Ozonesonde measurement from the Amundsen-Scott Station at the South Pole on 22 October. The ozone profile is shown on the left and the temperature profile on the right. The station is operated by the US National Oceanic and Atmospheric Administration (NOAA). One can see the large ozone "bite-out" from 14-20 km altitude. Higher up, around 23 km, there is a layer of ozone rich air causing total ozone to reach a value of 271 DU. The 12-20km partial ozone column is 38 DU, which is typical of ozone hole conditions. One can also see that stratospheric temperatures are significantly warmer than average. The horizontal bars show the 1σ standard deviation for the 1991-2012 time period using data up to three days earlier or later than the date shown.
Executive Summary

The area of the ozone hole reached a maximum of 24.0 million km² on 16 September according to OMI data from NASA. This is more than in 2012 and 2010, but less than in 2011. Data from KNMI, based on GOME-2, show that the ozone hole area averaged over the ten last days of September was 20.9 million km². This is more than in 2012 but less than in 2010 and 2011. The ozone mass deficit averaged over the same period was 19.59 megatonnes. This is more than in 2010 and 2012 but less than in 2011. The results are similar for the average ozone hole area and ozone mass deficit for the time period from 7 September to 13 October. If one considers the last twenty ozone holes (1994 until present), fifteen ozone holes have been larger/deeper than in 2013 and only four have been smaller (2002, 2004, 2010, 2012). Average ozone hole area and mass deficit for other time periods will be reported in later issues as they become available.

The daily minimum temperatures at the 50 hPa level were below the 1979-2012 average from early April until mid October. From mid June until early September the minimum temperature was well below the long term mean. From 9 to 13 August the minimum temperature was below the 1979-2012 minimum for those dates. The same also happened on 14 September. From early October the minimum temperature has increased and is above the long term mean at the middle of October.

The average temperature over the 60-90°S region was below the long-term (1979-2012) mean from April until late August. On 11 August it dipped below the 1979-2012 minimum. From mid August until mid July the NAT volume was close to or above the 1979-2012 average. From mid July until mid August the NAT volume was somewhat smaller than the long-term mean. After that it has been oscillating around the long-term mean. The NAT volume has been significantly larger in 2013 than in 2010 and 2012 and it was similar to the volume seen in 2011 until late August. During September and October it has been significantly smaller than in 2011, but quite close to the long term mean.

During May, June and most of July the 45-day mean of the heat flux was lower than or close to the 1979-2012 average. In August the heat flux oscillated around the long term mean. One can see that the heat flux was smaller (closer to zero) in 2013 than in the most recent years on most days until mid August. In September and so far in October the heat flux has been larger than the long-term average, indicating that the vortex has been more disturbed than usual. At the 46.4 hPa level [altitude of ~18.5-19.5 km] hydrochloric acid (HCl) has reformed after having been entirely depleted earlier in the season. The entire vortex is now filled with 2-3 ppb of HCl. There is no ClO (active chlorine) left in the polar vortex, which means that ozone depletion has come to a stop. However, the vortex is still severely depleted in ozone with large regions containing less than 0.2 ppm of ozone at 46.4 hPa.

Measurements with ground based instruments and with balloon sondes show clear signs of ozone depletion at most sites. In this issue data are reported from the following stations: Arrival Heights, Belgrano, Davis, Dôme Concordia, Dumont d’Urville, Halley, Macquarie Island, Marambio, Mirny, Neumayer, Novolazarevskaya, Rio Gallegos, Rothera, South Pole, Syowa, Ushuaia, Vernadsky, Vostok, and Zhong Shan.

Since the active chlorine has disappeared there will be no further ozone depletion. The development of the ozone hole will from now on depend on the dynamics of the polar vortex. Forecasts indicate that the vortex will extend relatively far north into the Indian Ocean at the end of October and the beginning of November.

WMO and the scientific community will use ozone observations from the ground, from balloons and from satellites together with meteorological data and model results to keep a close eye on the development during the coming weeks and months.
**Introduction**

The meteorological conditions in the Antarctic stratosphere found during the austral winter (June-August) set the stage for the annually recurring ozone hole. Low temperatures lead to the formation of clouds in the stratosphere, so-called polar stratospheric clouds (PSCs).

The amount of water vapour in the stratosphere is very low, only 5 out of one million air molecules are water molecules. This means that under normal conditions there are no clouds in the stratosphere. However, when the temperature drops below -78°C, clouds that consist of a mixture of water and nitric acid start to form. These clouds are called PSCs of type I. On the surface of particles in the cloud, chemical reactions occur that transform passive and innocuous halogen compounds (e.g. HCl and HBr) into so-called active chlorine and bromine species (e.g. ClO and BrO). These active forms of chlorine and bromine cause rapid ozone loss in sunlit conditions through catalytic cycles where one molecule of ClO can destroy thousands of ozone molecules before it is passivated through the reaction with nitrogen dioxide (NO₂).

When temperatures drop below -85°C, clouds that consist of pure water ice will form. These ice clouds are called PSCs of type II. Particles in both cloud types can grow so large that they no longer float in the air but fall out of the stratosphere. In doing so they bring nitric acid with them. Nitric acid is a reservoir that liberates NO₂ under sunlit conditions. If NO₂ is physically removed from the stratosphere (a process called denitrification), active chlorine and bromine can destroy many more ozone molecules before they are passivated. The formation of ice clouds will lead to more severe ozone loss than that caused by PSC type I alone since halogen species are more effectively activated on the surfaces of the larger ice particles.

The Antarctic polar vortex is a large low-pressure system where high velocity winds [polar jet] in the stratosphere circle the Antarctic continent. The region poleward of the polar jet includes the lowest temperatures and the largest ozone losses that occur anywhere in the world. During early August, information on meteorological parameters and measurements from ground stations, balloon sondes and satellites of ozone and other constituents can provide some insight into the development of the polar vortex and hence the ozone hole later in the season.

The situation with annually recurring Antarctic ozone holes is expected to continue as long as the stratosphere contains an excess of ozone depleting substances. As stated in the Executive Summary of the 2010 edition of the WMO/UNEP Scientific Assessment of Ozone Depletion, severe Antarctic ozone holes are expected to form during the next couple of decades.

For more information on the Antarctic ozone hole and ozone loss in general the reader is referred to the WMO ozone web page: [http://www.wmo.int/pages/prog/arep/gaw/ozone/index.html](http://www.wmo.int/pages/prog/arep/gaw/ozone/index.html)
**Meteorological conditions**

**Minimum temperatures**

Meteorological data from the National Center for Environmental Prediction (NCEP) in Maryland, USA, show that stratospheric temperatures over Antarctica were below the PSC type I threshold of -78°C from 8 May and below the PSC type II threshold of -85°C from 30 May, as shown in Figure 2. This figure also shows that the daily minimum temperatures at the 50 hPa level were below the 1979-2012 average from early April until mid October. From mid June until early September the minimum temperature was well below the long term mean. From 9 to 13 August the minimum temperature was below the 1979-2012 minimum for those dates. The same also happened on 14 September. From early October the minimum temperature has increased and is above the long term mean at the middle of October.

![Figure 2. Time series of daily minimum temperatures at the 50 hPa isobaric level south of 50°S. The red curve shows 2013 (until 18 October). The blue line shows 2012, the green line 2011 and the orange line 2010. The average of the 1979-2012 period is shown for comparison in grey. The thin black lines represent the highest and lowest daily minimum temperatures in the 1979-2012 time period. The light blue-green shaded area represents the 10th and 90th percentile values and the dark blue-green shaded area the 30th and 70th percentiles. The two horizontal green lines at 195 and 188 K show the thresholds for formation of PSCs of type I and type II, respectively. The plot is made at WMO based on data downloaded from the OzoneWatch web site at NASA, which are based on data from NOAA/NCEP.](image-url)
Mean temperatures

Figure 3 (left panel) shows temperatures averaged over the 60-90°S region at 50 hPa. It can be seen from the figure that the average temperature was below the long-term (1979-2012) mean from April until late August. On 11 August it dipped below the 1979-2012 minimum. From mid August the mean temperature has increased somewhat and since mid September it has been above the long-term mean. In mid October it is approx. 5 K above the mean.

At 10 hPa, the 60-90°S mean temperature was below or near the long term mean until the end of June. In late June and early July it was near the long-term mean. After that the mean temperature cooled down before starting on a gradual rise. In August, September and October it has oscillated between the long-term mean and temperatures about 10 K above the mean.

The mean temperature over the 55-75°S region has behaved quite similarly to the temperature averaged over the 60-90°S region at all levels from 10 to 150 hPa.

