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Anomalously low ozone of 1997 and 2011 Arctic spring: Monitoring results and analysis

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Abstract Total ozone observations from the Total Ozone Unit (TOU) aboard the Chinese second generation polar orbiting meteorological satellite, Fengyun-3/A (FY-3/A), revealed that total column ozone over the Arctic declined rapidly from the beginning of March 2011. An extensive region of low column amount formed around mid March; monthly mean total column ozone in March 2011 was about 30% lower than the average observed during 1979—2010. Daily total column density of ozone near the center of low ozone area in mid March was less than 240 Dobson units, about half the total column ozone amount observed during the same period of the prior 10 years. We analyzed total column ozone data from different satellites during 1979—2011. Results show that the Arctic depletion of ozone in spring 2011 was initiated by the cold polar vortex in the lower stratosphere. The March mean total ozone over the Arctic has shown a decreasing trend over the past 32 years, and its variation is strongly correlated with the polar vortex. A similar low ozone process of spring 1997 was compared to that of 2011, but daily variations of total ozone in March over the Northern Hemisphere in 1997 and 2011 have different patterns.

Keywords **Arctic ozone loss, polar vortex, ozone hole, polar stratospheric clouds**

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0 Introduction

Ozone is an atmospheric trace gas that is important for ecosystems, climate and the environment[1]. It was observed at ground-based stations in the mid 1980s that total column ozone over Antarctica in local spring had fallen about 30%—40% from previous decades[2-3]. Satellite data from Nimbus-7/TOMS showed that in each Antarctic springtime, there was a region with total column ozone below 220 Dobson units (DU). The ozone hole is geographically defined as the area wherein the total ozone amount is less than 220 DU[4]. Since the first observation of the Antarctic ozone hole, more than half the total ozone is destroyed each spring[5]. Total ozone over the Arctic had a decreasing trend from the end of the 1970s to the end of the 1990s. Satellite data show that the March mean value of total column ozone from 63°N to 90°N decreased to 354 DU in 1997, about 21% lower than the pre-1990s value of 450 DU[6]. Total ozone satellite data show that Arctic ozone has had an increasing trend since the end of 1990s. The March mean value of total ozone over the Arctic in 2010 was about 446 DU, close to the 1980s value. In March 2011, unprecedented Arctic ozone loss was observed by different satellites and ground-based stations, and the process had lasted for more than two weeks. Average total ozone in March 2011 was less than 336 DU.

The photochemical process for ozone loss in polar regions is well understood[7-9]. However, compared with the Antarctic, ozone loss in the Arctic has a large interannual variability, owing to interannual variability of the Arctic

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polar vortex[10]. The most severe ozone losses were observed over the Arctic in March 1997 and 2011. Recent research has shown that chemical ozone loss in spring 2011 far exceeded any previously observed over the Arctic[11]. In this study, 33-year ozone products from different satellites and NCEP/NCAR reanalysis data[12] are used to analyze the relationship between Arctic ozone loss and the polar vortex system. Arctic ozone loss in 2011 was analyzed based on daily ozone products from the FY-3A/TOU satellite. The difference in chemical ozone loss of March 1997 and March 2011 was studied by comparing daily variability of total Arctic ozone.

1 Data

All ozone data in this study are based on satellite products that infer atmospheric ozone from backscattered ultraviolet (BUV) solar radiation measurements[13]. The satellites include NIBUS-4/BUV (1970-1980)[14-15], NIMBUS-7/TOMS (1978—1993)[14-15], Meteor-3/TOMS(1994), EP/TOMS (1997—2005), AURA/OMI[16], NOAA-9/SBUV-2, and FY-3A/TOU[17-19]. Compared to ground-based ozone instruments, spaceborne instruments have the advantage of providing global coverage on a continuous basis. FY-3A/TOU was the first BUV-type ozone instrument, and was aboard the second generation polar orbiting meteorological satellite launched in May 2008. The total column ozone retrieval algorithm of the Total Ozone Unit (TOU) is based on differential ozone absorption across a pair of wavelengths[13], i.e., total column ozone is derived from a pair of measurements of backscattered solar radiation at two wavelengths, at which ozone absorption has apparent differences. An intercomparison of global ozone from the TOU, Ozone Monitoring Instrument (OMI) and ground-based measurements was made. This showed that average root mean square (RMS) biases in total column ozone between FY-3A/TOU and AURA/OMI, and between TOU and ground-based measurements, were about 3% and 4%, respectively[17-18].

