Effect of uncertainties in sea surface temperature dataset on the simulation of typhoon Nangka (2015)

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1 INTRODUCTION

High sea surface temperature (SST) is necessary to ensure sufficient energy supply in terms of entropy flux from the underlying ocean surface for the development and maintenance of tropical cyclones (TCs, Malkus & Riehl, 1960). Indeed, SST determines the maximum potential intensity (MPI) of a TC (Emanuel, 1997) and is a key factor determining the TC intensity change (Emanuel, DesAutels, Holloway, & Korty, 2004; Kaplan & DeMaria, 2003). In turn, a strong TC may interact with the underlying ocean, leading to cooling in the upper ocean by upwelling and turbulent vertical mixing (Price, 1981; Shay, Goni, & Black, 2000). Previous studies have shown that a cold wake in SST often occurs to the right of the TC track (Price, 1981). The cold SST could result in reduced surface entropy flux, leading to reduced intensification rate and final intensity of a TC (Lin et al., 2013). Using a simple coupled atmosphere–ocean model, Lin et al. (2005) demonstrated that the presence of warm eddies can efficiently isolate typhoons from the cold wake.

Because of the importance of SST to TC intensity change (DeMaria, 1994), accurate measurement of SST during a TC is crucial to intensity prediction (Emanuel, 1999). In recent years, satellite infrared and microwave SST products lead to various high resolution SST datasets. However, various factors, such as the undetected clouds and aerosols (Reynolds,
1993; Reynolds, Folland, & Parker, 1989), may limit the accuracy of SST retrievals. Moreover, due to differences in SST retrieval algorithms and increasing noise with increasing resolution, differences among SST datasets are sometimes considerably large (Huang et al., 2016). Reynolds and Chelton (2010) compared six SST analyses to identify problems in various datasets and found that the best SST dataset is hard to be determined because of the mismatch between feature resolution and grid spacing as well as the cloud covering. This means that large uncertainties may exist in SST datasets, in particular under TC conditions due to the presence of various degrees in cloud organizations.

In this study, the effect of uncertainties in SST dataset on the simulation of typhoon Nangka (2015) is studied using the Advanced Weather Research and Forecast (ARW-WRF) model. Typhoon Nangka formed over the western North Pacific (WNP) on July 3, 2015, and then successively experienced rapid intensification and rapid weakening periods. Such rapid intensity change was not captured in the official forecast from either Joint Typhoon Warning Center (JTWC) or China Meteorological Administration (CMA). Even though the official track forecasts issued by the two agents were quite good during the rapid intensification period (Figure 1a and c), the intensification rate was significantly underpredicted, resulting in large intensity forecast errors when Nangka reached its maximum intensity and the subsequent weakening.

Here, we will first show the uncertainties in different SST datasets and then examine how sensitive the simulated Typhoon Nangka is to the use of different SST datasets. The SST dataset from National Centers for Environmental Prediction (NCEP) Global Forecast System (GFS) analysis shows a strong cold eddy to the south of the track when Typhoon Nangka experienced its rapid weakening, while other datasets either show no cold eddy or show at different locations. We will show that the cold SST eddy played a critical role in leading to the TC weakening. Next section gives an overview of typhoon Nangka (2015) and the differences in several SST datasets. The model and experimental design are described in Section 3. Section 4 discusses results from model simulations. Major conclusions are given in Section 5.

2 AN OVERVIEW OF TYPHOON NANGKA (2015) AND UNCERTAINTIES IN SST DATASETS

Typhoon Nangka (2015) was first identified as a tropical depression over the WNP on July 3, 2015 by JTWC. It quickly developed into a tropical storm within the first day and then moved northwestward and experienced a rapid intensification from July 5 to 7. After attaining its peak intensity of 67.5 m/s at around 1800 UTC July 9, Nangka slowed down and weakened rapidly to 37.5 m/s in the following 48 hr by 1800 UTC July 11 before it sharply turned northward (Figure 1a and c). Prior to the arrival of Nangka, typhoon Chan-Hom (2015) traveled over the same ocean

![Figure 1](link-to-figure)
area. Chan-Hom initially moved westward and intensified slowly before the sudden track change at 0000 UTC July 3 and then traveled northward over the WNP as a tropical storm. Chan-Hom left a cold wake centered at around 145°E, 5°N.