Figure 3. Time series of temperature averaged over the region south of 60°S at the 50 hPa level (left) and at 10 hPa (right). The red curve shows 2013 (until 18 October). The blue, green and orange curves represent 2012, 2011 and 2010, respectively. The average of the 1979-2012 period is shown for comparison in grey. The two thin black lines show the maximum and minimum average temperature for during the 1979-2012 time period for each date. The light blue-green shaded area represents the 10th and 90th percentile values and the dark blue-green shaded area the 30th and 70th percentiles. The plot is made at WMO based on data downloaded from the Ozonewatch web site at NASA, which are based on data from NOAA/NCEP.
PSC Area
Since 21 June, temperatures low enough for nitric acid trihydrate (NAT or PSC type I) formation have covered an area of more than 20 million square kilometres at the 460K isentropic level (Figure 4). Since the onset of NAT temperatures in early May the NAT area has been close to or above the long-term average. The NAT area reached a peak of 26.3 million km² on 19 July. Since early June 2013 the NAT area has been close to or a bit smaller than in 2011 but larger than in 2010 and 2012 on most days. As of 18 October the NAT area is essentially zero, which is also the case for the long term average.

Figure 4. Time series of the area of the region where temperatures are low enough for the formation of nitric acid trihydrate (NAT or PSCs of type I) at the 460K isentropic level. The red curve shows 2013 (until 18 October). The blue, green and orange curves represent 2012, 2011 and 2010, respectively. The average of the 1979-2012 period is shown for comparison in grey. The two thin black lines show the maximum and minimum PSC area during the 1979-2012 time period for each date. The light blue-green shaded area represents the 10th and 90th percentile values and the dark blue-green shaded area the 30th and 70th percentiles. The plot is made at WMO based on data downloaded from the Ozonewatch web site at NASA, which are based on data from NOAA/NCEP.
PSC Volume

Rather than looking at the NAT area at one discrete level of the atmosphere it makes more sense to look at the volume of air with temperatures low enough for NAT formation. The so-called NAT volume is derived by integrating the NAT areas over a range of input levels. The daily progression of the NAT volume in 2013 is shown in Figure 5 in comparison to recent winters and long-term statistics. Since the onset of PSCs in early May until mid July the NAT volume was close to or above the 1979-2012 average. From mid July until mid August the NAT volume was somewhat smaller than the long-term mean. After that it has been oscillating around the long-term mean. The NAT volume has been significantly larger in 2013 than in 2010 and 2012 and it was similar to the volume seen in 2011 until late August. During September and October it has been significantly smaller than in 2011, but quite close to the long term mean.

The area or volume with temperatures low enough for the existence of PSCs is directly linked to the amount of ozone loss that will occur later in the season, but the degree of ozone loss depends also on other factors, such as the amount of water vapour and HNO$_3$. In the previous issue of the Bulletin it was argued that the near-average magnitude of the NAT area and the NAT volume in 2013 gave reason to foresee that ozone depletion later in the season would be close to average in comparison to recent years. A forecast based solely on the temperature conditions and hence NAT area and NAT volume indicated that the amount of ozone loss in 2013 would be larger than in 2010 and 2012, and probably similar to that experienced in 2011. The first ozone hole statistics, covering the 21-30 September and 7 September - 13 October time periods mostly confirms this prediction as described on page 72.

Figure 5. Time series of the volume of the region where temperatures are low enough for the formation of nitric acid trihydrate (NAT or PSCs of type I). The red curve shows 2013 (until 18 October). The blue, green and orange curves represent 2012, 2011 and 2010, respectively. The average of the 1979-2012 period is shown for comparison in grey. The two thin black lines show the maximum and minimum PSC area during the 1979-2012 time period for each date. The light blue-green shaded area represents the 10th and 90th percentile values and the dark blue-green shaded area the 30th and 70th percentiles. The plot is made at WMO based on data downloaded from the Ozonewatch website at NASA, which are based on data from NOAA/NCEP.
Vortex stability

The longitudinally averaged heat flux between 45°S and 75°S is an indication of how much the stratosphere is disturbed. During May, June and most of July the 45-day mean of the heat flux was lower than or close to the 1979-2012 average. In August the heat flux oscillated around the long term mean. The development of the heat flux is shown in Figure 6. One can see that the heat flux was smaller (closer to zero) in 2013 than in the most recent years on most days until mid August. In September and so far in October the heat flux has been larger than the long-term average, indicating that the vortex has been more disturbed than usual.
Ozone observations

Satellite observations

The sun is now back all over Antarctica and minimum ozone columns were reached at the end of September. Figure 7 shows minimum ozone columns as measured by the GOME-2 instrument on board MetOp in comparison with data for recent years back to 2006 (SCIAMACHY and GOME-2). In late October the minimum columns are above average of the last seven years for this time of the year. Minimum ozone columns are now around 150 DU. The minimum reached around 26 September was just below 120 DU. OMI data from NASA reached the minimum on 29 September with 116 DU.

Figure 8 shows satellite maps from OMI for 24 October for the years 2006 - 2013. One can see that ozone depletion on 24 October 2013 covers an area similar to that in 2012 and significantly less than in the other years shown here.

Figure 7. Daily minimum total ozone columns in the Southern Hemisphere as observed by GOME-2, and in the past by SCIAMACHY. The black dots show the GOME-2 observations for 2013 as of 24 October. The data now show minimum ozone columns around 160 DU. The forecast for the next few days show minimum ozone columns around 160DU or a bit below (open circles on the plot). The figure is adapted from a plot provided by the Netherlands Meteorological Institute (KNMI).
Figure 8. Total ozone maps for 24 October 2006, 2007, 2008, 2009, 2010, 2011, 2012 and 2013 based on data from OMI on board the AURA satellite. The data are processed and mapped at KNMI.
Ozone observations

Ground-based and balloon observations

Ozone depletion peaked around 1 October and the Antarctic ozone layer is slowly recovering. Many stations still report substantial ozone loss.

In this issue there is data from Arrival Heights, Belgrano, Davis, Dôme Concordia, Dumont d’Urville, Halley, Macquarie Island, Marambio, Mirny, Neumayer, Novolazarevskaya, Río Gallegos, Rothera, South Pole, Syowa, Ushuaia, Vernadsky, Vostok, and Zhong Shan. This constitutes all the stations carrying out ozone measurements in Antarctica, as well as a few outside Antarctica. The map on the next page shows the location of the stations that provide data during the ozone hole season.

The table to the right shows the lowest ozone values observed so far at the individual stations, measured by remote sensing (Dobson, Brewer, SAOZ or filter instruments) or in situ by ozonesondes. The number of days with total ozone equal to or below the 220 DU threshold starting 1 August (or later depending on when the measurements start up after the polar night) is also indicated for each station. The number of days with total ozone equal to or below 220 DU is calculated from ground based measurements (Dobson, Brewer, SAOZ) if available, otherwise from satellite overpass data.

