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THE STRUCTURE OF TROPICAL CYCLONE BY TOVS AND ITS APPLICATION IN NUMERICAL WEATHER PREDICTION

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ABSTRACT: The TOVS data are used to study the structure of a number of tropical cyclones for the year 2000. Differences are found to some extent between what is found and classic conceptual models in that (1) the horizontal structure is asymmetric and variable so that the low-value centers at low levels of the geopotential height field (or the high-value centers at high levels) do not necessarily coincide with the high-value centers of the temperature field; (2) the vertical structure is also variable in the allocation of the anomalies of the geopotential height field between low values at low levels and high values at high levels. It is especially noted that the centers of the anomalies are tilting at both high and low levels or the high level is only at the edge of a high-pressure zone. There is not any significant high-value anomalous center in a corresponding location with the tropical cyclone.

The structure of tropical cyclone in the TOVS is also used as reference to modify the structure of typhoon BOGUS in the numerical prediction model system of tropical cyclones. It is found that the modified BOGUS performs better in coordinating with the environment and predicting the track of the tropical cyclone. The demonstration is two-fold —the structure of the typhoon BOGUS is such that it means much in the track prediction and the use of the TOVS-based tropical cyclone structure really helps in improving it. It provides the foundation for modification and evolution of typhoon BOGUS.

Key words: structure of tropical cyclones; typhoon BOGUS; numerical prediction of tropical cyclone track

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1 INTRODUCTION

The tropical cyclone is an important synoptic regime over the tropical ocean. It used to be grossly understood in terms of the structure due to scarcity in observations over the tropical ocean. Some existing conceptual models is expository only for some typical typhoons. The models are insufficient in solving many of the issues in analyzing and predicting the tropical cyclone. In fact, the structure can various and complex[1, 2]. We are now in a stage when we can have access to increasingly abundant and reliable satellite-derived observations, which have become one of the principal means of and paved the way for analyzing and forecasting the tropical cyclones. Though with some error, the TOVS data have some degree of reliability in terms of the anomaly. Especially, they will be much more accurate if treated with correction techniques. The current work uses the TOVS data for some tropical cyclones in 2000 in the analysis of structure and obtains models that are different from the conceptual ones. Effects of the difference on track prediction are also studied. The result shows that the modified typhoon BOGUS can efficiently improve the numerical model prediction of the tropical cyclone when it is made to be close to the structure observed with TOVS.

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2 STRUCTURE OF TROPICAL CYCLONE BY TOVS

Existing tropical cyclone structures are typical (composite) state summarized from strong (relatively strong) cases. They are usually quasi-symmetric with the geopotential height center of the storm generally coincided with the temperature center[3]. In the TOVS dataset, some of the structures are found to be inconsistent with the conceptual models. Owing to the structure variability, the observed storm may be more complex and variable than the general models. When the centers of geopotential height and temperature fields coincide with each other, the structure is labeled a "consistent" one and otherwise an "inconsistent" one. The conceptual models are close to the consistent structure. Studying the TOVS data, we find another three types of tropical cyclones, which are described below.

2.1 *Severe tropical cyclones with inconsistent structure*

Tropical cyclone No.0003 (Kirogi) was located at 29.9°N, 137.7°E at 0600GMT July 7, 2000. With a central pressure of 965 hPa, maximum wind speed of 38 m/s and Force-eight wind radius of 450 km, the severe tropical cyclone was moving northeast. Figs.1a & 1b show the radial

