Ozone Vertical Profile Characteristics over Qinghai Plateau Measured by Electrochemical Concentration Cell Ozonesondes①

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ABSTRACT

An analysis of 50 ozonesondings in Xining (36.43°N, 101.45°E, 2296 m, ASL), between April 1995 and August 1996 is presented. General vertical distribution characteristics and seasonal changing of ozone profile are reported. The analysis indicates that the stratospheric ozone concentrations of Autumn and Summer are lower than those of Spring and Winter; and the highest value of the tropospheric ozone concentrations is found in Summer; ozone concentration changing is bigger from the troposphere to the lower stratosphere altitude region, while it is stable in the middle and upper stratosphere region; there is a lower ozone concentration region in 10–15 km altitude; the result why higher ozone concentration of the troposphere occurs in Summer is the ozone injecting from the middle and upper stratosphere.

Key words: Ozone profile characteristics, ECC ozonesonding, Qinghai Plateau

I. INTRODUCTION

Recent studies have shown that average ozone concentration in the troposphere of the Northern Hemisphere have increased during last decades at a rate approaching 1% per year (Janach, 1989; Staehelin and Schmid, 1991). On the other side, ozone concentration in the lower stratosphere decreased during the past 20 years (WMO, 1992; Stolarski et al., 1992). Satellite data records and ozonesonde measurements demonstrated that the decline in the stratospheric ozone concentration below 25 km at northern middle latitude is about 10% per decade during this period, consistent with the observed decrease in column ozone by ground-based Dobson spectrophotometer. The absolute magnitude of radiation forcing and solar UVB (ultraviolet B) radiation due to changes in atmospheric ozone depends highly on the altitude where changes occur. So, ozone perturbations in the upper troposphere and lower stratosphere are most important to thermal structure and ground UVB radiation value (Lacis et al.,1990; Wang et al.,1993). Unfortunately, the number of ozonesounding stations that provide information on vertical ozone profile is still limited.

Zhou and Luo (1994) first reported a continuously decreasing trend in the total ozone over China, and the maximum depletion center occurring over the Qinghai-Tibetan Plateau area during summer using total ozone mapping spectrophotometer (TOMS) ozone data from 1979 to 1991. They are called "Ozone Valley". This discovery rapidly captured the great attention of the international scientific community and prompted an increased effort to monitor not only total ozone but also ozone vertical profile over the Qinghai-Tibetan Plateau area.

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Although ground-based Brewer Umkehr measurements have been routinely made in China Waliguan GAW station (36.24°N, 100.34°E, 3870 m, ASL) about 100 km away from Xining for more than five years, so far, the ozone profile data sets of direct measuring method, that is to say, ECC (Electrochemical Concentration Cell) ozonesonde profile data records have not been obtained over the Qinghai–Tibetan Plateau area. This experiment, which was conducted in cooperation with Vaisala Oy of Finland, provides a good opportunity to investigate and understand the fine ozone layer structure of the Qinghai–Tibetan Plateau and evaluates the accuracy and precision of Brewer Umkehr measurements served at Waliguan GAW station routinely. This paper will use the first ozone profile data set of ECC over the Qinghai –Tibetan Plateau area to study the seasonal cycle and vertical distribution characteristic of ozone profiles. Additionally, the intercomparison of ozone profiles between ozonesondes and Brewer Umkehr measurements will be discussed in another paper later (Liu et al., 1998).

II. INSTRUMENT AND DATA PROCESSING

The ozonesonding system used at Xining is that of Vaisala. It consists of Vaisala DigiCora MW11 ground unit for the telemetry together with ECC–5A type ozonesonde (Science Pump Co., U.S.A), Vaisala RS80 / 18–NE radiosonde, and OMEGA & ALPHA VLF station windfinding system. Measurements are based on the use of a free flying, balloon–borne ozonesonde and radiosonde transmitting data to the ground station at a frequency of 403MHz. Radiosondes are used to measure pressure, temperature, humidity and wind. The ECC ozonesonde and radiosonde data are transferred to a PC–computer for displaying edited data, graphing on a PC–computer screen and archiving the data files onto PC– computer hard disk etc. at interval of 10 s by Vaisala Metgrapher Software. The Model TSC–1 Ozonizer / Test unit is used for conditioning type 5A ECC ozonesonde and checking the performance of the ozonesonde prior to flight. The preparation, operating and calibrating procedure of ECC–5A ozonesonde used at site strictly follow the guide table of Ozonesonde OES Technical Manual presented by Vaisala. The balloons used in the experiment are 1500 g rubber ones from Japan Totex. The average balloon ascending rates are controlled about 5–7 m / s , so the ozone profile vertical resolution is 50–70 m.

