Article ID: 1006-8775(2009) 01-0054-05

NUMERICAL EXPERIMENTS ON THE IMPACTS OF SEA SPRAY ON TROPICAL CYCLONES

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Abstract: The latest version of sea spray flux parameterization scheme developed by Andreas is coupled with the PSU/NCAR model MM5 in this paper. A western Pacific tropical cyclone named Nabi in 2005 is simulated using this coupled air-sea spray modeling system to study the impacts of sea spray evaporation on the evolution of tropical cyclones. The results demonstrate that sea spray can lead to a significant increase of heat fluxes in the air-sea interface, especially the latent heat flux, the maximum of which can increase by up to about 35% - 80% The latent heat flux seems to be more important than the sensible heat flux for the evolution of tropical cyclones. Regardless of whether sea spray fluxes have been considered, the model can always simulate the track of Nabi well, which seems to indicate that sea spray has little impact on the movement of tropical cyclones. However, with sea spray fluxes taken into account in the model, the intensity of a simulated tropical cyclone can have significant increase. Due to the enhancement of water vapor and heat from the sea surface to the air caused by sea spray, the warm core structure is better-defined, the minimum sea level pressure decreases and the vertical speed is stronger around the eye in the experiments, which is propitious to the development and evolution of tropical cyclones.

Key words: numerical simulation; tropical cyclone; sea spray; parameterization scheme

CLC number: P444 **Document code:** A **doi:** 10.3969/j.issn.1006-8775.2009.01.008

1 INTRODUCTION

Over the open ocean and with high winds, large amount of minute water droplets get loose from wavy sea surface to form so-called sea spray, due to the effect of broken-up waves and air bubbles [1]. Being an intense synoptic system generated over the surface of tropical or subtropical oceans, the tropical cyclone (TC) is a hotbed for the generation of sea spray as high winds, strong waves and rainstorms are the major weather it brings about during its active period. The appearance of large amount of sea spray is undoubtedly affecting the heat exchange between the atmosphere and sea. As shown in a series of findings from recent research [2-6], there is significant increase in the air-sea fluxes of latent and sensible heat and abundant heat is supplied for the formation and persistence of hurricanes when sea spray as well as high winds are being taken into account for the Atlantic Ocean, reducing the sea level pressure, increasing the maximum wind speed near the eye of the simulated hurricane, and making it more likely to improve the forecast of hurricane intensity.

It is by changing the air-sea fluxes of latent and sensible heat that sea spray influences the development and evolution of TCs. At present, parameterization is the only way to determine its contribution to the flux exchange between the air and sea, because maritime measurement with high winds is extremely difficult. During the 1980s and 1990s and with the Humidity Exchange over the Sea (HEXOS) experiment, schemes for parameterizing the contribution of sea spray to air-sea flux were put forward in Fairall et al.[7-8] and Andreas [9-10]. The former scheme is for overall

Received date: 2007-11-02; **revised date:** 2009-01-15
Foundation item: Key Program of National Natural Science Foundation of China (40830235, 40333025); State Key Development Program of Basic Research (973 Program) of China (2004CB418301)
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parameterization, which, when applied to an axisymmetric TC boundary layer model, yields simulations that reproduce a more realistic structure of the boundary layer if sea spray is taken into account. The latter scheme is also a parameterization model that has the same feature and has been improved a number of times [11 – 17].

In the existing numerical prediction models, the computation of air-sea or land-air latent and sensible heat fluxes are usually included in the parameterization of the planetary boundary layer without considering the role of sea spray though. The Andreas' parameterization scheme with sea spray (V1.0) was coupled with the MC2 model of Canada to run numerical simulation on extratropical cyclones in the Atlantic and typhoons in the West Pacific [3, 18 - 19]. In order to probe into the contribution of sea spray to air-sea flux and its impacts on the development and evolution of Northwestern Pacific TCs, this study couples the latest version of the Andreas' sea spray fluxes parameterization scheme with MM5V3, a fifth-generation mesoscale model that has been widely applied in the operational forecast of TC in the world, to conduct sensitivity experiments for the case of TC Nabi (coded No.0514 in China).

2 PARAMETERIZATION SCHEMES FOR SEA SPRAY FLUXES

The computation of Andreas' scheme is made up of two parts, the interfacial flux and the spray flux. The former refers to air-sea fluxes of momentum, sensible and latent heat in normal circumstances, which can be determined generally by a total flux algorithm. The mathematical equations will be omitted here.

