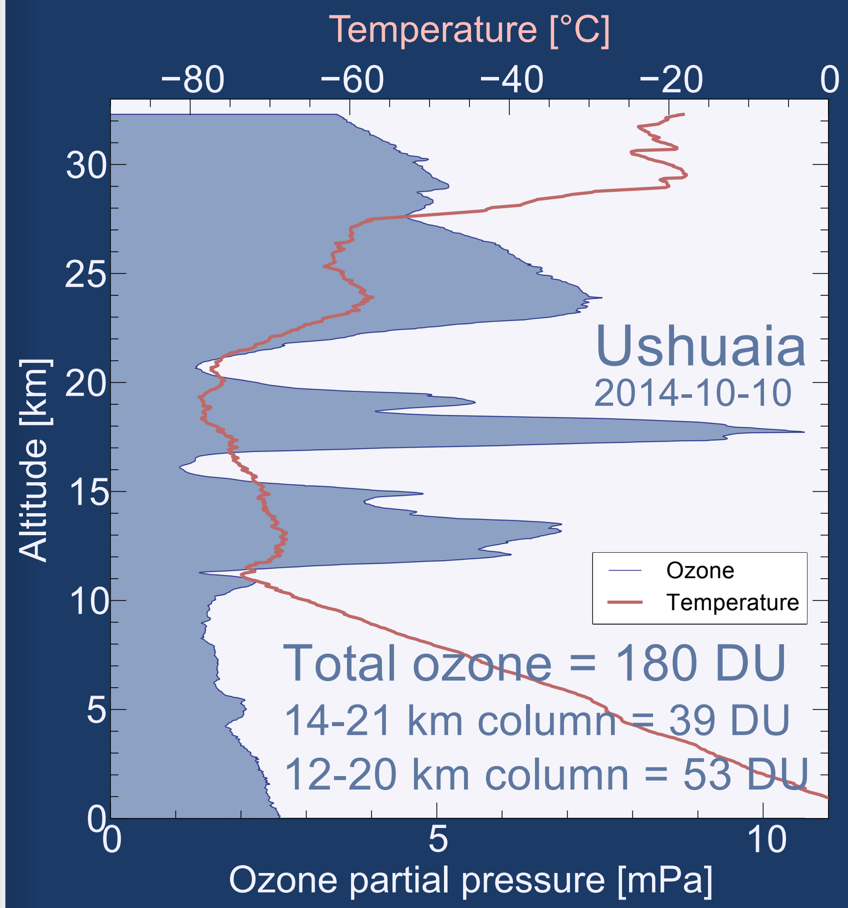
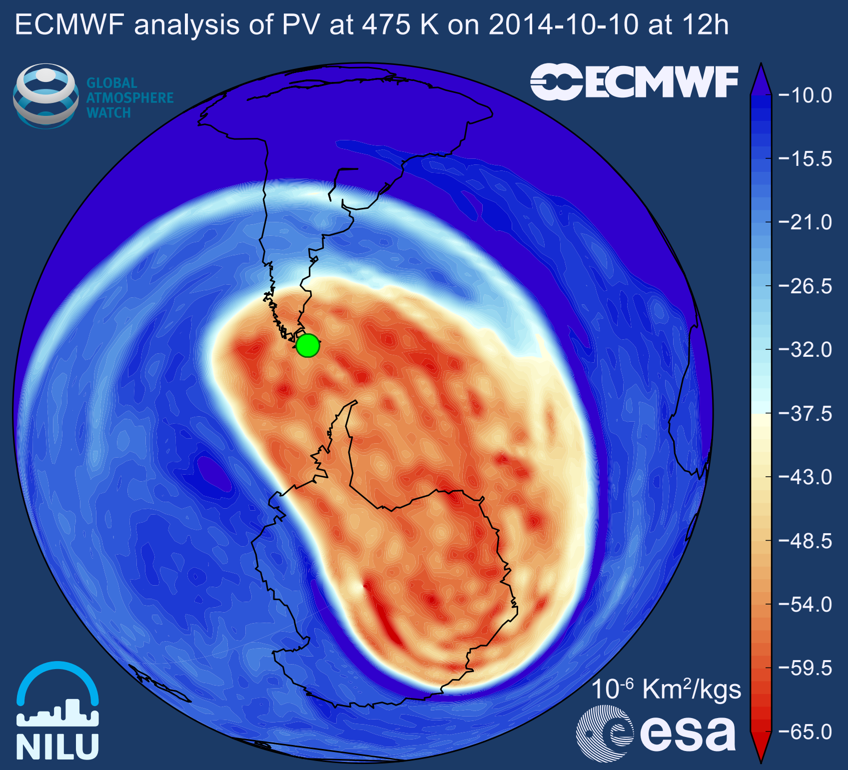
Antarctic Ozone Bulletin

No 4/2014





In 2014, Ushuaia celebrates 20 years as GAW Global station. Ushuaia is situated at the southernmost tip of the South American continent. Occasionally the polar vortex passes over the station and total ozone can drop significantly. The plot on the left shows the ozone profile above the station as measured with an electrochemical ozonesonde on 10 October. One can see two large "bite-outs" of ozone around 16 and 21 km, respectively, indicating that Ushuaia is inside the Antarctic ozone hole. The right hand plot shows potential vorticity (PV) at the 475 K potential temperature level (approx. 19 km altitude). Ushuaia is marked with a green dot. One can see that Ushuaia is well inside the polar vortex. The PV data originates from the European Centre for Medium Range Weather Forecasts (ECMWF) and are made available by the Norwegian Institute for Air Research (NILU) through a project funded by the European Space Agency (ESA).

WMO OMM

17 October 2014

Global Atmosphere Watch

GAW

Executive Summary

Satellite observations show that the area where total ozone is less than 220 DU ("ozone hole area") has been significantly above zero since 6 August. The ozone hole area reached a maximum so far this year on 11 September with 24.1 million square kilometres. A second maximum on 1 October showed an ozone hole area of 23.9 million square kilometres. That is essentially the same as the maximum reached in 2013 (24.0 million km^2) and more than the 21.1 million km^2 reached in 2012.

The ozone mass deficit reached a maximum of 30.1 megatonnes on the 1st of October. That is more than the 24.6 megatonnes reached in 2013 and the 21.6 megatonnes reached in 2012, but less than the 36.8 megatonnes reached in 2011.