Both the total ozone measurements and ozone vertical profiles using the Umkehr method were made with #54 Brewer spectrophotometer at Waliguan baseline station simultaneously during the experiment. The Brewer ozone spectrophotometer and the method by which it measures total ozone and Umkehr profile have been described by Kerr et al. (1985) and McElroy (1989), and will not be repeated here.

III. RESULTS AND DISCUSSION

Four times of ozonesonding field study during October–November 1995, January 1996, April 1996 and July–August 1996 were made for researching ozone profile characteristics of spring, autumn, summer and winter, respectively. 44 ozonesondings were launched successfully, and 6 ozonesonding data were lost or incomplete in a total of 50 ozonesondings. Of the 50 ozonesondings, 7, 31, 8 and 4 were scheduled in spring, summer, autumn and winter, respectively. The reason why extensive experiment was made in summer is that the Qinghai–Tibetan "Ozone Valley" occurs in summer. Table 1 gives a list of the launching dates, maximum flight altitudes, ozone profile peak heights, maximum and minimum ozone partial pressure and their occurring heights.

Table 1. Summary of the ECC 5A Ozonesonde Flights. MAXFA: Max Flight Altitude; MAXOPP: Max Ozone Partial Pressure; HMAXOPP: Height of Max Ozone Profile Pressure; MINOPP: Min Ozone Partial Pressure; HMINOPP: Height of Min Ozone Partial Pressure

Date	MAXFA (m)	MAXOPP (mPa)	HMAXOPP (m)	MINOPP (mPa)	HMINOPP (m)
16 Oct, 1995	36517	13.87	25302	1.34	10211
19 Oct, 1995	35085	13.97	25264	1.62	14423
23 Oct, 1995	35791	6.83	22366	0.61	11742
25 Oct, 1995	35402	13.58	24924	1.42	13488
01 Nov, 1995	36265	15.00	23934	1.49	13559
11 Jan, 1996	37156	16.23	22299	1.85	9748
12 Jan, 1996	37485	17.14	24197	1.94	8237
14 Jan, 1996	36987	15.87	22876	1.76	9897
15 Jan, 1996	36565	15.64	23167	1.49	9331
11 Apr, 1996	33407	17.55	21662	1.52	10679
13 Apr, 1996	36830	16.08	22323	1.70	11273
15 Apr, 1996	36058	15.05	21308	1.76	10346
18 Apr, 1996	35700	15.82	21992	1.63	9531
20 Apr, 1996	28953	15.32	21132	1.57	11466
22 Apr, 1996	35498	15.29	21432	2.39	8116
05 Jul, 1996	35888	14.73	25654	1.34	15287
06 Jul, 1996	36575	14.02	25545	1.16	12481
07 Jul, 1996	18717			1.15	15203
08 Jul, 1996	36999	14.98	24786	1.39	15835
09 Jul, 1996	37043	14.20	25873	1.46	14565
10 Jul, 1996	36804	14.91	25057	2.18	14668
11 Jul, 1996	17691			2.20	13031
12 Jul, 1996	19486			2.13	15229
13 Jul, 1996	38508	14.59	24631	1.76	13881
14 Jul, 1996	36688	15.14	24087	2.07	13999
15 Jul, 1996	27024	14.52	25121	1.66	13743
16 Jul, 1996	36640	14.72	24129	2.56	13052
17 Jul, 1996	36438	14.58	24393	1.82	11722
18 Jul, 1996	35345	13.83	25390	1.82	13150
19 Jul, 1996	26664	14.17	24492	1.84	13417
21 Jul, 1996	35938	13.43	23275	1.68	13224
22 Jul, 1996	34688	13.47	25596	1.66	11940
23 Jul, 1996	36991	14.33	25037	1.55	12288
24 Jul, 1996	31454	14.06	24393	1.22	14986
25 Jul, 1996	34974	13.35	24693	1.92	13573
26 Jul, 1996	37022	13.27	24612	0.69	15289
27 Jul, 1996	38961	13.31	24989	0.70	14635
28 Jul, 1996	35350	14.26	25432	1.37	12754
29 Jul, 1996	31152	13.66	24784	1.31	12827
30 Jul, 1996	37410	13.97	24384	1.48	13428
31 Jul, 1996	36754	13.70	24813	1.41	13555
01 Aug, 1996	35170	14.03	26230	1.39	13129
02 Aug, 1996	34961	14.00	25999	1.32	12736
03 Aug, 1996 (1)	36545	12.85	26087	1.14	13359
03 Aug, 1996 (2)	35832	14.12	24235	1.16	13243

