Bias Correction of Satellite data in GRAPES 3DVAR

***Wei Han*[1]*, Jishan Xue*[1]*, Zhiquan Liu*[2,3]**

1 Chinese Academy of Meteorological Sciences, Beijing, China

2 National Satellite Meteorological Center of China, Beijing, China

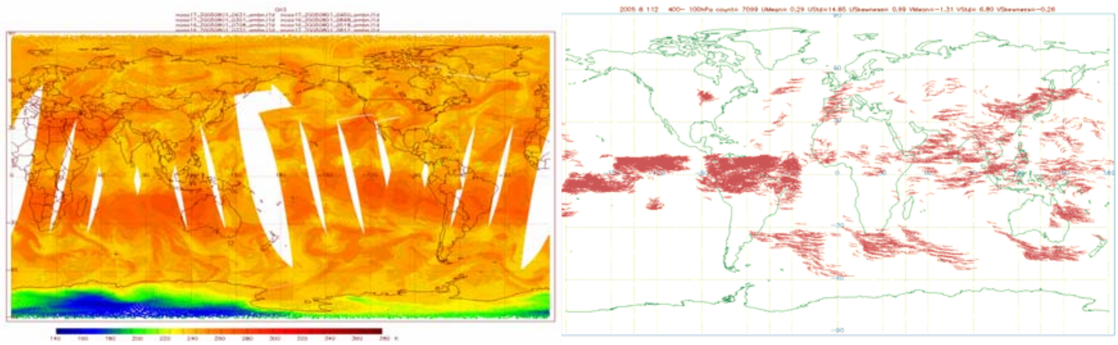
3 National Center for Atmospheric Research, Boulder, Colorado,U.S.A

Abstract

The bias correction of satellite radiances is crucial for enhancing the impact on forecast skill. This paper will firstly give the current status of satellite data assimilation in GRAPES 3DVAR and detail the current method of satellite data bias correction and discuss the results comparing uncorrected and bias-corrected AMSU radiances in GRAPES global and regional meso-scale model. The results of bias correction seem to be very promising.

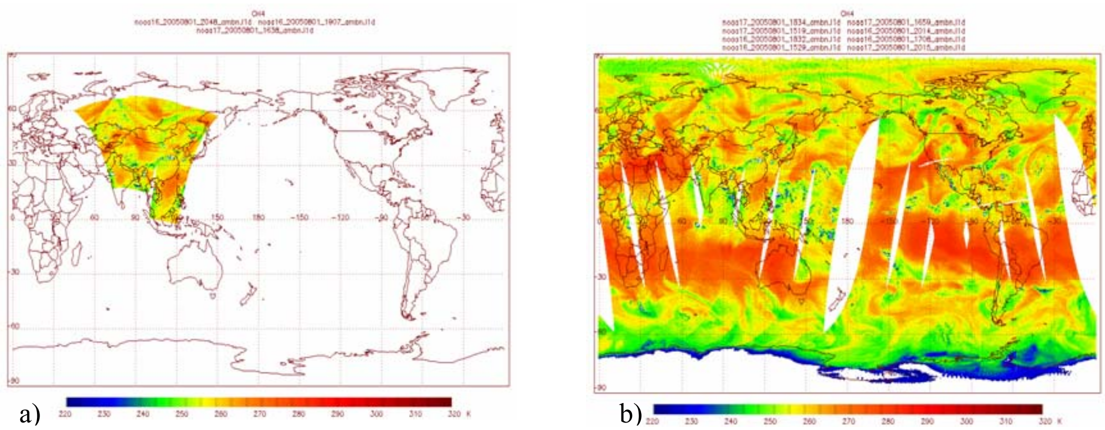
Introduction

Two main types of satellite observation assimilation has been developed in GRAPES-3DVAR, includingv ATOVS radiances from polar orbit satellites(Xue et al. 2003; Dong et al. 2005) and AMVs from geostationary satellites including FY2C which is the first operational meteorological satellite of China launched on 19 Oct 2004(Han et al.,2006) , as shown in Fig. 1.



a) b)

Fig. 1: An example of satellite data assimilated in GRAPES. a) ATOVS data, b)AMV data.



a) b)

Fig.2: ATOVS data assimilation in GRAPES: from regional to global. a) NOAA16/17 AMSUB CH4 2005080118(-3h~3h),Local received; b) NOAA16/17 AMSUB CH4 2005080118 (-3h~3h), From NESDIS.

Before November 2005, CMA can only operationally use the locally received ATOVS data by three ground stations as shown in Fig2.a, since then, CMA has been pre-operationally using global ATOVS(on board NOAA-15, -16, -17) 11b raw data from the NOAA/NESDIS as shown in Fig2.b. The ATOVS 11b data is preprocessed in CMA to 11c data used in regional and global version of GRAPES 3DVAR.

