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Vertical ozone profiles deduced from measurements of SBUS on FY-3 satellite

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The FY-3 satellite is a second-generation Chinese polar-orbit meteorological satellite. The Solar Backscatter Ultraviolet Sounder (SBUS), one of the main payloads on the FY-3 satellite, is the first Chinese ozone-monitoring instrument on a meteorological satellite. As part of the in-orbit validation of FY-3, we carried out a retrieval trial using measurements from SBUS during the period of 17–30 July, 2008, and compared those data with measurements and retrieved profiles from the National Oceanic and Atmospheric Administration (NOAA) satellite SBUV/2. The results show that the precision of the measurements and retrieved profiles are quite good. The averaged relative difference percentages of the ozone profiles retrieved from SBUS and those from SBUV/2 are within ±7%.

FY 3 meteorological satellite, Solar Backscatter Ultraviolet Sounder, vertical ozone profile

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The FY-3 satellite launched in May 2008 is a second-generation Chinese polar-orbit meteorological satellite. The Solar Backscatter Ultraviolet Sounder (SBUS), one of the main payloads on the FY-3 satellite, is the first Chinese ozone-monitoring instrument on a Chinese meteorological satellite [1]. Solar ultraviolet backscatter technology for the remote sensing of atmospheric ozone was first used in 1970 in the Backscatter Ultraviolet (BUV) backscattering instrument carried on the American Nimbus-4 satellite. Since then, the Solar Backscatter Ultraviolet (SBUV) sounder and now the improved SBUV/2, both developed from the BUV, have been carried on the National Oceanic and Atmospheric Administration (NOAA) satellite series for more than 30 years; these sounders provide a great deal of fundamental data for the inspection and evaluation of the changes in the atmospheric ozone, as well as the impact on global climate change [2–6]. The FY-3 SBUS operates on similar channels and wavelengths as the SBUV/2 on NOAA-16, -17 and -18 satellites. However, there are some differences in how they perform [1].

Using TOMS total ozone data, Zhou et al. [7–9] discovered that the Tibetan Plateau was at the center of a low-ozone area in the middle latitudes of the northern hemisphere. Zou et al. [10,11] studied the relationship between the atmospheric column ozone variation over the Tibetan Plateau and QBO and ENSO. Bian et al. [12] compared ozone profiles from SBUV/2 on the NOAA satellite series against the ozonesonde data in Beiijng. Overall, in the past, Chinese research in the fields of ozone monitoring and influence of ozone change on climate change was insufficient partly due to the lack of ozone measurements by satellite. With the successful launch of SBUS and TOU on the

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FY-3 satellite, we can expect an increase in China's ability to monitor atmospheric ozone.

The theoretical study of deducing ozone products from solar backscatter ultraviolet measurements by satellite began in the 1960s. The minimum information mathematical inversion procedure was established by Twomey [13]. Yarger summarized and summed up the iterative method of calculation of the radiation transfer equation [14]. The concept Lambert-equivalent reflectivity (LER), put forward by Dave, helped to solve the problems in calculating reflection for the solar backscatter ultraviolet radiance [15]. Rodgers improved the iterative calculation method of the vertical atmospheric profiles [16]. Following the launch of BUV, the National Aeronautics and Space Administration (NASA) formed in 1974 the Ozone Processing Team (OPT) to develop the ozone-profile retrieval algorithm and processing software. The OPT has since developed several versions of the ozone-retrieval algorithm. Primary versions include those put forward in the early 1980s for processing BUV and SBUV measurements [17–19]. Version six (V6), developed in 1995, and version eight (V8), in 2002, are currently in use for NOAA/NESDIS operational inversion [20].

