Implement and preliminary experiment of FY-3 and NPP microwave satellite data assimilation in WRFDA

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1. Background

As we all know, satellite observation plays a very important role in the improvement of accuracy of numerical weather prediction. In the near future decade, FY3 and NPP/JPSS, together with METOP serial satellites are the important meteorological satellites for NWP. Compared to AMSUA/MHS, MWTS/MWHS and ATMS onboard on FY-3A/B and NPP, respectively, are two new microwave sensors. Taking the microwave satellite observation is the top contributor to the improvement of numerical weather forecast into consideration, the use of those microwave satellite observation in data assimilation system is developed or going on, such as FY-3A in ECMWF (Lu et al., 2011), ATMS in ECMWF (NIELS B et al., 2012), ATMS in NCEP (Collard, A et al., 2012). The implement of FY-3 and NPP microwave satellite data assimilation in WRFDA presents a crucial issue.

This presentation reports on the implement and preliminary experiment with FY-3 and NPP microwave satellite data in WRFDA, both in terms of the analysis of satellite observation characteristics, and in terms of initial assimilation trials in regional numerical forecast. In addition, the extension and investigation of microwave particle scattering module RTTOV-SCATT in WRFDA is also briefly introduced.

Following, the description of the implement and experiment of FY-3A/B MWTS/MWHS and NPP ATMS data assimilation in WRFDA is presented in section 2 and section 3, respectively. Section 4 discusses the calculation under cloudy condition by using both RTTOV and CRTM in the coincident framework of WRFDA. Finally, the conclusion and discussion are summarized in the last section.

2. The implement of FY-3 and NPP microwave satellite data assimilation in WRFDA

Prior to the introduction of the implement of FY-3 and NPP microwave satellite data assimilation, the characteristics of sensor MWTS/MWHS and ATMS compared to AMSUA/MHS is shown in table 1 and table 2, respectively.

There are two special items associated with FY-3 MWTS/MWHS:

1) MWTS has four channels;
2) Difference in window channel;

- MWTS has ONLY one window channel;
- MWHS channel 1 is switched from 89 to 150 GHz, the same as channel 2 except the polarization.

Table 1 The characteristics of sensor MWTS/MWHS compared to AMSUA/MWHS

Channel Number		Centre Frenquency (GHz)		Bandwidth (MHz)		NEΔT (K)		Nadir Resolution (km)		Weight Function Peak (hPa)		Swath Width (km)	
AMSU-A	MWTS	AMSU-A	MWTS	AMSU-A	MWTS	AMSU-A	MWTS	AMSU-A	MWTS	AMSU-A	MWTS	AMSU-A	MWTS
3	1	50.30(V)		180		0.40	0.50	48	62	surface	Surface	2300	2250
5	2	53.596±0.115(H)		2*170		0.25	0.40	48	62	700	700	2300	2250
7	3	54.94(V)		400		0.25	0.40	48	62	270	300	2300	2250
9	4	57.29(H)		330		0.25	0.40	48	62	90	70	2300	2250
Channel Number		**Centre Frenquency (GHz)**		**Bandwidth (MHz)**		**NEΔT (K)**		**Nadir Resolution (km)**		**Weight Function Peak (hPa)**		**Swath Width (km)**	
MHS	MWHS	MHS	MWHS	MHS	MWHS	MHS	MWHS	MHS	MWHS	MHS	MWHS	MHS	MWHS
1	1	89(V)	150(V)	1000*2		0.84	0.90	15	15	surface	Surface	2250	2700
2	2	157(V)	150 (H)	1000*2		0.84	0.90	15	15	surface	Surface	2250	2700
3	3	183.31±1(H)	183.31±1(H)	500*2		0.60	1.10	15	15	400	400	2250	2700
4	4	183.31±3(H)	183.31±3(H)	1000*2		0.70	0.90	15	15	600	600	2250	2700
5	5	183.31±7(H)	183.31±7(H)	2000*2		1.06	0.90	15	15	800	800	2250	2700

ATMS has several unique characteristics compared to AMSUA/MHS:

1) ATMS has seven channels in humility unit;

2) The increase of swatch width and observation number, especially in temperature unit;

3) Also, difference in window channel:

- Channel 4 is added while channel 15 is taken away in AMSUA temperature unit;
- The frequency of channel 17 is changed from 150 in MHS to 165 GHz.

