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ANALYSIS OF RAINSTORMS ASSOCIATED WITH SIMILAR TRACK TROPICAL CYCLONES HAITANG (0505) AND BILIS (0604)

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Abstract: It is generally thought that the influence of comparable track typhoons is approximately similar, but in fact their wind and especially their rainstorm distribution are often very different. Therefore, a contrastive analysis of rainstorms by tropical cyclones (TCs) Haitang (0505) and Bilis (0604), which are of a similar track, is designed to help understand the mechanism of the TC rainstorm and to improve forecasting skills. The daily rainfall of TC Haitang (0505) and Bilis (0604) is diagnosed and compared. The result indicates that these two TCs have similar precipitation distribution before landfall but different precipitation characteristics after landfall. Using NCEP/GFS analysis data, the synoptic situation is analyzed; water vapor transportation is discussed regarding the calculated water vapor flux and divergence. The results show that the heavy rainfall in the Zhejiang and Fujian Provinces associated with Haitang (0505) and Bilis (0604) before landfall results from a peripheral easterly wind, a combination of the tropical cyclone and the terrain. After landfall and moving far inland of the storm, the precipitation of Haitang is caused by water vapor convergence carried by its own circulation; it is much weaker than that in the coastal area. One of the important contributing factors to heavy rainstorms in southeast Zhejiang is a southeast jet stream, which is maintained over the southeast coast. In contrast, the South China Sea monsoon circulation transports large amounts of water vapor into Bilis – when a water-vapor transport belt south of the tropical cyclone significantly strengthens – which strengthens the transport. Then, it causes water vapor flux to converge on the south side of Bilis and diverge on the north side. Precipitation is much stronger on the south side than that on the north side. After Bilis travels far inland, the cold air guided by a north trough travels into the TC and remarkably enhances precipitation. In summary, combining vertical wind shear with water vapor transportation is a good way to predict rainstorms associated with landing tropical cyclones.

Key words: weather forecast; tropical cyclones; typhoon rainstorms; similar tracks; water vapor flux; vertical wind shear

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1 INTRODUCTION

Tropical cyclone disasters are often caused by the induced flooding, and the research conducted on tropical cyclone rainstorms has long been one of most important aspects of tropical cyclone research [1]. As early as the late 1970s, it was pointed out that the maintenance and stagnation of a typhoon after landing, steady water vapor transport, interaction between low- and mid-latitude circulations, influence of mesoscale systems and terrain effect are all important factors leading to heavy typhoon rainfall [2]. Over the past decade, the factors of storm rainfall (distant from the typhoon), formation of a spiral rain band, impact of underlying surface characteristics on heavy rains, and sudden increased amplitude of heavy rain have all been

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largely studied by domestic and foreign scholars. The prediction of the typhoon rainstorm – especially that of rainstorm strength and distribution in the typhoon landing area, however – is still a challenge [3].

The 'similar track typhoons forecasting method' is commonly used in the actual operational prediction of the typhoon rainstorm [4, 5], but occasionally there is a considerable difference in the distribution of storm rainfall with similar typhoon tracks (such as the "9608" and "7508" typhoons) causing heavy torrential rain. Examples are: Winnie (9711) and Tim (9406), resulting in different precipitation distributions at the Liaodong Peninsula, and Chebi (0121) and Toraji (0108), leading to a great precipitation difference in Zhejiang, China [5-7]. It is integral to a study to contrastively analyze the causes leading to the rainstorm of similar track typhoons. This helps us to understand the similar track typhoon mechanism and to improve forecasting level. Rainstorms of tropical cyclones Haitang (0505) and Bilis (0604) have been researched for their serious repercussions on China [8-11]. In fact, Haitang and Billis both moved westward after landing on the coastal area of Central Fujian with very similar moving tracks, and both caused obvious precipitation in southeast Zhejiang and northeast Fujian before landing; however, there is a very big difference in precipitation after landing. The precipitation mainly distributed on the north side of the moving track for Haitang, and on the south side for Bilis. This paper will carry out diagnostic analyses of the precipitation of Haitang and Bilis, and discuss the possible reasons causing the varying precipitation distribution of TCs with similar tracks. It will also investigate the forecast of this type of rainstorm by considering water vapor transport and vertical wind shear.