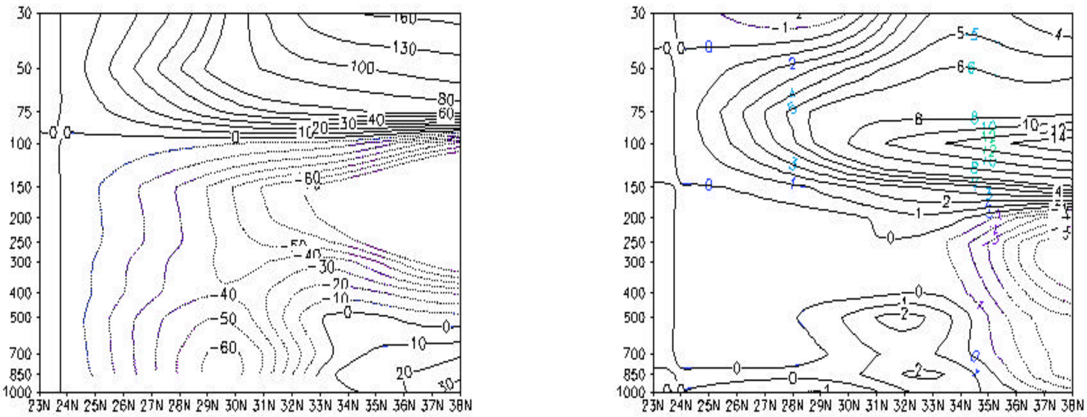

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Fig.1 The vertical profile passing through the eye of TC Kirogi at 0700GMT July 7, 2000. a. geopotential height; b. temperature.

vertical profiles of geopotential height and temperature fields. The structure is shown to be inconsistent. The geopotential height field displays a strong negative anomalous center at low levels, which corresponds to the center located for the tropical cyclone. The line connecting the two negative centers, furthermore, is vertical. At higher levels of the troposphere, an anti-cyclonic center can be non-existent, which is again different from the concept of tropical cyclones. For the temperature anomalies, the center of positive anomalies can be far away from that located for the tropical cyclone, with the distance up to 300 km or so. Centers of positive anomalies of temperature are found at the middle and lower layers of the troposphere rather than at higher layers of 200 hPa ~ 300 hPa. It differs substantially from the concept of temperature structure in the conceptual model. Anomalies of high temperature form around 100 hPa as a result of interactions between clouds and solar radiation.

2.2 *Weak tropical cyclones with inconsistent structure*

Tropical cyclone No.0009 (Ewiniar) was located at 29.2°N, 135.9°E at 0600GMT August 12,

2000. With a central pressure of 985 hPa, maximum wind speed of 25 m/s and Force-eight wind radius of 300 km, the weak tropical cyclone was moving northeast. Figs.2a & 2b show the radial vertical profiles of geopotential height and temperature fields. The structure is shown to be inconsistent. The geopotential height field displays a weak negative anomalous center at low levels, which corresponds to the center located for the tropical cyclone. The line connecting the two negative centers, furthermore, is slantwise. At higher levels of the troposphere, an anti-cyclonic center can be non-existent, with the tropical cyclone just at the edge of circulation area of a high-level high and a weak center of positive anomalies at 150 hPa ~ 300 hPa. The line connecting the centers is also slantwise. It is also different from what we know in the conceptual model for the tropical cyclone. For the temperature anomalies, the center of positive anomalies can be far away from that located for the tropical cyclone. Significant centers of positive anomalies can be at both high and low layers of the troposphere while the one at the middle layer is a little weaker. All of these findings suggest large difference from the conceptual temperature structure.

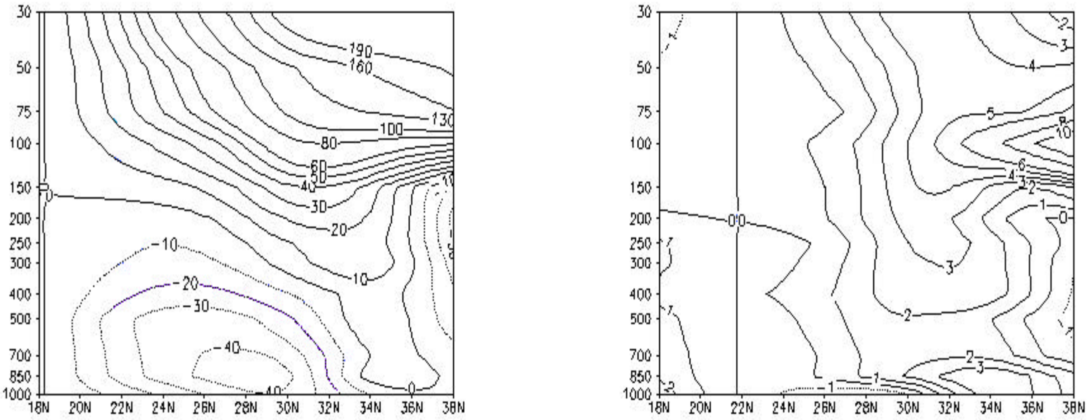

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Fig.2 Same as Fig.1 but for TC Ewiniar on August 12, 2000.

