A Quality Control Procedure for FY-3A MWTS Measurements with Emphasis on Cloud Detection Using VIRR Cloud Fraction Applications

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Introduction

On May 27, 2008, FY-3A was launched with eleven instruments on board. It is a sun-synchronous polar-orbiting environmental research satellite. FY-3A carries three sounding instruments: the Microwave Temperature Sounder (MWTS), the Microwave Humidity Sounder (MWHS), and the Infrared Atmospheric Sounder (IRAS), providing atmospheric sounding data for the first time by China (Zhang *et al.*, 2009). Besides MWTS, MWHS and IRAS, a visible and infrared instrument called Visible and InfraRed Radiometer (VIRR), is also on board FY-3A. VIRR cloud fraction information within MWTS field-of-view (FOV) provides a direct method for MWTS cloud detection needed in MWTS data assimilation – one of the advantages of having VIRR on board the same satellite platform.

MWTS is a four-channel cross-track scanning radiometer that is similar to the Microwave Sounding Unit (MSU) on board the early NOAA satellites from Tiros-N(Tiros(Television Infrared Observation Satellite)) through NOAA-14 from 1979 to 2007, and it is also similar to Advanced Microwave Sounding Unit-A (AMSU-A) channels 3, 5, 7, and 9 on board NOAA-15, -16, -17, -18,-19 and Aqua (You *et al.*, 2012). AMSU-A data have long been incorporated in almost all operational numerical weather prediction (NWP) systems in the world, including the National Center for Environmental Prediction (NCEP) and the European Center for Medium-range Weather Forecasts (ECMWF). It is widely proven that direct assimilation of microwave temperature sounding data can significantly improve the accuracy of global and regional weather analysis and forecasts. An initial evaluation of FY-3A MWTS against NOAA-18 AMSU-A by Zou *et al.* (2011) showed that MWTS data compares favorably with AMSU-A data in terms of its global bias, with MWTS standard deviations slightly larger than those of AMSU-A data. A similar comparison of data from four observing instruments on board FY-3A and instruments on board MetOp-A can be found in Lu et al. (2010). Moreover, Wang and Zou (2012) showed that the temperature dependence of FY-3A MWTS measurement biases is mainly introduced by a post-launch frequency shift found by Lu *et al.* (2011). By incorporating the shifted frequencies into radiative transfer models, MWTS biases are nearly constant with respect to scene temperature. The addition of FY-3 vertical atmospheric sounding radiance data will increase the current global coverage of satellite observations. It is anticipated that MWTS data might be useful for NWP modeling systems if properly assimilated.

Challenges of satellite radiance data assimilation are associated with instrument biases, cloud contamination and surface emissivity. Several cloud detection methods were developed for satellite microwave measurements. Scatter index (SI) method is applied in ATOVS and AVHRR Pre-processing Package (AAPP) to detect scattering hydrometeors over ocean (Klaes and Schraidt, 1999), where SI is defined by the difference between the physical retrieval based on AMSU-A channels 1, 2 and 3 and observations of AMSU-A channel 15 over ocean. Another cloud detection algorithm used in Microwave Surface and Precipitation Products System (MSPPS) is based on cloud liquid water path (LWP) estimated by AMSU-A channels 1 and 2 (Weng and Grody, 1994). However, these methods are mainly developed for AMSU-A channels. The two surface-sensitive channels used for LWP retrieval and the 89 GHz channel used in the SI method are not included by MWTS. Instead MWTS data are screened for clouds by using a cloud fraction product derived from a visible and infrared instrument, VIRR, on board FY-3A. A series of QC steps dealing with problems associated with cloud, surface emissivity, high terrain and outliers are thus developed and implemented for FY-3A MWTS data in July 2011.

