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A STUDY ON SATELLITE DATA ASSIMILATION WITH DIFFERENT ATOVS IN TYPHOON NUMERICAL EXPERIMENTS

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Abstract: Based on the newly developed Weather Research and Forecasting model (WRF) and its three-dimensional variational data assimilation (3DVAR) system, this study constructed twelve experiments to explore the impact of direct assimilation of different ATOVS radiance on the intensity and track simulation of super-typhoon Fanapi (2010) using a data assimilation cycle method. The result indicates that the assimilation of ATOVS radiance could improve typhoon intensity effectively. The average bias of the central sea level pressure (CSLP) drops to 18 hPa, compared to 42 hPa in the experiment without data assimilation. However, the influence due to different radiance data is not significant, which is less than 6 hPa on average, implying limited improvement from sole assimilation of ATOVS radiance. The track issue is studied in the following steps. First, the radiance from the same sensor of different satellites could produce different effect. For the AMSU-A, NOAA-15 and NOAA-18, they produce equivalent improvement, whereas NOAA-16 produces slightly poor effect. And for the AMSU-B, NOAA-15 and NOAA-16, they produce equivalent and more positive effect than that provided by the AMSU-A. Second, the assimilation radiance from different sensors of the identical satellites could also produce different effect. The assimilation of AMSU-B produces the largest improvement, while the ameliorating effect of HIRS/3 assimilation is inferior to that of AMSU-B assimilation, while the AMSU-A assimilation exhibits the poorest improvement. Moreover, the simultaneous assimilation of different radiance could not produce further improvement. Finally, the experiments of simultaneous assimilation radiance from multiple satellites indicate that such assimilation may lead to negative effect due to accumulative bias when adding various radiance data into the data assimilation system. Thus the assimilation of ATOVS radiance from a single satellite may perform better than that from two or three satellites.

Key words: typhoon numerical prediction; ATOVS radiance; WRF-3DVAR; data assimilation cycle

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1 INTRODUCTION

Being closed to the Northwest Pacific Ocean, China is one of the countries frequently affected by the typhoon, with an average of 7 to 8 landfall typhoons every year[1]. The landfall typhoons could induce storm surge and tides to cause tremendous disaster as well as bringing about plenty of rainfall to ease the local dry weather. Therefore, the research on the typhoon has become one of the most issues that is focused most frequently. However, the typhoon originates over the vast tropical ocean with sparse conventional observations, which has been one of the major obstacles to improve the accuracy of typhoon forecast. Meanwhile, due to low resolution and lack of observations, the structure and intensity of typhoon vortexes are always misplaced and too weak in the forecast of global models[2]. With the rapid development of atmospheric science, remote sensing and data assimilation techniques, the all-weather data with high spatio-temporal resolution from remote sensing has become an indispensable supplement to the observations over the tropical ocean. Currently, major numerical weather prediction centers (e.g., National Centers for Environmental Prediction (NCEP), European Center for Medium-Range Weather Forecasts and Joint Typhoon Warning Center) have assimilated satellite data into their daily

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operational forecasting systems. One of the important data sets is the ATOVS radiance provided by the NOAA-KLM series polar-orbiting meteorological satellites, and the utilization of ATOVS radiance has become one of the most useful methods to improve the global forecasting skills[3].

ATOVS radiance has been widely applied in recent studies, which achieved many encouraging results. Zhang et al.[4] employed the Global/Regional Assimilation Prediction System (GRAPES) developed by the Chinese Academy of Meteorological Sciences, a three-dimensional variational data assimilation (3DVAR) system, and the Weather Research and Forecasting (WRF) model to investigate the effect of direct assimilation of ATOVS radiance on the track simulation of Typhoon Rammasun (0205). Their result indicated that the direct assimilation of ATOVS radiance could improve typhoon track forecast efficiently. Wang et al.[5] proposed a new scheme that combined the MM5 four-dimensional variational data assimilation (4DVAR) system with the BDA (Bogus Data Assimilation) technique for assimilating ATOVS radiance and demonstrated that the new scheme could successfully reconstruct the mesoscale characteristics of inner-core structure to improve typhoon track forecast. However, some of the superiority of the BDA technique may come from an appropriate bogus model. The closer the structure of the constructed bogus model to the observation, the better performance the BDA technique may have[6]. Since plenty of satellite data is available, it is possible to directly assimilate satellite data to improve the typhoon forecasting. TOM et al.[7, 8] indicated that the assimilation of ATOVS radiance in the NCEP global data assimilation system (GDAS) can effectively improve the global forecast skill, especially in the Southern Hemisphere. James et al.[9] further demonstrated that the successive addition of each NOAA polar-orbiting satellite in GDAS could improve forecast quality, and the forecast improvements from two satellites were generally smaller than that from three satellites, consistent with the increasing areal coverage obtained from the third satellite. Overall, previous studies primarily focused on the application of ATOVS radiance to the global model or using radiance from a single satellite in the regional model, yet few researches are involved with the application of radiance from multiple satellites in high-resolution regional models. Furthermore, it is necessary to investigate whether the simultaneous assimilation of ATOVS radiance from multiple satellites in the regional model would perform better than that from two satellites or a single one.

The purpose of this study is to evaluate the impact of assimilating different ATOVS radiance on the typhoon forecast. Here we carry out a case study of Super Typhoon Fanapi from 1200 Coordinated Universal Time (UTC) 17 September to 0000 UTC 20 September 2010. And the Weather Research and Forecasting (WRF) model and its three-dimensional variational data assimilation (3DVAR) system are employed to construct twelve experiments on different ATOVS radiance. The impact of assimilating different ATOVS radiance on initial vortex circulation, inner-core structure of typhoon and subsequent intensity and track forecasts are analyzed to explore the potential of ATOVS radiance in data assimilation and to provide a reference for typhoon operational prediction.