2.3 *Weak tropical cyclones with consistent structure*

Tropical cyclone No.0012 (Prapiroon) was located at 22.5°N, 126.1°E at 0600GMT August 28, 2000. With a central pressure of 985 hPa, maximum wind speed of 23 m/s and Force-eight wind radius of 380 km, the weak tropical cyclone was moving northwest. Figs.3a & 3b show the

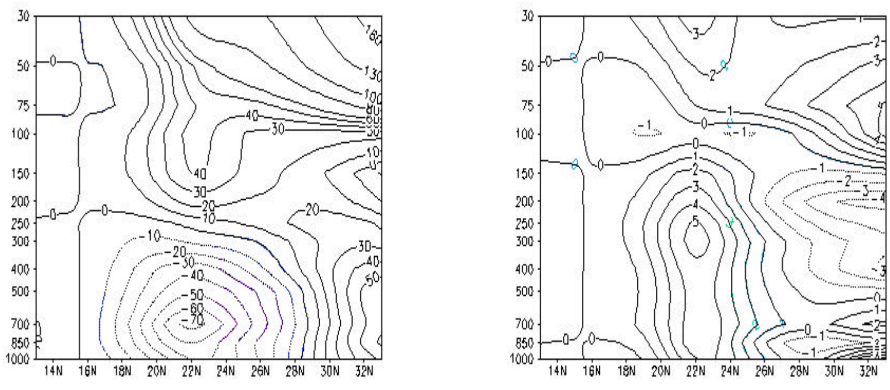

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Fig.3 Same as Fig.1 but for TC Prapiroon on August 28, 2000 radial vertical profiles of geopotential height and temperature fields. The structure is shown to be consistent. The geopotential height field displays a weak negative anomalous center at low levels, which corresponds to the center bcated for the tropical cyclone. It displays, however, a strong negative anomalous center at 700 hPa and the line connecting the two negative centers is vertical. At higher levels of the troposphere, a mild anti-cyclonic (positive geopotential height anomalous) center can be existent. The line connecting the centers of positive anomalies is vertical, which corresponds to the center of negative anomalies at lower levels. The tropical cyclone is also at the edge of circulation area of a high-level high. It is basically agreeable with what we know in the conceptual model for the tropical cyclone, though some differences do exist. For the temperature anomalies, the center of positive anomalies can be the same as those located for the tropical cyclone and negative anomalous center at the low-level geopotential height field. Significant centers of positive anomalies can be at both high and low layers of the troposphere, with the positive anomalies the highest at 300 hPa and negative anomalies very weak at 100 hPa. The finding is generally the same as the conceptual temperature, though with some differences. In the conceptual model, there are not any significant centers of positive temperature at the middle and lower levels of the troposphere.

3 COMPARISONS OF TROPICAL CYCLONE STRUCTURE BETWEEN THE BOGUS AND TOVS DATA

In the numerical prediction system of typhoons developed at the Guangzhou Institute of Tropical and Oceanic Meteorology, a typhoon GOGUS has been incorporated into the initial field. The BOGUS is successful in describing the main structure of most tropical cyclones and works well in achieving desirable results in routine forecasting of tropical cyclones in recent years[4]. Though giving good track forecast for most of the tropical cyclones, the BOGUS performs poorly for some. Is it that the typhoon BOGUS is different from the observation to lead to large forecast errors? The answer is affirmative.

Large errors exist in quite a number of techniques, including the Guangzhou typhoon numerical model, with regard to the track forecast for 0000GMT August 28, 2000. Figs. 4a and 4b show the structure of the geopotential height and temperature fields as described by the BOGUS, which is close to the normal conceptual model for the tropical cyclone. When it is compared with the structure derived with the satellite-based TOVS data (Figs.3a & 3b), however, we can find that there are still some differences between them. The most outstanding difference in the geopotential height field is that the positive anomalies are stronger in the upper levels of the typhoon BOGUS than that of the TOVS data but the horizontal asymmetry of the field is much more significant in the TOVS data than in the typhoon BOGUS. The largest difference in the geopotential height field is that the negative anomalies are stronger in the upper levels of the typhoon BOGUS than that of the TOVS data.

