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A NUMERICAL STUDY OF THE INFLUENCE OF SEA SURFACE TEMPERATURES WITH DIFFERENT TEMPORAL RESOLUTIONS ON TYPHOON DUJUAN OVER THE SOUTH CHINA SEA

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Abstract: Daily and weekly sea surface temperature data of Tropical Rainfall Measuring Mission (TRMM) Microwave Imager and Advanced Microwave Scanning Radiometer-Earth Observing System sensors are used as forcing of the underlying sea surface in the mesoscale numerical model to simulate Typhoon Dujuan that moved across the South China Sea in 2003. The numerical results show that different SSTs near the typhoon center result in differences in the atmospheric wind field, indicating that the model has a fast and obvious response to SSTs. Different SST influences the intensity and track of Dujuan to some degree and has significant impacts on its precipitation and latent heat flux near the eye. The SST influence on Dujuan is mainly fulfilled by changing the latent heat flux between the ocean surface and the atmosphere above.

Key words: mesoscale numerical models; typhoon Dujuan; sea surface temperature; South China Sea

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1 INTRODUCTION

Medium-range weather forecast models are widely used in research and operational weather prediction, and the demand for skilled models continues to grow [1]. When using medium-range forecast model to simulate a typhoon, our most concerns are its path and intensity. Simulating typhoon intensity is still very challenging, due to limited model resolution, optimization of parameterization scheme, and quality of the initial field [2-5]. As an external heat source, sea surface temperature (SST) tremendously influences atmospheric circulations [6-8]. Therefore, the prediction models may give different simulation results when SST varies with different temporal resolutions [9-10]. For a dynamic model, highly accurate SST fields are very important for simulating typhoon intensity[11]. Models constructed by weekly averaged SST are liable for missing some of the structural details during the whole time span (2 to 3 days) of a typhoon. SSTs are considered to be relatively stable, changing more slowly with time, than weather. Due to this feature, in addition to the lack of in situ ocean measurements, SST was normally set as a constant or simply a weekly averaged value when simulating a typhoon.

Due to the advanced satellite technology, SST data now can be obtained from the high resolution radiator (AVHRR) and the tropical precipitation satellite microwave image (TMI). Data are composited twice per day, which has increased the temporal resolution to allow for examining short-term air-sea interaction. Chen et al.[12] simulated the passage of a winter front in the Japanese Sea using AVHRR-SST data in the model. Therefore, it is proposed here that SST datasets with different temporal resolutions can have impacts on the simulation of typhoons in the South China Sea.

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Typhoon Dujuan that entered the South China Sea from the Northwest Pacific Ocean in September, 2003 was simulated in this paper. Two sensitive experiments were conducted using MM5 with different types of data: the daily and weekly averaged SSTs. The model test runs were used to determine (1) the model sensitivity to external enforcing factors of SST for mesoscale forecasting; and (2) the effects of the two SST datasets of different temporal resolutions on typhoon track and intensity.

2 DATA AND MODEL

2.1 *Data*

The model initial and boundary conditions are obtained from the National Centers for Environmental Prediction (NCEP) Final analysis data (FNL), which are four times daily with horizontal resolution of 1°×1° and 26 vertical pressure levels. The daily and weekly averaged TMI-AMSRE SSTs were obtained from TRMM (Tropical Rainfall Measuring Mission (TRMM) TMI (TRMM Microwave Imager (TMI) and AMSRE (Advanced Microwave Scanning Radiometer version-5) (ftp: //ftp.discover- earth .org/sst/daily/tmi_amsre/). The dataset has a horizontal resolution of 0.25°×0.25°. TMI can penetrate clouds with little attenuation from aerosol and water vapor.

The SST data at each grid point was generated by an interpolation method. In order to construct complete SST datasets for the atmospheric model domain, the grids were replaced with FNL SSTs wherever TMI-AMSRE SST data were not available. SST was updated every 6 hours during model integration. When the weekly averaged SST was used, the same weekly SST was applied every 6 hours for one week. The model forced by daily SST also invoked the same SST over a day. The tropical cyclone data were obtained from "Tropical Cyclones: Encyclopedia" edited by the China Meteorological Administration.