Table 1 indicates that the maximum of ozone partial pressure of autumn and summer is lower than that of winter and spring. The heights of maximum ozone partial pressure are about 21–26 km. The profile peak heights of spring are lower than those of summer, autumn and winter about 2–3 km. There is a lower ozone concentration region between the upper troposphere and the tropopause.

Table 2 is a summary of average, maximum and minimum of ozone partial pressure at 1–km interval altitude range for spring, summer, autumn and winter, respectively. It indicates that day–to–day variations of ozone partial pressure between the troposphere and the lower stratosphere are relatively large, but relatively stable at and above ozone layer.

Table 2. Seasonal Statistics of the Partial Pressure of Ozone (mPa) Averaged over 1 km

	winter			spring			summer			autumn		
km	Ave	Min	Max	Ave	Min	Max	Ave	Min	Max	Ave	Min	Max
3	0.49	0.00	1.45	3.53	2.82	4.25	3.63	1.38	5.23	2.99	2.21	3.92
4	2.43	2.11	2.68	3.61	2.95	4.21	4.28	3.73	4.94	2.96	2.25	3.45
5	2.64	2.43	2.89	3.29	2.90	3.64	3.89	2.43	4.63	2.65	2.11	3.25
6	2.47	2.38	2.62	3.02	2.46	3.83	3.59	1.71	4.32	2.64	1.97	3.42
7	2.26	2.14	2.34	2.45	1.98	2.71	3.93	1.98	5.04	2.34	1.98	3.27
8	2.04	1.76	2.38	2.31	2.16	2.42	3.34	1.92	3.93	2.28	1.78	2.83
9	1.87	1.53	2.08	2.11	1.83	2.84	2.91	2.28	3.24	2.54	1.66	5.41
10	2.15	1.70	2.54	1.94	1.66	2.66	3.22	2.21	4.31	2.15	1.36	3.07
11	4.05	3.78	4.62	2.08	1.54	3.27	2.97	1.64	5.23	2.19	1.52	2.45
12	7.75	6.47	8.54	2.66	1.81	4.10	2.68	1.23	4.95	2.21	1.01	2.40
13	6.26	5.21	7.78	4.74	2.69	7.24	1.91	1.27	1.61	1.93	1.38	2.34
14	6.08	3.22	8.43	4.96	2.58	8.41	1.93	1.47	2.58	2.19	1.52	3.12
15	4.70	3.32	5.96	3.98	2.25	9.80	1.94	1.58	2.55	2.66	1.39	3.81
16	5.99	5.68	6.27	5.25	2.89	7.94	2.42	1.38	4.47	2.64	4.35	1.48
17	10.03	9.67	10.29	5.86	2.62	9.68	3.15	1.60	5.61	3.41	2.07	3.97
18	14.26	12.34	16.08	7.32	5.21	10.28	3.86	2.03	6.09	4.86	2.42	5.89
19	9.81	9.46	10.09	10.84	8.24	13.29	5.47	4.02	6.91	6.19	4.22	9.09
20	9.59	9.01	10.19	12.78	11.06	16.09	8.59	6.71	9.68	8.93	5.51	10.04
21	14.30	13.05	15.64	14.38	12.68	15.67	10.24	9.33	10.95	10.08	6.33	11.51
22	15.52	15.07	16.10	15.03	13.67	17.24	12.29	12.78	11.22	12.23	6.39	12.97
23	15.66	15.13	15.91	14.54	12.90	15.66	12.88	11.90	14.01	12.97	6.31	14.14
24	16.13	15.32	16.78	13.92	12.38	15.86	14.04	13.23	14.98	13.25	6.01	14.73
25	15.11	14.43	15.64	13.16	11.69	14.52	13.89	13.39	14.78	12.28	5.50	14.79
26	13.63	12.52	14.50	13.03	11.61	14.69	13.76	13.26	14.22	12.78	5.62	14.58
27	12.29	12.10	12.38	12.13	10.51	13.55	13.23	12.79	13.63	12.29	5.13	13.35
28	11.00	9.91	12.05	11.14	10.02	12.22	12.23	11.47	12.85	11.53	4.92	11.58
29	9.66	8.63	10.64	9.82	8.91	10.78	11.19	10.39	11.63	10.07	4.39	10.69
30	8.44	7.23	9.35	8.37	7.36	9.30	9.87	9.30	10.69	8.45	3.73	8.94
31	6.80	6.61	6.91	7.15	6.03	8.29	8.51	7.92	9.17	7.23	2.69	8.34
32	7.46	6.21	8.64	6.11	5.03	7.28	7.29	6.84	7.98	5.96	5.47	6.46
33	5.51	4.52	6.29	5.21	4.40	6.22	6.13	5.78	6.95	5.07	4.65	5.49
34	4.77	3.29	5.96	4.55	3.76	5.33	5.13	4.88	5.87	4.21	3.59	4.93
35	4.38	2.88	5.78	3.83	3.19	4.35	4.23	3.98	4.99	3.47	2.84	4.17
36	3.49	2.45	4.39	3.06	2.66	3.71	3.49	3.22	4.41	3.18	3.11	3.26
37	2.53	1.01	3.88				2.72	2.64	2.88			