Cloud Detection

Cloud detection for MWTS channels is carried out using cloud fraction from VIRR also on board FY-3A. VIRR is a visible and infrared instrument that has 10 channels spanning the spectrum 0.43 to 12.5 um. Channels 1-5 are similar to the Advanced Very High Resolution Radiometer (AVHRR) on board NOAA series of satellites. The FY-3A VIRR cloud detection algorithm is similar to the MODIS cloud detection algorithm described in Ackerman et al. (2010). Analysis of the test results conducted in July 2011 indicates that most clouds are identifiable by applying an FY-3A VIRR cloud fraction threshold of 37%. This result is verified with cloud liquid water path (LWP) data from MetOp-A (The Meteorological Operational satellite programme), which further demonstrates that the FY-3A VIRR cloud detection method is more effective than using an O-B (brightness temperature differences between observations and model simulations) scheme of surface MWTS channel 1. On average, 56.1% global clouds are removed by the FY-3A VIRR-based cloud detection method.

Table 1: Channel characteristics of FY-3A MWTS.

Channel No	Center Frequency (GHz)	Peak WF (hPa)	NEΔT (K)
1	50.227	surface	0.5
2	53.656	700	0.4
3	55.020	300	0.4
4	57.373	90	0.4

Table 3: Channel selection based on cloud fraction, terrain height (z), and surface types.

Variables		Channel 2	Channel 3	Channel 4
f_{VIRR}>37%				√
land	z>500 m			√
	z ≤500 m		√	√
ocean	SST>273.15 K	√	√	√
	SST≤273.15 K		√	√

Table 2: Percentages of cloudy radiances over global ocean estimated from FY-3A VIRR cloud fraction data, FY-3A MWTS O-B values, and MetOp-A AMSU-A CLW retrievals using one-month data in July 2011.

Threshold			Cloudy FOVs (%)		
f_{VIRR}(%)	$(O-B)_{ch1}$ (K)	LWP (kg m^{-2})	$MWTS_{VIRR}$	$MWTS_{O-B}$	$AMSU-A_{LWP}$
37	-1.5	0.01	58.3	58.6	58.1
97	-4.0	0.10	24.4	24.2	24.2
100	-4.9	0.14	18.8	18.8	18.6

QC scheme and O-B bias after QC

MWTS quality control is carried out sequentially in the following order: (1) coastal FOVs are removed; (2) FOVS of channel 2 over sea ice are removed; (3) FOVs at scan edges (two from both sides of a scan line) are removed; (4) FOVs of channel 3 over terrain higher than 500 m are removed; (5) channel 2 over land are removed; (6) cloudy FOVs with f_{VIRR} greater than 37% are identified and removed; and (7) the remaining outliers identified by the biweighting check are eliminated.

The final results of the percentages of data eliminated by the above seven steps are shown in Fig. 5 for data in July 2011. About 18%, 26% and 71% of data pass the MWTS quality control channels 2, 3 and 4, respectively. The O-B differences of outliers and their standard deviations are much larger than those of the remaining data after quality control in Fig.6 and Fig.7. After quality control, the O-B distributions become more homogeneous. Figure 8 presents the latitudinal variation of scan biases of MWTS channels 2-4. They are calculated within every 5° latitudinal bands for each scan position for the entire month of July 2011. After quality control, scan biases become small and homogeneous without a strong latitudinal dependence. Frequency distributions of O-B differences before and after quality control for MWTS channels 2-4 are provided in Fig. 9. Biases are removed from the frequency distributions of data after quality control. The frequency distribution of the O-B differences between observations and model simulations become more Gaussian-like after quality control and bias correction.