To meet the need of deducing ozone vertical profiles from SBUS on the FY-3 satellite, we developed our retrieval algorithm; a great deal of the algorithm derives from the V8 algorithm, but we have added some new characteristics. This algorithm is called FY_V1.0 [1]. The main differences between FY_V1.0 and V8 lie in two aspects. First, the SBUS could not obtain from ATOVS measurements sufficient information concerning cloud height, so we used global climate cloud-height sets in calculating effective cloud coverage. Second, we changed the climate ozone vertical profiles set. To make the climate ozone profile set more suitable for the Chinese ozone profile retrieval, we added some information regarding the Chinese ozone profiles; we obtained this information from the Chinese ozonesonde profiles. The retrieval trial comparing the FY_V1.0 and V8 algorithms, using one-week measurements from NOAA SBUV/2, showed that the deviation of FY_V1.0 relative to V8 was roughly ±2% [1].

For this paper, we carried out an ozone-profile retrieval trial, using measurements from SBUS during the period of 17–30 July, 2008, which was in its in-orbit validation phase. We also provide the preliminary results from the comparison of the retrieved ozone profiles from SBUS against those from SBUV/2 on NOAA-16, -17 and -18.

1 Data and methods

The data used in the retrieval trial were L1b data from SBUS measurements during the period of 17–30 July, 2008. The *N*-value data, rather than solar irradiance or solar backscatter ultraviolet radiance measurements, were used in ozone profile retrieval. The *N*-value variables are defined as

$$N_\lambda = -100 \times \log \frac{I_\lambda}{F_\lambda}, \quad (1)$$

where λ refers to the channel with central wavelength of λ, and I_λ and F_λ are the solar backscattered ultraviolet radiance and solar irradiance measurements of the channel, respectively.

To evaluate the performance of SBUS, we compared the solar-irradiance measurement and observed *N*-values between SBUS and SBUV/2 on the NOAA satellite series. To compare the observed *N*-values at the five channels with wavelengths shorter than 290 nm, we chose these pixels that had different solar zenith angles; the latitude and longitude positions were all within 0.5° from measurements of SBUS and SBUV/2, and the data was captured on the same date.

Finally, we carried out a primary comparison between the ozone profiles deduced from SBUS and SBUV/2, and produced a primary estimate of the precision of the SBUS ozone profiles relative to those from SBUV/2. In the comparison, the relative difference percentage was defined as:

$$\delta_i = \frac{(X_i - Y_i)}{[(X_i + Y_i)/2]} \times 100, \quad (2)$$

where i=1, 2,...,21, referring to the numbers of the retrieved layer. δ_i is the relative difference percentage between SBUS and SBUV/2 at layer i. Here, X_i and Y_i represent the retrieved ozone values for layer i of SBUS and SBUV/2, respectively.

2 Results and analysis

2.1 Comparison of solar irradiance measurements

Figure 1 shows the comparison of solar-irradiance measurements obtained from SBUS on FY-3 and SBUV/2 on NOAA-17 and -18

The largest difference between SBUS and SBUV/2 was about 9.9%, and the smallest difference was zero (0). The absolute averaged relative difference percentages between SBUS and SBUV/2 on NOAA-17 and NOAA-18 were 4.45% and 3.6% respectively.

The difference is partly caused by the difference in central wavelengths and bandwidths. Table 1 compares the central wavelengths of SBUS and SBUV/2.

In Table 1, column 1 lists the channels of SBUS and SBUV/2. Column 2 shows the central wavelengths for each channel on FY-3 SBUS. Column 3 provides the central wavelengths on NOAA-17 SBUV/2, and column 4 the central wavelengths for NOAA-18 SBUV/2. Columns 5 and 6 show the results of the SBUS wavelengths minus SBUV/2 for NOAA-17 and -18, respectively. From Table 1, we can see that there exist some differences between the wavelengths on SBUS and SBUV/2. The largest difference is approximately 0.109 nm and the smallest approximately 0.03 nm.

