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TWO BIAS CORRECTION SCHEMES FOR ATOVS RADIANCE DATA

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Abstract: To better assimilate Advanced TIROS Operational Vertical Sounder (ATOVS) radiance data and provide more accurate initial fields for a numerical model, two bias correction schemes are employed to correct the ATOVS radiance data. The difference in the two schemes lies in the predictors use in air-mass bias correction. The predictors used in SCHEME 1 are all obtained from model first-guess, while those in SCHEME 2 are from model first-guess and radiance observations. The results from the two schemes show that after bias correction, the observation residual became smaller and closer to a Gaussian distribution. For both land and ocean data sets, the results obtained from SCHEME 1 are similar to those from SCHEME 2, which indicates that the predictors could be used in bias correction of ATOVS data.

Key words: ATOVS radiance data; bias correction schemes; model first-guess

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1 INTRODUCTION

The Advanced TIROS-N Operational Vertical Sounder (ATOVS), which is on board the National Oceanic and Atmospheric Administration (NOAA) series of polar-orbiting satellites, provides atmospheric temperature and water vapor data that are very useful in Numerical Weather Prediction (NWP), as reported by Andersson et al. [1] and Rabier et al. [2]. ATOVS radiance assimilation has brought about significant improvements in forecast performance not only in the Southern Hemisphere but also in the Northern Hemisphere, as further reported by Simmons and Hollingsworth [3]. However, radiance observations from the satellites include biases from instrument characteristics, aging, and pre-processing. Fast radiative transfer models may also include biases from the approximation used to speed up the model and the inaccuracy of spectroscopic databases. The observations' biases may distort the observed minus calculated radiances (O-B) and sometimes cause serious problems in analyses.

Much progress has been made in the direct assimilation of satellite radiance measurements in numerical weather prediction systems during the last two decades. The original radiance-bias correction scheme in use at the European Centre for Medium-Range Weather Forecasts (ECMWF) relied on the observed brightness temperatures from the Microwave Sounding Unit (MSU) channels as predictors. Many researchers proposed that the bias in O-B relied on the air-mass dependent nature [4-7]. Eyre [8] studied some minor changes made involving the use of cloudy radiances, but the basic scheme remained unchanged. Harris and Kelly [9] took into account latitudinally dependent scan correction and used the information of model first-guess instead of radiances from MSU as predictors. Liu et al. [10] corrected the bias based on Harris and Kelly's [9] scheme and by taking into account both ATOVS instrument characteristics and weather conditions in China. Okamato et al. [11] relied upon both model first-guess and the observed brightness temperatures from several Advanced Microwave Sounding Unit-A (AMSU-A) channels as air-mass bias predictors. Two bias correction schemes are employed to correct ATOVS radiance data, Harris and Kelly's [9] scheme, which is called "SCHEME 1," and Okamato et al.'s [11] scheme, which is called "SCHEME 2." This paper will describe

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the detail of the two bias correction schemes and use them to correct the NOAA16 AMSU-A radiance data. The satellite radiance data and its bias correction schemes will be introduced in section 2. Two independent bias correction schemes are employed in section 3 to correct the bias in the observation. Finally, the discussion and conclusion are given in section 4.

2 SATELLITE RADIANCE DATA AND CORRECTION SCHEMES

2.1 *Satellite radiance data and quality control*

NOAA-16 is the fifth-generation polar-orbiting routine environmental series satellite. The Advanced Microwave Sounding Unit (AMSU) in NOAA-16 consists of Type A (AMSU-A) with 15 channels and Type B (AMSU-B) with 5 channels, which are used to improve the vertical sounding of atmospheric temperature and humidity. In comparison with conventional infrared and visible light sounding units, AMSU units have the unique capability to penetrate heavy clouds in order to sound the vertical structure of atmospheric temperature and humidity. The horizontal resolution of AMSU-A is 45 km, and that of AMSU-B is 15 km.