2 OVERVIEW OF THE TYPHOON CASE AND BRIEF INTRODUCTION TO ATOVS RADIANCE

Super Typhoon Fanapi generated over the sea about 740 km southeast off Yilan City of Taiwan Island at 1200 UTC 15 September 2010. Figure 1 is the observational track of Fanapi every 6 hours issued by the National Meteorological Center of China. It is shown that Fanapi moved slowly and mainly towards the northwest after its formation, then intensified to be a tropical storm at 0300 UTC 16 September, and further developed to be a strong typhoon at 1000 UTC 17 September. Subsequently it shifted southwestwards and accelerated. After that point, Fanapi continued to intensify to be a super typhoon at 0800 UTC 18 September, and made two landfalling courses at Hualien coast of the island at 0100 UTC 19 September and Zhangpu coast of Fujian province at 2300 UTC 19 September, respectively. On the offshore area of Guangdong and southern Fujian province, the daily precipitation exceeded 250 mm, affecting people's livelihood and property immensely.

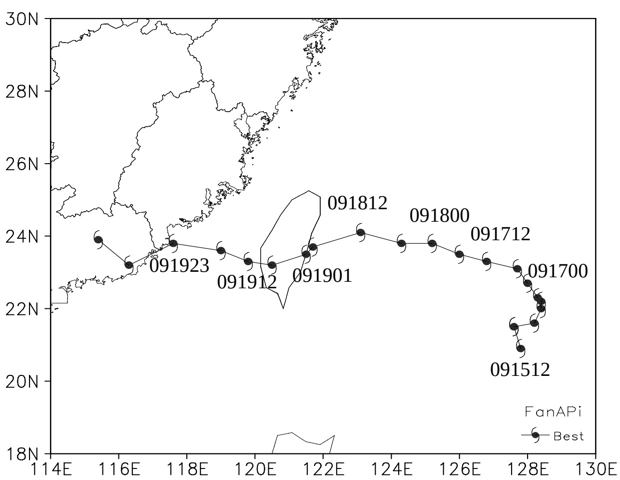

Figure 1. 6-hourly interval observational track of Super Typhoon Fanapi.

ATOVS is the advanced TIROS Operational Vertical Sounder (TOVS), primarily onboard the NOAA-KLM series of polar-orbiting meteorological satellites. The ATOVS instrument is composed of the

High Resolution Infrared Radiation Sounder (HIRS/3), the Advanced Microwave Sounding Units-A (AMSU-A) and -B (AMSU-B). The HIRS/3 contains 20 channels, of which 19 are infrared channels and one is visible channel, and the spatial resolution at nadir is 20 km. The AMSU-A is a cross-track and stepped-line scanning radiometer composed of 15 channels, and the half-power point of the instantaneous field-of-view angle is 3.3° with a spatial resolution at nadir of about 45 km. The AMSU-B is a cross-track but a continuous line scanning radiometer composed of five channels, whose half-power point of the instantaneous field of view is 1.1°, and its spatial resolution at nadir is 15 km[10]. With multiple channels and high spatial resolution, the remote sensing of ATOVS instrument can detect all-weather conditions, not only atmospheric information under clear sky, but also atmospheric temperature and moisture profiles under cloudy sky. In this study, the ATOVS radiance data of level 1b is supplied by NCEP historical archive, which includes data from 0000, 0600, 1200 and 1800 UTC, available four times per day within a 6-h time window from the NOAA-KLM series of satellites. Note that the horizontal resolution of the radiance data is interpolated to 120 km in the WRF-3DVAR system, therefore, it can be flexibly used on the satellite platform with different serial number and type of sensors. The HIRS/3 and AMSU-B include data from NOAA-15, -16 and -17, while the AMSU-A includes data from NOAA-15, -16 and -18. Considering some instrument problems that occurred on NOAA-17, here we just estimate the impact of assimilating ATOVS radiance data from NOAA-15, -16 and -18. In addition, we also designed an experiment for further examination with the assimilation of conventional observations, which are composed of surface observations (SYNOP), radiosonde profiles (SOUND), aircraft reports (PILOT) and ship reports (SHIP) from the Global Telecommunication System (GTS).

3 WRF MODEL CONFIGURATION AND EXPERIMENT DESIGN

In this study, experiments were performed with the WRF model (version 3.2) and its three-dimensional variational assimilation (3DVAR) system[11], and the initial field and lateral boundary conditions (at 3-h intervals) were provided by the China Air Force global model T_L511L60 (denoted as T511) forecasts with about 0.5°×0.5° grid resolution. A two-way interactive nested grid technique with two levels is employed. The horizontal resolution of the large and small grid is 18 km and 6 km with a grid number of 400×361 and 320×250, respectively. And the centers of both domains locate at 25°N, 120°E. The vertical structure of model comprises 35 σ levels. Model physical schemes include the new Kain-Fritsch cumulus scheme (not used in the 6-km inner domain), the WRF Single Moment 6-class simple ice microphysics scheme, the Yonsei University planetary boundary layer scheme, the Rapid Radiation Transfer Model longwave radiation and the Dudhia shortwave radiation scheme.

For evaluating the impact of assimilating different ATOVS radiance on typhoon intensity and track forecast, a control forecast (CT) without additional data assimilation was carried out first, and then data assimilation cycle (denoted as DAC) experiments were employed[13-15]. Instead of directly adopting T511 forecasts for the first guess in the DAC experiments, a WRF simulation was first integrated 6 hours from 1200 UTC to 1800 UTC 17 September 2010 to provide a first-guess field for data assimilation in order to remove the spin-up effect in the regional model[12]. (During the initial stage of simulation, inconsistency may exist between the vapor and thermal field to degrade the forecast quality.) Then the CT continued the simulation of Fanapi without additional data assimilation and integration for the remaining 54 hours. For the DAC experiments, data assimilation was conducted with three consecutive 6-hourly data assimilation within a 12-hourly assimilation window (from 1800 UTC 17 to 0600 UTC 18 September 2010). During each cycle, the background field came from the forecast of the previous cycle. Note that all the DAC experiments were performed on the outer domain, and the initial condition for the inner domain was derived from the outer domain using an interpolation scheme. However, all of the forecasts were run for both domains until 0000 UTC 20 September 2010 (Figure 2).