Averaging over the period from 7 September to 13 October, which covers the period with the most depletion, the ozone hole area was 19.2 million square kilometres in 2014 vs 19.3 million square kilometres in 2013 and 17.0 million square kilometres in 2012. The ozone mass deficit averaged over the same time period reached 15.5 megatonnes in 2014 vs 15.9 megatonnes in 2013 and 12.8 megatonnes in 2012. To summarise, these numbers show that the 2014 ozone hole is very similar to the one of last year and significantly larger than the one of 2012.

Stratospheric temperatures over Antarctica have been below the PSC type I threshold of 194.6 K since 9 May and below the PSC type II threshold of 187.8 K since 6 June. The daily minimum temperatures at the 50 hPa level were near the 1979-2013 average until mid June. From mid June until late September the minimum temperature was below the long term mean. From early October the minimum temperature has been slightly above the long term mean.

The average temperature 50 hPa over the 60-90°S has been close to the 1979-2013 mean during most of the period winter and spring. From early October the 60-90°S average temperature has been somewhat above the long term mean. At 10 hPa the 60-90°S mean temperature was close to or below the long term mean until mid July. After that it has been close to or somewhat above the long term mean.

Since the onset of NAT temperatures on 9 May the NAT area was near or slightly above the 1979-2012 average until late July. The NAT area reached a peak of 27.2 million km^2 on 21 July. During most of winter the NAT area has been close to or a bit below the NAT area seen in 2013 but larger than in 2012. The NAT volume in 2014 has followed the evolution of 2013 quite closely.

During May and June the 45-day mean of the heat flux was lower than or close to the 1979-2013 average. In July and August the heat flux has been noticeably larger than the long term mean. This is an indication of a relatively unstable vortex. During September it was close to the long term mean. In October it has increased rapidly and is now much larger than the long term mean.

At the 46.4 hPa level (altitude of ~18.5-19.5 km) the vortex is no longer depleted of hydrochloric acid (HCl), one of the reservoir gases that can be transformed to active chlorine. On 11 October the vortex is essentially devoid of active chlorine, which means that ozone depletion has now come to a halt.

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, Artigas, Belgrano, Davis, Dôme Concordia, Dumont d'Urville, Halley, Kerguelen, Macquarie Island, Marambio, Mirny, Neumayer, Novolazarevskaya, Rothera, South Pole, Syowa, Ushuaia, Vernadsky, Vostok and Zhongshan.

In earlier issues of the Bulletin it was forecast that the degree of ozone loss in 2014 would be similar to that observed in 2013 and larger than in 2010 and 2012. With the data now available, this forecast can be confirmed.

In 2014 the polar vortex has been shifted towards the Atlantic sector and South America during long periods. This has led to low ozone over stations on this side of the continent and even reaching as far north as Ushuaia. Stations facing the Pacific sector have been outside of the vortex for long periods and have experienced large total ozone values.

WMO and the scientific community will use ozone observations from the ground, from balloons and from satellites together with meteorological data 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 sun-lit 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 (NO_2).

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 NO_2 under sunlit conditions. If NO_2 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.

Meteorological conditions

Temperatures

Meteorological data from the National Center for Environmental Prediction (NCEP) in Maryland, USA, show that stratospheric temperatures over Antarctica have been below the PSC type I threshold of 194.6 K since 9 May and below the PSC type II threshold of 187.8 K since 6 June, as shown in **Figure 1**. This figure also shows that the daily minimum temperatures at the 50 hPa level were near the 1979-2013 average until mid June. From mid June until late September the minimum temperature was below the long term mean. From early October the minimum temperature has been slightly above the long term mean. On 24 August the minimum temperature dropped more than 2 K below the 1979-2013 minimum for that date.

Figure 2 (upper panel) shows temperatures averaged over the 60-90°S region at 50 hPa. It can be seen from the figure that the average temperature has been close to the 1979-2013 mean during most of the period shown on the graph. From early October the 60-90°S average temperature has been somewhat above the long term mean.

At 10 hPa (**Figure 2**, lower panel), the 60-90°S mean temperature was close to or below the long term mean until mid July. After that it has been close or somewhat above the long term 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.

PSC Area and Volume

Since 27 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 460 K isentropic level (**Figure 3**, upper panel). Since the onset of NAT temperatures in early May the NAT area was near or slightly above the 1979-2013 average until late July. From early August is dipped down for a couple of weeks before picking up again. During September the NAT area was mostly above the long term mean. In October the NAT area has dropped rapidly and is now (13 October) essentially zero. The NAT area reached a peak of 27.21 million km^2 on 21 July. During most of winter the NAT area has been close to or a bit below the NAT area seen in 2013 but larger than in 2012.

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 2014 is shown in **Figure 3** (lower panel) 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 and on some days above the 1979-2013 average. From mid July until mid August the NAT volume stayed below the long-term mean, before picking up in mid August. In September the NAT volume was close to the long term mean. In October it has declined in parallel with the long term mean and within the next few days it will probably reach zero. The NAT volume has in 2014 followed the evolution of 2013 quite closely.

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 also depends on other fac-

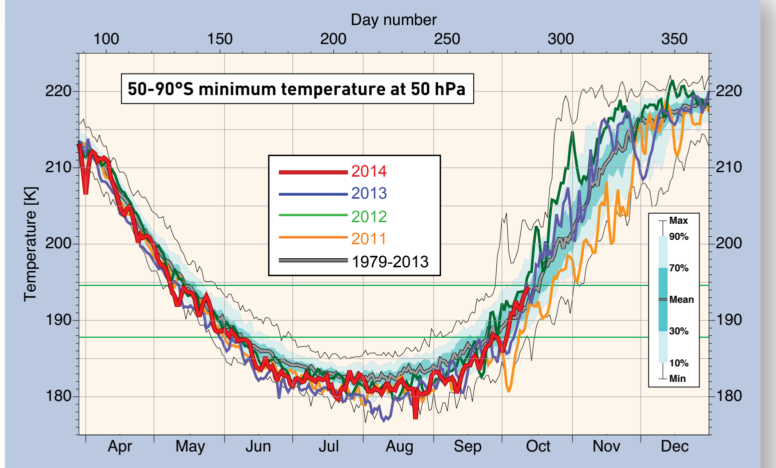


Figure 1. Time series of daily minimum temperatures at the 50 hPa isobaric level south of 50 °S. The red curve shows 2014 (until 13 October). The blue line shows 2013, the green line 2012 and the orange line 2011. The average of the 1979-2013 period is shown for comparison in grey. The thin black lines represent the highest and lowest daily minimum temperatures in the 1979-2013 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.

