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A Study of the Vertical Distribution and Sub-Peaks of Ozone below 12 km over Wuyishan Region Based on Ozone Sounding in Winter

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Abstract: An understanding of the vertical distribution of ozone is critical to assessing the ozone variabilities both in the stratosphere and the troposphere. We collected the profiles of atmospheric ozone partial pressure and ozone volume mixing ratio (VMR) by a sounding system at the Wuyi Mountain National Meteorological Observation Station (Shaowu sounding station 58725) from November 2021 to February 2022. In this study, the vertical distribution and sub-peak phenomenon of tropospheric ozone below 12 km are investigated using mathematical statistics and synthetic analysis. The results show that the ozone partial pressure decreased from the ground to the tropopause, which is consistent with the temperature profile. However, 66.7% of cases first showed an increasing trend from the ground to about 3 km, while there were one or more temperature inversions in the corresponding temperature profiles and the atmosphere was stable and the relative humidity was high; then, in the stratosphere, the ozone partial pressure began to increase significantly, The ozone partial pressure reaches its maximum at an average height of 24.9 km, and the maximum value was 14 mPa. The ozone VMR in troposphere is the fluctuating increase from the ground to the tropopause, and 83.3% of the cases begin to rise rapidly at about 2–5 km away from the tropopause, and the ozone surge height is 2.9 km lower than the tropopause on average. Some of these tropopause ozone VMR have shown the characteristics of stratospheric ozone. The sub-peaks of tropospheric ozone below 12 km has four cases. All the sub-peaks occur between 6.7 km and 11.5 km vertically, and peak ozone VMR is 1.6–1.9 times larger than that of the average state at the same height. The maximum stratospheric ozone VMR is 8649 ppb on average, occurring at an average height of 31.3 km, and this average height of the maximum stratospheric ozone VMR is 6.4 km higher than that for the ozone partial pressure. The total ozone in the boundary layer (0–1.5 km) is 4.3 DU on average, accounting for 1.5% in total ozone column. The total ozone in the troposphere is 39.5 DU, accounting for 13.1% in total ozone column, and the total ozone in the stratosphere is 262.4 DU, accounting for 86.9% in total ozone column.

Keywords: ozone sounding observation; vertical profile; ozone partial pressure; ozone volume mixing ratio; Shaowu

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1. Introduction

Ozone, one of the most important trace gases in the Earth's atmosphere, not only prevents excess solar ultraviolet radiation in the stratosphere from reaching the surface and protects life on Earth, but also greatly affects the Earth's ecological environment, climate system, and human life in the troposphere [1–4]. The temporal and spatial distribution of ozone in the atmosphere is non-uniform because of natural and human factors. The ozone concentration changes through various physical and chemical processes are very complicated. Especially, the climate effect of ozone not only depends on the total amount of ozone but also strongly depends on the vertical distribution of ozone in the atmosphere [5–7]. It is necessary to obtain detailed information on ozone changes at different altitudes through ozone-sounding observation. The vertical profile data of ozone from the ground to a height of 35 km and above is obtained by using a meteorological balloon to carry an ozone sonde into the sky (upper stratosphere), so that the observed profiles could reveal ozone vertical distribution characteristics and variations. The ozone-sounding observation is of great scientific significance and practical value to study the radiative forcing of the atmosphere system, climate and environmental changes, and atmospheric correction in remote sensing [8–12].

