

Experiment of the Use of Satellite Microwave Data Affected by Cloud in Numerical Prediction

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Abstract

Currently, only cloud-free satellite data are used in most data assimilation systems. The observations in cloudy area contain useful information for the numerical weather forecast. The use of satellite data affected by cloud may improve the accuracy of numerical weather forecasts.

The Community Radiative Transfer Model (CRTM), being developed currently in the Joint Center for Satellite Data Assimilation (JCSDA) USA, is implemented in our Grapes-3dvar, a three dimensional variational data assimilation system developed by Chinese Academy of Meteorological Sciences, to conduct research associated with the use of satellite data, especially the data affected by cloud and rain.

Taking the typhoon 0604 "Bilis" as research case, a set of experiments is designed to use the satellite data affected by cloud in numerical forecast firstly based on the cloud examination scheme. The simulation of satellite observation in cloudy area is verified by using CRTM with input of cloud and rain information. The cloud examination methods include Scattering Index, precipitation probability, precipitation examination and the bias between simulated bright temperature and observation. The screen of satellite data affected by cloud, together with their influences on the numerical forecast of Bilis's three periods, corresponding to formation, maturation and landing, respectively are examined. The characteristics of simulated bright temperature in cloudy and rainy area is investigated to show how the satellite observation affected by cloud and rain be improved under the consideration of the radiant effect of cloud and precipitation particle.

Introduction

Satellite data are used in numerical weather prediction and already are the main data source among the observations used because of the good data coverage, thus providing high spatial resolution atmospheric information, especially for the wide zones of ocean, plateau and desert with few conventional observations, it improves greatly the quality of initial condition and the accuracy of numerical weather forecast.

However, more than 97% satellite data passes the pre-process are discarded before they enter into the data assimilation system. Among them, it is shown that the satellite data affected by cloud held more than 75% in the ECMWF statistical report. For the complexity to cope with the radiant effect of cloud and rain particles in radiative transfer model, only cloud-cleared satellite data are used in most current data assimilation systems. But, the observations in cloudy and rainy area imply much information to weather system and numerical forecast. The use of satellite data affected by cloud and precipitation will be one of the effective technological methods to improve the accuracy of numerical weather forecast continuously.

At present, the satellite data affected by cloud is examined through the cloud examination method.

Different cloud examination schemes are taken in different numerical forecast centers. For example, the bias between the simulated bright temperature and observation of AMSU-A channel 4 is used in Météo-France. The AMSU-A data is contaminated by cloud when the bias is beyond 1.5 K. In MetOffice UK, the observation of AMSU-A channel 4, 5 and AMSU-B channel 5 is thought to be affected by cloud when the total perceptible water is greater than 100 gm⁻². The AMSU-A channel 4-8 and AMSU-B all channel data are discarded by precipitation examination. In addition, Cirrus examination is performed for three AMSU-B high frequency channels. The Bennartz Scattering Index is used for AMSU-B in Canadian Meteorological Centre. The thresholds are 0, 15 and 40 for land, sea and sea ice, respectively. The cloud examination schemes in AAPP include Scattering Index, precipitation probability, precipitation examination and so on.

At the same time, the code for simulation of cloud-affected radiance is being developed in the fast radiative transfer model. In the RTTOV latest version 9.1 developed within the context of the EUMETSAT Satellite Application Facility on Numerical Weather Prediction (NWP SAF), the cloud radiant effects for the infrared are parameterized rather than treated explicitly, while a slower, explicit approach is applied to the microwave in an individual module RTTOV-SCATT. The Community Radiative Transfer Model (CRTM), being developed currently in the Joint Center for Satellite Data Assimilation (JCSDA) USA, is designed to make use of satellite data under all weather conditions by including scattering and emission from the earth's atmosphere. The CRTM is already implemented in our Grapes-3dvar, a three dimensional variational data assimilation system developed by Chinese Academy of Meteorological Sciences.

A set of experiments to use the satellite data in cloudy and rainy area through the cloud examination scheme, together with the verification of simulation of satellite observation with input of cloud and rain information by CRTM are presented in our talk. The details are described in the following two sections, respectively. The final section is a brief conclusion and discussion.