With the ongoing improvement of the Andreas' scheme, multiple versions have been established [13 - 15] in addition to the latest version of V3.1 used in this study. V3.1 has three major improvements over V2.0 in that (i) it has been verified and adjusted jointly with the HEXOS and FASTEX data [20], and (ii) it adopts a more efficient way to calculate the effective wave height [17]. Apart from that, a rapid microphysical algorithm rather than a complete microphysical model is used for the determination of empirical functions for wind speed [16]. Fig.1 graphically depicts the variation of the air-sea flux, which is determined with the Andreas' V3.1 scheme, with that of wind speed. It shows that the flux of sea spray rapidly increases and particularly so as far as sea spray latent heat is concerned; it is even greater than the interfacial flux when wind speed is more than 35 m/s. As shown in the curves of air-sea flux variation with sea surface temperature (SST) as presented in Fig.2, the flux of sea spray tends to increase with temperature, indicating

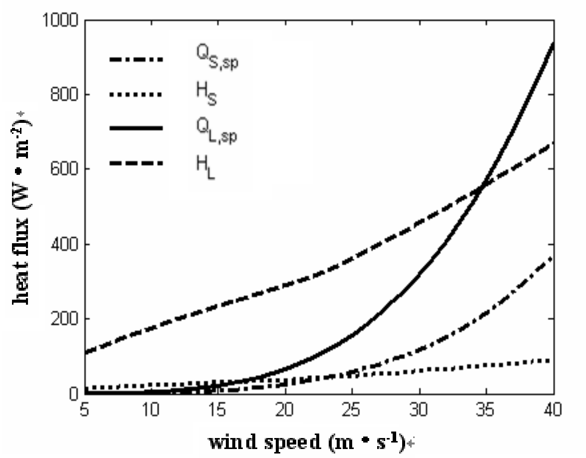

Fig.1 Variations of wind speed with the interfacial flux and sea spray flux. They are the computations for both fluxes when the reference altitude is taken at 18 m, relative humidity at 80%, pressure at 980 hPa, temperature at 23 C, SST at 25 C, and salinity at 34 psu. $Q_{S,sp}$ and $Q_{L,sp}$ stand for the sensible and latent heat respectively while H_S and H_L for interfacial sensible and latent heat respectively.

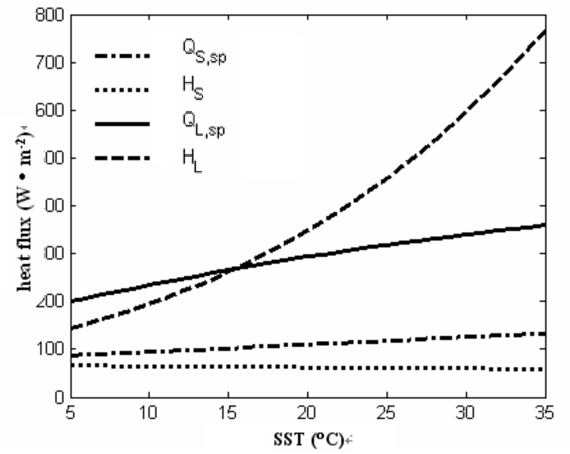

Fig.2 Variations of air-sea flux with SST. The computations are for the interfacial flux and sea spray flux when the reference altitude is taken at 18 m, relative humidity at 80%, pressure at 980 hPa, wind speed at 30 m/s, air temperature at being 2 C lower than SST, and salinity at 34 psu. The symbols of $Q_{S,sp}$, $Q_{L,sp}$, H_S and H_L have the same denotation as in Fig.1.

that the TCs that form and develop over the tropical low latitudes are affected more greatly by sea spray than those of the subtropics. It is different from the graphics as given by Li et al.[3], due to, according to Andreas, some degree of dependence of sea spray flux on temperature, and improvement has been made to the existing algorithm for sea spray flux [15].

3 NUMERICAL MODEL AND EXPERIMENT SCHEME

The numerical model being used in this study is the third version of MM5 by PSU / NCAR, U.S.A. Being a limited area and primitive equations model, MM5 adopts the sigma coordinates in the vertical direction and includes multiple physical processes such as cloud physics and boundary layer, each of which generally has a number of parameterization schemes to choose from.

In this study, there are 121×151 gridpoints in the horizontal direction at intervals of 30 km and 25 vertical layers with varying distance. The selected resolution is relatively high for the boundary layer, with about 18 m at the bottom layer of the model. The time step is 60 s for model integration. A simple ice scheme is used for explicit moist physical processes and the Grell scheme is used for the parameterization of cumulus convection with the effect of shallow convection taken into account. The cloud radiation scheme is for radiation process and the relaxation boundary condition is for the lateral boundary.

superimposing the large-scale field from NCEP / NCAR onto a Bogus model [21] and the center of Nabi at initial time was determined using the observations analyzed by the Central Meteorological Observatory of China.

