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# AN ANALYSIS OF THE ASYMMETRICAL STRUCTURE OF TYPHOON AERE'S PRECIPITATION

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**Abstract:** The structural characteristics of 2004 typhoon Aere's precipitation are analyzed using the high-resolution data from the Tropical Rainfall Measuring Mission (TRMM) of the National Aeronautics Space Administration (NASA). It is found that the typhoon's characteristics vary at different stages of its development. To analyze the asymmetric causation of precipitation distribution, data from the National Center for Environmental Prediction (NCEP) reanalysis are used to calculate the vertical integral of the water vapor flux vector. The results show that because of this process, along with the unique phenomenon of twin-typhoon circulation, the easterly air current of the typhoon's northern side and the southwesterly air current of its southern side play a joint role in transporting water vapor. Furthermore, its transport effects vary greatly at the different stages of development, showing the peculiarity of the water source for this typhoon process. The distributions of the typhoon convection area—characterized by heavy precipitation and a maximum-value area of the water vapor flux, as well as a strong ascending-motion area—differ at different stages of the typhoon's development. The non-uniform distribution of water vapor flux and the vertical motion bring about asymmetrical distribution of the typhoon precipitation.

**Key words:** typhoon precipitation; TRMM; vapor flux vector; asymmetrical structure

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## 1 INTRODUCTION

Typhoons are extremely destructive weather systems, usually accompanied by strong weather changes such as a gale, heavy rain, billow, storm tide, or tornado, among others. Therefore, a typhoon is considered a major disastrous weather system in the world. On the other hand, however, there is no doubt that rainwater from typhoons alleviates the harmful effects of drought and heat waves.

Over the past 10 years, there has been new progress in the theory on the formation of heavy rains and spiral rain bands during typhoons, as well as on other topics such as the influence of the typhoon system on the precipitation of mid-latitude areas, heavy rain distribution, the impact of surface characteristics on heavy rains, and the sudden increase of heavy rains [1]. With regard to the asymmetric structure of typhoons, the interaction of a small-scale vortex and a typhoon has been examined through the use of a quasi-geostrophic barotropic model, with the β effects causing the non-symmetrical structure of tropical cyclones [2]. Furthermore, the respective relationships between a typhoon's asymmetric structure and its path of movement [3], as well as that between the asymmetric distribution of the environmental flow field and the temperature field and a typhoon's heavy rain, have been studied in the past[4].

However, owing to the scarcity of maritime observations and the spatial and temporal non-continuity of precipitation distribution, the obtainment of precipitation data has become a very difficult task.[5] With this, it can thus be said that the quantitative analysis of the structure of a typhoon, as well as its occurrence and development mechanism, is still immature. To address this problem, satellite remote sensing data and radar data have been extensively studied and applied in recent years. From such efforts, TRMM was developed successfully by the

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United States' NASA and the Japan Universe Exploitation Corporation in 1995. This joint endeavor was launched in November 1997 and was first used to quantitatively measure the tropical rainfall in a space satellite program. It was also designed to generate a clearer understanding of the impact of tropical rainfall on the global climate system [6]. From these studies, we know that TRMM satellite data have better applications in tropical precipitation measurements, improvement of precipitation forecast accuracy, rainstorm research, data assimilation of forecasting models, tropical sea surface temperature inversion, and observation of tropical cyclones [7-10]. The TRMM Precipitation Radar (PR) is particularly the first choice among a variety of space-borne sensors which can obtain three-dimensional rainfall information.[11] In relation to this, scholars have discussed recently the impact of the vertical wind shear and storm movement on the asymmetric structure of a tropical cyclone's precipitation with the use of TRMM data [12].

This article employs high-resolution TRMM observation data to analyze the evolution of the 2004 typhoon Aere, especially with regard to the asymmetrical structure of typhoon precipitation. To further understand the reasons behind this kind of structure, the NCEP reanalysis data were used to calculate the vertically integrated water vapor flux vector. The analysis was conducted with a focus on both the water vapor transmission and vertical velocity.

## 2 OVERVIEW OF THE TYPHOON AERE

In the development process of Aere, a double-typhoon phenomenon emerged due to the impact of the typhoon Chaba. Table 1 shows the storm's life history and its intensity change in the process.

