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Evaluation of Vertical Ozone Profiles from Ozonesonde over Pohang, Korea against coinciding HALOE datasets

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Abstract: In Korea, the ozone profiles have been acquired by using ozonesonde at Pohang station of the Korea Meteorological Administration (KMA) since 1995. These ozone soundings were performed at 0500 UTC on a weekly basis (every Wednesday) in a clear sky. The ozonesonde is equipped with the model 5A ECC sensor, which is one of the most common ozonesonde systems. There have been no attempts to evaluate the Pohang ozonesonde profiles compared with satellite. This paper will provide the first evaluation results for the ozonesonde profiles against HALogen Occultation Experiment (HALOE) measurements over Korea. During 1995-2004 periods, a total of 450 and 188 ozone profiles were obtained from the ozonesonde measurements from HALOE measurements over Korea, respectively. Hence, a total of 34 coincident profile pairs are extracted. Among those total profiles, 26 profiles from ozonesonde are compared against nearly coincident HALOE measurements in time and space. For ozone profiles, the results of statistical analyses showed that the best agreement between two measurements occurs in the 20-25 km and 30-35 km region, where the mean and RMS percent differences are less than ±5 and 14%, respectively. For temperature profiles, the mean and RMS percent differences in 20-25 km region are estimated to be about −0.1 and 1.7%, respectively. According to the scatter plots between two measurements, ozone data are strongly correlated each other above 20 km altitude range with more than 0.8 correlation coefficients. It is found that the altitude (pressure level) differences between two measurements would mainly lead to the discrepancy (over 40% below 18 km) below 20 km in ozone profiles.

Keywords: ozonesonde, HALOE, ozone, vertical profile, comparison

Introduction

The global total ozone distribution and long-term variations are well monitored and established with numerous sensors on various platforms since the ozone discovery in the Earth's atmosphere. However, the vertical structure of the ozone is less informed on a global scale due to the lack of data. There were various evaluation/comparison studies about total ozone contents and vertical distribution to provide the confident datasets into the related community in the world. Lu et al. (1997) reported the inter-comparison of stratospheric ozone profiles obtained by Stratospheric Aerosol and Gas Experiment II (SAGE II), HALOE, and ozonesondes during 1994-1995 periods. Vervack et al. (2003) presented the inter-comparison of Midcourse Space Experiment/Ultraviolet and Visible Imagers and Spectrographic Imagers (MSX/UVISI) drived ozone and temperature profiles with ground-based, SAGE II, HALOE, and Polar Ozone and Aerosol Measurement III (POAM III) data during 1996-2000. Lingenfelser et al. (1999) compared the ozone measurements of HALOE and in-situ NASA ER-2 aircraft in the lower stratosphere for six years (1991-1996) data sets. Petelina et al. (2004) statistically compared the Optical Spectrograph and Infrared Imager System (Odin/OSIRIS) stratospheric ozone profiles with coincident POAM III and ozonesonde measurements.

Recently, Petelina et al. (2005) reported the validation of the first stratospheric ozone retrieval from Atmospheric Chemistry Experiment-Michelson Fourier Transform Spectrometer (ACE-FTS) through the statistical comparison with coincident ozone

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profiles measured by the OSIRIS on the Odin satellite. McHugh et al. (2005) also presented the comparison of the atmospheric retrievals from ACE with HALOE datasets. A comparative work of the HALOE (version 19) profiles with the SAGE II (version 6) profiles was performed by Morris et al. (2002) using trajectory mapping method for 8-year data sets. In addition, the long-term comparison between two instruments was carried out by Nazaryan et al. (2005) for ten years.

In Korea, the stratospheric ozone monitoring has been carried out by the two agencies: Global Environment Laboratory (GEL) at Yonsei University and Korea Meteorological Administration (KMA) (Cho et al., 2003). The GEL ozone monitoring at Seoul station (37.6°N, 121.0°E) has been carried out by measuring the total ozone and the vertical ozone distribution using a Dobson spectrophotometer since May 1984 and February 1986, respectively. This station was established in the frame of the World Meteorological Oganization/Global Ozone Observing System (WMO/GO$_3$OS) with the identification number of #252. Cho et al. (2003) presented the climatological analysis of stratospheric ozone obtained by the ground-based Dobson instrument for 16 years over Seoul, Korea. In contrast, two types of instruments for ozone measurements have been employed by the KMA. The total ozone has been measured by a Brewer spectrophotometer since 1994 at Pohang site (36.02°N, 129.23°E) and the vertical ozone distribution has been obtained by ozonesonde (5A ECC model) measurements since 1995 at the same location. The Pohang station was also established in the frame of the WMO/GO$_3$OS with the identification number of #332. Kim et al. (2000) analyzed the vertical ozone distributions in the Pohang, Korea from 1995 to 1997.