Quality control is vital for the use of any type of data. Many factors can cause large errors in satellite observations, such as the weather conditions (clear, cloudy, or overcast), the ground conditions (sea surface, land, sea ice, etc.), the geographical location (as in middle-latitudes or the tropics), observational geometrical conditions (sub-satellite point or an edge measure), the response characteristics and accuracy in the process of the sensor moving in the orbit, the error of the forward model and the error of the background field, etc. In order to guarantee the consistency between neighboring data and the quality of the analysis result, quality control procedures must be done first. It is conducted in two steps to reject the bad radiance data. The two steps are: 1) the radiance brightness temperature data outside of the interval 150－350 K are rejected, and 2) a check for departures between the simulated observation from the background field and the actual observation. Any radiance brightness temperature data that cannot satisfy the following inequality

$$\left| y_j^{\,b} - y_j^{\,o} \right| < k\sigma^o \qquad (1)$$

are excluded, where $y_j^{\,b}$ and $y_j^{\,o}$ are the values of the simulated observation from the background field and the actual observation in channel j, respectively, σ^o is the value of the variance of radiance brightness temperature data; k is a parameter (set k = 6 according to the experience from the experiments.)

2.2 *Scan bias correction*

Eyre [8] proposed that the radiance bias can be categorized into two types: scan bias and air-mass bias. According to a statistical study, scan biases vary with the latitude. Thus, the scan bias correction has been subdivided into 18 latitude bands of 10º for each latitude. Some smoothing is required to produce continuous correction coefficients across the latitude bands. The mean values for each scan position and band are computed, which are then used to compute the scan correction via the following equation:

$$d_s(\phi,\theta) = \overline{D}_s(\phi,\theta) - \overline{D}_s(\phi,\theta=0) \qquad (2)$$

where ϕ is the latitude band, θ is the scan angle, s is the scan position, $\overline{D}$ is the averaged observed radiance, and d is the scan bias. Once the mean scan correction for each position and each band has been computed, a simple smoothing method is then used to produce a smooth transition between bands. Specifically, the smoothed scan correction is given by the following equation:

$$d'_s(\phi,\theta) = \frac{1}{4}d_s(\phi-1,\theta) + \frac{1}{2}d_s(\phi,\theta) + \frac{1}{4}d_s(\phi+1,\theta) \qquad (3)$$

2.3 *Air-mass bias correction*

The air-mass regression scheme uses a set of bias predictors, $X_i(i=1,\cdots,n)$, to predict the radiance bias B_j in each channel j through the following linear regression equation:

$$B_j = \sum_{i=1}^{n} A_{ji}X_i + C_j\,, \qquad (4)$$

where coefficients A_{ji} and C_j are computed by performing a least-squares fit on a large sample, usually around two weeks of data.

The coefficients are given by

$$A_{ji} = \sum_{k=1}^{n} \langle D_j, X_k\rangle \cdot [\langle \boldsymbol{X},\boldsymbol{X}\rangle]^{-1}_{ki} \qquad (5)$$

where <…,…> denotes covariance, $\boldsymbol{X}$ is the vector of X_i, and the observation residuals (O-B) D_j in channel j are

$$D_j = (\boldsymbol{y}_o - \boldsymbol{H}(\boldsymbol{x}_b))_j \qquad (6)$$

where $\boldsymbol{y}_o$ refers to the observed radiances, $\boldsymbol{x}_b$ is the background field, and $\boldsymbol{H}$ is an observation operator.

2.4 *Observation operator*

Radiative Transfer for TIROS-N Operational Vertical Sounder (RTTOV) is a fast radiative transfer model which has been under development at ECMWF since 1990 [12]. In this study, the fast radiative transfer model RTTOV-7 is used as the observation operator $\boldsymbol{H}$ as mentioned above. The model allows rapid simulations of radiances for satellite infrared or microwave nadir scanning radiometers, which could give an atmospheric profile of temperature, variable gas concentrations, and cloud and surface properties, and is referred to as the state vector. An important feature of the model is that it not only performs forward (or direct) radiative transfer calculation but also calculates the gradient of the radiances with respect to state vector variables for the input state vector values. This model supplies for the vertical temperature and moisture profiles in 43 pressure levels from 1013.25 hPa to 0.1 hPa.

3 RESULTS FROM TWO BIAS CORRECTION SCHEMES

According to the formula in the previous section, air-mass bias predictors should be set to correct air-mass bias. Harris and Kelly [9] found high correlations between radiance bias and the layers 1000 – 300 hPa, 200 – 50 hPa, surface skin temperature (Ts), and total precipitable water (TPW) of model first-guess. Thus, they chose the following four predictors.