At present, ozone-sounding observations have been included in the meteorological and environmental sounding operations in Canada, the United States, Japan, and other countries [13–15]. The global atmospheric background stations and special ozone-sounding network have been built for more than 70 years [16]. The number of global sites for ozone-sounding observations has reached more than 100. However, there is still lack of ozone-sounding observations. A few prior studies were primarily for short-term experiments and were not routinely observed at regular periods [17–19]. Ozone-sounding observation and research in China begins from the 1980s. Shi et al. [20], in collaboration with the Institute of Aeronautics and Electricity of Nagoya University, Japan, conducted the first balloon-borne sounding test on 23 August 1984 in China. Their task was to detect the vertical distribution characteristics of atmospheric ozone and the variation trends of ozone partial pressure, temperature, and humidity profiles, as well as the maximum value and height of ozone VMR vertically from the surface to 33 km. Since then, scientists have made ozone-sounding observations in Beijing, Lhasa, Kunming, Xining, Lin'an, Shanghai, and other places successively, and obtained the vertical distribution characteristics and variations of ozone at different times and heights in various places. They compared atmospheric ozone in different places using these sounding data, as well as conducted in-depth research on the mechanism and numerous accomplishments [21–27]. Wang et al. [28] analyzed the data of the vertical distribution of atmospheric ozone observed in Beijing from March 2001 to February 2002. Their results showed that the boundary layer and lower stratosphere in this region are active areas of ozone concentration changes, with significant seasonal changes. The changes of the ozone vertical profile is diverse with a single peak in summer and autumn, and double peaks and usually multi-peak structures in winter and spring. The ozone profile structure is relatively complex, which is closely related to the dynamic transport mechanism of ozone. Using the ozone-sounding observation data in Baoshan National Climate Observatory in Shanghai from May 2007 to December 2009, Peng et al. [29] found that the vertical profile of ozone in Shanghai has obvious seasonal changes. Especially in the boundary layer in spring, the ozone concentration and the peak ozone concentration change dramatically. The ozone peak in the lower troposphere in spring is closely related to temperature. The single or multiple inversion layers correspond to single or multiple ozone peaks. The ozone concentration in the upper troposphere–lower stratosphere in spring is obviously higher than in other seasons. A more obvious ozone sub-peak is formed near 14 km, which reflects the influence of the dynamic transport process on the vertical distribution of ozone. Based on the ozone-sounding observations at Lin'an, Kunming, and Hong Kong in the spring of 2001, Zheng et al. [30] compared and analyzed the similarities and differences in the vertical distribution of ozone at the above three locations and analyzed the relationship between the background of the large-scale circulation and the distribution of ozone in the troposphere in spring. In regions of high or low latitudes, stratospheric intrusions associated with subtropical upper jets lead to higher ozone concentrations in the upper troposphere. Using ozone-sounding data and NCEP reanalysis data, Zhao et al. [31] deeply studied the continuous occurrence of sub-peaks in ozone profiles and ozone concentration anomalies in the range of 10–14 km in the Beijing area in the winter of 2008 through the analysis of the weather situation, atmospheric circulation background, and tropopause height disturbance. The existences of these ozone anomalies fully confirm that the main cause of the southern snow disaster in January–February 2008 was the strong subsidence movement of stratospheric air and its exchange with the troposphere. The subsidence movement and stratosphere–troposphere exchange are due to the special weather background during the period, and the anomalous characteristics of the ozone vertical profile found from sounding observations provide strong observational evidence for the cause analysis of the snow disaster event.

Located at the junction of northwestern Fujian Province and Jiangxi Province, Wuyi Mountain has a subtropical monsoon climate with four distinct seasons and abundant rainfall. The forest coverage rate of Wuyi Mountain is as high as 96.3%, and there is basically no industrial pollution source. The observation station in Wuyi Mountain is the regional background station of atmospheric environment in the southeast coastal area. At the end of 2021, relying on the construction of the three-dimensional ozone observation network in the Wuyi Mountain National Meteorological Observation Station of the China Meteorological Administration, the scientific experiment of ozone sounding observation has been performing at the Shaowu sounding station (one of the three national sounding stations in Fujian Province), which fills the area for the vertical ozone observation in the southeast coastal area. The Shaowu sounding station is also one of the first six stations on the Chinese mainland (Beijing, Nanjing, Chongqing, Hangzhou, Qingyuan, Guangdong, and Shaowu) to carry out ozone-sounding observation. This study focuses on the evaluation of this new observation system, observation process, data quality, and stability. This observation has important scientific significance for proving the vertical distribution and trend of ozone in the background points (non-urban sites) of the atmospheric environment in the southeast coastal area, and also provides observational evidence for revealing the synoptic diagnosis mechanism of near-surface ozone pollution. It also lays a foundation for China's ozone-sounding observation to move forward to routinely observing at regular intervals.