In the traditional framework of variational assimilation, the observation $\mathbf{y}$ are combined with the background $\mathbf{x}^b$ by minimizing a functional

$$J(\mathbf{x}) = (\mathbf{x}-\mathbf{x^b})^T \mathbf{B}^{-1}(\mathbf{x}-\mathbf{x^b}) + [\mathbf{y}^o - H(\mathbf{x})]^T \mathbf{R}^{-1}[\mathbf{y}^o - H(\mathbf{x})], \quad (1)$$

with respect to the model state $\mathbf{x}$, where $H(.)$ denotes a set of observation operators and the matrices $\mathbf{B}$ and $\mathbf{R}$ represent covariances associated with background and observation errors(including the effects of approximations in the observation operators, e.g. $\mathbf{R}=\mathbf{O}+\mathbf{F}$) respectively. The NWP background and observations are all assumed to have normal and unbiased distributions.

Nevertheless, departures between the operational observations and the equivalent from the NWP model first-guess (innovations or first-guess departures) show systematic errors. In operational assimilation of satellite data, a key element for successful satellite data assimilation is bias correction. Bias correction of FY2C AMVs was presented in Han et al.(2006) which is mainly on the adjustment of assigned AMV height. The first-guess departures of AMSU are analyzed and the bias correction scheme, the predictors in the bias model, the estimation method of the predictor coefficients are all re-examined in GRAPES global and regional models respectively and the results will be given.

Bias Observed and Bias Correction

For the assimilation of radiances, biases are due both to the satellite instrument, and the underlying airmass, resulting from inaccuracies in the fast radiative transfer model that converts NWP fields into simulated radiances. The innovations are defined as the first guess minus observations in this work, e.g.,

$$\mathbf{d} = H(\mathbf{x}^b) - \mathbf{y}^o. \quad (2)$$

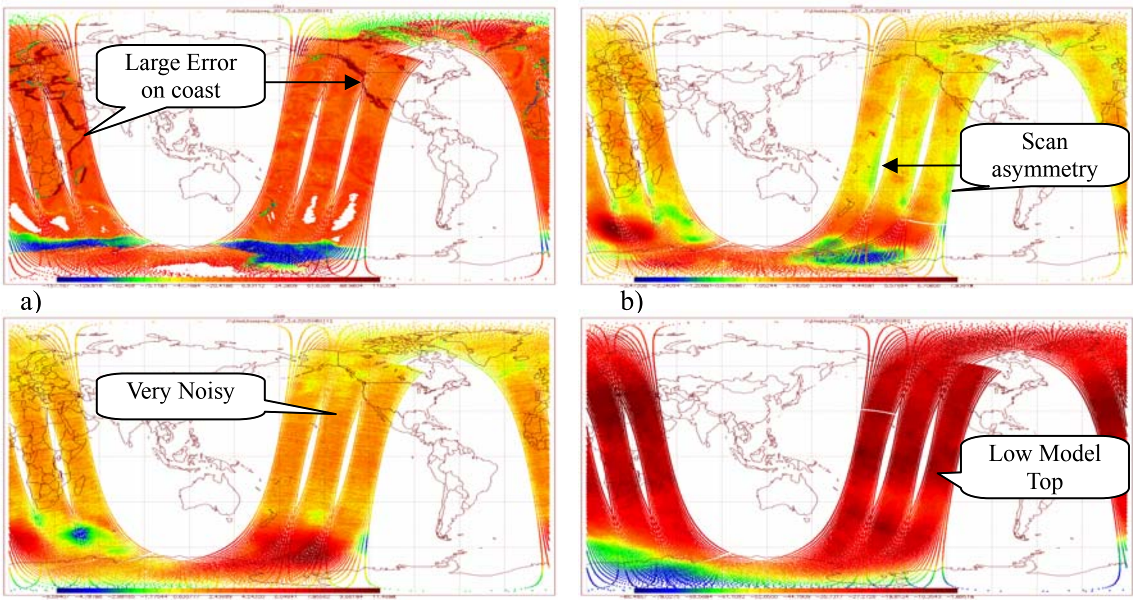


Fig.3: AMSU Bias observed in GRAPES 3DVAR. The innovations of AMSUA(NOAA16,

2005080109~2005080112) ch1, ch6, ch8 and ch14.

Firstly, the innovations are analyzed to identify the sources of systematic bias in observations, forward model and the background and assigning them a priority. The innovations of AMSUA(NOAA16, 2005080109~2005080112) ch1, ch6, ch8 and ch14 show four types of systematic errors: large errors on coast due to no provision in RTTOV for coast surface(ch1, Fig. 3.a), varying with the scan position of the satellite instrument and demonstrating asymmetry as shown in (ch6, Fig. 3.b), very noisy observations(ch8, Fig. 3.c), large errors due to the extrapolation of the background(ch14, Fig. 3.d).

For initial implementation, a bias correction scheme based on simple linear regression (Harris and Kelly,2001) is adopted in GRAPES global and regional model. The scheme is based on a separation of the biases into scan-angle dependent which is a function of latitude as well as scan position and state dependent components which is expressed as a linear combination of a set of state-dependent predictors which are computed from the background field of T213 from National Meteorological Center (NMC). Four predictors are used: (1) 1000-300 hPa thickness, (2)200-50 hPa thickness, (3) model surface temperature and (4) total precipitable water. The predictor coefficients for the state-dependent component of the bias are obtained by linear regression based on two weeks innovation statistics. Fig.4 provides an example of the scan bias of AMSUA(NOAA16) based on the statistics of innovations during the period from Aug.1st, 2005 to Aug. 15th,2005 in different latitude band. The scan bias of AMSUB demonstrates similar structure which is not shown here.