The experiment of cloud examination

1) Cloud examination method

Table 1: The cloud examination method for AMSU data

Data	Examination method	Formula
AMSU-A	Scattering Index	$SI = ETB15 - TB15$ $ETB15 = a + b \times TB1 + c \times TB2 + d \times TB3$ Where, a, b, c and d are tri-polynomial for tangent of scanning angle.
	Precipitation probability	$P = 1 / (1 + e^{-f}) \times 100$ Where, $f = 10.5 + 0.184 \times TB1 - 0.221 \times TB15$
	Precipitation examination	$R = ETB1 - TB1$ Where, $ETB1 = 38 + 0.88 \times TB2$
AMSU-B	Bias between simulated bright temperature and observation for Channel 2	$\Delta = obs - fg _{ch2}$ Where, ob and fg are simulated bright temperature and observation, respectively.
	Bennartz Scattering Index	$SI = \square TB1 - TB2 \square - (-39.2010 + 0.1104\Theta)$ Where, Θ is the local zenith angle of scanning field.

Different screen of the satellite data in cloudy and rainy area will be brought about by different cloud examination method. In our experiment, Scattering Index, precipitation probability and precipitation

examination are taken for AMSU-A. The bias between simulated bright temperature and observation of AMSU-B channel 2 and Bennartz Scattering Index are utilized in the cloud examination for AMSU-B. The cloud examination method and their formula for AMSU satellite data are given in Table 1.

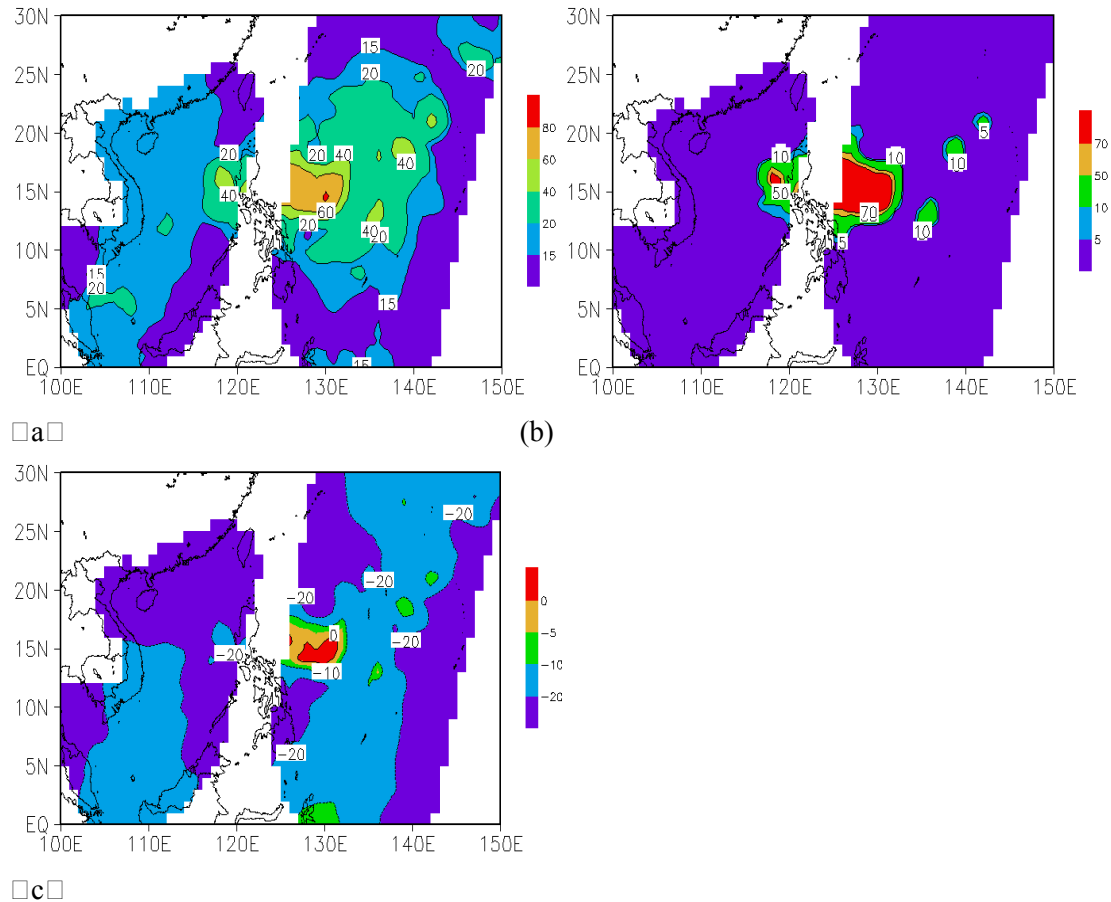


Fig. 1: The value of cloud examination methods for AMSU-A. (a) Scattering Index; (b) precipitation probability; (c) precipitation examination

