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Validation of total ozone data between satellite and ground-based measurements at Zhongshan and Syowa stations in Antarctica

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Abstract We present validation between total ozone from satellite and ground-based observations of the Dobson and Brewer spectrometers and ozone radiosonde at Zhongshan and Syowa Antarctic research stations, for September 2004 to March 2009. Results show that mean bias error between Zhongshan (Syowa) and Ozone Monitor Instrument Total Ozone Mapping Spectrometer (OMI-TOMS) data are −0.06%±3.32% (−0.44%±2.41%); between it and OMI Multi Axis Differential Optical Absorption Spectroscopy (OMI-DOAS) data, the error is −0.34%±4.99% (−0.22%±4.85%). Mean absolute bias error values of OMI-TOMS data are less than those of OMI-DOAS. This means that total ozone of OMI-TOMS is closer to ground-based observation than that of OMI-DOAS. Comparison between direct observational total ozone of ground-based and integrated ozone from the ozone profile measured by ozone radiosonde shows that ozone amount calculated with the Solar Backscatter Ultraviolet (SBUV) method above balloon burst height is similar to corresponding Microwave Limb Sounder (MLS) data. Therefore, MLS data can be substituted with SBUV data to estimate ozone amount above that level. Mean bias error of the MLS ozone column is 2% compared with the ozonesonde column, with standard deviation within 9.5%. Comparison of different layers from ozone profiler and MLS data indicates that at the 215 hPa layer, the MLS ozone value is high, with relative deviation more than 20%. At the 100 hPa and 68 hPa layers, the MLS ozone value is also high. This deviation is mainly in spring, during Antarctic ozone hole appearance. In this period, at the height of severe ozone loss, relative deviation of MLS ozone values is especially large.

Keywords **validation, Antarctic ozone, satellite, ground-based, deviation**

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0 Introduction

Ozone exists in the stratospheric atmosphere. UV radiation energy absorbed by ozone can warm the stratosphere, which affects tropospheric circulation and temperature fields[1]. There are a variety of instruments for measuring total ozone, the ozone vertical profile and ground ozone; Dobson and Brewer spectrometers and the ozone radiosonde are the most accurate instruments. Satellites began observing spatial and temporal distributions of global ozone in 1978[2] and comparative study of data accuracy using ground and satellite observations of total ozone has progressed considerably[3-6]. Balis et al. pointed out that global average deviation is less than 2% between satellite and ground-based observations[7]. McPeters et al.[8] described average deviations of 0.4%–1.1% with clear seasonal variation, between ground-based observations of 76 stations in the Northern Hemisphere and satellite data. Buchard et al.[9] revealed relative deviations of 5% and 7% from satellite data with ground-based data of two stations in France, respectively; these deviations are greater than the global average. Radio ozonesonde measurement of high-resolution ozone profile data furnish the total amount of atmospheric ozone by integration. The main source of error in integration relative to ground-based observation originates from the ozone amount above the level of balloon burst.

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This error can be generally estimated by the ozone mixing ratio[10-11]. Total ozone observations at the Antarctic Zhongshan Station began with a Brewer instrument in 1993[12]. During the International Polar Year 2007/2008, radio ozonesonde observations were made for a year at Zhongshan. Such ozone profile data provides a foundation for studying the mechanism of the Antarctic ozone hole and for comparing with the accuracy of satellite data[13]. Validation of satellite and ground-based data in the Antarctic region is rare because of few observations[7,14]. Therefore, it is important to verify Antarctic total ozone data from different sources. To provide the basis for further study of the trend of the Antarctic ozone hole and its role in climate change, total ozone data of the Dobson and Brewer observations, radio ozonesonde profile data from the Antarctic Zhongshan and Syowa stations, and ozone data of satellite observations (Ozone Monitoring Instrument, OMI) are analyzed and contrasted with precision in this paper.

1 Data Description

Data of atmospheric ozone column content were collected by platforms mounted on Nimbus 7, Meteor 3, and Aura satellites. Corresponding to data from ground-based observations, datasets from OMI-TOMS (Ozone Monitor Instrument Total Ozone Mapping Spectrometer) and OMI-DOAS (OMI Multi Axis Differential Optical Absorption Spectroscopy) were selected, with 1 254 and 1 237 samples, respectively. Radio ozonesonde profile (Microwave Limb Sounder, MLS) data from satellites (http://aura.gsfc.nasa.gov) were used with the latest MLS version (v2.2) available from the Aura Validation Data Center (http://avdc.gsfc.nasa.gov). According to the data quality description document, data screening parameters of MLS v2.2 ozone data are shown in Table 1.