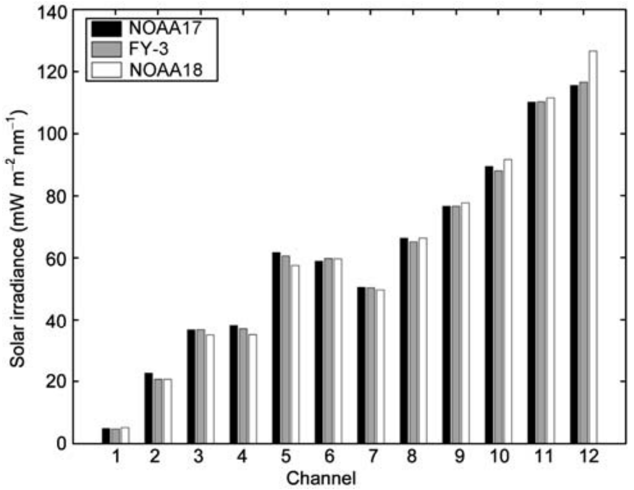

Figure 1 Comparison of solar-irradiance measurements obtained from SUBS on FY-3 and SBUV/2 on NOAA-17 and -18.

Table 1 Comparisons of central wavelengths of SBUS and SBUV/2 on NOAA-17 and -18

Channel	SBUS (nm)	N17* (nm)	N18* (nm)	SBUS-N17 (nm)	SBUS-N18 (nm)
1	251.997	251.911	252.039	0.086	–0.042
2	273.605	273.509	273.702	0.096	–0.097
3	283.089	283.049	283.164	0.040	–0.075
4	287.693	287.619	287.732	0.074	–0.039
5	292.287	292.178	292.364	0.109	–0.077
6	297.585	297.534	297.643	0.051	–0.058
7	301.956	301.925	302.032	0.031	–0.076
8	305.869	305.795	305.901	0.074	–0.032
9	312.551	312.494	312.671	0.057	–0.120
10	317.549	317.503	317.604	0.046	–0.055
11	331.250	331.222	331.318	0.028	–0.068
12	339.882	339.830	339.923	0.052	–0.041

* Here N17 is NOAA-17 satellite, and N18 is NOAA-18 satellite.

All of the central wavelengths on SBUS are longer than those on NOAA-17 SBUV/2, but shorter than those on NOAA-18 SBUV/2.

Table 2 shows how much of an effect the difference in central wavelengths might have on solar-irradiance measurements. The data are from continuous spectrum scan measurements made by NOAA-16 SBUV/2.

The continuous scan data makes a measurement every two grating positions. We used the NOAA-16 SBUV/2 data to investigate the extent to which the solar-irradiance measurements change over each 0.15 nm. The first column of Table 2 is the reference central wa velength (CWs). The following three columns show the percent changes in the solar data between three consecutive measurements. The second column shows the change in solar irradiance between the CWs value and the next shorter one. The third column shows the change between the CWs value and the next longer one. Finally, the fourth column shows the percentage difference between the shorter and longer wavelengths—they are separated by approximately 0.3 nm. This gives us an idea how much of an effect the differences in central wavelengths on the SBUS and SBUV/2 might have on the solar-irradiance measurements.

Table 2 Influence of difference in central wavelengths on solar-irradiance measurements

CW (nm)	CW–0.15 nm (%)	CW+0.15 nm (%)	CW+0.30 nm (%)
251.951	–2.2	3.1	5.3
273.677	–1.5	8.4	9.9
283.134	1.2	1.0	–0.2
287.699	–2.8	2.3	5.1
292.255	–1.0	2.2	3.2
297.532	3.0	–3.3	–6.3
301.919	–0.7	–0.6	0.1
305.859	–2.5	2.0	4.5
312.552	0.0	–0.9	–0.9
317.629	–1.9	2.6	4.5
331.191	–0.3	0.2	0.5
339.935	1.6	–1.3	–2.9

2.2 Comparison of *N*-values

To compare the observed *N*-values of SBUS and SBUV/2, we chose those SBUS deduced profiles and SBUV/2 data; the data were all captured on the same date, and the differences in latitude and longitude position and the solar zenith angle were all smaller than 0.5°. We obtained roughly 60 profiles. Figure 2 presents an example of the comparison of *N*-values at five short wavelengths for SBUS and NOAA-17 SBUV/2. Table 3 provides the information of those pixels compared in Figure 2.