Table 3. Summary of Tropopause Heights (m), Integrated Troposphere Ozone (DU) and Total Ozone (DU) from ECC Ozonesonde

Launching Date	Tropopause Height	Troposphere Ozone	Total Ozone
95-10-16	10580	44.84	282.99
95-10-19	16368	34.49	269.14
95-10-25	15135	45.92	268.93
95-11-01	15895	33.45	297.08
96-01-11	10702		314.95
96-01-12	10878		369.97
96-04-11	10191		357.14
96-04-13	11081	62.79	330.21
96-04-15	11968	96.78	321.45
96-04-18	12802		330.06
96-04-20	12334	39.78	430.47
96-04-22	15550	57.83	331.01
96-07-05	17730	47.45	304.19
96-07-06	16337	31.18	273.70
96-07-07	16975	37.81	
96-07-08	16545	37.48	285.87
96-07-09	17254	45.86	
96-07-10	10133	30.78	430.47
96-07-11	16591	29.31	
96-07-12	15294	47.21	
96-07-13	14918	41.24	302.80
96-07-14	15024	43.84	308.57
96-07-15	16696	46.55	
96-07-16	16569	60.02	322.31
96-07-17	14691	43.12	323.95
96-07-18	16389	47.54	317.90
96-07-19	16402	41.99	
96-07-21	17145	47.77	304.09
96-07-22	17026	42.20	292.76
96-07-23	16881	40.81	285.24
96-07-24	15894	34.27	350.89
96-07-25	16032	47.74	287.91
96-07-26	16265	17.74	251.69
96-07-27	16150	18.51	243.57
96-07-28	17942	44.90	301.94
96-07-29	16621	38.78	343.71
96-07-30	17427	44.88	288.51
96-07-31	17717	45.76	280.23
96-08-01	6875	21.40	303.46
96-08-02	16345	43.01	297.54
96-08-03(1)	17713	42.21	249.75
96-08-03(2)	16609	45.24	316.21