### Station Statistics

<table>
<thead>
<tr>
<th>Station name</th>
<th>Lowest Total Ozone (Dobson, Brewer, SAOZ, filter)</th>
<th>Lowest Total Ozone from Sonde</th>
<th>Lowest 12-20 km partial column</th>
<th># of days with total ozone below 220 DU</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arrival Heights</td>
<td>151 DU (16.9 and 19.9)</td>
<td></td>
<td></td>
<td>26 [24.8 to 20.10]</td>
</tr>
<tr>
<td>Belgrano</td>
<td>138 DU 1 (2.10)</td>
<td>131 DU (2.10)</td>
<td>22 DU (2.10)</td>
<td>47 [1.8 to 23.10]</td>
</tr>
<tr>
<td>Davis</td>
<td>185 DU 2 (26.9)</td>
<td>190 DU (24.9)</td>
<td>37 DU (8.10)</td>
<td>6 [1.8 to 21.10]</td>
</tr>
<tr>
<td>Dôme C</td>
<td>170 DU (8.8)</td>
<td></td>
<td></td>
<td>15 (2.8 to 22.10)</td>
</tr>
<tr>
<td>Dumont d’Urville</td>
<td>228 DU (6.9)</td>
<td></td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>Halley</td>
<td>127 DU (23.9) and 106 DU 3 (23.9)</td>
<td></td>
<td></td>
<td>69 [3.8 to 20.10]</td>
</tr>
<tr>
<td>Marambio</td>
<td>148 DU (13.10)</td>
<td>144 DU (17.10)</td>
<td>27 DU (12.10)</td>
<td>50 [10.8 to 22.10]</td>
</tr>
<tr>
<td>Mirny</td>
<td>213 DU (30.8)</td>
<td></td>
<td></td>
<td>3 [1.8 to 20.10]</td>
</tr>
<tr>
<td>Neumayer</td>
<td>153 DU 4 (22.9)</td>
<td>154 DU (23.9)</td>
<td>19 DU (3.10)</td>
<td>47 [2.8 to 20.10]</td>
</tr>
<tr>
<td>Novolazarevskaya</td>
<td>157 DU (6.10)</td>
<td></td>
<td></td>
<td>45 [15.8 to 20.10]</td>
</tr>
<tr>
<td>Rothera</td>
<td>124 DU 6 (29.9)</td>
<td></td>
<td></td>
<td>60 [1.8 to 20.10]</td>
</tr>
<tr>
<td>South Pole</td>
<td>135 DU 7 (30.9)</td>
<td>124 DU (29.9)</td>
<td>24 DU (29.9)</td>
<td>27 2, 3 [24.9 to 21.10]</td>
</tr>
<tr>
<td>Syowa</td>
<td>161 DU (25.9)</td>
<td>176 DU (23.9)</td>
<td>36 DU (27.9)</td>
<td>21 [15.8 to 24.10]</td>
</tr>
<tr>
<td>Ushuaia</td>
<td>214 DU (16.9)</td>
<td>161 DU (16.10)</td>
<td>37 DU (16.10)</td>
<td>4 [1.8 to 16.10]</td>
</tr>
<tr>
<td>Vernadsky</td>
<td>152 DU (15.9)</td>
<td></td>
<td></td>
<td>57 [1.8 to 23.10]</td>
</tr>
<tr>
<td>Vostok</td>
<td>149 DU (28.9)</td>
<td></td>
<td></td>
<td>16 [6.9 to 30.9]</td>
</tr>
<tr>
<td>Zhong Shan</td>
<td>178 DU (29.8)</td>
<td></td>
<td></td>
<td>10 [22.8 to 21.10]</td>
</tr>
<tr>
<td>Minimum</td>
<td>124 DU</td>
<td>124 DU</td>
<td>19 DU</td>
<td></td>
</tr>
</tbody>
</table>

1From ozonesonde data.  
2From OMI overpass data.  
3First measurement after the polar night starting on 24 September.  
4From SAOZ NRT data.
Ozone observations
Ozone observations

Arrival Heights

The GAW/NDACC station Arrival Heights (77.845°S, 166.67°E), operated by New Zealand, started the regular observations of total ozone after the polar night on 16 September. On that day, total ozone was 151 DU. On 23-27 September the vortex edge moved away from the station and total ozone increased to 319 DU. At the end of the month the vortex moved back over the station and total ozone dropped below 200 DU. Based on OMI overpass data, total ozone has been below the 220 DU threshold on 23 days so far this season (24.8 to 5.10). The Dobson data, together with OMI overpass data can be seen in Figure 9.

Dobson observations have been carried out at Arrival Heights since January 1988. The entire time series, together with satellite overpass data from OMI and the Multi-Sensor Reanalysis (MSR) of KNMI can be seen in Figure 10.

At Arrival Heights there are also a UV/Visible spectrometer and an FTIR instrument. A suite of species are measured with these instruments and data for 2013 together with data from earlier years are shown on Page 16 (Figure 11). See the figure caption for more details on those measurements.
Figure 9. Time series of total ozone from the Arrival Heights Dobson spectrophotometer and satellite overpasses by OMI on board the AURA satellite. Dobson data have been provided by New Zealand’s National Institute for Water and Air Research (NIWA). Satellite overpass data have been downloaded from the TEMIS web site. The plot is produced at WMO.
Figure 10. Time series of total ozone from the Arrival Heights Dobson spectrophotometer and satellite overpasses by OMI on board the AURA satellite (2004 - present) and satellite overpass data from the Multi-Sensor Reanalysis data set (1978 - 2008).
Figure 11. Time series of various parameters relevant to ozone depletion from ground-based instruments at Arrival Heights (77.8°S, 166.7°E): Total ozone measurements are from a Dobson spectrophotometer; HCl, ClONO₂ and HNO₃ measurements are from a Bruker Fourier Transform spectrometer; BrO and NO₂ measurements are from a zenith viewing DOAS spectrometer. The graphs show selected recent years; 2006, 2010, 2011, 2012 and 2013. The small grey dots show all the data from the beginning of the time series until 2012 in order to show the range of values for each parameter. The upper left panel shows total ozone. The middle panel to left shows the differential slant column of chlorine nitrate (ClONO₂), one of the reservoir gases that liberate active chlorine through reactions on PSCs. The lower left panel shows the differential slant column of bromine monoxide (BrO). This molecule takes part in one the catalytic cycles that destroy ozone. The upper right panel shows the total column of hydrochloric acid (HCl), also a reservoir gas that liberates active chlorine by reactions on PSCs. One can see that the HCl column is very low when the measurements start up around day 250 (7 September). As the stratosphere heats up after the winter and the PSCs evaporate the amount of HCl recovers. The middle panel to the right shows the total column of nitric acid (HNO₃). When the stratosphere cools and PSCs start to form in May, the amount of HNO₃ in the gas phase goes down. As the stratosphere heats up again in the spring the PSCs evaporate and HNO₃ goes back into the gas phase. The lower panel to the right shows the vertical column of NO₂. One can see the annual cycle with a maximum of NO₂ during summer and a gradual decline as the sun descends in the sky. After the polar night NO₂ comes gradually back. The Dobson measurements are carried out within WMO’s Global Atmosphere Watch Programme and the other measurements shown here are done as part of NDACC (Network for the Detection of Atmospheric Composition Change).
The vertical distribution of ozone is measured at the Argentine GAW station Belgrano (77.8740°S, 34.6264°W, 202 masl) with electrochemical ozonesondes. Two sondes were launched in July, three in August six in September, and four so far in October. The profiles measured in August, September and October are shown in Figure 12. The profiles measured on 10 and 24 July are quite similar to the one of 8 August. The profiles from 12 September onward show clear signs of ozone depletion. The 2 October profile has a 12-20 km partial ozone column of 22 DU, one of the lowest detected at any station in Antarctica this year. The other October profiles also show significant ozone depletion in the 15-20 km altitude range. In Figure 13 total ozone derived from ozonesondes is compared to total ozone from OMI overpass data. Satellite data do not start until 25 August after the polar night. On 25 and 26 August total ozone was less than 220 DU. Then the column rose to approx. 250 DU before making a dive, crossing the 220 DU threshold on 10 September. Since then and until now (23 October) total ozone has remained well below the 220 DU threshold. Total ozone has been below the 220 threshold on 47 days between 25 August and 23 October.
Figure 13. Total ozone columns from soundings at Belgrano (green circles). The red diamonds show data from the OMI satellite instrument. The plot is made at WMO based on sonde data from INTA and the Meteorological Service of Argentina. The OMI overpass data have been downloaded from the TEMIS web page at KNMI.
Ozone observations

From the Australian GAW site Davis (68.5767°S, 77.9695°E, 15 masl) ozonesondes are launched weekly. The measurement programme is run in partnership by the Australian Bureau of Meteorology and the Australian Antarctic Division. Figure 14 shows ozone profiles measured between 1 and 22 October. All four profiles have the typical signature of an ozone hole profile with a large “bite-out” from 15-19 km. However, the layers above are quite rich in ozone so that the total column is above the 220 DU threshold. Partial ozone columns from 12-20 km are shown in Figure 15. This plot shows the development in 2013 (thick red curve) in comparison to earlier years (2003-2012). It shows that the development so far in 2013 follows the pattern of earlier years with the exception of the ozone rich profile.

Figure 14. Ozonesonde profiles measured at Davis between 1 and 22 October 2013.
of 17 September. The rate of decrease in the 12 to 20 km partial column between mid-August and mid-October is comparable to previous years.

The minimum seasonal 12-20 km partial columns for the years 2003 until present are shown in Figure 16. The minimum partial column between 12 and 20 km so far in 2013 is lower than the 2012 minimum, but has not yet been as low as that observed in other years. The 2013 ozone hole season is not over yet, so the 2013 minimum is provisional.

The development of total ozone above Davis, as observed by the OMI instrument on board the AURA satellite is shown in Figure 17 together with total ozone calculated from ozonesonde profiles.
Figure 16. Seasonal minima of the 12-20 km partial ozone profile. The plot has been provided by the Australian Bureau of Meteorology.