Table 2 The characteristics of sensor ATMS compared to AMSUA/MHS

ATMS Channel Number	AMSU Channel Number	Centre Frenquency (GHz)	Absobr	Weight Function Peak	Polarisation ATMS	Polarisation AMSU
1	1	23.8	H_20	Surface	V	V
2	2	31.4	H_20	Surface	V	V
3	3	50.3	0_2	Surface	H	V
4		51.76	0_2	Surface	H	
5	4	52.8	0_2	Surface	H	V
6	5	53.596+/-0.116	0_2	700 hPa	H	H
7	6	54.4	0_2	400 hPa	H	H
8	7	54.94	0_2	250 hPa	H	V
9	8	55.5	0_2	180 hPa	H	H
10	9	f_0=57.290334	0_2	90 hPa	H	H
11	10	f_0+/-0.217	0_2	50 hPa	H	H
12	11	f_0+/-0.3222+/-0.048	0_2	25 hPa	H	H
13	12	f_0+/-0.3222+/-0.022	0_2	10 hPa	H	H
14	13	f_0+/-0.3222+/-0.010	0_2	6 hPa	H	H
15	14	f_0+/-0.3222+/-0.0045	H_20	3 hPa	H	H
16	15/16	88.2	H_20	Surface	V	V
17	17	165.5+/-0.925	H_20	1000 hPa	H	V
18	20	183.31+/-7.0	H_20		H	V
19		183.31+/-4.5	H_20		H	
20	19	183.31+/-3.0	H_20	800 hPa	H	H
21		183.31+/-1.8	H_20		H	
22	18	183.31+/-1.0	H_20	440 hPa	H	H

The configuration for assimilating FY-3A/B MWTS/MWHS and NPP ATMS satellite data in namelist.input will be:

```
rtminit_nsensor=5,
rtminit_platform=23,23,23,23,17 # 23 for FY3 and 17 for NPP
rtminit_satid=1,1,2,2,0              # 1 for FY-3A, 2 for FY-3B, 0 for NPP
rtminit_sensor=40,41,40,41,19     # 40 for MWTS, 41 for MWHS, 19 for ATMS
```

The radiance data ingested are named by instrument name and each file contains global brightness temperature within 6-hour assimilation window. FY3 is CMA binary format and ATMS is NCAP BUFR file. The former is not, and the latter is available through public ftp server. The naming convention is:

```
CMA binary file names            WRF-Var naming convention
fy3_yyyymmddhh_mwt.dat          mwtsa.dat or mwtsb.dat
fy3_yyyymmddhh_mwh.dat          mwhsa.dat or mwhsb.dat
```

and

```
NCEP bufr file name               WRF-Var naming convention
atms.gdas.yyyymmddhh             atms.bufr
```

Other processing of radiance data including ATMS noise reducing, channel selection, cloud detection and so on, is implemented inside WRFDA. They are summarized in table 3.

Table 3　The processing scheme of radiance data

	FY-3 MWTS/MWHS	NPP ATMS	NOAA AMSUA/MHS
Noise reducing	none	average	none
Channel selection	1) MWTS 1～4 and MWHS 1～5 are not used for mixed surface; 2) MWTS 1～3 and MWHS 1～5 are discarded for land, ice and snow; 3) MWTS 2 and MWHS 5 are aborted when Ps<850 hPa and Ps<800 hPa, respectively。	1) All channels 1～22 are not used for mixed surface; 2) 1～8 and 16～22 are discarded for land, ice and snow； 3) channel 6 and 18 are aborted when Ps<850 hPa and Ps<800 hPa, respectively; 4) 11～15 are not used.	1) AMSUA 1～15 and MHS 1～5 are not used for mixed surface; 2) AMSUA 1～7 and MHS 1～5 are discarded for land, ice and snow; 3) AMSUA 5 and MHS 5 are aborted when Ps<850 hPa and Ps<800 hPa, respectively; 4) AMSUA 10～14 are not used.
Cloud detection	1）MWTS 1 dtb, not use MWTS 1～3; 2）MWHS 1 dtb, not use MWHS 1～5.	1）channel 3 abs(dtb), not use 1～8 and 16～22; 2）channel 1 dtb，not use 1～8 (test); 3）scattering Insex combined channel 16 and 17, not use 16～22 (test).	1）scattering Index combined AMSUA 1 and 15, not use AMSUA 1～7; 2）scattering Index combined MHS 1 and 2, not use MHS 1～5.
Outermost scan	MWTS 3～13 MWHS 9～89	1～96	AMSUA 4～27 MHS 9～82
Bias correction	VarBC	VarBC	VarBC

Note：dtb is the bias of observed and simulated brightness temperature and abs is absolute value.