2. Data and method

2.1. Instrument and Elements Detected

The ozone-sounding system in the Shaowu sounding station (station number: 58725, 27.32 N, 117.49 E, altitude: 218.9 m) mainly consists of five instruments including CTY-1 ozone sounding sensor, CYDT-1 ozone-sounding sensor detector, HYDF-MCRS1 satellite navigation sounding receiver, satellite navigation sounding instrument, and TD2A electronic sounding instrument base measuring box. The measurement precision of the ozone sounding sensors is 0.00 mPa. The sounding balloon uses a 1600 g Zhuzhou ball with a net lift of 2200 g. The net lift of this kind of balloon is 1.5–2 times larger in weight than that of the conventional meteorological element sounding balloon (750 g).

The basic elements of detection are as follows: balloon lift-off time, average speed of ascension, background current, air pump flow, blasting time, flight time, maximum detection altitude, and the altitude of the sonde falling once without signal. The measurement elements obtained after data processing are air pressure, air temperature, relative humidity, wind direction, wind speed, and ozone partial pressure.

2.2. Ozone Content

The ozone content is expressed in two units of ozone partial pressure (mPa) and ozone VMR (ppb). The ozone partial pressure refers to the pressure formed by the ozone gas occupying the same volume of the air mixture. The ozone VMR refers to the volume of ozone contained in billion-unit volume of air. The formula for calculating the ozone partial pressure Po_3 is as follows:

$$P_{O_3} = \frac{R}{M_{O_3}} T \rho_{O_3} \quad (1)$$

where R is the universal gas constant, T is the atmospheric temperature, and Mo_3 and ρ_{O_3} are the molecular weight and mass density of ozone, respectively. With ozone partial pressure Po_3 and air pressure P (unit: hPa), the ozone VMR r' can be expressed as:

$$r' = 10,000 \times \frac{P_{O_3}}{P} \quad (2)$$

2.3. Total Ozone Column

Given ozone VMR and atmospheric pressure at each height, the total amount of ozone from the ground to the height of the balloon blasting point, which represents the tropospheric and stratospheric column X (unit: DU) [32], can be calculated; namely:

$$X = 0.7890 \int_{P_2}^{P_1} r\left(\times 10^{-6}\right) \mathrm{dp(hPa)} \quad (3)$$

3. Results

3.1. Overview of Ozone Sounding

Starting from 24 November 2021, an ozone-sounding observation experiment has been performed at the Shaowu sounding station every Wednesday at 14:00. If there are special scientific mission requirements, intensive observations can be carried out. If it rains on Wednesday, the observation will be postponed to the same time on Thursday. If it rains both on Wednesday and Thursday, the ozone observation for that week will be cancelled. From November 2021 to February 2022, 12 ozone-sounding observations in total were carried out at Shaowu station. There was a lack of observation from 2 to 3 February and 16 to 17 February because of precipitation.

In the winter of 2022, the average maximum height of ozone sounding observation at Shaowu station is 37.2 km, and the highest detection height is 39 km (Table 1). The average flight time is 97 min, the average speed up is 390 m/min, the average background current is 0.099/μA, and the average air pump flow rate is 3.28 mL/s. The average height of the tropopause is 17.2 km (Table 1), the temperature in the troposphere decreases with height, and the average vertical decrement rate of temperature is 5.9 °C/km.

Table 1. Overview of the 12 ozone sounding tests at Shaowu station in the winter of 2022.

Terms	Maximum Height/km	Tropopause */km	Ozone Partial Pressure		Ozone Partial Pressure		Ozone VMR	
			Maximum /mPa	Height with Maximum/km	Minimum /mPa	Height with Minimum/km	Maximum /ppb	Height with Maximum/km
Range	33.6–39.0	15.6–18.2	12.0–16.6	21.8–29.0	0.3–1.5	12.7–17.1	7131.3–12,665.6	29.4–34.3
Average	37.2	17.2	14.0	24.9	0.8	14.6	8649.0	31.3

* In 1957, World Meteorological Organization (WMO) defined the tropopause as the minimum altitude at which the vertical decrement rate falls to 2 K/km or below above the 500 hPa isobaric surface, and maintains at least a minimum boundary of 2 km.