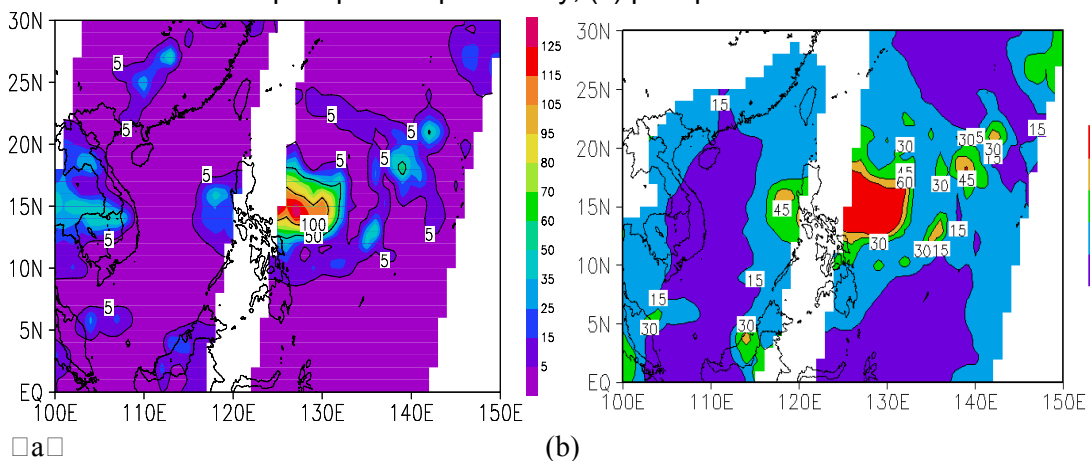


Fig. 2: The value of cloud examination methods for AMSU-B. (a) Bias between simulated bright temperature and observation for Channel 2; (b) Bennartz Scattering Index

Taking the typhoon 0604 “Bilis” as research case, the values of cloud examination at 1800 UTC 10 July, 2006 are shown in Fig. 1 and Fig. 2 for AMSU-A and AMSU-B, respectively. It could be found that the Scattering Index is a nice match for the corresponding cloud map (not presented) for AMSU-A. While only a rainy core is mainly figured out by both precipitation probability and precipitation

examination. For AMSU-B, the bias between simulated bright temperature and observation for Channel 2 matches the cloud distribution much better than the Bennartz Scattering Index. Even the clearance between cloud and clear sky is distinguished.

2) Experiment design

The list of experiments is presented in Table 2. The discussion is mainly applied for AMSU-A channel 5-7 and AMSU-B channel 3-5, respectively. Several experiments are designed for the different threshold of Scattering Index and channel selection including AMSU-A channel 8-10.

Table 2: List of numerical experiment design

Experiment design			
Control experiment	The initial background without data assimilation is used for numerical simulation		
Assimilation experiment	The initial condition with the correction by satellite data is used		
	Data	Criterion	Channel selection
Experiment 1	AMSU-A	SI>10	5□7
Experiment 2		SI>10	5□10
Experiment 3		SI>15	5□7
Experiment 4		SI>20	5□7
Experiment 5		P>5	5□7
Experiment 6		R>0	5□7
Experiment 7	AMSU-B	$\Delta \geq 5K$	3□5
Experiment 8		Bennartz SI>15	3□5

3) Screen of data affected by cloud

For AMSU-A Scattering Index, the number of satellite data affected by cloud decreases with the increase of the value of threshold. Only a few satellite observations are distinguished by the precipitation probability and precipitation examination. Even the number of satellite data affected by cloud decided by Scattering Index with threshold 20 is greater than that of precipitation probability and precipitation examination. The number of satellite observation decided by precipitation examination is the least.