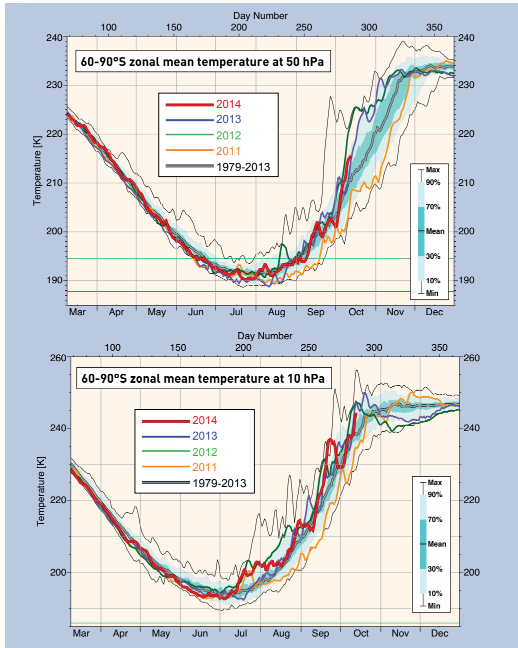


Figure 2. Time series of temperature averaged over the region south of 60 °S at the 50 hPa level (left) and at 10 hPa (right). The red curve shows 2014 (until 13 October). The blue, green and orange curves represent 2013, 2012 and 2011, respectively. The average of the 1979-2013 period is shown for comparison in grey. The two thin black lines show the maximum and minimum average temperature for during the 1979-2013 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.

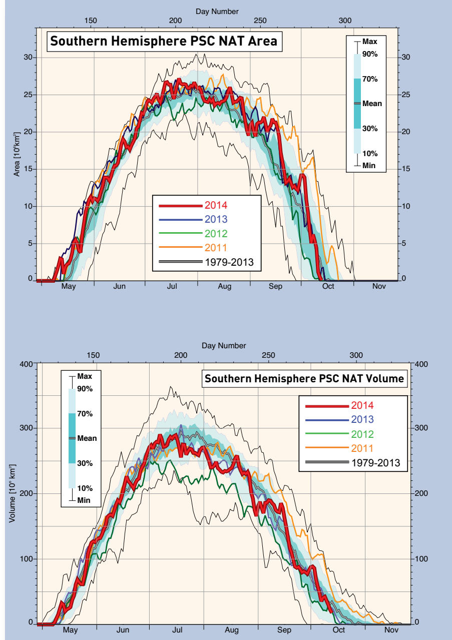


Figure 3. Upper panel: Time series of the area of the region where temperatures are low enough for the formation of nitric acid trihydrate (NAT or PSCs of type I) at the 460 K isentropic level. Lower panel: Time series of the volume of the region where temperatures are low enough for the formation of nitric acid trihydrate (NAT or PSCs of type I). The red curve shows 2014 (until 13 October). The blue, green and orange curves represent 2013, 2013 and 2011, respectively. The average of the 1979-2013 period is shown for comparison in grey. The two thin black lines show the maximum and minimum PSC area during the 1979-2013 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.

tors, such as the amount of water vapour and HNO_3. In earlier issues of the Bulletin it was forecast, based on the amounts of NAT, that the degree of ozone loss in 2014 would be similar to that seen in 2013. As shown later in this Bulletin this turns out to be the case.

Vortex stability

The longitudinally averaged heat flux between 45°S and 75°S is an indication of to what degree the stratosphere is disturbed. During May and June the 45-day mean of the heat flux was lower than or close to the 1979-2013 average. In July and August the heat flux was noticeably larger than the long term mean. During September it was close to the long term mean. In October it has increased rapidly and is now much larger than the long term mean. The development of the heat flux is shown in **Figure 4.** See the figure caption for more details on how to interpret the graph.

Figure 5 shows maps of potential vorticity (PV) at the isentropic level of 475 K. This level corresponds to approximately 19 km altitude. Whereas the vortex was well centred over the South Pole on this date in 2009 and 2010, one can see that in 2013 and 2014 it was shifted towards the Atlantic Ocean and South America. One can also see that the absolute value of the PV was larger (more negative and more red colour) in 2009-2011 than in 2012-2014. This is an indication that the vortex was more stable in mid October of 2009, 2010 and 2011 than in 2012, 2013 and 2014.

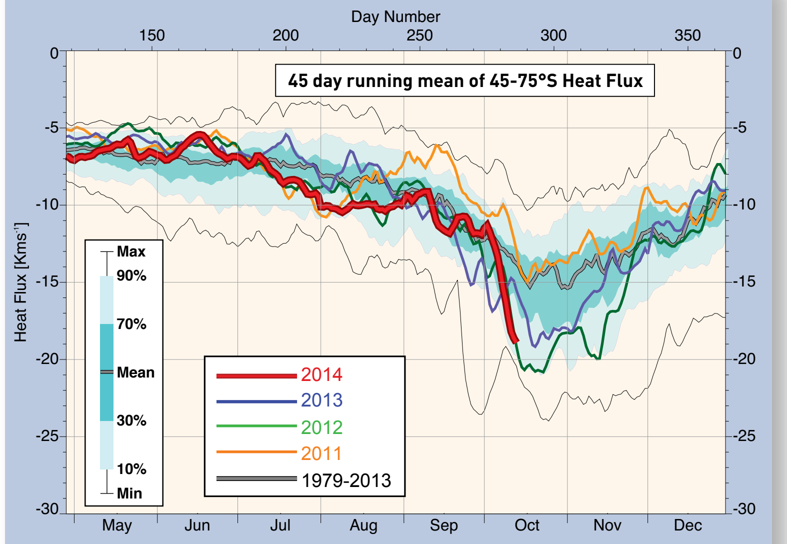


Figure 4. Time series of the meridional heat flux averaged over the 45-75°S region. The red curve shows data for 2014 (updated until 13 October). Please note that a large negative number means a large heat flux. Values closer to zero means a small heat flux. The plot is made at WMO based on data downloaded from the Ozonewatch web site at NASA, which are based on data from NOAA/NCEP.

