Chinese Journal of Polar Science, Vol.13, No.1, 75 - 82, June 2002

Vertical characteristics of ozone variation over the Arctic Chukchi Sea region in 1999

Zhou Libo (周立波), Liu Yu (刘 宇) and Zou Han (邹 捍)
Institute of Atmospheric Physics, Chinese Academy of Sciences, Beijing 100029, China

Received August 20, 2001

Abstract In 1999 summer, Chinese Arctic Research Expedition operated the Chukchi Sea. On Chinese icebreaker Xuelong, we made many high-resolution ozonesonds measurements. During the period from August 18 to 24, a synoptic scale observation was taken at 75°N, 160°W. Using the above data, together with TOMS total ozone and NCEP circulation data, we showed that atmospheric ozone amount experienced a high-low-high variation, with low-high-low tropopause altitude. Correlation analysis showed a close relation between the total ozone and ozone below 13 km, while the variation of the maximum concentration at about 20 km didn't show any relation to the column ozone. In 500 hPa height maps, there was also the weak-strong-weak southwesterly pattern. Therefore we suggested that the synoptic system might be responsible to a low ozone advection during this ozone variation.

Key words ozonesonds, TOMS, tropopause, synoptic system.

1 Introduction

Arctic climate and environment are very important in the global change systems (WMO/UNEP 1990; WMO 1991). Observations and modeling results indicate that the global warming will be enhanced in the polar regions, especially in the North Hemisphere, with a predicted warming of about 3 - 4°C in the coming fifty years or more (Manabe and Stouffer 1993; Mitchell *et al*. 1995; Dickson 1999). Such huge warming changes are of concern because the polar region is expected to amplify any change in Earth's climate. As one of most important trace gases influencing climate system, ozone is also of great concern by more and more scientists (WMO 1985; WMO 1999). Studying on ozone distribution and variation are helpful for understanding the Arctic climate system and its impact on the globe. There was a lot of work on the Arctic ozone change, especially on total ozone using satellite data (Bojkov *et al*. 1990; Stolarski *et al*. 1992; Manney *et al*. 1994; Waibel 1999). The satellite data on vertical ozone distribution are in low resolution, especially in troposphere. Therefore, several large experiments were made during last decades with ozonesonds, including European Arctic Stratospheric Ozone Experiment (EASOE) in Northern Europe region, in 1991/1992 winter and SOLVE/THESEO 2000 campaign (Orsolini *et al*. 1995; Stroh *et al*. 2000). However, the results were of great difference among different case studies (Hollandsworth *et al*. 1995; Miller *et al*. 1995), and there were no available observation for vertical ozone distribution in the Chukchi Sea sector. Therefore, more observations should be made over the Arctic region, especially over the Chukchi Sea. Also, as a member of International Arctic Science Committee (IASC), China has the responsibility to take expedition to the Arctic.

During 1st July – 9th Sept., 1999, China operated the First Scientific Research Expedition to the Arctic Ocean, with 60 scientists on board of the Chinese icebreaker Xuelong. The expedition was supported by the Chinese Ocean Administration, Chinese Academy of Sciences and the other 5 Chinese governmental organization. The disciplines in this survey include atmospheric sciences, geo-sciences, oceanography, sea-ice studies, biology, etc.. The research topic was focused on the sea-ice-air interaction and its impact on global climate, the water mass exchange between the Arctic Ocean and the North Pacific Ocean and its climate effects, and biological environment and the fishery resources.

The Institute of Atmospheric Physics (IAP), Chinese Academy of Sciences, designed and carried out "Arctic Upper-air Observation 1999" in this Arctic Ocean survey. During the expedition, more than 20 radiosondes were released for measuring the atmospheric structure and vertical ozone profile in the Arctic Ocean. The measurement made unique high-resolution (vertical resolution 30 – 50 m) data available in the Chukchi Sea for climate and environment study (Zou 1999*). This article is to study the ozone variation in the Arctic Ocean during the expedition period for understanding the mechanism in Arctic ozone variation, and to provide a high-resolution vertical ozone structure of this region in summer for climate model constructors.

2 Observation and data

Based on the navigation and observation schedule, "Arctic Upper-air Observation 1999" was modified and carried out in the following three parts:

* In the middle of July, as the Chinese icebreaker, Xuelong, entered the Chukchi Sea, several normal and ozone radiosondes were released to collect the background data over this region, with TMT (tethered meteorology tower) observation for atmospheric boundary study;

* August 5 – 6, 1999, daily variation observation was completed on a sea ice at 73.37°N, 165.00°W, with 4 radiosondes released at 11:45, 17:04, 23:11, August 5, and 4:30, August 6, GMT;

* August 18 – 25, 1999, under the guidance of the Canadian RADARSAT and helicopter, Xuelong found a stable sea ice suitable for observation at 75°N, 160°W. Therefore 8-day ozone sonde observation was carried out at the temporal station with one ozone sonde each day.

