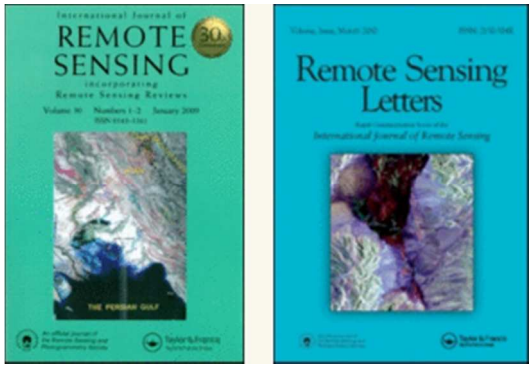

Ozone monitoring in Salekhard and Tomsk, western Siberia

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Ozone monitoring in Salekhard and Tomsk, western Siberia

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Abstract

The atmospheric ozone plays an important role in understanding of the processes occurring in the atmosphere and changes in the climate. This paper relates to the experimental results from balloon-borne research in the stratosphere for study of chemical and dynamical processes influencing the climate change and for validation of satellite observations. Total ozone observations in western Siberia were performed by Brewer MKIV S/N 049 spectrophotometer in Tomsk, and SAOZ UV-Vis spectrometer in Salekhard. We also use 2Z-ECC ozonesondes for ozone profile observations in winter/spring period at the Salekhard aerological station. During the winter/spring season of 2011, Arctic ozone in the 19-21 km altitude region was observed to be more than 70% less than typical values. In the winter/spring season of 2012, on the other hand, Arctic conditions were overall much warmer than in 2011, and no evidence of significant ozone loss was seen above the Asiatic regions of Russian Federation. The aim of the paper is to describe which and where these measurements were carried out and illustrate their performances by some examples of ozone data measured in western Siberia, Russia such as that which occurred in the winter/spring season of 2011.

1. Introduction

Monitoring and evaluation of the ozone layer are carried out using Brewer MKII spectrophotometer (Dorokhov, 1990; Kerr et al., 1990; Dorokhov et al., 1995), Brewer MKIV spectrophotometer (Belan et al., 2008, 2011; Ivlev et al., 2013), SAOZ UV-Vis spectrometer (Pommereau and Goutail, 1988; Goutail et al., 1994, 2005; Hendrick et al., 2011; Pommereau et al., 2013), ECC ozonesonde (Rex et al., 1997, 2006; Yushkov et al., 2002; Tsvetkova et al., 2002; Sugita et al., 2006; Tsvetkova et al., 2007), filter M-124 ozonometer (Bazhenov and Burlakov, 2011), and satellite instruments. For ozone monitoring in western Siberia we are using Brewer MKIV spectrophotometer S/N 049 for total ozone observations in Tomsk (56.5°N, 85.1°E). The SAOZ UV-Vis spectrometer is used for total ozone and NO2 measurements at Salekhard aerological station

(66.5°N, 66.7°E) in western Siberia. Ozone profile measurements are carried out at Salekhard station. Salekhard is currently the only place for regular vertical ozone profile observations in winter/spring conditions in Russian Federation. The network of ozone stations in the Arctic is shown in figure 1.

2. Instruments and settings

The Brewer spectrophotometer was developed in the 1970s and introduced into the global network in 1982 to measure total ozone in the atmosphere. The Brewer instrument derives total ozone column from UV measurements using two operational modes: observing either direct sunlight (DS) or zenith sky (ZS) scattered sunlight. Total ozone observations by the Brewer MKIV S/N 049 spectrophotometer in Tomsk have been conducted since 2003.

The SAOZ instrument is a UV-visible diode array spectrometer developed at the Service d'Aeronomie, CNRS, France in the late 80s. Ozone measurements in the visible Chappuis bands between 450-600 nm for the first time allow the continuous monitoring of the species throughout the year at the latitude of the polar circle, in all weather conditions. Data for the atmospheric content of O_3 and NO_2 measured by SAOZ spectrometers have been available at the NDACC database. The first Asiatic SAOZ station started operation at Zhigansk aerological station, eastern Siberia since 1991. The SAOZ spectrometer has been operating at Salekhard aerological station since 1998.

