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NUMERICAL SIMULATION OF SOUTH CHINA SEA MONSOON ONSET BASED ON GRAPES MODEL AND EXPERIMENTS ON INITIAL MODEL FIELDS

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Abstract: The Global and Regional Assimilation and Prediction System (GRAPES), a limited-area regional model, was used to simulate the onset of South China Sea summer monsoon. In view of the relatively insufficient information about the initial field in simulation predictions, the Advanced Microwave Sounding Unit-B (AMSU-B) data from a NOAA satellite were introduced to improve the initial values. By directly using the 3-dimensional variational data assimilation system of GRAPES, two schemes for assimilation tests were designed. In the design, Test 1 (T1) assimilates both sounding and AMSU-B data, and Test 2 (T2) assimilates only the conventional sounding data, before applying the model in simulation forecasts. Comparative experiments showed that the model was very sensitive to initial fields and successful in reproducing the monsoon onset, allocation of high- and low-level wind fields during the pentad of onset, and the northward advancement of the monsoon and monsoon rain bands. The scheme, however, simulated rainfall and the location of the subtropical high with deviations from observations. The simulated location of the subtropical high was more westward and northward and the simulated rainfall for the South China Sea was larger and covered a broader area.

Key words: numerical simulation; GRAPES model; South China Sea summer monsoon; onset; three-dimensional variational assimilation

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1 INTRODUCTION

Located in the Asian monsoon region, China is subject to the effect of monsoons and damages brought about by seasonal droughts and floods[1]. Thus forecasting monsoon activity is important. With the fast development of computing technology and numerical weather prediction (NWP) models and the increase of data amount, much progress has been made in the research of numerical approach on the monsoon[2]. With regard to the numerical simulation of East Asian monsoon, an increase has been observed in the number of studies that tend to use global air-sea coupled models and regional climate models to simu1ate its seasonal variations and anomalies[3-5]. For example, Liu et al.[5] used the Predictive Ocean Atmosphere Model for Australia to forecast the onset of the South China Sea summer monsoon (SCSSM) in 2003 and 2004. Results showed that the model had some degree of capability to forecast the SCSSM onset, with 20 days of maximum lead time 1imit of forecast, slightly more than the two-week upper limit of the existing mid-term forecast. During the SCSSM experiment, numerical simulations of the onset mainly focused on the simulation of SCSSM activity in 1998 using a mesoscale model, a regional climate mode1 and an air-sea coupled model[6-9]. To some extent, these studies have successfully simulated the seasonal progression of the monsoon and associated rain bands in the South China Sea and East Asian regions. Despite this,

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detailed simulation and research on the onset process of SCSSM are still lacking. Due to the unique geographical position of the South China Sea, it is necessary to develop regional models suitable for research on the SCSSM onset.

NWP models have two main errors: one is generated by dynamic and thermal processes and physical parameters of the model and the other results from initial conditions and boundary conditions of the model. In addition, NWP models are quite sensitive to the simulated region, grid resolution, vertical hierarchy, and choice of parameterization schemes[10-15]. Significant work has been performed on these issues but conclusions have been inconsistent, making conduct of further research necessary.

The Global and Regional Assimilation and Prediction System (GRAPES), developed by China independently[16], was the result of a research project on Technical Innovation of Numerical Weather Forecasting of the 10th National Five-Year Plan of Key Technologies Research & Development Program of China, undertaken by the Chinese Academy of Meteorological Sciences. Using GRAPES 3D-Variation (3D-Var) System, this paper assimilates the AMSU-B data of NOAA17 into the initial field of the model, conducts simulation experiments with GRAPES, and tests and analyzes the effects of improved initial values on the simulation/forecast of the SCSSM onset.

2 DESIGN OF SCHEMES

2.1 *Variational data assimilation systems of GRAPES*

The 3D-Var is an analysis system comprised of longitude/latitude meshes of Arakawa A gridpoint system in the horizontal and *p*-plane in the vertical. These are adjustable in both the horizontal and vertical directions. The method of increments was used in the system. The LBFGS approach was utilized in dealing with the minimization of controlled variables, and the Fortran90 language and module structures were used in the procedure. The system is useful in assimilating observations of sounding, cloud-derived winds and satellite radiance rates (brightness temperature).