It is then concluded that the variability of the tropical cyclone may lead to structures being different from general conceptual models, based on which the existing typhoon BOGUS is constructed in the prediction system in Guangzhou. It is then inevitable that difference occurs under specific conditions. In fact, Tropical Cyclone Prapiroon being studied above is a consistently structured storm that differs from the conceptual model substantially. The difference is even greater with inconsistent ones. Possible effects of the difference in structure between the typhoon BOGUS and real storms (as described in the TOVS) on track forecasting will be discussed in the section that follows.

4 MODIFICATION OF TYPHOON BOGUS & EFFECTS OF NUMERICAL PREDICTION OF TROPICAL CYCLONE TRACK

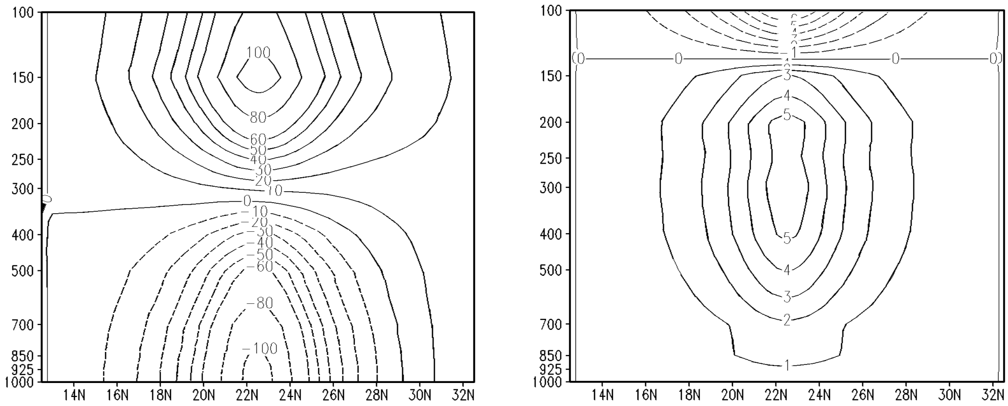

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Fig.4 The vertical profile of TC Prapiroon BOGUS at 0000GMT August 28, 2000.
a. geopotential height; b. temperature

Significant differences are found, as presented in the preceding section, between the typhoon BOGUS constructed from general conceptual models and observed tropical cyclones. It requires more study before we could understand the possible effects on the prediction and develop methods to improve it.

Figs.5a & 5b give the structure of the typhoon BOGUS modified on the basis of that derived from the TOVS data (Figs.3a & 3b). It is known from the comparison of Figs.3a, 3b, 4a and 4b that considerable changes have taken place in its main characteristics and are more like the actual structure of the tropical cyclone (as what is described in the TOVS data). These include sharp weakening of the positive anomalous center in the upper-level geopotential height field, more asymmetric horizontal distribution of the geopotential height field and disappearance of the negative anomalous center in the upper-level geopotential height field. More study has shown that the modified typhoon BOGUS has better coordination with the environment.

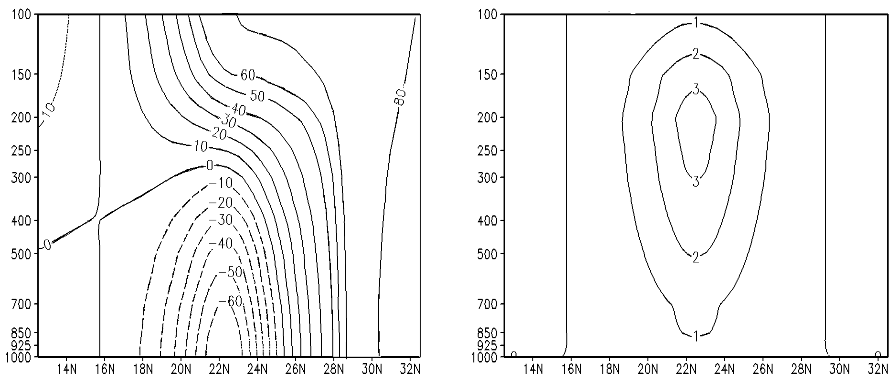

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Fig. 5 Same as Fig.4 but with modification to the BOGUS.

The modification of the structure of typhoon BOGUS can have significant effects on the track prediction. Fig.6a gives the comparison of track for Tropical Cyclone Prapiroon at 0000GMT August 28, 2000 between the forecast and observation. GZTM is the result of the operational forecast of Guangzhou, RTJD that of Japan and BABJ that of Beijing. Due to the "unusual" movement of the storm, errors are all quite large for the three forecasters (See Tab.1

for errors in distance). The cause is that the particular structure present with the storm at the time is poorly assessed. The large error is general, existing in models besides that for Guangzhou.