Table 1 Parameters of MLS v2.2 ozone data

Parameter	Values
Useful vertical range	215–0.2 (hPa)
Quality	> 0.4
Status	Even
Convergence	< 1.8
Precision	> 0

Dobson and Brewer observations of total ozone data and MLS data from Zhongshan and Syowa stations are considered the most accurate data. Total ozone data are measured at Syowa by the Atmospheric Environment Division of the Japan Meteorological Agency (JMA). Ozone data from Zhongshan were collected by the Chinese Academy of Meteorological Sciences from February 2008 to January 2009. Table 2 shows information on ground-based stations and data. For validating the OMI, total ozone data were from August 2004 to 2009.

Table 2 Ground-based stations and ozone data information

Name	Latitude	Longitude	Altitudes above sea level/m	Period	Instruments
Syowa	–69.00°S	39.60°E	21	2004–2007 2004–2007	Dobson Ozonesonde
Zhongshan	–69.37°S	76.38°E	11	2004–2009 2008–2009	Brewer Ozonesonde

2 Method

We selected total ozone data from the Dobson and Brewer ground-based observations under direct alignment with the sun. These data are the most accurate relative to directly aligned moonlight or zenith measurements. Daily satellite total ozone data were selected and ground-based measurements corresponding to the selected standard were from the OMI satellite sensors above the site. To evaluate a high-resolution profile measured by ozonesonde and a lower-resolution MLS-retrieved profile, we performed a running mean over 2.5 km to convert the ozonesonde dataset to the MLS grid, since the best vertical resolution for MLS is about 2.7 km. In the same way, we applied mean bias error (MBE), mean absolute bias error (MABE), and ozone partial column at different levels to indicate biases of the two datasets.

Various statistical parameters describe deviation between the data using linear regression analysis ($Y=aX+b$) – linear regression slope (a), intercept (b), correlation coefficient (R^2), the relative deviation (MBE) and absolute deviation (MABE). The relative deviation and absolute deviation formulae are as follows:

$$MBE = \frac{100}{N}\sum_{i=1}^{N}\frac{OMI_i - Brewer_i}{Brewer} \tag{1}$$

$$MABE = \frac{100}{N}\sum_{i=1}^{N}\frac{|OMI_i - Brewer_i|}{Brewer} \tag{2}$$

where N is the number of samples.

3 Comparison of ozone data between satellite and ground-based observation

To obtain satisfactory statistics, we focus on matching data between satellite (OMI) and ground-based total ozone. Daily averages of total ozone measured under direct sun are compared with OMI overpass total ozone, which may have several values during the same day. For the most collocated value, the criterion is the shortest distance between the station and OMI cross-track position. Figure 1 shows the scatter of OMI ozone column data and total ozone measured by ground-based instruments. These instruments for measuring total ozone are a Dobson at Syowa and a Brewer at Zhongshan. The data are from September 2004 to December 2007 above Syowa, and from September 2004 to March 2009 above Zhongshan. As seen in Figure 1, the ozone columns show good correspondence between OMI and ground-based data. A fine distinction is that the points between OMI-DOAS and Dobson and Brewer are more scattered than those between OMI-TOMS and Dobson and Brewer above the two stations. This is corroborated by the coefficients of correlation R^2, which are smaller overall for OMI-DOAS than for OMI-TOMS data. More detailed statistical information for Zhongshan and Syowa data is shown in Tables 3—5, respectively. Both OMI-TOMS and OMI-DOAS mean slopes are close to but less than unity, which indicates that OMI total ozone observations slightly underestimated the ozone column measured by ground-based instruments. MBE of Zhongshan (Syowa) data is −0.06%±3.32%(−0.44%±2.41%) with OMI-TOMS, and −0.34%±4.99% (−0.22%±4.85%) with OMI-DOAS. MABE value of OMI-TOMS is lower than that of OMI-DOAS data.