Figure 17. Total ozone columns from soundings at Davis (green circles). The red diamonds show data from the OMI satellite instrument. The plot is made at WMO based on sonde data from the Australian Bureau of Meteorology and the Australian Antarctic Division. The OMI overpass data have been downloaded from the TEMIS web page at KNMI.
Total ozone is measured with a SAOZ spectrometer at the French/Italian GAW/NDACC station at Dôme Concordia (75.099870°S, 123.333487°E, 3250 masl) on the Antarctic ice cap. The measurements started up again on 2 August after the polar night. During August daily averaged total ozone varied between 170 and 312 DU. During September daily averaged total ozone varied between 199 and 359 DU. So far during October (until the 22nd) total ozone has varied between 198 and 409 DU.

So far this season total ozone has been below the 220 DU threshold on 15 days. Figure 18 on the next page shows the 2013 measurements in comparison to earlier years.
Figure 18. Time series of total ozone measured with the SAOZ spectrometer at Dôme Concordia on the Antarctic ice cap until 22 October. The thick grey curve is the 2007-2010 average. The white shaded area gives the range from minimum to maximum values for each day during the 2007-2010 time period. The measurements are carried out in the framework of the Network for the Detection of Atmospheric Composition Change (NDACC). The plot is produced at WMO based on data downloaded from the SAOZ web site at CNRS.
Dumont d’Urville

The French GAW/NDACC station Dumont d’Urville (66.662929°S, 140.002546°E) is located at the polar circle, which allows for SAOZ measurements around the year. From the beginning of August until 22 October daily averaged total ozone has varied between 228 DU and 399 DU. Figure 19 shows the progression of daily averaged ozone. The most striking is the large day-to-day variability, as the polar vortex moves back and forth above the station. The daily average value is calculated as the mean of the total ozone values at sunrise and sunset. On some days the difference between the sunrise and sunset values can reach several tens of DU. It might also happen that the station is inside the ozone hole at sunrise and outside at sunset or vice versa, but the daily mean is above the 220 DU threshold. This has happened on two days so far this season.
Figure 19. Time series of daily mean total ozone in 2013, in comparison to earlier years, as measured by a SAOZ spectrometer at Dumont d’Urville. The plot is updated until 22 October 2013. The plot is produced at WMO based on data downloaded from the SAOZ web site at CNRS.
Total ozone has been measured with a Dobson spectrophotometer at the UK GAW station Halley (75.6052°S, 26.2100°W, 33 masl) since 1957. Due to its high latitude the measurement season starts in late August. In 2013 the measurements started up again on 27 August after the polar winter with a total ozone value of 188 DU. From then until 20 October, total ozone has been below the 220 DU threshold on all days except two. Figure 20 shows the total ozone time series at Halley for the most recent years together with long term statistics (1957-2012). On 23 September total ozone dropped to 127 DU, the lowest value observed at any station so far this year with a Dobson spectrophotometer. In early 2013 a SAOZ spectrometer was put into service at Halley. The SAOZ measures the scattered light from zenith around sunrise and sunset. This allows for measurements at higher solar zenith angles and this leads to a longer measurement season with 24 more days in the autumn and starting 24 days earlier in the spring. The SAOZ also measures the total column of NO₂. During the time period when there are NAT PSCs, NO₂ is removed from the gas phase and bound up in the PSCs as HNO₃.
Figure 20. Time series of daily mean total ozone in 2013, as measured by a Dobson spectrophotometer at Halley. The thick grey line shows the average ozone column for the 1957-2012 time period. The white shaded area shows historical maxima and minima calculated for the 1957-2012 time period. The plot is produced at WMO based on data downloaded from WOUDC and from Jonathan Shanklin’s Antarctic web site at British Antarctic Survey.

Figure 21. Time series of total ozone and NO$_2$ in 2013, as measured by a newly deployed SAOZ spectrometer at Halley starting in late January 2013. The green line shows the daily average ozone column. The blue line shows the NO$_2$ column at sunrise and the red line shows total NO$_2$ at sunset. It can be seen that in August the NO$_2$ column is very small, showing that the stratosphere above Halley is denoxified. During September the NO$_2$ column has increased gradually and in early October the increase gets more rapid. The plot is produced at WMO based on data downloaded from Jonathan Shanklin’s Antarctic web site at British Antarctic Survey.
The GAW/NDACC station Macquarie Island is located at 54.499531°S and 158.937170°E. It is about 2000 km from the southeast coast of Australia and about 1500 km from the Antarctic coastline. Dobson observations of total ozone have been made there since 1957.

The plot (Figure 22) shows daily ozone values in August-October 2013 (red line) compared to the 1987-2012 climatology. The light blue area represents the 10th-90th percentile range, the medium blue the 30th-70th percentile range and the blue line the daily mean. A relatively low ozone value of 276 Dobson Units was observed on the 5th of September. Also satellite overpass measurements showed low values on the same day.

Dobson observations at Macquarie can be seen in comparison with OMI overpass data in Figure 23.
Ozonesondes are launched at Macquarie once per week. Profiles observed since late September 2013 are shown in Figure 24. Some profiles show a deficit of ozone around 15 km altitude, in particular the profile of 22 October.

The full time series of Macquarie Dobson data is shown in Figure 25 (next page). Except for a gap in the early 1960s this station has measured total ozone continuously since 1957. Such long time series are very valuable and it is important that they are continued so that we can see the expected ozone recovery in the long term perspective.
Figure 25. Total ozone over Macquarie Island from 1957 until now (31 August 2013) measured with Dobson spectrophotometer (blue dots) compared to satellite overpass data. The orange dots show data from KNMI’s Multi-Sensor Reanalysis (1979-2008) and the red dots show OMI overpass data (2004 until now).
Ozone observations

Marambio

Ozone profiles are observed at the Argentine GAW station Marambio (64.2400°S, 56.6300°W) with ozonesondes. Soundings are carried out approx. twice per week. Nine ozonesondes were launched in June, nine in July, eight in August, eight in September and seven so far in October. The profiles measured between 3 and 24 August are shown in Figure 26. Several profiles (see Figure 27) show clear signs of ozone destruction in the 15-22 km altitude range. Already on 3 August, both the total ozone column and the 12-20 km column were quite low. After that date ozone depletion has progressed more or less gradually, both around 13-15 km and also around 22 km. The profiles of 4 and 7 September both display two rather clear ozone “bite-outs” at these two altitude levels. The sondes of 12 October shows the lowest 12-20 km partial columns (27 DU) so far this season at this station.

An ozone map based on data from the BASCOE data assimilation model (Figure 28) shows that Marambio was inside the ozone hole on 28 September.

Total ozone is measured at Marambio with a Brewer MkIII instrument. The Brewer measurements have been carried out since February 2010. In 2013 the measurements started up after the winter on 10 August. From that date until 22 October total ozone has varied between 305 DU (12 August) and 148 DU (13 October). Total ozone has been below the 220 DU threshold on 50 days so far this season. The Brewer measurements, together with OMI overpass data and total ozone deduced from ozone soundings are shown in Figure 29. At Marambio, total ozone is also measured with a Dobson spectrophotometer. Those measurements started in August 1987. The entire Dobson time series together with OMI and MSR overpass data can be seen in Figure 30.
Ozone observations

Figure 27. Ozone profile measured with electrochemical ozonesonde launched from the Argentinian GAW station Marambio from 30 August to 23 October. Some of the profiles show a “bite-out” at around 13-15 km altitude, and also around 22 km. The 21 September sonde experienced a balloon burst already at 23 km, so the total ozone deduced from that sounding is not reliable.
Figure 28. Assimilated ozone on 28 September 2013 at 43.4 hPa. The position of Marambio is indicated with a red circle. The data is calculated with the BASCOE model, which uses data from the MLS instrument on AURA. The plot shows that Marambio was affected by low ozone mixing ratios at that level on this day.

Figure 29. Total ozone over Marambio as measured by ozonesondes (green circles), Brewer spectrophotometer (blue line and squares) and by the OMI satellite instrument on board AURA.
Figure 30. Total ozone over Marambio from Dobson spectrophotometer (blue diamonds), from the OMI satellite instrument on board AURA (red squares) and from the MSR data set calculated by KNMI from various satellite instruments.
At the Russian GAW station Mirny (66.558270°S, 93.001017°E) total ozone is measured with a filter instrument (M-124). The data are submitted by Elena Sibir and Vladimir Radionov of the Arctic and Antarctic Research Institute, St. Petersburg.