The instruments used in "Arctic Upper-air Observation 1999" were: 1) DigiCora II MW15 by Vaisala co. for GPS wind measurement; 2) RS80-25GE radiosonde by Vaisala co. for air temperature, pressure, humidity measurement; and 3) 6A ECC ozone sonde by Science Pump co. for ozone concentration measurement.

In this study, data from the third observation period is used, including 7-day atmospheric structure and vertical ozone distribution available up to 25 km a.s.l. with 50-meter vertical resolution, from August 18 to 24, 1999. The analysis on synoptic system and total ozone are based on NCEP reanalysis (available from NCAR/NCEP) and TOMS (available from NASA), respectively. TOMS ozone amount at 75°N, 160°W is selected for the expedition area.

3 Ozone variation

* Zou H, Wang W, Zhou LB (1999): Project summary of Arctic upper-air obdifudiesservation 1999, Institute of atmospheric physics. Beijing: Chinese Academy of Sciences.

In Fig. 1 showing the ozone concentration observed at 75°N, 160°W, August 18 – 24, 1999, the vertical ozone distribution is in a double-peak shape, with the highest concentration 12 – 14 mPa located within 20 – 22 km from the ground and second highest 4 – 8 mPa located in 10 – 12.5 km from the ground. The first high ozone was located within 20 – 21 km altitude in period August 18 – 21, 1999, and then descended to about 20 km altitude. The area with ozone concentration larger than 12 mPa was in 18 – 22 km (with maximum ozone over 13 mPa) on August 19 – 21, and compressed in 19 – 21 km after August 22. However, the altitude of the second high ozone was at about 10 km on August 18 and 19, (with maximum ozone concentration about 7 mPa) ascended to 13 km on August 21, and descended to 11 – 12 km on August 23 and 24. Therefore, the air column with relatively low ozone below the second maximum expanded from August 18 to 21, and compressed from August 21 to 24.

Fig. 2 shows the variation of TOMS ozone, and the integrated total ozone in 0 – 25, 0 – 13 and 13 – 25 km layers, at 75°N 160°W, during the expedition period. From this chart, one can see that TOMS ozone experienced a variation from 292 DU on 18 and 291 DU on 19, decreasing (42 DU) to 249 on 21, and increasing (25 DU) to 274 DU on 24, August, 1999. The observed ozone from 0 – 25 km increased 41 DU from 178 DU on 18 to 219 DU on 19, decreased 40 DU to 179 DU on 21, increased 8 DU to 188 DU on 24, in August, 1999. Therefore, the observed total ozone in 0 – 25 km covers about 2/3 TOMS ozone, and varies in the same phase and amplitude as TOMS ozone, except the increase between August 18 and 19. The multi-coefficient between TOMS ozone and 0 – 25 km ozone is 0.89 from 19 to 24 in August, and the result is 99% believability. The increase in 0 – 25 kmozone from 18 to 19 August might be another ozone variation not covered by this observation, therefore it is omitted in the following discussion. When examining the ozone variation in mid and low stratosphere (total ozone in 13 – 25 km), it increased 28 DU (about 3/4 as the 0 – 25 kmozone increased) from 126 DU on 18 to 154 DU on 19, and steadily decreased to 127DU on August 24, 1999. The variation is different from those in 0 – 25 km total ozone and TOMS ozone after August 21. However, integrated total ozone in the lower atmosphere (0 – 13 km) increased 13 DU from 53 DU on 18 to 66 DU on 19 (about 1/4 increase of 0 – 25 km ozone), decreased 23 DU to 43 DU on 21, and increased 18 DU to 61 DU on 24, in August, 1999. Correlation analyses on the TOMS ozone and the 0 – 13 km ozone and 13 – 25 km ozone result in correlation coefficients, –0.78 and –0.59, respectively. The results show that the close relationship between TOMS ozone variation and lower atmosphere ozone variation. From Fig. 2, the observed 0 – 25 km total ozone increase from August 18 to 19 didn't meet TOMS ozone variation, the 0 – 25 km ozone decrease from August 19 to 21 met TOMS ozone variation, and the increase from August 21 to 24 was only 1/3 of TOMS ozone variation. The mid-low stratospheric ozone didn't meet the increase from August 21 to 24, 1999. The ozone below 13 km met the variation of 0 – 25 km from August 18 to 24, and shared the increase from 18 to 19 with mid-low stratospheric ozone, and contributed to increase from August 21 to 24 by overcoming the decrease in mid-low stratospheric ozone.