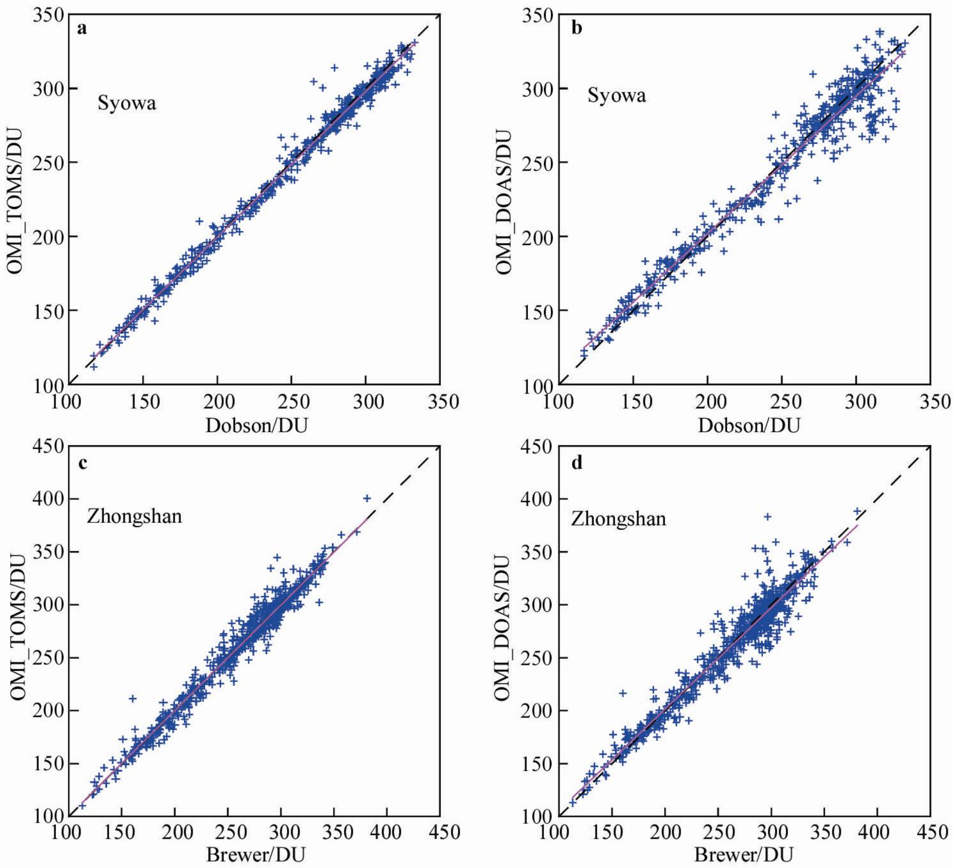

Figure 1 Comparison of OMI-TOMS, OMI-DOAS total ozone versus columns measured by Dobson between September 2004 and December 2007 at Syowa (**a**,**b**), and by Brewer between September 2004 and March 2009 at Zhongshan (**c**,**d**). The pink lines are the linear fits to the data and the dashed lines shows unit slope.

Table 3 Parameters of correlation analysis between OMI data and Dobson measurements in seasons and all standard deviation in brackets at Syowa

	Algorithm	*N*	*a*	*b*	R^2	MB/DU	MBE/%	MABE/%
2004–2007	TOMS	530	0.98	2.93	0.990 2	-1.28(5.78)	-0.44(2.41)	1.76(1.70)
	DOAS	519	0.93	16.25	0.955 0	-1.69(12.56)	-0.22(4.85)	3.48(3.38)
Spring(SON)	TOMS	234	1.00	-0.41	0.982 5	0.01(6.22)	0.01(2.94)	2.11(2.04)
	DOAS	221	0.94	13.35	0.975 9	2.25(7.51)	1.56(4.05)	3.29(2.82)
Summer(DJF)	TOMS	250	0.98	3.06	0.964 6	-2.75(4.77)	-0.94(1.67)	1.46(1.24)
	DOAS	250	0.90	22.14	0.725 6	-7.15(14.21)	-2.41(4.83)	3.63(3.99)
Autumn(MAM)	TOMS	46	1.01	-3.32	0.907 0	0.17(6.64)	0.06(2.35)	1.64(1.67)
	DOAS	48	1.10	-20.45	0.891 6	8.57(8.05)	3.00(2.79)	3.52(2.08)