3. The preliminary experiment of FY-3 and NPP microwave satellite data assimilation in WRFDA

Several initial assimilation trials are carried out to illustrate the impact of FY-3 and NPP microwave satellite data on regional numerical forecast. For typhoon case “Fungwong” (2008), it is found that the intensity forecast error could be greatly reduced by the use of FY-3A microwave data (Figure 1). Further experiment indicates that the set-up of threshold is a crucial factor when the single window channel is utilized as cloud detection (Figure 2).

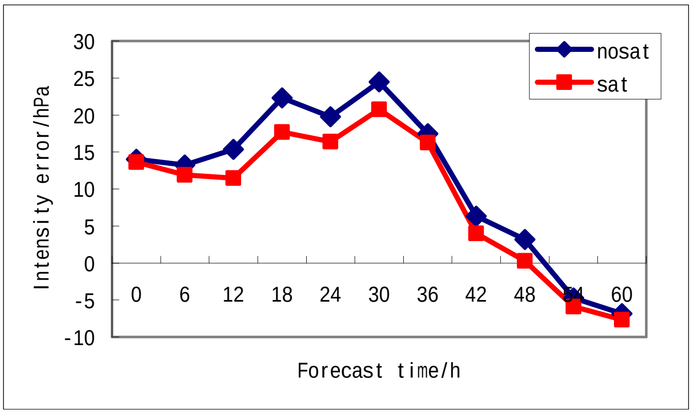

Figure 1: The effect of FF-3A microwave data on the intensity forecast error for typhoon “Fungwong” (2008)

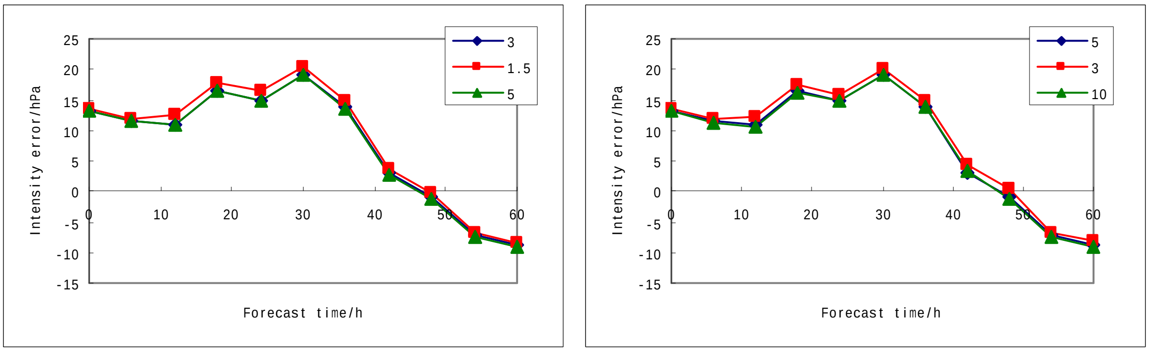

Figure 2: The experiment of cloud examination scheme in the use of FY-3A MWTS/MWHS data

The result of NPP microwave satellite data is investigated against that of AMSUA/MHS abroad on NOAA 18 with almost similar equator crossing time for typhoon case “SAOLA” (2012). Figure 3 shows the RMS of observed and simulated brightness temperature over sea. Generally speaking, ATMS is of good quality and comparable to or better than that of AMSUA/MHS.

Taking account of ATMS data is sampled more densely, however with larger noise, the process of noise reducing is considered necessary to the use of ATMS data in numerical weather prediction. It is processed here by the simple averaging of the neighboring 3 scan-positions and scan-lines. It is shown that the approach could decrease the bias of observation and simulated brightness temperature in Figure 4.