2.2 *Model*

The Fifth-Generation NCAR/Penn State Mesoscale Model (MM5) is a non-hydrostatic, and has multiple-nest capability, as well as many other physics options. The model was designed to simulate or predict mesoscale atmospheric circulation events (See Table 1).

The constructed model was tested by simulating Typhoon Dujuan of 2003. It formed in the Pacific Ocean east of the Philippines on August 28, 2003 and then moved in the direction of north by northwest. On September 1 at 18:00 (Coordinated Universal Time used hereafter), the typhoon entered the South China Sea after passing through the Bashi Channel, and continued to move toward the north by northwest. On September 2 at 12:00, it made landfall in Shenzheng, China. On September 3, after entering inland Guangxi, China, Dujuan weakened to a tropical storm, and then gradually dissipated. This typhoon caused severe casualty and property loss in Guangdong province.

Table 1 Parameter settings in MM5 model.

Parameter	Settings in model
Basic equation	Original nonhydrostatic equations
Ordinate	Terrain-following σ coordinate
Number of domains	Two domains
Center location	23.0°N, 117.0°E
Horizontal resolution	90 km, 30 km
Grid points	49×46×23, 106×85×23
Time step	120 s
Cumulus parameterization	Kuo scheme
Boundary layer scheme	MRF
Radiation scheme	Cloud-radiation scheme
Lateral boundary file	FNL analysis data
Initial field file	FNL analysis data
Length of time integration	48 h

Analysis of model output was performed for 48 h time span from September 1 to 3. The NCAR-AFWA bogus scheme in the MM5v3 model [17] was selected, using the following parameters: the maximum wind speed V_{max} = 40 m/s, maximum wind speed radius R_{max} = 80 km, and tangential wind field morphological factor α = 0.75.

3 DIFFERENCE BETWEEN DAILY AND WEEKLY AVERAGED SST DATASETS

Figure 1 shows the daily and weekly averaged TMI-AMSRE during the experimental period. Comparing the daily and weekly averaged TMI-AMSRE SSTs, it can be seen that the daily-averaged SSTs can reflect more details of the SST spatial distribution due to its high temperature resolution. The daily-averaged SST distribution demonstrated that the ocean water surrounding the Taiwan Island was warmer, though not significantly. In the typhoon center east of the Bashi Channel, the SST was obviously cold, which also appeared north of the South China Sea.

The weekly-average SST is relatively cooler in the northern South China Sea, whereas the ocean around and in the east of Taiwan Is. had obvious warmer SST. Warmer SST was also found in the east coast of Indo-China Peninsula and oceans off the Philippine Islands.

On September 1 and 2, 2003, the daily-averaged SST was higher than the weekly-averaged in the northern South China Sea. In the typhoon center area east of the Bashi Channel, the weekly-averaged SST was much cooler than that of daily-averaged SST. Thus the daily-averaged SST was more accurate in determining SST distribution during a typhoon process.