Table 4 Same as Table 3, but between OMI data and Brewer measurements at Zhongshan

	Algorithm	N	a	b	R^2	MB/DU	MBE/%	MABE/%
2004-2009	TOMS	724	1.00	-0.24	0.972 6	-0.14(8.40)	-0.06(3.32)	2.33(2.37)
	DOAS	718	0.96	9.13	0.931 7	-1.34(13.34)	-0.34(4.99)	3.48(3.60)
Spring(SON)	TOMS	285	1.01	-2.22	0.975 0	-0.2(8.89)	-0.12(3.97)	2.96(2.64)
	DOAS	289	0.95	10.20	0.964 5	-0.85(10.56)	-0.06(4.70)	3.46(3.18)
Summer(DJF)	TOMS	365	0.96	12.90	0.879 8	0.29(7.96)	0.13(2.81)	1.86(2.11)
	DOAS	361	0.90	27.97	0.638 5	-2.38(15.29)	-0.76(5.32)	3.61(3.98)
Autumn(MAM)	TOMS	74	0.98	2.48	0.854 3	-2.02(8.44)	0.70 (2.80)	2.15(1.92)
	DOAS	68	0.99	5.28	0.709 8	2.08(12.22)	0.73(4.15)	2.82(3.11)

Table 5 Same as Table 4, but all data from the both stations, between OMI data and Brewer and Dobson measurements

	Algorithm	N	a	b	R^2	MB/DU	MBE/%	MABE/%
All	TOMS	1 254	0.99	1.07	0.98	-0.62(7.43)	-0.22(2.98)	2.09(2.13)
	DOAS	1 237	0.95	12.47	0.94	-1.49(13.01)	-0.29(4.93)	3.48(3.51)
Spring(SON)	TOMS	519	1.01	-1.27	0.98	-0.11(7.79)	-0.07(3.54)	2.58(2.42)
	DOAS	510	0.94	12.31	0.97	0.49(9.48)	0.64(4.50)	3.39(3.03)
Summer(DJF)	TOMS	615	0.97	8.47	0.91	-0.95(7.00)	-0.31(2.47)	1.70(1.81)
	DOAS	611	0.90	25.38	0.67	-4.33(15.03)	-1.44(5.19)	3.62(3.98)
Autumn(MAM)	TOMS	120	0.99	2.28	0.87	-1.18(7.84)	-0.41(2.65)	1.95(1.83)
	DOAS	116	1.01	1.33	0.77	4.77(11.13)	1.67(3.80)	3.11(2.75)

To discover if the differences have seasonal dependence, we analyzed seasonal differences between OMI and ground-based data. There are no collocated data in winter, because of the choice of only direct sun measurement data. As shown in Table 3, at Syowa in spring (September/October/November) and autumn (March/April/May), the OMI-TOMS (OMI-DOAS) overestimated Dobson measurements by 0.01% (1.56%) and 0.06% (3.00%), respectively. In contrast, the slope value is less than one unit in summer. However, compared with Zhongshan Station using statistical parameters, this showed significant differences. The slope value shows opposing seasonal patterns with OMI-TOMS data. The maximum of correlation coefficient value appears in spring. The MABE and uncertainty values are smaller for OMI-TOMS than OMI-DOAS data at both stations. Correlation coefficient values at the stations are 0.72 and 0.63.

Figure 2 shows differences of all collocated pair data in time sequence. This reveals a significant seasonal dependence. At Syowa, seasonal variation of total ozone for OMI-DOAS and Dobson is more remarkable, with an amplitude range from about −5% to 4%. This deviation may be caused by the OMI-DOAS algorithm, owing to the Dobson measurements suffering from temperature dependence. For the comparison at Zhongshan, Figure 3 shows variation of mean differences between OMI data and ground-based ozone through solar zenith angle (SZA). OMI-DOAS comparison with Dobson measurements at Syowa indicates that the differences become larger with increasing SZA. However, for OMI-DOAS relative to the Brewer instrument at Zhongshan, and OMI-TOMS relative to both the Dobson and Brewer at both stations, the comparisons do not reveal obvious solar zenith angle dependence. This may be caused by the Dobson instrument. Figure 4 shows the total ozone dependence of differences between OMI data and ground-based total ozone. This shows that for OMI-TOMS at Syowa, mean differences were nearly constant. However, OMI-DOAS data overestimate Dobson data by an average of 2.63% below 205 DU (Dobson Unit), and underestimate those data on average by −2.1% above 285 DU. For both OMI-TOMS and OMI-DOAS at Zhongshan, the variation of differences between OMI and Brewer ozone data is similar, and the amplitude of variation of OMI-DOAS is greater than OMI-TOMS. Below 155 DU, OMI-TOMS and OMI-DOAS data overestimate Brewer ozone on average by 1.3% and 3.4%, respectively.