The measurements of vertical ozone concentration by a rocket-borne radiometer have been performed by Korea Aerospace Research Institute (KARI) in Korea since the first launch in 1993 (Kim et al., 1997; Kim et al., 2001; Hwang et al., 2004a). The Korea Sounding Rocket (KSR) series have three version of the rocket; KSR-I, -II, and -III. The KSR-I series was unguided, fin-stabilized, and single-staged rockets with the capability to reach up to about 75 km. As an upgraded version, the KSR-II series was two staged, solid propellant, canard-fin guided and firstly adopted an inertial guidance system. As a last series of KSR series, KSR-III, the first Korean rocket has been introduced with a liquid propulsion system. It was successfully launched on Nov. 28, 2002 from the west coast of the Korean Peninsula. Hwang et al. (2004b) presented the detailed description and performance of these KSR series. All the rockets had the onboard UV radiometer to detect the vertical ozone distribution during the ascending phase over the Korean Peninsula. The detailed description of the onboard UV radiometer was reported in Hwang et al. (2006).

There has been no evaluation reports of ozone profiles from ozonesonde measurements in Korea in related with satellite observations for a decade (1995-2004). In this paper, we statistically analyze and evaluate the vertical ozone profiles from ozonesonde at Pohang, Korea using the datasets of HALOE overpass profiles onboard the UARS (Upper Atmospheric Research Satellite) during 1995-2004 periods.

Data sets

Ozonesonde

The Electrochemical Concentration Cells (ECC) ozonesonde, which was developed by Komhyr (1969), is commonly used instrument to measure ozone concentration by chemical means as the balloon ascends through the atmosphere since early 1970s. The detailed configuration and specifications were presented and the performance of these types of the ECC ozonesondes was analyzed by Komhyr et al. (1995). Previous publications showed that the performance of the ECC was generally reliable based on numerous inter-comparison works with other instruments (e.g., Hilsenrath et al., 1986; Kerr et al., 1994; Komhyr et al., 1995). It was estimated that the relative precision was 6-10% from the surface up to 200 mbar, 5-6% from there up to 10 mbar, and degraded rapidly to 16% at 6 mbar. The errors up to

50 mbar could be considerably reduced by modifying the background signal correction technique and by reducing the sensing solution concentration. Vertical resolution of the data can be about 10 m with measurement uncertainty. The accuracies for this type of ozonesonde are estimated to be about ± 6% near the ground, decrease to −7 to 17% in the high troposphere where ozone concentration are low, increase to about ± 5% in the lower stratosphere, and remain constant at an altitude of about 10 mbar (~32 km). Then the accuracies decrease to −14% to 6% at 4 mbar (~38 km) where ozone concentration are again low (Komhyr et al., 1995). Reid et al. (1996) reported the accuracy of ozonesonde measurements in the troposphere against a UV-absorption photometer. The airborne inter-comparison showed that the accuracy of the ECC system adopted a revised correction of the background signal in the troposphere was less than 4%, considerably better than the accuracy limits of 6-13% that Komhyr et al. (1995) reported. Recently, the ozonesonde inter-comparison studies in the troposphere and stratosphere have been conducted by the SPARC (Stratospheric Processes And their Role in Climate).

In Korea, the ozone profiles with temperature are acquired by using ozonesonde at Pohang station of the KMA since 1995. These ozone soundings have been performed at 0500 UTC on a weekly basis (every Wednesday) in a clear sky. The ozonesonde is equipped with the model 5A ECC sensor, which is generally used in most ozonesonde systems. The vertical resolution of the ozone profile is about 20 m. The horizontal wind and direction have been also measured with Vaisala RS-80 rawinsonde over Pohang. For the period of 1995-2004, a total of 450 available numbers of sounding were retrieved over Pohang, Korea. Each data set provides time in [min and sec], pressure in [hPa], height in [m], air temperature in [degC], relative humidity in [%], and ozone partial pressure in [mPa].