Table 3 is a summary of the tropopause heights, integrated tropospheric column ozone and integrated total column ozone for 50 flights. The ozonesonde profile is integrated by adding up the amount of ozone as a function of height to the tropopause for tropospheric column ozone and to the bursting altitude of the measured profile, and then to 1 hPa for total column ozone. The residual ozone above balloon bursting point is calculated by assuming the ozone mixing ratio to be equal to 1 hPa, and its value is that measured at the time of balloon bursting. The integration ozone value of the ozonesonde profile depends on the measured pressure and temperature profiles. If bursting altitude is lower than 10 hPa (about 31.5 km), integrated total ozone will not be included in Table 3. The vertical resolution of ozone partial pressure for integrating total ozone is 50−70 m. It is very clear that the tropospheric column ozone of winter and spring is lower than that of summer and autumn because the tropopause heights of summer and autumn are higher. The total column ozone of summer and autumn is lower than that of winter and spring.

In order to understand the changing characteristics of ozone concentration in different seasons and different vertical ranges for the period of 1995−1996, Table 4 divides the atmosphere into four layers of ground−10 km, 10−20 km, 20−28 km (ozone layer) and 28 km − atmosphere top, and also shows the mean integrated column ozone of these different altitude ranges. From ground to 10 km altitude, column ozone amounts of summer and spring are higher than those of winter and autumn. From 10 to 20 km altitude, that is to say, the range between the upper troposphere and the lower stratosphere is the strongest region of ozone depletion, column ozone amounts of winter and spring are higher than those of summer and autumn. In 20−28 km altitude, column ozone amounts of winter and spring are higher than those of summer and autumn. It is agreed with the seasonal characteristic of total ozone column because ozone layer takes up the most of total ozone amounts. In summer, ozone column amounts are lower in the range between the upper troposphere and the upmost of ozone layer, but in the range between the upmost of ozone layer and the top of atmosphere, ozone column amounts are higher than those of any other seasons. It should be emphasized that ozone column amounts are higher in the range between the ground and the middle troposphere, and are lower in the range of the troposphere to the lower stratosphere in summer. Furthermore, ozone column amounts exhibit bigger gradient from 10−20 km region to the region above 20 km. So, the reason why ozone column amounts are higher in the range between the ground and the troposphere in summer may be possibly ozone injecting downward from the middle and the upper stratosphere through the 10−20 km region where ozone level is lower.

Table 4. Mean Integrated Column Ozone from ECC Ozone Profiles in Different Seasons and Height Ranges

Height Range (km)	Winter(DU)	Summer(DU)	Autumn(DU)	Spring(DU)
Ground—10 km	18.19	26.11	19.61	23.89
10—20 km	82.48	32.87	37.42	63.15
20—28 km	149.91	134.94	128.49	145.23
28 km—Top	91.88	103.29	94.02	101.71
Mean Total Ozone	343.63	297.21	279.79	333.98

Fig. 1 shows the average ozone partial pressure profiles for different seasons. Winter, spring, autumn and summer include all ozone profile datasets of January, April, July−August and October−November of a year, respectively. It is clear that the stratospheric ozone maximum concentration occurs in winter and spring, and its minimum concentration occurs in autumn and summer. There is a seasonal characteristic for maximum ozone partial pressure. The heights of maximum ozone partial pressure for summer, autumn and winter are about the same altitude at 24−26 km, but they are lower in spring at the height about 22 km. Maximum

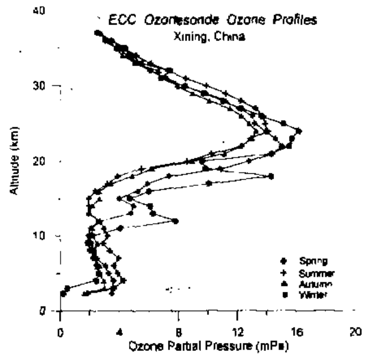

Fig. 1. Average Ozone profiles for different seasons in Xining, China.

