## P1.93 NUMERICAL SIMULATIONS OF THE FORMATION OF TYPHOON ROBYN (1993) USING MM5

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### 1. Introduction

In this study, numerical simulations are performed on the formation of Typhoon Robyn (1993) in the western North Pacific (WNP) during the Tropical Cyclone Motion (TCM-93) field experiment. One objective is to assess the role of tropical mesoscale convective systems (MCSs) in the development. This TCM-93 case is chosen because additional in-situ and aircraft data are available to define the structure of several MCSs associated with the formation process, and for model verification (Harr et al. 1996). This study identifies the mesoscale processes responsible for Typhoon Robyn's formation where the background vorticity associated with the monsoon trough and passages of tropical disturbances are both essential factors.

### 2. Formation of Typhoon Robyn (1993)

Typhoon Robyn formed at the end of July 1993 in the monsoon depression between 150°E and 160°E. The 850-hPa large-scale flow obtained from the Navy Operational Global Atmospheric Prediction System (NOGAPS) analyses at 1200 UTC 31 July 1993 [hereafter 93073112, one hour before a TC formation alert (TCFA) was released (ATCR, 1993)] indicates a cyclonic area north of the equator between these longitudes formed by the cross-equatorial southwesterlies and easterlies south of the subtropical high (Fig. 1a). This confluence monsoon region is actually one of the common large-scale patterns for TC formation in the WNP. At 200 hPa, divergence flows that favor development of deep convection are found in the area where pre-Robyn occurred (Fig. 1b).

During the TCFA and the first warning of Robyn at 93080112 (ATCR 1993), two MCSs developed in the monsoon depression (not shown). One of them was at the southern portion of the monsoon depression that had been a region of convergence between the circulation and the cross-equatorial southwesterlies. Due to this favorable low-level environment, it was expected to develop further and likely to intensify into a tropical depression. However, it elongated in the following hours and dissipated into smaller cells. At about the same time, another MCS persisted at the northern portion of the monsoon depression where easterlies dominated. It rotated westward along the circulation during the following ten hours. Eventually, the circulation of the monsoon depression began to be centered around the MCS, and the MCS was upgraded to a tropical depression by the Joint Typhoon Warning Center.

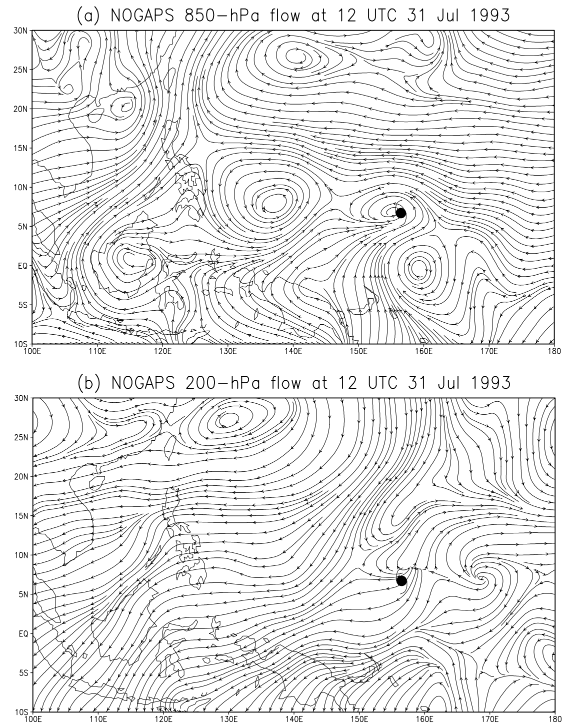


Fig. 1 (a) 850-hPa and (b) 200-hPa streamline from NOGAPS analyses at 1200 UTC 31 July 1993. The typhoon symbol indicates the position where typhoon Robyn started to develop.

### 3. Experiments on the MM5

The Pennsylvania State University (PSU)-National Center for Atmospheric Research (NCAR) mesoscale model MM5 version 3 with an 81-km resolution coarse grid and 27-km resolution inner grid is used for the simulations. The model is initialized with large-scale analyses from NOGAPS. Model integration is from 93073112, and lasts for 60 hours until 93080300.

