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MM5 typhoon simulation using autonomous moving nest

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1. Introduction

Regional Data Assimilation and Prediction System (RDAPS), the operational model in Korea Meteorological Administration (KMA) has gone through many upgrades since it was initially up in operation in 1991. The current version of RDAPS based on PSU/NCAR MM5V2 (Grell *et al*. 1995) runs twice daily in the supercomputer (NEC SX5/12A). RDAPS uses a grid distance of 30 km in a 191×171×33 grid system so that the domain is wide enough to cover the KMA tropical cyclone (TC) watch area (west of 140 ^{o}E and north of 20 ^{o}N). The model has fine physics on a very wide domain so that it may serve not only as a regional forecast model but also as a typhoon model upon successful implementation of the TC initialization.

In the current work, an attempt is made to apply the GFDL TC bogus algorithm to the community model MM5 in robustness. As in Kurihara et al. (1995), winds are initialized in a straightforward manner within the filter region surrounded by 24 boundary points. The main difficulty lies in the generation of other variables, such as humidity, temperature, geopotential, etc. which are dynamically consistent with the prescribed wind. It can be handled by the built-in function of MM5, the four-dimensional data assimilation (FDDA). A further attempt is made on building-up a MM5-based moving nest model.

2. GFDL TC bogussing procedure

(1) Wind initialization

After the DATAGRID is finished, we take the latitude, longitude information of the model grids and the horizontal winds from the DATAGRID output. The initialization of wind consists of the nest few steps.

(a) Apply a spatial smoother to the original wind field and separate the basic field that contains only the large-scale field. Subtract the basic field from the original field in order to obtain the disturbance field of smaller-scale motion than about 1000km.

(b) By using the disturbance field, determine the filter region where the bogussing will be applied. The bogus region is the inner side surrounded by 24 points.

(c) Obtain the non-TC component inferred from the values of the 24 boundary points by using the optimum interpolation.

(d) Construct the axi-symmetric wind and add to the non-TC and basic wind, which is the final bogus wind.

Figure 1 shows the non-TC component and the axi-symmetric wind.

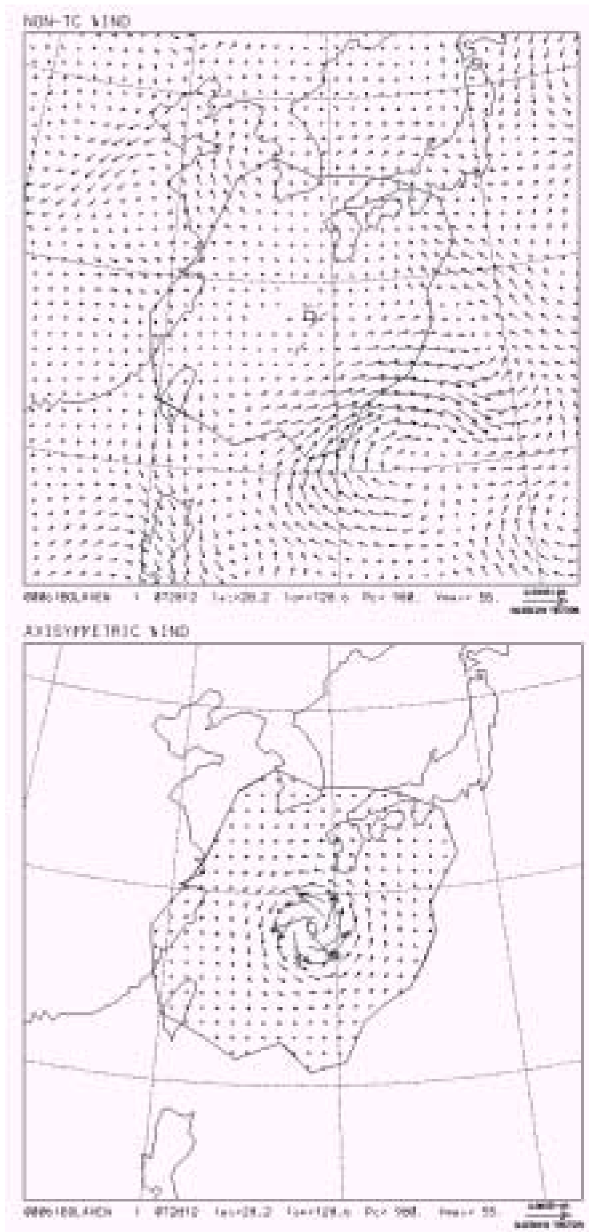

Fig. 1. Non-TC wind and axi-symmetric wind.