Table 3: The number of cloudy satellite and the root mean square error of the bias between background simulated bright temperature and observation for AMSU-A channel 5□10

Cloud examination and threshold	The number of cloudy satellite observation	Channel RMSE						
		5	6	7	8	9	10	
SI>10	1827	0.89	0.34	0.43	0.53	0.32	0.28	
SI>15	1399	1.00	0.35	0.44	0.53	0.32	0.28	
SI>20	646	1.38	0.41	0.52	0.57	0.33	0.30	
P>5	73	3.47	0.61	0.67	0.61	0.49	0.43	
R>0	20	4.54	0.59	0.77	0.60	0.63	0.51	
Threshold of the bias between simulated bright temperature and observation		1.14	0.54	0.51	1.02	0.66	0.63	

The screen of satellite data used in the assimilation system is done by both cloud examination and the extreme check of the bias between background simulated bright temperature and observation. Table 3 is a statistic of the number of cloudy satellite observation and the root mean square error of the bias

between background simulated bright temperature and observation for AMSU-A channel 5-10. It cloud be found that most of the satellite data affected by cloud distinguished by Scattering Index with threshold 20, precipitation probability and precipitation examination could also be discarded by the extreme check. Most satellite data could be used for these three cloud examination methods. While most satellite data are discarded for the Scattering Index with threshold 10.

For AMSU-B, the number of satellite data affected by cloud distinguished by the bias between simulated bright temperature and observation of AMSU-B channel 2 is less than that of Bennartz Scattering Index. That is, more satellite data could be used in the assimilation system (Table 4).

Table 4: The number of cloudy satellite and the root mean square error of the bias between background simulated bright temperature and observation for AMSU-B channel 3□5

Cloud examination and threshold	The number of cloudy satellite observation	Channel RMSE	3	4	5
$ \text{obs}-\text{fg} _{\text{ch2}} \geq 5\text{K}$	1160		9.17	16.54	28.44
Bennartz SI > 20	2843		6.73	10.99	18.33
Threshold of the bias between simulated bright temperature and observation			7.98	7.14	7.38

4) Effect on the numerical forecast

The numerical integral is performed for typhoon Bilis's three periods, corresponding to formation, maturation and landing, respectively. The error between simulated and observation trace is presented in Table 5.

Comparing with Exp1, it is shown that the numerical forecast is degraded in Exp2. It is confirmed that there is no need of cloud examination for the use of AMSU-A channel 8-10 satellite data. The forecast of Exp3, in which more satellite data are used than Exp1, is much better than that of Exp1. It means that the introduction of more AMSU-A data in cloudy area by Scattering Index with threshold 15 have positive effect on the forecast. While with the number of satellite data increasing by using Scattering Index with threshold 20, precipitation probability and precipitation examination (Exp4-Exp6), the forecast becomes worse. It is indicated that the negative effect is brought by the use of more satellite data in cloudy area. It seems that the Scattering Index with threshold 15 is a suitable cloud examination scheme for the use of AMSU-A data. It is pointed out that the result is not supported by the forecast of first period, which suggests that the assimilation of satellite data is a complex issue. There is a need to verify it by doing a long period run.

For AMSU-B, the forecast of Exp7 is the same as that of Exp1. It is attributed to the cloud examination for AMSU-A in Exp1 is used, while the cloud examination for AMSU-B in Exp7 is utilized in Exp1. It is found that the forecast of Exp7 is better than that of Exp8.

Verification of simulation of satellite microwave data in cloudy and rainy area

1) Input of cloud and rain information

With the cloud and rain information as input to CRTM, the satellite observation could be simulated including the radiant effect of cloud and precipitation particle. The cloud and rain information is provided by the forecast of WRF model. The total cloud water, rain water and ice water contents are presented in Fig. 3. The distributions match well with the weather system. Together with the analysis of vertical profile (not presented), it is shown that the cloud and rain water concentrate near the lower level and the ice water is on the upper.