For the sake of comparison, four daily SST datasets were used, respectively, from the NCEP GFS analysis and real-time Global SST (RTG_SST) analysis with a spatial resolution of 0.5°, the NOAA 0.25° daily optimum interpolation SST (OISST), and the ECMWF Interim reanalysis (ERA-Interim). Figure 2 shows these four SST datasets from July 1 to 13, 2015, divided into four stages, before and during Nangka passed through the ocean region. The cold SST feature mentioned above was visible to various degrees but with quite different spatial distributions from July 1 to 6, 2015 in the four SST datasets. As Chan-Hom moved northward and Nangka arrived, the cold SST feature shifted northward from July 7 to 9, which is present in most of the SST datasets (Figure 2c, k and o) except for the OISST product (Figure 2g), which shows that the cold SST feature began to weaken at this stage. The missing of the cold SST feature induced by a TC was also previously mentioned by Wentz, Gentemann, Smith, and Chelton (2000). The cold SST feature in the GFS dataset was elongated along Chan-Hom’s track and continued to strengthen when typhoon Nangka was approaching (Figure 2c and d), while the cold SST feature in other three datasets considerably weakened from July 10 and disappeared eventually (Figure 2h, l and p).

3 \ MODEL AND EXPERIMENTAL DESIGN

To examine how sensitive the simulated typhoon Nangka is to the SST dataset and the effect of the cold SST feature on the intensity change, in particular the rapid weakening of the storm, we conducted a series of numerical experiments using the ARW_WRF version 3.3.1 modeling system (Skamarock et al., 2008). The model domain was two-way interactive and triply nested with horizontal resolutions of 18, 6, and 2 km, respectively. There were 43 uneven σ vertical levels...
from the surface to the model top at 20 hPa. Both the 6 and 2-km meshes automatically moved following the TC center so that the TC inner core was covered by the innermost mesh, while the outermost 18-km mesh was fixed during the simulations. The dynamical initialization (DI) scheme (Cha & Wang, 2013) was used to improve the initial conditions of the TC. The model was initialized at 0600 UTC July 7, 2015 and integrated for 168 hr up to 0600 UTC 14 July with the initial and lateral boundary conditions interpolated from the NCEP GFS analysis, which had a horizontal resolution of 0.5°× 0.5°. Therefore, the simulation covered part of the rapid intensification and the subsequent rapid weakening period of Nangka, as well as its sudden northward turning motion after the rapid weakening (Figure 1).

Because the main differences lied in the distribution of the cold SST feature during July 7–9 and its persistence during July 10–13 among different SST datasets (Figure 2) and the major differences can be clearly seen between the GFS and RTG SST datasets, we chose these two datasets as the model SST to conduct several sensitivity experiments. Four experiments were designed to examine the effect of the cold SST feature on the TC intensity changes: (a) the control experiment using the SST dataset from the GFS analysis (denoted as EXP_GFS), which captured the cold SST wake induced by Chan-Hom; (b) an experiment using the GFS SST dataset but with the cold wake induced by Chan-Hom to the south of Nangka’s track removed by replacing SST lower than 28.5°C with 28.5°C (denoted as EXP_GFS-RW, see Figure 3a and b; (c) an experiment with the SST dataset from the NCEP RTG_SST (denoted as EXP_RTG), in which the cold SST wake induced by Chan-Hom did not appear during the rapid weakening period of Nangka; and (d) an experiment with the perturbation SST representing the cold SST wake south of Nangka’s track (obtained from the GFS SST) added to the SST field used in experiment EXP_RTG (denoted as EXP_RTG-AW, see Figure 3c and d).