Figure 2 shows the comparisons of the *N*-values for SBUS and NOAA-17 SBUV/2 at channel wavelengths shorter than 290 nm. The abscissa is the *N*-value data for NOAA-17 SBUV/2; the ordinate is the *N*-values for SBUS. The diagonal line represents the fully equal *N*-values for SBUS and SBUV/2. From Figure 2, we can see that, at the shorter wavelengths, the *N*-values cohere very well, but not so well at the longer wavelengths.

2.3 Comparison of retrieved ozone profiles

To compare the retrieved profiles from SBUS and SBUV/2, we chose pixels from SBUS and SBUV/2 that were taken at a similar position. Similar position is defined as the latitude and longitude positions differing by less than 0.5°. All of the profiles were divided into low-latitude (less than 20°), mid-latitude (between 20° and 50°), and high-latitude zones (between 50° and 90°). From these data, we obtained 132, 188 and 570 profiles for the low-, mid- and high-latitude zones, respectively. Figure 3 shows the comparisons of the retrieved ozone profiles from SBUS and SBUV/2; Table 4

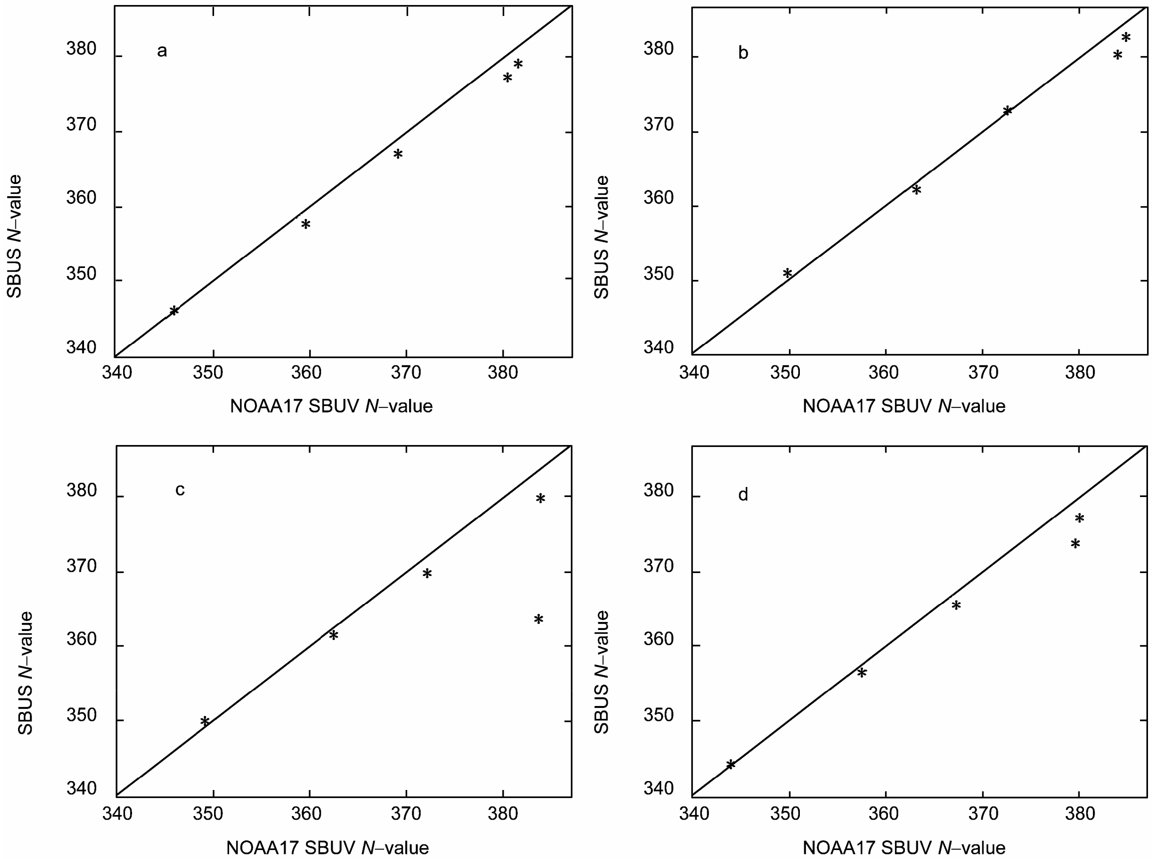

Figure 2 Comparison of *N*-values of five short wavelength channels for SBUS and NOAA-17 SBUV/2.

provides the information for the profiles compared in Figure 3.