Table 5: The error between simulated and observation trace for Bilis

Date	Control	Exp1	Exp2	Exp3	Exp4	Exp5	Exp6	Exp8
First period								
0918	151.91	151.91	151.91	151.91	151.91	151.91	151.91	151.91
1000	136.20	89.49	136.2	89.49	89.49	89.49	89.49	89.49
1006	210.09	163.00	210.09	163.00	163.00	163.00	163.00	163.00
1012	197.80	162.26	197.80	197.80	162.26	126.63	126.63	162.26
1018	210.16	165.79	165.79	165.79	144.81	97.48	97.48	144.81
1100	208.05	200.85	208.05	200.85	156.74	150.73	150.73	206.43
1106	163.61	112.70	112.70	112.70	129.66	62.23	62.23	175.73
1112	177.93	196.42	177.93	177.93	152.37	82.00	82.00	225.00
1118	203.69	216.23	213.86	165.00	165.00	100.85	100.85	234.29
1200	186.33	186.33	206.73	137.95	137.95	75.61	75.61	206.73
1206	194.50	194.50	222.17	178.38	127.25	125.14	125.14	222.17
Second Period								
1018	144.81	144.81	144.81	144.81	144.81	144.81	144.81	144.81
1100	208.05	208.05	208.05	200.85	208.05	208.05	208.05	200.85
1106	163.61	163.61	163.61	163.61	163.61	163.61	163.61	163.61
1112	177.93	177.93	177.93	173.15	173.15	177.93	177.93	177.93
1118	203.69	151.65	203.69	155.49	155.49	151.65	203.69	151.65
1200	186.33	126.76	179.02	136.92	126.76	179.02	179.02	126.76
1206	194.50	127.25	178.38	125.14	127.25	178.38	178.38	178.38
1212	212.77	141.08	186.51	70.89	186.51	212.77	257.11	186.51
1218	291.46	178.75	292.26	104.97	252.37	292.26	335.00	219.74
1300	339.96	191.28	278.91	155.96	155.96	344.53	377.78	191.28
1306	403.84	272.11	346.57	168.26	382.28	403.84	451.30	272.11
Third period								
1218	76.36	76.36	76.36	76.36	76.36	76.36	76.36	76.36
1300	76.36	44.52	44.52	44.52	84.08	76.36	76.36	84.08
1306	102.13	100.78	100.78	100.78	100.78	152.63	152.63	152.63
1312	83.32	83.32	83.32	61.19	61.19	166.73	166.73	83.32
1318	71.22	71.22	71.22	71.22	71.22	176.99	175.53	71.22
1400	89.13	89.13	114.97	114.97	114.97	194.06	194.06	89.13
1406	100.76	113.03	100.76	100.76	153.72	213.02	213.02	113.03
1412	22.34	44.07	38.35	44.07	22.34	139.24	139.24	44.07
1418	99.45	162.28	162.28	185.07	152.04	45.76	111.90	162.28
1500	170.49	192.27	239.49	251.28	239.49	119.94	110.41	239.49
1506	210.68	234.29	281.16	308.45	281.16	234.29	161.88	308.13