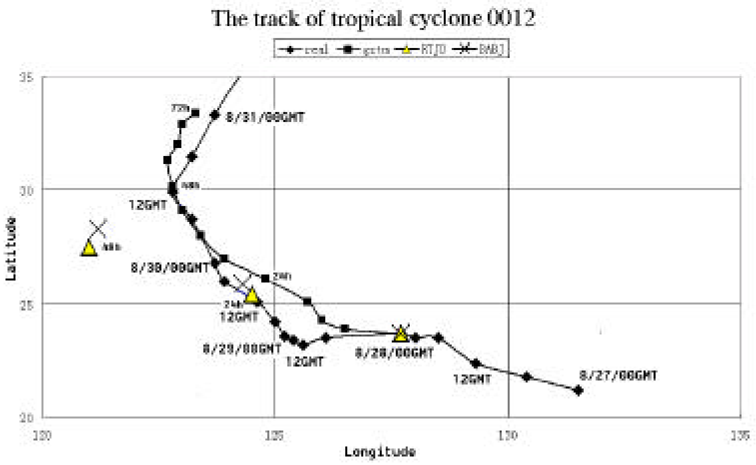

Fig.6a Track forecast of TC Prapiroon. ◆ real, ■ Guangzhou numerical forecast, △ Japan forecast, ╳ Beijing forecast.

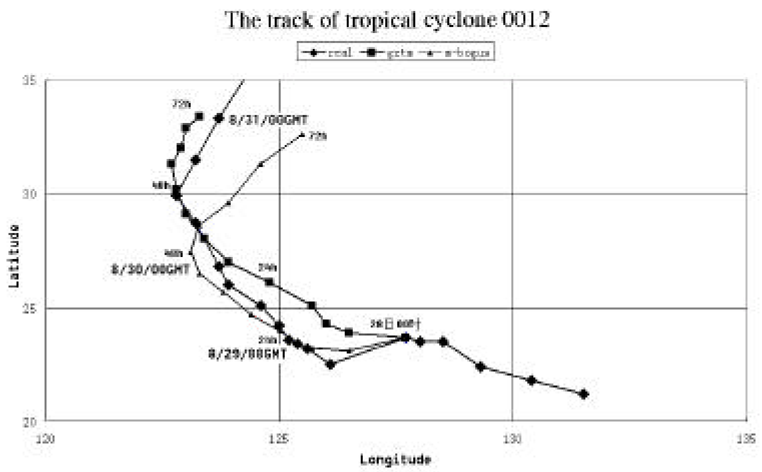

Fig.6b Track forecast of TC Prapiroon. ◆ real, ■ Guangzhou numerical forecast, ▲Guangzhou numerical forecast with modified BOGUS.

Tab.1 Distance error of forecast (unit: km)

schemes	12 h	24 h	36 h	48 h	60 h	72 h
BABJ		271.4		297.6		
RTJD		212.3		278.3		504.0
GZTM	128.9	280.9	343.8	388.2	233.7	38.7
M-bogus	10.3	48.9	104.4	89.3	111.3	185.1

Fig.6b compares the track forecast by the Guangzhou numerical model, with and without the modification, with the observation. The M-bogus is a track forecast with the modified typhoon BOGUS. As shown in the figure, the modification has resulted in significant improvement of the track forecast. Tab.1 lists the distance error of the forecast, which indicates how the modified typhoon BOGUS affects the track forecast. The inclusion of a realistic typhoon BOGUS can efficiently improve the track forecast while useful information about the storm structure is extracted from the TOVS to increase the accuracy of forecast.

5 CONCLUDING REMARKS

a. Structures of tropical cyclones are found from the TOVS that are inconsistent with the conceptual models. It shows that the tropical cyclone is variably structured, which is more complex and variable than the model.

b. Significant differences in structure are found between the typhoon BOGUS, constructed from general conceptual model, and actual tropical cyclone.

c. The typhoon BOGUS structure could have significant effects on the track forecast based on numerical prediction models.

d. The inclusion of a realistic typhoon BOGUS can efficiently improve the track forecast.

e. Useful information about the storm structure is extracted from the TOVS to increase the accuracy of forecast.

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