16D.9 Ensemble forecast of typhoon Fanapi (2010) using a high-resolution coupled model: Effects of TC-ocean interaction

Kuan-Jen Lin[1]*, Shuyi S. Chen[2], and Shu-Chih Yang[1]

[1] Department of Atmospheric Sciences, National Central University, Taiwan

[2] Department of Atmospheric Sciences, University of Washington, Seattle, WA, USA

1. Introduction

Tropical cyclone (TC) form and develop on the open ocean, therefore ocean plays an important role in TC's life cycle. On one hand, ocean provides energy for TC to grow through upward heat and moisture fluxes. On the other hand, as TC intensify, the TC induced sea surface temperature (SST) cooling act as a break that can stop the intensification of TC. The effect of TC-Ocean interaction has been widely studied using either observation or numerical model.

In the early modeling studies, due to the limitation of computational resources and/or to simplify the problem, idealized air-sea coupled model is used to investigate the mechanism of TC-ocean coupled effect. In recent year, with the advance in numerical modeling, full-physics atmosphere-ocean coupled models are developed to better understand the role of the ocean in TC evolution and try to improve the TC prediction. However, still limited by the computational resources, recent studies using full-physics coupled model are mostly TC case studies with deterministic forecast/simulation.

In this study, ensemble forecast of typhoon Fanapi (2010) is conducted using high-resolution coupled model. With high-resolution coupled ensemble forecast, we try to statistically investigate the impact of TC-ocean coupled effect on TC forecast and the uncertainty in the coupled process.

2. Model and experiment setup

a. Coupled Atmosphere-Wave-Ocean Model

The coupled model used in this study is the UWIN-CM (Unified Wave INterface-Coupled Mode, Chen et al. 2013; Chen and Curcic 2016). The UWIN-CM is a high-resolution regional atmosphere-wave-ocean coupled model, which consists of atmosphere component—WRF (Weather Research and Forecasting) model, surface wave component—UMWM (University of Miami Wave Model) and ocean circulation component—HYCOM (HYbrid Coordinate Ocean Model). All components are coupled using ESMF coupler.

Due to the limitation of computational resources, we turned off the wave component in this study, therefore the coupled model is run in Atmosphere-Ocean (AO) coupled mode. The AO forecast is compared with the Uncoupled Atmosphere (UA) model forecast, which is WRF only, to investigate the impact of TC-Ocean interaction on TC prediction. The WRF model was configured to triply-nested domain with 12 (600x445), 4 (151x151) and 1.33 (301x301) km grid spacing (points), respectively. The HYCOM model was configured to 0.04-degree resolution and 1541x1441 grid points.

b. Coupled model initial conditions

The initial condition for atmosphere model is generated from WRF-LETKF (Local Ensemble Transform Kalman Filter) ensemble data assimilation system (Lin et al 2018). For Fanapi cases, the data assimilation system is cold start at 1200 UTC 13 Sep. 2010 and continue the 6-hr forecast-analysis cycle until 0000 UTC 16 Sep. The ensemble analysis is then used as the atmospheric initial condition for the coupled model.

For the ocean initial condition, we use the HYCOM 0.08-degree resolution global analysis provided by HYCOM.org. We note that the ocean initial condition is identical in the coupled ensemble forecast, thus the ocean perturbation in the forecast is mainly driven by difference in atmospheric forcing.

*Corresponding author: Kuan-Jen Lin, Department of Atmospheric Sciences, National Central University, Taiwan
Email: kjlin7@gmail.com

3. Results

a. Uncoupled Atmosphere (UA) forecast

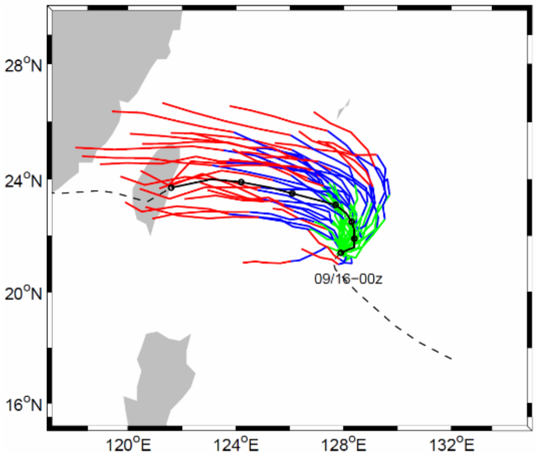

Figure 1. 3-day forecast track of UA ensemble. The greed, blue and red indicates the forecast track of day1, 2 and 3, respectively. The black line is the best track from JTWC.