The first part of the study (Cheung and Elsberry 2004) focuses on the sensitivity of the simulations of Robyn's intensification to the choice of cumulus parameterization, PBL parameterization, and explicit moisture scheme in the model. Among the experiments, the control experiment (BM1) with the Betts-Miller cumulus parameterization, PBL treatment as in the NCEP MRF model, and Reisner explicit moisture scheme with predicted number concentrations of snow, ice and graupel has the closest intensification profile to the best track.

Other comparisons of the control experiment with available observations collected during the TCM-93

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experiment are made to further validate the model. In particular, observations from the aircraft observation period (AOP-3A) that occurred just before the first warning of Robyn with NOGAPS large-scale fields as background, and then compared to the MM5 simulations. The control simulation is generally able to reproduce the successive MCS systems occurred during the formation of Robyn, although there are spatial and temporal deviations from those revealed in satellite imageries. However, the simulated fields do include more mesoscale features than the analyzed fields such as some mesoscale circulations associated with the convective centers. While the analyzed fields are only rough estimation of the actual mesoscale circulations due to the spatial separation of the dropwindonde observations (most of them are about 100 km apart), the validation of the control simulation primarily from satellite evidence of MCSs cannot be said to be conclusive. Simulations of the more recent TC formation cases for which high-resolution products such as satellite-derived winds and in situ aircraft observations are required to enable more detailed grid-scale validations.

Various sensitivity experiments with different cumulus parameterizations demonstrate that this choice largely determines the degree of intensification of Robyn. Experiment BM2 with a more tropical reference profile (i.e., less unstable) in the Betts-Miller scheme, and the simulations with the Kain-Fritsch (KF) scheme and Grell (GRL) scheme all underestimate the intensity of Robyn throughout the model integration. Whereas most of the results may be interpreted from the inherent characteristics of each parameterization (e.g., the amount of convective rainfall each scheme produces), the relative outcomes from the BM1 and KF simulations do not agree with the Davis and Bosart (2002) study in which the formation of Hurricane Diana (1984) was simulated using the same model. In Davis and Bosart's simulations, the Kain-Fritsch scheme generates a deeper intensification of Hurricane Diana than does the standard Betts-Miller scheme. In this study, the Kain-Fritsch scheme simulates a highly unorganized convection pattern that leads to the non-development of the associated cloud clusters. It is believed that these differences may be due to the lower (27 km versus 9 km) model grid resolution in this study, and the different synoptic situation associated with the two formation cases.

In addition to the NCEP MRF model, the PBL scheme from the NCEP eta model (ETA), the Burk-Thompson scheme (BTS), and the Gayno-Seaman scheme (GSM) are tested. The impacts on the intensification and track of Typhoon Robyn due to changes in the PBL treatment are found to be small. However, a peculiar feature in experiment ETA is that a spurious vortex is spun up in the monsoon depression west of Robyn. Comparisons of the predicted convection and cloud water in the PBL from these two experiments reveal that the PBL in the MRF scheme is relatively dry (as found by Braun and Tao 2000) due to its active vertical mixing. The eta PBL is found to be overly moist with extended precipitation probably due to the viscous sublayer in the scheme, which evidently leads to the spurious vortex generation.

Although the impact is smaller than that of the cumulus parameterization, using different explicit moisture schemes indeed affects the simulation of the intensification of Typhoon Robyn through the interaction of the explicit moisture with the Betts-Miller cumulus parameterization. The three explicit schemes tested [simple ice (SIMICE) calculation, the mixed-phase model (MIX), and the Schultz scheme] all underestimate the intensity of Robyn compared to the complex and computationally demanding Reisner scheme. This suggests a decision between computational efficiency and accuracy may have to be made because the other three schemes include fewer predicted moisture species to reduce the computational burden. Among the experiments, the Schultz scheme may be an alternative to the control Reisner scheme due to its efficient computations, since it is still able to reproduce a reasonable intensification profile of Robyn. All of the explicit moisture calculations generate similar amounts of non-convective rainfall. However, major deviations in convective rainfall among these experiments arise due to modified convective cloud patterns by the explicit moisture variables.

**4. Future work**

Simulations with a configuration similar to the control experiment in this study and with higher resolution versions of the model will be presented in the conference along with more detailed diagnostics through budget analysis.

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