HALOE

Generally, the HALOE is recognized as a representative instruments onboard the satellite for analysis of the ozone vertical profiles. The HALOE aboard the UARS was launched in September 1991 into a 585 km circular orbit with 57° inclination (Russell et al., 1993). The instrument provides high resolution vertical profiles of ozone using a solar occultation technique over a wide range of latitudes. The HALOE uses a broadband radiometer channel in the 9.6-mm band which is used to obtain the ozone concentration by measuring solar attenuation by the limb of the atmosphere as the Sun rises and sets relative to the satellite. The HALOE instrument has a total of eight channels, four of which are gas filter channels (HCl, HF, CH_4, and NO) while the other four are radiometer channels (O_3, H_2O, NO_2, and CO_2). The HALOE yields ozone profiles with good vertical resolution even at altitudes below the 100 hPa level and provides near-global coverage on an approximately monthly time scale (Bhatt et al., 1999), which is the main reason to choose the HALOE data sets for this study. By measuring the absorption lines in the spectrum of well-known background source, the Sun, HALOE measurements are practically self-calibrating and highly precise (Morris et al., 2002). The numerous previous publications reported the validation of ozone profiles from HALOE comparing with other satellites, ozonesondes, and ground measurements (e.g., Brühl et al., 1996; Lu et al., 1997; Lingenfelser, et al., 1999; Bhatt et al., 1999; Bramstedt et al., 2002; Wang et al., 2005). Recently, Nazaryan et al. (2005) compared the HALOE and SAGE II ozone profiles for the period of 1991-2000 revealing the remarkable agreement between two instruments. With the improved retrieval algorithm, Version 19 HALOE profiles could provide detailed structures comparable to the ozonesonde data at lower altitudes. More details of the instrument are described in an overview paper by Russell et al. (1993). Since the UARS completes 15 orbits each day, the HALOE returns 30 profiles daily: 15 at sunrise, 15 at sunset and its final occultation event was ended on November 21, 2005. Due to the orbit characteristics, the ozone and temperature data were archived with extended locations from 32°N, 120°E to 40°N, 135°E, which covers the Korean Peninsula region where the Pohang site is located at the south-eastern coastal area of the Korean peninsula. With the HALOE Version 19 data sets downloaded in the HALOE homepage (http://haloedata.larc.nasa.gov), total 188 profiles were found over passing the Korean Peninsula over 1995-2004 periods.

Coincident Profile Pairs

To compare the ozonesonde profiles with HALOE's, temporal coincident criteria of two days (maximum 48 hour) is used to determine the close in time. The maximum time difference is estimated to about 40 hours. As a spatial criteria for HALOE, a box range of 32N-40N, 120E-135E is selected which covers the Korean Peninsula region where the Pohang site is located at the south-eastern coastal area of the Korean Peninsula. Fig. 1 shows the data points of HALOE extracted for this study. A filled star indicates the Pohang site and unfilled circles are extracted data points of HALOE over Korea.

A total of 34 profiles meet the coincident criteria in time and space. Four profiles (e.g., 15-DEC-1995, 28-DEC-1999, 11-JAN-2001, and 04-SEP-2001) from the ozonesonde measurements are excluded in this study because of lack of the data points in profiles. To eliminate the errors in HALOE data caused by interference from aerosol, cloud, or other unknown factors, we excluded four profiles (e.g., 11-JAN-1995, 23-OCT-1996, 21-NOV-1996, and 10-FEB-1999 profile pairs) where the percent difference is exceeding 30% over 25 km. Therefore, total 26 profile pairs are used for this comparison work. The maximum latitude difference between two measurements is −3.83° and the maximum longitude difference is 9.1°. The latitudinal and longitudinal minimum differences are −0.06° and 0.02°, respectively. The minimum and maximum latitude are 32.38° and 39.85° and the minimum and maximum longitude are 120.13° and 134.46° among 26 profiles from HALOE measurements, respectively. The average distances are −0.081° (−9.02 km) in latitude and 2.75° (306 km) in longitude. The maximum horizontal distance between two measurements is about 1056.4 km and minimum is 20.2 km with the 563.7 km average distance. Table 1 summarizes the nearly coincident ozone profiles during 1995-2004 periods with latitudinal and longitudinal differences between two measurements.

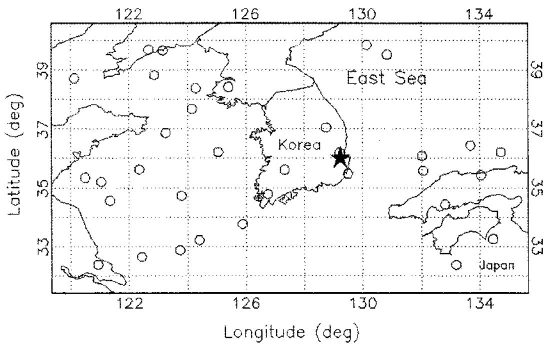

Fig. 1. Map of data points of HALOE measurements. Filled star indicates the ozonesonde Pohang site and unfilled circles are data points of HALOE over Korea to compare with.

Fig. 2 shows four sample profiles measured by ozonesonde (solid line) and HALOE (dashed line) over Korea on 11-SEP-1996, 24-JUN-1997, 22-NOV-2000, and 11-AUG-2004, respectively. Normally the sonde profiles have large ozone contents than HALOE's below 25 km. All profile pairs from both measurements are linearly interpolated onto the 0.1 km resolution to compare the datasets with valid altitude range from 10 to 35 km.