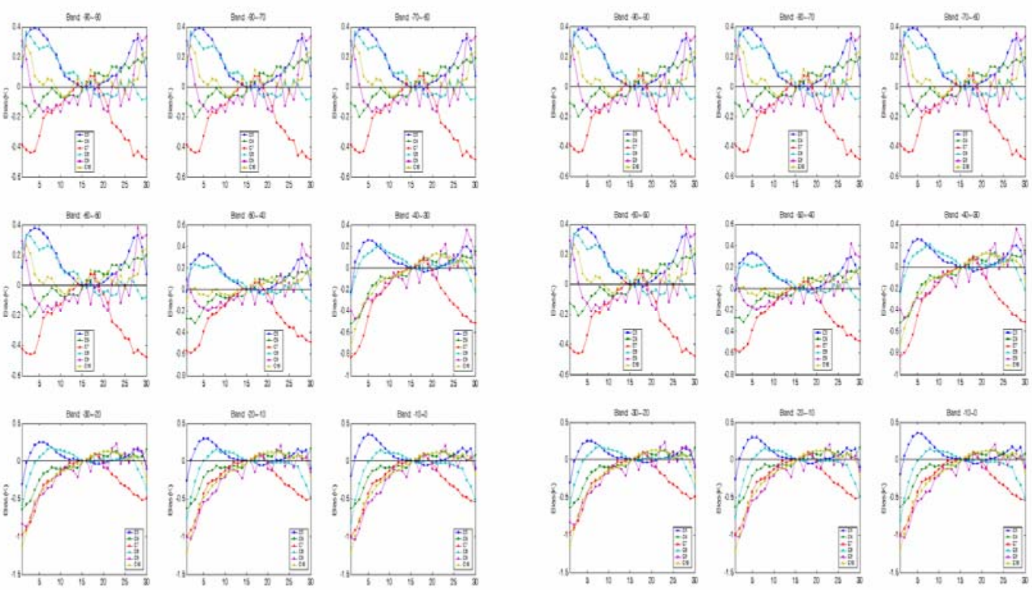


Fig.4: AMSUA(NOAA16) scan bias based on the statistics of innovations during the period from Aug.1st, 2005 to Aug. 15th,2005 in different latitude band.

Time series of latitude band averaged innovations with bias correction and without bias correction of AMSUA(NOAA16) are shown in Fig.5, the STDs (standard deviations) are also displayed. As an example in the 6 hour time window(09~15UTC,Aug.1st, 2005), the bias-corrected radiances and bias-uncorrected radiances versus the equivalent from the background are compared in the scatter plot as shown in Fig.6. It can be seen that the systematic departures are removed by the bias correction from Fig.5 and Fig.6.

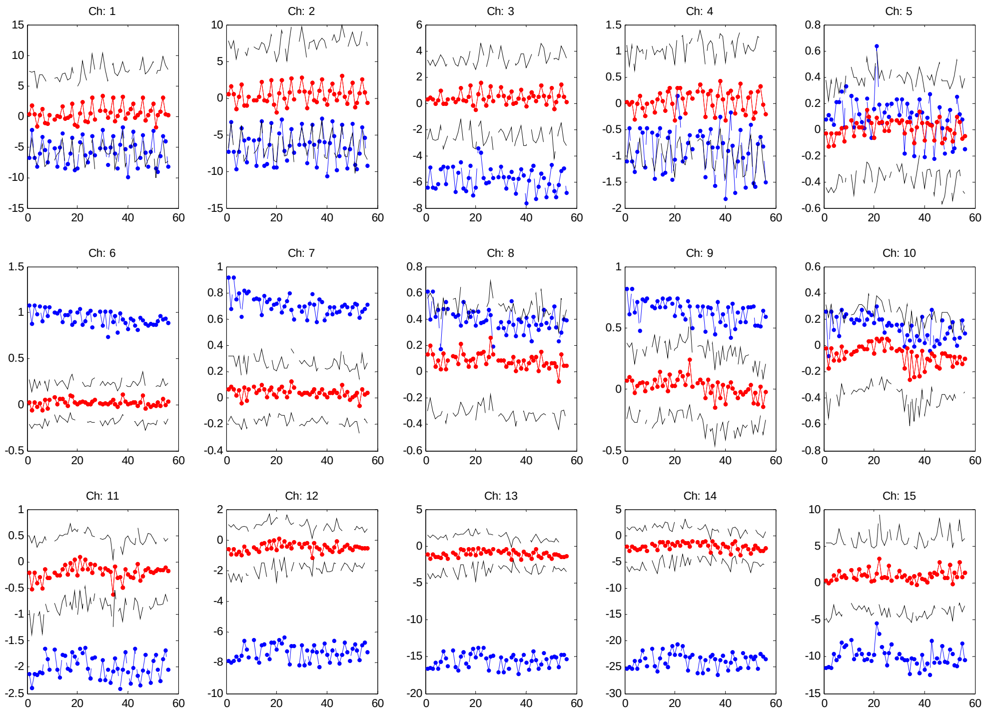


Fig.5: Time series of latitude band averaged innovations with bias correction and without correction of AMSUA(NOAA16) during the period from Aug.1st, 2005 to Aug. 15th,2005. The blue curve stands for band averaged innovations without bias correction, while the red one stands for band averaged innovations with bias correction, the black curve stand for +STD and –STD.