The ECC ozonesonde is a lightweight, balloon-borne instrument that is mated to a conventional meteorological radiosonde. It measures ozone and standard meteorological quantities such as pressure, temperature and humidity. The balloon will ascend to altitudes of about 30-35 km before it bursts. The heart of the ozonesonde is an electrochemical concentration cell that senses ozone as is reacts with a dilute solution of potassium iodide to produce a weak electrical current proportional to the ozone concentration of the sampled air. Ozone profile observations were carried out at the Yakutsk aerological station, eastern Siberia since December 1994 to 2006, and the Salekhard aerological station since January 1997 to the present time. It should be noted that the Salekhard station is the only place for ozone profile observations in Russian Federation at the present time.

3. Analysis

3.1. Brewer total ozone observation in the western Siberia.

Total ozone observed in the western Siberia in the middle of March 2011 was less than usual about 130-150 Dobson Unit (DU), and the negative ozone anomaly has been observed even in the first decade of April. Such a large and long-listed Arctic ozone loss was possible due to the significant denitrification in the Arctic stratosphere at abnormally low stratospheric temperature and formation of polar stratospheric clouds (Manney et al., 2011; Balis et al., 2011; Varotsos et al., 2012; Ivlev et al.,

2013). The level of total ozone over the territory of the Russian Federation in 2011 was significantly lower than that observed in the late 1970s, but above the minimum in the late 1990s. Spring time anomaly in high latitudes has been one of the most significant ozone anomalies in the Northern Hemisphere for the time more than half a century of observations. This is a record amount of ozone loss over the entire period of observations in the Arctic. The previous extreme low ozone (116 DU) was observed in winter/spring season of 2004/2005. The Arctic ozone loss 2011 was well observed by the Brewer, SAOZ and 2Z-ECC ozonesonde network at the polar regions of the Russian Federation.

The Brewer spectrophotometers were originally designed for total ozone measurements. In 2011 we have only one Brewer spectrophotometer in the Asiatic part of Russia, which was nearby the Arctic area where the Arctic ozone losses have been observed. The low total ozone was measured in Tomsk by Brewer MKIV S/N 049 spectrophotometer between in the first two weeks of April. In March-April 2011 a very low total ozone observations were carried out at Brewer stations in Scandinavia. The low ozone values were measured in Finland at Sodankylä station (67.4°N, 26.6°E). The Sodankylä total ozone measurements have been performed with a Brewer spectrophotometer since 1988. On March 9, 2011 this Brewer MKII S/N 037 instrument measured as low as 242 DU. The Brewer MKII spectrophotometer in Andøya, Norway (69.3°N, 16.0°E), operated by NILU and the University of Tromsø, observed the similar amount of total ozone values in the middle of March. Unusually low total ozone columns were measured from mid-March to first decade of April 2011 at all Arctic stations compared to the previous years. The low total ozone 259 DU was observed at the Sammit station (72.6°N, 38.5°W) in Greenland on March 28, 2011. The Brewer spectrophotometers were used in the Canadian stratospheric ozone and UV monitoring program, with 12 sites established in Canada that routinely collect and process data on a daily basis. The instruments measure total ozone and spectral UV irradiation (290-325 nm) every 10-20 minutes during the daytime. The Brewer spectrophotometers in the Northern Canada measured the total ozone values which were 20-25% below the climatic norm at the end of February to mid-March 2011.

The Brewer instrument at Tomsk station in the western Siberia has good quality with high precision ground-based total ozone for the Asiatic part of Russia. Figure 2 shows the time series of total ozone observed in Tomsk from 2003 to 2012 by the Brewer MKIV S/N 049 spectrophotometer. The result of the Brewer total ozone measurements in Tomsk in 2011 are shown in Figure 3. The Brewer Data Management System (BDMS) is located with the World Ozone and Ultraviolet Radiation Data Centre (WOUDC) and both are located in Toronto and operated by Environment Canada staff. The BDMS acts as the permanent archive of Canadian Brewer data. Although the main focus of the BDMS initially was for Canadian data only, this system is now available to the international Brewer community. The data of the Brewer spectrophotometer total ozone measurements in Russia are

available from the WOUDC database http://www.woudc.org/.