3.2. Ozone Partial Pressure and Temperature Profile

The maximum heights of the ozone partial pressure in 12 experiments fluctuate between 21.8 and 29 km (Table 1), indicating that the air masses in the stratosphere are strongly moveable in winter. On 8 December 2021, the maximum of ozone partial pressure reaches 16.6 mPa with the height of 29 km. The average height of the maximum ozone partial pressure is 24.9 km, and the average maximum value is 14 mPa. The layer of minimum ozone partial pressure varies from 0.2 to 4.3 km below the tropopause, and the average height of the minimum layer is 14.6 km, the minimum value is 0.8 mPa on average.

Based on 12 ozone partial pressure and temperature profiles, it can be seen that there are two trends of ozone partial pressure with height. One is that it decreases from the ground to the tropopause (four cases), which is consistent with the temperature profile (Figure 1a). The second is that the ozone partial pressure first shows an increasing trend from the ground to about 3 km (eight cases), corresponding to one or more layers of temperature inversion structures in the temperature profile when the atmosphere is static and the relative humidity is stable(Figure 1b). Then the ozone partial pressure decreases toward the tropopause (consistent with the former). Both of these two types of the ozone partial pressure start to increase significantly after reaching the stratosphere and keep increasing to around 25 km at which it reaches a maximum value. Above 25 km, the ozone partial pressure decreases again as the height increases until the end of the observation.

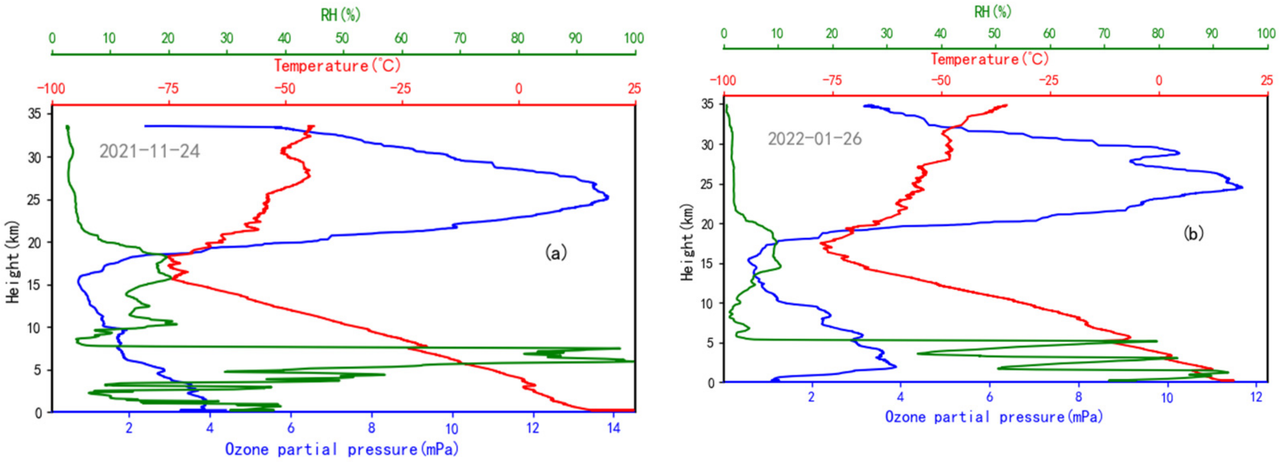

Figure 1. Profiles of ozone partial pressure, temperature, and humidity at the Shaowu observation station. 24 November 2021 (**a**) and 26 January 2022 (**b**).

