THE EFFECT OF TOPOGRAPHY ON TYPHOON: A NUMERICAL SIMULAITON

Su-Tzai Soong and Jun Kong

University of California, Davis
Davis, CA 95616

ABSTRACT

A set of numerical experiments were made with intense, moderate, and weak typhoons crossing over the southern, central and the northern part of Taiwan in order study the topographic effect on the behavior of typhoons. Specifically, this work attempts to search out the factors that may be used to predict if a typhoon will cross the Central Mountain Range directly or it will decay and be replaced by a secondary vortex over the Taiwan Strait. In addition, the cause for the track deflection often observed when a typhoon approaches Taiwan is also investigated. This work has determined that the Froude number may be used to determine the behavior of the typhoons. If the Freude number is greater than 5, the typhoon will likely cross Taiwan directly. In case the Freude number is less than 5, a secondary vortex is likely to be generated in the west of Taiwan. The area of precipitation will have a strong effect on the typhoon track. Most typhoons deflect northward as they approach Taiwan because the northern part of the typhoon is in the windward side of the mountain, and the lifting due to the mountain causes the production of a center of intensive precipitation. This precipitation and the associated heating causes the typhoon to turn northward.

1. Introduction

In the past two decades, the orographic effect on typhoons has attracted many researchers' attention (Ishijima and Estoque,1987; Brand and Blelloch, 1974; Wang, 1980, 1992, Chang, 1982; Bender et al., 1987, Yeh et al., 1993 and Chang et al. 1993). The work of Wang is the most extensive, and in a summary report (Wang, 1992) he has presented the structure, path, translation speed, intensity, the detailed distribution of wind and precipitation, and the terrain effects of 180 typhoons passing over Taiwan island and its vicinity. Based on the behavior of typhoon passing over Taiwan, Wang (1980) classified typhoons into two types. Type I typhoons are those which can pass over the CMR directly and maintain a continuous track, while Type II typhoons are those which generate secondary vortexes to the west of Taiwan. This newly generated vortex will move westward while the original typhoon will disappear at the east side of the CMR. Chang(1982) examined the intensity of 34 typhoons and indicated that Type II typhoons, in average, are significantly weaker than Type I typhoons. He therefore emphasizes that the intensity of typhoons is the deciding factor in the behavior of typhoons in passing a high mountain range.

In a recent combined observational and numerical study about the terrain effects on typhoons, Yeh et al. (1993a, b) investigated the characteristics of westbound typhoons initiated in different latitudes. From their extensive work, they concluded that the orographic effects tend to be larger on weaker and slower moving typhoons. All of the typhoons also tend to deflect northward after reaching Taiwan. After decomposing the wind field into symmetric and asymmetric components, they found that the northward movement of a southern-crossing typhoon is caused by the generation of asymmetric current which is toward northwest in the windward side of the CMR in Taiwan. The present study attempts to address the following questions: (1) Can the behaviors of typhoons (Type I or Type II) be predicted before the landfall of the typhoons? (2) What are the physical processes that contribute to the track deflection of typhoons?

2. Model description

The model used in this simulation is the Mesoscale Atmospheric Simulation (MAS) model recently developed at the University of California, Davis and the Lawrence Livermore National Laboratory. MAS is a hydrostatic model in s coordinate. The unique feature of the MAS model is the adaptation of a third order advective scheme designed by Takacs (1985) and Hsu and Arakawa (1990). This scheme preserves the peak values well and produces no phase error and little computational oscillations. The steep and complex topography over our area of interest is the major factor in generating these computational oscillations. If they are not dealt with properly, they may either generate false clouds or cause computational instability. The model also include explicit representation of the microphysical processes, radiation, and a soil and boundary layer module. In this particular study, a simpler version including only the large-scale condensation and Kuo's (1965) cumulus parameterization is used.

The integration domain covers a 2000 x 1200 km area with a 20 km horizontal resolution on C grid. In the vertical, the model has 20 uniform layers. The initial condition for our experiments is obtained in two steps: First, a symmetric, well developed typhoon is simulated without topography. Second, this simulated typhoon is embedded in a base easterly flow, which provides the steering flow to move the typhoon westward toward Taiwan. In the steady state, the base easterly flow goes around the CMR of Taiwan, instead of crossing it. The temperature and humidity profiles used in the model are obtained from the mean West Indies tropical soundings during hurricane season (Jordan, 1958).