To analyze the relationship between Arctic ozone depletion and the polar vortex, NCEP/NCAR reanalysis data were used to calculate monthly mean temperature at the 50 hPa level. These data are on 2.5×2.5 degree grids and 17 pressure levels[12].

2 Data analysis

2.1 Satellite data

Figure 1 shows the typical daily distribution of total column ozone in March over the Arctic. It is clear from this figure that in March, values of total column ozone over most Arctic areas exceed 400 DU, and are 500 DU or more in many areas. Total column ozone over the Arctic showed a rapid decrease from the end of February 2011, dropping below 230—300 DU in the central Arctic. This process lasted more than two weeks, until the end of March. Figure 2 shows the daily distribution of total column ozone over the

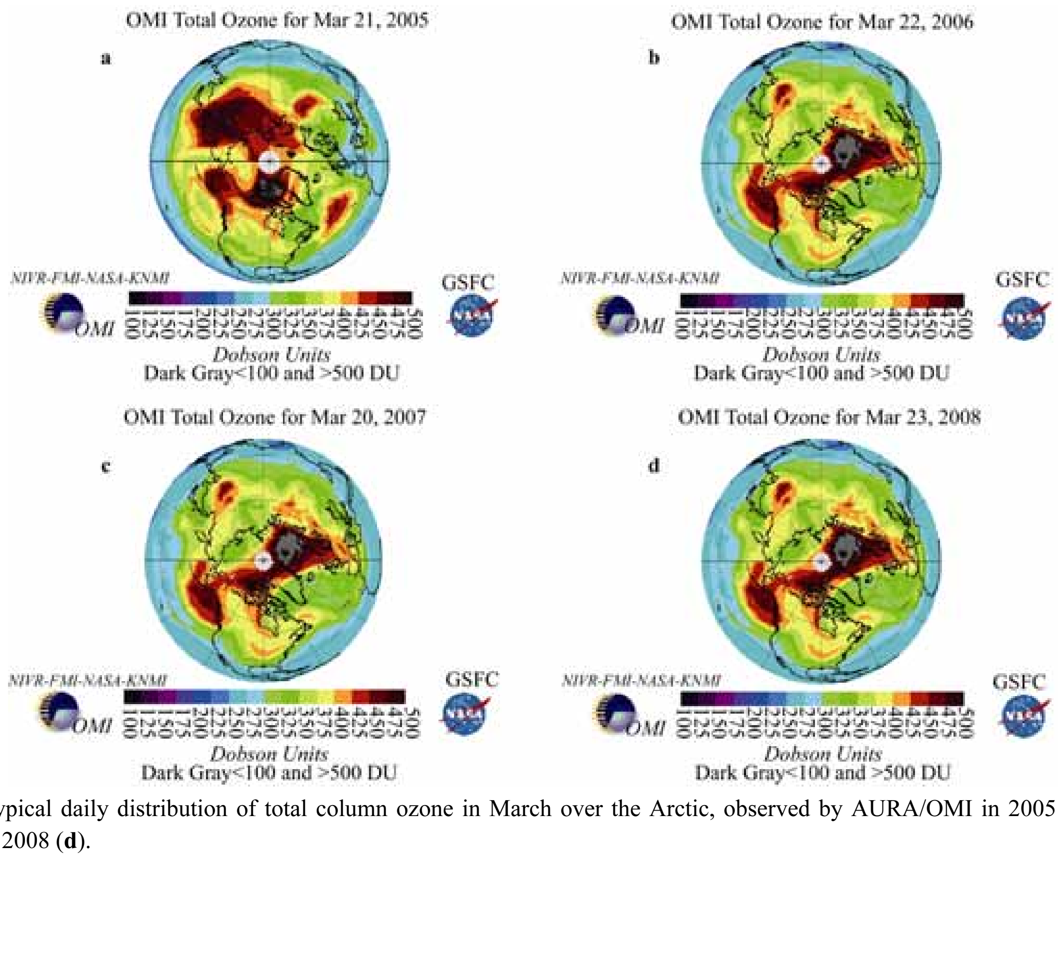

Figure 1 Typical daily distribution of total column ozone in March over the Arctic, observed by AURA/OMI in 2005 (**a**), 2006 (**b**), 2007 (**c**), and 2008 (**d**).