3.3. Tropospheric Ozone VMR

3.3.1. Trends with Height

There are also two trends in the tropospheric ozone VMR. One is the fluctuating increase from the ground to the tropopause. After reaching the tropopause, the ozone VMR begins to rise rapidly; that is, the height of the ozone surge is consistent with the height of the tropopause. This phenomenon appeared on 24 November 2021 and 29 December 2021 (Figure 2a), when the tropopause ozone VMR was about 75 ppb and 125 ppb, respectively. Except for these two cases, the tropospheric ozone VMR in the remaining 10 cases increases rapidly about 5 km away from the tropopause with ozone VMR variability larger than 20 ppb/km (Figure 2b). The starting point of the ozone surge layer (the inflection point in the change of ozone VMR from low to high altitudes) is between 12.7–15.5 km, which is 2.9 km lower than the tropopause on average. In this surge layer, the ozone VMR increased three to four times in five cases, and the ozone VMR at tropopause was about 190–240 ppb. There is one case that increased by six times, and the ozone VMR at tropopause reached 745 ppb (appearing on 19 January 2022), which has the same characteristics as stratospheric ozone. This high VMR at the tropopause is mainly due to the transport of stratospheric ozone to the upper troposphere by dynamic transport. Usually, the maximum height obtained from meteorological elements sounding through a T-lnP map can be up to 200–150 hPa with altitudes of about 12–13 km. Therefore, the reason for the surge phenomenon of the ozone VMR at tropopause that generally exists in the upper troposphere (above 12 km) until the tropopause can be inferred to be the influence of stratospheric ozone subsidence and transport downward, plus intense photochemical reaction.

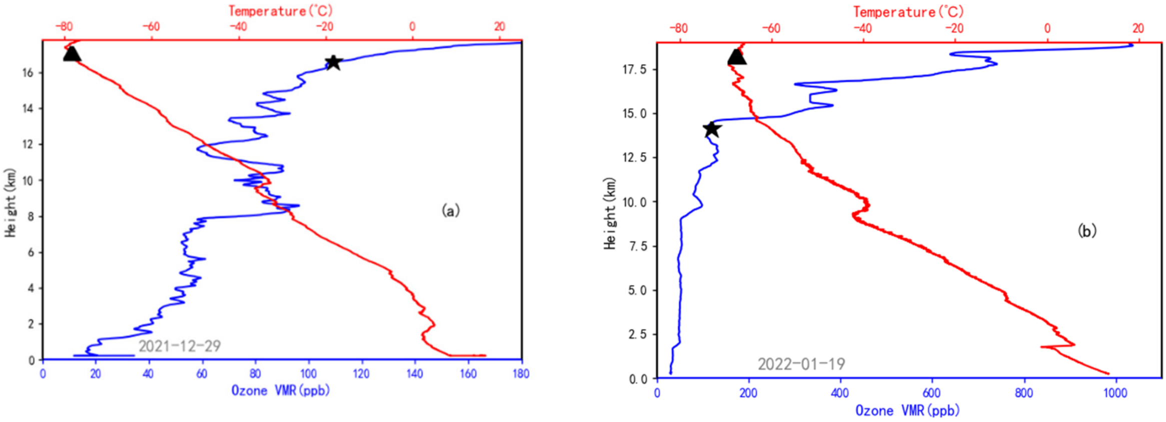

Figure 2. Profiles of tropospheric ozone VMR (blue lines) and temperature (red lines) at the Shaowu observation station. 29 December 2021 (**a**) and 19 January 2022 (**b**). The triangle sign indicates the location of the tropopause and the star sign indicates the starting point of the ozone surge layer.

3.3.2. Characteristics of Ozone Vertical Distribution

Figure 3 is the average vertical profile of the tropospheric ozone VMR at the Shaowu station in the winter of 2022. It can be seen that the tropospheric ozone VMR gradually increases from the ground to the tropopause.