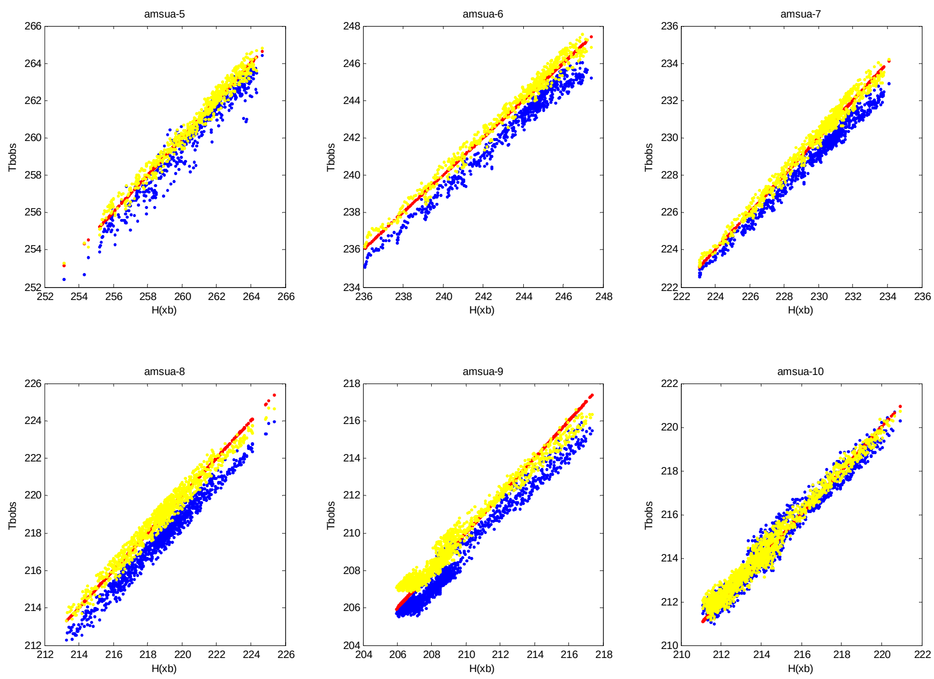


Fig.6: Scatter plot the bias-corrected radiances and bias-uncorrected radiances of of AMSUA ch5~ch10(NOAA16, 2005080109~2005080112) versus the equivalent from the background. The yellow scatters denote the bias-corrected radiances and the blue

scatters denote the bias-uncorrected radiances.

In order to estimate the systematic biases of different channels, the time and area averaged bias before bias correction are shown in Fig.7. In Fig.7.a, for NOAA16-AMSUA ch5~ch10 which are the effectively assimilated in GRAPES 3DVAR, the averaged innovations demonstrate a systematic warm bias (or cold bias of observation), imply that the background is warmer than the observations globally, which maybe mainly due to the inaccuracies of the radiative transfer model (RTTOV7) which does not consider the cloud and precipitation effects. For the surface sensitive channels (ch1~ch4 and ch15), the averaged innovations demonstrate a systematic cold bias, which maybe mainly due to the inaccuracies of microwave surface emissivity model. For the high level sounding channels (ch11~ch14), the bias demonstrate a large systematic cold bias, which maybe mainly due to the error in the background because of the extrapolation of the model level since the top model level of T213 is only 10hPa.