4 Atmospheric structure

Fig. 3 shows the vertical temperature distribution and variation during the expedition. The thermal tropopause is clearly showed in this figure with the temperature inversion –55℃ to –45℃. The altitude of tropopause increased from 10 km on 18 and 19 to about 12.5 km on 21,

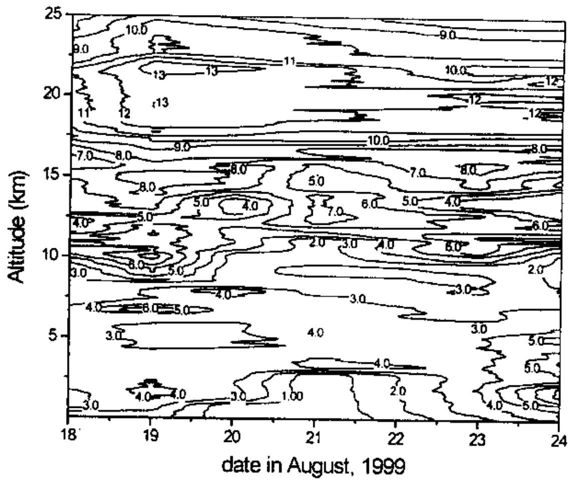

Fig. 1. Ozone concentration (mPa) observed at 75°N, 160°W, August 18 – 24, 1999.

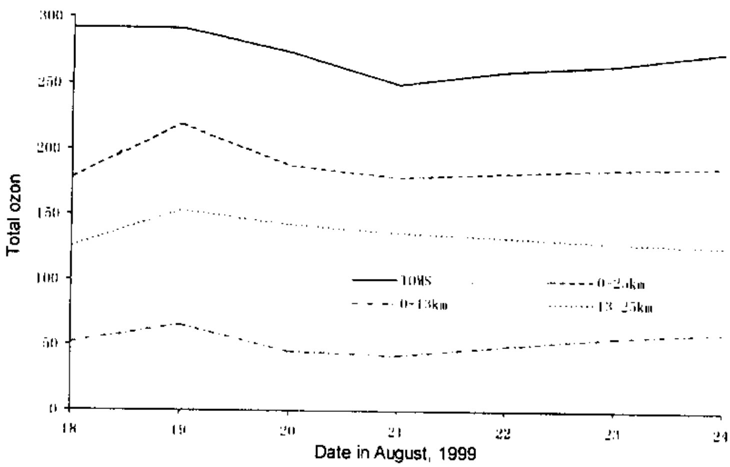

Fig. 2. TOMS ozone (solid) and integrated total ozone in 0 – 25 km (long-dashed lines), 0 – 13 km (short dashed) and 13 – 25 km (dot-dashed) layers in DU, at 75°N, 160°W, August 18 – 24, 1999.

and decreased to 10.5 km on August 24, 1999. This variation coincided with the variation of TOMS ozone and integrated ozone in 0 – 25 and 0 – 13 km, except from 18 to 19. In the low troposphere, the temperature experienced a warm-cold-warm variation, while the temperature in the most part of troposphere had cold-warm-cold variation coincident with the altitude of tropopause. From this temperature variation, one can see that the observation site has experienced a passing warm air mass, and the warm air mass brought a high tropopause over this region. Comparing the variation of tropopause height and total ozone over this area, a high tropopause is consistent with low ozone aloft, and vice versa. This has been noticed by other studies (Steinbrecht *et al*. 1998).

Figs. 4 – 6 shows the synoptic system on 500 hPa surface over the expedition region. The observation site is located at 75°N latitude and 0° relative longitude (marked by a star) in these charts. In Fig. 4, there were two lows on the east and west of the observation site, located at 64°N, 20°W (marked by A, strength 5250 ghm) and 76°N, 25°E (marked by B, strength 5350 ghm), respectively, and a high ridge was approaching this area from the south, on August 19, 1999. Therefore, wind over the observation site during this period was calm. In Fig.5, low A moved eastward and down to 60°N, 15°W with strength 5350 ghm, therefore the observation site was on the northeast of low A, which moved southeasterly, on August 21, 1999. In this period, the air mass came from south region to the expedition region, along the northeast side of low A. In Fig. 6, low A passed the expedition area to 55°N, 10°E with strength 5400 ghm, and a high came into the observation area, on August 24, 1999. The observation site was located in the high with no northward air transportation.