2.2 *Test runs*

With a horizontal resolution of 30 km and a total of 31 layers, GRAPES uses surface and upper-level reports as well as the AMSU-B data of NOAA17 satellite in its initial field, without the input of radar data. It operates by a time step of 600 s with the model set within the domain (54°–160°E，20°S–40°N). Simple ice microphysics (NCEP cloud 3, with NCEP standing for the U.S. National Centers for Environmental Prediction), Kain-Fritsch convection, Dudhia shortwave and RRTM longwave radiation scheme, and MRF boundary layer scheme, among others, were used in the parameterization. To investigate the performance of the AMSU-B data applied in the numerical simulation, two assimilation schemes were designed, both set against the background of T_{213} analysis. While Test 1 (T1) assimilates both the sounding data and AMSU-B data, Test (T2) takes care of the assimilation of conventional sounding data only. GRAPES 3D-Var was used to assimilate the initial field with the setting of time window at 2 h. Then, the limited regional model of GRAPES was used in simulation. Results were compared and analyzed.

For the simulation/forecast of the SCSSM onset in 2004 and 2005, the onset period of respective monsoons were chosen as the time of simulation, [i.e., from 1200 (Coordinated Universal Time (UTC)) 15 May to 1200 UTC 20 May for the 2004 monsoon and from 1200 UTC 20 May to 1200 UTC 25 May for the 2005 monsoon[17]. For the background field at initial time, the objective analysis of the T_{213} model was used with the forecast field of model as the boundary layer, whose conditions were updated every 12 h.

2.3 *Data of initial field*

Fig.1 shows 3 730 pieces of satellite-derived radiance data for the initial time (1200 UTC 15 May) in the 2004 case. The data set effectively covers Tropical Cyclone Nida in the South China Sea, which intensified to a tropical depression at 1800 UTC 15 May (coded 05W-04) and then to a tropical storm. At the initial time, Nida was located in the Phillippines and the Phillippine Sea (10.1°N, 128.4°E). The satellite data had a partial coverage of the southwest portion of the storm.

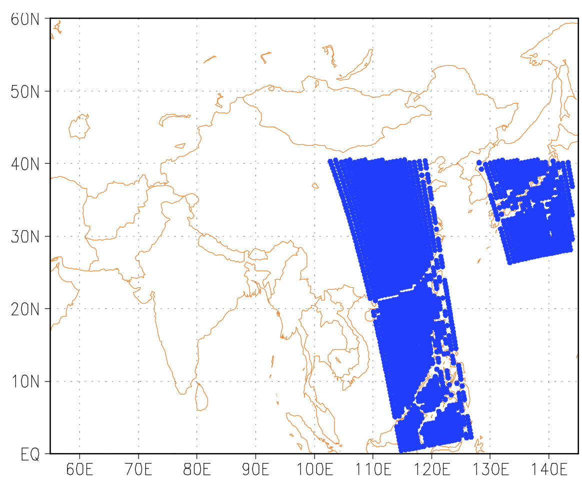
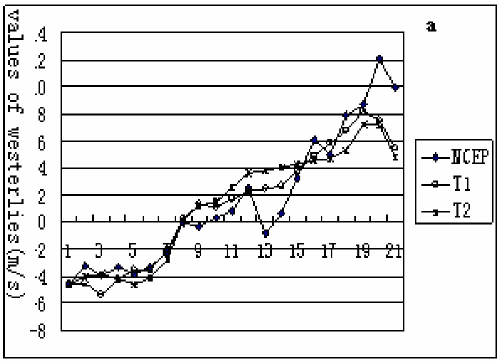