Furthermore, based on the serial number of satellites and type of sensors, twelve experiments were designed. As shown in Table 1, all the experiments were employed for assimilating ATOVS radiance (e.g. Exp.12 aims to assimilate AMSU-A radiance from NOAA-15, -16 and -18 at 1800 UTC 17, 0000 UTC 18 and 0600 UTC 18 September 2010 respectively) except Exp.2, which was designed for assimilating conventional observations.

(1) To test the impact of assimilating radiance data of the same type from different satellites on typhoon forecast, experiments were designed to assimilate AMSU-A from different satellites (e.g. Exp.3, Exp.4 and Exp.5) and AMSU-B (Exp.6 and Exp.7).

(2) To test the impact of assimilating radiance data in different types from identical satellites, experiments were designed to assimilate radiance data from NOAA-15 (e.g. Exp.3 and Exp.6) and NOAA-16 (e.g. Exp.4, Exp.7, Exp.8, Exp.9 and Exp.10).

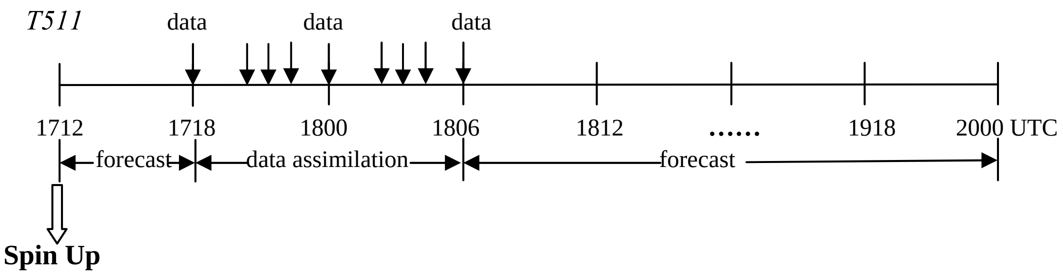

Figure 2. Schematic diagram for data assimilation cycle.

Table 1. Experimental design for ATOVS radiance.

Experiment		Satellite	Type of observations	Time of data assimilated
Exp.1	CT	NO	NO	NO
Exp.2	DAC_obs	Conventional Observations	SYNOP, SOUND, PILOT,SHIPS	1718, 1800, 1806
Exp.3	DAC_15a	NOAA-15	AMSU-A	1718, 1800, 1806
Exp.4	DAC_16a	NOAA-16	AMSU-A	1800, 1806
Exp.5	DAC_18a	NOAA-18	AMSU-A	1718, 1806
Exp.6	DAC_15b	NOAA-15	AMSU-B	1718, 1800, 1806
Exp.7	DAC_16b	NOAA-16	AMSU-B	1800, 1806
Exp.8	DAC_16h	NOAA-16	HIRS/3	1800, 1806
Exp.9	DAC_16ab	NOAA-16	AMSU-A, AMSU-B	1800, 1806
Exp.10	DAC_16abh	NOAA-16	AMSU-A, AMSU-B, HIRS/3	1800, 1806
Exp.11	DAC_68a	NOAA-16, NOAA-18	AMSU-A	1718, 1800, 1806
Exp.12	DAC_568a	NOAA-15, NOAA-16, NOAA-18	AMSU-A	1718, 1800, 1806
Exp.13	DAC_56b	NOAA-15, NOAA-16	AMSU-B	1718, 1800, 1806
Exp.14	DAC_568ab	NOAA-15, NOAA-16, NOAA-18	AMSU-A, AMSU-B	1718, 1800, 1806

(3) To test whether the impact of assimilating radiance data from multiple satellites could bring more improvement than that from a single satellite, experiments were employed to assimilate radiance of the same type from multiple satellites simultaneously (e.g. Exp.11, Exp.12 and Exp.13) and different sensors from multiple satellites (Exp.14).

As shown in Table 2, NOAA-15 scanned the outer domain respectively at 1800 UTC 17, 0000 UTC and 0600 UTC 18 September 2010 in the DAC experiments, so that plenty of data were available (note that the number in the brackets denotes the total observations, while the number outside the brackets denotes the number of available observations assimilated into model that pass the quality control). The radiance data from NOAA-16 was available near 0000 UTC and 0600 UTC 18, but was invalid near 1800 UTC 17 September 2010 as the scanned area is out of the model outer domain. Although the scanned area of NOAA-18 is beyond the model domain near 0000 UTC 18, a lot of data were still available near 1800 UTC 17 and 0600 UTC 18 September 2010. Therefore, data assimilation experiments on ATOVS radiances at different time should be employed on suitable satellites. Besides, additional satellite radiance can be assimilated into the model through the data assimilation cycle.

4 ANALYSIS OF EXPERIMENT RESUTLS

The typhoon movement usually brings about storm surge and heavy rainfall to cause large disaster to the surrounding region. Thus it worths the effort to concentrate on the forecasting of typhoon intensity and track, especially for the 36-to-60-hour forecasts, which are of vital importance to typhoon monitoring and warning. For clarifying the impact of assimilating different ATOVS radiance, contrast analysis will be carried through different experimental schemes (Table 1). We will discuss and analyze results from the inner domain since it can provide more detailed characteristics of typhoon evolution[16].

4.1 *Analysis of intensity*

Due to the lack of sufficient conventional observations over the ocean, the structure of typhoon vortex tends to be ill-defined in the global model, and the position error is relatively large. Figure 3a is the background field at 1800 UTC 17 September 2010, which represents a fairly weak typhoon circulation. However, after adjusting for assimilation of ATOVS radiance, the circulation is intensified remarkably, with significantly dropped sea level pressure (SLP) and a compact vortex structure (Figure 3b, similar results are also produced by other schemes).

Table 2. List of data assimilated in DAC experiments.