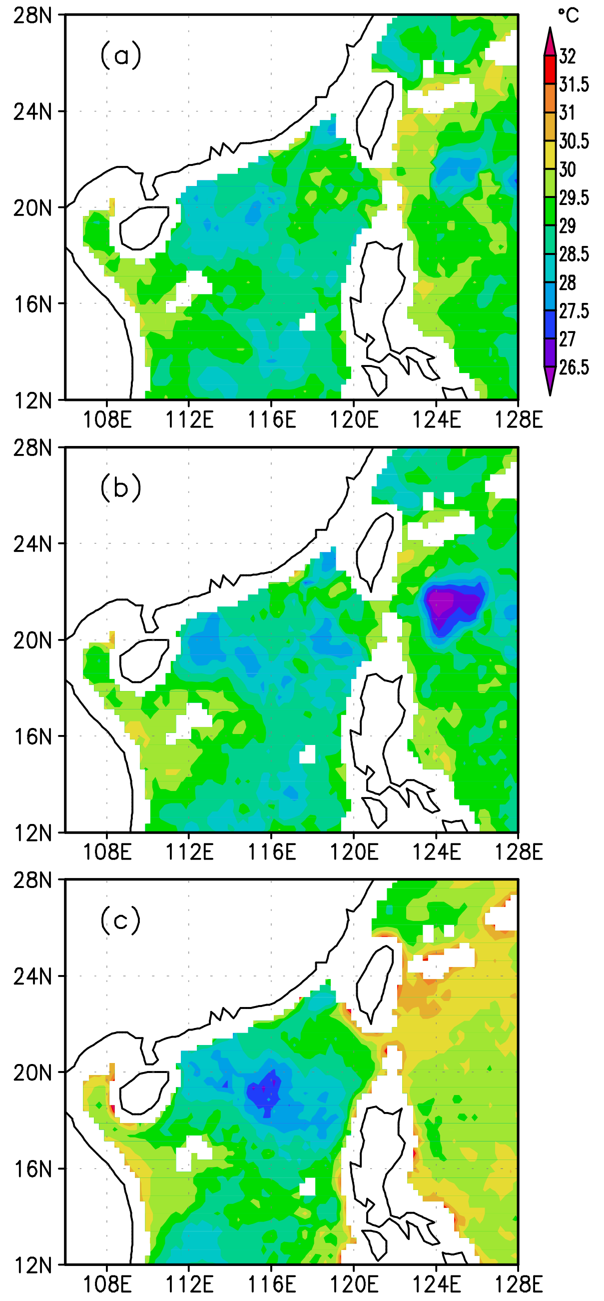

Fig.1 The distribution of TMI-AMSRE SST, (a) daily averaged SST on September 1, 2003, (b) daily averaged SST on September 2, 2003, and (c) weekly averaged SST.

4 COMPARISON OF THE TWO MODELS

4.1 *Typhoon track and intensity*

The observed and simulated tracks of Typhoon Dujuan are shown in Fig. 2. When simulated with the daily and weekly SSTs, the predicted typhoon tracks turned northward away from the actual path 12 h after the integration started. The other sections of the simulated typhoon path were more accurate; e.g., the errors of typhoon track at 24 h and 48 h were all within 200 km (Table 2). In the first 24 h, the two typhoon tracks predicted using daily and weekly averaged SSTs were basically parallel to each other.

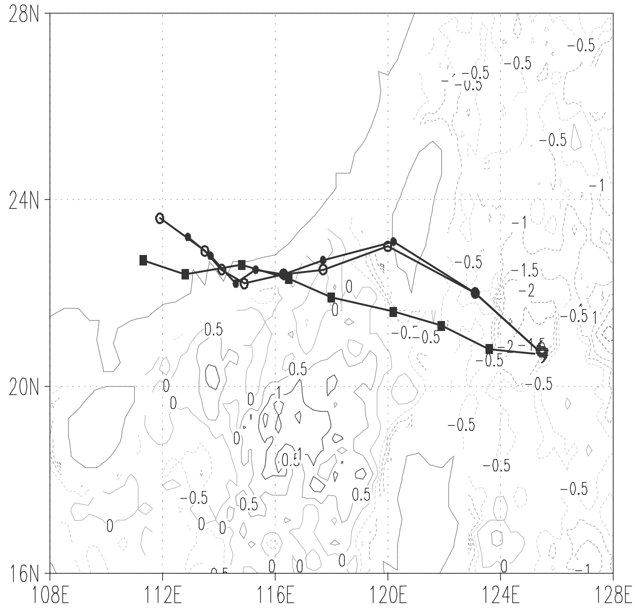

Fig.2 Tracks of typhoon Dujuan. Closed cycles: experimental result of daily averaged SST; open cycles: experimental result of weekly averaged SST; closed squares: observational tracks. Typhoon symbol: initial location of Dujian. Isolines: differences of daily averaged SST on September 1, 2003 minus weekly averaged SST, at intervals of 0.5°C.

Table 2 The errors of typhoon tracks simulated by using daily averaged and weekly averaged SST.