In the experiments of this study, all of the algorithms as suggested by Andreas were used to calculate the air-sea fluxes of sensible and latent heat. Two experiments, one with spray and the other without spray, were designed, to be called Exp.W and Exp.N, respectively.

4 RESULTS ANALYSIS

To explain the impacts of sea spray on the generation and development of TCs, the spatial distribution of the latent and sensible heat fluxes during the evolution are given. Only the results for the time after 18 h into the integration will be presented to avoid repetition (Fig.3).

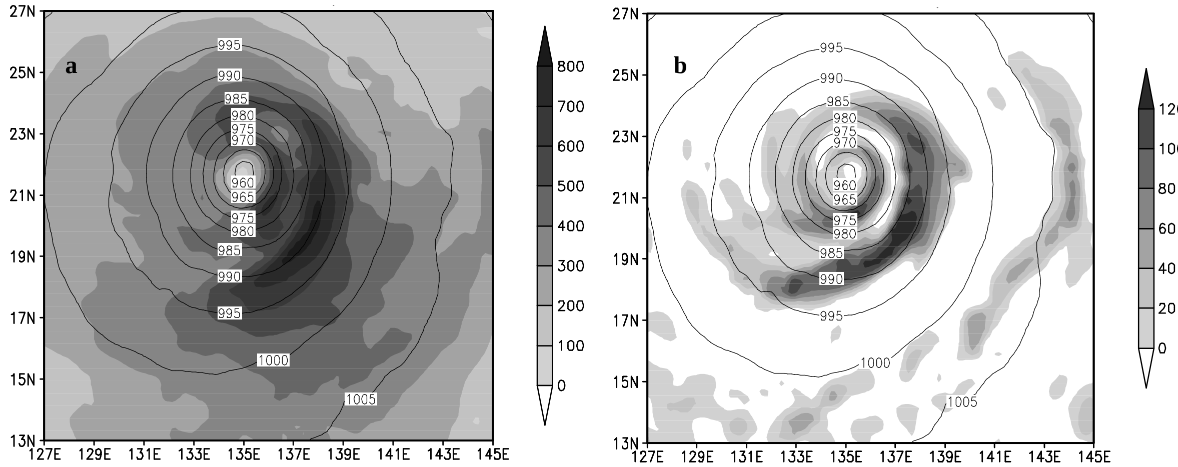

Fig.3 Heat fluxes of Exp.W for 18:00 September 2, 2005 (as indicated by the shade and only the region greater than 0 is given with the unit of W/m^2) and sea level pressure (the solid line in the unit of hPa). a. latent heat flux and sea level pressure; b. sensible heat flux and sea level pressure.

The coupled model is used to simulate Nabi for a period of 48 h from 00:00 September 2 to 00:00 September 4, 2005 (UTC, the same below). Intensifying to a tropical cyclone over waters east of Guam on August 29, 2005, Nabi moved west to northwest with maximum wind speed once above 50 m/s before recurving north and making landfall in Japan, weakening and dissipating eventually. The period of simulation in this study is the 48 h from the acquisition of the intensity of severe typhoon by Nabi to the point of northward recurvature.

For the background field of the experiments in this study, the reanalysis data of NCEP / NCAR was used, which is available 4 times daily and at a resolution of 1°×1°. In view of the fact that Nabi was typical supertyphoon, the model initial field was established by

The latent heat fluxes in the simulation experiments Exp.W and Exp.N and the distribution of their difference (Figure omitted) further demonstrate how sea spray latent heat flux affects the evolution of the TC. With the inclusion of sea spray effects, the latent heat flux increased dramatically and its maxima differed by a range of 200 – 400 W/m^2 between the two experiments with the increment roughly from 35% to 80% over the entire period of simulation. For both experiments, the maxima of latent heat flux appeared in the zone of maximum TC wind speed.

Fig.4 gives the comparison of the simulated tracks of the TC with the observed one with and without the effect of sea spray, respectively for Exp.W and Exp.N. To illustrate the effect of sea spray on TC intensity, Fig.5 presents the comparison of minimum sea level pressure within the TC as simulated by MM5V3 with and without the inclusion of sea spray effect. Table 1 gives the comparison of simulated maximum wind speed with the observed one as analyzed by the Central Meteorological Observatory for various moments of time.

Table 1 The comparison of maximum wind speed between the simulation and observations (Unit: m/s)

Integration time / h	6	12	18	24	30	36	42	48
Observations	60	60	60	60	60	55	50	50
Exp. N	47	41	39	39	39	38	38	37
Exp. W	48	43	42	42	43	43	43	42

For details of the computation of air-sea momentum, sensible and latent heat, numerical models and experiment schemes and analysis of results, see the Chinese edition of the journal.