In Figure 3, a, b and c, three groups of profiles represent the comparison of retrieved profiles from SBUS and SBUV/2 in low-, mid- and high-latitude zones, respectively. We can see that some differences exist between the retrieved profiles from SBUS and SBUV/2.

Figure 4 shows the averaged relative difference percent age of SBUS retrieved profiles compared with those from SBUV/2 on the NOAA satellite series in the three latitude zones.

Table 3 Information of the profiles compared in Figure 2

Date	Satellite	Solar zenith angle (°)	Latitude & longitude (°)	
a 2008-07-17	FY-3	64.487495	L. 81.221367,	L. −12.911753
	NOAA-17	64.813637	L. 81.452690,	L. −13.095590
b 2008-07-17	FY-3	67.346252	L. 80.793861,	L. −17.861513
	NOAA-17	67.627548	L. 80.69051,	L. −17.756449
c 2008-07-18	FY-3	67.298752	L. 80.868004,	L. −40.033260
	NOAA-17	67.386909	L. 80.871613,	L. −40.064587
d 2008-07-18	FY-3	62.923748	L. 80.914886,	L. −122.535919
	NOAA-17	63.224167	L. 81.312012,	L. −122.582268

In Figure 4, the results of the primary comparison show that the averaged relative difference percentages between the retrieved profiles from SBUS and those from SBUV/2 are within ±7% at most layers. Deviations of layers with a height lower than 15.8 hPa are generally within ±3%, but deviations of most layers with a height higher than 15.8 hPa are ±5–7%. Considering the causes of the deviation percentages, we feel that, apart from the possible observation-errors of SBUS, two other factors should be included. First, there are some differences in the pixel location and the time of observation, which may cause, to some extent, the difference seen in the compared profiles. Second, the absolute

Table 4 Information of the profiles compared in Figure 3

Date	Satellite	Latitude & longitude (°)
a 2008-07-23	FY-3	L. 17.53224, L. −48.7904
	NOAA17	L. 17.8528, L. −48.9651
b 2008-07-22	FY-3	L. 20.89409, L. −52.7407
	NOAA16	L. 20.84364, L. −52.7385
c 2008-07-17	FY-3	L. 79.31586, L. −131.946
	NOAA17	L. 79.11755, L. −131.548