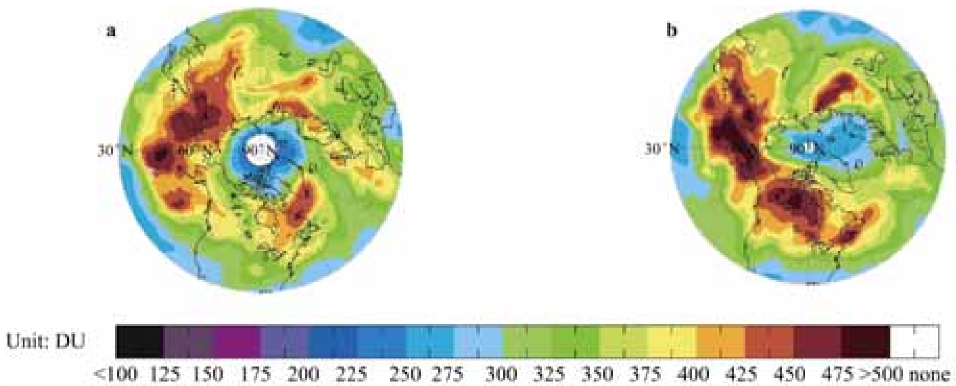

Figure 2 Daily distribution of total column ozone over the Arctic, observed by FY-3A/TOU on 14 March 2011 (**a**), and 26 March 2011 (**b**).

Arctic on 14 March and 26 March 2011, as observed by FY-3A/TOU. Contour analysis based on FY-3A/TOU and AURA/OMI ozone data shows that the smallest value of total ozone on March 14 near the central Arctic declined below 240 DU (Figure 3). The monthly mean total column ozone over the Arctic also shows severe ozone loss in March. Figure 4 shows a comparison between March means of total ozone in 2010 and 2011.

2.2 Relationship between ozone loss and polar vortex

It is understood that stratospheric ozone loss is caused by anthropogenic release of halogen compounds. Ozone depletion substances including chlorine are activated by heterogeneous chemistry involving polar stratospheric clouds (PSCs), followed by catalytic ozone destruction[20-21]. This process only occurs under certain meteorological conditions, such as an extremely cold polar vortex[22]. Figure 5 shows a composite of FY-3A/TOU total column ozone and temperature distribution over the Arctic on 26 March 2011, at 50 hPa pressure level. It is clear from Figure 5 that low ozone is closely related to the lower stratospheric polar vortex. Over the past 33 years, total ozone values over the Arctic showed a remarkable decreasing trend from 1979 to

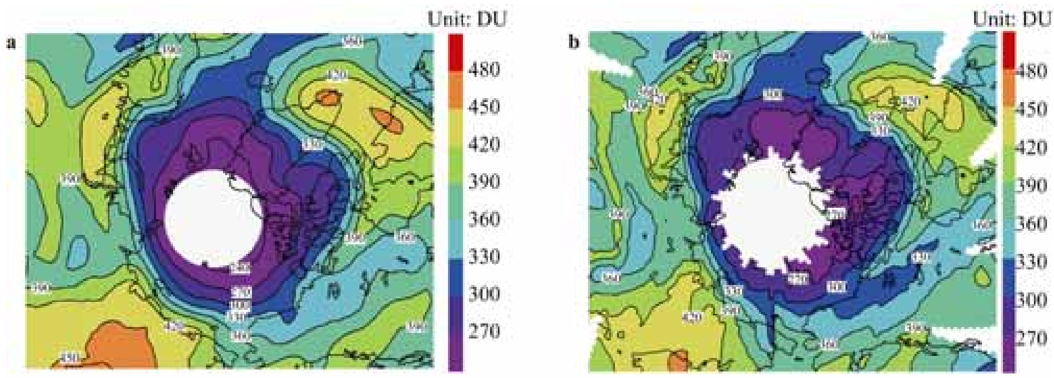

Figure 3 Contours of total column ozone in the Arctic from TOU (**a**), and OMI (**b**), on 4 March 2011.