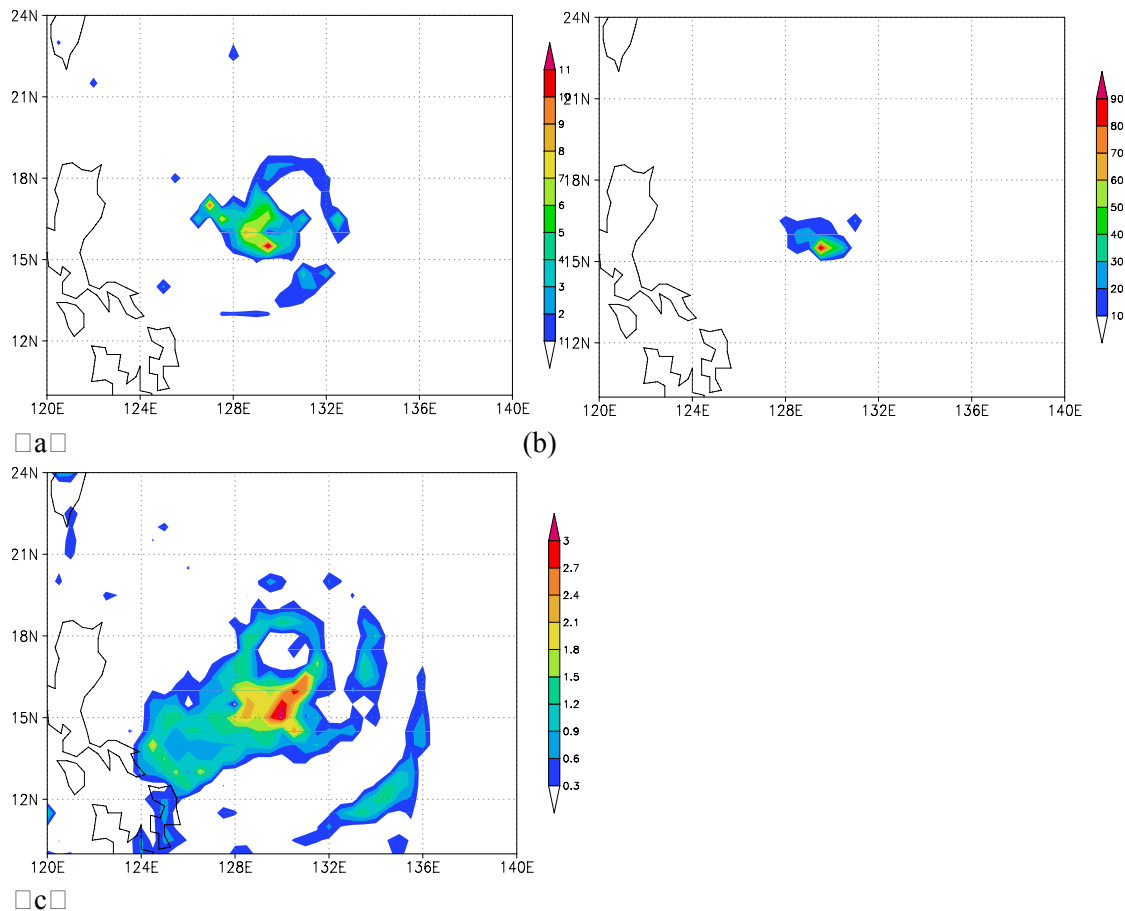


Fig. 3: The total cloud water (a), rain water (b) and ice water (c) contents.

2) Characteristics of the simulated satellite observation

The investigation is performed on the simulated bright temperature with no water contents, with cloud water, rain water, ice water and all water contents against the observation. Only the patterns for AMSU-A channel 1 and AMSU-B channel 5 are presented in Fig. 4 and Fig. 5, respectively. Generally speaking, the inclusion of radiant effect of water contents in radiative transfer model makes the simulation match the observation closely. For AMSU-A window channel 1-3, the cloud and rain water contribute to the high bright temperature core associated with the typhoon system. Rain water has greater effect on channel 1-2 than cloud water. While the latter takes the leading role in channel 3. The inclusion of water contents contribute to the low bright temperature core from channel 4 to the channels after. The contribution is going less with the increase of channel number. It is noted that the effect of water contents is not obviously shown in channel 5-7. These channels are thought to be affected by cloud and rain. Cloud examination is taken when they are used in the assimilation system. For AMSU-A channel 15, the radiant effect of water contents contribute to the low bright temperature core in the high bright temperature area associated with the typhoon. Rain water plays a much important role. Ice water performs as a minor part in all AMSU-A channels.

For AMSU-B channel 1-2, the water contents perform almost the same as that of AMSU-A channel 15. The effect is most obvious in channel 2. What is more, the effect of ice water is presented in channel 2. The scattering of ice particle dominates the radiant effect in AMSU-B channel 3-5. It implies that the cloud examination should pay special attention to the effect of ice water.

The bias between observation and simulation for all AMSU is also presented in Fig. 6. It is shown that the simulation of satellite observation in cloudy and rainy area could really be improved by the

inclusion of the radiant effect of cloud and rain particle in the fast radiative transfer model.