The measurements started up again after the polar night on 1 August and are up to date as of 20 October. The maximum total ozone value observed so far was 455 DU on 9 and 20 September and 4 October. The minimum so far was 213 DU on 30 August. The maps in Figure 31 (next page) shows total ozone observed by MLS on the AURA satellite. On 9 August the station is inside the polar vortex and total ozone derived from the map is around 220 DU. On the 20th of September the station is outside the vortex and one can see that it is influenced by ozone rich air masses. Total ozone derived from the MLS map is around 310-320 DU. The ground-based data are shown together with OMI satellite overpass data in Figure 32.
Figure 31. Total ozone observed by MLS on Aura. The position of Mirny is shown with a blue circle. The plots are produced at WMO based on data downloaded from NASA’s GES-DISC.
Figure 32. Total ozone above Mirny as measured by a M-124 filter instrument and by the OMI instrument on board the AURA satellite.
Ozone observations

The vertical distribution of ozone is measured with ozonesondes from the German GAW/NDACC station at Neumayer (70.666°S, 8.266°W). Sondes were launched on 1, 7, 13, 21, 24 and 27 August, on 3, 6, 14, 16, 19, 23 and 28 September, and on 1, 3, 5, 7, 11, 14, 19, 21 and 24 October as shown in Figure 33. The profile of 13 August shows a 12-20 km partial ozone column of 95 DU. By 3 October this partial column has dropped to 19 DU, the lowest 12-20 km columns measured so far in 2013 at any station in Antarctica. The ozone mixing ratio at around 80 hPa (approx. 15-16 km) from the BASCOE model is shown for five different dates in Figure 34. On 7 August there is no sign of ozone depletion. This can be seen both from the ozonesonde profile...
and from the BASCOE data (about 1.9 ppm ozone above Neumayer). On 13 August one can see from the sonde profile that ozone is reduced at several levels. This is also clear from the BASCOE map with around 1.2 ppm at 79hPa above Neumayer.

On 27 August, the ozone profile shows that ozone partial pressure at 16 km has dropped from approx. 16 mPa on 7 August to approx. 7 mPa. This drop in ozone is also reflected in the BASCOE data at this level (below 0.9 ppm). The ozone profiles observed on 3 and 6 September show a bit less depletion than on 27 August, but total ozone is close to the 220 DU threshold and there are quite visible ozone “bite-outs”, especially around 20-22 km. From 14 September onward all the profiles show a large degree of ozone depletion. The map in the lower centre in Figure 34 shows that Neumayer is situated in a region with low ozone mixing ratios on 23 September. On 3 October the ozone partial pressure is around 0.2 mPa between 15 and 16 km. The BASCOE map for 83.9 hPa (15.7 km) is shown at the lower right of Figure 34.

Ozonesonde data from Neumayer have been used to calculate monthly means of the 12-20 km partial ozone column. The results of these calculations, performed on data from 1992 until present are shown in Figure 35 on the next page.
Figure 35. Time series of monthly average 12-20 km partial ozone column at Neumayer from 1992 to present. The 12-20 km column is calculated from ozonesonde data. The red circles, connected with green lines, show the average partial column for the actual month. The cyan diamonds show the median value. Using the median gives a more representative value since there can be episodes where the station is outside the vortex and this will influence the arithmetic mean to a larger extent than the median. The error bars show the standard error of the mean (1σ). The data points for October 2013 are preliminary as there might be more soundings carried out during this month.
At the Russian GAW station Novolazarevskaya (70°7'6739"S, 11°8'22138"E) total ozone is measured with an M-124 filter instrument. The data are submitted by Elena Sibir and Vladimir Radionov of the Arctic and Antarctic Research Institute, St. Petersburg. The measurements started on 15 August and are up to date until 20 October. During this time period total ozone has varied between 157 (6 Oct) and 264 DU (11 Oct). Total ozone has been below the 220 DU threshold on 45 days so far this season. Figure 36 on the next page shows the filter instrument data together with OMI satellite overpass data.
Figure 36. Total ozone above Novolazarevskaya as measured by a M-124 filter instrument and by the OMI instrument on board the AURA satellite.
The lidar system in Río Gallegos.

The lidar system in operation at Río Gallegos. Photo: CONICET.

Río Gallegos

The NDACC station “Observatorio Atmosférico de la Patagonia Austral” in Río Gallegos (51.600496°S, 69.31946°W) is equipped with a differential absorption lidar (DIAL) for the measurement of profile ozone and with a SAOZ spectrometer for the measurement of total ozone and NO₂. A GUV-541 filter radiometer measures UV radiation. The station is operated by the Lidar Division of CEILAP (Laser and Applications Research Center) and belongs to UNIDEF (MINDEF, [Ministerio de Defensa]) and CONICET (Consejo Nacional de Investigaciones Científicas y Técnicas, Argentina). It is supported by JICA. CEILAP is associated with LATMOS through a collaboration agreement. The University of Magallanes, Chile, collaborates with the ozone measurements and the Nagoya University has a millimetric wave radiometer for ozone profile measurement operating at the station. The following report has been written by scientists at the station.

Ozone monitoring in Río Gallegos NDACC Station, Santa Cruz, Argentina

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Total ozone evolution during August - September 2013

As a part of systematic observations of the ozone layer in southern Patagonia, measurements of the total ozone column taken with a SAOZ spectrometer and stratospheric ozone vertical profiles (14-45 km) measured with a differential absorption lidar (DIAL) are reported.

The total ozone columns over Río Gallegos present typical fluctuations around mean values for this time of the year. The development of the polar vortex around Antarctica is...
a natural barrier that avoids the ozone rich air transported from the equatorial zone to reach the pole. This produces the pile-up of ozone rich air in the equatorial side of the polar vortex. This situation was observed on 21 August 2013 (Figure 37) when the total ozone column over the station was around 400 DU, approximately 60 DU above the mean value for this month.

Since the development of the Antarctic ozone hole in this season, the OAPA site was outside the vortex most of August. Towards the end of the month (Aug. 29), the ozone hole passed over the station and the total ozone column dropped to 283 DU, as measured from the ground based SAOZ instrument.

On September 17 [day of year 260], the ozone hole passed over the Río Gallegos station, and total the ozone column dropped to 274 DU (Figure 37). 29 August and 17 September were the only two days with total a ozone column below one standard deviation of the ozone climatologic monthly mean value (1978-2009).

During the August - September period, several ozone vertical profiles were measured with the Differential Absorption Lidar operative at OAPA. On average, the integration time of each lidar experiment was around 3 hours. Selected stratospheric ozone profiles are presented in Figure 38 in correspondence with the days of interest.

Higher total ozone columns registered on 21 August are produced by air of elevated ozone contents in the lower stratosphere, below 21 km as can be seen from the DIAL ozone profile on this day (Figure 38). The proximity of the polar vortex to the zenith line of Río Gallegos produces a reduction of the ozone content in the middle stratosphere (profiles of 29 Aug. and 17 Sep.; Figure 38). The reduction zones are clearly visible in comparison with the September climatologic ozone profile.

OMPS satellite images confirm the position of ozone hole over Río Gallegos (Figure 39). Rapid recovery of total ozone happens after this day as a consequence of the polar vortex movement away from the station. Figure 39 shows the sequence of images of total ozone column measured by OMPS instrument aboard the NPP platform corresponding to the ozone profiles shown in Figure 38.
The overpass of poor ozone air for these days induce a slight increase in UV levels at the ground. Measurements of UV radiation with a GUV 541 moderate narrowband multi-filter radiometer reach moderate UV indices (around 3-3.5).

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Figure 38. DIAL stratospheric ozone profiles measured on August 21 (dashed dotted green line), August 29 (dashed red line) and September 17 (blue line) in Río Gallegos site. Fortuin & Kelder September climatologic profile for latitude belt (45-55°S)(black dashed line).