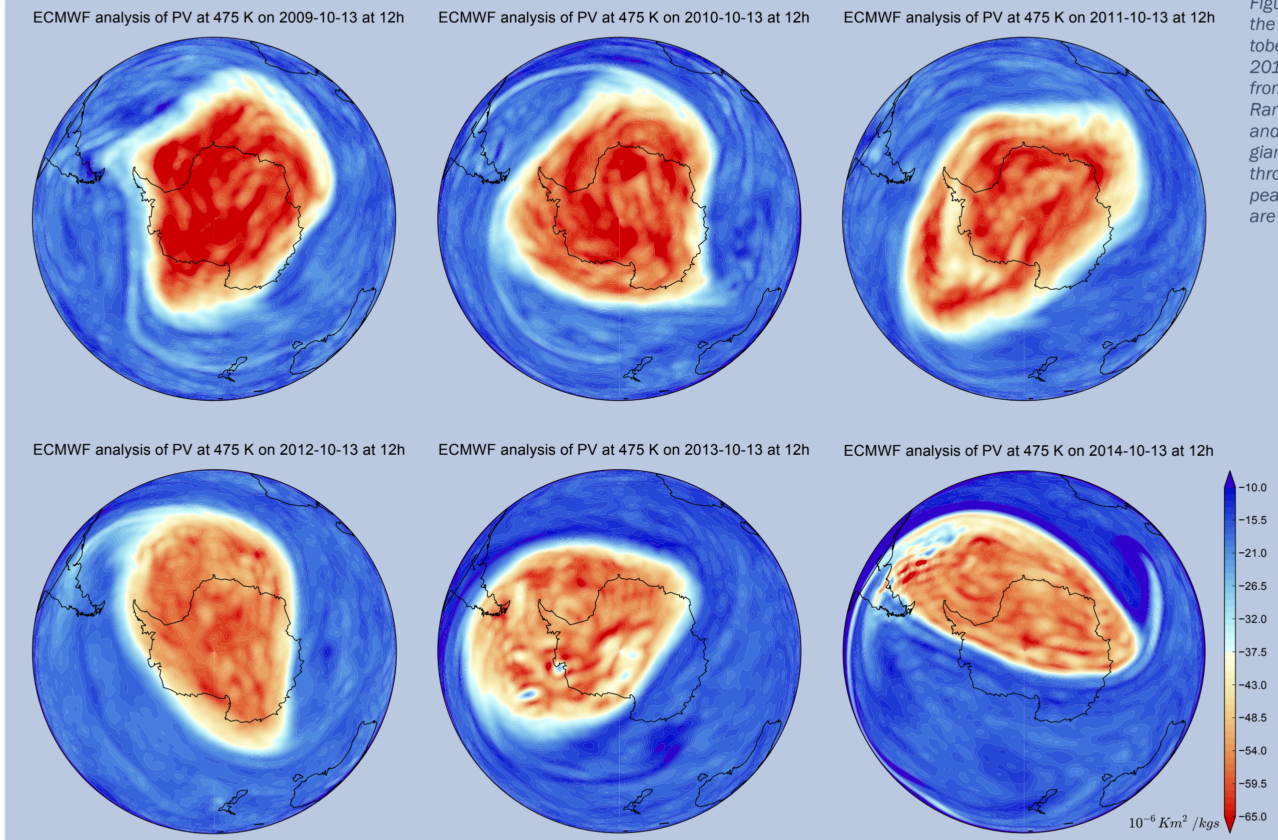


Figure 5. Maps of potential vorticity at the isentropic level of 475 K on 13 October in 2009, 2010, 2011, 2012, 2013 and 2014. The data originates from the European Centre for Medium Range Weather Forecasts (ECMWF) and are made available by the Norwegian Institute for Air Research (NILU) through a project funded by the European Space Agency (ESA). The plots are produced at WMO.

Ozone observations

Satellite observations

The rate of ozone depletion has passed the maximum and is now on the way down. The minimum values of total ozone passed through a minimum on 1 October and are now on the way back up. On 16 October the minimum value is 146 DU. **Figure 6** shows minimum ozone columns as measured by the GOME-2 instrument on board MetOp in comparison with data for recent years back to 2007 (SCIAMACHY and GOME-2). In August, September and so far in October the minimum columns have been close to average for the time of the year in comparison to the seven most recent years. According to data from NASA, the minimum daily ozone went through a minimum of 114 DU on 30 September.

Figure 7 (next page) shows satellite maps from OMI for 7 October for the years 2006 - 2014. From these maps one can see that ozone depletion in 2014 is similar to that seen in 2011 and 2013 and covering a larger area than in 2012. On the other hand, the ozone depleted region covers a smaller area on 7 October in 2014 as compared to the same date in 2006 and 2008.