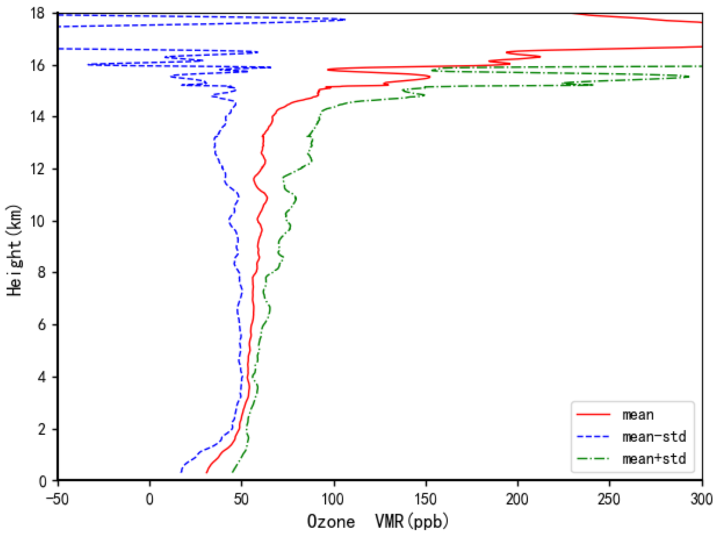

Figure 3. The averaged profiles of ozone VMR at the Shaowu observation station in the winter of 2022. The red line represents the mean state of ozone VMR. The blue or green dashed line represents the profile of mean state minus or plus standard deviation of ozone VMR, respectively.

The dispersion degree of ozone VMR is large between the average state and positive or negative standard deviation below 1.5 km. The dispersion coefficient (standard deviation/average) is between 0.2 and 0.5. The ozone VMR within the boundary layer is unstable for the cause that is closely related to pollution source emissions, regional transport, atmospheric structuring stability, and meteorological conditions. The dispersion degree of ozone VMR in 1.5–8 km is relatively small between the average state and positive or negative standard deviation, and the dispersion coefficient is 0.05–0.2. The dispersion degree grows gradually with the height from 8 km to 12 km, then the dispersion degree increases rapidly at 12–14 km, which indicates that the vertical VMR of ozone at the Shaowu station in the winter of 2022 is less affected by abnormal weather processes. In Section 3.3.3, it is also found that the ozone sub-peak phenomenon in the layer from 8 km to 12 km only accounts for 25% of the total sub-peak phenomenon. In the layer between 8 and 14 km, especially within 12 km, the changes of ozone VMR in the troposphere tend to be affected by several special weather processes and the corresponding changes in atmospheric humidity, temperature, wind field, and radiation. In the layer between 12 to 14 km, some cases are with stratospheric ozone intrusions, and some are not, leading to the dispersion degree of further ozone VMR increases. Above 14 km, the average state of ozone VMR and the positive (+) standard deviation gradually approached, which is related to the combined influence of dynamic transport of ozone from stratosphere main and strong photochemistry in the upper troposphere.

3.3.3. Tropospheric Ozone Sub-Peak Phenomenon below 12 km

The tropospheric ozone profile below 12 km has three types: no sub-peak (eight cases), single sub-peak (the three cases on 1 December 2021, 29 December 2021, and 19 January 2022 (Figure 4a)) and multiple-sub-peak phenomenon (the case on 15 December 2021 (Figure 4b)). The sub-peak is defined as the vertical variability of ozone VMR variability is larger than 15 ppb/km, the relative humidity is less than 15%, and the peak VMR is 1.5 times more than the average state at the same height. It is found that the sub-peak phenomenon distributes in the height range of 6.7–11.5 km, of which the sub-peak in one case appears below 8 km, four cases appear between 9–11.5 km, and the corresponding relative humidity is less than 12%. The sub-peak VMR is 1.6–1.9 times larger than the average state at the same height, and the maximum value of ozone VMR is between 78–99 ppb, which is consistent with the characteristics of ozone in the middle and lower troposphere. The main reason for the sub-peak phenomenon of tropospheric ozone VMR below 12 km in winter is that the ozone VMR is affected by many factors such as temperature, air pressure, wind field, and radiation, and is restricted by atmospheric dynamics and weather processes.