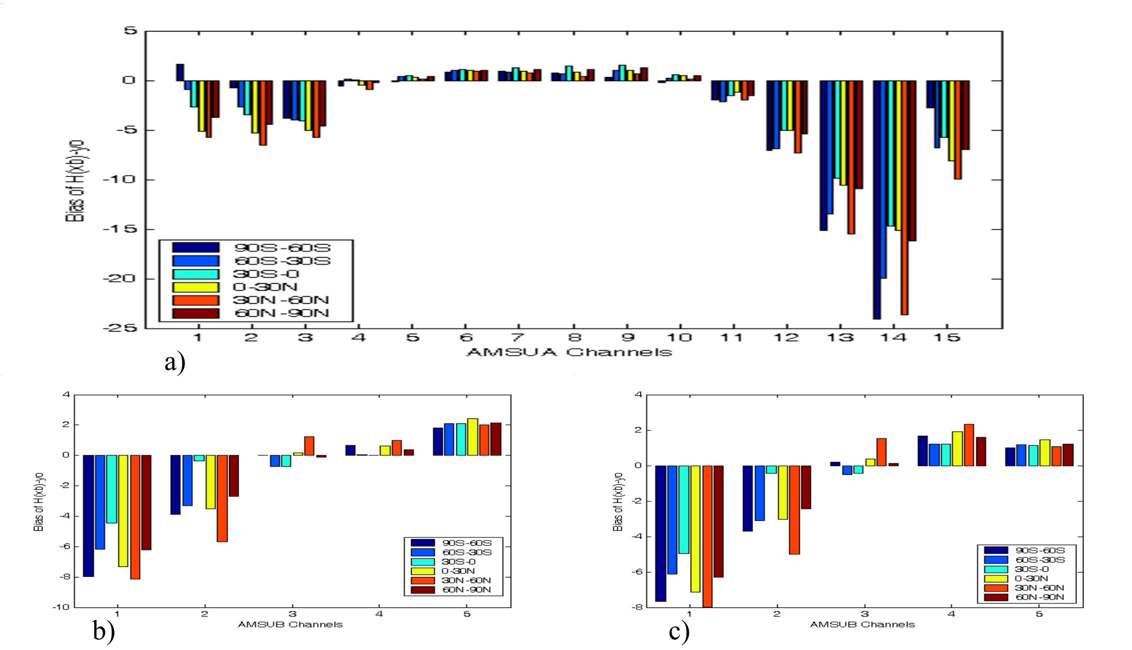


Fig.7: The time and area averaged bias before bias correction, a) NOAA16-AMSUA; b) NOAA16-AMSUB; c) NOAA17-AMSUA. The period for average is from Aug.1st, 2005 to Aug. 15th,2005.

Impact on Analyses and Forecasts

Impact studies of bias correction of AMSU have been undertaken, the 500hPa anomaly correlation coefficients of forecasts in Northern Hemisphere and Southern Hemisphere are verified against their own analyses.

Three group of data assimilation experiments were performed to investigate the impact of bias correction of AMSU on GRAPES global model analyses and forecasts. All experiments use GRAPES 3DVAR without cycle(e.g. assimilating observations only once at the analysis time) and the first guess (the background) is the 12h forecast of the operational T213 model running in National Meteorological Center (NMC) of CMA. After assimilation, a 6-day forecast was run from each 12Z(UTC) analysis over the period 1-10 August 2005.In order to verify the forecast to its own analysis, another 6 assimilations are performed over the period 11-16 August 2005 at 12Z UTC.

The forecast model is GRAPES Global Model, with horizontal resolution: 0.5 x 0.5 degrees, 31 vertical levels. The first group of experiments is the control experiments (ctrl), where no observations are assimilated. The second group of experiments (NoBC) is mainly to investigate the impact of AMSU, where only NOAA16-AMSUA, NOAA16-AMSUB and NOAA17-AMSUB are assimilated without bias correction. The third group of experiments (BC) is to investigate the impact of bias correction of AMSU, where only NOAA16-AMSUA, NOAA16-AMSUB and NOAA17-AMSUB are assimilated with bias correction. The bias correction coefficients are based on the statistics during two weeks before.

The impact of assimilation of AMSU with and without bias correction is shown in Fig.8.