Table 1 Life history of Typhoon Aere.

| time/UTC | Sea level central pressure / hPa | Max. wind speed /(m/s) | latitude / °N | longitude / °E | Level of intensity |
|---|---|---|---|---|---|
| 0000 Aug.20 | 996 | 18 | 13.6 | 135.1 | TS |
| 0000 Aug.21 | 985 | 25 | 17.5 | 134.0 | TS |
| 0000 Aug.22 | 980 | 33 | 20.2 | 129.8 | TY |
| 0000 Aug.23 | 975 | 35 | 22.9 | 126.2 | TY |
| 0000 Aug.24 | 960 | 40 | 24.9 | 123.9 | TY |
| 0000 Aug.25 | 960 | 40 | 25.4 | 121.5 | TY |
| 0000 Aug.26 | 985 | 20 | 23.8 | 117.2 | TS |
| 1800 Aug.26 | 995 | 15 | 23.4 | 114.4 | TD |

## 3 ANALYSIS OF THE STRUCTURAL CHARACTERISTICS OF TYPHOON AERE'S PRECIPITATION

### 3.1 *Horizontal distribution of rainfall characteristics*

Surface rainfall intensity (rainfall rate) distribution maps (Fig. 1) showed that during the initial stage of the typhoon, precipitation was scattered, sporadic, and weak; spiral rain bands were not clear. When Aere was at its development stage, counter-clockwise spiral rain bands developed strongly, but only in the southern part of the typhoon, with the rain bands showing asymmetric characteristics. When the maximum wind speed continued to increase, the non-uniform distribution of the entire heavy precipitation areas, the intensity of the contrast, and the spiral rain bands were still very clear. When Aere was in the prime development period, the structure of the spiral rainbands in the maturity period was tight, with these rain bands taking the shape of an arc. The degree of asymmetry of the precipitation structure was also reduced.

At the initial stage of the typhoon's development, therefore, the precipitation rate in the cloud wall was smaller. At its development peak, heavy precipitation was distributed along the cloud wall, showing asymmetric characteristics, that is, the degree of development of convection along the cloud wall was characterized by uneven distribution.

Analysis with the use of TRMM/TMI-85.5 GHz microwave images (chart omitted) shows that the high or low value of brightness temperature denoted the characteristics of heavy precipitation as generated by convective clouds. When Aere was gaining strength during the early stage of its peak period, a low-value area of brightness temperature occurred in the spiral rain bands at the southern side of the typhoon, showing that the precipitation here was mainly convective. Meanwhile, in the prime period, there were low-value brightness temperature areas along the location of the cloud wall, indicating that strong convective cloud precipitation was very clear in the cloud wall, and that convective cloud precipitation was stronger at the eastern side of the cloud wall.

### 3.2 *Analysis of the three-dimensional structure of precipitation*

The three-dimensional structure and distribution of the typhoon rainstorm were accurately depicted using the precipitation data provided by the TRMM satellite/PR, .

Figure 2 shows the three-dimensional structure of the typhoon rainstorm. The threshold value of 6.0 mm/h in Fig. 2a indicates that the precipitation was of stratiform clouds and convection did not develop.

When Aere was gaining strength during the early stage of its peak period (Fig. 2b, where the threshold value was at 10.0 mm / h), all of the precipitation towers were dense and strong, and even for just one tower, only a part of the spiral rain bands located in the south-west part of the typhoon can be seen because of the limited scanning range. Meanwhile, there were no precipitation towers along the cloud wall. At the typhoon's peak period (Fig. 2c, the threshold value was at 10.0 mm/h), the typhoon eye area was clear, and there were no convection cells. Prime rainstorm cells were in the cloud wall area and a strong convection was at the eastern part of the eye area. These pagoda-shaped cells linked to each other closely and were extending to heights that were basically the same. At the west side of the typhoon eye area, there were gaps among the rainstorm cells, but the spiral rain band structure was very clear. With a change in the threshold value, the characteristics of convective asymmetry can be analyzed further. The precipitation zones of the spiral rain bands were made up of many precipitation towers. These towers were linked at the bottom rather than at the top, from which the convection also developed strongly. With the weakening of Aere (Fig. 2d), stratiform precipitation became a major event.