(2) Little RDAPS to initialize the other variables

The TC initialization is to generate the complete three-dimensional bogus vortex within the filter domain. It includes the initialization of all synoptic variables as well as specifying the bogus wind as in Kurihara et al. (1995). The GFDL-type wind initialization is not simple, but it can be readily done through the straightforward procedure. The difficulty is the initialization of other variables such as humidity, temperature, geopotential, etc. that are dynamically consistent with the already prescribed wind. In Kurihara et al., it is done by integrating the axisymmetric version of the original model. During the time integration, the tangential component of wind is gradually forced toward the target wind profile based on the storm information provided by the National Hurricane Center. If we follow a similar procedure, we should write a computer code for the axisymmetric version of MM5, which may require a tremendous amount of additional work. Meanwhile, the next version of the GFDL hurricane prediction model uses three-dimensional vortex generation. For given three-dimensional target state that slowly varies from the calm state, any other variables are also slowly generated by forcing the model. MM5 has a built-in function that can do the above forcing, namely, four-dimensional data assimilation (FDDA). The idea of FDDA is to combine current and past data in an explicit dynamical model such that the model's prognostic equations provide time continuity and dynamic coupling among the various fields (Grell *et al.* 1995). FDDA is accomplished though Newtonian relaxation or nudging (Hoke and Anthes 1976). The nudging relaxes the model state toward the target state (usually data blended with observation). In actual application of FDDA in MM5, a user just turns on the FDDA switch and prescribes the target state to be nudged onto.

Since we need the TC structure only within the bogus area through the built-in function of MM5, we construct a miniature of the original model which is identical to the original except for a smaller horizontal domain (Fig. 2). This is done simply for cost-effectiveness. We will call it "little RDAPS". The little RDAPS is constructed with 111×111 grid system which corresponds to 3000 km × 3000 km domain. The center of the little RDAPS domain is determined by the center of the filter domain in the previous step. The little RDAPS is located between DATAGRID and RAWINS step and runs for every TC that exists over the KMA's TC watch area. In order to do so, TERRAIN is run to generate data regarding the model domain for each TC. The locations of the model grids should be different from those of the original model. DATAGRID is also run again to put the initial data into the little RDAPS grid. We take DATAGRID output to construct the three-dimensional bogus wind. We separate the basic and the disturbance wind and obtain the non-TC wind with the use of information of the bogus boundary that is transferred from the previous stage. We then construct the axisymmetric wind with the use of the empirical formula (Holland 1980) and the TC information provided by the typhoon center. When constructing the three-dimensional bogus wind, the axisymmetric wind are vertically weighted. The weights are 0.95, 1.00, 0.97, 0.88, 0.82, 0.65, 0.40., 0.35 for p = 1000 hPa, 850 hPa, 700 hPa, 500 hPa, 400 hPa, 300 hPa, 250 hPa, 200 hPa, respectively, and 0 above p = 150 hPa. This is the wind of the bogus TC, which will serve as the target state in nudging. All the other variables are generated through the nudging to the target wind, which will be discussed in section c for details. Then data will be put back into the original RDAPS domain and the TC initialization is completed.

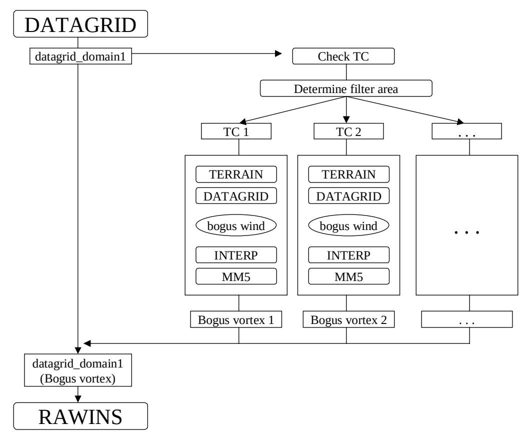

Fig. 2. Flow chart showing the procedure of tropical cyclone bogus.