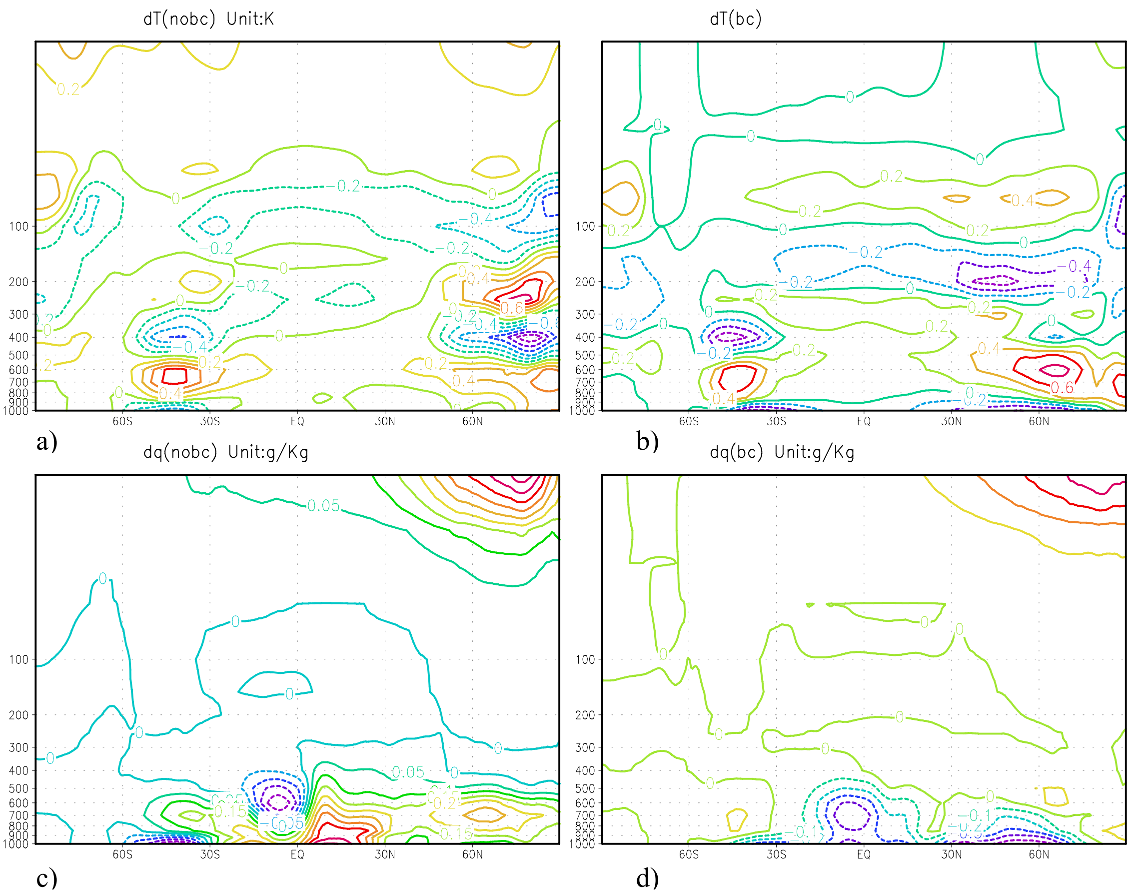


Fig.8: Impact of bias correction on analyses. a) Vertical distribution of temperature analysis increments of AMSU without bias correction along latitude, longitude averaged (180°E-180°W) over the period of 2005080112-2005081612, at every 0012Z UTC; b) As in a),but for the experiments with bias correction; c) As in a), but for humidity analysis increments; d) As in c),but for the experiments with bias correction.

Table1: The 500hPa anomaly correlation coefficients of forecasts

	Northern Hemisphere(20°N-90 °N)						Southern Hemisphere(90°S-20 °S)					
days	1	2	3	4	5	6	1	2	3	4	5	6
ctrl	0.9744	0.9232	0.8498	0.7708	0.6869	0.5829	0.9521	0.8413	0.6972	0.5557	0.4220	0.3152
NoBC	0.9691	0.9195	0.8487	0.7605	0.6624	0.5679	0.9441	0.8345	0.6953	0.5575	0.4265	0.3159
BC	0.9684	0.9217	0.8525	0.7722	0.6955	0.5987	0.9467	0.8362	0.6903	0.5621	0.4545	0.3668

The 500hPa anomaly correlation coefficients of forecasts are also listed in Table 1, from a validation of each experiment against its own analysis (This avoids penalizing the experiments without assimilation of AMSU). Fig. 9 also shows the scores, it is demonstrated that the bias correction of AMSU leads to a positive impact on 6 days forecast scores over the Northern Hemisphere and the Southern Hemisphere. The positive impact of bias correction of AMSU on 6 days forecast over the Southern Hemisphere is more obvious. But for the 24h and 48h forecasts, the 500hPa ACCs of both NoBC and BC are all lower than ctrl, it is probably due to the background (T213 12h forecast) which does not assimilate AMSU observation. Cardinali et.al. found that (Cardinali et al. 2003) 15% of the global influence is due to the assimilated observations in any one analysis (12h time window, 4DVAR), and the complementary 85% is the influence of the prior (background) information. In the present GRAPES 3DVAR, only AMSU observations in 6h time window are assimilated, so the results seem to be reasonable.

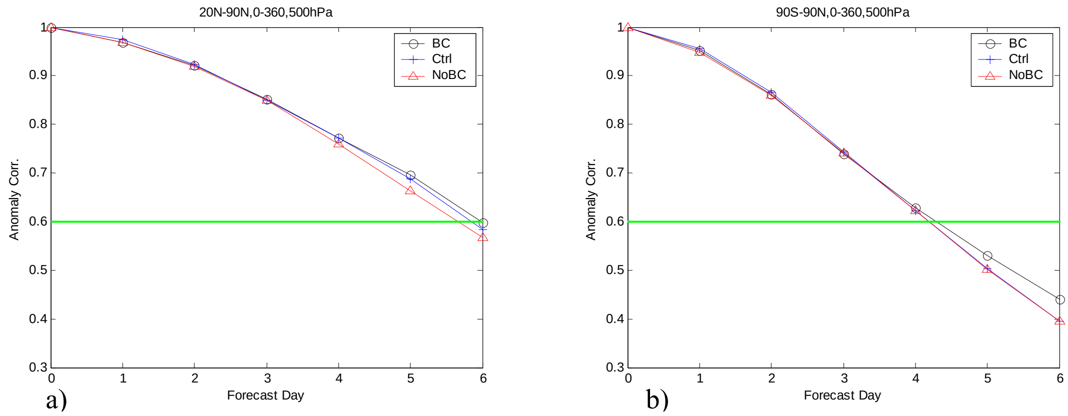


Fig. 9: Anomaly correlation of the geopotential forecasts from the experiments, ctrl(blue line with plus sign), NoBC (red line with triangle sign), BC (black line with circle sign). a) and b) show scores for the Northern and the Southern Hemisphere at 500hPa respectively. The forecasts have been validated against its own analysis.

Impact on Tropical Cyclone Forecasts

Another two experiments for tropical cyclone forecasts have also been conducted, one is for Typhoon RANANIM (2004) using GRAPES-Meso(15km resolution) and the other is for Typhoon MATSA(2005) using GRAPES-Global. Fig.10 shows the AMSUA(ch5~ch8) observations effectively assimilated in GRAPES 3DVAR(mesoscale version)on 06Z, Aug. 12th ,2004. It can be seen without bias correction, only few observations can be assimilated because of the first guess check in quality control, while more observations are effectively assimilated with bias correction since the systematic departures has been removed. The track forecasts of Typhoon Rananim 2004 are shown in Fig. 11a. For Typhoon MATSA (2005), 144h forecasts are made with three different analysis: NCEP analysis, GRAPES 3DVAR with assimilation of conventional observations from GTS, GRAPES 3DVAR with assimilation of AMSU and bias correction. The three different forecast tracks are shown in Fig. 11b. In both cases, it could be seen that the skill of the track forecast is improved by assimilation of AMSU and bias correction.