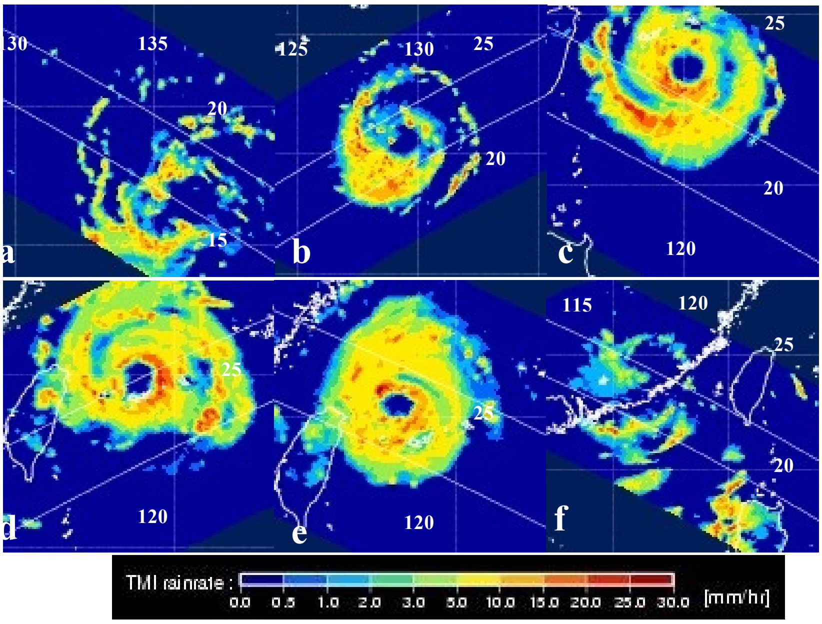



Fig.1 Surface rain intensity distribution. a. 1034 UTC 20 August 2004, Orbit Number: 38552, Area: 10.2°N－24.6°N, 128.0°E－140.9°E; b. 0208 UTC 22 August 2004, Orbit Number: 38578, Area: 14.7°N－26.9°N, 122.8°E－136.8°E; c. 0923 UTC 23 August 2004, Orbit Number: 38598, Area: 16.6°N－28.6°N, 119.5°E－130.3°E; d. 0154 UTC 24 August 2004, Orbit Number: 38609, Area: 18.9°N－30.3°N, 118.5°E－129.6°E; e. 0827 UTC 24 August 2004, Orbit Number: 38613 Area: 19.9°N－30.5°N, 118.1°E－129.0°E; f. 0812 UTC 26 August 2004, Orbit Number: 38644, Area: 16.1°N－28.8°N, 110.6°E－125.3°E.

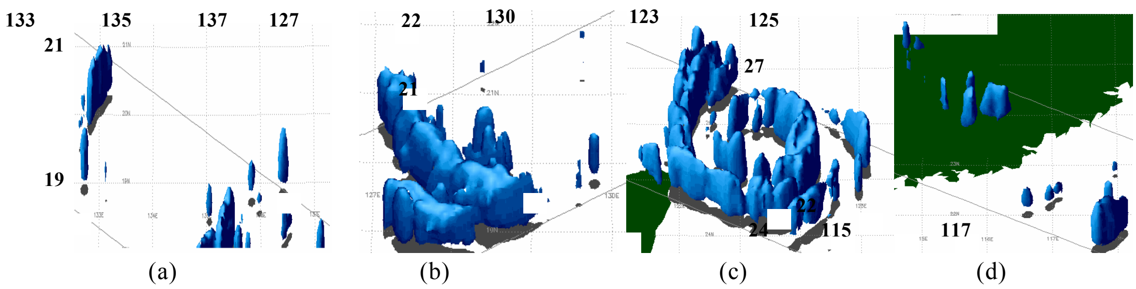



Fig.2 Three-dimensional chart of typhoon precipitation compiled with TRMM/PR data (figures in the charts are longitude and latitude). a: 1034 UTC 20 August 2004; b: 0208 UTC 22 August 2004; c: 0827 UTC 24 August 2004; d: 0812 UTC 26 August 2004.

## 4 PRELIMINARY ANALYSIS OF THE REASONS BEHIND ASYMMETRIC TYPHOON PRECIPITATION

From both aspects of water vapor transmission and vertical velocity, the reasons behind typhoon precipitation for an asymmetrical structure are explored.