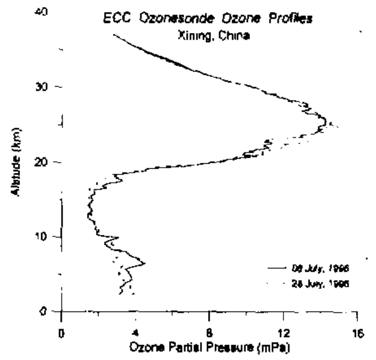

Fig. 2. The first type of ozone profile in Xining, China.

ozone concentration height of the troposphere occurs between surface and the lower troposphere. There is a lower ozone concentration region between the upper troposphere and the tropopause for all four seasons. This region is about 9–10 km altitude in winter and spring, and is a little higher in summer and autumn at the height about 13–14 km. Below 10 km altitude, ozone concentration of summer is the highest of all seasons. From the troposphere to the lower stratosphere ozone concentration has not only a larger fluctuation, but also a secondary ozone maximum in winter and spring.

All individual profiles for four seasons during the experiment in Xining can be divided into four types. Fig. 2 shows the first type of ozone profile whose main vertical distribution characteristics include that higher ozone concentration occurs at the ground; lower ozone region is at about 12–15 km altitude, concentration variation of ozone profile is relatively stable, and ozone maximum concentration occurs at about 25 km usually called ozone layer. Fig. 2 displays the ozonesonding results of 8 July, 1996 and 28 July, 1996. It can be seen that these two ozone profiles are almost the same except that ozone values have a little difference in the troposphere, the lower stratosphere, and the ozone layer. Fig. 3 shows the second type of ozone vertical distribution. The cases shown are the results of 25 October, 1996 and 1 August, 1996. These two ozone profiles have a common characteristic that ozone maximum concentration height is about 25–26 km, and the lower ozone partial pressure region is about 13 km, furthermore a clear secondary the ozone maximum occurs below 10 km. The third type of ozone profile is shown in Fig. 4. It has a higher ozone level at ground, and has a lower ozone region at about 10 km altitude. This type of ozone profile shows a complicated variation of ozone concentration between the tropopause and the lower stratosphere; and has more than one secondary ozone peak region. Ozone concentration of ozone layer is higher and ozone concentration variation is relatively stable in this type of ozone profile. The cases shown in Fig. 4 are ozonesonding results of 11 April, 1996 and 18 April, 1996. The fourth type of ozone profile is shown in Fig. 5 which is similar to the third type of ozone profile. The differences comparing with the third type include that ozone concentration near the ground is not high, and the lower ozone region is weak or not clear, but the secondary ozone peak from

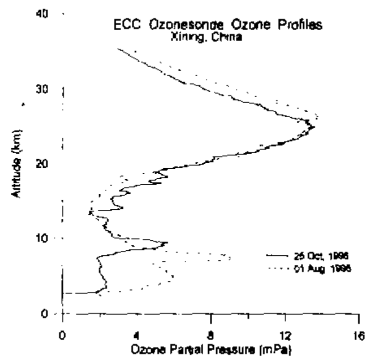

Fig. 3. The second type of ozone profile in Xining, China.

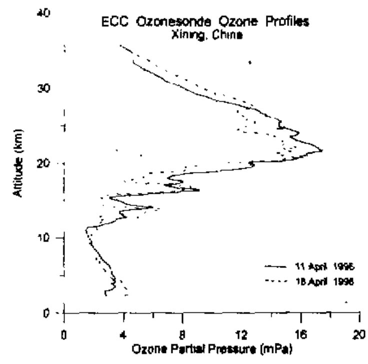

Fig. 4. The third type of ozone profile in Xining, China

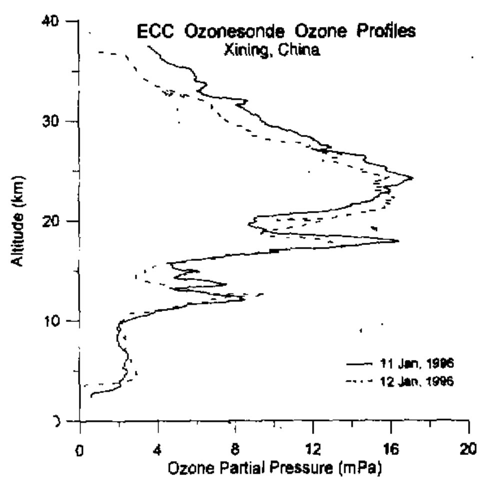

Fig. 5. The fourth type of ozone profile in Xining, China.