The DATAGRID output is modified with the new bogus wind. At this stage, the wind and the other variables are not in dynamical harmony. We expect that the dynamical inconsistency will disappear at the end of the four-dimensional data assimilation. We assume that the target state does not change in time during the nudging. For a practical purpose, exactly the same data set are put in order for every 12 hours during the whole nudging periods. Then we turn on the FDDA switch in MM5 and perform the analysis nudging to the wind. Since RDAPS is an operational model, we need to consider the timeliness for the operational schedule, meaning that there should be a compromise between the perfectness and the practicality. Tests have shown that 24 hour nudging suffices for the practical purpose. After 24 hour, all the variables except the target wind do vary in time, but only to the extent of the nonlinear quasi-equilibrium.

Figure 3 shows the mean sea level pressure (MSLP) field before and after 24 hour FDDA period. It is evident that the original smooth and loose vortex becomes sharp and tight. The MSLP at the vortex center drops from 990 hPa to 983 hPa and the geopotential height at the 700 hPa level drops from 2972 meter to 2921 meter. Monsoon gyre-like circulation surrounding Bolaven becomes clearer than before the bogus procedure so that one may expect that the TC will move toward north.

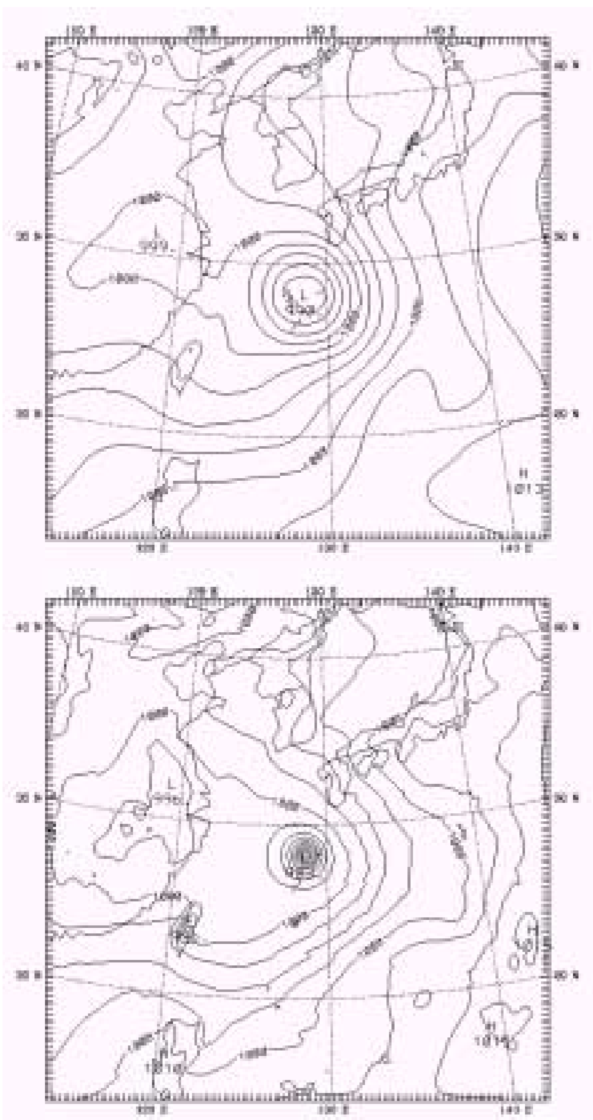

Fig. 3. Mean sea level pressure field before and after 24 hour FDDA is completed.

(3) Back to the original domain

After we obtain the complete bogus TC in the little RDAPS, we need to put all the data back to the bogus region of the original RDAPS domain. In doing so, a care must be taken for three factors. First, if we put the bogus field of the little RDAPS to the original RDAPS to the bogus region literally, there always occurs a discontinuity across the filter boundary. Second, wind definitions of the two systems are different because of the different axes so that there must be an adjustment of the wind.

The MSLP fields before and after the bogus are shown in Fig. 4. Even though the sharp and tight vortex is put into the original domain, the bogus TC harmonize well with the environment so that one cannot figure out where the bogus boundary is.