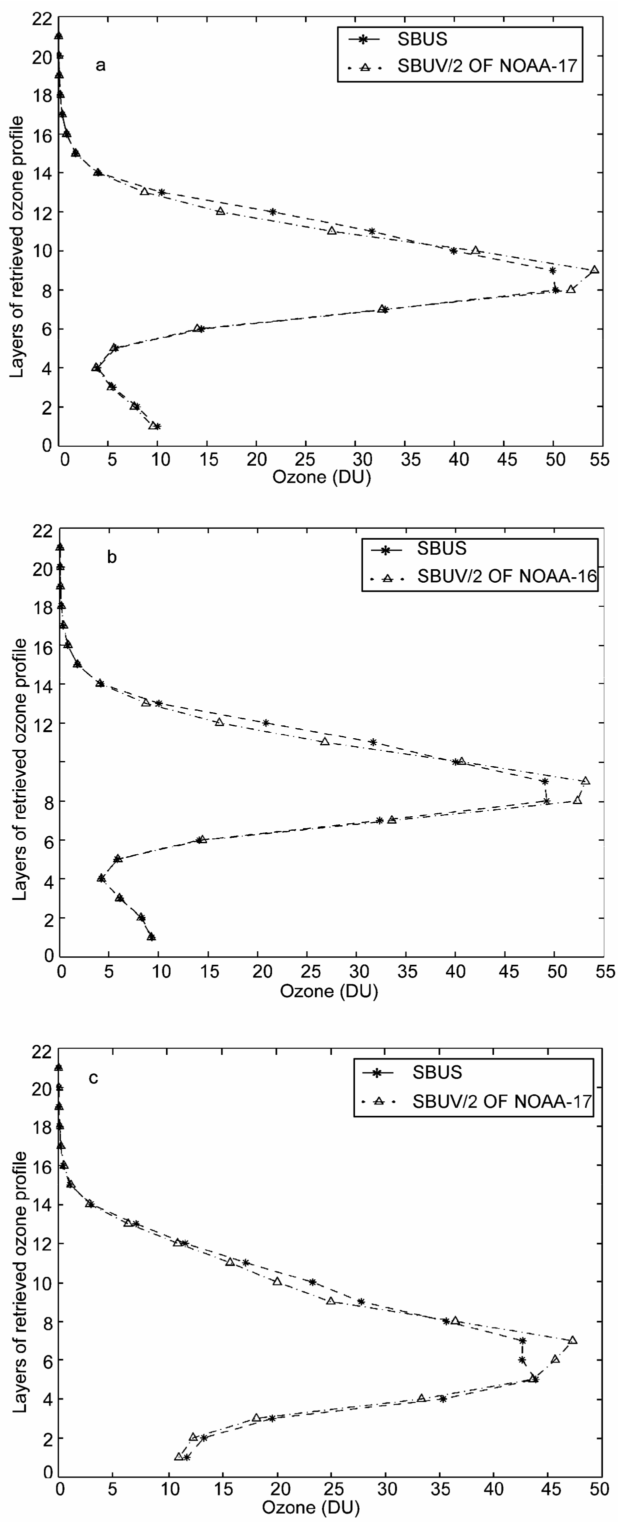

Figure 3 Partial comparisons of retrieved profiles from SBUS and SBUV/2.

quantities of ozone in the higher layers are very sparse, in which case, very small errors in the SBUS retrieved profiles may cause quite large deviation percentages.

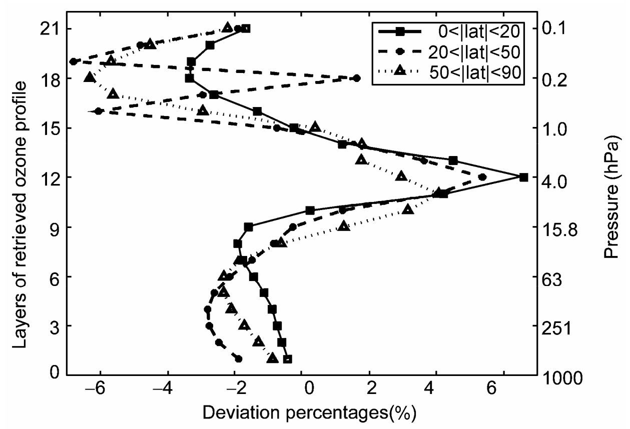

Figure 4 The averaged relative difference percentage of SBUS retrieved profiles compared with these of SBUV/2 in three zones.

3 Conclusions

The Solar Backscatter Ultraviolet Sounder on the FY-3 satellite is the first Chinese ozone-monitoring instrument on a meteorological satellite. As part of the in-orbit validation of FY-3, the retrieval trial and primary comparison of measurements and retrieved profiles of SBUS with these of NOAA SBUV/2, during the period of 17–30 July, 2008, show that the precision of the measurements and retrieved ozone profiles are quite good. The averaged relative difference percentages of the ozone profiles retrieved from SBUS and those from SBUV/2 are within ±7%. In the future, we would like to perform a more systematic comparison in evaluating and improving the accuracy of the retrieved profiles from the FY-3 SBUS.

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