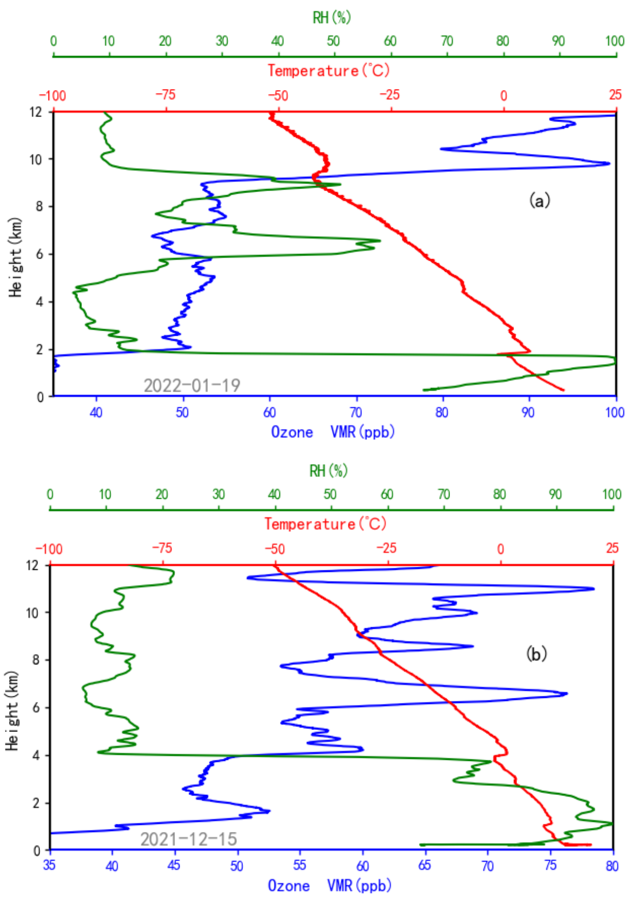

Figure 4. Profiles of ozone VMR (blue lines), RH (green lines), and temperature (red lines) in the troposphere at the Shaowu observation station. 19 January 2022 (**a**) and 15 December, 2021 (**b**).

3.4. Stratospheric Ozone VMR

It can be seen from Table 1 that the layer of the maximum stratospheric ozone VMR is within the height of 29.4–34.3 km, and the maximum value of the stratospheric ozone VMR can reach 7131.3–12,665.6 ppb. The highest height of the maximum stratospheric ozone VMR reaches to 34.3 km, and the corresponding value of ozone VMR is 12,665.6 ppb on 8 December 2021. During this process, the observed maximum and height of ozone partial pressure are consistent with the time. The average height of the maximum layer of the stratospheric ozone VMR is 31.3 km, with the average VMR of 8649 ppb. This average height is 6.4 km higher than that of ozone partial pressure, for the reduction in air pressure is still rapid, since the reduction in ozone levels is slower in the layer of maximum ozone partial pressure (about 25 km). Finally, the VMR continues to rise when the ozone partial pressure drops, and the maximum height of the VMR also rises.

3.5. Total Ozone Analysis

The total ozone column ranges from 220.4 to 406.0 DU (Table 2). The total ozone in the boundary layer (0–1.5 km) is 4.3 DU on average, accounting for 1.5% in total ozone column. The total ozone in the troposphere is 39.5 DU on average, accounting for 13.1% in total ozone column. The total ozone in the stratosphere is 262.4 DU on average, accounting for 86.9% in total ozone column.

Table 2. The column burdens and proportions of ozone in different layers at the Shaowu station in the winter of 2022.

Terms	Boundary Layer	Troposphere	Stratosphere
Range/DU	2.4—7.3	32.0—48.2	185.0—363.1
Average/DU	4.3	39.5	262.4
Proportion/%	1.5%	13.1%	86.9%

* The height of the boundary layer ranges from 0–1.5 km; the height of troposphere is from the surface to the tropopause (average height is 17.2 km); the height of the stratosphere is from the tropopause to the height of the balloon burst.

4. Discussion

In the study, we found three interesting facts. First, 66.7% cases first showed that the ozone partial pressure increased from the ground to about 3 km, while there were one or more temperature inversions in the corresponding temperature profiles and the atmosphere was stable and the relative humidity was high, which was related to the special atmospheric structure near the ground in winter. Second, the height of the ozone surge is inconsistent with the height of the tropopause, in which 83.3% of the cases, ozone VMR begins to rise rapidly at about 2–5 km away from the tropopause, and the ozone surge height is 2.9 km lower than the tropopause on average, rather than the general thought that ozone rises rapidly from the tropopause. Third, the total ozone varies greatly in different observation cases, ranging from 220.4 to 406.0 DU, with an average value of 301.9 DU. Although the sounding heights of ozone are different each time (ranging from 35.5 km to 39 km), this is not the main factor affecting the total ozone. The main factor is whether the stratospheric ozone invades the troposphere more, which should be the essential reason affecting the total ozone.