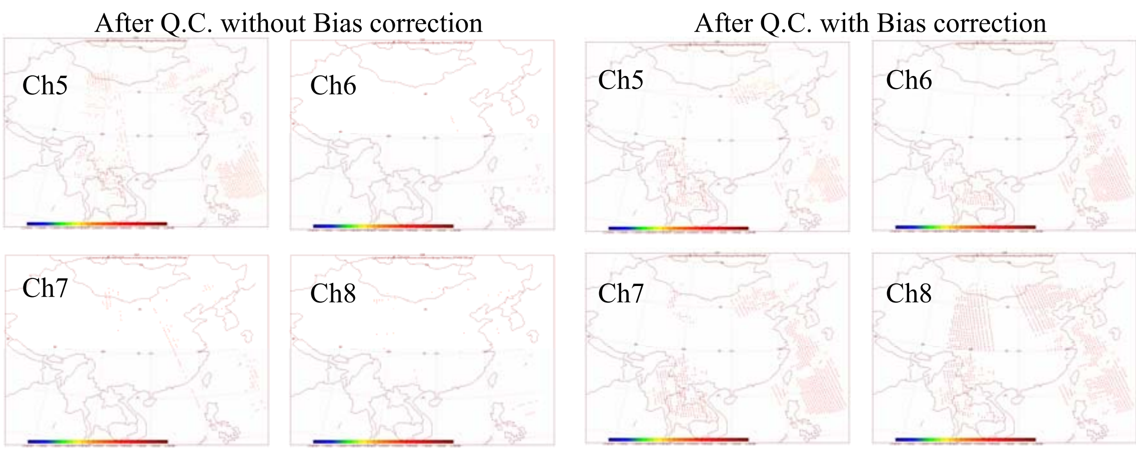
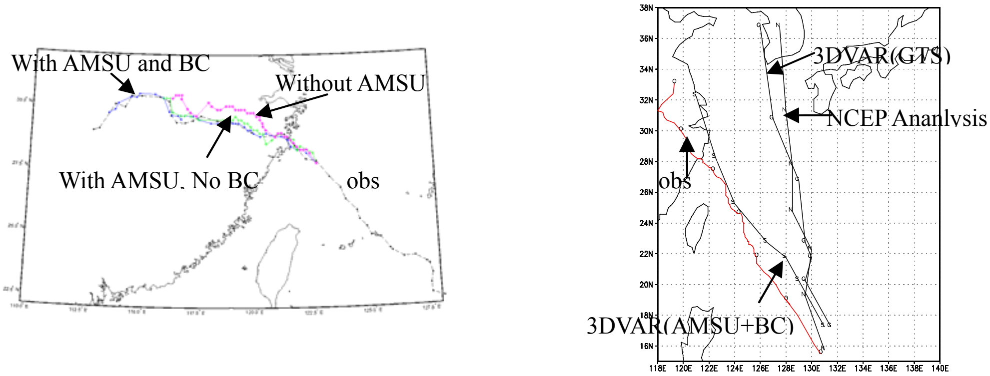


Fig.10: The AMSUA(ch5~ch8) observations effectively assimilated in GRAPES 3DVAR

(mesoscale version) on 06h, Aug. 12th ,2004.



a) b)

Fig. 11: Two examples of the impact of AMSU and bias correction on Typhoon forecast. a) RANANIM(2004);b)MATSA(2005).

Discussions and Ongoing work

Monitoring of the innovations is very helpful for the bias identification and corrention. Preliminary result indicates that the bias correction of AMSU in GRAPES 3DVAR in the medium and short range numerical weather forecast is promising and the assimilation of AMSU with bias correction also improves typhoon forecast. The tuning of observation errors in GRAPES 3DVAR are going. More trials will be needed in an operational environment and more works are conduted for using satellite data effectively and efficiently.

Acknowledgements

This work is supported by the National Key Scientific Program of China under Grant No. 2001BA607B and the National Natural Science Foundation of China under Grant No. 40605015 and No. 40305017.

Reference

Cardinali, C., S. Pezzulli and E. Andersson. 2003: Influence matrix diagnostic of a data assimilation system. Proc. ECMWF Seminar on “Recent Developments in Data Assimilation for Atmosphere and Ocean”, 8-12 Sept 2003, Reading, U.K.

Dong Peiming, Liu Zhiquan and Xue Jishan et al. 2005: The use of ATOVS microwave data in the Grapes-3Dvar System. In proceedings of the 14th international TOVS Study Conference (ITSC- XIV), 25 – 31 May 2005, Beijing, China.