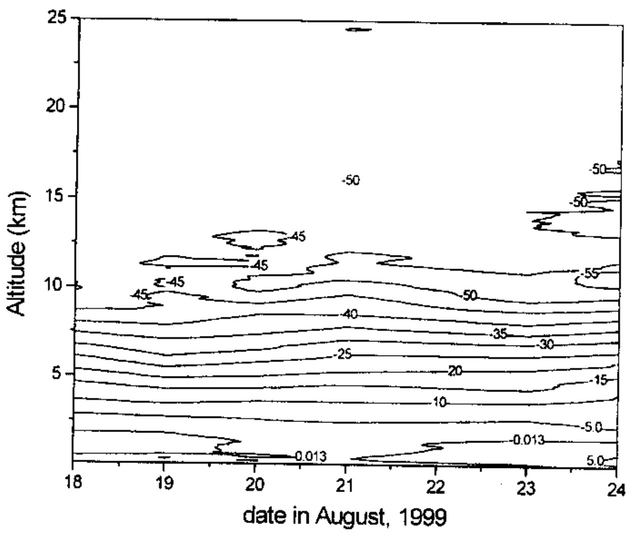

Fig. 3. Atmospheric temperature (℃) at 75°N, 160°W, August 18 – 24, 1999.

From the discussion on the synoptic situation during the expedition, it is clear that air mass transportation from the southeast induced the high temperature in troposphere over the observation site, and the warm troposphere was featured with high tropopause. The change in synoptic situation during the expedition period was quite related to the ozone reduction from August 19 to 21 and the recovery from August 21 to 24.

5 Discussion and conclusion

In the discussion on the total ozone variation in different layers, the atmospheric structure and synoptic situation during the expedition, the facts are showed in the following:

1) TOMS total ozone is related to the 0 – 25 km integrated total ozone, and the 0 – 25 km ozone is greatly decided by the ozone of lower atmosphere (0 – 13 km) in the high-low-high vari-

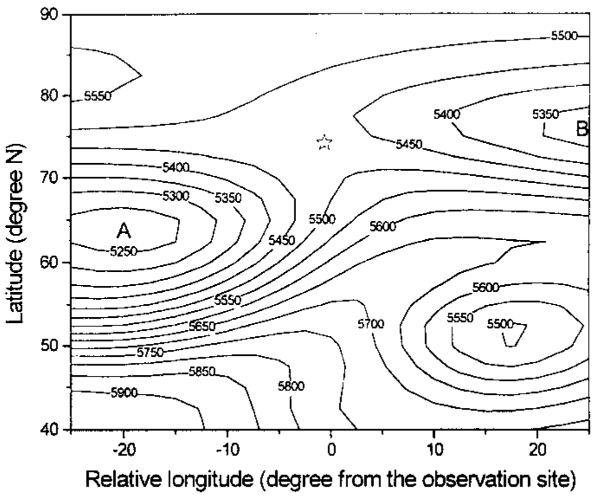

Fig.4. Synoptic situation (ghm) on 500 hPa surface, August 19, 1999.

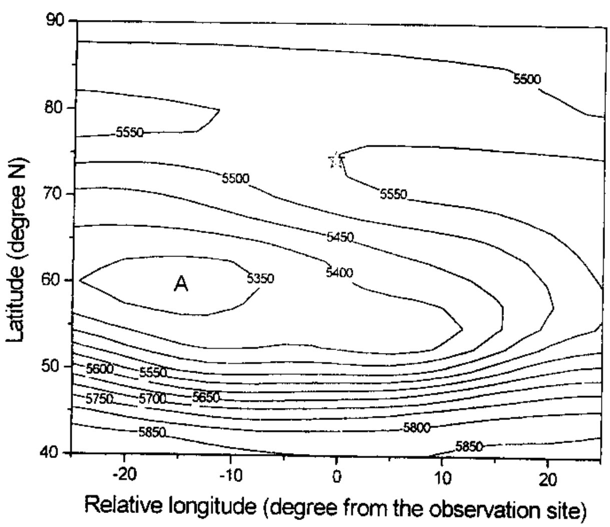

Fig.5. Synoptic situation (ghm) on 500 hPa surface, August 21, 1999

ation during August 19 – 24. Therefore, the ozone variation in 0 – 13 km atmosphere could partly decide the total ozone change during the expedition;

2) The expansion of the troposphere (indicated by the high tropopause) made the air column portion of low ozone concentration enlarged in the total atmospheric column, and therefore, the total column ozone was reduced;