4 | RESULTS

Figure 4 illustrates the 7-day track and intensity hindcast from the four experiments described in Section 3. In experiment EXP_GFS with the strong cold SST feature to the south of the storm track, the simulated track was close to the observed before 1200 UTC July 11, namely before the storm turned northward (Figure 4a). However, the subsequent sudden northward turning in the control simulation occurred about 18 hr earlier than that in the best-track with the turning point about 1° longitude east of the observation. Nangka reached its peak intensity in the control simulation at 1800 UTC July 9 in good agreement with the observation and the timing was also well captured. Especially, the rapid weakening period in the simulation was consistent with the observation as well (Figure 4b). Such an improved simulation should be attributed to the good global analysis used as the initial and lateral boundary conditions and the realistic SST. It is evident that most features of Nangka’s intensity evolution and track were better reproduced in the control experiment than in any of the other three experiments.

In the sensitivity experiment EXP_GFS-RW with the cold SST feature removed from the GFS SST (Figure 3a and b), the simulated track was similar to that in the control experiment, only the sudden northward turning motion occurred at 1800 UTC 11 July, 6 hr later than that in EXP_GFS (Figure 4a), slightly closer to that observed. However, EXP_GFS-RW failed to simulate the observed intensity change (Figure 4b). The intensification and weakening in the early simulation period (between 0600 UTC
July 8 and 1200 UTC July 10) were not well captured in the simulation and the subsequent rapid weakening was considerably underestimated, resulting in a too strong storm from 0600 UTC July 11 to 0600 UTC July 14. This suggests that the cold SST feature was critical to the rapid weakening of typhoon Nangka.

In the sensitivity experiment EXP_RTG, the cold SST feature existed between July 7 and 9 before typhoon Nangka reached its peak intensity but was totally missing when Nangka experienced its rapid weakening during July 10–13 (Figure 2l). This temporal evolution of the SST field was completely opposite to that in EXP_GFS. The simulated storm track in EXP_RTG was very similar to that in EXP_GFS (Figure 4a). However, the intensity of the simulated storm in this experiment showed no significant changes during the simulation period. This further suggests that the cold SST feature to the left of the storm track had little effect on the storm motion but was a key to the storm intensity change (Figure 4b), in particular, the early intensification and the subsequent rapid weakening before the storm turned northward.

In the experiment EXP_RTG-AW with the cold SST feature added to the SST field used in experiment EXP_RTG (Figure 3c and d), the simulated Nangka moved slightly to the left of the observed track before it turned northward. The evolution of the simulated storm intensity was much improved compared with its counterpart experiment EXP_RTG (Figure 4b), much closer to the observation, although the simulated storm weakened more rapidly than the observed during July 9–11.

The above results strongly suggest that the simulated storm intensity change is sensitive to the SST dataset used and that the SST dataset that includes the strong cold SST feature seems to be more reliable. Note that since the simulated tracks showed differences not directly to the uncertainties in the SST dataset nor to the existence of the cold SST feature, the motion of the storm might not be significantly affected by the cold SST feature in the SST field used in the simulations for the typhoon Nangka case. We showed that the intensity evolution in the two experiments with the cold SST feature present was much closer to that...
observed than the two experiments without the cold SST feature, especially during the rapid weakening period (Figure 4b). This suggests that the cold SST feature contributed largely to the rapid weakening of typhoon Nangka after it reached its peak intensity on July 9.