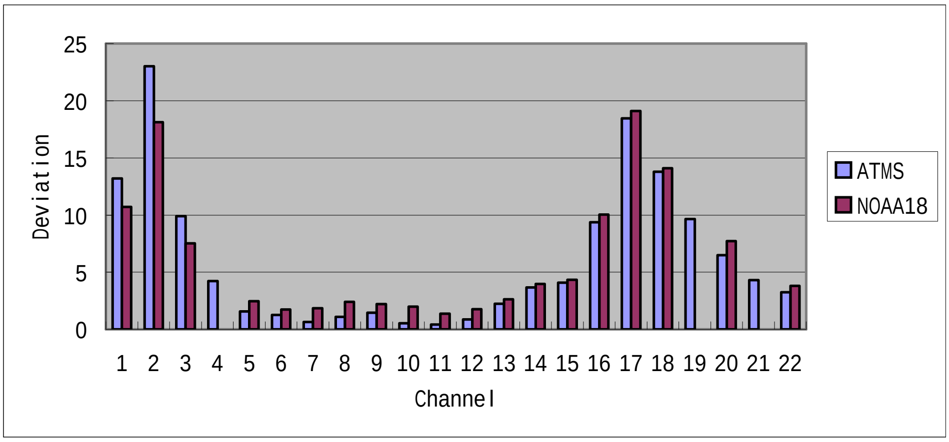

Figure 3: The RMS of observed and simulated brightness temperature over sea

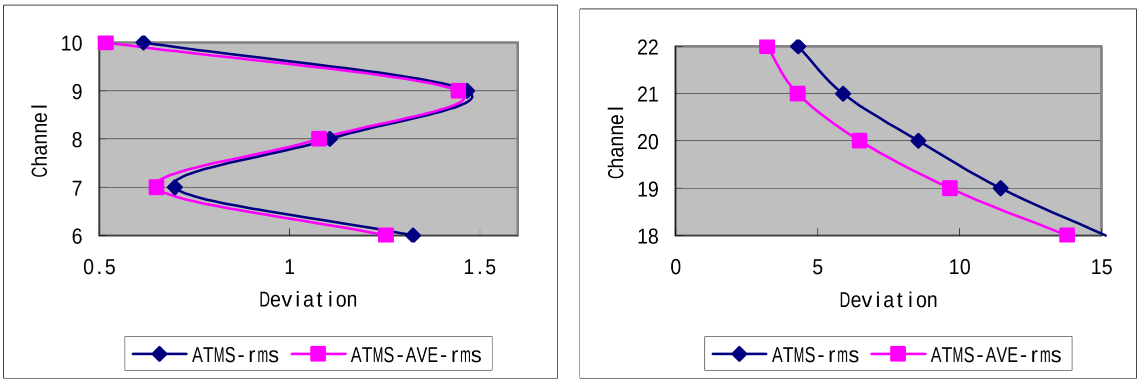

Figure 4: RMS of observed and simulated brightness temperature without and with noise reducing to ATMS data over sea

Table 4 is a list of the number of satellite observation and that of data passed the cloud examination for both ATMS and NOAA18 AMSUA/MHS. It is seen that the absolute value of the FG-departure for channel 3 seems to be a reasonable scheme for ATMS data.

Table 4 The list of the number of observation and data passed the cloud examination

ATMS	6	7	8	18	19	20	21	22
Observation number	12123	12123	12123	12123	12054	11979	11974	11972
Passed channel 3 abs(dtb)	3710	3710	3710	3710	3710	3690	3690	3690
Passed channel 1 dtb and scattering Index combined 16 and 17	9156	9156	9156	10838	10836	10831	10831	10831
Passed all exminations	3495	3495	3495	3665	3665	3665	3665	3665

AMSUA/MHS	5	6	7	3	4	5
Observation number	3003	3003	3003	3322	3322	3322
Number of data passed	2940	2940	2940	2919	2919	2919

The RMS of observation and simulated brightness temperature for satellite data used finally in assimilation is given in Figure 5. Generally the ATMS RMS is smaller than NOAA18 AMSUA/MHS with the exception of channel 20 and 22. It is founded that the bias of channel 9 is pronounced in temperature unit. There is a need for bias correction to handle this issue properly (Figure 6).

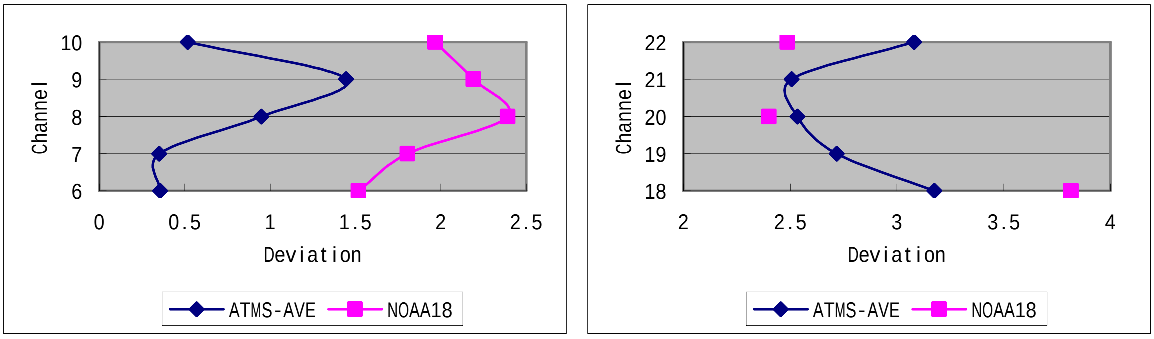

Figure 5: The RMS of observation and simulated brightness temperature for data used finally in assimilation