Assimilation time	Data type		Number of observations assimilated
1800 UTC 17 Sept 2010	NOAA-15	ASMU-A	620(2438)
		AMSU-B	629(21996)
	NOAA-18	AMSU-A	1802(9225)
	GTS OBS	SOUND	5(5)
		SYNOP	1022(1051)
		PILOT	56(57)
		SHIPS	53(58)
0000 UTC 18 Sept 2010	NOAA-15	AMSU-A	1067(4006)
		AMSU-B	1090(36328)
	NOAA-16	AMSU-A	1730(6422)
		AMSU-B	1767(57833)
		HIRS/3	1797(14240)
	GTS OBS	SOUND	127(128)
		SYNOP	2398(2424)
		PILOT	98(105)
		SHIPS	53(56)
0600 UTC 18 Sept 2010	NOAA-15	AMSU-A	1159(4392)
		AMSU-B	1180(39560)
	NOAA-16	AMSU-A	215(823)
		AMSU-B	222(7474)
		HIRS/3	214(1729)
	NOAA-18	AMSU-A	1840(9681)
	GTS OBS	SOUND	6(6)
		SYNOP	1341(1384)
		PILOT	13(17)
		SHIPS	59(66)

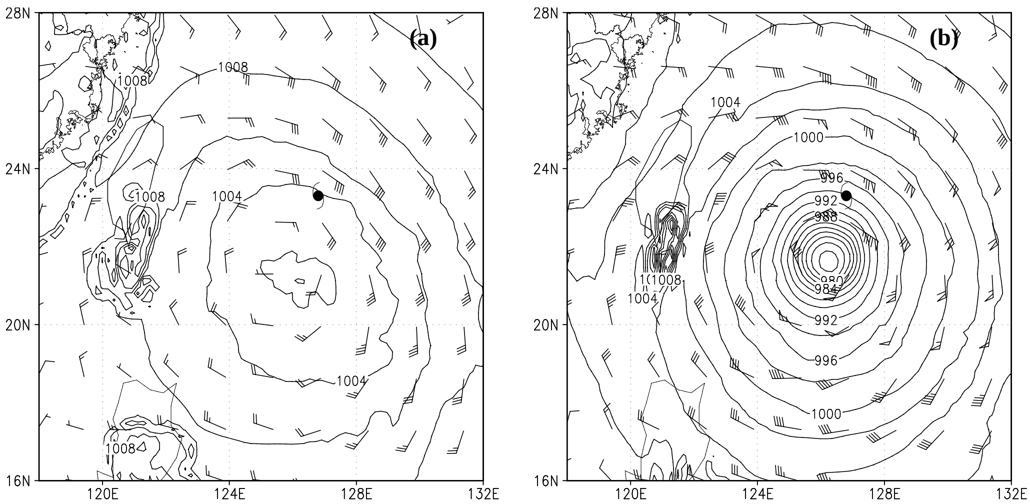

Figure 3. Sea level pressure (contour interval is 2 hPa) and wind fields (full bar represents 5 m/s) at 1800 UTC 17 September 2010 for experiments. (a): background field; (b): Exp.5 (typhoon symbol denotes the observed position of Fanapi).

In order to further investigate the impact of assimilating different ATOVS radiance on the initial intensity of the typhoon, the variation of geopotential height and wind fields in the inner center region of the typhoon were analyzed. Figure 4 is the pressure-longitude cross section through the typhoon center at 0600 UTC 18 September 2010. It shows that after the adjustment of data assimilation (all DAC experiments), the geopotential height on isobaric surfaces has decreased. Meanwhile, the wind fields are balanced by the dynamical and statistical relations embedded in the WRF-3DVAR system. The wind at the amplitude of 30 m/s appears in the lower troposphere from 900 to 700 hPa. The decreased geopotential height and increased wind speed on isobaric surfaces imply that the initial intensity of the typhoon has enhanced to generate a more compact vortex structure[17]. Although no significant difference seems to exist among assimilations of different ATOVS radiance, the results with the ATOVS radiance assimilation reveal information more efficiently than those with only conventional observations. Therefore, the assimilation may act as a supplement of conventional observations over the sea (Table 2). Compared with the Exp.4 result (DAC_16a), the reduced geopotential height and increased wind in the center of typhoon from Exp.7 (DAC_16b) are more obvious, especially in the middle troposphere near 500 hPa. It is very interesting to see that Exp.4 (DAC_16a) and Exp.5 (DAC_18a) exhibit an equivalent adjustment of geopotential height and wind speed (figure not shown), while the assimilation of AMSU-A radiance from two satellites in Exp.11 (DAC_68a) could not provide further improvement. Meanwhile, Exp.7 (DAC_16b) and Exp.13 (DAC_56b) generate an equivalent adjustment of geopotential height and wind speed, but the improvement in Exp.14 (DAC_568ab) is declined. It indicates that the improvement resulting from simultaneous assimilation of ATOVS radiance from three satellites may be even smaller than that due to assimilation of ATOVS radiance from a single satellite.

In fact, certain instrumental bias is present with different sensors of identical satellites. Moreover, identical sensors from different satellites may also result in bias due to the performance of the instrumental and scanning bias. As a result, when assimilating various radiance data (from various sensors of a single satellite or multiple satellites) simultaneously, bias may accumulate to cause degradation.

For detailed investigation of the impact of assimilating different ATOVS radiance on intensity forecast of Typhoon Fanapi, Figure 5 shows the simulated intensity from the DAC experiments from 1800 UTC 17 to 0000 UTC 20 September 2010. Considering the insignificant difference among the experiments, only part of the experiment result is given. As shown in Figure 5, compared with the control experiment (Exp.1), both the assimilation of conventional observations and ATOVS radiance can improve typhoon intensity effectively, that is, the average bias of central sea level pressure (CSLP) drops from 42 hPa in the no-assimilation experiment to 18 hPa in the experiments with assimilation. However, the difference among the data assimilation experiments is not obvious and less than 6 hPa on average, indicating limited improvement in typhoon intensity when solely assimilating ATOVS radiance. This may be attributed to the Radiative Transfer Model (RTM) built in the current WRF-3DVAR. It can primarily simulate satellite radiance under clear sky conditions, but could not effectively deal with the radiance influenced by cloud or precipitation[18].