As mentioned in Section 1, SST affects the TC intensity change through modulating surface entropy flux. In particular, the surface entropy flux in the inner core region (namely within about two to three times of the radius of maximum wind) is most relevant to TC intensity change (Wang & Xu, 2010; Xu & Wang, 2010). In our simulations, the radius of maximum wind was about 40–50 km, therefore, we calculated the area-average entropy (latent plus sensible heat) flux within a radius of 150 km from the storm center in all four experiments, with the results shown in Figure 5. As expected, the entropy flux decreased considerably after July 10 in both EXP_GFS and EXP_RTG-AW with the cold SST feature while increased with time in both EXP_GFS-RW and EXP_RTG without the cold SST feature present during the major weakening stage of the observed TC. This is consistent with the failure of EXP_GFS-RW and EXP_RTG in reproducing the rapid weakening phase of the TC. Note that care needs to be taken since the consistent evolution of the storm intensity and the surface entropy flux in the inner core region of the simulated storm included contributions from both surface winds and underlying SST.

In addition to SST, the intensity change of a TC may be affected by other factors, such as the environmental vertical wind shear (VWS, e.g., Wang, Rao, Tan, & Schönemann, 2015; Zeng, Wang, & Wu, 2007). To examine the possible effect of VWS on the rapid weakening of typhoon Nangka and also to see whether the SST effect was partly strengthened or offset by VWS, we calculated the environmental VWS between 200 and 850 hPa averaged within a radius of 500 km from the typhoon center. Figure 5b shows the evolution of the calculated VWS in the four experiments. The VWS increased dramatically during the rapid weakening period of typhoon Nangka in all four experiments. Note that the peak VWS in EXP_RTG was the largest (over 20 m/s) but the storm did not weaken in this simulation. This means that even in the strong VWS the simulated storm did not experience any significant weakening in experiment EXP_RTG without the cold SST feature. The similarity of the evolution of VWS among the four experiments strongly suggests that the differences in the intensity evolution in the four experiments should be mainly due to the effect of the cold SST feature, which affected surface entropy flux from the underlying ocean and thus the storm intensity change. The results are in general consistent with those reported in some previous studies (e.g., Lin et al., 2005).

5 | CONCLUDING REMARKS

In this study, we have found that large uncertainties exist in different SST datasets over the WNP during typhoon Nangka. In particular, the cold SST feature that was seemingly induced by the previous typhoon Chan-Hom was not well captured in some SST datasets. We have shown that the simulated intensity of typhoon Nangka was very sensitive to the SST dataset used in the ARW-WRF model. The results show that the experiments with the cold SST feature to the left of Nangka’s track well-simulated the rapid weakening of the storm. Namely, the simulation with the SST dataset from the NCEP GFS analysis was the most skillful, while the experiment without the cold SST feature, such as the RTG SST, failed to simulate the rapid weakening of the storm. We also found that the environmental VWS increased steadily during the weakening stage of typhoon Nangka. However, the weakening of the simulated storm did not directly result from the environmental VWS. This strongly suggests that it was the cold SST feature that played a critical role in leading to the rapid weakening of typhoon Nangka.

We showed that except for GFS SST, all other three SST datasets (namely OISST, RTG_SST, and ERA-Interim analysis) did not display the cold SST feature, suggesting that large uncertainty exists among different SST datasets. The simulation results suggest that without the cold SST feature to the south of its track, Nangka’s peak intensity was underestimated, and the rapid weakening was completely missing. In this sense, the SST dataset derived from GFS seems to be more reliable. We also showed that the decrease in surface entropy flux in the inner core was well correlated with the rapid weakening of the simulated storm. Results from this study strongly suggest that large uncertainty may exist.

![FIGURE 5](image-url) Evolutions of (a) air–sea entropy (latent plus sensible heat) flux (W m⁻²) averaged within 150 km radius from the typhoon center and (b) vertical wind shear (m/s) between 200 and 850 hPa averaged within 500 km radius from the typhoon center in the four experiments.
among different SST datasets and the use of realistic SST data is important for TC intensity prediction. Finally, we should mention that even in an atmosphere–ocean coupled model, the initial SST would affect the subsequent SST evolution and thus may affect TC intensity forecasts.

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