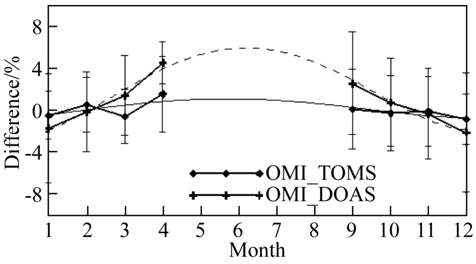

Figure 2 Differences between OMI ozone columns and Dobson, Brewer total ozone at Syowa and Zhongshan.

4 Comparison of Dobson/Brewer total ozone and ozonesonde column ozone

Total ozone from the ozonesonde is divided into two parts.

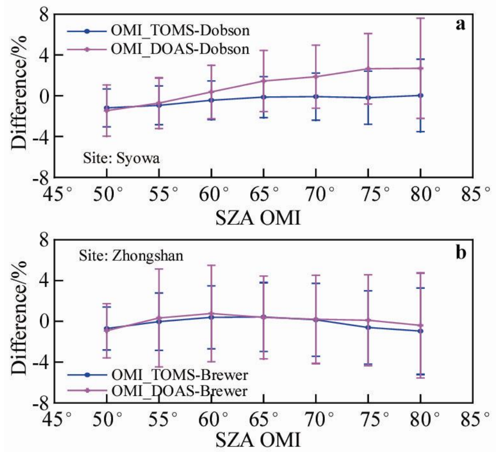

Figure 3 The differences between total ozone column data of OMI and Dobson total ozone data as function of solar zenith angle at Syowa (**a**) and Zhongshan (**b**). The error bars shows the standard deviation on the mean of 5 zenith angle.

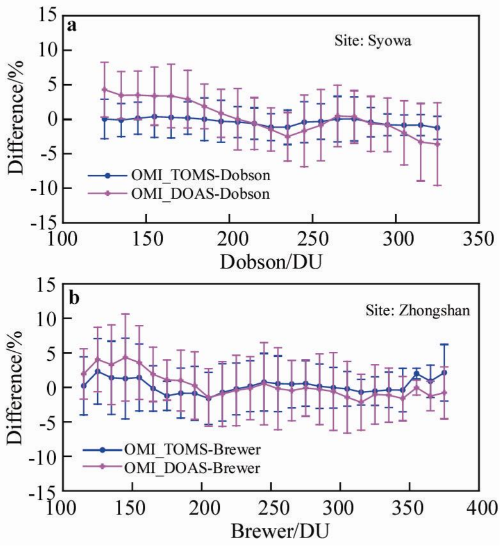

Figure 4 Differences of OMI and Dobson, Brewer observations as a function of the Dobson, Brewer total ozone at Syowa (**a**) and Zhongshan (**b**). The error bars shows the standard deviation on the mean of 10 DU.

One can be calculated from the ozone profiles until balloon burst height, and the other is based on SBUV satellite climatology of McPeters et al[8]. We also calculated residual ozone from balloon burst height to the top of the atmosphere from MLS profile data.

Figure 5 gives scatter plots between ozonesonde total ozone and ground-based ozone column measured by the Dobson and Brewer. The results show that both ozonesonde with SBUV and MLS total ozone agree well with ground-based ozone data. The average difference of ozonesonde with SBUV and ground-based total ozone is about −1.99%. The mean difference of total ozone calculated using MLS instead of SBUV is about −1.17% lower than the ground-based ozone column. Figure 6 shows time series of differences (%) between ozonesonde and ground-based measurements (Dobson and Brewer) from August 2004 to February 2009 at the two sites. From August 2004 to December 2007, comparison of integrated total ozone computed with SBUV (MLS) relative to the Dobson ozone column is different from total ozone relative to Brewer between February 2008 and February 2009. The former mean differences with SBUV and MLS are about −3.3% and −4.0%, respectively. The latter integrated total ozone computed with SBUV (MLS) overestimates the ozone column measured by Brewer by about 2.4% (3.5%). This may be caused by differences between Dobson and Brewer total ozone observations. Consequently, we can use MLS data to calculate residual ozone instead of SBUV satellite climatology to improve the precision of total ozone.