3.2. SAOZ spectrometers in Siberia.

An unprecedented depletion of Earth's protective ozone layer above the Arctic in the 2010/2011 Arctic winter and spring has been documented (Manney et al., 2011), caused by an unusually prolonged period of low temperatures in the stratosphere. The unusually large Arctic ozone loss in 2011 appears to resulting from an extreme meteorological event and there is no indication of possible strengthening related to climate change. Unusually low total ozone columns were measured from mid-March to late March and first decade of April 2011 compared to the previous years (Pommereau et al., 2013). In collaboration with the French CNRS within the frame of the Network for the Detection of Atmospheric Composition Change (NDACC) two SAOZ instruments are operating at the polar circle where those instruments allow year round observations: in Zhigansk in eastern Siberia operating since 1991 and in Salekhard in western Siberia since 1998. Altogether these instruments cover a vast polar region in the Northern Hemisphere allowing the monitoring of amplitude of Arctic ozone destruction each year. As an example those instruments significantly contributed to the quantification of the unprecedented ozone loss in 2011 caused by a combination of long lasting denoxified vortex resulting in a record daily loss rate never seen before in the Arctic. Indeed as one may see in the WOUDC ozone mapping, the ozone depleted polar vortex passed over Salekhard and Zhigansk in late March - early April 2011 where losses of about 40% were observed above the two stations located at the northern Polar Circle. The total ozone reduction in the vortex conditions was 38 % +/– 3% or 165 DU in 2011 with the loss rate 0.2% per day until mid-February and 0.8% per day between February 20 and March 20, 2011. The total ozone was as low as 235 DU at Zhigansk on March 23, 2011 and 242 DU in Salekhard on March 31, 2011. The total ozone reduction in the vortex conditions in 2012 was about 14 % +/– 4% or 60 DU and the loss rate 0.35% per day between end of December and early February, 2012. The low total ozone columns for some days in January-April 2011 at Salekhard station are shown in Fig. 4, when the polar vortex was located above the station. Figure 5 shows the WOUDC total ozone mapping on 31 March 2011 when the low ozone vortex passed over Salekhard.

The measurements of total ozone and NO_2 by SAOZ instruments version V-1024 in western and eastern Siberia, providing data all year round, cover a vast polar regions in the Northern Hemisphere. The data of total ozone and NO_2 observations by the SAOZ UV-Vis spectrometers in Siberia are submitted and presented at the World SAOZ database in France http://saoz.obs.uvsq.fr/SAOZ-RT.html and at the NDACC database http://www.ndsc.ncep.noaa.gov/. We plan to try some ozonesonde flights at Tomsk station in March 2014.

3.3. Ozonesounding in Siberia.

At the Yakutsk aerological stations coordinated ozonesonde flights were started in late 1994. At the same time coordinated measurements of vertical ozone distribution were made by European scientists at 30 stations of the Northern Hemisphere in the frame of international program on investigation of mechanisms of ozone layer depletion. Ozonesonde flights were performed in a manner to monitor the changes of ozone concentration in the same air masses. For this purpose the local time and date of ozonesonde launches were determined using the daily forecasts of air mass trajectories. Using the data of balloon ozonesounding at Yakutsk quantitative estimation of ozone depletion in the lower stratosphere were made for spring months of 1995-1997 inside and outside the polar vortex. Comparison of given estimations of daily ozone variations with theoretical rates of photochemical ozone reduction make it possible to conclude about chemical ozone depletion mechanism during winter/spring months inside the polar vortex at the territory of eastern Siberia.

It is well established that extensive depletion of ozone, initiated by heterogeneous reactions on polar stratospheric clouds can occur in both the Arctic and Antarctic lower stratosphere. Moreover, it has been shown that ozone loss rates in the Arctic region in recent years reached values comparable to those over the Antarctic. But until now the accumulated ozone losses over the Arctic have been much smaller than those over the Antarctic, mainly because the period of Arctic ozone loss has not persisted far into springtime. If the apparent cooling trend in the Arctic lower stratosphere is real, more dramatic ozone losses may occur in the future (Manney et al., 1994, 1995; von der Gathen et al., 1995; Tsvetkova et al., 1997; Rex et al., 1997, 1998; Solomon, 1999). The model calculations of the rate of chemical ozone loss in the lower stratosphere using the chemical transport model have proved to be underestimated relative to the experimental observation in eastern Siberia within the zone of action of the circumpolar stratospheric vortex. This discrepancy may have resulted from the fact that the process of intensive ozone depletion during the spring months due to the formation of polar stratospheric clouds of orographic nature not only over Scandinavian mountains, but also over the Urals, has not been taken into account in the model concerned. To verify this hypothesis, balloon-borne measurements were carried out of ozone vertical distribution at Salekhard station located on the lee side at air masses transport in the atmosphere with westerly winds. The measurements at Yakutsk and Salekhard stations were performed during 1996/1997 season, i.e. from the beginning of the formation of the polar stratospheric cyclone and during the period of its intensive development and destruction in winter and spring. The measurements of the vertical ozone distribution were coordinated with balloon-borne measurements conducted at other European stations as to help trace ozone changes within the same air masses of the Northern Hemisphere. Balloon-borne ozone data and weather data on temperature and potential vorticity fields have been analyzed to show that during the spring months of