Figure 3 shows the water vapor flux vector in the typhoon region. When Aere was in the tropical storm period, the water vapor came mainly from tropical south-west air currents at the southern regions of the typhoon.. When Aere was gaining strength during the early stage of its peak period, the water vapor came from the south-east air currents in the north of the typhoon, while westerly airstreams from the South China Sea area also had a role in water vapor transmission. The largest area of water vapor flux did not coincide with the strong convective precipitation area. In addition, during the prime period of Aere, the water vapor came mainly from the westerly airstream from the South China Sea, and the largest area of water vapor flux coincided with the strong convective precipitation area. After Aere hit the land, the transmission of water vapor by the westerly airstream from the South China Sea was still very significant.

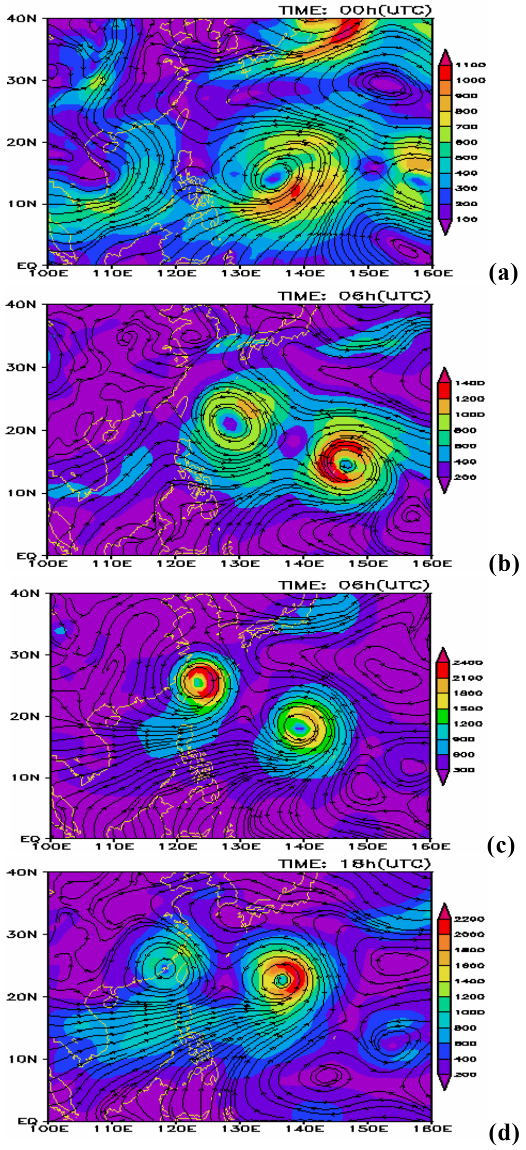
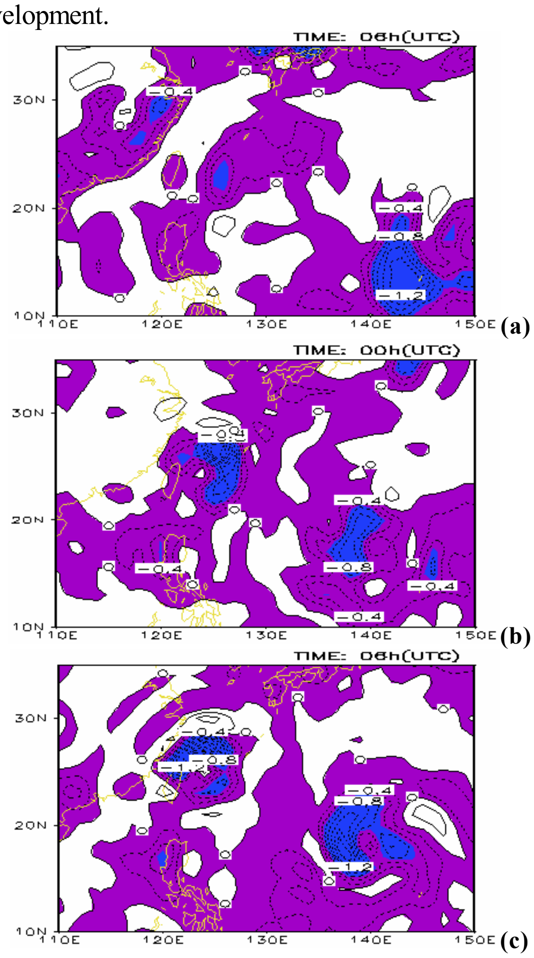



Fig.3 Distribution of water vapor flux vectors in the unit of kg/(m·s). a: 0000 UTC 20 August 2004; b: 0600 UTC 22 August 22 2004; c: 0600 UTC 24 August 2004; d: 1800 UTC 25 August 2004.