Han Wei, Xue Jishan,Xu Jianmin and Zhang Qisong,2006: Assimilation of FY2C AMVs in GRAPES, Eighth International Winds Workshop, 24 - 28 April 2006, Beijing, China. (link:http://www.eumetsat.int/Home/Main/Publications/Conference_and_Workshop_Proceedings/SP_1154618862781?l=en)

Harris, B. and Kelly, G. 2001: A satellite radiance bias correction scheme for data assimilation. Quart. J. Roy. Meteor. Soc., 127, 1463-1468.

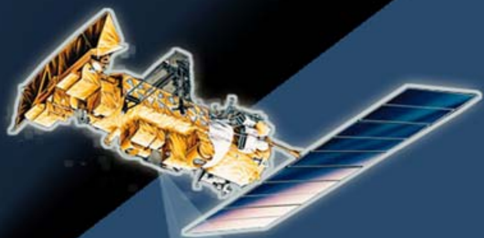
Xue Jishan, Zhang Hua and Zhu Guofu et al.. 2003: Development of a 3D Variational Assimilation System for ATOVS Data in China. In proceedings of the 13th international TOVS Study Conference (ITSC-XIII), 28 Oct – 4 Nov 2003, Ste Adèle, Canada.

INTERNATIONAL TOVS WORKING GROUP

Sharing ideas, plans and techniques

to study the earth's weather

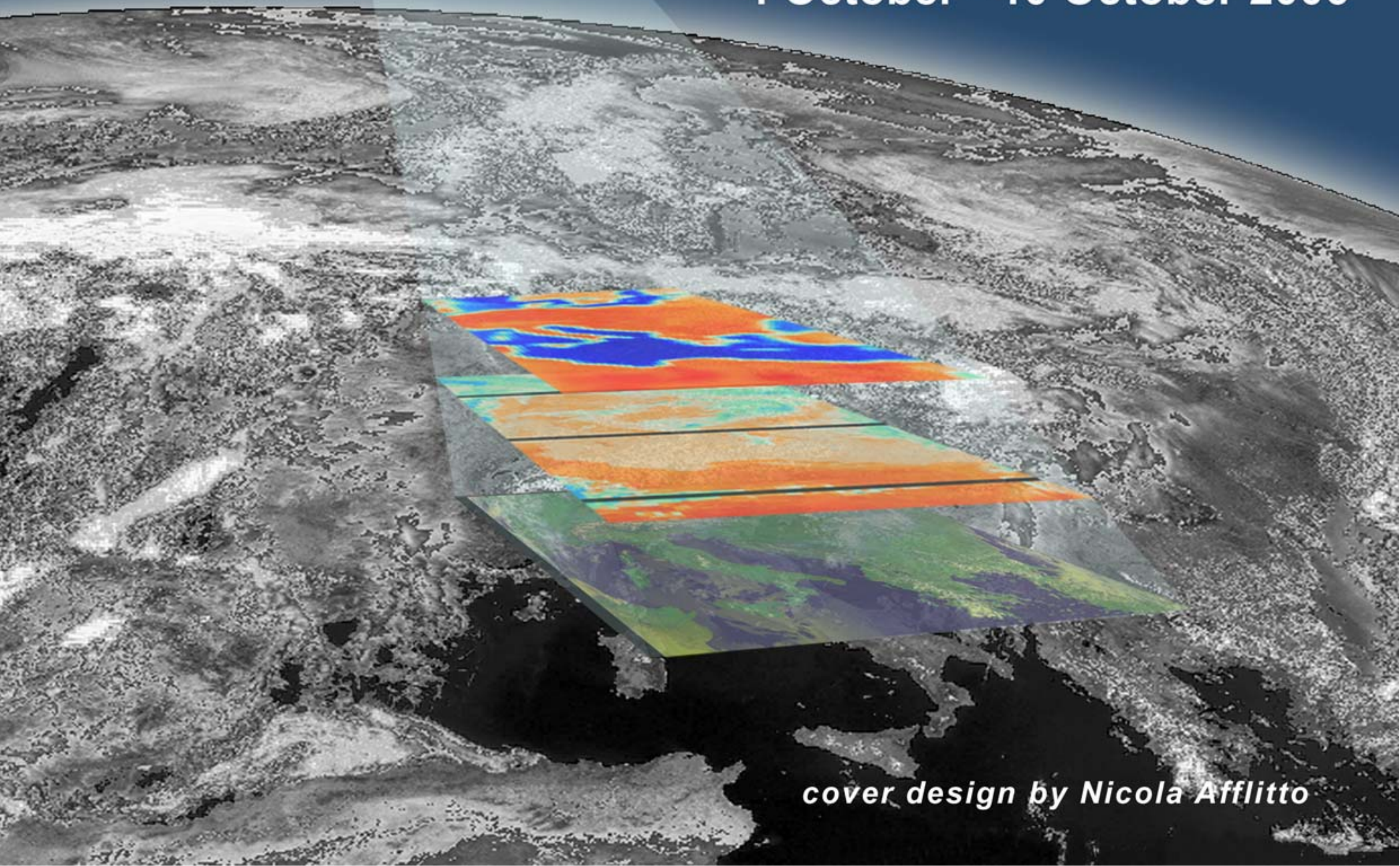
using space-based observations



Proceedings of the Fifteenth International TOVS Study Conference

Maratea, Italy

4 October - 10 October 2006



cover design by Nicola Afflitto