5 CONCLUSIONS

Under the circumstances of strong wind speed with the TC, sea spray evaporation significantly enhanced the latent and sensible heat fluxes within it, especially so with the latent heat for which the maximum could increase as much as by 35% - 80% for the case of TC Nabi in this study. The zone of large latent heat flux was corresponding to the one of large wind speed near the eye. Regardless of the sea spray effect, the model was successful in simulating the migratory track of Nabi such that the mean 48-hour error was smaller than 110 km, suggesting mild impacts of sea spray effects on the TC track. With the inclusion of sea spray effects, however, the warm-core structure was more evident and the ascending airflow more intense near the eyewall due to the enhanced upward transport of water vapor and latent heat from the sea surface, a consequence arising from continuous release of fine sea spray droplets from the sea surface into the atmosphere. In the comparison between the two experiments, 48-hour minimum pressure over sea surface differs by 9 hPa and maximum wind speed by 5 m/s, showing that the simulation is closer to the observation if sea spray is included.

It should be kept in mind that this study has just coupled parameterization schemes for sea spray flux with one of the boundary layer schemes of MM5V3. More research and observational facts are needed to probe into the mechanisms by which sea spray affects the evolution of the TC, due to the complexity found in the structure and evolution of the TC and the uncertainties in relevant parameterization schemes themselves. It is our plan to work more on this issue in the future.

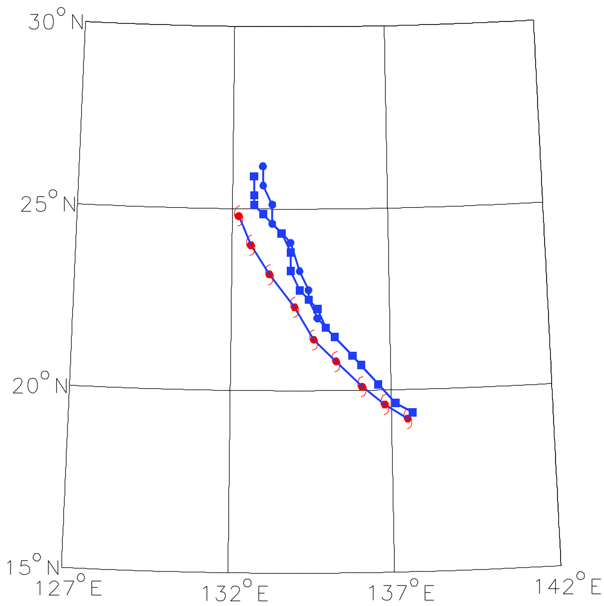

Fig.4 Tracks of Nabi from 00:00 September 2 to 00:00 September 4. : 6-hourly analysis; ●: 3-hourly simulations by Exp.W; ■: 3-hourly simulations by Exp.N.

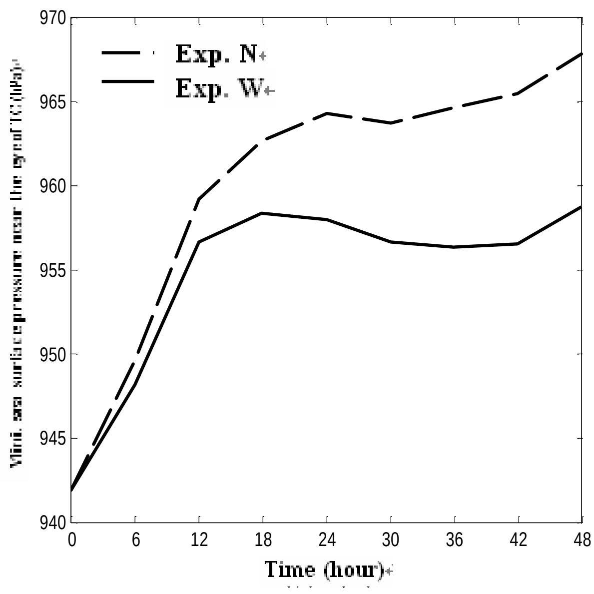

Fig.5 Comparisons of minimum sea level pressure near the eye of Nabi with and without the inclusion of sea spray effect.

Acknowledgement: The sea spray parameterization scheme used in this study is available by the courtesy of Edgar L Andreas from Cold Regions Research and Engineering Laboratory (CRREL).

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Citation: ZHENG Jing, FEI Jian-fang and WANG Yuan et al. Numerical experiments on the impacts of sea spray on tropical cyclones. *J. Trop. Meteor.*, 2009, 15(1): 54-58.