Percentages of Cloudy MWTS FOVs

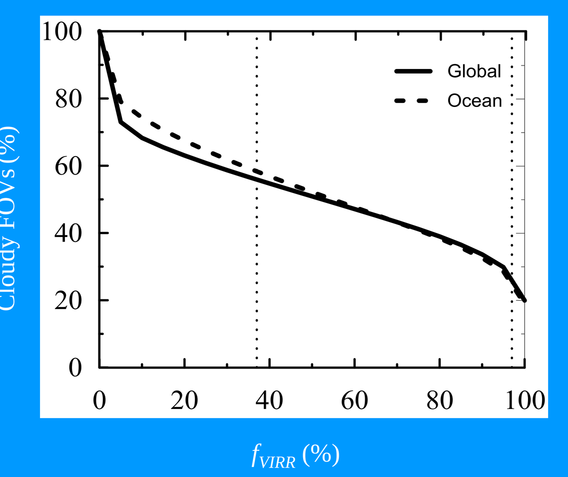

Fig. 1: (a) Percentages of cloudy MWTS FOVs when cloud fraction (f_{VIRR}) varied in July 2011. The three threshold values, f_{VIRR} =37%, 97% and 100%, are indicated in (a) by the vertical dotted lines.

Distributions of Cloudy FOVs

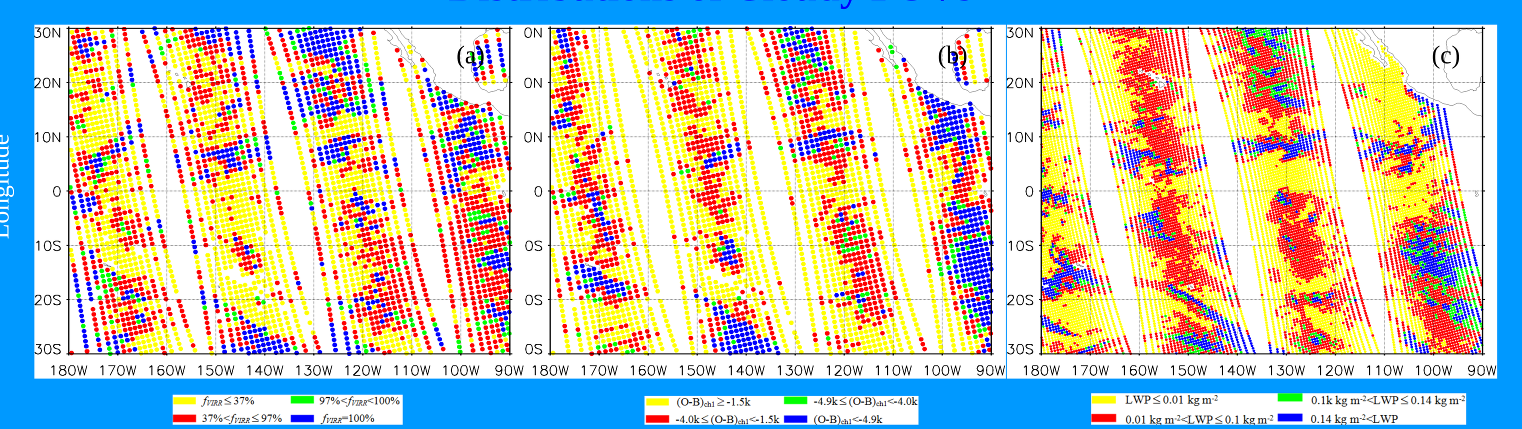

Fig. 2: Distributions of cloudy FOVs when values of three variables (a) f_{VIRR}, (b) $(O-B)_{ch1}$ and (c) LWP are within four different ranges for data during 0300UTC-1500 UTC July 1, 2011.

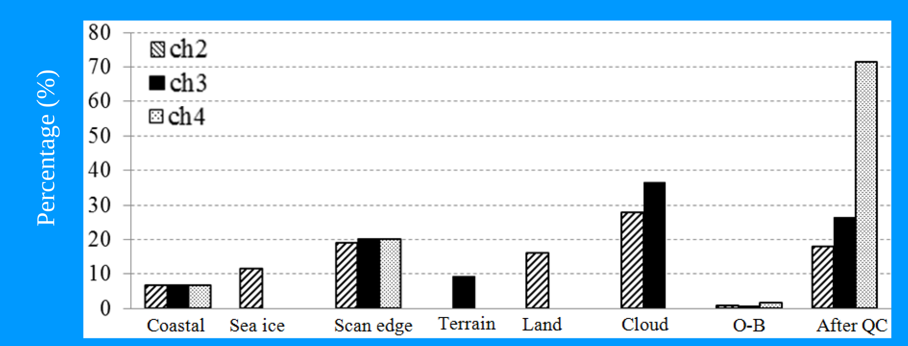

Fig. 5: Percentage of outliers identified by land, coastal FOVs, sea ice, scan edge, terrain

