13C.5 IMPLEMENTATION AND EVALUATION OF EMANUEL CUMULUS PARAMETERIZATION SCHEME IN COAMPS™ FOR TROPICAL CYCLONE PREDICTIONS

Yi Jin[1 *], Chi-Sann Liou[2], and William T. Thompson[2]
[1]SAIC, and [2]Naval Research Laboratory, Monterey, CA

1. INTRODUCTION

The Emanuel cumulus parameterization scheme (EM) (Emanuel and Zivkovic-Rothman 1999) has been implemented in the Coupled Ocean/Atmosphere Mesoscale Prediction System (COAMPS™)** (Hodur 1997) at the Naval Research Laboratory as we continue to improve the model performance in track and intensity forecasts of tropical cyclones (TC). The results of a recent study by Peng et al. (2004) suggest that the modified EM scheme implemented in NOGAPS has led to better forecasts of TC tracks. The objective of this study is to test the sensitivity of COAMPS to different physical parameterization schemes and ultimately to find a best possible combination of different schemes for TC forecasts. The impact of the EM scheme on TC track and intensity forecast are examined and compared with those from the control runs using the Kain-Fritsch (KF) scheme. Physical processes such as surface heating and moisture fluxes associated with convective cell initiation and maintenance are also studied.

2. TC FORECAST ERROR COMPARISON

Six TCs of the 2002 season are chosen for this study. They are Edouard, Isidore, and Lili over the Atlantic, and Phanfone, Rusa and Sinlaku over the West Pacific. Except for the Lili case that has only one 48-hr simulation covering both the quick intensification and weakening stages, there are two 48-h simulations for each storm, with one simulation covering the developing stage, and the other the weakening stage. All the simulations presented here use the COAMPS model with two nested grids with the resolution of 45 km and 15 km, respectively. All simulations are initialized with the NOGAPS analysis as the first guess and for boundary conditions. Average track forecast errors for the 11 simulations using the EM scheme are depicted in Fig. 1 and compared against the similar simulations using the KF scheme. The difference in the track errors between the KF runs and EM runs is negligible during the first 24 hours in domain 1 and for the first 30 hours in domain 2. The track errors from the EM runs increase later into the simulation and becomes about 10 to 15 nm more in domain 1 and 8 nm more in domain 2 than the track errors from the KF runs. For the intensity forecast comparison, the EM runs tend to have a weaker cyclone than the KF runs. The KF scheme performs much better in intensity forecasts in domain 1 of the 45 km resolution. The EM scheme has some improvement in domains 2 of the 15-km resolution than in domain 1 so that the EM results become comparable with the KF results in domain 2. While this is true, our results indicate that those cases demonstrating better intensity forecast from the EM runs are during the weakening stage of the system.

Another difference between the EM runs and KF runs is seen in the surface accumulated precipitation fields. For most of the cases, the EM results have more precipitation early in the simulations (the first 12 to 24 hours). However, for the rapidly intensifying cases (such as Lili) or during the mature stage of strong TCs (i.e., Phanfone and Rusa during their category 4 periods), the KF results accumulate more precipitation and have much better defined eye structure than in the EM results (not shown). After partitioning the total accumulated precipitation into convective precipitation and grid-scale precipitation, we find that more contribution of precipitation from the grid-scale explicit microphysics in the KF runs than in their EM counterpart.

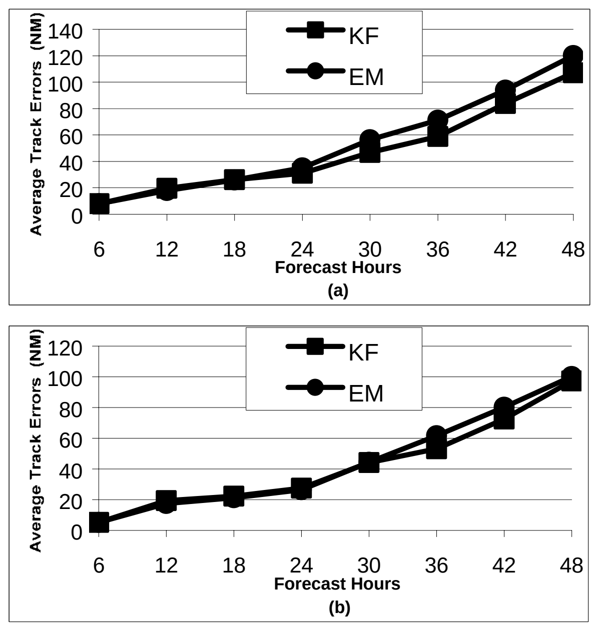

Fig.1. Average track errors in (a) domain 1 and (b) domain 2.

3. TC BOUNDARY LAYER FEATUERS

It is also our interest to examine the boundary layer features of TC cases and examine how applicable the current PBL scheme in the model is to TC environment. Take hurricane Lili as an example, the cyclone boundary layer is relatively deep (~1000 m) and well-mixed in terms of both temperature and specific humidity in the eye wall and in the spiral band. The eye is characterized by strongly stable stratification due to strong subsidence and resultant warming. The undisturbed tropical marine boundary layer, by contrast, is 400-500 m deep with a well-mixed temperature and moisture profiles. Not surprisingly, the latent and sensible heat fluxes are strongly upward in the vicinity of

* *Corresponding author address:* Yi Jin, SAIC/NRL, 7 Grace Hopper Avenue, Monterey, CA 93943; e-mail: jiny@nrlmry.navy.mil.

** COAMPS™ is a trademark of Naval Research Laboratory.

the tropical cyclone. The latent heat flux reaches values over 500 W m^{-2} in the eye wall and 300-400 W m^{-2} in the spiral band. Both surface latent and sensible heat fluxes are small in the eye due to the very stable stratification.