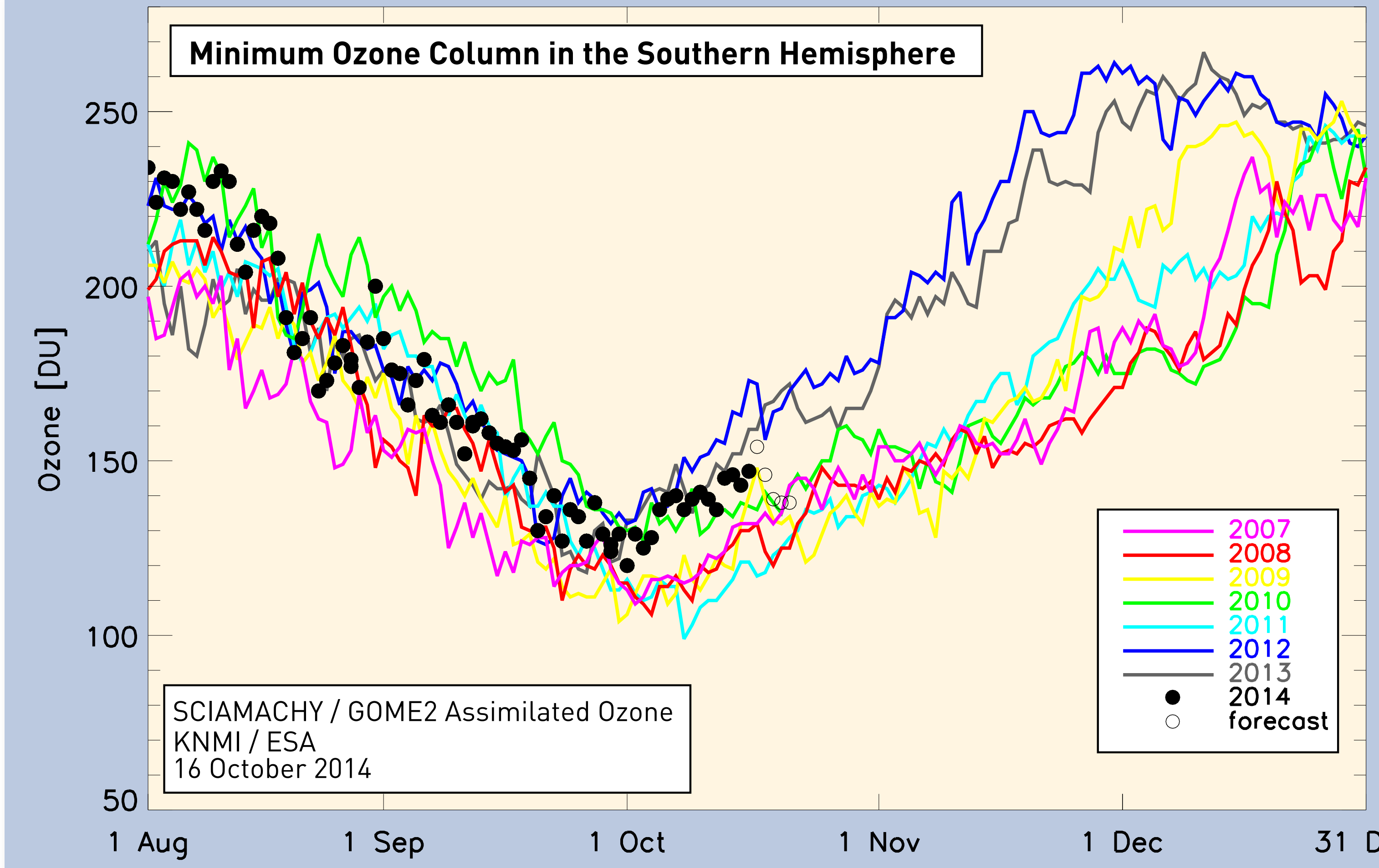


Figure 6. Daily minimum total ozone columns in the Southern Hemisphere as observed by GOME-2, and in the past by SCIAMACHY. The black dots show the GOME-2 observations for 2014 as of 16 October. The data now show minimum ozone columns around 150 DU after going through a minimum of about 120 DU on 1 October. The forecast for the next few days show that minimum ozone will continue to increase before a new drop (open circles on the plot). The figure is adapted from a plot provided by the Netherlands Meteorological Institute (KNMI).

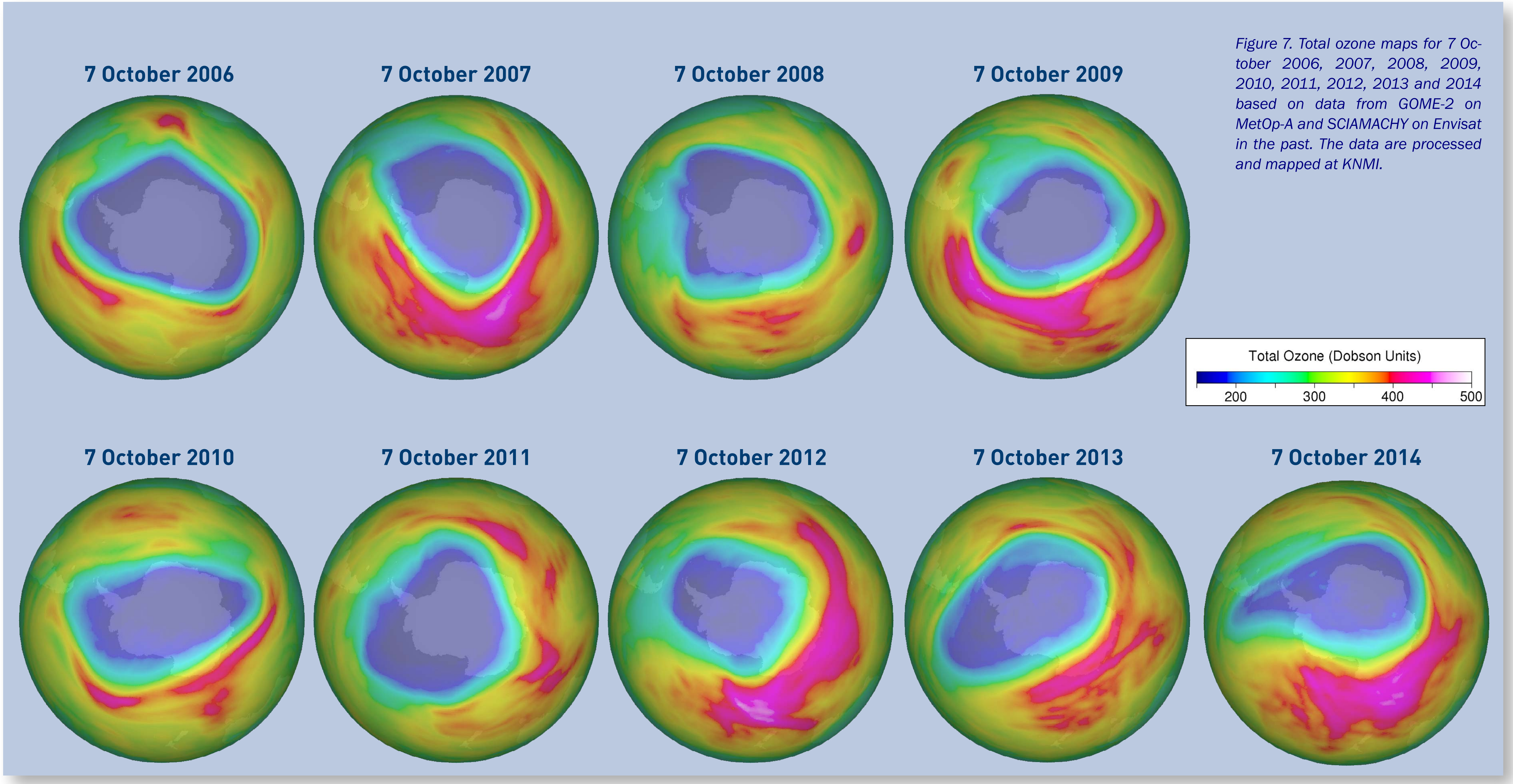
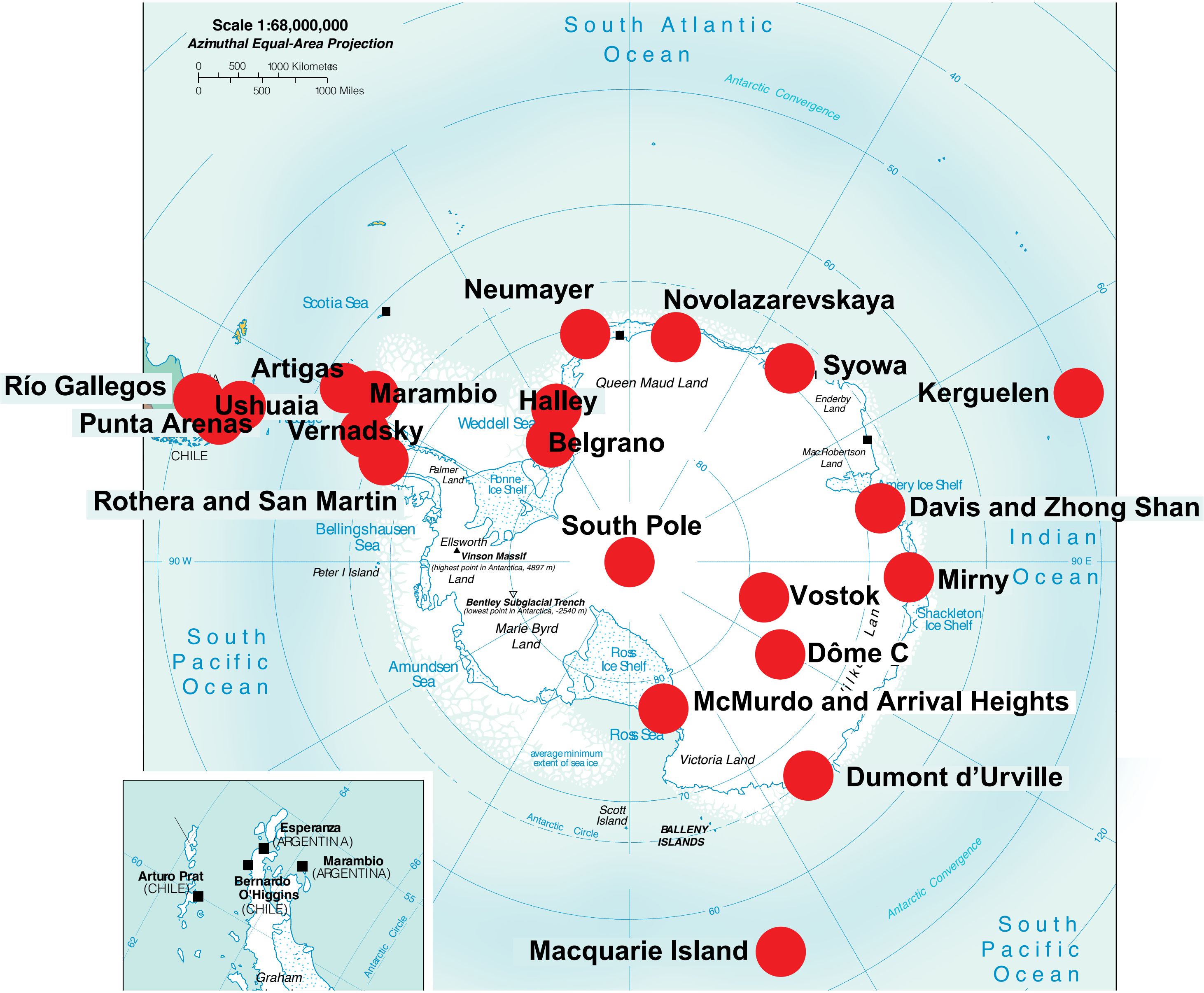