Outliers and Remaining Data Identified by Biweighting Check

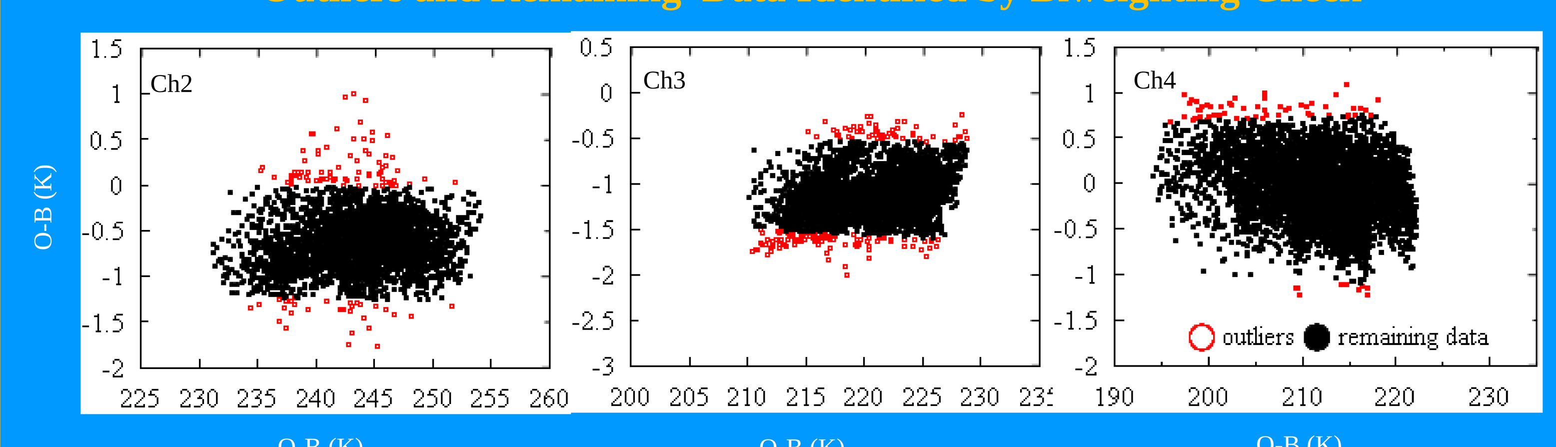

Fig. 4: Scatter plots of differences of brightness temperatures between observations and model simulations for data within 30N-30S on 1 July 2011. Outliers identified by the biweighting check are in red.