SST category	12 h error/km	24 h error/km	36 h error/km	48 h error/km
Daily averaged SST	275.3	197.0	49.7	186.4
Weekly averaged SST	283.5	197.0	78.6	120.3

The typhoon track simulated with daily averaged SST was closer to the observation than that with the weekly averaged SST in the first 36 h, but not too different after 36 h. This reveals the effect of SST temporal resolution on typhoon track simulation.

The typhoon intensity predicted with daily SST was weaker than that with weekly averaged SST, which suggests that SST also has impact on typhoon intensity. However, the impact was not significant, possibly due to small variations of SST over the regions where typhoon passed through. The fact that the simulated typhoon track passed through Taiwan Island might also contribute to this outcome.

Simulation of typhoon intensity is very difficult in normal circumstances. In this study, both model runs do not reasonably simulate the typhoon intensity (Table 3), which could be caused by several factors, such as the strength of bogus velocity inserted in the model, model resolution and capability or the quality of the initial fields, among others.

Table 3 Center pressure of Dujuan from observation and 48-h simulations using daily averaged and weekly averaged SST.

Time	Simulation of daily SST/hPa	Simulation of weekly SST/hPa	Observation/hPa
2003090100 UTC(simulation at 00 h)	988	988	955
2003090106 UTC(simulation at 06 h)	987	987	950
2003090112 UTC(simulation at 12 h)	994	993	950
2003090118 UTC(simulation at 18 h)	995	994	950
2003090200 UTC(simulation at 24 h)	997	996	950
2003090206 UTC(simulation at 30 h)	998	997	950
2003090212 UTC(simulation at 36 h)	999	998	960
2003090218 UTC(simulation at 42 h)	1000	999	988
2003090300 UTC(simulation at 48 h)	1003	1002	996

4.2 *Simulated wind fields*

Figure 3 shows differences in 10-m wind field between the two simulations at 12 h, 24 h, 36 h and 48 h. It can be seen that the daily SST variation causes rapid alteration in sea-surface wind fields.

As the integrated effects spread to other regions in addition to moving and landfall of the typhoon, the surface wind field near the typhoon also changes significantly. At the early stage of the model integration, anomalous wind convergence can be seen in the regions where SST difference (daily minus weekly averaged SST for a given time) is positive, while anomalous wind diverges where the SST difference is negative (Fig. 3a). After the model has been integrated for 24 h, the difference in the surface wind field has spread into other regions.

4.3 *Precipitation and heat flux analysis*

Within the typhoon circulation range, SST can affect the local evaporation and precipitation during the typhoon.

The 24-h typhoon precipitation was predicted using the model with daily averaged SST, and the SST differences between daily and weekly averaged values are shown in Fig. 4. The precipitation simulated by the daily SST mainly occurred south of the typhoon center, and has multiple centers of heavy precipitation.

The 24-h precipitation distributions simulated using daily and weekly averaged SST vary significantly. The maximum difference was over 40 mm (near 116.5ºE, 21.5ºN). Meanwhile, the region with large precipitation disparity is close to where large SST variation exists, namely in the northern South China Sea. This analysis indicates that SST variation affects typhoon precipitation.

As a heat source, tropical oceans can also influence upper atmosphere through heat fluxes. In order to examine the sensitivity of heat budget in the lower atmosphere to SSTs of different temporal resolution, we analyze the typhoon center where large SST variation is identified (at 115º to 119ºE and 18º to 22ºN) at 24 h (0000 UTC September 2, 2003). The two model runs are compared for regional averaged sensible and latent heat fluxes (with positive flux value going upwards), as well as their time evolution (figure omitted). It shows that the latent heat flux simulated using warmer daily averaged SST is obviously higher than the one using the weekly SST. This indicates that small variation in SST can cause significant change in latent heat flux, and thus has large influence on air-sea heat flux. The daily averaged SST is very warm prior to the arrival of the typhoon, which should benefit large evaporation from ocean to atmosphere.

Typhoon center has lower SST than the surrounding sea surface. Because SST is cooler than the air temperature above in summer, the heat flux should be negative. As the daily SST is relatively warmer, the cooling effect is smaller.