1. Model first-guess thickness (1000 – 300 hPa),
2. Model first-guess thickness (200 – 50 hPa),
3. Ts, and
4. TPW

The air-mass bias predictors in SCHEME 1 are based on the statistical results of TOVS radiance. However, ATOVS has a smaller bias than TOVS, and is not influenced by NWP model bias [10]. Okamato [10] proposed that we take into account ATOVS observations for the following predictors:

1. Ts,
2. TPW,
3. Brightness temperatures from NOAA16 AMSU-A channel 5,
4. Brightness temperatures from NOAA16 AMSU-A channel 7, and
5. Brightness temperatures from NOAA16 AMSU-A channel 10 (their weighting functions peak at the mid- and upper-troposphere, and the lower stratosphere).

A large data set, containing NOAA16 AMSU-A data and model first-guess from 1 to 15 August 2006, was used to calculate the coefficients of scan bias and air-mass bias by utilizing SCHEME 1 and SCHEME 2. Here, the first-guess used is the National Center for Environmental prediction (NCEP) 1°×1° reanalysis data. At present, the assimilation system has not been developed completely, so the NCEP reanalysis is used as the first-guess of bias correction. Liu et al. [10] adopted data from the global model T213 as the first-guess of bias correction while GRAPES-3DVAR was being developed. Then we can use these coefficients to correct the radiance data for the time after 15 August 2006. The period of corrected radiance data must be close to the time period of the radiance data that were used to compute the bias coefficients. This is due to the fact that the main changes in air-mass coefficients are related to seasonal changes, and therefore, it may be considered necessary to update the coefficients to take into account possible instrument drifts, as often as one wishes. It is possible to update the coefficients after a period of time with little computational cost if so desired.

To compare the correction results of SCHEME 1 and SCHEME 2, we divided the radiance data into ocean data and land data and investigated the impact of bias correction on both data sets. We used the coefficients from SCHEME 1 and SCHEME 2 to correct NOAA16 AMSU-A radiance data from 16 to 31 August 2006. The means of observation residuals after bias correction for ocean and land are shown in Fig. 1 and Fig. 2, respectively. For both the land and ocean data sets, most channels successfully came closer to zero after bias correction; however, the O-B of several channels, such as channels 2 – 3 and channels 12 – 15 on ocean, and channels 1 – 2 and channels 12 – 15 on land, was still far from zero. Some possible reasons may account for these phenomena. First, even if the bias correction scheme is perfect, the O-B that includes a first-guess bias should be shifted from 0 by the amount of the first-guess bias. Second, the first-guess bias in the upper stratosphere and humidity may produce less accurate correction coefficients and predictors. Third, the radiosonde observation bias itself may not be negligible in the upper stratosphere. Let us take an example from the ocean data. Table 1 shows that there is a minor difference between SCHEME 1 and SCHEME 2: the O-B of channel 2 and channels 4 – 9 in SCHEME 1 is a little better than that in SCHEME 2. However, the air-mass coefficients are changed by using the radiance data of different periods, so we cannot make a conclusion as to which scheme is better.

The histogram of O-B on the ocean data set for each channel with SCHEME 1 and without bias correction is shown in Fig. 3, respectively. Fig. 4 shows the results of the data on land. The peak of O-B for each channel is shifted to zero. Obviously, the distribution of O-B is more similar to a Gaussian distribution than without bias correction. The results of SCHEME 1 and SCHEME 2 from the histogram are similar, so the figure for SCHEME 2 is not shown. Why do the results of these two schemes appear to be so consistent? The two predictors of SCHEME 1 are the model first-guess 1000 - 300 hPa and 200 - 50 hPa thickness, which could embody the information of the whole atmosphere almost entirely. However, the brightness temperatures of channels 5, 7, and 10 are used in SCHEME 2, which is similar to the model first-guess 1000 - 300 hPa and 200 - 50 hPa thickness. The weighting function peaks of channels 5, 7, and 10 are at about 700 hPa, 270 hPa, and 50 hPa, respectively, which could be a better representative of the whole atmosphere. In order to further explain the consistency of the two schemes, SCHEME 3 is set up that only adopts two predictors (Ts and TPW) of SCHEME 1 or SCHEME 2. The percentage of improvement (ImP) is given by:

$$\mathrm{ImP}\ (\%) = (|\beta| - |\alpha|) / |\alpha| \tag{7}$$

where α denotes O-B without bias correction, β represents O-B with bias correction, and $|\ |$ is the absolute value. The results of ImP are given in Table 1. It is clear that the results of SCHEME 3 are a little worse in the majority of channels, but are as a whole similar to the results of SCHEME 1 or SCHEME 2. It means that the two predictors (Ts and TPW) act as the primary predictors. There is a possible case that model first-guess thicknesses (1000 - 300 hPa and 200 - 50 hPa) are also the primary predictors, however, they have little effect on bias correction after using the Ts and TPW predictors. This happens when there is high correlation between Ts, TPW and thickness from the statistical and physical point of view. Consequently, it is understandable that the result of SCHEME 1 is nearly the same as that of SCHEME 2. In fact, microwave channels are highly sensitive to surface conditions (AMSU-A channels 1 - 3 and 15), and they are excluded in the procedure of channel selection because microwave surface emissivity is difficult to estimate accurately. At the same time, over land or sea ice, more channels with weighting functions that peak at low altitudes (AMSU-A channels 4 and 5) are not used.

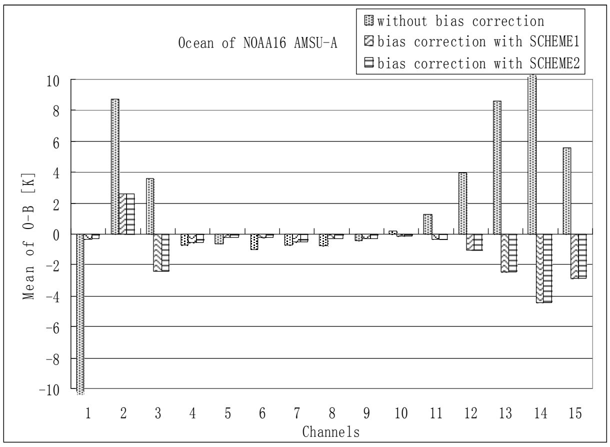

Fig.1 The mean of observation residuals for the period 16–31 August 2006 in the case without bias correction, bias correction with SCHEME1 and bias correction with SCHEME2, respectively, for the AMAU-A channels 1–15 of NOAA16 radiance data over the ocean.

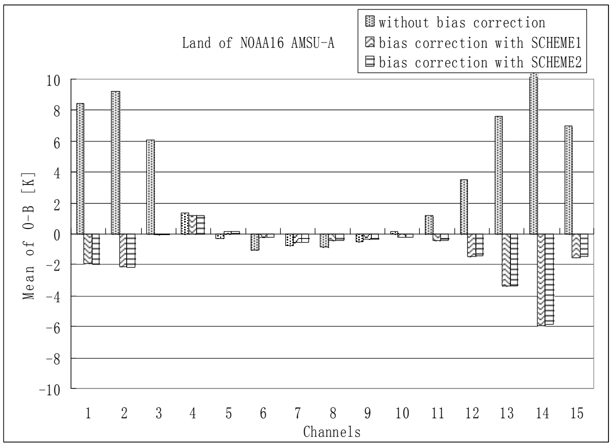

Fig.2 Same as Fig.1, but for the NOAA16 AMUU-A radiance data over land.

4 CONCLUSIONS AND DISCUSSIONS

In this paper, two bias correction schemes are used to correct the AMSU radiance data. Bias correction includes scan bias and air-mass corrections. Scan bias correction is the same for the two schemes, but air-mass correction is different. The predictors used in SCHEME 1 are all obtained from model first-guess. In SCHEME 2, the predictors used are from model first-guess and radiance observations. Both SCHEME 1 and SCHEME 2 indicate that the O-B becomes smaller, and the distribution of O-B is more similar to a Gaussian distribution after bias correction. When SCHEME 1 is compared with SCHEME 2, the results of both bias corrections are found to be very similar, which indicates that the seven predictors could be used in bias correction of ATOVS data.

We may need to adjust and test the bias correction schemes according to the model and data assimilation system. Furthermore, the capability of the bias correction schemes needs to be established further through the results of future studies.

Table 1 The mean of observation residuals for the period 16 – 31August 2006.