Comparison Results and Discussion

The profile-by-profile comparison works are conducted for the available coincident measurements. The percent difference of each profile pair is defined as % Diff. = 100% × (HALOE − Ozonesonde)/Ozonesonde. The mean and RMS difference are defined as mean % Diff. = (% Diff.)/N and RMS % Diff. = $\sqrt{(\Sigma\%\mathrm{Diff.}^2)/N}$, where N is the number of profiles. These definitions of differences are followed by McHugh et al. (2005). Fig. 3 shows the results of mean and RMS percent differences of ozone profiles

Table 1. Summary of nearly coincident ozone profiles during 1995-2004 periods (φ is degrees north latitude and λ is degrees east longitude. Δφ = ozonesonde φ-HALOE φ, Δλ = ozonesonde λ-HALOE λ)

	Ozonesonde	HALOE		
case	Date (Time, UT)	Date (Time, UT)	φ, Δφ	λ, Δλ
1	19950111 (0500)	19950110 (2307)	35.20, 0.82	121.04, 8.19
2	19950914 (0500)	19950914 (0955)	39.69, -3.67	122.68, 6.55
3	19951004 (0500)	19951005 (2144)	32.87, 3.15	123.74, 5.49
4	19951129 (0500)	19951128 (0845)	32.38, 3.64	120.93, 8.3
5	19951214 (0500)	19951215 (2204)	32.37, 3.65	133.20, -3.97
6	19960104 (0500)	19960104 (2320)	38.71, -2.69	120.13, 9.1
7	19960509 (0500)	19960509 (2101)	35.35, 0.67	120.49, 8.74
8	19960911 (0500)	19960910 (0950)	33.21, 2.81	124.40, 4.83
9	19961023 (0500)	19961024 (2129)	35.58, 0.44	132.07, -2.84
10	19961030 (0500)	19961030 (0835)	38.42, -2.4	125.41, 3.82
11	19961121 (0500)	19961121 (0820)	38.38, -2.36	124.29, 4.94
12	19970219 (0500)	19970220 (2155)	36.08, -0.06	132.03, -2.8
13	19970624 (0500)	19970624 (1034)	35.48, 0.54	129.49, -0.26
14	19980109 (0500)	19980108 (0805)	39.85, -3.83	130.14, -0.91
15	19980709 (0500)	19980710 (2054)	32.64, 3.38	122.43, 6.8
16	19990210 (0500)	19990210 (2152)	33.25, 2.77	134.46, -5.23
17	19990825 (0500)	19990826 (1011)	36.21, -0.19	125.05, 4.18
18	19990915 (0500)	19990916 (2136)	35.62, 0.4	122.35, 6.88
19	19991229 (0500)	19991228 (0846)	34.56, 1.46	121.34, 7.89
20	20000302 (0500)	20000302 (2202)	34.78, 1.24	126.75, 2.48
21	20000420 (0500)	20000420 (2105)	39.66, -3.64	123.16, 6.07
22	20001122 (0500)	20001121 (2233)	37.68, -1.66	124.16, 5.07
23	20010110 (0446)	20010111 (0844)	36.86, -0.84	123.26, 5.97
24	20010905 (0502)	20010904 (2038)	36.21, -0.19	134.73, -5.5
25	20010412 (0509)	20010413 (2118)	34.73, 1.29	123.79, 5.44
26	20020123 (0527)	20020124 (2232)	36.20, -0.18	129.21, 0.02
27	20020220 (0518)	20020221 (0851)	34.43, 1.59	132.83, -3.6
28	20020828 (0539)	20020828 (2036)	35.43, 0.59	134.05, -4.82
29	20021212 (0551)	20021211 (0747)	39.52, -3.5	130.84, -1.61
30	20030822 (0554)	20030821 (2050)	37.05, -1.03	128.75, 0.48
31	20031203 (0600)	20031203 (0821)	38.82, -2.8	122.87, 6.36
32	20040303 (0458)	20040302 (0928)	33.76, 2.26	125.88, 3.35
33	20040811 (0548)	20040812 (2052)	35.61, 0.41	127.33, 1.9
34	20041124 (0544)	20041123 (0748)	36.44, -0.42	133.69, -4.46