4.2 *Analysis of track*

Figure 6 shows the 6-hourly tracks of Super Typhoon Fanapi produced by different experiments being compared with the observed track (indicated by the typhoon symbols). Note that the forecasts include the first 12-h analysis period. We can see that large bias appears in Exp.1 (CT), especially during the middle and late period with asymmetric swinging deviation, which may be caused by weaker initial circulation (Figure 3a). However, after assimilating the ATOVS radiance, the initial circulation and pressure field of the typhoon become more compact and intensify significantly (Figure 3b). Thus the subsequent track moves more smoothly and much closer to the observation. Figure 6a shows the simulated track with assimilating conventional observations and AMSU-A data from different satellites, respectively. During the early stage, the southward bias produced by Exp.2 (DAC_obs) appears to be larger, while the bias of Exp.3 (DAC_15a) and Exp.5 (DAC_18a) are much smaller. Figure 6b presents the results of assimilating different radiance from NOAA-16. The forecast tracks produced by Exp.6 (DAC_16b) and Exp.8 (DAC_16h) are superior to that of Exp.4 (DAC_16a), and much closer to the observed track, especially in the late 48 hours. The moving speed simulated by Exp.4 (DAC_16a) tends to be slower. Figure 6c and 6d describe the tracks simulated by models with assimilating ATOVS radiance from multiple satellites simultaneously. It can be seen that the assimilation of ATOVS radiance from various sensors of multiple satellites could not produce further improvement than that from single satellite.

PU et al.[13] indicated that during the DAC, not only more observations will be assimilated to the data assimilation system, but also strong constraints will be set to correct the errors from the model forecasts. Thus the model physical processes can be improved effectively. For evaluating the impact of assimilating ATOVS radiance on typhoon track forecast using DAC in detail, Table 3 shows the simulated track bias in all experiments. Compared with Exp.1 (CT), it can be seen from Table 3 that the bias from DAC experiments are quite positive except Exp.10 (DAC_16abh). The results show that if more observations were assimilated to the model (listed in Table 2) through DAC, the initial field simulation may be improved to make the simulated tracks much closer to the observation. The "Improving Ratio" in Table 3, exhibiting increasing versus decreasing forecast times of simulated track bias as compared with that of Exp.1, implies that the forecasting times of simulation error are degrading little in most data assimilation experiments even when the size of cases increases, which further verifies the rationality and validity of the DAC method.

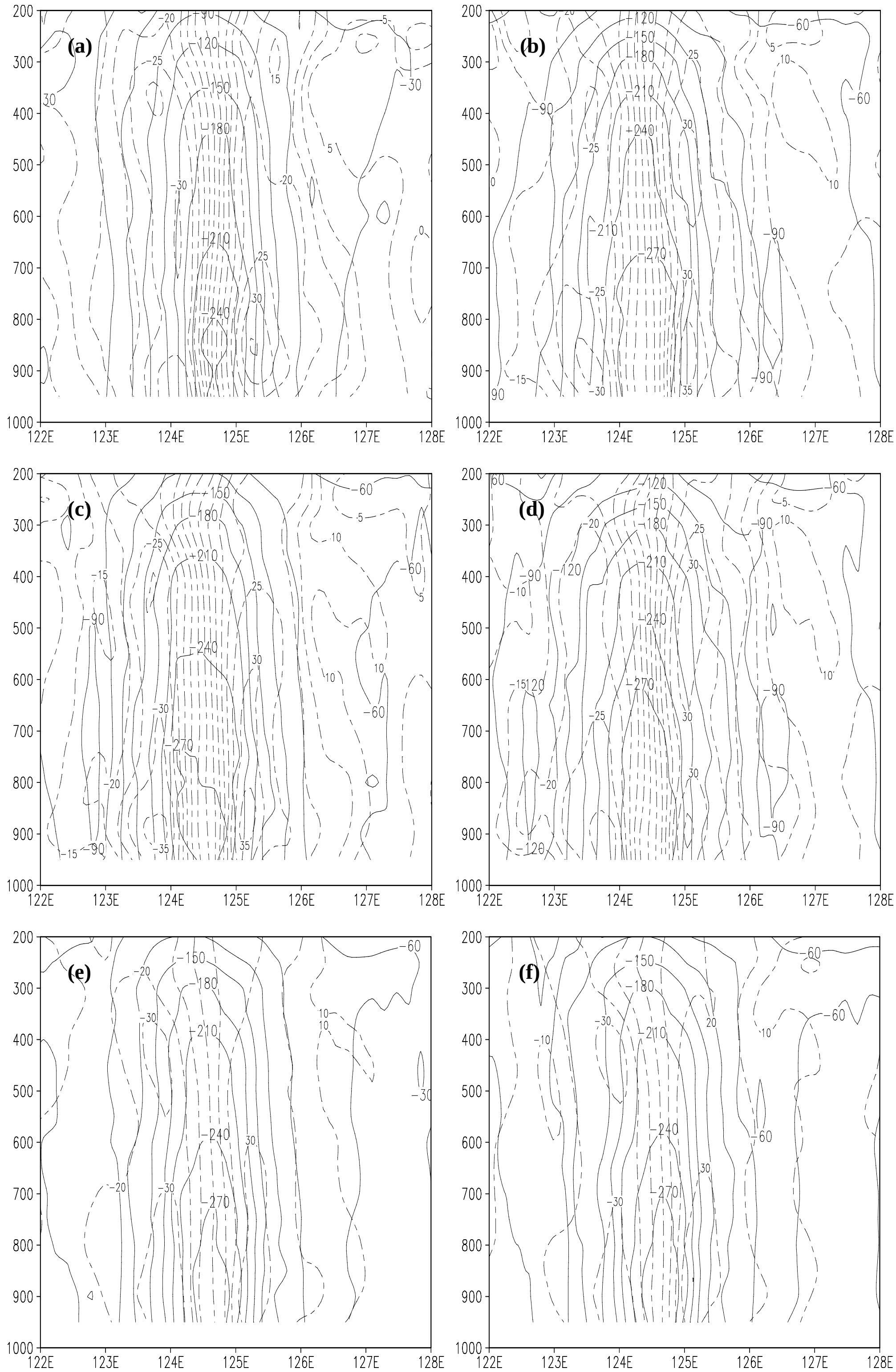

Figure 4. Pressure-longitude cross section of the geopotential height (gpm) and *v*-component wind speed (m/s) increments through the typhoon center at 0600 UTC 18 September 2010 for (a) Exp.2 (DAC_obs), (c) Exp.4 (DAC_16a), (e) Exp.11 (DAC_68a); (b) Exp.7 (DAC_16b), (d) Exp.13 (DAC_56b), and (f) Exp.14 (DAC_568ab).