Fig. 1. Areas covered by the AMSU-B data of NOAA17 at initial time

3 COMPARISON AND ANALYSIS OF THE SIMULATED ONSET OF SCSSM

3.1 *Changes in mean zonal winds at 850 hPa*

Figure 2 shows comparisons of the curves of 850 hPa mean zonal wind variations with time. The abscissa is the axis of time. The time around the onset of the 2004 and 2005 SCSSMs, at intervals of 6 h, are separately taken as the time to be covered in the simulation. The area being monitored for the onset is within 10°–20°N, 110°–120°E. As shown in the comparisons between T1 and T2 (with the observations being the NCEP reanalysis at a resolution of 1°×1°), both experiment schemes for 2004 were accurate in simulating the date of 16 May as the time when the westerly wind shifted directions in the South China Sea and the subsequent process of westerly growth began. However, mean values of the westerly wind speed were, over most of the simulated time, larger than those of the NCEP reanalysis and did not decrease to a point smaller than the NECP value until the 96th hour after the commencement of model integration. Toward the end of the model integration, however, the formally small differences between the simulations and the NCEP data grew larger again. When correlation was sought between the time series of westerly areal averages of T1 and T2 and the westerly areal averages of NCEP reanalysis, coefficients were determined at 0.834 and 0.791 respectively. Confidence level was smaller than 0.01. This indicates that the variation tendency of the westerly wind simulated by T1 is closer to the NCEP reanalysis compared to T2.



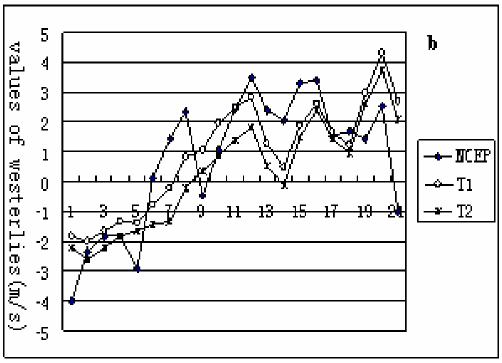


Fig. 2. Comparisons of the curves of mean zonal wind at 850 hPa changing with time. T1: Test 1; T2: Test 2. a: 2004; b: 2005

3.2 *Longitudinal cross-sections in mean zonal winds at 850 hPa*

In Fig. 2a, it was found that as the mean zonal wind turned into a westerly on 16 May and grew subsequently, it suddenly dropped on 18 May. What had caused it? From an analysis of 500 hPa observations (figure omitted), Nida travelled west on 17 May and passed the longitude of 130°E, reaching its westernmost point (123.5°E) on 18 May. At that time, the tropical storm weakened and disappeared from the South China Sea due to the negative effect exerted by the easterly wind field at the periphery of Nida on the persistence and growth of the westerly wind in the South China Sea. This reduced the progression of the westerly growth and caused the sudden drop of the mean zonal wind.

This sudden drop of the mean zonal wind was clearly shown in the longitude-time cross-sections of the 850 hPa zonal wind averaged across the area 110°–120°E (Fig. 3). The westerly wind began to travel north and passed 10°N on 16 May and then controlled the southern South China Sea on 17 May. Afterwards, it largely dominated over the region despite some shrinkage of the westerly wind at 1200 UTC 18 May, and became a dominant system for the entire South China Sea on 19 May. Neither T1 nor T2 yielded satisfactory results in simulating the decreasing mean westerly wind values, though the tests were successful in simulating close-to-observations interactions between the middle and lower latitudes during the monsoon onset. Compared with T2, T1 was closer to the NCEP reanalysis and more superior in reflecting the 18 May withdrawal of the westerly wind from the South China Sea and reproducing the northward progression of the wind field. With both schemes, however, the northward progression of tropical wind fields were slightly faster and the southward advancement of the westerly across the south of China was slightly slower than the NCEP reanalysis.

3.3 *Mean circulation fields at the pentad of SCSSM onset*

Based on 200 hPa mean vector wind fields (Fig. 4) at the pentad of SCSSM onset in 2005 (1200 UTC 20 May through 1200 UTC 25 May), the centre of an anticyclone had moved to an area around 20°N over the Indochina Peninsula. Thus, the South China Sea was in the control of a northeasterly wind. With T1, the distribution of the upper-level field was well reproduced and similar to reality: the center of South Asia high was mainly over the east coast of the Bay of Bengal and western Indochina Peninsula, the northern South China Sea was dominated by west winds or northwest diverging flows, and the southern part of the sea was controlled by a northeasterly flow. With T2, the distribution of the upper-level field was also well simulated and the position and intensity of the simulated South Asia high were consistent with the observation, except that the simulated westerly flow in the northern part of the South China Sea and the northeasterly flow in the southern part were weaker. This indicates that the simulations were similar for the east coast of the Bay of Bengal and western Indochina Peninsula, for which there was no coverage of satellite data and only sounding data were assimilated.