Figure 1 shows the 3-day forecast track of UA ensemble. During the period of 0000UTC 16 to 17 Sep., the track of Fanapi turns from moving north-eastward to north-westward. This curing feature has larger uncertainty and is reflected by the large ensemble spread in forecast track. The diverse in ensemble TC track leads to the 72-hr forecast track error ranging from less than 100km to more than 500km compared with JTWC best track data (Fig.2a).

The ensemble forecast TC intensity is provided in Fig.2c and 2d. We found that in the UA ensemble, more than 75% of members have overestimated the Maximum surface Wind Speed (MWS). However, the Minimum Sea Level Pressure (MSLP) forecasts are very close to JTWC, except that the TCs become over-intensify after 48hr. The TC size (here defined as the radius of 34 knots wind) forecasts is also comparable with JTWC's estimation (Fig.2b).

b. Impact of TC-ocean interaction on TC prediction

Figure 3 shows the distance between TC center of UA and AO. At 72hr, the ensemble averaged TC track difference become 27km with standard deviation 15km. Verify with t-test, the track difference is statistical significance. We then separate the difference into zonal and meridional direction and found that the track difference is mostly in meridional direction. The result indicates that in Fanapi case after coupled with ocean, the TC track have deflected to the north.

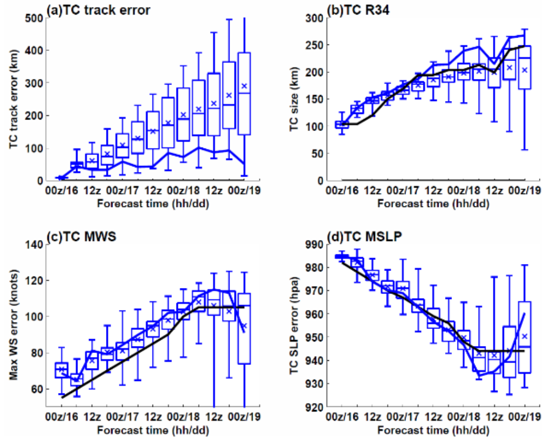

Figure 2. Box plot of (a) Forecast track error, (b) TC size, (c) MWS and (d) MSLP. The solid blue line is the deterministic forecast initialized from ensemble mean. The black line is the best track data from JTWC.

Figure 4 shows the forecast MSLP of UA and AO. The ensemble averaged intensity difference between UA and AO increase gradually and reach the maximum of 14 hPa at 72hr with standard deviation 8 hPa. This result has demonstrated the strong negative impact of ocean coupling on TC intensity.

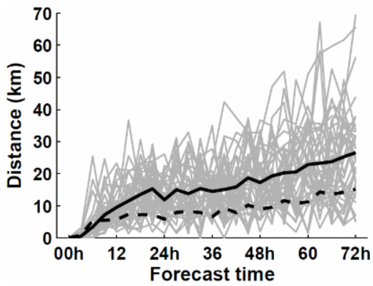

Figure 3. Track difference between UA and AO ensemble forecast (grey). The solid (dashed) black line is the ensemble mean (spread).

For the TC structure, we found that after coupled with ocean, the TCs become 13.5% smaller, the cloud top height are 6.5 % shallower and the vertically tilt increase. Also, the TCs become more asymmetry.

C. How TC-Ocean interaction affect TC forecast?

For the TC track, we found that the track difference between UA and AO is related to the vertical development of TC. As suggested by Bender et al. (2017), they pointed out that TC with deeper circulation appears to be steered sooner by the upper-level flow. In our case, the TCs in UA have higher vertical development, therefore is steered by the easterly at the higher level. In contrast, AO is affected more by the southerly at the lower level.