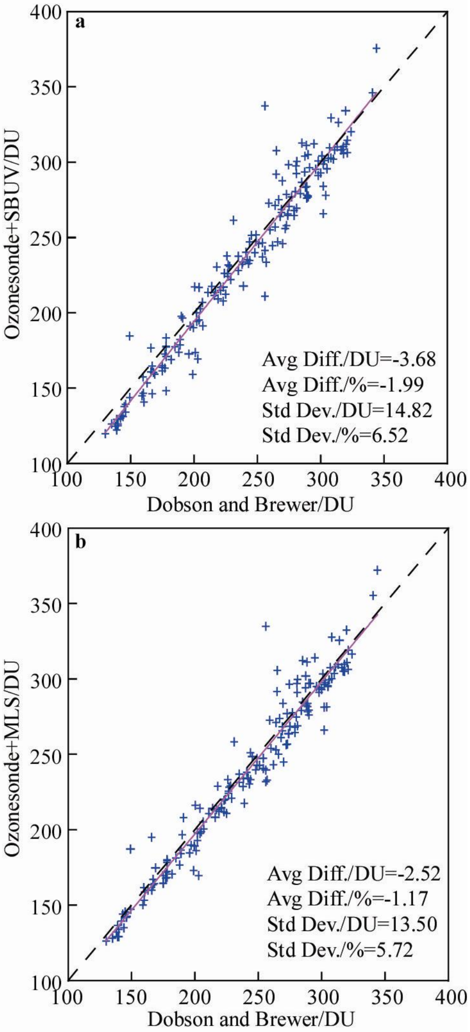

Figure 5 Scatter plots of ozonesonde ozone columns versus Dobson and Brewer total ozone. Ozonesonde ozone columns are integrated total ozone computed with SBUV(**a**) and MLS(**b**).

5 Comparison of MLS and ozonesonde

The mean difference results for MLS versus ozonesonde profiles are provided in Figure 7. MLS ozone values are smaller than the coincident grid of ozonesonde values from

31.6 hPa to 6.81 hPa, by a mean of about 4.9%. In contrast, MLS values are greater than ozonesonde values above 31.6 hPa, except at the 147 hPa level. In addition, the difference is sharp (24.5%; Table 6) at 215 hPa and the differences do not demonstrate obvious seasonal dependence. This result is similar to previous studies[15]. Validation also shows that MLS values between 150 and 3 hPa agree well with ozonesonde values within 8% of the global average. Because this average may smooth the characteristics of a certain region, we obtained differences between MLS and ozonesonde values in Antarctica. Table 6 presents the result at each collocated grid level. At 100 hPa and 68 hPa, mean differences are 11.44% and 13.48%, respectively, which are larger than the global average. Regarding seasonal variation, Table 6 shows that the high values depend on spring differences at 100 hPa and 68 hPa, which is consistent with the ozone depletion level in Antarctica.

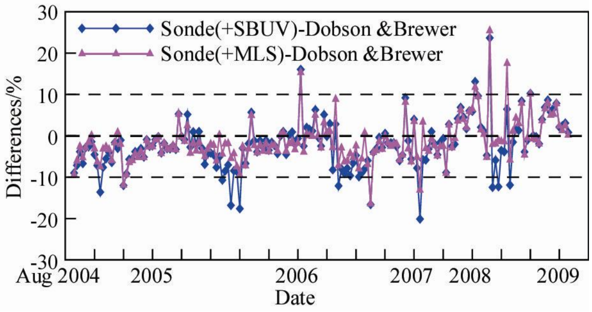

Figure 6 Comparison of integrated ozone column computed with SBUV and MLS to ground-based Dobson and Brewer total ozone from August 2004 to February 2009 above Syowa and Zhongshan stations.