5. Conclusions

(1) Using China's self-developed CTY-1 ozone-sounding sensor and HYDF-MCRS1 satellite navigation sounding receiver, the Shaowu sounding station of the Wuyi Mountain National Meteorological Observation Station performed the first scientific experiment of ozone-sounding observation in Fujian Province on 24 November 2021. The ozone-sounding observation is made regularly every Wednesday or Thursday (non-rainy days), and is of great scientific significance and practical value.

(2) In the winter of 2022, the average maximum height of ozone-sounding observation at the Shaowu station is 37.2 km. The average flight time of the sounding balloon is 97 min; its average rise speed is 390 m/min. The average height of the tropopause is 17.2 km, and the average vertical decrement rate in the troposphere is 5.9 °C/km.

(3) There are two trends of ozone partial pressure with height. One is that the ground decreases toward the tropopause, which is consistent with the temperature profile. The second is that the ozone partial pressure first shows an increasing trend from the ground to about 3 km, corresponding to one or more layers of temperature inversion structures in the temperature profile when the atmosphere is static and the relative humidity is stable. Then the ozone partial pressure decreases toward the tropopause. Both of these two types of the ozone partial pressure start to increase significantly after reaching the stratosphere and keep increasing to around 25 km, at which it reaches a maximum value. Above 25 km, the ozone partial pressure decreases again as the height increases until the end of the observation. The average height of the maximum ozone partial pressure is 24.9 km, and the average maximum value is 14 mPa.

(4) There are also two trends of variation in the tropospheric ozone VMR with height. One is the fluctuating increase from the ground to the tropopause. After reaching the tropopause, the ozone VMR begins to rise rapidly; that is, the height of the ozone surge is consistent with the height of the tropopause. This phenomenon appeared in two cases. The tropospheric ozone VMR in the remaining 10 cases increases rapidly about 5 km away from the tropopause with ozone VMR variability larger than 20 ppb/km. The starting point of ozone surge layer is between 12.7–15.5 km, which is 2.9 km lower than the tropopause on average. In this surge layer, the ozone VMR increased three to four times in five cases, and the ozone VMR at tropopause was about 190–240 ppb. There is one case that the ozone VMR increased by six times, and the ozone VMR at tropopause reaches 745 ppb, which has the same characteristics as stratospheric ozone. This high VMR at tropopause is mainly due to the transport of stratospheric ozone to the upper troposphere by dynamic transport.

(5) The tropospheric ozone profile below 12 km has three types: no sub-peak (eight cases), single sub-peak (three cases), and a multiple sub-peak phenomenon (one case). It is found that the sub-peak phenomenon distributes in the height range of 6.7–11.5 km, and the corresponding relative humidity is less than 12%. The sub-peak VMR is 1.6–1.9 times larger than the average state at the same height, which is consistent with the characteristics of ozone in the middle and lower troposphere. The main reason for the sub-peak phenomenon of tropospheric ozone VMR below 12 km in winter is that the ozone VMR is affected by many factors such as temperature, air pressure, wind field, and radiation, and is restricted by atmospheric dynamics and weather processes.

(6) The layer of the maximum stratospheric ozone VMR is within the height of 29.4–34.3 km, and the maximum value of the stratospheric ozone VMR can reach 7131.3–12,665.6 ppb. The average height of the maximum stratospheric ozone VMR is 31.3 km, with the average VMR of 8649 ppb. This average height is 6.4 km higher than that of ozone partial pressure.

(7) The total ozone column ranges from 220.4 to 406 DU. The total ozone in the boundary layer (0–1.5 km) is 4.3 DU on average, accounting for 1.5% in total ozone column. The total ozone in the troposphere is 39.5 DU on average, accounting for 13.1% in total ozone column. The total ozone in the stratosphere is 262.4 Du on average, accounting for 86.9% in total ozone column.

(8) Our study shows that the overall quality of 12 ozone-sounding observations at the Shaowu station in the winter of 2022 is high, and the data reliability is also high. The characteristics of various ozone profiles conform to the general law of the vertical distribution of ozone at low latitudes in the northern hemisphere.

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