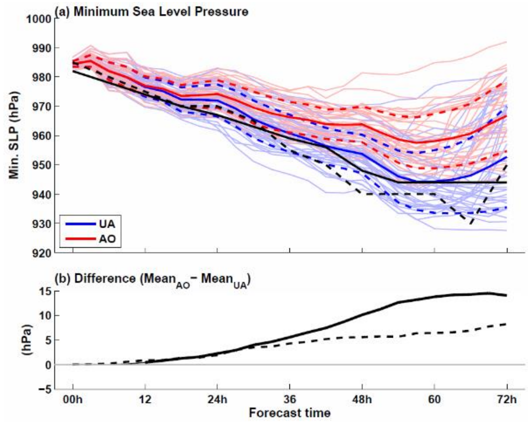

Figure 4. (a) 3-day forecast MSLP of UA (blue) and AO (red). The thick solid (dashed) line is the ensemble mean (mean plus and minus 1 standard deviation). (b) The black solid line is the ensemble averaged difference between UA and AO. The dashed line is the standard deviation of difference.

For the TC intensity, because Fanapi is a TC that pass by cold core eddies, thus significant cold wake have been generated. Cione and Uhlhorn (2003) showed that reducing the SST, especially SST below the inner-core region of the TC, is an effective thermodynamic pathway to reduce the TC intensity. We found that with 1.3 ℃ SST cooling at 72hr, the surface sensible heat flux has been reduced by 45% thus the TCs in AO become much weaker.

4. Summary

In this study, using high-resolution coupled ensemble forecast, the importance of ocean coupling and its impact on TC prediction have been examined. The main findings of this study are:

Ocean coupling has significant impact on TC track, intensity, and structure.

Track: Northward track deflection in AO.

Intensity: TCs in AO become much weaker.

Structure: TCs in AO are smaller, shallower, more tilted and asymmetry.

Analysis shows that the track difference between UA and AO is because the ocean coupling reduces the TC's vertical development in AO, thus TCs are affected more by the southerly at the lower level.

The significant intensity reduction in AO is because the large SST cooling generated by TC induced cold wake. The ensemble averaged 1.3 ℃ SST cooling at 72hr have caused 45% reduction in surface sensible heat flux, which causes the weakening of TCs.

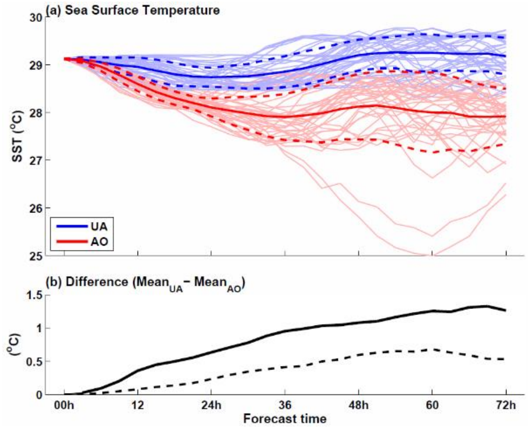

Figure 5. As in Fig.4, but for SST.

Reference:

Bender, M.A., T.P. Marchok, C.R. Sampson, J.A. Knaff, and M.J. Morin, 2017: Impact of Storm Size on Prediction of Storm Track and Intensity Using the 2016 Operational GFDL Hurricane Model. *Wea. Forecasting*, **32**, 1491–1508.

Chen, S. S., and M. Curcic, 2016: Ocean surface waves in Hurricane Ike (2008) and Superstorm Sandy (2012): Coupled model predictions and observations. *Ocean Model.*, **103**, 161–176.

Chen, S. S., W. Zhao, M. A. Donelan, and H. L. Tolman (2013), Directional wind-wave coupling in fully coupled atmosphere-wave-ocean models: Results from CBLAST-Hurricane, *J. Atmos. Sci.*, **70**, 3198–3215.

Cione, J. J., and E. W. Uhlhorn, 2003: Sea surface temperature variability in hurricanes: Implications with respect to intensity change. *Mon. Wea. Rev.*, **131**, 1783–1796.

Lin, K.-J., S.-C.Yang, and S. S. Chen, 2018: Reducing TC position uncertainty in ensemble data assimilation and prediction system: A Case Study of Typhoon Fanapi (2010). Submit to *Wea. Forecasting.*