Figure 39. Total ozone from the Ozone Mapper and Profiler Suite (OMPS). OMPS is one of five new instruments flying aboard NASA’s Suomi National Polar-orbiting Partnership satellite (NPP), which was launched on Oct. 28, 2011. Suomi NPP is the result of a partnership between NASA, the National Oceanic and Atmospheric Administration and the Department of Defence. The Rio Gallegos station is near the southern tip of the South American continent.
At the British GAW/NDACC station Rothera (67.5695°S, 68.1250°W) total ozone is measured with a SAOZ spectrometer. Since the station is close to the polar circle, observations can be carried out around the year. Total ozone was oscillating between 300 and 380 DU in June. On 2 August total ozone dropped to 154 DU before going back up to near 300 DU on 8 August. After that total ozone oscillated between 124 and 296 DU until the end of August. From 27 August until 19 October total ozone has been below (mostly well below) the 220 DU threshold. Figure 40 shows the 2013 data in comparison to earlier years and long term statistics. Figure 41 (next page) shows a map of total ozone from MLS on 2 and 8 August as well as 29 September, where Rothera is indicated with a red circle. It can be seen that on 2 August the station is influenced by air masses with ozone depleted air, on the 8th it was on the outer edge of the vortex and on the 29th it was well inside the vortex with a total ozone column of around 120 DU. Total ozone has been below the 220 DU threshold on 60 days so far in 2013 (1 August to 20 October).
Figure 41. Maps of total ozone from MLS for 2 and 8 August, and 29 September, showing the location of Rothera. On 2 August the station is influenced by ozone poor air masses with total ozone around 200 DU. On 8 August total ozone is approx. 290 DU and on 29 September it is near 120 DU. Note that the colour scale has been extended down from 160 to 120 DU on the 29 September plot.
The vertical distribution of ozone at the GAW/NDACC South Pole station (Amundsen-Scott base) has been measured by NOAA/ESRL with electrochemical concentration cell (ECC) ozonesondes since 1986. Figure 42 shows the four soundings between 20 July and 26 August. Figure 43 (next page) shows soundings carried out from 1 September to 22 October. Since 7 September all the profiles show clear signs of ozone depletion. Also the profile of 26 August displays a clear ozone “bite-out”. This probably stems from air masses being transported from the vortex edge region where depletion starts some weeks earlier than at the South Pole. On 29 September there is a region around 16-17 km altitude where essentially all ozone is destroyed. Total ozone is measured with a Brewer spectrophotometer operated by NOAA and that belongs to Environment Canada. This instrument was installed at the South Pole in February 2008. The measurements started up again on 10 October after the polar night. Total ozone values deduced from the sondes are shown together with Brewer and OMI satellite overpass data in Figure 44. Due to the late sunrise at the South Pole after the winter the satellite data started reporting from 24 September. On the cover of this Bulletin is shown the ozonesonde profile measured on 22 October. One can see the typical ozone “bite-out” between 14 and 20 km, but also the ozone rich layer at around 23 km. This ozone rich layer causes total ozone to surpass the 220 DU threshold, which means that the South Pole was outside the ozone hole according to this definition. However, the large depletion in the 14-20 km range shows that the station was well inside the ozone hole. This is an example that this definition not always is representative during years when there is a lot of transport of ozone rich air from middle latitudes.
Ozone observations

Figure 43. Ozone soundings from the South Pole station from between 1 September and 22 October. Since 7 September the 12-20 km partial column is typical of ozone hole conditions. Also the 26 August profile displays a characteristic ozone loss “bite-out”, probably due to air masses advected from the vortex edge region. Due to the large amount of ozone above 20 km the scale on the abscissa is different on the 22 October plot. The plots are produced at WMO based on data downloaded from the NOAA/ERSL/GMD ftp server.
Figure 44. Total ozone above the South Pole as measured by a Brewer spectrophotometer, which belongs to Environment Canada, ozonesondes (green circles) launched by NOAA and by the OMI instrument on board the Aura satellite. Due to the late sunrise at the South Pole after the polar night, the satellite retrievals start only at 24 September and the Brewer measurements start at 10 October.
Total ozone is measured at the Japanese GAW station Syowa (69.006°S, 39.577°E) with a Dobson spectrophotometer. These measurements have been carried out since 1961. Measurements started up on 15 August after the winter. The total ozone value measured with the Dobson spectrophotometer on that day showed 218 DU. Between 15 and 31 August total ozone values varied between 209 DU (on the 28th) and 243 DU (on the 24th). In September total ozone varied between 161 DU (on the 25th) and 341 DU (on the 16th). From 1 to 6 October, total ozone varied between 431 DU on the 3rd and 182 DU on the 7th. This rapid variation in total ozone shows the importance of the position of the polar vortex with respect to the station.

Ozone profiles are measured at Syowa with ozonesondes. So far six soundings have been carried out, on 12, 16, 21, 26 and 31 August, on 5, 10, 13, 19, 23 and 27 September,

Figure 45. Ozonesonde profiles measured at Syowa from 12 August to 23 October 2013. Please note that the plots of 1 and 20 October profile has a different abscissa range (0-20 mPa instead of 0-17 mPa).
Ozone observations

and on 1, 12, 19 and 23 October [Figure 45]. Several profiles show characteristic “bite-outs” of ozone, both in the 16-19 km range and also around 21 km. The profiles measured on 27 September and on 1 October show very different situations. In the first case there is substantial ozone depletion between 15 and 20 km. In the second case there is almost 20 mPa of ozone at 18-19 km altitude. Ozone mixing ratio maps for those two days at 46.45 hPa (approx. 19 km) from the BASCOE data assimilation model is shown in Figure 46. The map shows that Syowa is well inside the polar vortex on 27 September and just outside the vortex edge on 1 October.

Between 15 August and 24 October Syowa has experienced less that 220 DU on 19 days. As some of the ozone profiles show, there can be substantial ozone depletion in the 15-20 km altitude range, yet total ozone is above 220 DU.
Figure 47. Total ozone observations carried out at Syowa from mid July 2013 with a Dobson spectro-photometer (blue line and squares) and with electrochemical ozonesondes (green circles). Satellite overpass data from the OMI instrument on board the AURA satellite are shown for comparison (red diamonds).
Figure 48. Total ozone observations carried out at Syowa since 1961 with Dobson instruments compared to satellite overpass data (KNMI Multi-Sensor Reanalysis from 1979 - 2008 and from OMI from 2004-2013).
The global GAW station Ushuaia (54.848334°S, 68.310368°W) is operated by the Servicio Meteorológico Nacional of Argentina. This station is mainly influenced by middle latitude air masses, but on certain occasions the south polar vortex sweeps over the southern tip of the South American continent. On such occasions Ushuaia can be on the edge of or even inside the ozone hole. Ozone profiles measured with electrochemical ozonesondes in August and September are shown in Figure 49. On 21 August the ozone partial pressure is around 17 mPa at 20 km. On 4 September it has dropped to around 10 mPa and on 17 September it has dropped further to 2 mPa at about 22 km altitude. The partial ozone column between 12 and 20 km dropped from 133 to 65 DU between the two dates. The launches on 30 September and 16 October were timed with the help of various forecast data provided by the MACC-II project. These forecasts have proven very reliable and has allowed for launching of ozonesondes into the ozone hole on those occasions when the south polar vortex sweeps over the southern tip of South America. Such episodes only last a few hours.
Figure 50 shows maps of BASCOE model calculated ozone mixing ratios for three dates, one data when Ushuaia was outside the vortex and on two dates when the station was inside. One can see that on 21 August Ushuaia was located outside the vortex. On 17 September the station is inside the vortex. One can also see that the air masses inside the vortex in general have become much more depleted in ozone compared to 21 August. The total ozone columns derived from the sondes agree very well with columns from OMI overpass data on most days. On 21 August total ozone derived from the ozonesonde was 333 DU and from OMI it was 343 DU. On 4 September the ozone column derived from the sonde was 205 DU and from the OMI overpass it was 222 DU. On 17 September total ozone from the ozonesonde is 194 DU and from two OMI overpasses on that day the average is 238 DU. On 30 September the total ozone calculated from the sonde is 216 DU and from OMI overpass it is 241 DU.

Ozone observations

Figure 51 on the next page show total ozone as measured by Dobson, satellite and ozonesondes since May 2013. One can see the episodes when the vortex passes close to the station resulting in a rapid dip in total ozone.

Figure 52 on the page after next shows the entire time series of MSR overpass data for Ushuaia, starting in late 1978 until 2008, the OMI overpass data from 2004 until present and the Dobson time series from September 1994 until present.
Figure 51. Total ozone over Ushuaia in 2013. The green circles show total ozone deduced from ozone balloon soundings, the blue line shows the Dobson observations (until 16 October) and the red diamonds show OMI overpass data (until 20 October).
Figure 52. Total ozone observations carried out at Ushuaia with Dobson instruments compared to satellite overpass data (KNMI Multi-Sensor Reanalysis from 1979-2008 and from OMI from 2004-2013). One can clearly see episodes where the ozone hole has passed over Ushuaia with total ozone columns dropping as low as approx. 140 DU on some occasions.
Vernadsky station (65.2458°S, 64.2573°W) is run by the National Antarctic Scientific Centre of Ukraine. Total ozone is measured with a Dobson spectrophotometer. The data are processed by the British Antarctic Survey. Total ozone observations have been carried out here since mid 1957. Observations recommenced after the polar night on 21 July, with initial results around 270-290 DU. During August total ozone values have oscillated between 178 DU (31 Aug) and 287 DU (7 Aug). In September total ozone was below the 220 DU threshold on most days. The data from Vernadsky are reported to WMO’s Global Telecommunication System (GTS) daily. The Dobson and OMI overpass data are shown in Figure 53.