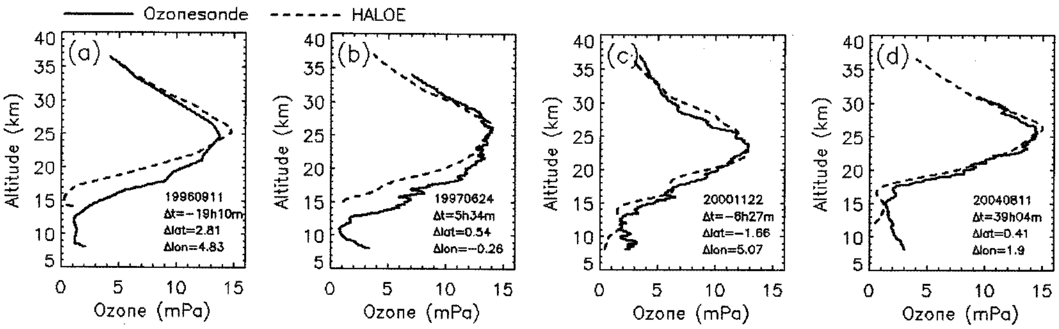

Fig. 2. Sample ozone profiles measured by ozonesonde (solid line) and HALOE (dashed line) over Korea on 11-SEP-1996, 24-JUN-1997, 22-NOV-2000, and 11-AUG-2004, respectively.

between two measurements. Fig. 3(a) shows the mean profiles of ozone with standard deviations plotted as horizontal bars. The thick line is ozonesonde mean profiles and the thin line is HALOE mean profiles, respectively. The mean percent difference of ozone are less than ± 5% above 20 km altitude showing in good

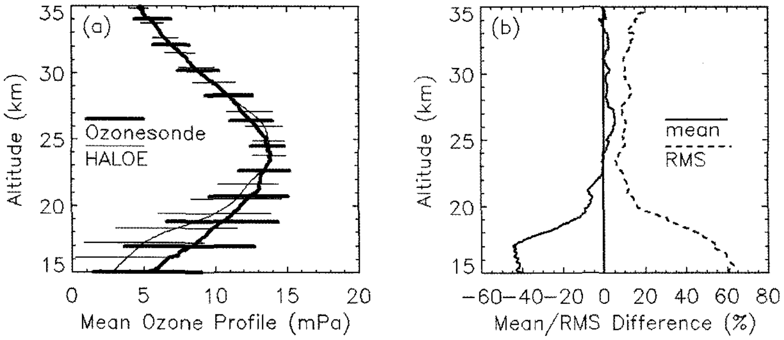

Fig. 3. Mean ozone profiles (a) and mean/RMS percent differences (b) of coincident profiles between ozonesonde and HALOE.

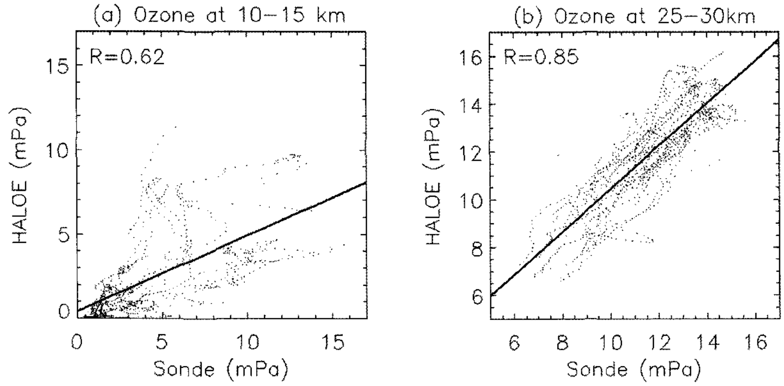

Fig. 4. Scatter plots of ozone profiles from ozonesonde versus HALOE measurements at (a) 10-15 km and (b) 25-30 km altitude range, respectively. Black straight lines of each plot indicate the linear regression lines.

agreement. The agreement is getting poor in ozone profile pairs below 20 km exceeding 30% differences with maximum difference of −44.7% at 17.4 km as shown in Fig. 3(b). The solid line in Fig. 3(b) indicates the mean percent differences and the dotted line is the RMS percent differences. The RMS difference of ozone is less than 20% above 20 km but this is getting larger with lower altitude where the maximum of −63.2% at 15.5 km as shown in Fig. 3(b). The mean and RMS percent differences of temperature profile pairs are well agreed within ± 1.5% and less than 3% at all altitude ranges, respectively (not shown here). Fig. 4 shows scatter plots of ozone for two altitude ranges. The linear lines of each plot indicate the linear regression lines. Fig. 4(a) is the ozone scatter plot between two measurements at 10-15 km range with low correlation coefficient of 0.62. However, Fig. 4(b) shows the high (R = 0.85) correlation coefficient at 25-30 km range. For temperature profile pairs, the correlation coefficient in this range is 0.84. This correlation analyses support the results of Fig. 3(b). The ozone profile pairs are well agreed in 20-35 km range with less than ± 5% mean percent differences.