1998 and 1999 in contrast to the same period of 1995 and 1996, no intense processes of the chemical loss of stratospheric ozone had been observed over the polar latitudes of western and eastern Siberia. Such an interannual variability of ozone amount in the lower stratosphere, within the zone of action of the northern circumpolar vortex, is due to the weather conditions of its formation.

During the winter/spring season of 2011 the observed ozone decrease exceeded 70% within the 19-21 km altitude range. For the Arctic winter/spring 2012, the stratospheric temperature is quite high and there is no significant ozone loss above Salekhard station. Ozonesonde data from the Salekhard station during the Arctic winter/spring season of 2010/2011 and 2011/2012 are available from the NDACC database. Chemical ozone destruction occurs over the Arctic and Antarctic regions in local winter/spring. In the Antarctic, essentially complete removal of lower-stratospheric ozone currently results in an ozone hole every year, whereas in the Arctic, ozone loss is highly variable from year to year and has until now been much more limited. We study the Arctic ozone losses using the results of the ozonesonde observations in the Arctic during the Match campaigns in 1994-2012. The two main aims of Match campaigns are to measure the chemical ozone loss in the Arctic polar regions, and to check our understanding of the underlying processes. The idea of Match campaign is to probe, i.e. to determine the ozone content of, a lot of air parcels twice during their way through the atmosphere. This is achieved by coordinating the soundings roughly in the following way. The trajectories (transport paths) of air masses, which had been measured by ozonesondes previously, are analyzed and forecasted by meteorologists at the Freie Universität Berlin (FU Berlin). These trajectories are checked for cases when such an air mass reaches the vicinity of one of the participating measuring sites (ozonesonde station) within 10 days. The staff at the ozonesonde station gets informed and is asked to launch an ozonesonde in order to examine the same air mass for a second time. A decrease in the ozone concentration within the time period of the two sonde flights can then be attributed to chemical ozone depletion. Due to the great number of sonde pairs, statistically significant ozone loss rates can be determined.

Some results of ozonesounding at the Salekhard aerological station in polar vortex conditions in March-April 2011 and February 2012 are shown in Figure 6. The total 150 ozonesondes were launched at Yakutsk aerological station during the winter/spring season of 1994-2006 and 250 ozonesondes, version 2Z-ECC, were used for vertical ozone profile observations in Salekhard station. The data of the Salekhard ozonesonde measurements in 2005-2012 are available from the NDACC database: ftp://ftp.cpc.ncep.noaa.gov/ndacc/station/salekhar/ames/o3sonde/. In winter-spring season of 2013/2014 we plan to start the ozonesounding at Bolshevik Island (78.6°N, 102.5°E) in the central Arctic.

4. Conclusions

The Brewer spectrophotometer detected anomalously low total ozone at Tomsk station in March-April 2011. The January-March 2012 total ozone observations from these Brewer spectrophotometers in Russia did not show any episodes of unusually low total ozone. The measurements of total ozone and NO_2 by SAOZ instruments in Russia provide data all year round. The unprecedented depletion of Earth's protective ozone layer above the Arctic in winter and spring 2011, caused by an unusually prolonged period of low temperatures in the stratosphere, is reflected in the measurements presented here. In January-March 2012, SAOZ observations in Russia did not show any evidence of unusually low Arctic ozone. During the winter/spring season in 2011, Arctic ozone in the 19–21 km altitude region was observed to be more than 70% less than typical values. In the winter/spring season of 2012, on the other hand, Arctic conditions were overall much warmer than in 2011, and no evidence of significant ozone loss was seen above the Salekhard area.