Figure 7. Total ozone maps for 7 October 2006, 2007, 2008, 2009, 2010, 2011, 2012, 2013 and 2014 based on data from GOME-2 on MetOp-A and SCIAMACHY on Envisat in the past. The data are processed and mapped at KNMI.

Ground-based and balloon observa-tions

It is still early in the ozone hole season and the degree of ozone loss is still very modest. Some stations, though, show some first signs of ozone depletion. Most of the stations are already mentioned in this issue. More stations will be presented in forthcoming issues. The map to the right shows the location of the stations that provide data during the ozone hole season. In this issue there is data from Arrival Heights, Artigas, Belgrano, Davis, Dôme C, Dumont d'Urville, Halley, Kerguelen, Macquarie Island, Marambio, Mirny, Neumayer, Novolazarevskaya, Rothera, South Pole, Syowa, Ushuaia, Vernadsky, Vostok and Zhongshan.



The NIWA Observatory at Arrival Heights. Photo: NIWA.

At the GAW/NDACC station Arrival Heights (77.845°S, 166.67°E), operated by New Zealand, Dobson observations have been carried out since January 1988. In 2014, the regular observations of total ozone started after the polar night on 19 September. On that day, total ozone was 230 DU. The following days total ozone dropped below 220 DU. The Dobson data, together with OMI overpass data and long term (1992-2012) statistics can be seen in **Figure 8**. Due to bad weather only a limited number of observations have been possible so far this season.

During the time period from 3 October to 9 October the vortex gradually moved away from Arrival Heights and a maximum of 411 DU was measured on 11 October. This can be seen in **Figure 9**, which shows the 14-21 km partial ozone column based on output from the BASCOE data assimilation model on three selected dates: on 22 September, when total ozone was 183 DU and the 14-21 km partial column was 25 DU, on 4 October, when total ozone was 213 DU and the partial column was 58 DU, and on 11 October when total ozone was 411 DU (from Dobson) and the 14-21 km partial column was 141 DU.