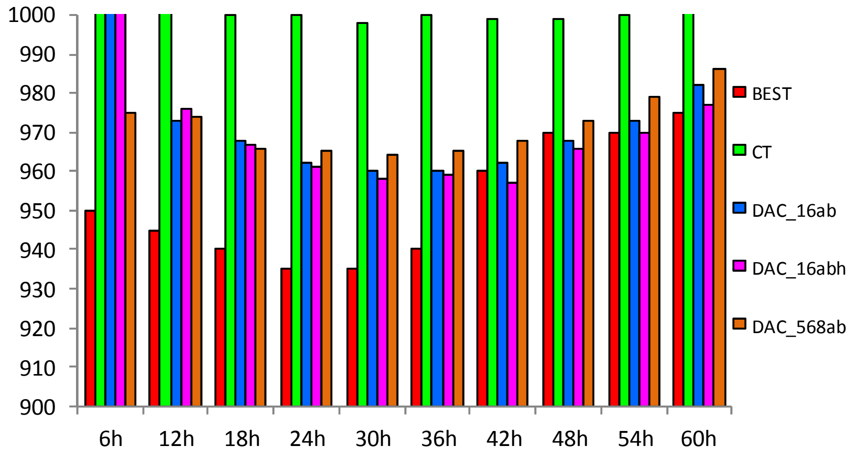

Figure 5. 6-hourly variations of the typhoon minimum central SLP from 1800 UTC 17 to 0000 UTC 20 September 2010 for partial experiments ("BEST" represents the observational SLP of Fanapi).

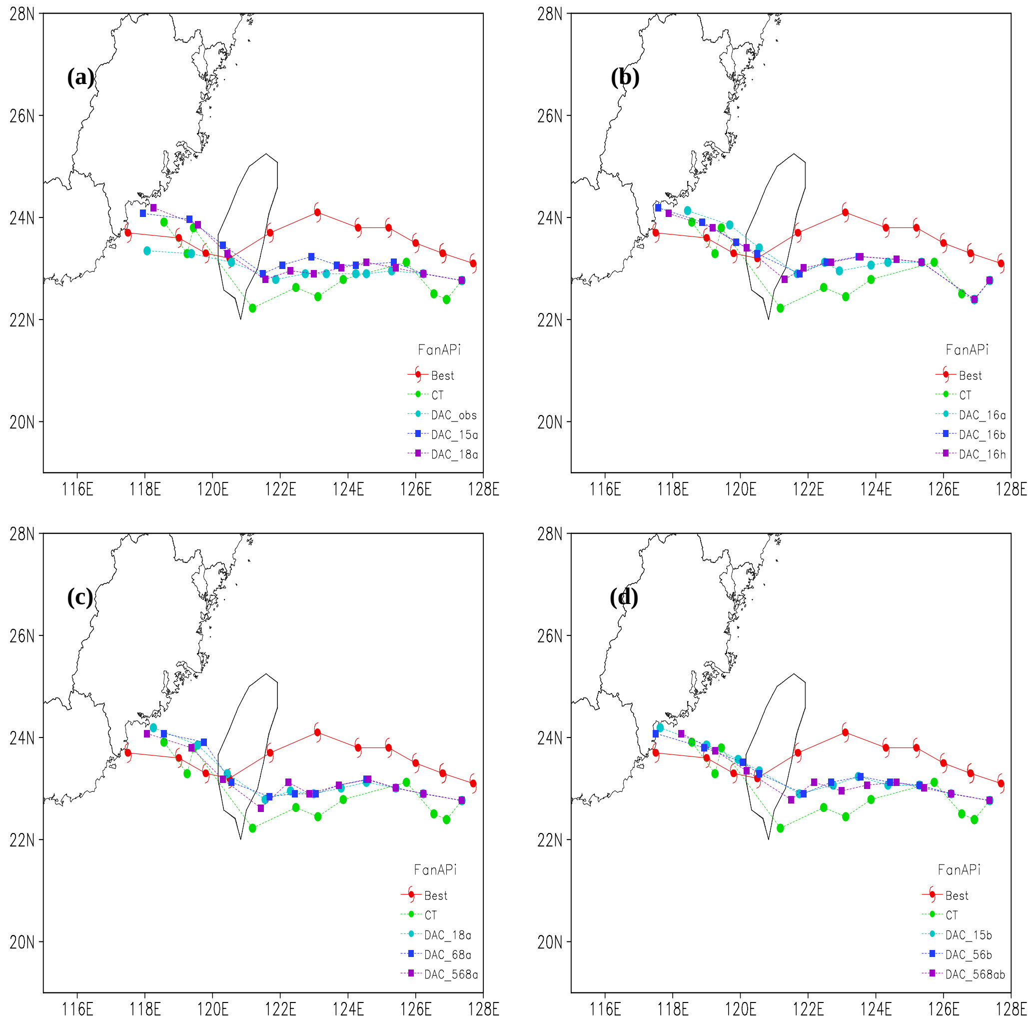

Figure 6. Tracks of typhoon Fanapi during the period from 1200 UTC 17 to 0000 UTC 20 September 2010 for the experiments. (a): Assimilation of conventional observations and AMSU-A from different satellites respectively; (b) assimilation of AMSU-A, AMSU-B, HIRS/3 from NOAA-16 respectively; (c): assimilation of AMSU-A from multiple satellites simultaneously; (d): assimilation of AMSU-B and AMSU-A+AMSU-B from multiple satellites respectively.

