7A.5 EVALUATIONS OF THE AFWA WEATHER RESEARCH FORECAST MODEL WESTERN NORTH PACIFIC TROPICAL CYCLONE PREDICTIONS

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1. INTRODUCTION

Statistical, statistical-dynamical, and dynamical models have little to no skill in tropical cyclone intensity prediction in the western North Pacific (Blackerby 2005). In the case of the dynamical models, this deficiency is in part due to the relatively coarse resolution (e.g., the Geophysical Fluid Dynamics Lab—Navy version has 1/6th latitude horizontal resolution). This work is a preliminary investigation into the feasibility of using the Air Force Weather Agency (AFWA) version of the Advanced Research Weather and Research Forecast (ARW) model to forecast western North Pacific tropical cyclone intensity. The AFWA version of the ARW (hereafter just the ARW) has been developed in collaboration with the National Center for Atmospheric Research, which has had success in predicting a number of 2005 Atlantic hurricanes (see paper 2A.5 by Wang et al. in this conference). The goal of this preliminary study is to determine if the ARW model produces a better intensity forecast than the operational AFWA MM5 model.

2. MODEL DESCRIPTION

The information on the ARW dynamical core and physics packages is available on the website [http://www.mmm.ucar.edu/wrf/users/tutorial-2005.htm]. In this application, the ARW has a double nest with 12 km horizontal resolution in the outer domain and 4 km resolution on the inner nest, which automatically follows the position of the 500-mb height minimum. The lateral boundary conditions and initial condition are interpolated from the National Centers for Environmental Prediction Global Forecast System (GFS).

In this preliminary test, a cold-start procedure is used in which the 12 km, and then the 4 km, values for ARW are simply interpolated values from archived 0.5° lat./long. GFS winds, temperatures, moistures, and sea-level pressures. Since no synthetic tropical cyclone observations are incorporated, it is the relocated vortex in the GFS fields that provides the initial vortex structure in these preliminary ARW tests.

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Ten cases were selected primarily to test various challenging aspects of the intensity change prediction problem (Blackerby 2005): Early intensification after becoming a named tropical cyclone; decay and re-intensification cycles of a mature cyclone; and decay over land. In general, the tracks of these cyclones are considered to be relatively easy to predict.

Details of the model initialization and boundary conditions and a synoptic description of the 10 cases are found in http://theses.nps.navy.mil/06Mar_Ryerson.pdf.

3. TRACK FORECAST ERRORS

In three of the 10 cases in this study, the ARW algorithm based on the 500-mb height minimum failed to appropriately move the nest with the tropical cyclone and lost track of the storm vortex. In two of these integrations, the nest drifted away from the intended tropical cyclone vortex toward an area around the Philippines. This nest movement could be due to a 500-mb low associated with convection occurring there, an interpolation error caused by steep terrain gradients, or some other reason. Regardless of the reason, the experience with these three ARW integrations is that for weak tropical cyclones the present ARW nest-moving algorithm needs to be revised.

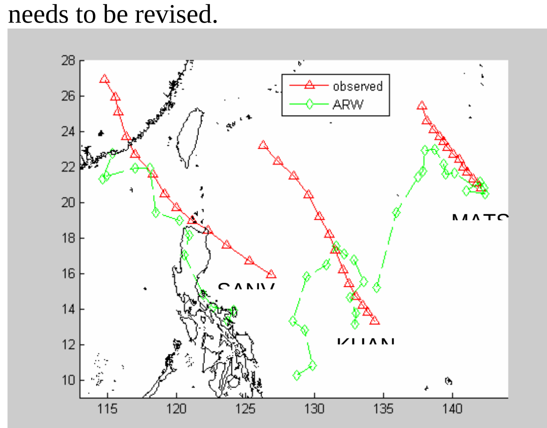

Fig. 1. The observed tracks (solid red lines with triangles) and ARW vortex tracker-generated tracks (dashed green lines with diamonds) for the three cases when the tracker algorithm failed. All three cases were initialized early in the life cycle of the storm, when estimated tropical cyclone winds were ≤ 45 kt.

The mean tropical cyclone track error (great-circle distance) of the ARW and MM5 predictions for the seven cases that did not cause failure of the ARW moving nest are shown in Fig. 2. Overall, the ARW track forecasts were more skillful than the MM5 forecasts at all forecast intervals. Except for the 12-h track forecasts, the ARW overall outperformed the CLIPER (C120) for the seven cases. In contrast, the MM5 did not outperform C120 at any forecast hour except for a slight advantage at the 36-h forecast. Therefore, ARW had skillful track predictions for these seven cases, and the MM5 did not.