Scatter Distribution of O-B

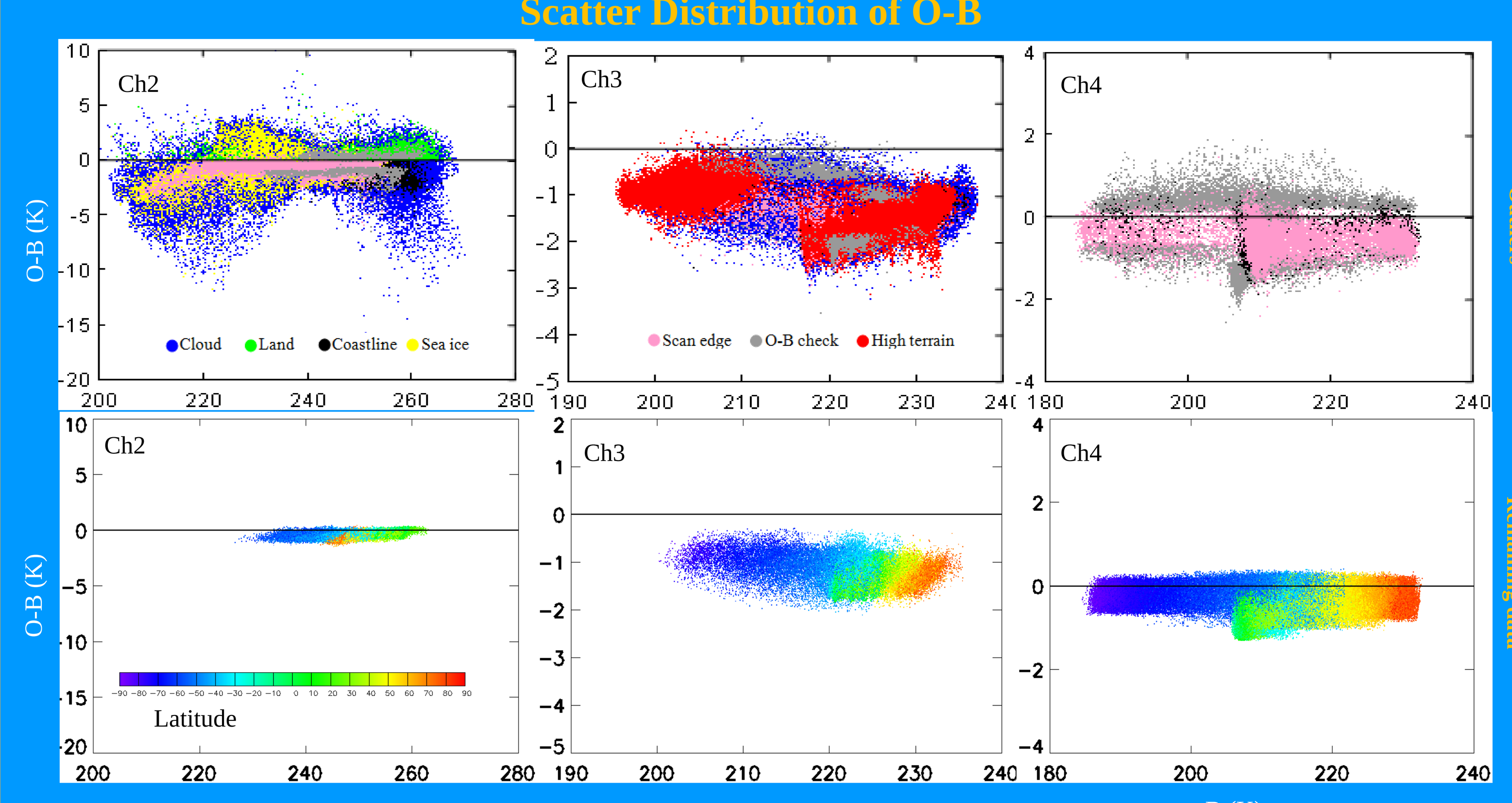

Fig. 6: Scatter plots of the differences of brightness temperature between observations and model simulations for MWTS outliers and data that pass quality control during 1-5 July 2011.