Ch	Without bias correction	Bias correction with SCHEME 1		Bias correction with SCHEME 2		Bias correction with SCHEME 3	
	O-B(K)	O-B(K)	ImP (%)	O-B(K)	ImP (%)	O-B(K)	ImP (%)
1	-10.34183	-0.35112352	96.60482	-0.28822197	97.21304	-0.37558963	96.36825
2	8.742074	2.571092	70.58945	2.614526	70.09261	2.6543978	69.63652
3	3.597443	-2.388385	33.60882	-2.384478	33.71742	-2.384502	33.71676
4	-0.6865542	-0.5575866	18.78476	-0.5658952	17.57458	-0.5658999	17.57389
5	-0.6171512	-0.1838411	70.21133	-0.1916264	68.94984	-0.1926245	68.78812
6	-1.013065	-0.2015178	80.10811	-0.209042	79.36539	-0.2090466	79.36494
7	-0.7363555	-0.4961397	32.62226	-0.4977796	32.39955	-0.4977809	32.39938
8	-0.7397066	-0.2934507	60.32877	-0.2961109	59.96914	-0.2962083	59.95597
9	-0.398049	-0.2681451	32.63515	-0.2650783	33.40561	-0.2650813	33.40486
10	0.1795139	-0.1601238	10.80145	-0.1539692	14.22993	-0.1539719	14.22843
11	1.286816	-0.3443522	73.23998	-0.3290607	74.4283	-0.3690669	71.31937
12	3.95954	-1.054494	73.36827	-1.022827	74.16803	-1.022841	74.16768
13	8.599297	-2.495935	70.97513	-2.459589	71.39779	-2.459616	71.39748
14	12.65444	-4.453978	64.80304	-4.428226	65.00655	-4.428273	65.00617
15	5.568825	-2.877192	48.33395	-2.873038	48.40854	-2.873057	48.4082