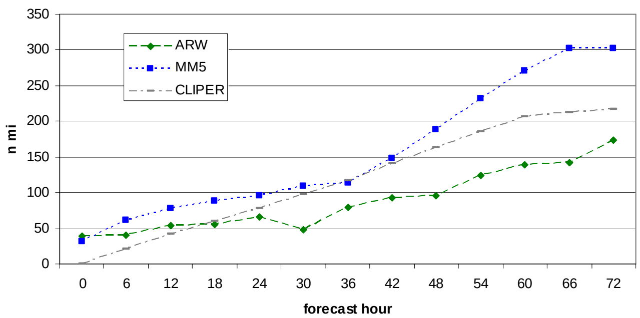

Fig. 2. The mean tropical cyclone position errors of the ARW prediction, MM5 prediction, and CLIPER for the seven tropical cyclone cases that did not cause failure of the moving nest algorithm.

Erratic track changes of various amplitudes were predicted during the early hours of all seven cases. These track changes were traced to an apparent "wobbling" of the typhoon structure during the early hours of the integrations (Fig. 3), which often caused the upper-level circulations to be laterally displaced from the low-level circulations by a significant distance. In this Typhoon Nabi case, wobbling of the typhoon was so severe the low-level circulation passed south of Saipan while the 0.4940 sigma-p level pressure minimum (and the track indicated by the tracker algorithm) passed north of the island.

The chaotic nature of these oscillations, which occur at different frequencies at different levels of the model, was the source of the wobbling or "sloshing" of the mass fields at different levels, which created the erratic ARW track forecasts during the early stages of the integrations. These track changes during spin-up were exacerbated by the nature of the ARW vortex tracker since it tracks the 500-mb height minimum. The mid-level height minima of the tropical cyclones generally had larger track oscillations during spin-up than the more identifiable low-level circulation.

(a)

(b)

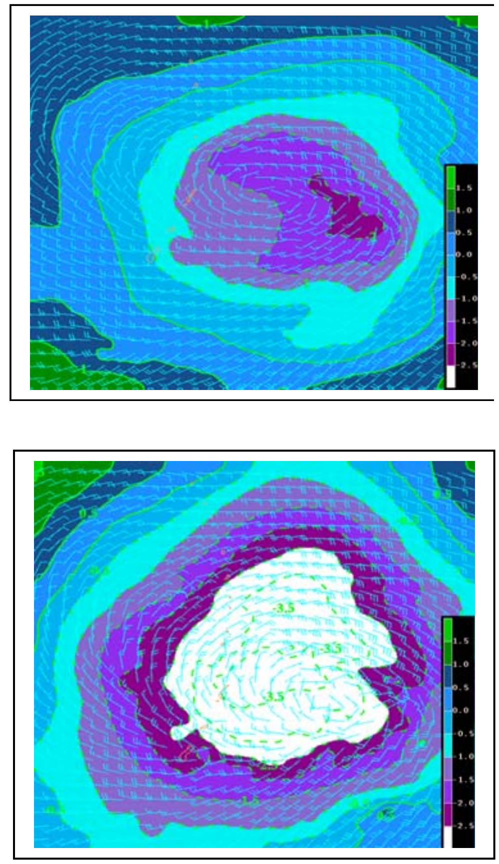

Fig. 3. Oscillations in the typhoon structure in the ARW inner nest during spin-up of the first Typhoon Nabi integration initialized 12 UTC 30 August 2005. Panels (a) and (b) are the 3-h and 6-h forecasts, respectively. The shaded contours show the 0.4940 sigma-p level pressure perturbation field (difference in pressure from a standard value at the sigma-level, in mb). The wind barbs are the 10 m winds (kt), and are displayed at every tenth gridpoint. At the 3-h forecast, the low-level circulation is WNW of the mid-level low. At the 6-h forecast, the low-level circulation is ESE of the mid-level low.

4. INTENSITY FORECAST ERRORS

The mean intensity errors of the ARW, MM5, and CLIPER techniques for the seven cases are shown in Fig. 4. The CLIPER technique used for comparison of the ARW and MM5 intensity forecasts is the Statistical Typhoon Intensity Forecast 5-Day Model (ST5D) developed by Knaff et al. (2003) using data from western North Pacific tropical cyclones during 1967-2000. The MM5 had a lower mean intensity error than the ARW at all forecast hours, and neither the MM5 or ARW have skill relative to ST5D, especially during the first 54 forecast hours.

Blackerby (2005) had previously shown with a large sample of 2003 and 2004 western North

Pacific tropical cyclones that the AFWA MM5 had similar intensity forecast errors. As in Blackerby (2005), a large fraction of the MM5 intensity error is due to a bias (not shown) that begins with a vortex that is too weak even though a bogus vortex is included. Similarly, the ARW intensity forecast errors in Fig. 4 are primarily due to a bias. For these seven cases, the ARW bias was about – 50 kt at the initial time and was only reduced to about -30 kt by 72 h.