Our results also demonstrate that the latent heat flux is one order larger in magnitude than the sensible heat flux. This suggests that the latent heat flux is more important, which is consistent with the previous studies.

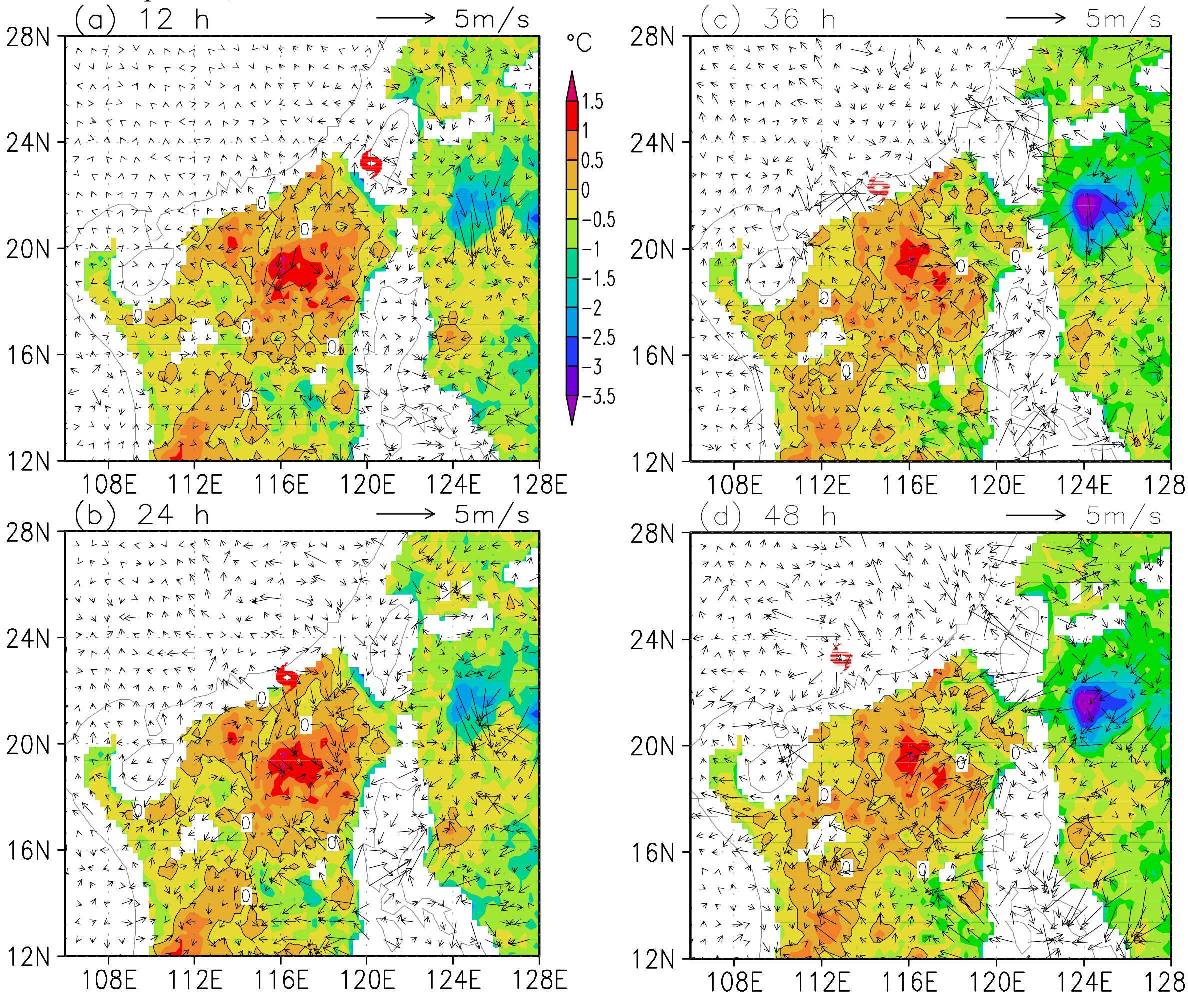

Fig.3 The difference of 10-m wind field simulation and corresponding SST between two groups of experiments, (a) simulation at 12 h, (b) simulation at 24 h, (c) simulation at 36 h, (d) simulation at 48 h. 12 h and 24 h differences of SST are daily averaged SST on September 1, 2003, minus weekly averaged SST. 36 h and 48 h differences of SST are daily averaged SST on September 2, 2003, minus weekly averaged SST. Typhoon symbol: center location of the simulation by using daily averaged SST.