It is note that the large discrepancy of percent difference of the ozone in the troposphere (below 20 km) is may caused by the differences of altitude (pressure height) measurements between two instruments. Borchi et al. (2005) reported that the agreement between SAOZ (Système D'Analyse par Observations Zénithales) and HALOE degraded rapidly below 22 km, where large differences with SAOZ of either altitude or ozone concentration. In this study, the measured pressure difference at the altitude range of 15-20 km was 12.7 hPa with the maximum 28.6 Pha at 8.9 km whereas the difference at 20-25 km was

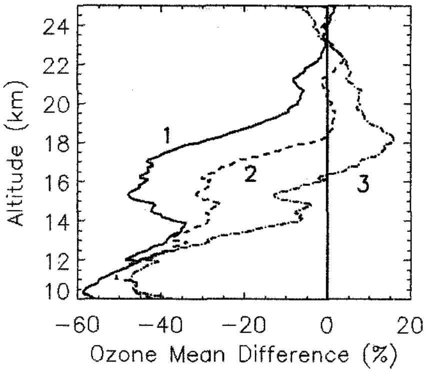

Fig. 5. Comparison result of ozone mean percent difference. The solid line (No. 1) is the same result of Fig. 3. The dotted and dash-dotted line (No. 2 and 3) are the results where the altitude of the HALOE profile is shifted down by 1 km and 2 km, respectively.

estimated to only about 4.2 hPa. This pressure differences could be one of systematic error sources in ozone profiles below 20 km. Fig. 5 shows the comparison result of ozone mean percent difference between two measurements. The solid line (No. 1) is the same result of Fig. 3(b). The dotted and dash-dotted line (No. 2 and 3) are the results where the altitude of the HALOE profile is shifted down by 1 km and 2 km, respectively. There is a remarkable improvement at the altitude below 20 km after altitude adjustment. At the altitude of 18 km, the percent difference is largely decreased from -35% to about 0% in No. 2 case and at 16 km, the difference is reduced from −45% to about 0% in No. 3 case. Therefore, it is found that the systematic altitude (pressure height) differences between two measurements contribute largely to the discrepancy in ozone profiles below 20 km.

In case of comparison calculation with 30 profile pairs including four pairs excluded for eliminate the uncertainty of errors, there were no significant differences in 20-30 km region (less than 5%). It is also note that ozone profiles are suitable for a study of vertical structure of tropospheric ozone after altitude adjustment in this local area. The secondary ozone peak are clearly occurred normally in winter and spring months near the troposphere in some ozone profile pairs (Hwang et al., 2005), even though the differences are exceeding to about 45% between two measurements in 10~15 km range.

Summary

In this paper, the ozone profiles obtained by ozonesonde over Korea during 1995-2004 periods are evaluated against the coincident HALOE datasets. The V19 HALOE data sets were used to evaluate the ozonesonde profiles in this period. A total of 34 profiles were found as nearly coincident profiles with temporal (~48 hour) and spatial (32-40°N, 120-135°E) criteria. These relatively broad-band comparison criteria were chosen for this work, because the lack of satellite data. If we narrow the latitude range criterion to 35-37°N where the ozonesonde site is located, then just 14 profiles can be extracted from satellite data with showing -7.88% of mean percent difference at 20 km. A total of 26 profile pairs for a decade were used for this comparison between two measurements and the analysis showed reasonably good agreement above 20 km in altitude. At 20 km, the mean percent difference was -7.18% showing 0.1% difference compared with the estimation by narrower latitudinal criteria. From this result, it is found that the spatial criteria for HALOE datasets are reasonable in this work. Note that the excellent agreement occurred with less than ± 5% for mean ozone difference and −1.5% for mean temperature difference above 20 km. Table 2 shows the summary of the mean and RMS percent differences of coincident ozone and temperature profiles for both measurements as a function of five altitude ranges. The comparison of temperature profile pairs showed excellent agreements with HALOE profiles although the HALOE temperature profiles were merged with NCEP assimilation data below 34 km (not shown here). It is found that the large discrepancy below 20 km in ozone profile pairs. This discrepancy is abruptly increased below 20 km to about −63.2% at 15.5 km. The altitude shift of the HALOE profile below 20 km is found to be one of important systematic error sources causing discrepancy

Table 2. Summary of the mean and RMS percent differences of coincident ozone and temperature profiles between ozonesonde and HALOE measurements as a function of five altitude ranges

	Ozone		Temperature	
	Mean Diff., %	RMS Diff., %	Mean Diff., %	RMS Diff., %
10-15 km	-45.84	62.90	0.997	2.699
15-20 km	-31.09	45.97	-0.900	2.101
20-25 km	-2.36	10.26	-0.967	1.745
25-30 km	2.85	10.49	-1.059	1.517
30-35 km	1.02	13.23	-0.404	1.387

below 20 km. After 1 km down-shifted adjustment of the altitude of the HALOE profile, the agreement between two measurements is remarkably improved in 14-20 km range. Further comparison works with other nearby Japanese ozonesondes and satellite measurements like SAGE II, ACE-FTS, OSIRIS, and Michelson Interferometer for Passive Atmospheric Sounding (MIPAS) should be followed in order to clearly explain the found differences in this local area where the total ozone variation is sensitive in latitude. This work will provide more reliable ozonesonde data of vertical ozone distribution in this local area to the ozone community of remote sensing measurements.