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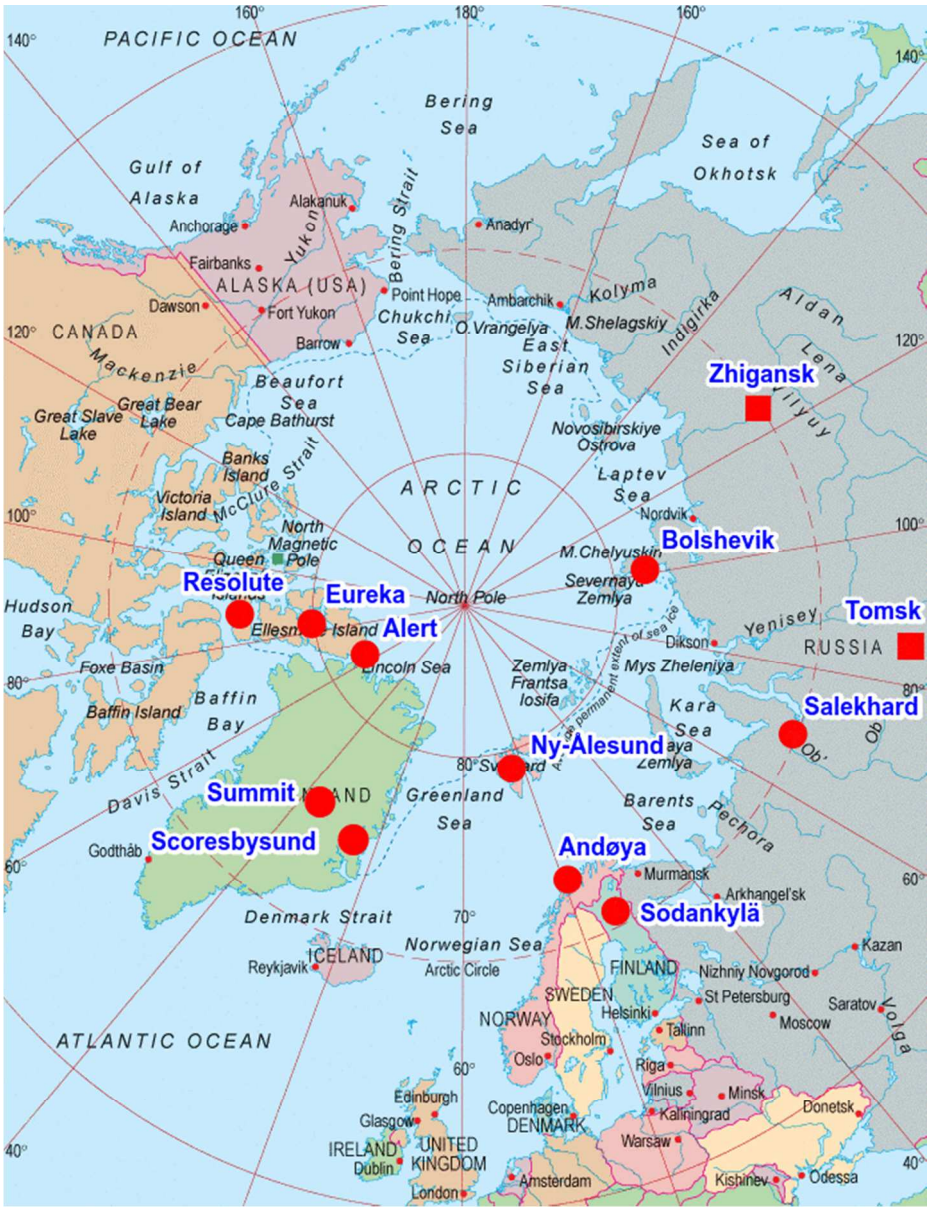

