower atmosphere close to Shanghai, because Shanghai was in front of a warm and moist air mass. This was a favorable environment for SVD. On higher levels near Shanghai, the moist isentropic surfaces were relatively looser than upstream, which was also favorable for the development of cyclonic vorticity.

4.2 Components of MPV

The part of MPV related to vertical vorticity was named as vertical component of MPV (MPV1) by WU. The rest was named as horizontal component of MPV (MPV2).

On 5 August, MPV1 was negative in the lower atmosphere and positive on higher levels, almost in accordance with MPV. Because the absolute vertical vorticity was positive everywhere, the sign of MPV1 was decided by that of vertical stability. This implied that the lower atmosphere was convectively unstable.

It is notable that, there was a region with high positive MPV2 below 700hPa near Shanghai (Fig.1). This region also had very steep moist isentropic surfaces. Further analyses showed that, MPV2 in this region was mainly decided by the vertical gradient of latitudinal wind and the longitudinal gradient of θ_e. At 00UTC 5 August, there was a southerly jet in the lower atmosphere, and the latitudinal wind was the largest at about 700hPa. The vertical gradient of latitudinal wind also increased with height below 700hPa. These factors together contributed to the positive center of MPV2 just below 700hPa.

4.3 Vertical Vorticity

Based on SVD theory, WU and Liu et al (1996) pointed out that high positive MPV2 in the lower atmosphere could be used as a tracer for low level jet and the activity of warm moist stream, which was often related to large cyclonic vorticity and heavy rainfall. In this case, in the region with high positive MPV2 and steep moist isentropic surfaces, the vertical vorticity was indeed very large (Fig.2) and also increased greatly compared with that of 00UTC 4 August. So, SVD is very important for the explosive development of cyclonic vorticity in this region.

In the upper atmosphere, a high vorticity center appeared in the region with the loosest isentropic surfaces. As the air stream flew from denser θ_e region to a looser region, its cyclonic vorticity increased due to the decrease of vertical stability.

It could be concluded that the outburst of a southerly jet in the lower atmosphere triggered the explosive development of cyclonic vorticity in the region with steep θ_e surfaces. That was slantwise vorticity development. While in the upper atmosphere, cyclonic vorticity increased notably as the air flew from west to east and entered a region with smaller vertical stability. The simultaneous sharp development of cyclonic vorticity in both the lower and upper atmosphere might be the main cause for the torrential rainfall. Further research is still needed to improve our forecast skill of such heavy rainfall.

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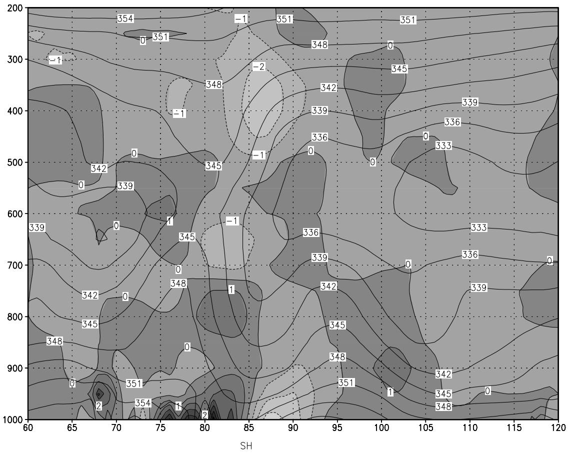

Fig.1 X-Z cross-section of θ_e (solid line, K) and MPV2 (Shaded, *1.e-7$m^2s^{-1}Kkg^{-1}$) across Shanghai

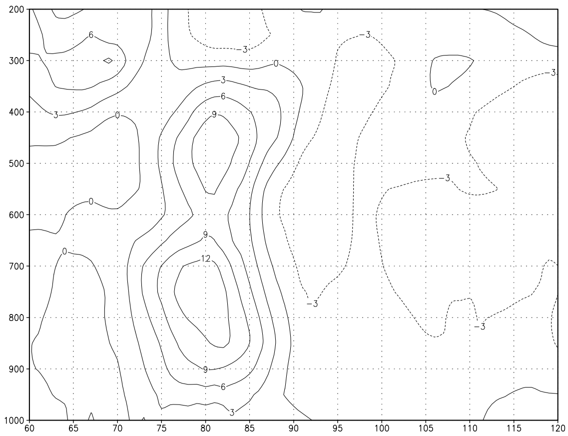

Fig.2 X-Z cross-section of vertical vorticity (*1.e-5s^{-1})

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