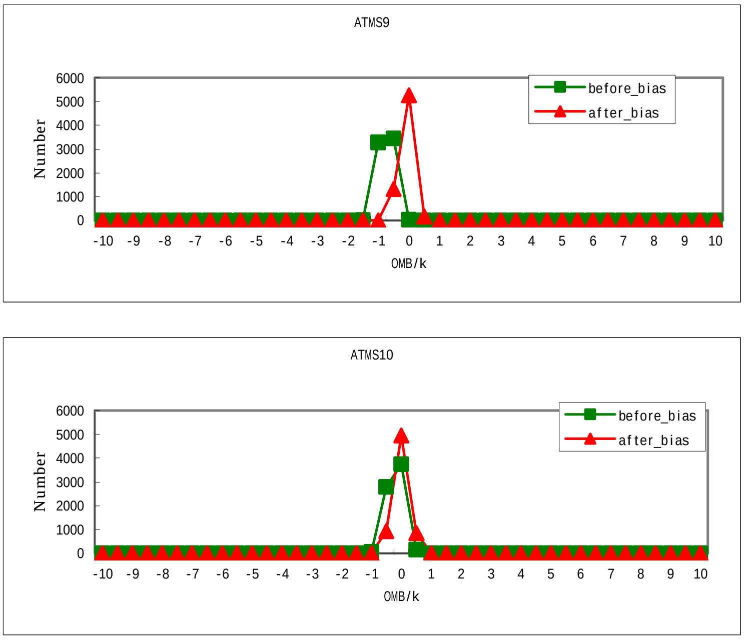

Figure 6: Bias correction for ATMS channel 9 and channel 10

Figure 7 shows the means and RMS of observation and simulated brightness temperature before and after assimilation. ave and rms represent the means and RMS. OI and AO stand for observed minus background and observed minus analysis, respectively. ATMS-AVE is the result of ATMS data with process of reducing the noise. It could be seen that the means and RMS all decrease after the assimilation of satellite data. In addition, the reducing of noise benefits the performance of ATMS data.

The impact of microwave satellite data on the typhoon “SAOLA” (2012) trace forecast is presented in Figure 8. The best track is just landing Taiwan Island at the end of forecast. Two forecasts from different initial time are performed. The forecast of the control run without satellite data misses the landing. It could be seen that all the forecast tracks of experiments with satellite data are close to the landing. Especially the result of ATMS, that almost perfectly repeats the landing of the best track. It indicates the potential of the use of ATMS data in numerical weather forecast.