Figure 1. The network of ozone stations in the Arctic.
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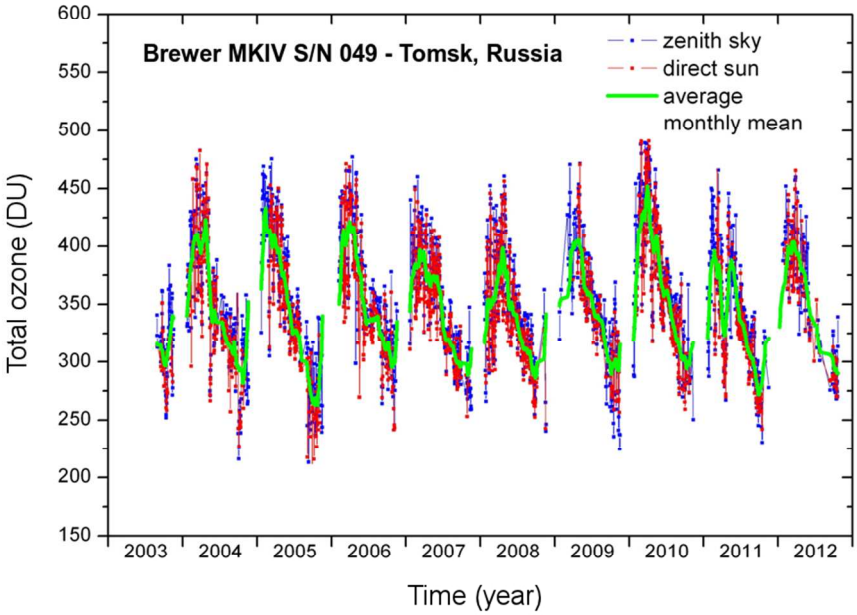

Figure 2. The result of the Brewer MKIV S/N 049 total ozone measurements in Tomsk in 2003-2012.

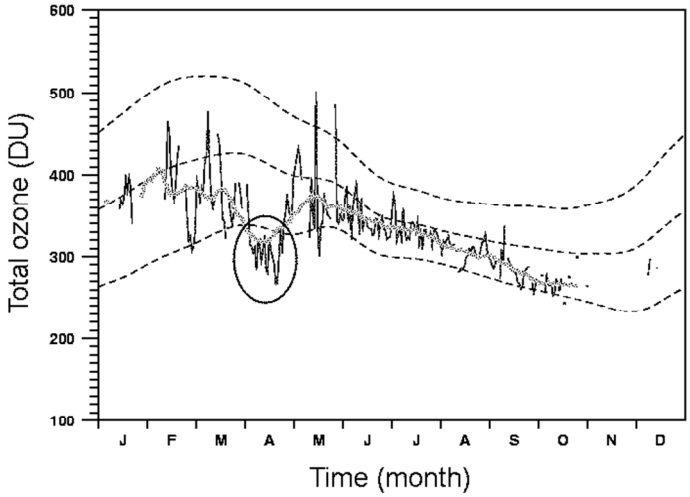

Figure 3. The results of the Brewer MKIV S/N 049 total ozone measurements in Tomsk in 2011.

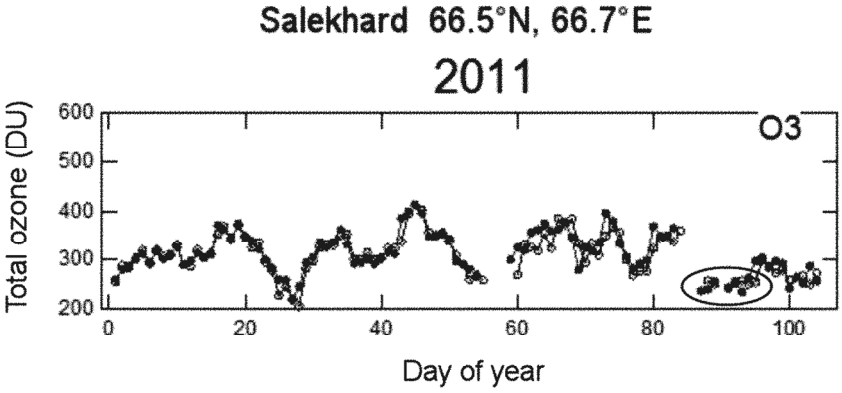

Figure 4. The SAOZ spectrometer total ozone real-time data at the Salekhard aerological station in January-April 2011.