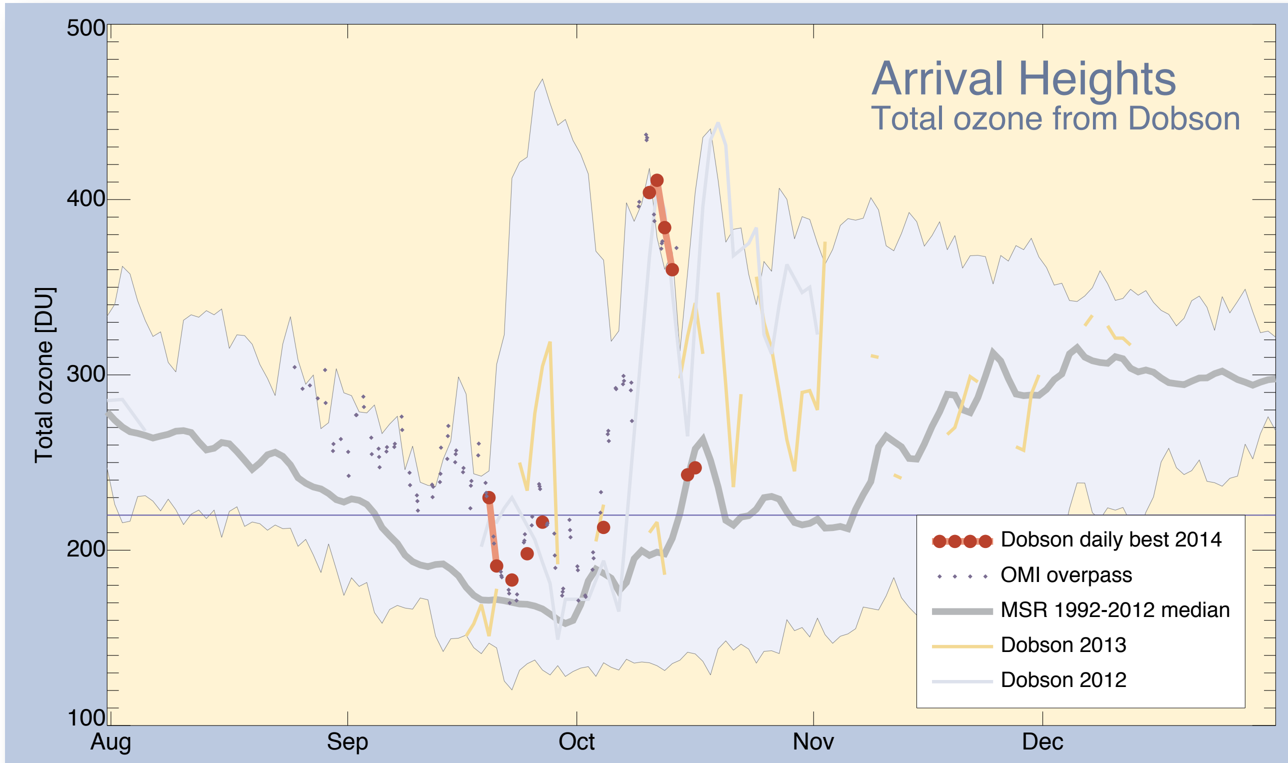


Figure 8. Time series of total ozone from the Arrival Heights Dobson spectrophotometer and satellite overpasses by OMI on board the AURA satellite. Dobson data have been provided by New Zealand's National Institute for Water and Air Research (NIWA). Satellite overpass data have been downloaded from the TEMIS web site. The plot is produced at WMO.

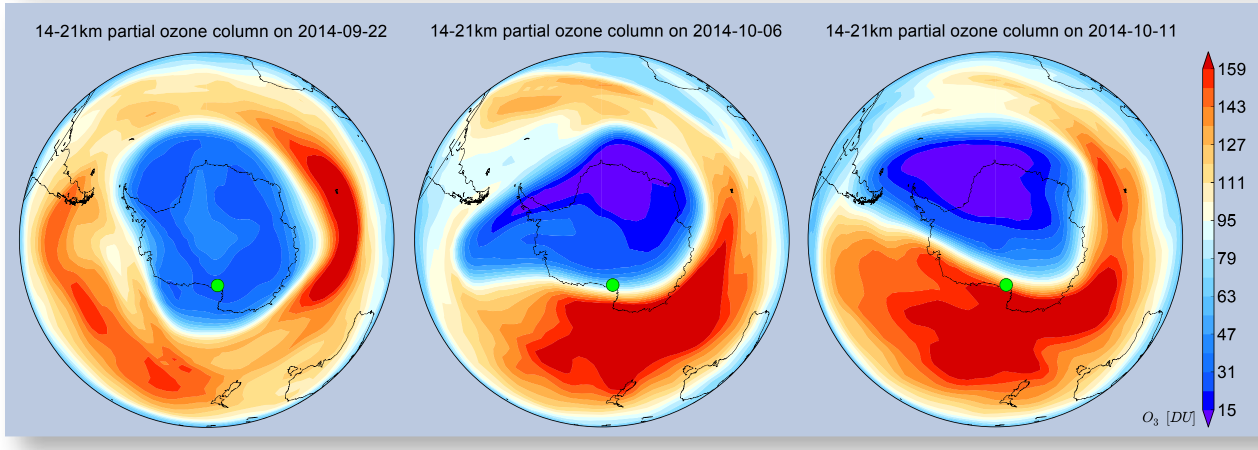


Figure 9. Ozone partial column between 14 and 21 km on three selected dates (see main text) from the BASCOE data assimilation model at IASB. The column is calculated between the levels 41 and 62 in the BASCOE model. These levels correspond to 32.6 and 114.7 hPa, which again correspond to approx. 13.9 and 21.2 km, respectively. This model assimilates data from the Microwave Limb Sounder (MLS) on board AURA. The location of the Arrival Heights station is marked with a green circle. One can see how the ozone depleted regions gradually moves away from the station. The colour scale is the same for all the three plots.

The Brewer instrument taking ozone measurements at Artigas.

The ozone station Artigas (62.1847°S and 58.9040°W) is located on the King George Island, which is the largest of the South Shetland Islands, lying 120 kilometres off the coast of Antarctica. It is the northernmost ozone observatory in Antarctica. Total ozone is measured with a Brewer spectrophotometer. Ozone has been measured here since 1998. The measurements are carried out in collaboration between the *Instituto Antártico Uruguayo* and the *Servicio Meteorológico de la Fuerza Aérea Uruguaya.* Brewer data for 2014 together with data from 2013 and data for the last part of 2012 are shown in **Figure 10** together with OMI overpass data. In the figure one can see the large variations in total ozone as the polar vortex moves back and forth over the station. The maps in **Figure 11** show the 14-21 km partial ozone column as calculated by the BASCOE data assimilation model. One can see from these maps that Artigas was inside the vortex and influenced by ozone depleted air masses on 25 August (total ozone 156 DU), outside the vortex and influenced by middle latitude air masses on 1 September (total ozone 373 DU) and back inside the vortex on 15 September with a total column of ozone down to 143 DU. The 14-21 km partial column above Artigas on these three dates was 74, 118 and 43 DU, respectively.