Figure 54 (next page) shows total ozone from the TM3 Data Assimilation Model, that is used in the MACC-II project, for two consecutive dates, 20 and 21 October. The ozone maps show how the ozone hole moves away from the station. The result of this vortex movement is seen in the Dobson time series in Fig X, with a rapid increase in total ozone.

In Figure 55 (page after next) is shown the entire time series at Vernadsky starting in 1957 together with satellite overpass data from KNMI’s Multi-Sensor Reanalysis from 1979 to 2008 and OMI overpass data from 2004 until now.

Figure 53. Total ozone over Vernadsky in 2013. The blue line shows the Dobson observations (until 23 October) and the red diamonds show OMI overpass data (until 20 October).
Figure 54. Total ozone from the TM3 Data Assimilation Model run by KNMI. This model assimilates data from the GOME-2 satellite instrument on EUMETSAT’s Metop-A satellite. The coloured circle shows the location of Vernadsky Station. On 20 October the station is inside the ozone hole and total ozone is below 220 DU. The day after, the ozone hole has moved away from the station and the total ozone column has increased by almost 150 DU in 24 hours.
Figure 55. Total ozone measurements from the Vernadsky station. On the plot are shown the Dobson time series (blue diamonds) together with satellite overpass data from the Multi-Sensor Reanalysis (1979-2008) of the Netherlands Meteorological Institute (orange dots) and from the OMI instrument (2004-now) on board the AURA satellite (red dots). This long time series is an excellent example of the value of the long term measurements which we need to see the ozone depletion phenomenon in the long term perspective and which we need to detect ozone recovery.
Vostok (78.464422°S, 106.837328°E, 3448 masl) is located near the South Geomagnetic Pole, at the center of the East Antarctic ice sheet. Although this is a Russian research station, scientists from all over the world conduct research here. One of the primary projects at this site, a coordinated Russian, French and American effort, is drilling ice cores through the 3,700 m thick ice sheet. These ice cores contain climate records back to almost half a million years before present.

Total ozone is measured at Vostok with a M-124 filter instrument. Data from 6 to 30 September are currently available. During this time period, total ozone was below the 220 DU threshold on 16 days. The minimum in September was 149 DU measured on the 28th. Figure 56 shows the M-124 data of September 2013 together with satellite overpass data from the OMI instrument on board the AURA satellite (until 20 October).

Figure 56. Total ozone observations carried out at the Vostok ice drilling site in 2013 with an M-124 filter instrument compared to satellite overpass data from OMI.
Zhong Shan

At the Chinese GAW station Zhong Shan (69.3731°S, 76.3724°E) total ozone is measured with a Brewer spectrophotometer. The measurement series started in March 1993. In 2013 the observations started up on 23 August after the polar night. The first direct sun measurement was carried out on 26 August. The total ozone value on that day was 226 DU. After that, direct sun measurements have varied between 178 DU and 397 DU. The station is often close to the vortex edge, and this can lead to large changes in total ozone. Total ozone has been below the 220 DU threshold on ten days so far this season. Figure 57 shows the Brewer measurements (blue) compared to OMI overpass data (red) until 21 October.

The entire time series from 1993 until now together with satellite overpass data from KNMI’s Multi-Sensor Reanalysis (1979-2008) and from the OMI instrument on AURA (2004-now) is shown in Figure 58.
Figure 58. Total ozone observations carried out at Zhong Shan since 1993 with Brewer instruments compared to satellite overpass data (KNMI Multi-Sensor Reanalysis from 1979 - 2008) and OMI (2004-2013).
Chemical activation of the vortex

Satellite data

Ozone profile data from MLS on board the Aura satellite data have been compared to sonde data from Neumayer for a few selected dates. The partial ozone profile between 100 and 38.3 hPa has been calculated both from the sonde data and the satellite data. As can be seen in Figure 59, the agreement between sonde and satellite data is generally good and the partial columns between 100.00 and 38.31 hPa agree quite well.

Data assimilation model results

The Belgian Institute for Space Aeronomy (BIRA-IASB) is in charge of the monitoring and evaluation of the stratospheric composition products delivered by the European MACC-II project. In this context, the BASCOE assimilation system was setup to deliver near real-time analyses and forecasts of ozone and related species for the stratosphere. The version used here was originally developed in the framework of the past GSE-PROMOTE program of ESA.

The BASCOE data assimilation system is run daily and as-similates the offline dataset (level-2, v3.3) retrieved from the Aura-MLS instrument. While delivered a few days later than the NRT stream, the offline dataset includes several species: \( \text{O}_3, \text{H}_2\text{O}, \text{HNO}_3, \text{HCl}, \text{HOCl}, \text{ClO} \) and \( \text{N}_2\text{O} \). More information about the MACC project and the BASCOE model with references can be found here: http://macc.aeronomie.be/4_NRT_products/3_Models_changelogs/BASCOE.php

Figure 60 (upper row) shows the extent of removal of hydrochloric acid (HCl), which is one of the reservoirs for active chlorine, on six different dates over the course of the season (1 June, 1 July, 1 August, 2 September, and 5 and 16 October) at the 46.4 hPa level. This isobaric level corresponds to an altitude of approx. 18.5 - 19.5 km inside the south polar vortex. As can be seen from the figure, HCl is somewhat depleted already on 1 June, much more depleted on 1 July and almost completely removed inside the vortex in early August and early September. On 5 October there are still some small regions that are depleted in HCl but also large area inside the vortex where HCl has reformed. By 16 October the vortex is filled with 2-3 ppb of HCl. Removal of HCl is an indicator of chemical activation of the vortex.

Another indicator of vortex activation is the amount of chlorine monoxide (ClO). It should be noted, however, that ClO dimerises and forms \( \text{(ClO)}_2 \) in darkness. The dimer is easily cracked in the presence of sunlight. ClO will therefore be present in the sunlit parts of the vortex, whereas the dark areas will be filled with \( \text{(ClO)}_2 \). The second row on the next page shows the mixing ratio of ClO at the same dates as above. Please note that these maps show the amount of ClO at one point in time (12 UT). They will therefore look different from the ClO maps from the MLS instrument on Aura because those maps use data from several orbits over the course of the day so that ClO typically shows up in two lobes on opposite sides of the vortex. By 16 October there is no more ClO in the vortex.

The third row shows the ozone mixing ratio at the same dates and the same level. In June, July and early August, ozone depletion has not started yet, so it is only in early September that one sees significant ozone depletion. By early October ozone depletion is even more advanced and on 16 October the vortex is still depleted of ozone.

The last row shows the amount of nitric acid (\( \text{HNO}_3 \)) in the polar vortex. Removal of gaseous HNO\(_3\) is an indication that this compound is condensed in the form of polar stratospheric clouds (nitric acid trihydrate, \( \text{HNO}_3\cdot3\text{H}_2\text{O} \)). The removal of nitric acid starts when the PSC temperatures set in during May. By 1 June HNO\(_3\) is already partially depleted inside the vortex and in early July, August and September the vortex is very low in HNO\(_3\). In early October the PSC temperatures are almost gone and HNO\(_3\) starts to come back to the gas phase. On 16 October the vortex is still depleted of HNO\(_3\), an indication that HNO\(_3\) has been removed from the stratosphere through sedimentation.
Figure 60. (Next page) Results from the BASCOE data assimilation model. This model is run daily as part of the MACC-II project, which is funded by the European Commission and coordinated by ECMWF. Thanks to the assimilation of the Aura-MLS offline retrievals, BASCOE delivers analyses of ozone, ClO, H2O, HNO3, HCl, HOCl and N2O with a delay of four days. These are freely available at the website of the MACC stratospheric ozone service: http://www.copernicus-stratosphere.eu

The upper row shows hydrochloric acid, the second row shows ClO, the third shows ozone and the last row shows nitric acid. All four rows show the temporal development from 1 June to 16 October with intermediate frames shown for 1 July, 1 August, 2 September and 5 October. Please note that the map projection used for ozone and ClO is different than for the other two compounds. The levels of the colour scale for ClO is different on 16 October and it shows ppt instead of ppb. On 5 October there was still more than 1.5 ppb of ClO in certain parts of the vortex. On 16 October there was less than 10 ppt of ClO inside the vortex. The

HCl map of 16 October also has a different scale than for the other dates. The maximum has been increased to 3.0 ppb. On 25 June 2013, ECMWF changed the number of levels in their model. This had as a consequence that the BASCOE data are not available on exactly the same levels before and after that date. The data for 1 June are at 49.1 hPa, whereas the other dates are given at 46.4 hPa.
Ozone hole area and mass deficit

Ozone hole area

The area of the region where total ozone is less than 220 DU ("ozone hole area") as deduced by KNMI from the GOME-2 instrument on Metop (and SCIAMACHY on Envisat in the past) is shown in Figure 61. During the first half of August 2013, the area increased more slowly than at the same time in many of the recent years. However, during the latter half of August it increased faster than in 2010, 2011 and 2012. Figure 62 (next page) shows the ozone hole area as deduced by NASA from the OMI satellite instrument. It can be seen that the 2013 ozone hole in August is increasing more rapidly than in 2010 and 2012 and similarly to 2011. After 7 October the ozone hole area has dropped rapidly and by the end of October it is similar to that observed in 2012.