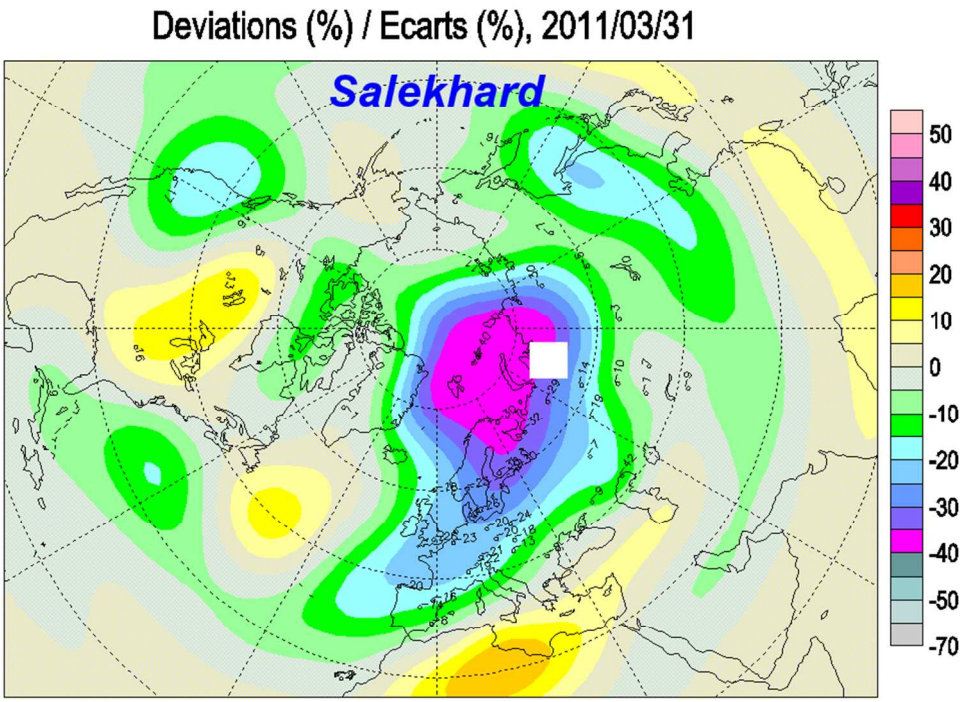

Figure 5. The total ozone mapping on 31 March 2011 when the low ozone vortex passed over Salekhard. The initial plot is from the WOUDC database http://www.woudc.org/data e.html.
352x256mm (72 x 72 DPI)

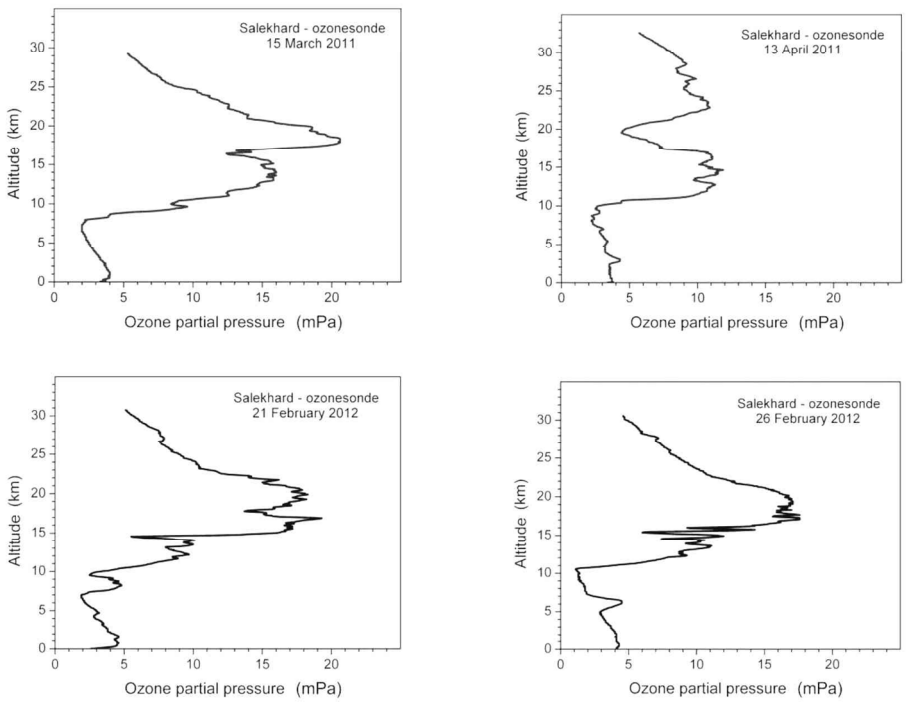

Figure 6. Ozone profiles from 2Z-ECC sonde in Salekhard in the polar vortex in March-April 2011 and February 2012.
152x118mm (300 x 300 DPI)