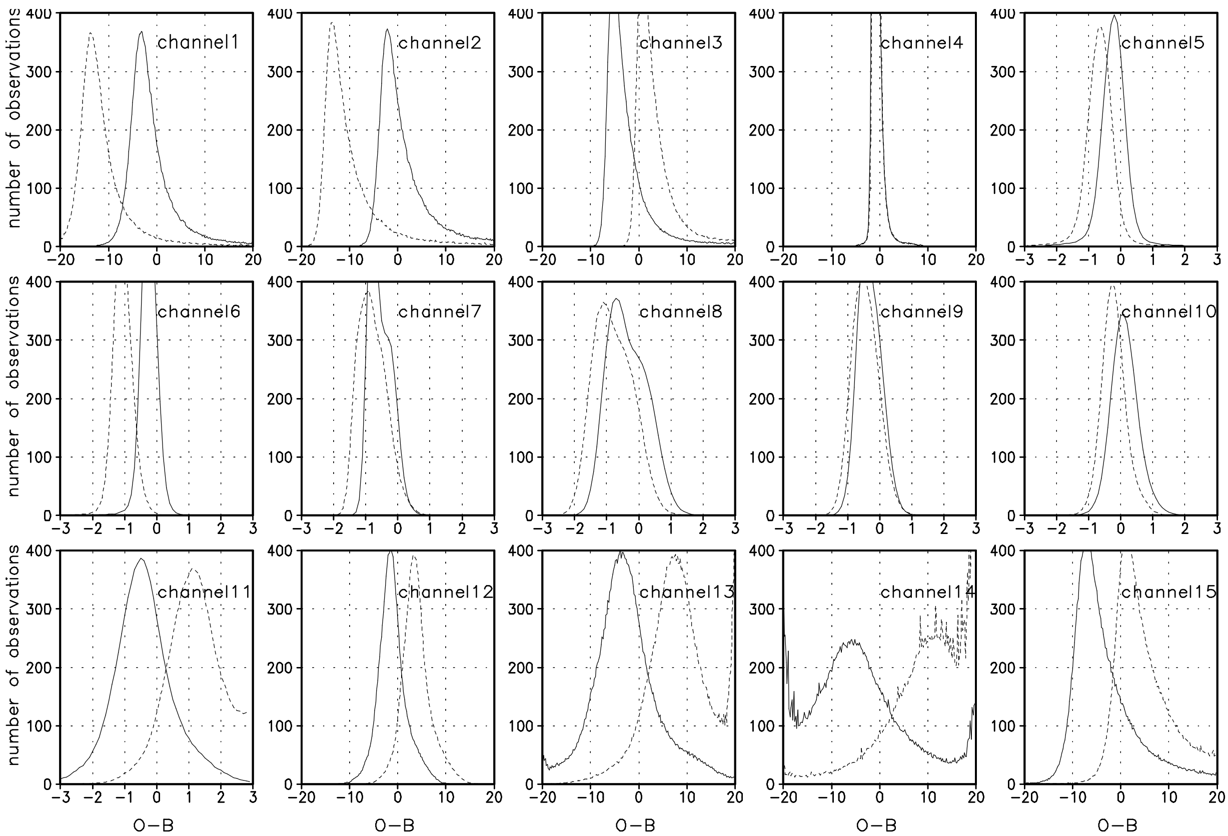

Fig.3 Histogram of observation residuals with SCHEME 1 for AMSU-A channels 1 – 15 of NOAA16 over the ocean, for the period 16 – 31August 2006. Solid line: with bias correction; dashed line: without bias correction.

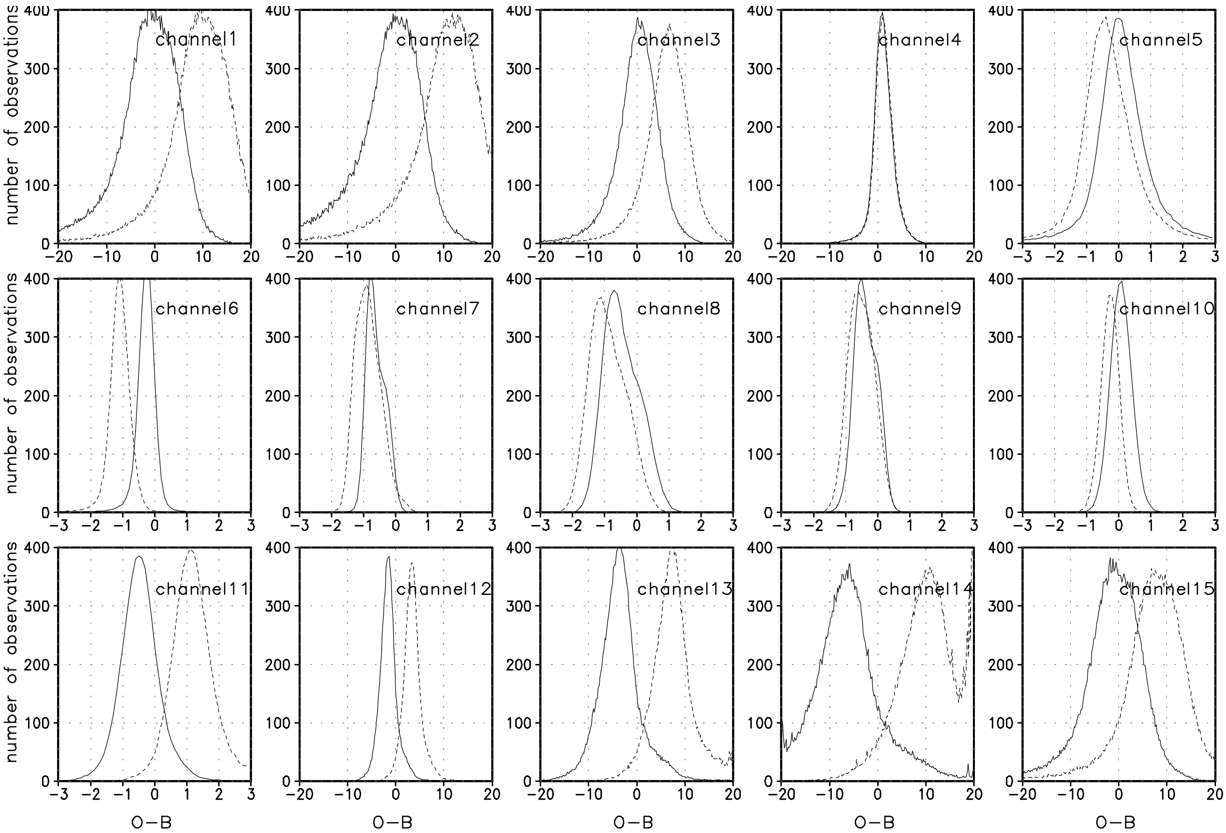

Fig.4 Same as Fig.3 but for the NOAA16 AMUU-A radiance data over land. Solid line: with bias correction; dashed line: without bias correction.

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