O-B Distribution

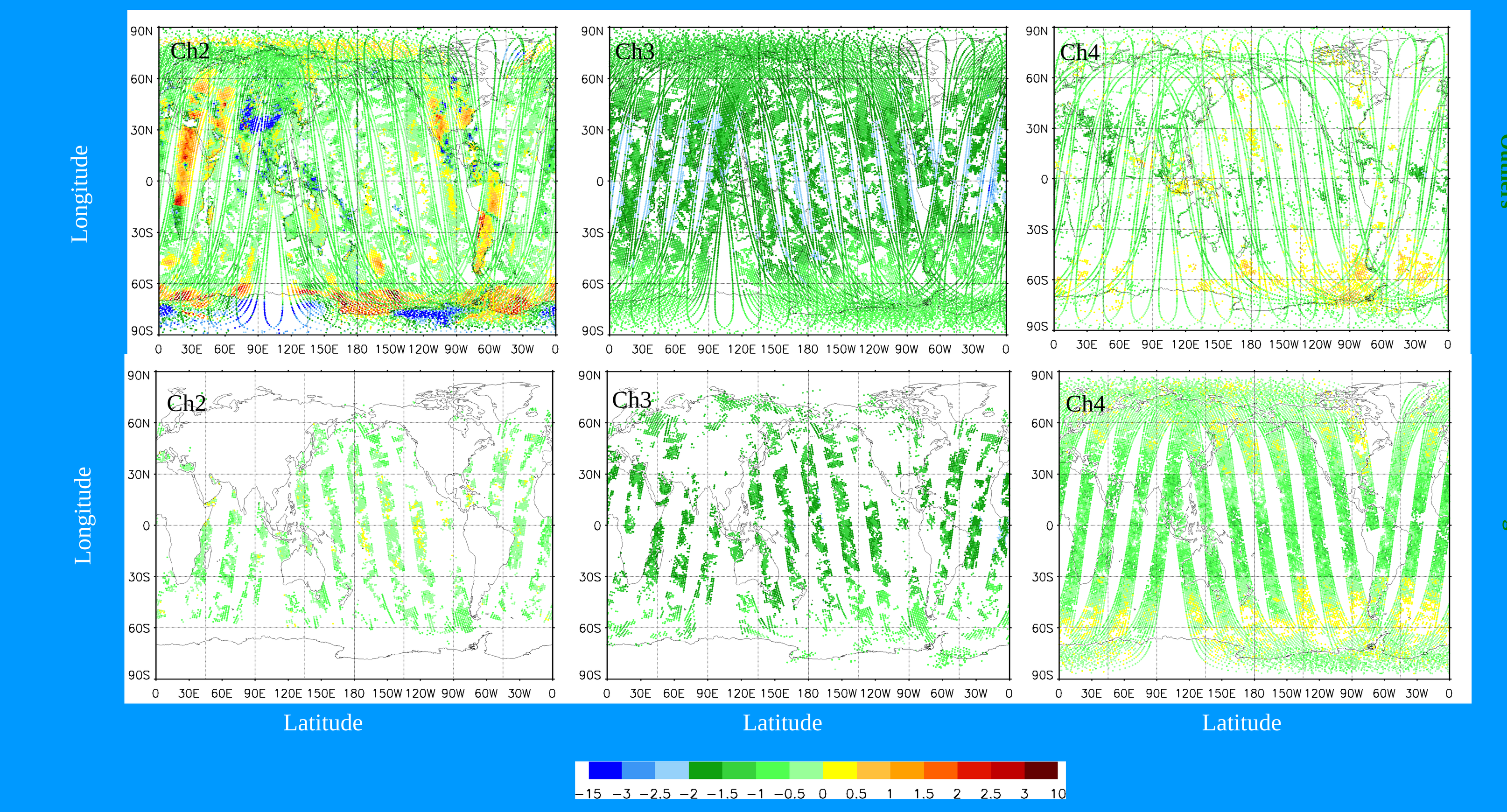

Fig. 7: Global distribution of brightness temperature differences between observations and model simulations for outliers and the remaining data on 0300UTC-1500 UTC July 1, 2011.