5 CONCLUSIONS

In this study, the daily and weekly averaged TMI-AMSRE SST data are used in MM5 to test the impact of temporal SST resolution on Typhoon Dujuan. The simulation results using the two SSTs of different temporal resolution are summarized as follows:

(1) Each SST dataset has some unique effects on the simulated typhoon track and intensity. However, when the difference between the two SST datasets is below the significance level, no substantial variations in the simulated typhoon properties are detected.

The simulation was sensitive to SST temporal resolution, e.g., variation in SST can cause rapid alteration in the wind field at sea surface. A convergence of wind fields is attributed to higher daily SST than weekly SST. This result agrees with the previous conclusions that warm (cold) sea surface can stimulate faster and stronger (slower and weaker) wind at sea surface [18-20].

(2) Small SST variation in the typhoon area could lead to significant change in latent heat flux and precipitation.

In addition, the latent heat flux is much larger than the sensitive heat flux in the typhoon center. Consequently, the effect of the air-sea sensible heat flux is very small. SST affects the upper ocean properties around the typhoon center mainly through latent heat flux.

The current study is a case study. We expect that better technology will be developed so that we can have high spatial and temporal resolutions of

SST data to improve the simulations of typhoon track and intensity

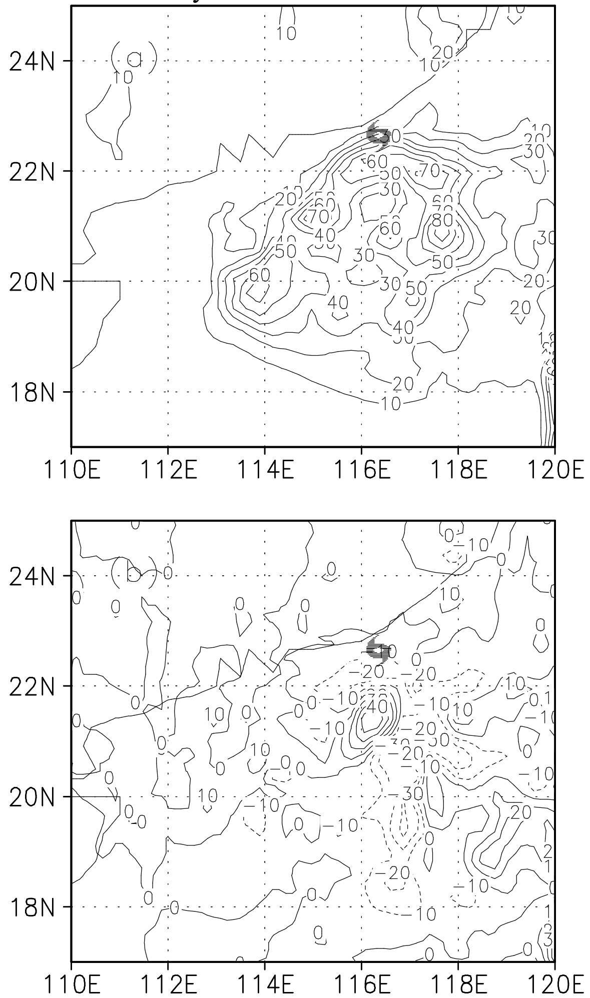

Fig.4 Distribution of 24-h typhoon precipitation simulated by using daily averaged TMI-AMSRE SST (a), and the difference of 24-h typhoon precipitation between the simulation by using daily averaged and weekly averaged TMI-AMSRE SST (b) (units: mm).

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