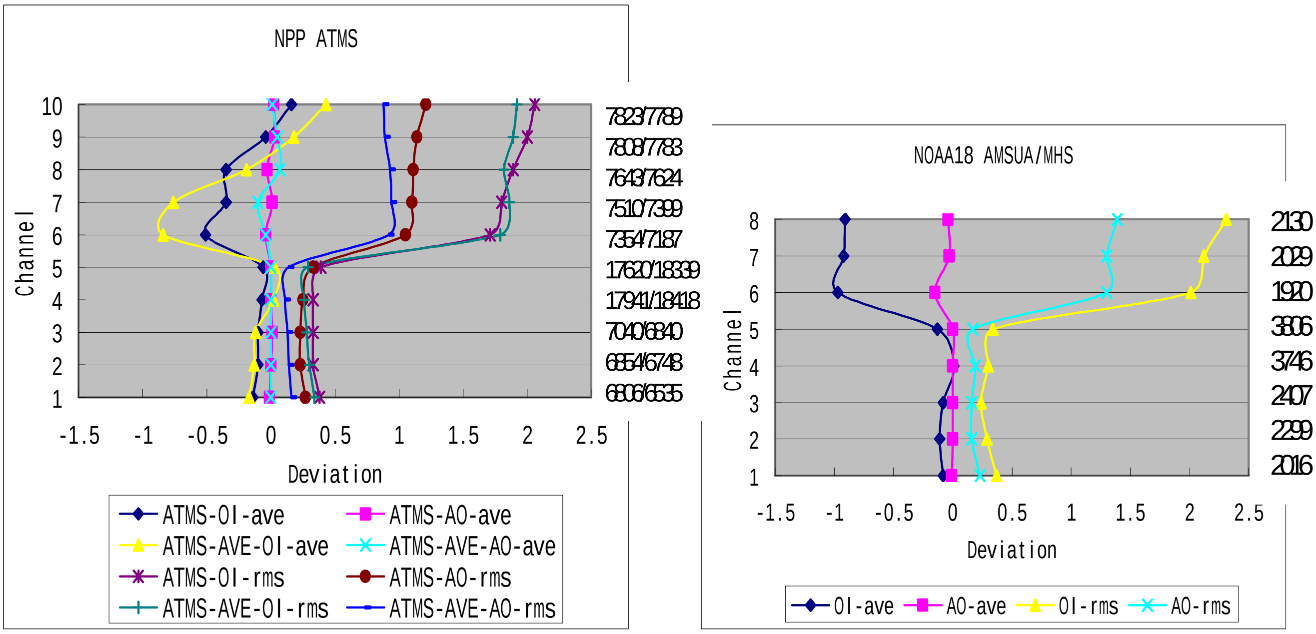

Figure 7: The bias and RMS of observation and simulated brightness temperature before and after assimilation for ATMS and NOAA18 AMSUA/MHS

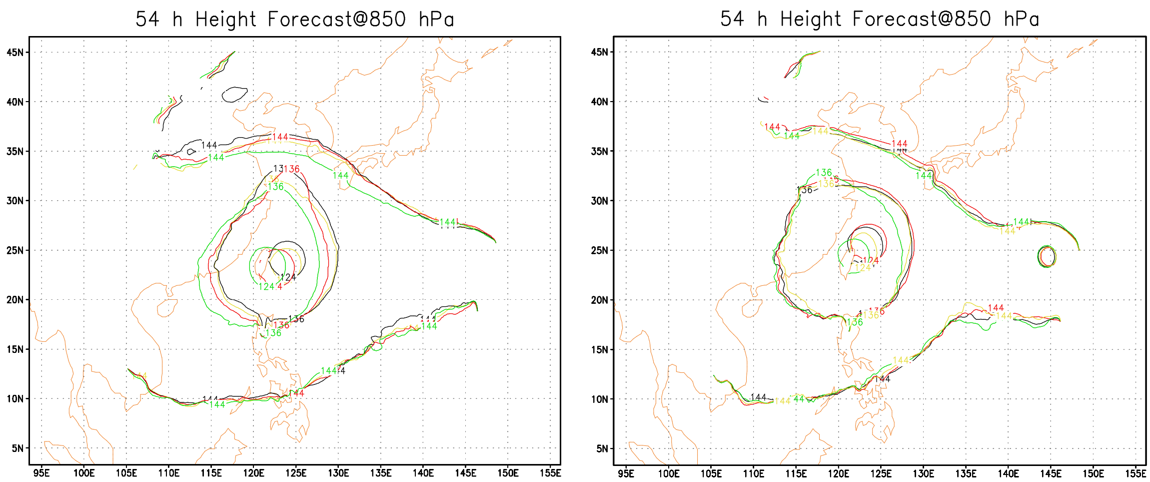

Figure 8: The impact of microwave satellite data on the typhoon “SAOLA” (2012) trace forecast (black: Control; green: ATMS; red: FY-3B; yellow: NOAA18)

4. The extension of RTTOV microwave particle scattering module in WRFDA

The interface for clear and cloudy condition is consistent in CRTM. But, there is a separate microwave particle scattering module RTTOV-SCATT in RTTOV that is not implemented in current released version. To make the calculation under cloudy condition available by using both RTTOV and CRTM in the coincident framework of WRFDA, RTTOV-SCATT module is extended. A logical parameter in namelist.input is set up to evoke this module:

rttov_scatt_d=T,

along with crtm_cloud=T for CRTM cloudy interface.

It is applied on the simulation of FY-3A microwave satellite observation. Figure 9 presents the observed brightness temperature of channel 1 for both MWTS and MWHS. The simulated brightness temperature under clear and cloudy condition is given in Figure 10 and Figure 11, respectively. It is obviously shown that there exists large bias between the observation and clear sky simulated brightness temperature. The inclusion of the radiative effects of hydrometeors in the rapid radiative transfer model makes the simulation match the observation much close.