2 BRIEF INTRODUCTIONS

Haitang (0505) formed as a tropical depression (TD) in the south of Minami Torishima at 1800 UTC 10 July 2005. It moved westwards and developed into a tropical storm (TS) at 0000 UTC 13 July. Moving west-southwestwards, it quickly developed into a typhoon (TY) at 1800 UTC 13 July. Turning westwards and then west-northwestwards, Haitang's intensity reached its peak with a maximum central pressure of 920 hPa at 0600 UTC 16 July. After it moved northwestwards over the sea south of Ishigakijima Island on 17 July, it turned in a counterclockwise direction off the eastern coast of Taiwan Island. Haitang turned northwestwards, and crossed the island on 18 July, then made landfall at Fujian coast on 19 July. It weakened into a TD at 0600 UTC 20 July and dissipated in Jiangxi Province at 1800 UTC 21 July. It brought long and intense rain to the southeast coastal areas of Zhejiang and northeast Fujian, which caused serious damage. According to preliminary statistics by State Flood Control and Drought Relief Headquarters, immediate economic losses in Zhejiang and Fujian Provinces reached RMB 11 billion.

Bilis (0604) formed as a tropical depression (TD) over the western North Pacific about 410 km northeast of Yap on the night of 8 July, and moved generally towards the northwest. On the night of 11 July, Bilis strengthened into a severe tropical storm and skirted the eastern part of the Luzon Strait the following day. On the night of 13 July, Bilis skirted northern Taiwan, and traversed the Taiwan Strait, then made landfall over Fujian on 14 July. Moving inland, it weakened gradually and dissipated over Jiangxi the next day. Bilis inflicted severe damage on Fujian, Zhejiang, Hunan, Jiangxi, Guangdong and Guangxi Provinces. Altogether, the direct economic losses exceeded RMB 24 billion.

3 PRECIPITATION CHARACTERISTICS

During the period that typhoon Haitang (0505) traversed the Taiwan Strait, the most precipitation was located in the Yucang mountain area between the Zhejiang and Fujian Provinces (figure omitted). Yu et al. [12] and Zheng et al. [13] indicated that the terrain in Southern Zhejiang and Northern Fujian offers a remarkable contribution to the typhoon rainfall under the influence of an easterly flow. After typhoon Haitang landed and moved inland, the key precipitation still existed in Zhejiang Province, especially the southeast coast (Fig.1a). After the typhoon travelled far inland, the precipitation abated, but was obvious on its north side (north Jiangxi and most of Anhui), north Zhejiang and the East China coastal areas (Fig.1c).

In the 24 hours after Bilis crossed the Taiwan Strait and landed in Fujian Province, it brought torrential rain to the southeast coast of Zhejiang, and primarily Fujian, south Jiangxi, south Hunan, and east Guangdong. The maximum precipitation center was located in east Guangdong and the area adjacent to the boundary of the Jiangxi and Hunan Provinces (Fig. 1b). In the 24 hours that Bilis stayed in Jiangxi, the precipitation distribution was maintained with westward expansion. The difference is that the strong precipitation at the boundary and around the area bordering Guangdong, Jiangxi and Hunan Provinces expands to Hunan; the strong precipitation center in east Guangdong moves to the north-middle, the precipitation at the Fujian coast strengthens with strong precipitation centers being distributed along the coastline. Then, the precipitation at the southeast coast of Zhejiang weakens (Fig.1d).