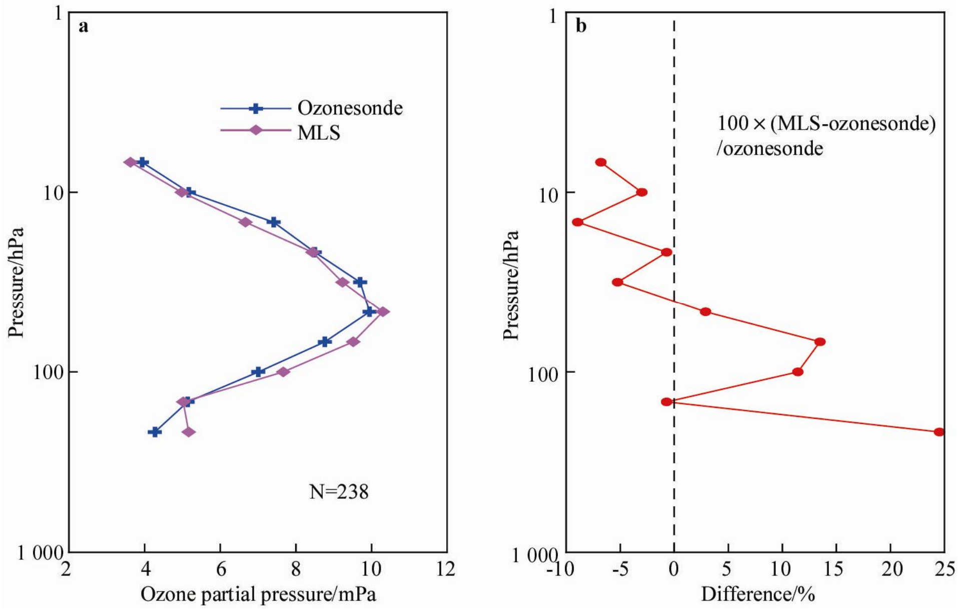

Figure 7 Averaged ozone profiles between MLS and ozonesondes from August 2004 to February 2009 at Syowa and Zhongshan station (**a**). Average ozone profiles differences (%) between MLS and ozonesonde data (**b**).

Figure 8 shows scatter plots of MLS ozone columns versus ozonesonde columns above four MLS standard pressure levels (316 hPa，215 hPa，147 hPa，100 hPa), all from coincident data. The MLS ozone and ozonesonde columns are integrated from four selected MLS standard pressure levels to balloon burst height. The correlation coefficient (*R*) and slope are about 0.92 and 0.918 for both column ozone above 316 hPa, and the column ozone differences increase as pressure decreases. Mean MLS column ozone are all less than ozonesonde column ozone to within 2%, with standard deviation less than 9.5%.

Table 6 Differences of MLS and ozonesondes data in seasons and all at MLS grid

P/hPa	Diff_All/%	Diff_Spring/%	Diff_Summer/%	Diff_Autumn/%	Diff_Winter/%
215.44	24.54	24.91	20.79	10.34	35.34
146.78	-0.71	5.46	-4.80	-10.18	-1.77
100.00	11.44	21.93	7.49	0.29	7.21
68.13	13.48	28.46	4.57	3.16	5.62
46.42	2.90	8.55	1.19	-3.84	-0.22
31.62	-5.24	-0.01	-6.14	-9.00	-10.71
21.54	-0.71	3.07	0.15	-4.24	-5.91
14.68	-8.94	-8.51	-11.25	-10.16	-6.76
10.00	-3.00	-0.07	-4.66	-6.69	-3.55
6.81	-6.79	-10.54	-3.02	-11.07	-5.71

Note: a Diff=100×(MLS-ozonesonde)/ozonesonde.