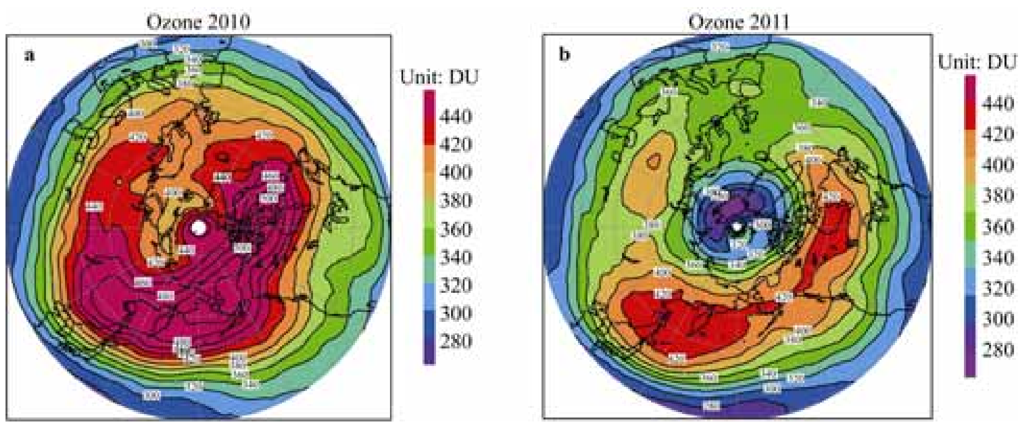

Figure 4 March mean values of total column ozone from FY-3A/TOU, in 2010 (**a**), and 2011 (**b**).

1997; after 1998, they recovered the level of the late 1980s. March 1997 and March 2011 had the lowest levels on record for the past 33 years of satellite observations. Variation of Arctic ozone is consistent with that of the Arctic polar vortex, which is represented by monthly mean temperatures at the 50 hPa pressure level (Figure 6). This figure shows March means of total column ozone and temperature at 50 hPa, from 63°N to 90°N for the past 33 years. The latitude band is used to avoid contamination of air masses from mid latitudes[22].

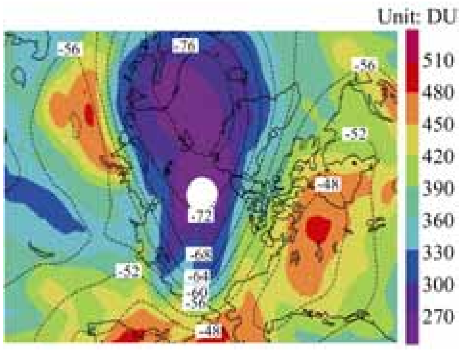

Figure 5 Composite of FY-3A/TOU total column ozone (colors) and temperature distribution (dashed lines) at 50 hPa over the Arctic, 26 March 2011.

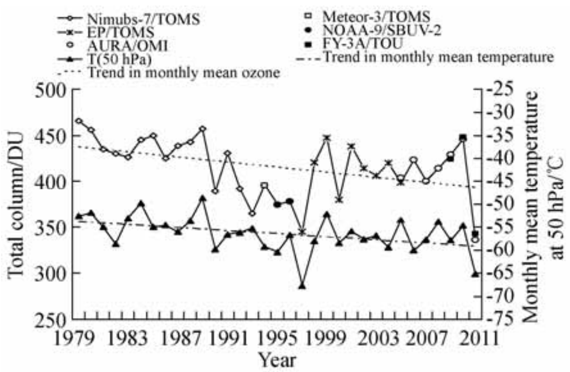

Figure 6 March mean values of total column ozone and temperature at 50 hPa, from 63°N to 90°N over the past 33 years.