Considering the scan bias and different instrument performance, even the assimilation of radiance from the same sensor of different satellites may bring about slight different effect on track forecast. In terms of the AMSU-A, Exp.3 (DAC_15a) and Exp.5 (DAC_18a) produce greater improvement (the average bias is 96 km) than that of Exp.4 (DAC_16a) (the average bias is 104 km). The difference may be attributed to the higher noise from the AMSU-A measurement of NOAA-16[19].

Table 3. The simulated track bias for all experiments.

Experiments		Improving Ratio	Tracks bias of typhoon Fanapi during the period from 1800 UTC 17 to 0000 UTC 20 September 2010										Average
Exp.1	CT		101	124	95	121	181	144	131	67	43	118	113
Exp.2	DAC_obs	6:4	77	99	122	99	135	144	157	86	53	73	105
Exp.3	DAC_15a	7:3	101	82	134	87	108	83	131	59	79	108	97
Exp.4	DAC_16a	6:4	101	81	119	94	128	108	133	84	80	113	104
Exp.5	DAC_18a	7:3	77	84	103	103	133	106	124	69	67	98	96
Exp.6	DAC_15b	9:1	77	91	122	108	120	88	17	32	28	56	74
Exp.7	DAC_16b	9:1	101	81	94	108	124	88	10	25	37	54	72
Exp.8	DAC_16h	8:2	101	82	98	103	117	78	100	43	30	59	81
Exp.9	DAC_16ab	8:2	101	82	94	108	132	83	17	37	46	48	75
Exp.10	DAC_16abh	5:5	101	82	140	99	139	110	129	118	76	155	115
Exp.11	DAC_68a	5:5	77	84	99	101	132	119	136	86	89	124	105
Exp.12	DAC_568a	7:3	77	84	97	101	135	87	121	58	46	75	88
Exp.13	DAC_56b	9:1	77	91	114	103	117	90	12	37	23	42	71
Exp.14	DAC_568ab	9:1	77	84	99	101	127	83	118	42	32	92	86

The assimilation radiance from different sensors of identical satellites may also produce different effect on track forecast, while the assimilation radiance from various sensors simultaneously could not produce further improvement. With respect to the assimilation radiance from NOAA-16, Exp.7 (DAC_16b) leads to the largest improvement (the average bias is 72 km), and Exp.13 (DAC_56b) produces equal improvement as that of Exp.7 (the average is 71 km), but the improvement of Exp.9 (DAC_6ab) appears to be slightly declined, with the average bias increased by 3 km. Although Exp.4 (DAC_16h) generates a considerable improvement (the average bias is 81 km), yet Exp.10 (DAC_16abh) brings a negative effect with the average bias even 2 km larger than that of Exp.1 (CT). Such results may be attributed to the imperfect quality control and bias correction for the HIRS/3 radiance in the current WRF-3DVAR system[18]. Therefore, the potential of HIRS/3 data needs to be further verified.

The impact of assimilating radiance from multiple satellites simultaneously on track forecast is relatively complex, which may lead to degradation. Exp.12 (DAC_568a) and Exp.11 (DAC_68a) produces larger improvement than that of Exp.5 (DAC_18a), with the average bias reduced by 8 and 9 km, respectively. Although the improvement of Exp.14 (DAC_568ab) is greater than that of the experiments for assimilation with the AMSU-A data (e.g. Exp.3, Exp.4, Exp5, Exp.11 and Exp.12), it is less than that of experiments with the assimilation of AMSU-B data (e.g. Exp.6, Exp.7 and Exp.13).

It is generally thought that typhoon track forecast is determined by three factors in the initial field: (1) large-scale environmental steering flow, (2) the initial intensity of typhoon, and (3) the initial position of typhoon[20]. The above results indicate that the impact of assimilating ATOVS radiance on typhoon track forecast remains relatively limited. Although the initial circulation, the vortex structure and the initial intensity of typhoon have been improved remarkably after they are adjusted by assimilation of ATOVS radiance data, the initial position error of typhoon is still obvious (Figure 3b) to generate a negative influence on the subsequent track forecast. In addition, the performance of regional prediction system depends critically on the initial conditions and the lateral boundary conditions provided by the global models[16]. As shown in Table 3, during the middle and late period of simulation (hour 24 to 42), the track bias of Exp.1 (CT) appears to be larger, and the improvement of assimilating ATOVS radiance on typhoon track is relatively significant. Specifically, the track bias of Exp.1 (CT) is about 131 km for hour 42 (0600 UTC 19 September 2010), while in Exp.7 (DAC_16b) it reduces to 10 km, which is very close to the observed location (Figure 6b). In the late 12 hours (hour 48 to 54), the track bias of Exp.1 (CT) is relatively small, thus the improvement is relatively limited and large track bias even occurs in some of the experiments.

5 CONCLUSIONS AND DISCUSSION

For investigating the impact of direct assimilation of different ATOVS radiance on typhoon intensity and track forecasting, the WRF model and its three-dimensional system (3DVAR) were employed to construct twelve data assimilation experiments using a data assimilation method. The main conclusions are as follows.

(1) Additional satellite radiance can be assimilated into the 3DVAR system through a data assimilation cycle. It is beneficial to improve the initial field and solve the problem of typhoon forecast due to the lack of conventional observations over the tropical ocean.

(2) Because of scan bias and different instrument performance, the assimilation of different ATOVS radiance may produce different impacts on typhoon forecast. Even the assimilation of radiance from identical sensors of different satellites may have slightly different effect. The improvement due to AMSU-A from NOAA-15 and NOAA-18 is greater than that from NOAA-16 while the AMSU-B from NOAA-15 and NOAA-16 produces larger equivalent improvement than the AMSU-A does. Assimilating radiance from different sensors of identical satellites could also produce different effect remarkably. The largest improvement comes from the AMSU-B, followed by the AMSU-B and the HIRS/3, whereas the AMSU-A results in the poorest improvement. Moreover, the assimilation of different radiance simultaneously could not produce further improvement. Then experiments of assimilating radiance from multiple satellites simultaneously indicate that it may lead to degradation due to accumulative bias when adding various radiance into the data assimilation system. Therefore, the assimilation of ATOVS radiance from a single satellite may perform better than from two or three satellites.