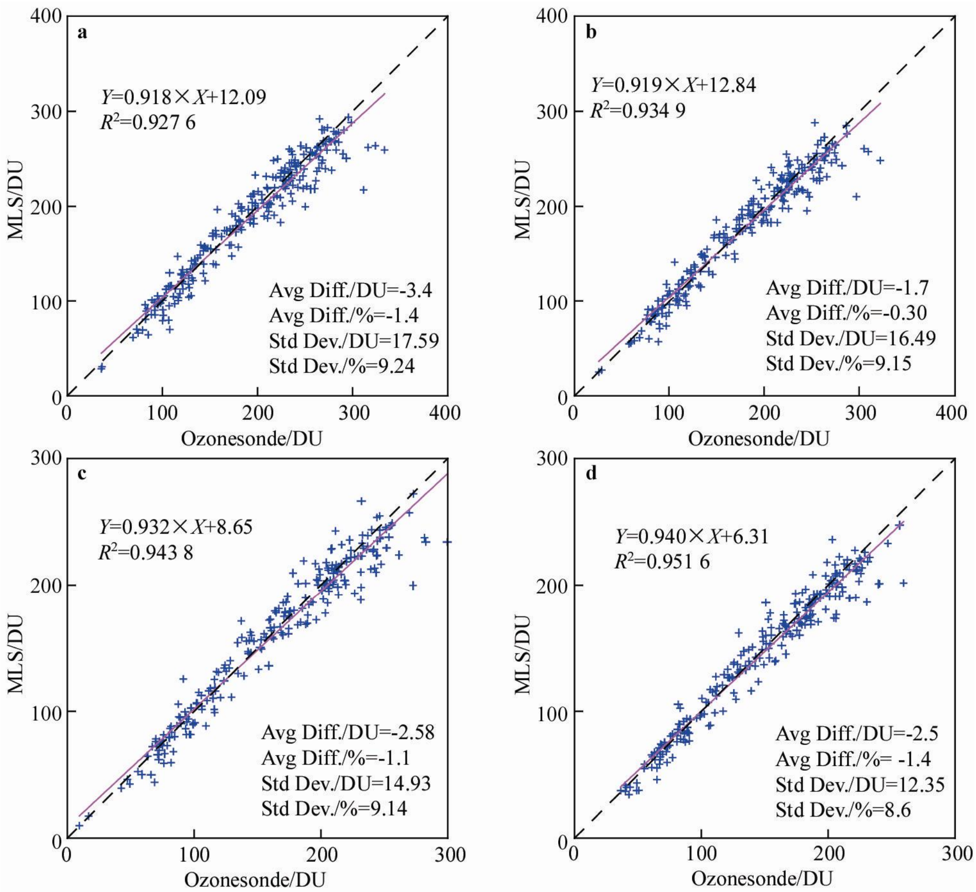

Figure 8 Comparison of MLS ozone partial column versus columns of ozonesonde integrated from the common levels (**a**, 316 hPa; **b**, 215 hPa; **c**, 147 hPa; **d**, 100 hPa) to the common upper pressure levels. The pink lines are the linear fits to the data and the dashed lines shows unit slope.

6 Conclusion and discussion

Analysis and validation was presented for total ozone of satellite and ground-based observations of the Dobson and Brewer spectrometers, and ozone radiosondes at Zhongshan and Syowa stations in Antarctica. Bias and precision of total ozone amount from satellite observation are needed for a reference, to study the trend of the Antarctic ozone hole and its role in climate change. The principal results are as follows.

(1) Total ozone from OMI-TOMS is closer to that of ground-based observation than is OMI-DOAS. OMI-DOAS total ozone observations in summer and autumn have larger deviations relative to ground-based observation. OMI-DOAS total ozone compared with Dobson observations shows that relative deviation increases with solar zenith angle when that angle is greater than 60 degrees. Deviation of OMI-TOMS observations with ground-based ones does not vary with solar zenith angle. Total ozone of ground-based observations during Antarctic ozone hole presence is less than 200 DU. The relative deviation of OMI-DOAS data is greater and OMI-TOMS smaller.

(2) Comparison between directly observed total ozone from ground-based instruments and integrated ozone from the ozone profile measured by ozone radiosonde shows that above balloon burst height, the SBUV method total ozone is similar to or less than corresponding MLS data. However, the MLS data have relatively small deviation. This shows that MLS data can be used in lieu of data from the SBUV method to estimate ozone amount above the balloon burst height.

(3) Comparison of different layers from ozone profiler and MLS data indicates that the 215 hPa layer MLS ozone value is high, with relative deviation in excess of 20%. For the 100 hPa and 68 hPa layers, this value is also high. Such deviation is mainly in spring, during occurrence of the Antarctic ozone hole. During this period at the height of severe ozone loss, relative deviation of MLS ozone values is especially large. Temperature profiles of MLS data and those measured by radiosonde show good consistency, with layer deviation of 3K–2K.

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