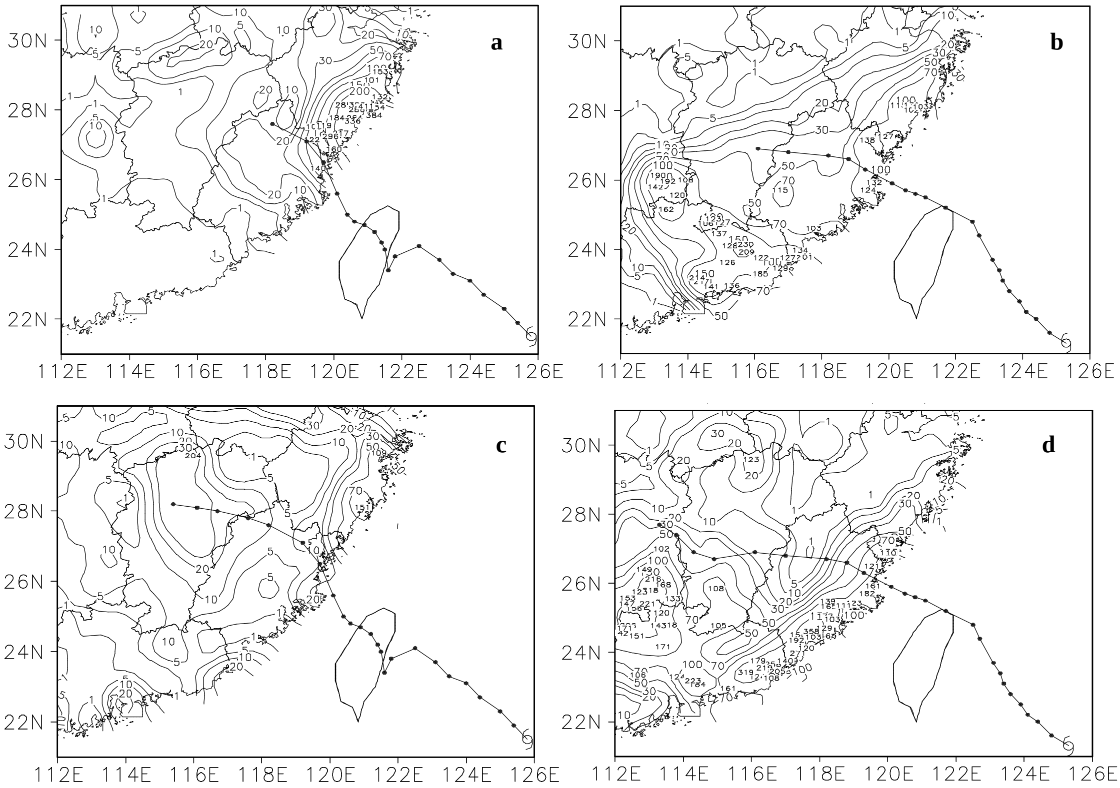

Fig.1 Distributions of 24-hr accumulated precipitation of the tropical cyclones (TCs) Haitang (0505) on (a) 19 and (c) 20 July 2005, and Bilis (0604) on (b) 14 and (d) 15 July 2006 (the black numbers larger than 100 mm are the precipitation observed at stations) and their moving tracks.

4 SYNOPTIC FIELDS AND WATER VAPOR CONDITIONS

Based on the twice daily (0000 and 1200 UTC) 1°×1° NCEP/GFS analysis data, the environmental fields and water vapor conditions of Haitang and Bilis were analyzed. The environmental field analyses (figures omitted) show that, before landfall, the strong east to southeast wind in the peripheral areas of Haitang and Bilis plays an important role in the strong precipitation in southeast Zhejiang and northeast Fujian. After landfall, the strong southeast jet stream maintains itself at the Zhejiang's southeast coast for a considerable time and provides abundant water vapor to the Haitang's inverted trough; this plays an important role in the heavy torrential rainfall at the coast. Bilis does not have the compact structure that Haitang demonstrates. After landfall, the southeast wind transforms into a southwest wind at the Zhejiang and Fujian coast, and the water vapor condition is relatively poor in the inverted trough of Bilis; therefore, the precipitation intensity is minor. However, the south jet stream on the south side of Bilis is maintained for a long time and provides sufficient water vapor and energy for the rainstorm. After Bilis travels far inland, the cold air behind the westerly trough infiltrates into the depression circulation, which causes stronger precipitation intensity and longer duration on the south side.

In addition to the advantageous environmental fields, the water vapor transport condition is also important to the typhoon rainstorm [14]. Water vapor flux and its divergent distributions (figures omitted) show that, before landing at the Fujian coast, the large water vapor flux area of Haitang is located in the southeast Zhejiang and northeast Fujian coastal areas. After landfall, the water vapor flux area moves northwards; the great value area, however, is always located on the north side of Haitang. Before landing at the Fujian coast, Bilis has the same water vapor flux distribution as Haitang; after landfall, however, the distribution of Bilis is obviously different from that of Haitang. After landing, the water vapor flux on the north side of Bilis begins to diminish, but the water vapor flux strengthens rapidly on the south side. After Bilis travels far inland, the water vapor flux on the south side is noticeably bigger than that on the north side. The water vapor flux (WVF) divergence distributions (figures omitted) show that the WVF convergence area of typhoon Haitang is maintained at the Zhejiang and Fujian coastal areas, particularly in southeast Zhejiang and northeast Fujian; this does not change into the WVF divergence area until Haitang travels far inland. Before Bilis' landing at Fujian, the WVF convergence area is also maintained in the Zhejiang and Fujian coastal areas. After landing, the convergence area transforms into the divergence area, and the WVF convergence area appears on the south side of Bilis; this is continuously maintained on the south side of the moving track, but it is the opposite on the north side.

5 VERTICAL WIND SHEAR

How the environmental wind vertical shear affects tropical cyclone precipitation intensity and distribution is a hot topic in tropical cyclone research [15-23]. References [15-23] primarily study the convection and precipitation in the inner core area of a TC. In actual forecasting, it is occasionally discovered that the strongest precipitation is located at the outside core area or the periphery away from the cyclone center, rather than in the inner core area. The study region is expanded to include the outside core area in order to research the vertical wind shear and study the precipitation after tropical cyclone landfall. Both typhoon Haitang and the tropical storm Bilis have good corresponding relationships between precipitation distributions (Fig.1) and vertical wind shear (Fig.2). Heavy precipitation is often located on the left side of the vertical wind vector, which is consistent with the observational results [21] and numerical findings [22]. Analyses of the vertical wind shear vectors and the moving tracks show that the vertical wind shear vector of Haitang is parallel to its track and points to the rear of the moving track. The vertical wind shear vector of Bilis is also parallel to its moving track, but points to the track frontage. Therefore, the fact that the vertical wind shear vector is parallel to the moving track is potentially an important reason for the distribution of strong precipitation along both track sides. The vertical wind shear vector of Haitang (Bilis) points to the rear (frontage) of the moving track, so the strong precipitation falls toward the right (left) side of the track.