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References

Bhatt, P.P., Remsberg, E.E., Gordley, L.L., Mclnerney, J.M., Brackett, V.G., and Russell III, J.M., 1999, An evaluation of the quality of Halogen Occultation Experiment ozone profiles in the lower stratosphere, Journal of Geophysical Research, 104, 9261- 9275.

Borchi, F., Pommereau, J.-P., Garnier, A., and Pinharanda, M., 2005, Evaluation of SHADOZ sondes, HALOE and SAGE II ozone profiles at the tropics from SAOZ UV-Vis remote measurements onboard long duration balloons, Atmospheric Chemistry and Physics, 5, 1381-1397.

Bramstedt, K., Eichmann, K.U., Weber, M., Rozanov, V., and Burrows, J.P., 2002, GOME Ozone Profiles: A global validation with HALOE measurements, Advances in Space Research, 29, 1637-1642.

Brühl, C., Drayson, S.R., Russell III, J.M., Crutzen, P.J., Mclnerney, J.M., Purcell, P.N., Claude, H., Gernandt, H., McGee, T.J., McDermid, I.S., and Gunson, M.R., 1996, Halogen Occultation Experiment ozone channel validation, Journal of Geophysical Research, 101 (10), 217-240.

Cho, H.K., Kim, J., Oh, S.N., Kim, S.-K., Baek, S.-K., and Lee, Y.G., 2003, A climatology of stratospheric ozone over Korea, Korean Journal of Atmospheric Sciences, 6, 97-112.

Hilsenrath, E., Attmanspacher, W., Bass, A., Evans, W., Hagemeter, R., Barnes, R.A., Komhyr, W., Maursberger, K., Mentall, J., Proffitt, M., Robins, D., Taylor, S., Torres, A., and Weinstock, E., 1986, Results from the balloon ozone intercomparison campaign (BOIC), Journal of Geophysical Research, 91, 13137-13152.

Hwang, S.-H., Lee, S.-J., Kim, J.-K., Jang, Y.-S., Park, J.-J., Cho, G.-R., Kim, J., Cho, H.K., Lee, S.-H., and Won, Y.-I., 2004a, Application of a rocket-borne UV radiometer onboard KSR-III for O_3 measurements, Journal of the Korean Physical Society, 44 (2), 435-441.

Hwang, S.-H., Lee, S.-J., Kim, J., Ma, K.-S., Kim, J., Park, J.-J., and Cho, G.-R., 2004b, Flight tests of the KSR-III: The enhanced onboard electronics system, Transactions of Japan Society for Aeronautical and Space Sciences, 47 (156), 108-115.

Hwang, S.-H., Kim, J., Won, Y.-I., Cho, H.K., Kim, J.S., Lee, D.-H., Cho, G.-R., and Oh, S.N., 2005, Statistical characteristics of secondary ozone density peak observed in Korea, Advances in Space Research, 36, 952-957.

Hwang, S.-H., Kim, H., Kim, J., Lee, E.-S., Lee, D.-H., Jang, M., Son, D.-R., and Cho, G.-R., 2006, Overview of scientific payloads onboard the KSR-III rocket, Acta Astronautica, doi:10.1016/j.actaastro.2006.11.010.

Kerr, J.B. Fast, H., McElroy, C.T., Oltmans, S.J., Lathrop, J.A., Kyro, E., Paukkunen, A., Claude, H., Köhler, U., Sreedharan, C.R., Takao, T., and Tsukagoshi, Y., 1994, The 1991 WMO international ozonesonde intercomparison at Vanscoy, Canada, Atmosphere Ocean, 32, 685-716.

Kim, J., Park, C.-J., Lee, K.Y., Lee, D.H., Cho, H.K., Kim, Y.O., Cho, G.R., and Park, J.H., 1997, Rocket soundings of ozone profiles in the stratosphere over the Korean Peninsula, Journal of Geophysical Research, 102, 16121-16126.

Kim, J., Lee, S.J., Lee, J.D., Cho, G.R., Won, Y.-I., and Cho, H.K., 2001, Measurement of middle atmospheric ozone density profile by rocket-borne radiometer onboard KSR-II, Advances in Space Research, 27, 2025-2030.