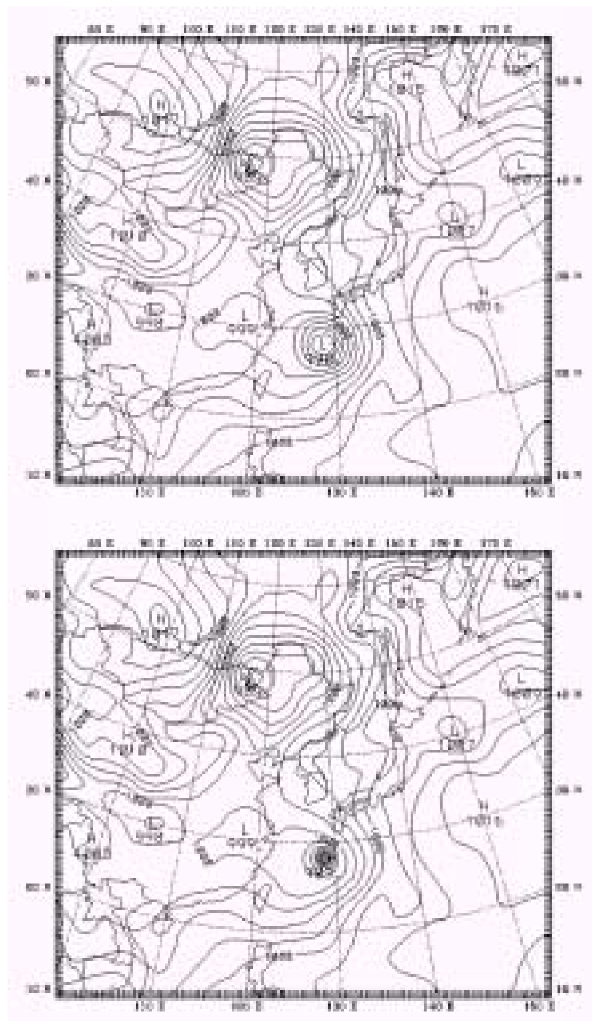

Fig. 4. Mean sea level pressure before and after bogus in the original model domain.

3. Forecasts

Several forecasts are made using the previous bogus algorithm for two TC's in the year 2000. Nine cases of Bolaven and ten cases of Jelawat are taken. The computational procedure is exactly the same as in operation such as the forecast fields of the global model supplied for the lateral boundary and 12 hour FDDA with the blending with observation provided by the GTS line. Although a tremendous amount of work is put in expectation of a great improvement of the model performance for the TC prediction, the results are not quite so. The trends found in the original model retains also in the bogus version. If the model TC moves to a certain direction in the forecast of the original RDAPS, the bogus version also shows a similar behavior. The bogus RDAPS never cures a correction of the failure of the original model. However, we have found after a careful examination that if the original RDAPS produces a reasonable forecast, the TC bogus helps to produce a better forecast. Among 19 forecast cases, we have separated two groups of good forecasts (9 cases) and bad forecasts (10 cases). Tables 1 and 2 show the mean forecast track error for the 9 cases when the original RDAPS produces reasonable forecasts and for the 10 cases when original RDAPS produces erroneous forecasts, respectively.

Table 1. Mean forecast track error for the case when the original RDAPS produces reasonable forecasts.

	12(9)	24(9)	36(8)	48(5)	60(4)	72(2)
No Bogus	101.1	143.8	210.0	282.0	422.4	406.1
Bogus	95.8	131.0	194.3	239.4	248.3	276.3

Table 2. Mean forecast track error for the case when the original RDAPS produces extremely erroneous forecasts.

	12(10)	24(10)	36(9)	48(9)	60(7)	72(5)
No Bogus	86.8	159.7	294.3	430.9	576.2	695.9
Bogus	88.6	200.8	324.7	469.7	637.8	752.6

4. Autonomous moving nest

It turns out that the current specification of the RDAPS is not satisfactory for TC modeling. The reason is that the horizontal grid size of uniform 30 km and the current choice of the cumulus parameterization often produce bogus cane, the spurious vortex during the course of time integration. Therefore, we decide to build a new TC model by using the moving nest function of MM5. Since the current setting of the moving nest function in MM5 is not appropriate in operational purpose, we need an enormous work in changing the original MM5 code in such way that it can be readily used in operation. First, we set up the nest use of the model. Second, in every 30 minutes or 1 hour, check the TC center to find out the need to move the nest. If there is a need to move the nest, specify the new location of the nest and restart the model. Moving nest is possible by repeating this procedure until the end of the model time (Fig. 5)

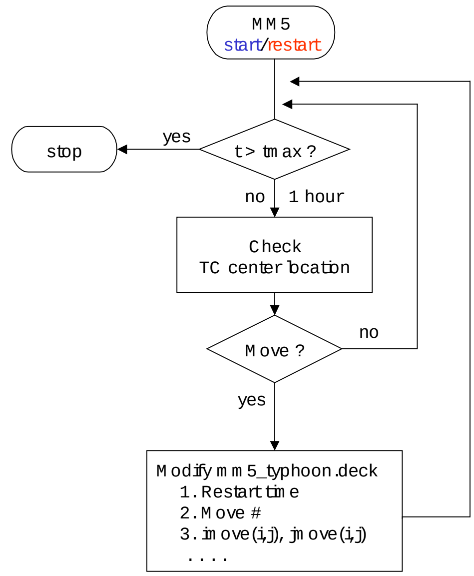

Fig. 5. Algorithm of the autonomous moving nest.