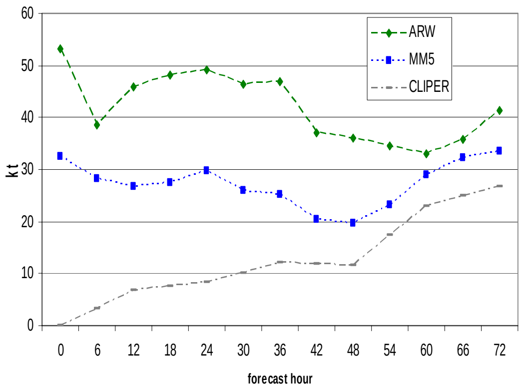

Fig. 4. Mean absolute intensity error (sustained surface winds) of the ARW prediction, MM5 prediction, and CLIPER technique for the seven cases.

The primary reason for the large ARW intensity bias at the initial time is the use of the 0.5° lat./long. GFS vortex to represent the tropical cyclone structure. As is evident from the initial 0.494 sigma-p level pressure perturbation field and 10-m winds in Fig. 3a, the interpolation from the GFS fields to generate the ARW initial conditions results in a broad vortex with a radius of maximum winds at a much larger radius than would be expected for an 85-kt typhoon. Furthermore, the maximum winds were not at the top of the planetary boundary layer, but were in the mid-troposphere.

Two modes of intensity change evolved in these seven ARW predictions. One mode was essentially a stable vortex in which the initial structure was sustained, and only small intensity changes occurred. Given the large initial bias, the intensity forecast errors continued to be large. Such a stable vortex is not surprising given that the maximum winds were in the mid-troposphere so that large air-sea fluxes of heat, moisture, and momentum are not predicted. Convection tended to also be at large radii and subsidence was favored over the central region.

A second mode of intensity change had two variations depending on the horizontal and vertical structure of the initial vortex in the GFS fields. If the initial vortex was circular and extended relatively close to the surface (albeit at large radius of maximum winds), the intensity increased rapidly as these winds were brought down to the surface (presumably by convective mixing). These more circular vortices seemed to then continue to develop more slowly, so that by 60-72 h the intensity may approach the actual intensity. When the initial vortex was highly elliptical and relatively near the surface, an immediate increase in intensity occurred, but then any further increase was slow.

5. DISCUSSION

Excluding the three cases with nest-movement problems, the ARW track prediction performance for the other seven cases was quite good (Fig. 2). Without the initial track oscillations related to the initial vortex problem (Fig. 3), one might reasonably expect excellent track prediction skill.

Although the ARW intensity prediction performance (Fig. 4) was unsatisfactory, it is clear that the primary reason for this deficiency is the poor representation of the initial intensity (and structure) that is obtained by interpolating the 12 km (and then 4 km) grid values from the 0.5° lat./long. GFS fields. Given this structure and an initial intensity bias error of -50 kt, the ARW model is unable to predict a vortex evolution that represents the real tropical cyclone.

Future developments will be along three pathways. First, a vortex-tracking algorithm appropriate for a tropical cyclone must be used in the nest-movement algorithm if cyclones weaker than about 45 kt are to be predicted. This tracker must follow the low-level winds rather than the minimum 500-mb heights anywhere in the domain. Second, the procedure used by NCAR (Wang et al. 2006) to initialize their ARW for Atlantic hurricane prediction will be tested for western North Pacific tropical cyclones. In the NCAR ARW, the initial conditions were interpolated from the Geophysical Fluid Dynamics Laboratory (GFDL) hurricane model that has a more representative initial vortex. For the western North Pacific cyclones, the initial fields can also be provided from the GFDL-Navy version that uses initial and lateral boundary conditions from the Fleet Numerical Meteorology and Oceanography Center global model. It is expected that these two developments will lead to skillful ARW tropical cyclone intensity (and track) predictions in the western North Pacific as have been achieved with the NCAR ARW for Atlantic hurricanes. A third future development would be to develop a warm-start capability in which the previous 6-h or 12-h ARW integration would be used to provide the first-guess or background field for the next forecast cycle.

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5. References

Blackerby, J. S., 2005: Accuracy of western North Pacific tropical cyclone intensity guidance. M. S. thesis, Naval Postgraduate School, Monterey, CA 93943-5114 [available at http:??theses.nps.navy.mil/05Mar_Blackerby.pdf]

Ryerson, W. R., 2006: Evaluation of the AFWA WRF 4-km moving nest model for western North Pacific tropical cyclone prediction. M. S. thesis, Naval Postgraduate School, Monterey, CA 93943-5114 [available at http://theses.nps.navy.mil/06Mar_Ryerson.pdf]

Wang, W., C. Davis, J. Klemp, G. Holland, and M. DeMaria, 2006: Evaluation of WRF-ARW high-resolution tropical storm forecasts in the 2005 season. Preprints, *27th Conf. Hurr. Trop. Meteor.*, Monterey, CA 24-28 April 2006, (Paper 2A.5).