(3) Due to the imperfect quality control and bias correction of the data assimilation system, the improvement of typhoon forecasts due to assimilating ATOVS radiance only is relatively limited, especially for the intensity forecast. The simulated SLP among different experiments (less than 6 hPa on average) are not significant either. Assimilating ATOVS radiance alone seems to be unable to improve the typhoon intensity forecast.

Generally, the results of this study are quite positive, but the conclusions may be limited since it was based on a case study, and more cases are needed for verification. In addition, forecast errors in the regional model come from both lateral boundary conditions and model error. And a longer period of data assimilation cycle is disadvantageous to improving the forecast. Consequently, it prevents regional models from improving forecast capabilities through data assimilation cycles[17]. As the data assimilation experiments in this study were carried out with an assimilation window of 12 hours, it is necessary in the future to assess whether longer data assimilation cycles could perform better.

REFERENCES:

[1] LI Ying, CHEN Lian-shou, ZHANG Sheng-jun. Statistical characteristics of tropical cyclones making landfalls on China [J]. J. Trop. Meteor., 2004, 20(1): 14-23. (in Chinese)

[2] QU An-xiang, MA Su-hong, LIU Qing-fu, et al. The initialization of tropical cyclones in the NMC global model Part I: Scheme design [J]. Acta Meteor. Sinica, 2009, 67(5): 716-726. (in Chinese)

[3] LIU Zhi-quan, ZHANG Feng-ying, WU Xue-bao, et al. A regional ATOVS radiance-bias correction scheme for radiance assimilation [J]. Acta Meteor. Sinica, 2007, 65(1): 113-123. (in Chinese)

[4] ZHANG Hua, XUE Ji-shan, ZHU Guo-fu, et al. Application of direct assimilation of ATOVS microwave radiances to typhoon track prediction [J]. Adv. Atmos. Sci., 2004, 21(2): 283-290.

[5] WANG Yun-feng, ZHANG Hai-yang, WANG Bin, et al. Reconstruct the mesoscale information of typhoon with BDA method combined with AMSU-A data assimilation method [J]. Adv. Meteor., 2010, 1-11.

[6] HAO Shi-feng, PAN Jing-song, CUI Xiao-peng. Research and experiments on tropical cyclone simulation using self data assimilation technique [J]. J. Trop. Meteor., 2010, 26(2): 181-186.

[7] ZAPOTOCNY T H, JUNG J A, Le MARSHALL J F, et al. A two-season impact study of satellite and in situ data in the NCEP global data assimilation system [J]. Wea. Forecast., 2007, 22(4): 887-909.

[8] ZAPOTOCNY T H, JUNG J A, Le MARSHALL J F, et al. A two-season impact study of four satellite data types and rawinsonde data in the NCEP global data assimilation system [J]. Wea. Forecast., 2008, 23(1): 80-100.

[9] JUNG J A, ZAPOTOCNY T H, Le MARSHALL J F, et al. A two-season impact study of NOAA polar-orbiting satellites in the NCEP global data assimilation system [J]. Wea .Forecast., 2008, 23(5): 854-877.

[10] XU J, RUGG S, HORNER M, et al. Application of ATOVS radiance with ARW WRF/GSI data assimilation system in the prediction of Hurricane Katrina [J]. Open Atmos. Sci. J., 2009, 3: 13-28.

[11] BARKER D M, HUANG W, GUO Y R, et al. A three-dimensional (3DVAR) data assimilation system for use with MM5: Implementation and initial results [J]. Mon. Wea. Rev., 2004, 132(4): 897-914.

[12] CHEN Zi-tong, HUANG Yan-yan, WAN Qi-lin, et al. Rapid updating cycle assimilation and forecasting system and its experiments and analysis in flood seasons [J]. J. Trop. Meteor., 2010, 26(1): 49-54. (in Chinese)

[13] PU Zhao-xia, LI Xuan-li, ZIPSER E J. Diagnosis of the initial and forecast errors in the numerical simulation of the rapid intensification of Hurricane Emily (2005) [J]. Wea. Forecast., 2009, 24(5): 1236-1251.

[14] LI Xuan-li, PU Zhao-xia. Sensitivity of numerical simulation of early rapid intensification of Hurricane Emily (2005) to cumulus parameterization schemes in different model horizontal resolutions [J]. J. Meteor. Soc. Japan, 2009, 87(3): 403-421.

[15] PU Zhao-xia, LI Xuan-li, VELDEN C S, et al. The impact of aircraft dropsonde and satellite wind data on numerical simulations of two landfalling tropical storms during the tropical cloud systems and processes experiment [J]. Wea. Forecast., 2008, 23(1): 62-79.

[16] HSIAO L F, PENG M S, CHEN D S, et al. Sensitivity of typhoon track prediction in a regional prediction system to initial and lateral boundary conditions [J]. J. Appl. Meteor. Climatol., 2009, 48(9): 1913-1928.
[17] LIANG Xu-dong, WANG Bin. Data assimilation cycle experiments in typhoon numerical prediction using the model-constrained 3DVar [J]. Acta Meteor. Sinica, 2010, 68(2): 153-161. (in Chinese)
[18] LIU Zhi-quan, BARKER D M. Radiance Data Assimilation in WRF-Var: Implementation and Initial Results [R]. 7th WRF Users' Workshop, 2006.
[19] CHOU C B, HUANG C Y, HUANG H -P, et al. The analysis of typhoon structures using advanced microwave sounding unit data and its application to prediction [J]. J. Appl. Meteor. Climatol., 2008, 47(5): 1476-1492.
[20] ZHANG Gen-sheng, FEI Jian-fang, HUANG Xiao-gang, et al. The application of the bogus data assimilation in the numerical prediction of the typhoon track [J]. J. Trop. Meteor., 2005, 21(5): 458-466. (in Chinese)

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