We have taken the autonomous moving-nest run for the case of typhoon Rosie at 00 UTC July 23, 1997. The nest configuration is as follows. The coarse domain (domain 1) consists of 91x81 grids with the grid size of 90 km and the nest domain (domain 2) consists of 112x112 grids with the 30 km grid size. The two-way interaction is chosen. There are 30 vertical levels. The GFDL TC bogus is done over domain 2. Figure 6 shows the movement of the domain 2 during the course of the integration time. The program checks every hour to see if the TC center moves enough to change the grid setting. During the 48 hour integration the domain 2 is moved three times following the model TC. The locations of the initial and the final TC positions are shown along with the corresponding nest domains.

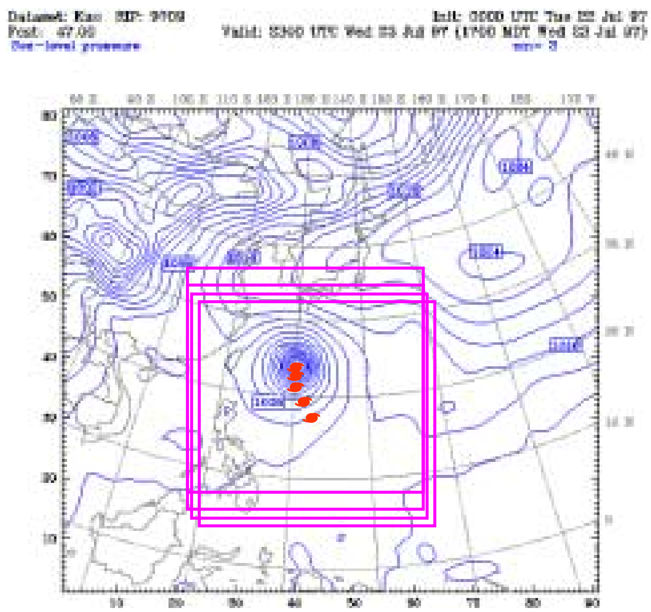

Fig. 6. Movement of the nest domain following the model TC center.

After the model is finished, the location and the time of the nest movement is written automatically in the main program MM5.deck (Fig. 7).

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;      *************** MOVING NEST OPTIONS ***************
;
IMOVE =    0.   1.   0.   0.   0.   0.   0.   0.   0.   0. ; move domain 0,1
IMOVCO =   1.   4.   1.   1.   1.   1.   1.   1.   1.   1. ; 1st move #
;          imovei(j,k)=L, ; I-INCREMENT MOVE (DOMAIN J, MOVE NUMBER K) IS L
IMOVEI =   0.   2.   0.   0.   0.   0.   0.   0.   0.   0. ; I move #01
           0.   2.   0.   0.   0.   0.   0.   0.   0.   0. ; I move #02
           0.   3.   0.   0.   0.   0.   0.   0.   0.   0. ; I move #03
IMOVEJ =   0.  -1.   0.   0.   0.   0.   0.   0.   0.   0. ; J move #01
           0.  -1.   0.   0.   0.   0.   0.   0.   0.   0. ; J move #02
           0.   0.   0.   0.   0.   0.   0.   0.   0.   0. ; J move #03
IMOVET =    0.  750.   0.   0.   0.   0.   0.   0.   0.   0. ; time of move #01
            0. 1650.   0.   0.   0.   0.   0.   0.   0.   0. ; time of move #02
            0. 2490.   0.   0.   0.   0.   0.   0.   0.   0. ; time of move #03
IFEED  =  3.      ; no feedback; 9-pt weighted average; 1-pt feedback w/o smoothing /
                  ; light smoothing / heavy smoothing - 0,1,2,3, and 4
&END
EOF
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Fig. 7. Part of MM5.deck after the autonomous moving nest run.

Acknowledgement

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