6 CONCLUSIONS

(1) The tracks of tropical cyclone Haitang and Bilis are similar. Their precipitation distributions are also similar before landfall; after landing, however, the difference in their precipitation distributions is considerable. Haitang's precipitation is primarily located on the north side of the track, and Bilis' precipitation is mainly on the south side.

(2) Before the Haitang and Bilis landing, the significant precipitation lies on the coast of southeast Zhejiang and northeast Fujian, which is caused by the

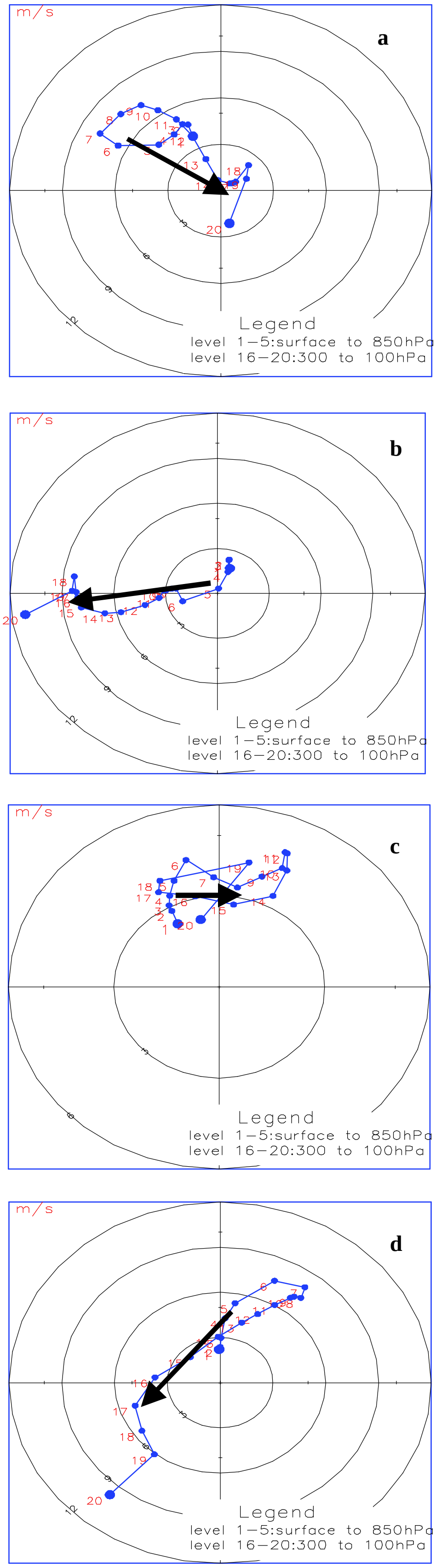

Fig.2 Distributions of vertical wind shear of the tropical cyclones (TCs) Haitang (0505) on (a) 19 and (c) 20 July 2005 and Bilis (0604) on (b) 14 and (d) 15 July 2006.

outer east to southeast streams of the TC. After landing, Haitang’s precipitation is determined by its circulation and inverted trough, in which the strong southeast wind jet leads to heavy rainfall on the coast; Bilis is not as compact as Haitang, but its long duration of maintaining the southerly jet in the southern part provides a great deal of water vapor and energy for the rainstorm. After Bilis travels far inland, the cold air infiltration behind the westerly trough renders the precipitation intensity stronger and the duration longer; the heavy precipitation then situates itself mainly on the south side of the track.

(3) After Haitang’s landing, the water vapor carried by its own circulation significantly decreases. After Bilis’ landing, the abundant water vapor carried by the South China Sea monsoon circulation merges into the Bilis circulation, which causes the low pressure circulation to be continuous and provides favorable heat and water vapor conditions for the rainstorm on the south side.

(4) Both Haitang and Bilis have a better relationship between the precipitation distributions and the regional average distributions of vertical wind shear near the center. The heavy precipitation areas are often located on the left side of a vertical wind shear vector. The vertical wind shear vector of Haitang (Bilis) points to the rear (frontage) of the moving track; the strong precipitation falls to the right (left) side of the track.

In summary, with respect to the actual forecasting of typhoons, it is probably a more effective method to forecast the heavy precipitation area of the landing tropical cyclone by combining vertical wind shear vector direction with water vapor transport conditions.

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