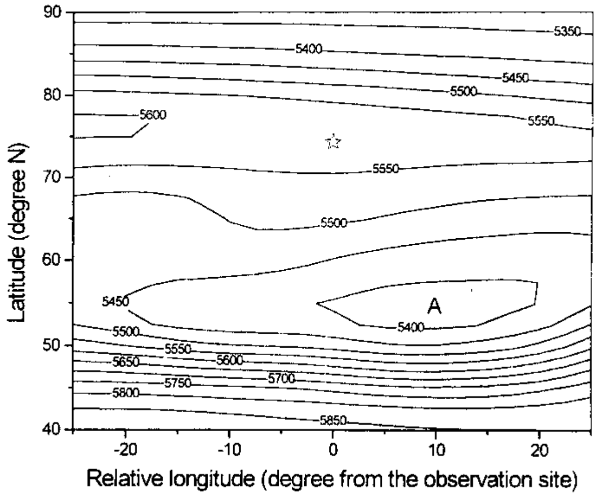

Fig.6. Synoptic situation (ghm) on 500 hPa surface, August 24, 1999.

3) An advection from southeast of the observation site transported warm air mass to this region, and caused the air column expanding in lower atmosphere.

Therefore, we conclude that the high-low-high variation in atmospheric total ozone during the expedition was mainly affected by the advection in lower atmosphere.

Acknowledgements This work was supported by the National Natural Science Foundation of China (40075029) and Institute of Atmospheric Physics, Chinese Academy of Sciences (8-2212). We would like to thank the data providers, TOMS data processing team at Godard Flight Center, NASA, NCAR/NCEP, and Chinese Arctic Expedition 1999, National Ocean Administration of China. In addition, authors give great appreciation to Mr. Wang Wei's data collecting work in the Chinese Arctic Expedition 1999.

References

Bojkov R, Bishop L, Hill WJ, Reinsel GC, Tiao GC(1990): A statistical trend analysis of revised Dobson total ozone data over the Northern Hemisphere. J. Geophys. Res., 95(D7): 9785-9807.

Dickson B(1999): All change in the Arctic. Nature, 397: 389-391.

Hollandsworth SM, McPeters RD, Flynn LE, Planet W, Miller AJ, Chandra S(1995): Ozone trends deduced from combined Nimbus 7 SBUV and NOAA 11 SBUV/2 data. Geophys. Res. Lett., 22(8): 905-908.

Manabe S, Stouffer RJ(1993): Century-scale effects of increased atmospheric CO_2 on the ocean-atmosphere system. Nature, 362: 215-217.

Manney GL *et al*. (1994): Chemical depletion of ozone in the Arctic lower stratosphere during winter 1992-93. Nature, 370: 429-434.

Miller AJ, Tiao GC, Reinsel GC, Wuebbles D, Bishop L, Kerr J, Nagatani RM, Deluisi JJ, Mateer CL(1995): Comparisons of observed ozone trends in the stratosphere through examination of Umkehr and balloon ozonesonde data. J. Geophys. Res., 100(D6): 11209-11217.

Mitchell J, Johns T, Gregory J, Tett S(1995): Climate response to increasing levels of greenhouse gases and sulphate

aerosols. Nature, 376:501 - 504.
Orsolini Y, Cariolle D, Deque M(1995):Ridge formation in the lower stratosphere and its influence on ozone transport: A general circulation model study during late January 1992. J. Geophys. Res., 100(D6):11113 - 11135.
Steinbrecht W, Claude H, Kohler U, Hoinka KP(1998):Correlations between tropopause height and total ozone: Implications for long-term changes. Journal of Geophysics Research, 3(D15):19183 - 19192.
Stolarski RS, Bojkov R, Bishop L, Zerefos C, Staehdin J, Zawodny J(1992):Measured trends in stratospheric ozone. Science, 256:342 - 349.
Waibel AE, Peter Th, Carslaw KS, Oelhaf H, Wetzel G, Crutzen PJ, P9 schl U, Tsias A, Reimer E, Fischer H (1999):Arctic Ozone Loss Due to Denitrification. Science, 283(5410):2064 - 2069.
WMO/UNEP(1990):Climate change. the IPCC scientific assessment, Cambridge University Press.
WMO(1991):Scientific concept of the Arctic climate system study (ACSYS). Report of the JSC study group on ACSYS, Bremerhaven, Germany, 10 - 20 June 1991 and London, U.K., 18 - 19 Nov.
WMO(1985):Atmosphere ozone 1985. Assessment of Our Understanding of Process Controlling Its Distribution and Change,Global Ozone Research and Monitoring Project. Rept. 16,Geneva.
WMO(1999):Scientific Assessment of Ozone Depletion. Geneva.