the upper troposphere to the lower stratosphere is more stronger and the ozone concentration above the ozone layer is still higher. The cases shown in Fig. 5 are ozone profiles of 11 January, 1996 and 12 January, 1996.

According to the summary of ozone profile types mentioned above, Table 5 gives the statistics of Xining ozone profile types for different seasons. It is clear that ozone profile type has its seasonal characteristic. Spring ozone profiles are mainly the third type, while summer and autumn ozone profiles are mainly the first type, and winter ozone profiles are mainly the fourth type.

Table 5. Summary of the Ozone Profile Types in Different Seasons

Season (Numbers of Profile)	Numbers of first type	Numbers of second type	Numbers of third type	Numbers of fourth type
Spring(6)	2		4	
Summer(30)	26	4		
Autumn (5)	4	1		
Winter(4)			1	3

ECC ozonesonding precision is mainly determined by preparation and calibration of the ozonesonde, the changing conditions during the flight, and the vertical altitude resolution of the RS80 / 18NE. The details of evaluating method and technical parameters of ECC 5A ozonesonde can be found in Ozonesonde OES Technical Manual (Vaisala, 1993; Komhyr,1986), and will not be repeated here.

The precision of the KI sensor, background current, sampling pump flow rate and pump temperature of ECC 5A used in Xining experiment are 0.02μA, 0.02μA, 2 ml / min and 1K, respectively. According to average ozone profile, Table 6 shows the precision of ozone measurement evaluated by sensor, background current, pump rate, pump temperature and sensor response in the troposphere and stratosphere. Solution evaporation during the flight changes the solution volume and leads to an increase of the solution concentration and to an overestimation of ozone concentration. On the other hand, due to decreasing the absorption efficiency, ozone concentration will be underestimated. All these are the most uncertain factors that influence the precision of ozone measurements. The resolution of altitude and temperature of RS80 / 18NE influences directly the precision of ozone measurements. According to average ozone profile, positive and negative ozone gradient, average ascending speed, response time of the ECC sonde, and resolution of altitude and temperature of RS80 / 18NE, Table 6 also gives the precision evaluation influenced by those factors in different altitude ranges.

Table 6. System Errors and Measuring Precision of ECC Ozonesonding System

	Troposphere(10 km)		Stratosphere(25 km)	
	Systematic error	Precision	Systematic error	Precision
Sensor current		± 2%		± 0.5%
Background current (determination at ground)		± 2%		± 0.5%
Pump flow rate (determination at ground)		± 1%		± 1%
Pump temperature		± 0.5%		± 0.5%
Evolution of the Background current	+4 ± 3%		+5 ± 2%	
Solution evaporation	± 0.5%		± 2.%	
Sensor response time 20s	+1%		+1%	
Pressure measurement		± 1%		± 3%
Total (without sensor contamination)	+5 ± 3.5%	± 6.5%	+6 ± 4%	± 5.5%

IV. CONCLUSIONS

In the Qinghai Plateau area, ozone vertical distribution has following characteristics:

1) The stratosphere ozone concentration of winter and spring is higher than that of summer and autumn. The troposphere ozone concentration is the highest in summer.

2) From the troposphere to the lower stratosphere ozone concentration has a larger fluctuation, but ozone concentration variation is stable above ozone layer. There is a higher ozone level at the ground, and a lower ozone level region about 10–15 km altitude in the troposphere.

3) In spring and winter, ozone profile structure is more complicated because there are some secondary ozone peak regions in the troposphere and the lower stratosphere besides ozone layer.

4) The reason why ozone concentration is higher at the ground in summer is possibly ozone injecting downward from the middle and upper stratosphere.

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