Scan Bias

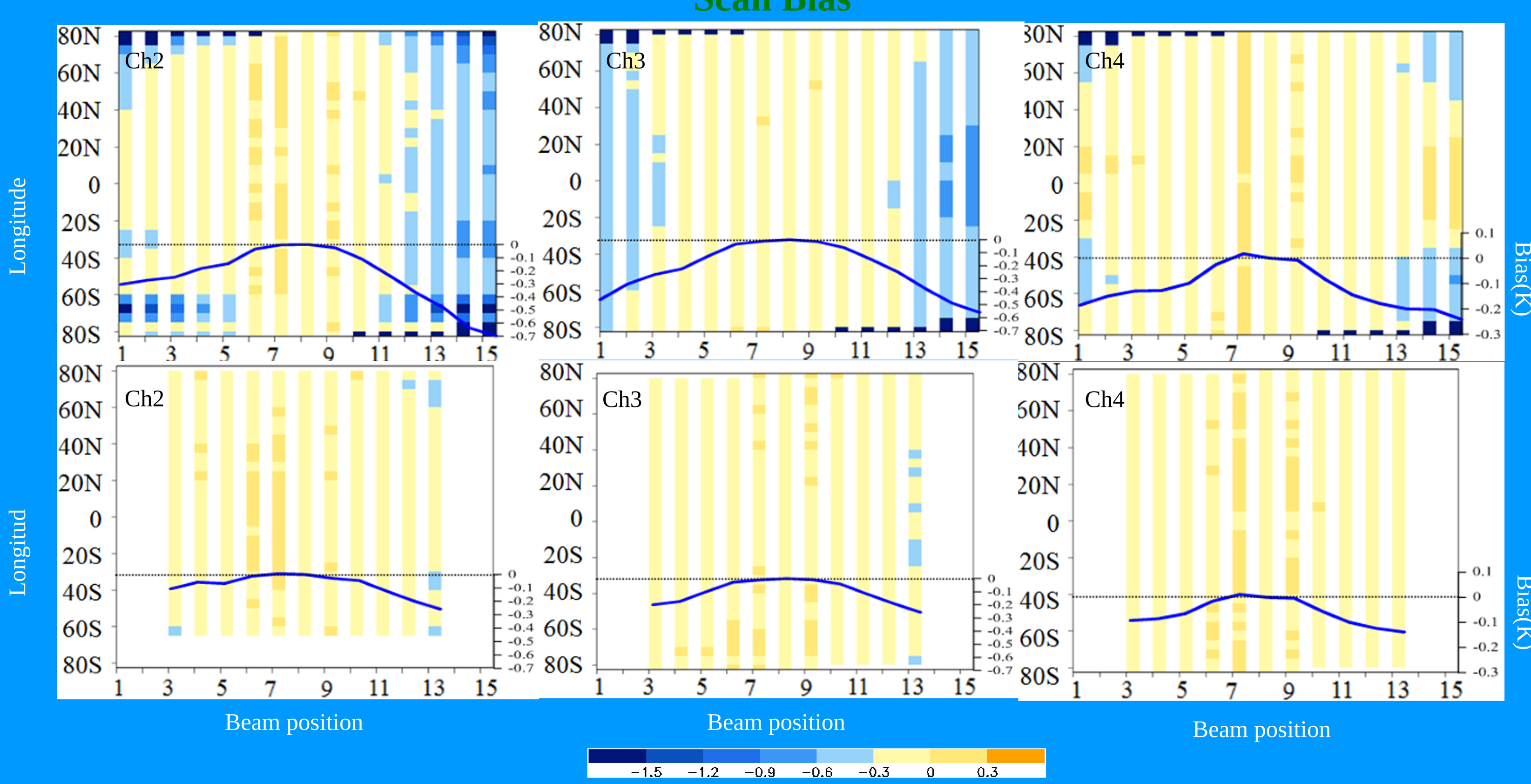

Fig. 8: Latitudinal dependences of scan biases (shaded) before and after quality control. Globally averaged scan biases are shown in blue solid line. Nadir biases are subtracted