The eddy diffusivity profile exhibits a strong relative maximum near cloud base (~1000 m) at certain locations in the eye wall and a similar relative maximum several hundred meters higher (1500-1600 m) in the spiral bands. In COAMPS, the eddy diffusivity is determined from the flux Richardson number, which is a function of stability and vertical wind shear. The eddy diffusivity is large under unstable conditions with small vertical wind shear; condition which are likely to prevail in the eye wall. Large values of this parameter are associated with large fluxes of heat and moisture. Thus, it appears that large, upward fluxes of heat and moisture exist at cloud base in the eye wall. The large fluxes are associated with strong buoyancy generation that enhances both cloud base mass flux and production of turbulent kinetic energy.

Comparison of the Lili simulations using the KF and EM schemes shows that the eddy diffusivity feature noted above is more robust and widespread in the KF simulation than in the EM. There are also significant differences in the surface latent heat flux. The largest surface latent heat flux in the vicinity of the tropical cyclone is 25% greater in the KF simulation. Under nearly neutral conditions, the surface latent heat flux is a function of wind speed and air-sea mixing ratio difference. The difference in wind speed can account for only 18% of the difference in latent heat flux, which indicates that the low level mixing ratio differs from the surface value to a larger extent in the KF simulation, leading to an additional 7% increase. A latent heat flux difference plot (KF-EM) at hour 24 is shown in Fig. 2. This shows that the KF simulation produces the largest latent heat flux in the immediate vicinity of the eye wall while the EM simulation has larger values at greater radii. This is presumably a reflection of better organization of the eye wall in the KF simulation.

The other aspect of the surface layer treatment in the model is the surface stress under high wind conditions. Powell et al. (2003) concluded from their analysis of 331 wind profiles in the vicinity of the hurricane eyewalls that the surface momentum flux levels off as the wind speed increases above hurricane force (i.e., >40 m s^{-1}), which is contrary to the traditional treatment of surface momentum flux in the numerical models. This mechanism is incorporated into the COAMPS surface flux calculation and is tested for the Lili case. Results from this sensitivity test depict about 5 kts increase in the surface maximum wind at the 15 km resolution and about 10 to 15 kts increase in the 5-km domain. However, the simulated surface maximum winds are still well below the observed values. A possible explanation is that the modeled hurricane will have to gain very strong surface winds before this mechanism has more noticeable impact on the TC circulations. For the Lili case, the simulated maximum winds hover right around 80 kts only in a small region of the eyewall.

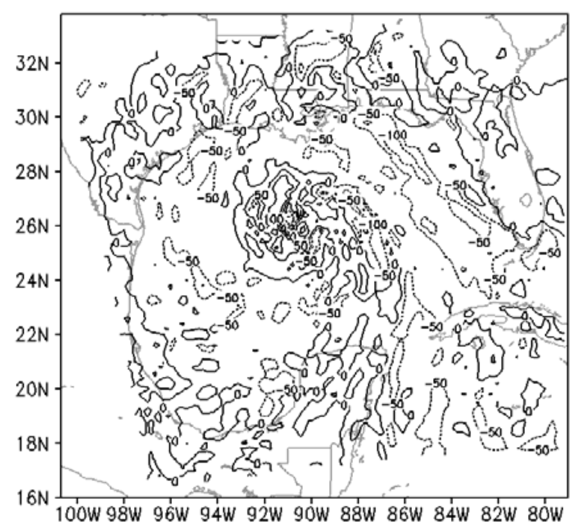

Fig. 2. Difference in surface latent heat flux (contoured at 50 W m^{-2} with dashed lines for negative values) between the KF and EM runs (KF-EM) for the Lili simulation at 24 hours valid for 00Z 3 Oct 2002

4. SUMMARY AND FUTURE WORK

The Emanuel cumulus parameterization scheme has been implemented into COAMPS and is under testing for TC cases. Our preliminary results with a small size sample indicate that the EM scheme has a similar performance to the KF scheme at a resolution of 15 km, but the EM scheme often produces a weaker system for a strong TC case. The different surface maximum wind and moisture fields result in a very different picture of surface latent heat fluxes for the KF and EM runs. We plan to further investigate the boundary layer processes active in the tropical cyclone environment and to identify those processes most important in tropical cyclone intensification. It is our intention to find a best possible combination of model physics packages for TC track and intensity forecasts.

5. ACKNOWLEDGEMENTS

This work is supported by the Office of Naval Research through program PE-0602435N and the Space and Naval Warfare Systems through program PE-0603207E. The authors also wish to thank Dr. Timothy Hogan for providing us with the EM scheme from NOGAPS and Drs. James Ridout and Shouping Wang for insightful discussions during this work.

6. REFERENCES

Emanuel, K. A., and M. Zivkovic-Rothman, 1999: Development of evaluation of a convection scheme for use in climate model. *J. Atmos. Sci.,* **56,** 1766-1782.

Hodur, R.M, 1997: The Naval Research Laboratory's Coupled Ocean/Atmosphere Mesoscale Prediction System (COAMPS). *Mon. Wea. Rev*. **125,** 1414-1430.

Peng, M. S., J. A. Ridout, and T. F. Hogan: 2004: Recent modifications of the Emanuel Convective Scheme in the Navy operational Global Atmospheric Prediction System. *Mon. Wea. Rev.* (in press).

Powell, M. D., P. J. Vickery, and T. A. Reinhold, 2003: Reduced drag coefficient for high wind speeds in tropical cyclones. *Nature*, **422,** 279-283.