3. The results and conclusion

Three typhoons of different intensity are simulated. For the weak typhoon, 27°C is used as the Sea Surface Temperature (SST). For the moderate typhoon, the SST is 28°C. For the strong typhoon, the SST is also 28° C but the initial lapse rate is reduced by 0.5° C/km so that the air becomes more unstable. The maximum wind speed and minimum surface pressure for these three typhoons in their mature stage are listed in Table 1.

Table 1. Maximum wind speed and minimum surface pressure of simulated typhoons

typhoon	weak	moderate	intensive
Vmax (m/s)	35	54	70
Min. Psfc (mb)	985	965	935

In order to examine the differences in the orographic effects on these typhoons, these typhoons are placed at three different locations so that they can pass over the CMR from its southern, central and northern portion. Each experiment will be assigned a name. The first letter in the name will be S, C or N to represent southern, central and northern-crossing typhoons. The second letter will be I, M or W to represent intense, moderate and weak typhoons. The speed of the background current used in all these experiments is 5 m/s.

Among these experiments, some of the typhoons directly passed Taiwan (Type I) and some of the typhoon's were stopped by the CMR and secondary vortices were formed over the Taiwan Strait. According to the way how a typhoon passes over Taiwan, the typhoons are grouped into the Type I and Type II categories. Table 2 lists all the experiments according to this classification.

Table 2 List of 9 experiments and the corresponding Froude numbers

	Type I	Type II	Other
Experiments	NI, NM, NW, CI, CM, SI	CW, SM	SW
Froude number	28. ,7.0 ,5.0 ,11.1 , 3.6, 7.6	2.9, 3.6	2.9

From Table 2 it can be seen that all the northern-crossing typhoons can directly pass Taiwan no matter how intensive they are. All of the intense typhoons are also of Type I. The secondary vortex will be generated for the weak central-crossing and the moderate southern-crossing typhoons. For SW typhoon, it moved around the southern tip of Taiwan, apparently following the steering current of the base flow.

However, the intensity is not a unique factor in deciding how typhoons pass over Taiwan, at least not for the moderate and weak typhoons. To search for an answer for the factors separating the Type I and Type II typhoon, we computed the Froude number for each of the nine experiments. The reason that the Froude number is chosen is because it is a measure of the ability of a flow to pass over a mountain. The Froude number is defined as:

$$F_r = \frac{U}{NH}$$

where U is the flow speed, N is Brunt-Väisällä frequency and H is the height of the mountain.

Because the CMR is basically aligned in the north-south direction, so only the wind speed in the east-west direction is used in computing the Froude number. The value of the U is chosen to be the maximum easterly wind speed of the typhoon. The value of H is decided by averaging the highest 20 grid points in the area with easterly, hence upslope, flow. For southern-crossing typhoons, the entire CMR is in the easterly, therefore, the 20 highest points is taken from the entire CMR. The value of H computed this way is about 2500. For central-crossing typhoons. the average is taking over the northern half of the CMR to yield a value of about 2400m. For the northern-crossing typhoons, the average is taken from the northern end of the CMR to the north coast of Taiwan to give a value of H about 1400m. These values will be used to compute the Froude numbers for the typhoons originated from different latitude.

The maximum Froude number of the 9 experiments are also listed in Table 2. All the Type I typhoons have a maximum Froude number of 3.6 or large. All of the Type II typhoons have a Froude number of 3.6 or smaller. But a closer look at the data indicated that the CM typhoon moved northward before reaching Taiwan and the mountain over its easterly flow area is much lower that the 2400m we used in computing the Froude number. For this reason, we feel that a higher Froude number of approximately 5 may be the real separation of the Type I and Type II typhoons.

In order to further demonstrate the effect of the Froude number on the behavior of typhoons, an additional experiment is made using the same condition as SW but the height of the CMR is reduced by half. In this situation, the Froude number was doubled to 5.8 but the intensity of the typhoon was still the same as before. Under this condition, the typhoon moved directly across the CMR with deflection to the south or producing a secondary vortex.

We also made close analysis on the relationship between the area of precipitation and the track of the typhoons. The reason that most typhoons tend to deflect northward when approaching Taiwan can be explained by the change in precipitation patterns effected by the mountains. As a typhoon approaches Taiwan, the southern part of the typhoon is in the lee side and the amount of precipitation there is greatly decreased. The northern part of the typhoon is in the windward side and the added lifting created a center of maximum precipitation. The heating due to this maximum precipitation is the force causing the typhoon to deflect northward. This is usually true except for weak typhoon crossing the southern part of Taiwan. In this case, the steering effect of the base current dominates and that causes the typhoon to turn southward.

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