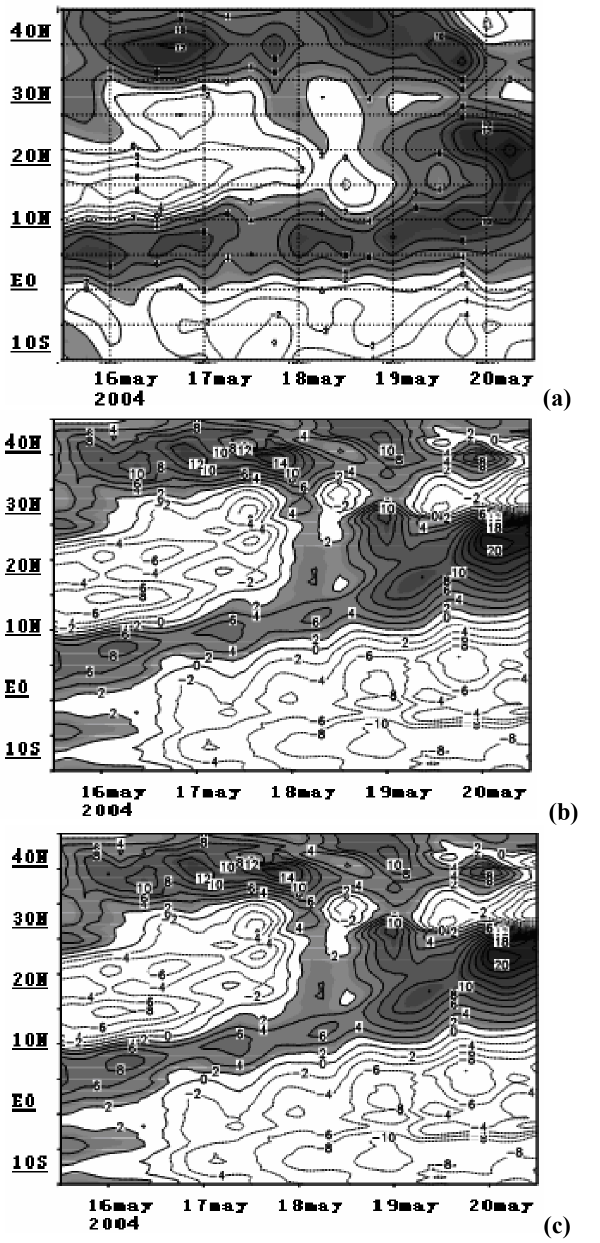


Fig. 3. Longitude-time cross-sections of 850 zonal winds over the simulated period of time in 2004. a: observation; b: T1; c: T2. The shades are for the west wind with speed > 2 m/s. Unit: m/s