2.3 Comparison of Arctic ozone loss between 1997 and 2011

Both 2011 and 1997 Arctic springs were characterized by anomalously strong and long-lasting stratospheric polar vortexes, which serve as barriers to ozone transport from lower to higher latitude regions. For the past 33 years, variation of spring Arctic ozone has been consistent with that of polar vortexes. However, it is difficult to estimate chemical ozone loss since it can be confounded by other effects, such as horizontal transport. Manney et al.[11] analyzed the difference between the ozone losses of March 1997 and March 2011, based on chemical models and the ozone deficit method. They concluded that chemical ozone loss was more important in spring 2011 than in spring 1997. Ozone deficit is the difference between daily values and a reference that is minimally affected by chemical loss[11]. First, monthly mean values of total column ozone in March 2011 and 1997 are compared (Figures 7 and 4b). The distribution of total column ozone March means for 2011 and 1997 are similar. The averages of total ozone north of 75°N are less than 300 DU for 2011 and 1997, but the distribution of 2011 has more detail than that of 1997.

To compare spring Arctic ozone loss in 1997 and 2011, daily distributions of total column ozone over the Arctic and Northern Hemisphere are compared (Figure 8). Figure 8a shows daily distributions of total ozone in March 2011 and 1997 over the area between 63°N and 90°N. Figure 8b shows corresponding distributions for the Northern Hemisphere. All ozone data in Figure 8 are from measurements of EP/TOMS (1997) and FY-3A/TOU (2011). In Figure 8a, patterns of daily variation of low ozone for 1997 and 2011 are similar. Both have decreasing trends during the first half of March and increasing trends during the second half. The only difference is that in 2011, daily mean ozone in the Northern Hemisphere showed a sudden decre-

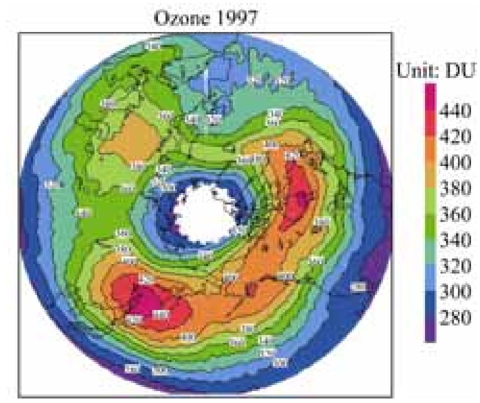

Figure 7 March mean values of total column ozone from EP/TOMS, for March 1997.

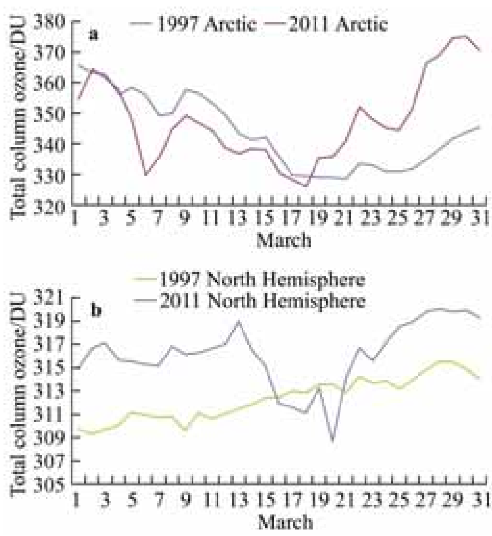

Figure 8 Comparisons of daily total column ozone observed by FY-3A/TOU in March 1997 and 2011, for 63°N to 90°N (**a**), and for Northern Hemisphere (**b**).

ase in mid March; there was no such sudden change in 1997 (Figure 8b).

3 Summary

Stratospheric ozone is of great importance, because it protects life on earth from harmful solar UV radiation. It is also important in climate change. In this study, extremely low ozone in spring 2011 was observed by the FY-3A/TOU satellite, and was compared with a process in 1997. Low ozone in Arctic spring is closely related to the cold polar vortex, and thus has interannual variability. The only difference between the two years was that daily variation of March mean total ozone in the Northern Hemisphere in 2011 showed a sudden decrease in mid March.

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