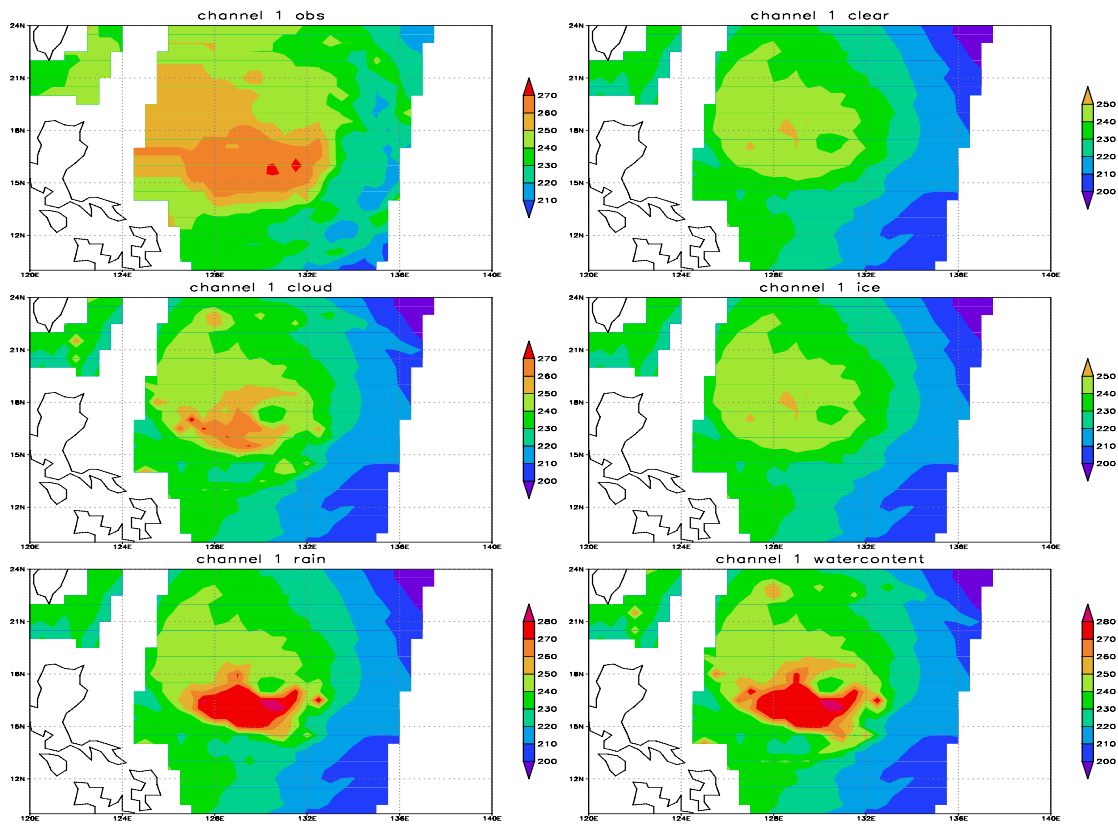


Fig. 4: The observation and simulation of bright temperature with no water contents, with cloud water, rain water, ice water and all water contents for AMSU-A channel 1.