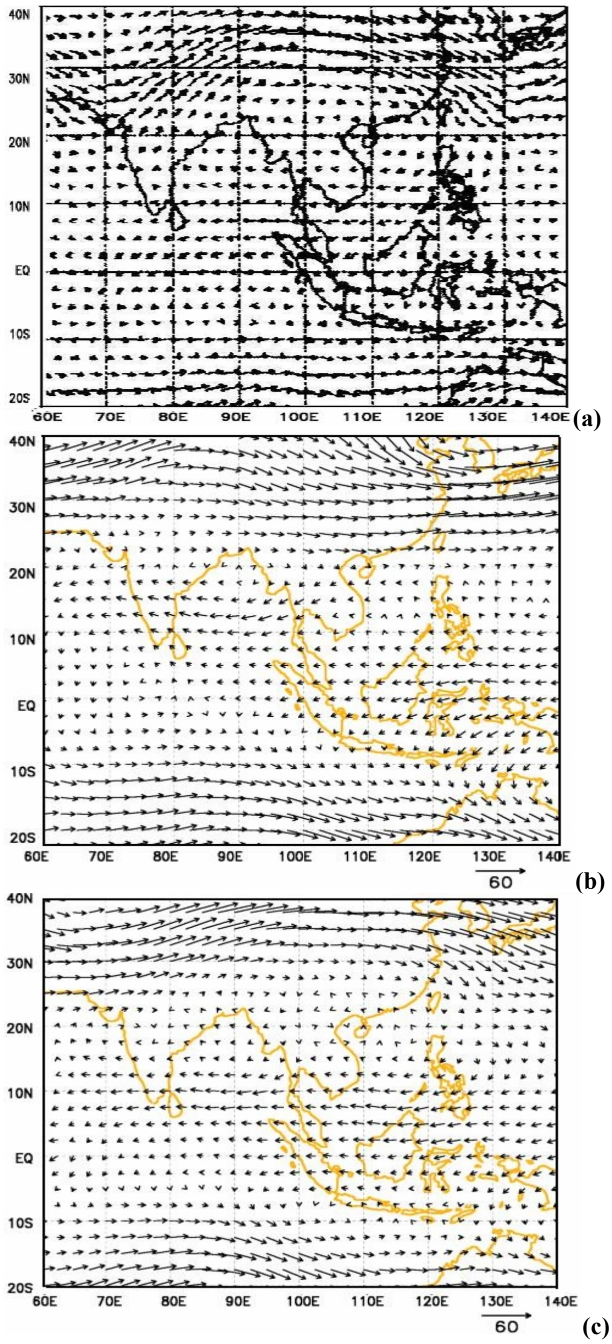
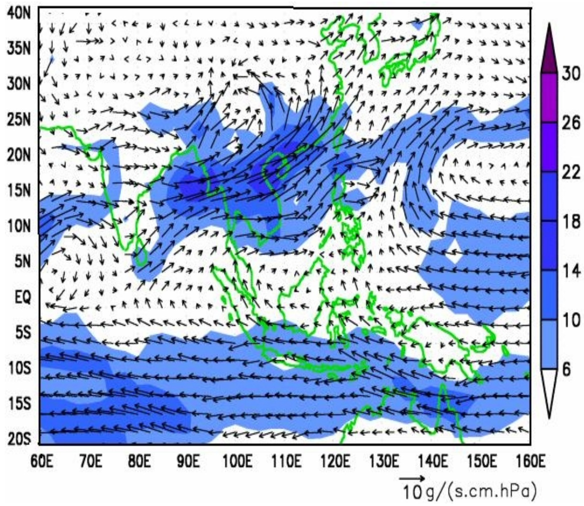


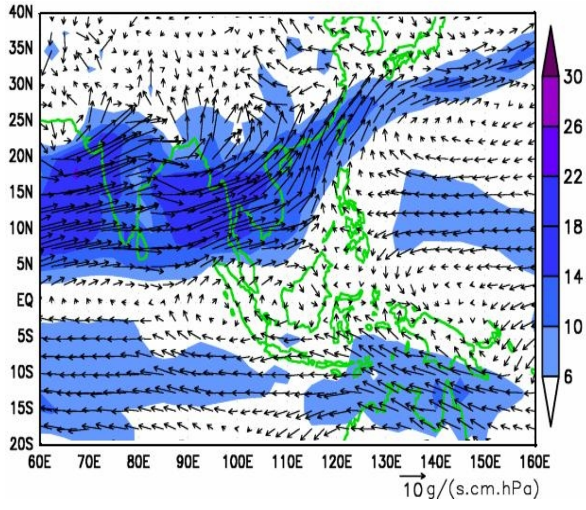
Fig. 4. 200 hPa mean vector wind field at the pentad of SCSSM onset in 2005. a: observation; b: T1; c: T2. Unit: m/s

3.4 *Mean moisture flux at the pentad of SCSSM onset*

At the pentad of SCSSM onset in 2005, the 850 hPa subtropical high also withdrew from the South China Sea (Fig. 5a). This suggested rapid development of intense convection and full-scale outbreak of the summer monsoon over the sea, as well as intensification and northward push of convection in the tropics. The moisture for the South China Sea is mainly made up of the southwest flow from the Bay of Bengal and the southeast flow from the West Pacific, which merge around 120°E before making recurvature toward waters south of Japan. Comparisons of Fig. 5b with Fig. 5c showed that T1 was better in simulating the basic characteristics of low-level wind fields and the eastward withdrawal of the subtropical high, though with location more to the west and intensity larger than observation, contributing to stronger-than-observation simulations of the southwest wind and larger-than-observation moisture flux throughout the South China Sea. For T2, differences existed compared with the observation in the simulated location and intensity of the West Pacific subtropical high, namely, it was stronger and more westward and northward. It was just because of the inaccurate reproduction of the subtropical high, the simulated southwest wind deviated from the observation, and the moisture flux was mainly in the southern and eastern sides of the sea. Both T1 and T2 were, therefore, not successful in simulating the mid- and low-level subtropical high possibly due to systematic model errors.