Figure 4 shows the vertical velocity distribution at an altitude of 500 hPa. When Aere was gaining strength during the early stage of its peak period (Fig. 4a), a strong ascending motion area was located in the south-west of Aere's center, corresponding to the strong convective precipitation area. During the prime period of Aere (Fig. 4b), there was a weak sinking motion corresponding with the eye area. The distribution of the ascending motion was asymmetrical, and a large-value area of ascending motion was located in the southeastern, eastern, and northern parts of the typhoon center, in which the distribution of water vapor flux vectors was fully consistent.

At 0600 UTC August 24 (Fig. 4c), easterly airstream convergence further increased on the northern side with the occurrence of twin typhoons. The large-value center was located at the northern part of the typhoon center, in which the large-value area of the ascending motion and that of water vapor flux coincided with the strong convective precipitation area. When Aere weakened into a tropical storm (Fig. 4d), a –0.4 Pa/s ascending motion area corresponded to the typhoon system, and its intensity and scope were significantly reduced. This shows that the asymmetrical characteristics of vertical movement in the typhoon system are not the same at different stages of typhoon development.



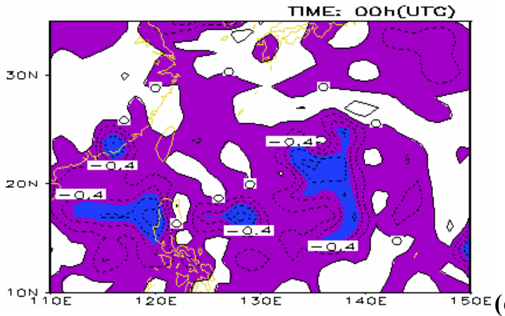



Fig.4 Vertical velocity distribution at 500 hPa (unit: Pa/s). a: 0000 UTC 22 August 2004; b: 0000 UTC 24 August 2004; c: 0600 UTC 24 August 2004; d: 0000 UTC 26 August 2004.

## 5 CONCLUSIONS

Using high-resolution data from NASA TRMM and NCEP reanalysis data, the structural characteristics of the 2004 typhoon Aere's precipitation were analyzed. Its structural characteristics were found to vary at different stages of the typhoon's development.

(1) The analysis of TRMM's TMI 2A12 surface precipitation rate and the TMI-85.5 GHz microwave image shows that with the use of high-resolution information, the detailed characteristics of the typhoon system's precipitation can be analyzed. The distribution of heavy precipitation during Aere's development process was characterized by asymmetrical features. In addition, a clear typhoon eye and the convection development intensity at the cloud wall can be seen on the brightness temperature map, which can determine the extent of typhoon development.

(2) With the use of high horizontal and vertical resolution precipitation data by the TRMM satellite/PR2A25, the three-dimensional structure of the typhoon's rainstorm can be obtained accurately at its different stages of development.

(3) Owing the unique phenomenon of twin-typhoon circulation, this process is characterized by the easterly airstream on Aere's northern side and the south-west airstream on its southern side, which played a role in the water vapor transport. However, the transport effects varied in different periods of Aere's development, forming unique characteristics of the water vapor source during the typhoon's course.

(4) The study also found that the distribution of the convection zone of heavy precipitation, the maximal value zone of water vapor flux, and the strong ascending motion area had large variations at different stages of the typhoon's development. When Aere was gaining strength during the early stage of its peak period, the convection zone of heavy precipitation was located at the south-west of Aere's center, which coincided with the strong ascending motion area, but did not match with the maximal value zone of water vapor flux. However, during Aere's peak period, the convection zone of heavy precipitation was located at the eastern and northern regions of Aere's center, with the three coincided to one another.

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