Kim, J.-Y., Yoon, Y.-H., Song, K.-B., and Kim, K.-H., 2000, Characteristics of vertical ozone distributions in the Pohang area, Korea, Journal of Korean Earth Science Society, 21 (3), 287-301.

Komhyr, W.D., 1969, Electrochemical concentration cells for gas analysis, Annales Geophysicae, 25, 203-210.

Komhyr, W.D., Barnes, R. A., Brothers, G. B., Lathrop, J. A., and Opperman, D. P., 1995, Electrochemical concentration cell ozonesonde performance evaluation during STOIC 1989, Journal of Geophysical Research, 100, 9231-9244.

Lingenfelser, G.S., Grose, W.L., Remsberg, E.E., Fairlie, T.D., and Pierce, R.B., 1999, Comparison of satellite and in situ ozone measurements in the lower stratosphere, Journal of Geophysical Research, 104 (D11), 971-979.

Lu, J., Mohnen, V.A., Yue, G.K., Atkinson, R.J., and Matthews, W.A., 1997, Intercomparison of stratospheric ozone profiles obtained by Stratospheric Aerosol and Gas Experiment II, Halogen Occultation Experiment, and ozonesondes in 1994-1995, Journal of Geophysical Research, 102 (16), 137-144.

McHugh M, Magill, B., Walker, K.A., Boone, C.D., Bernath, P.F., and Russell III, J.M., 2005, Comparison of atmospheric retrievals from ACE and HALOE, Geophysical Research Letters, 32, L15S10, doi:10.1029/2005GL022403.

Morris, G.A., Gleason, J.F., Russell III, J.M., Schoeberl, M. R., and McCormick, M. P., 2002, A comparison of HALOE V19 with SAGE II V6.00 ozone observations using trajectory mapping, Journal of Geophysical Research, 107(D13), 4177, doi:10.1029/2001JD000847.

Nazaryan, H., McCormick, M.P., and Russell III, J.M., 2005, New studies of SAGE II and HALOE ozone profile and long-term change comparisons, Journal of Geophysical Research, 110, D09305, doi:10.1029/2004JD005425.

Petelina, S.V., Llewellyn, E.J., Degenstein, D.A., Lloyd, N.D., Gattinger, R.L., Haley, C.S., von Savigny, C., Griffioen, E., McDade, I.C., W. Evans, F.J., Murtagh, D.P., and de La Noe, J., 2004, Comparison of the Odin//OSIRIS stratospheric ozone profiles with coincident POAM III and ozonesonde measurements. Geophysical Research Letters, 31, L07104, doi:10.1029/2003GL019299.

Petelina, S.V., Llewellyn, E.J., Walker, K.A., Degenstein, D.A., Boone, C.D., Bernath, P.F., Haley, C.S., von Savigny, C., Lloyd, N.D., and Gattinger, R.L., 2005, Validation of ACE-FTS stratospheric ozone profiles against, Odin/OSIRIS measurements, Geophysical Research Letter, 32, L15S06, doi:10.1029/2005GL022377.

Reid, S.J., Vaughan, G., Marsh, A.R.W., and Smit, H.G.J., 1996, Accuracy of ozonesonde measurements in the troposphere, Journal of Atmosphere and Chemistry, 25, 215-226.

Russell III, J.M., Gordley, L.L., Park, J.H., Drayson, S.R., Hesketh, W.D., Cicerone, R.J., Tuck, A.F., Frederick, J.E., Harries, J.E., and Crutzen, P.J., 1993, The Halogen Occultation Experiment, Journal of Geophysical Research, 98 (10), 777-797.

Vervack Jr, R.J., Yee, J.-H., DeMajistre, R., and Swartz, W.H., 2003, Intercomparison of MSX/UVISI-derived ozone and temperature profiles with ground-based, SAGE II, HALOE, and POAM III data, Journal of Geophysical Research, 108(D22), 4697, doi:10.1029/2003JD003671.

Wang, D.Y., Stiller, G.P., von Clarmann, T., Fischer, H., Glatthor, N., Grabowski, U., Höpfner, M., Kellmann, S., Kiefer, M., Linden, A., Mengistu Tsidu, G., Milz, M., Steck, T., Wohnsiedler, S., López-Puertas, M., Funke, B., Gil-López, S., Kaufmann, M., Koukouli, M.L., Murtagh, D., Lautié, N., Jiménez, C., Jones, A., Eriksson, P., Urban, J., de La Noé, J., Le Flochmoën, É., Dupuy, É., Ricaud, P., Olberg, M., Frisk, U., Russell III, J., Remsberg E., 2005, Comparisons of MIPAS/ENVISAT ozone profiles with SMR/ODIN and HALOE/UARS observations, Advances in Space Research, 36, 927-931.

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