(a)



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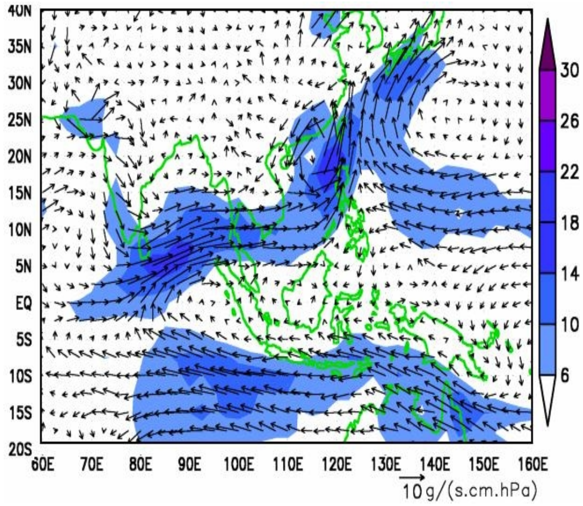


(c)

Fig. 5. Superposition of moisture flux and vector winds averaged for 850 hPa at the onset of SCSSM in 2005. a: observation; b: T1; c: T2. Unit: s·cm·hPa

3.5 *Rainfall at the pentad of SCSSM onset*

Comparisons of total rainfall at the pentad prior to the onset of SCSSM in 2005 (Fig. 6a) indicated significant intensification of precipitation with the monsoon onset (Fig. 6b) and northward movement of monsoon rain bands. As shown in the comparisons with the simulations, T1 and T2 were generally successful in simulating the increased precipitation in the South China Sea in post-onset time. However, deviations were observed in the increment of rainfall and rain areas as compared to observation because of the failure of position and intensity reproduction in relation to the subtropical high. For T1, the simulated rainfall was higher in terms of volume and covered a wider area due to larger-than-observation southwest winds. Thus, intense moisture supply over the entire South China Sea was observed. For T2, the simulated easterly flow was stronger than reality south of the subtropical high. This prevented a tropical southwest flow, originating from the Bay of Bengal, from covering the whole South China Sea, resulting in intense precipitation falling in the east and south of the sea.