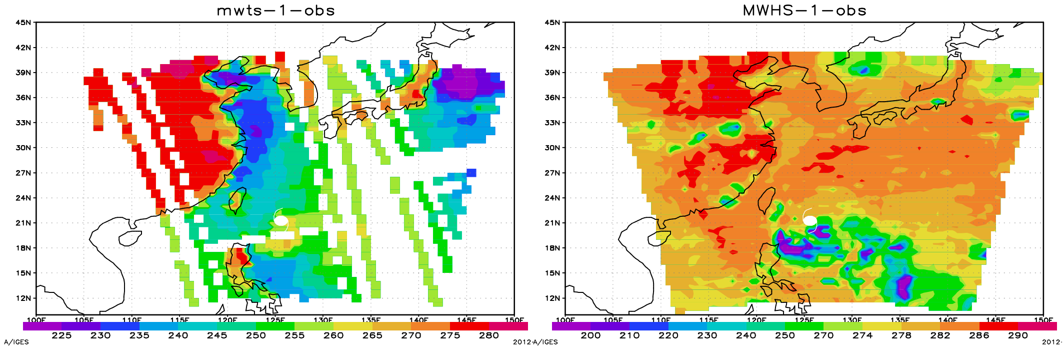

Figure 9: The observed brightness temperature of channel 1 for FY-3A MWTS (left) and MWHS (right)

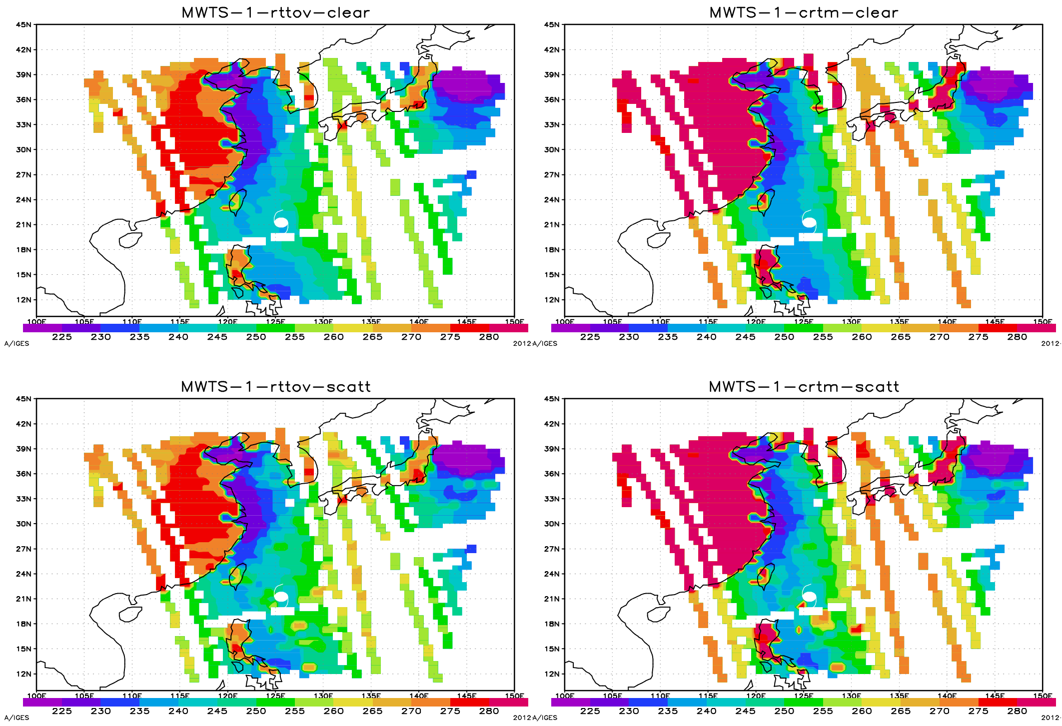

Figure 10: The simulated brightness temperature of channel 1 for MWTS under clear and cloudy condition by using both RTTOV and CRTM