Ozone mass deficit

The ozone mass deficit is defined as the amount of ozone (measured in megatonnes) that has to be added to the ozone hole in order for total ozone to come up to 220 DU in those regions where it is below this threshold. The ozone mass deficit as calculated by KNMI based on GOME-2 data is shown in Figure 63. The same parameter as calculated by NASA from OMI data is shown in Figure 64.

Long term statistics

In order to assess the severity of the ozone hole one can average the ozone hole area over various representative time periods. Several time periods have been used by various investigators, and four such time periods are commonly used to calculate the average ozone hole area for the years 1979 to present based on the Multi-Sensor Reanalysis data and SCIAMACHY and GOME-2 data as calculated at KNMI. So far results for two time periods (last ten days of September and 7 September to 13 October) could be calculated. These results are shown in Figure 65. It can be seen that the aver-
Ozone hole area and mass deficit

Average ozone hole area over the ten last days of September was larger in 2013 compared to 2012 but smaller than in 2010 and 2011. With the exception of 2002, 2004 and 2012, which all experienced unusually small ozone holes, one has to go back to 1990 to find a smaller ozone hole area for the 21 - 30 September time period. If one averages over the 7 September to 13 October time period one can see that the 2013 ozone hole was larger than the ones of 2010 and 2012.

Rather than looking at the area of the region where total ozone is below 220DU one can also calculate the amount of ozone that one would have to add to the ozone hole in order to bring total ozone up to 220DU in those regions where total ozone is inferior to this value. The result of this analysis, again based on the Multi-Sensor Reanalysis data and SCIAMACHY and GOME-2 from KNMI, is shown in Figure 65. The time periods are the same as those used for the ozone hole area calculations.

Now, with the exception of 2002, 2004, 2010 and 2012, the 2013 ozone hole is the weakest ozone hole since 1991 for the time period 21-30 September and the weakest since 1990 for the 7 September - 13 October time period.

If one considers the last 20 ozone holes (1994-2013), fifteen ozone holes have seen more ozone loss and four less ozone loss than the 2013 ozone hole.

As the season progresses it will be possible to calculate average ozone hole area and mass deficit for the other time periods.

![Figure 65](image-url)
Figure 63. Ozone mass deficit (megatons) inside the Antarctic ozone hole for the years from 2006 to 2013. Data for 2013 are shown as black dots (until 25 October). The ozone mass deficit is defined as the mass of ozone that would have to be added to the ozone hole in order to bring the total ozone column up to 220 DU in those areas where total ozone is less than 220 DU. This plot is produced by KNMI and is based on data from the GOME-2 and SCIAMACHY satellite instruments.

Figure 64. Ozone mass deficit (megatons) inside the Antarctic ozone hole for the years from 2009 to 2013 together with 1979-2012 statistics. Data for 2013 are shown in red (until 18 October). The ozone mass deficit is defined as the mass of ozone that would have to be added to the ozone hole in order to bring the total ozone column up to 220 DU in those areas where total ozone is less than 220 DU. The plot is made at WMO based on data downloaded from the OzoneWatch web site at NASA. The data are based on ozone observations from the OMI instrument (for recent data) and from various TOMS instruments (historical data).
Figure 65. Upper panels: Area of the ozone hole averaged over the time periods of 21 - 30 September and 7 September - 13 October. Lower panels: Ozone mass deficit averaged over the same time periods. The data are calculated at KNMI from the multi-sensor reanalysis (MSR) and GOME-2 data. The plots are produced at WMO.
UV radiation

UV radiation is measured by various networks covering the southern tip of South America and Antarctica. There are stations in Southern Chile (Punta Arenas), southern Argentina (Ushuaia) and in Antarctica (Belgrano, Marambio, McMurdo, Palmer, South Pole). Reports on the UV radiation levels will be given in futures issues when the sun comes back to the south polar regions. Links to sites with data and graphs on UV data are found in the “Acknowledgements and Links” section at the end of the Bulletin.

Distribution of the bulletins

The Secretariat of the World Meteorological Organization (WMO) distributes Bulletins providing current Antarctic ozone hole conditions beginning around 20 August of each year. The Bulletins are available through the Global Atmosphere Watch programme web page at http://www.wmo.int/pages/prog/arep/gaw/ozone/index.html. In addition to the National Meteorological Services, the information in these Bulletins is made available to the national bodies representing their countries with UNEP and that support or implement the Vienna Convention for the Protection of the Protection of the Ozone Layer and its Montreal Protocol.

Acknowledgements and links

These Bulletins use provisional data from the WMO Global Atmosphere Watch (GAW) stations operated within or near Antarctica by: Argentina [Comodoro Rivadavia, Rio Gallegos, San Martin, Ushuaia], Argentina/Finland [Marambio], Argentina/Italy/Spain [Belgrano], Australia [Macquarie Island and Davis], China/Australia [Zhong Shan], France [Dôme Concordia, Dumont d’Urville and Kerguelen Is], Germany [Neumayer], Japan [Syowa], New Zealand [Arrival Heights], Russia [Mirny, Novolazarevskaja and Vostok], Ukraine [Vernadsky], UK [Halley, Rothera], Uruguay [Salto] and USA [South Pole]. More detailed information on these sites can be found at the GAWGIS web site [http://www.empa.ch/gaw/gawsis].


Total ozone and ozone profiles (both images and data) from the new OMPS instrument can be downloaded here: http://ozoneaq.gsfc.nasa.gov/beta/data/omps/

Potential vorticity and temperature data are provided by the European Centre for Medium Range Weather Forecasts (ECMWF) and their daily T_{06} meteorological fields are analysed and mapped by the Norwegian Institute for Air Research (NILU) Kjeller, Norway, to provide vortex extent, PSC area and extreme temperature information. Meteorological data from the US National Center for Environmental Prediction (NCEP) are also used to assess the extent of PSC temperatures and the size of the polar vortex [http://www.cpc.ncep.noaa.gov/products/stratosphere/polar/polar.shtml]. NCEP meteorological analyses and climatological data for a number of parameters of relevance to ozone depletion can also be acquired through the OzoneWatch web site at NASA [http://ozonewatch.gsfc.nasa.gov/meteorology/index.html].

SAOZ data in near-real time from the stations Dôme Concordia and Dumont d’Urville can be found here: http://saoz.obs.uvq.fr/SAOZ-RT.html

Ozone data analyses and maps are prepared by the World Ozone and UV Data Centre at Environment Canada [http://exp-studies.tor.ec.gc.ca/cgi-bin/selectMap], by the Royal Netherlands Meteorological Institute [http://www.temis.nl/protocols/O3global.html] and by the University of Bremen [http://www.doas-bremen.de/]. UV indices based on the SCIAMACHY instrument on Envisat can be found here: http://www.temis.nl/uvradiation/

UV and ozone data from New Zealand can be found here: http://www.niwa.co.nz/our-services/online-services/uv-and-ozone

Plots of daily total ozone values compared to the long term average can be found here: http://ftpmedia.niwa.co.nz/uv/ozone/ozone_lauder.png

Forecasts of the UV Index for a number of sites, including the South Pole and Scott Base can be found here: http://www.niwa.co.nz/our-services/online-services/uv-and-ozone/forecasts

Ultraviolet radiation data from the Dirección Meteorológica de Chile can be found here: http://www.meteochile.cl

Data on ozone and UV radiation from the Antarctic Network of NILU-UV radiometers can be found here: http://polarvortex.dyndns.org

NRT results from the BASCOE data assimilation model can be found here: ftp://ftp-ae.oma.be/dist/macc/BASCOE/NRT

The 2010 WMO/UNEP Scientific Assessment of Ozone Depletion can be found here: http://www.wmo.int/pages/prog/arep/gaw/ozone_2010/ozone_asst_report.html

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The next Antarctic Ozone Bulletin is planned for 8 November 2013.