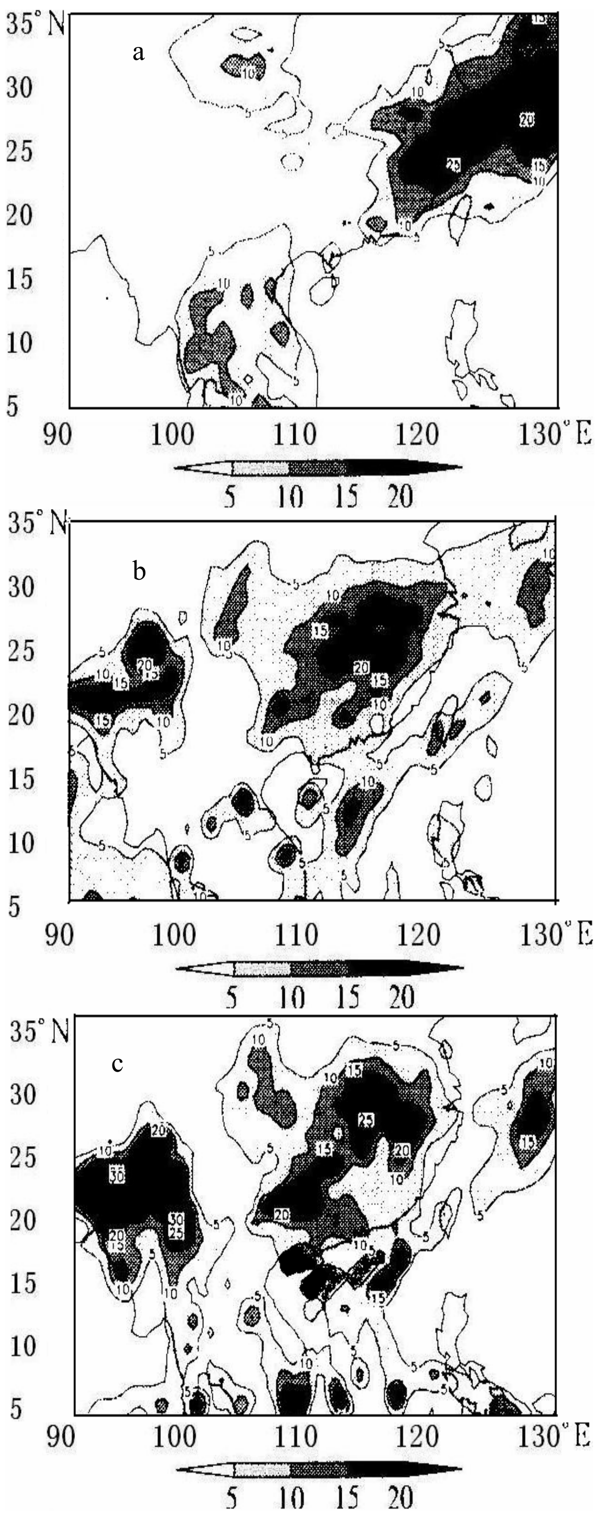
4 DISCUSSION AND CONCLUSIONS

GRAPES, a high-resolution regional model, was used in this work. Initial values were improved with the introduction of AMSU-B data of NOAA17 satellite. The 3D-Var data assimilation system of GRAPES was directly employed to run a series of sensitivity tests of the SCSSM onset in 2004 and 2005.

(1) The model was sensitive to the alterations of the initial field. T1 significantly corrected the onset forecast as compared with T2. Thus, it was able to simulate, with considerable success, the timing of direction shifts and subsequent growth of the westerly

wind over the South China Sea in 2004 and 2005. It likewise improved the forecast of the allocation of high- and low-level wind fields at the pentad of onset and the northward advancement of the monsoon, monsoon-related moisture flux and rain bands.

(2) T1 and T2 were both successful in simulating the upper-level wind field during the monsoon onset.



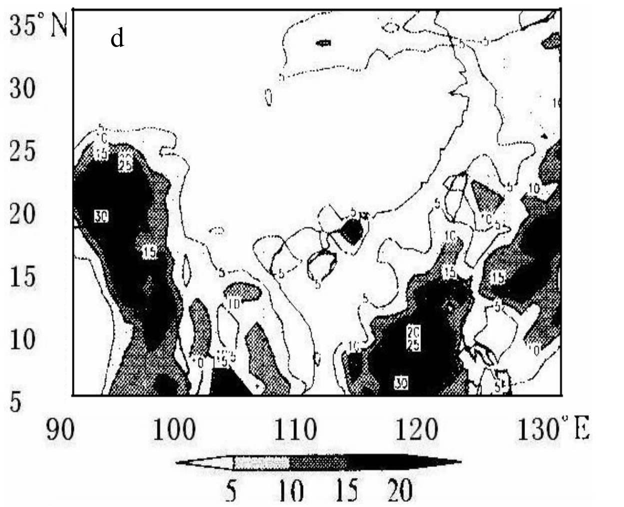


Fig. 6. Total rainfall for the pentad of SCSSM onset in 2005. a: observation for the pentad prior to onset; b: observation at onset; c: T1; d: T2. Unit: mm. Shades indicate rainfall greater than 5 mm.

(3) Some deviations existed between the simulations with both T1 and T2 and the observation in the rainfall and location of the subtropical high. The deviations were mainly the more westward and northward location of the subtropical high, and heavier and more extensive rainfall in the South China Sea.

(4) For both T1 and T2, the simulations of reduced mean west winds in the South China Sea in response to the effect of Typhoon Nida on 18 May 2004 were not satisfactory. The satellite data at initial time, covering only a small portion of the typhoon, did not effectively improve the initial field due to apparently insufficient data. Moreover, only three-dimensional variational data assimilations have been conducted with GRAPES in this study. It is necessary to further study four-dimensional techniques and incorporate as many types of data (such as those of radar) as possible to make the initial field more realistic to the observation among efforts toward better model forecasting.

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