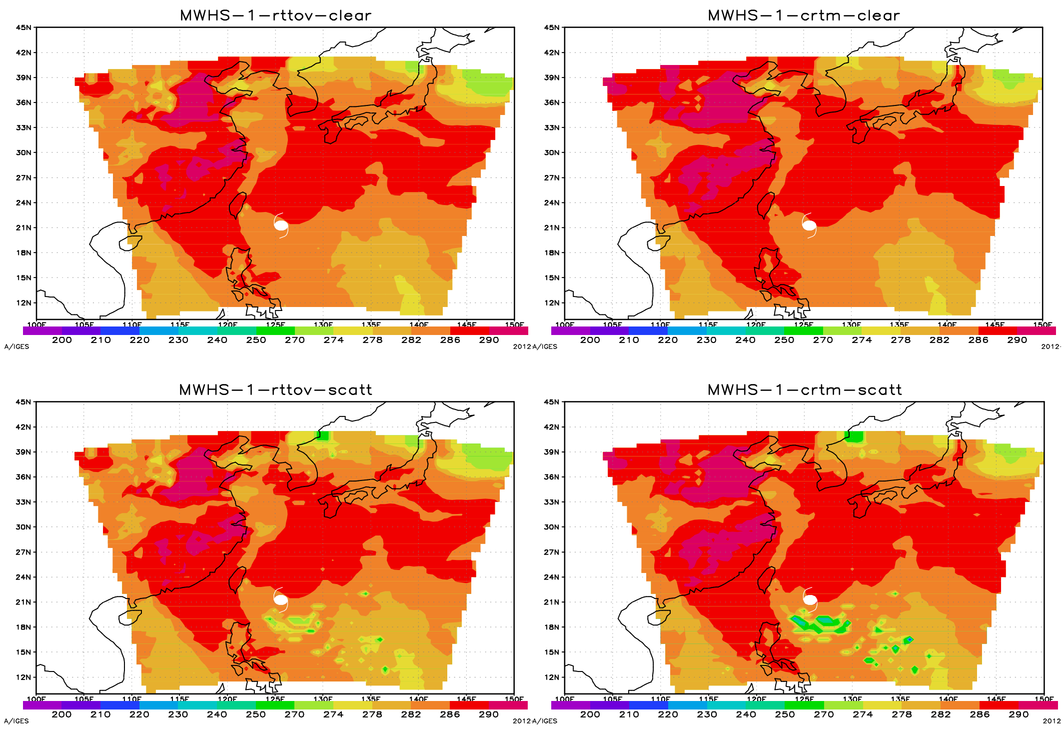

Figure 11: The simulated brightness temperature of channel 1 for MWHS under clear and cloudy condition by using both RTTOV and CRTM

The area average of bias and RMS of brightness temperature simulation between clear and cloudy condition of FY-3A MWTS/MWHS for both RTTOV and CRTM is shown in Figure 12. It could be found that the result of RTTOV and CRTM presents the similar characteristics, while the magnitude of CRTM is larger than that of RTTOV. It is also noticed that the impact of cloud and precipitation manifests itself in the lower satellite channel. It implies that special attention should be paid to the cloud detection as the satellite data sensitive to the surface conditions is used because that the data is always "contaminated" by cloud and precipitation at the same time.

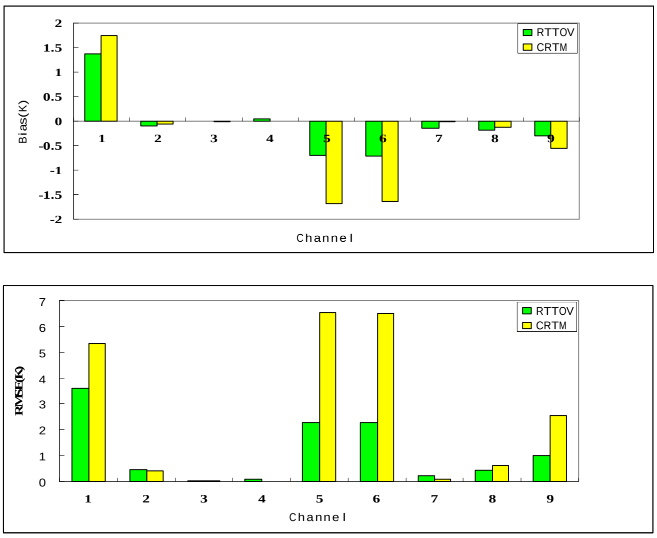

Figure 12: The area average of bias (top) and RMS (bottom) of brightness temperature between clear and cloudy simulation of FY-3A MWTS/MWHS for both RTTOV and CRTM

5. Conclusion and discussion

The implement and preliminary experiment of FY-3 and NPP microwave satellite data, along with the extension of RTTOV microwave particle scattering module in WRFDA is presented. The main conclusion and discussion are:

- WRFDA has been extended to have the capability of assimilating FY-3A/B and NPP microwave satellite data. Preliminary experiments show that the use of those satellite data benefits the improvement of numerical forecast.
- Specially, there is a need to revise and investigate the cloud detection scheme in the implement of FY3 and NPP microwave satellite data because the windows channel has changed significantly compared to AMSUA/MHS. More followed experiment should be carried out with the tuning of cloud detection, together with bias correction and observation error and so on.
- Additionally, RTTOV microwave particle scattering module is implemented to make the calculation under cloudy condition available by using both RTTOV and CRTM in the coincident framework of WRFDA.

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