Frequency Distributions of O-B

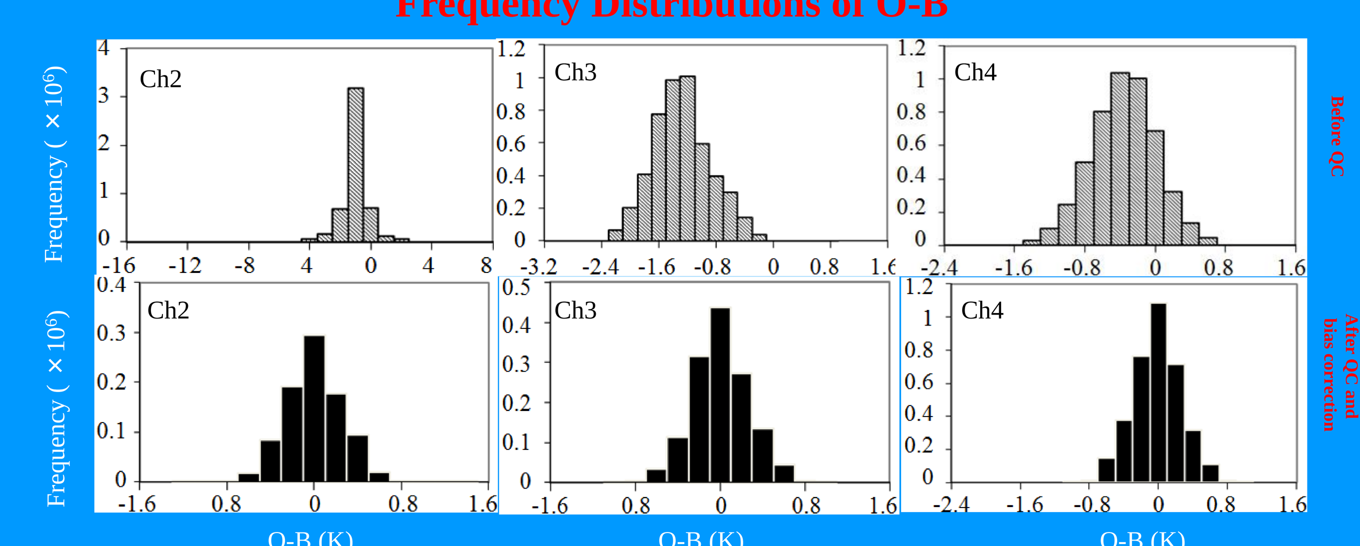

Fig. 9: Frequency distributions of O-B differences before QC (upper panel) and after QC and bias correction (lower panel) for MWTS channels 2-4.

Summary and Conclusions

A cloud detection scheme is tested using cloud fraction products provided by the VIRR instrument on board the same satellite platform. Results from applying this variable to MWTS data are compared with collocated cloud LWP products derived from MetOp-A two AMSU-A surface-sensitive channels. An analysis of test results conducted in July 2011 indicates that most clouds are identifiable by setting a VIRR cloud fraction threshold at 37%. It further demonstrates that FY-3A VIRR cloud detection method is more effective than using a simple O-B scheme of the MWTS surface-sensitive channel 1, especially away from the nadir. On average, the FY-3A VIRR-based cloud detection method found 56.1% of MWTS FOVs to be cloudy globally. In addition to cloud detection, observations over land and sea ice are also removed for the lowest sounding channels 2 or 3. Two outermost FOVs as well as coastal FOVs are eliminated for all channels. Finally, outliers that deviate greatly from model simulated MWTS radiances are also eliminated. About 18%, 26%, 71% observations are retained after quality control. After quality control, FY-3A MWTS data show a more coherent pattern compared with model simulations. The frequency distributions of the differences between observations and model simulations for all three MWTS sounding channels are more Gaussian-like after quality control and bias corrections. This work can be extended to the following FY-3 microwave temperature sounder measurements.

References:

Li, J. and X. Zou, 2012: A Quality Control Procedure for FY-3A MWTS Measurements with Emphasis on Cloud Detection Using VIRR Cloud Fraction, submitted to *J. Ocean Atmos. Tech.* (revised)

Zou, X. and Z. Zeng, 2006: A quality control procedure for GPS radio occultation data. *J. Geoph. Res.*, **111**, D02112, doi: 10.1029/2005JD005846.