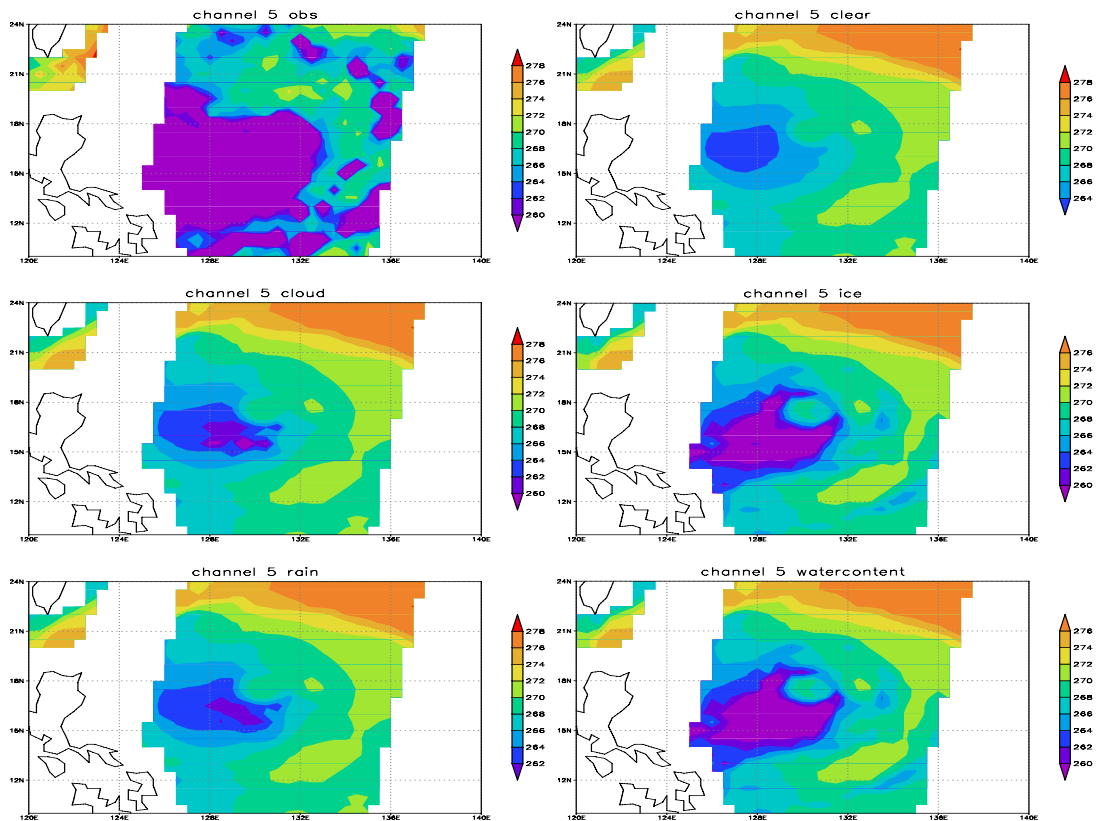


Fig. 5: The same as Fig. 4, but for AMSU-B channel 5.

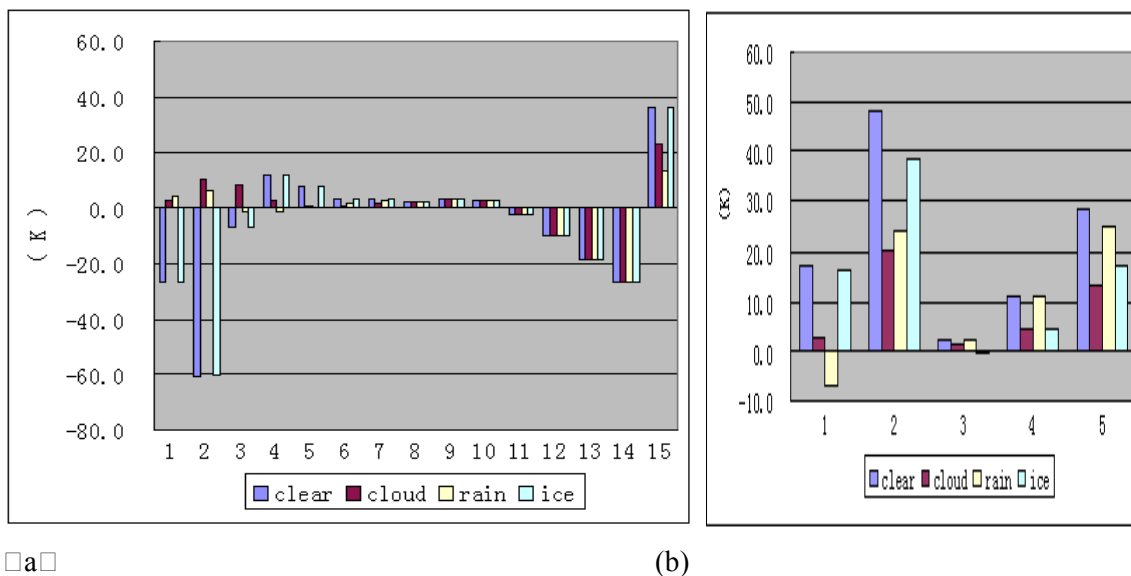


Fig. 6: The bias between observation and simulation. (a) AMSU-A; (b) AMSU-B.

Conclusion and discussion

A set of experiments has been described to use the satellite microwave data in cloudy area based on the cloud examination scheme. Scattering Index, precipitation probability and precipitation examination are taken for AMSU-A. For AMSU-B, the bias between simulated bright temperature and observation of AMSU-B channel 2 and Bennartz Scattering Index are utilized. The result shows that more AMSU-A satellite date could be screened by Scattering Index than precipitation probability and precipitation examination. The Scattering Index with threshold 15 is suitable for the use of AMSU-A date in regional model. For AMSU-B, the bias between simulated bright temperature and observation of AMSU-B channel 2 performs well than Bennartz Scattering Index.

With the cloud and rain information as input to CRTM, the simulation of satellite data in cloudy and rainy area is verified. It is found that the inclusion of radiant effect of water contents in radiative transfer model makes the simulation match the observation closely. The effect of water contents corresponding well with the observation characteristic of each channel. It will definitely push the use of cloudy radiances directly in NWP model and enhance the impacts of satellite data that have been demonstrated through clear radiance assimilation.

It should be pointed out that there is still a little large bias between simulated and observation though the effect of water contents is introduced in the radiative transfer model. More issues, including how the cloud and rain output from numerical model is competent for the background information and the sensitivity of simulation bias to the water contents error and so on, will be discussed further.

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