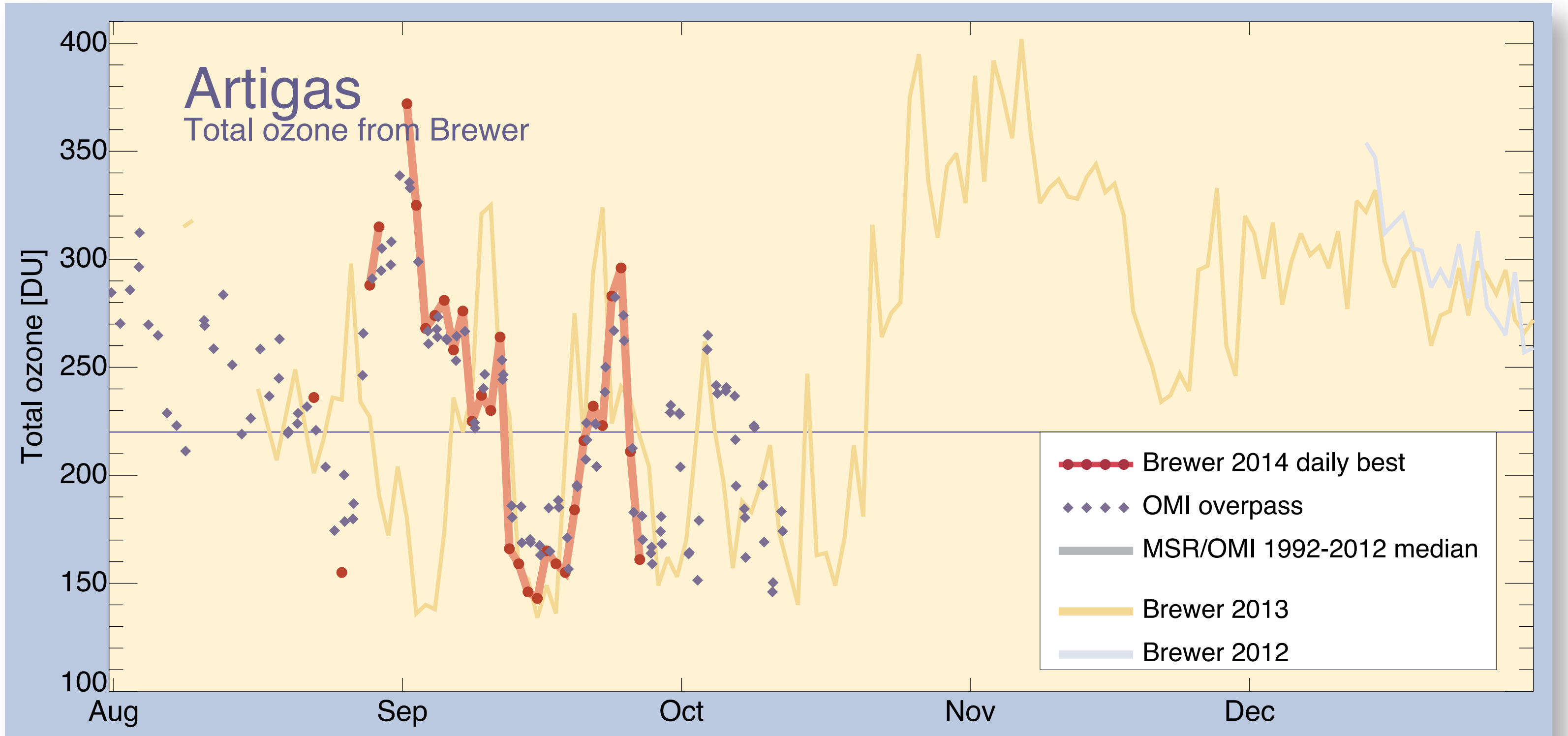


Figure 10. Brewer observations at the Uruguayan station Artigas, located on King George Island, just off the coast of the Antarctic Peninsula. The OMI data has been downloaded from the TOMS ftp server at NASA.

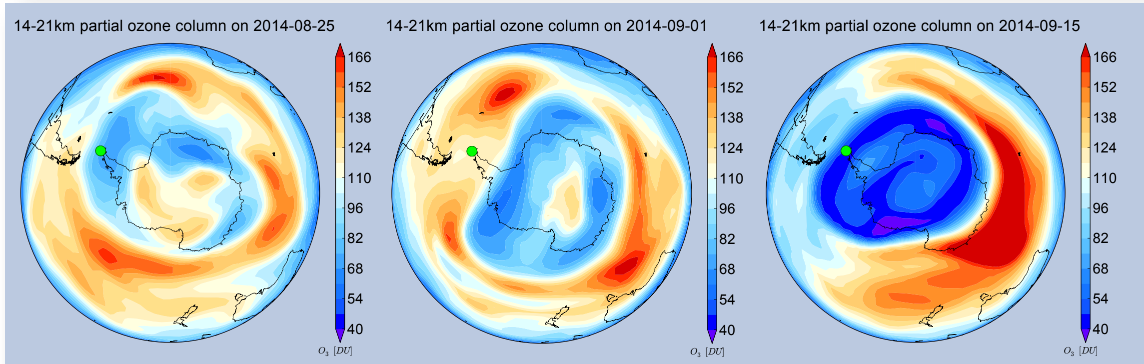


Figure 11. Ozone partial column between 14 and 21 km from the BASCOE data assimilation model at IASB. The column is calculated between the levels 41 and 62 in the BASCOE model. These levels correspond to 32.6 and 114.7 hPa, which again correspond to approx. 13.9 and 21.2 km, respectively. This model assimilates data from the Microwave Limb Sounder (MLS) on board AURA. The location of the Artigas station is marked with a green circle. The three days displayed here were chosen due their extreme total ozone values from the figure above: The low total ozone value of 156 DU on 25 August, the high ozone value of 373 DU on 1 September and the low total ozone value of 143 DU on 15 September.

Belgrano

Ozonesonde launch at Belgrano.

The vertical distribution of ozone is measured at the Argentine GAW station Belgrano (77.88°S, 34.63°W) with electrochemical ozonesondes. Four sondes were launched in August, five in September and three so far in October. The profiles are shown in **Figure 12**. No clear sign of ozone depletion can be seen in the August profiles, whereas the profiles in September and October show clear signatures of ozone depletion in the 14-21 km altitude range with total column ozone below 220 DU. Maps of the partial ozone column for the altitude region most affected by ozone depletion (14-21 km) calculated by the BASCOE data assimilation model are shown in **Figure 13**. These maps confirm the ozonesonde data, namely that no substantial ozone loss had occurred by 20 August over Belgrano. However, during September and October one can clearly see that the 14-21 km column has been reduced. The profile measured on 1 October shows a 14-21 km partial ozone profile of 13 DU, one of the lowest measured anywhere this year.

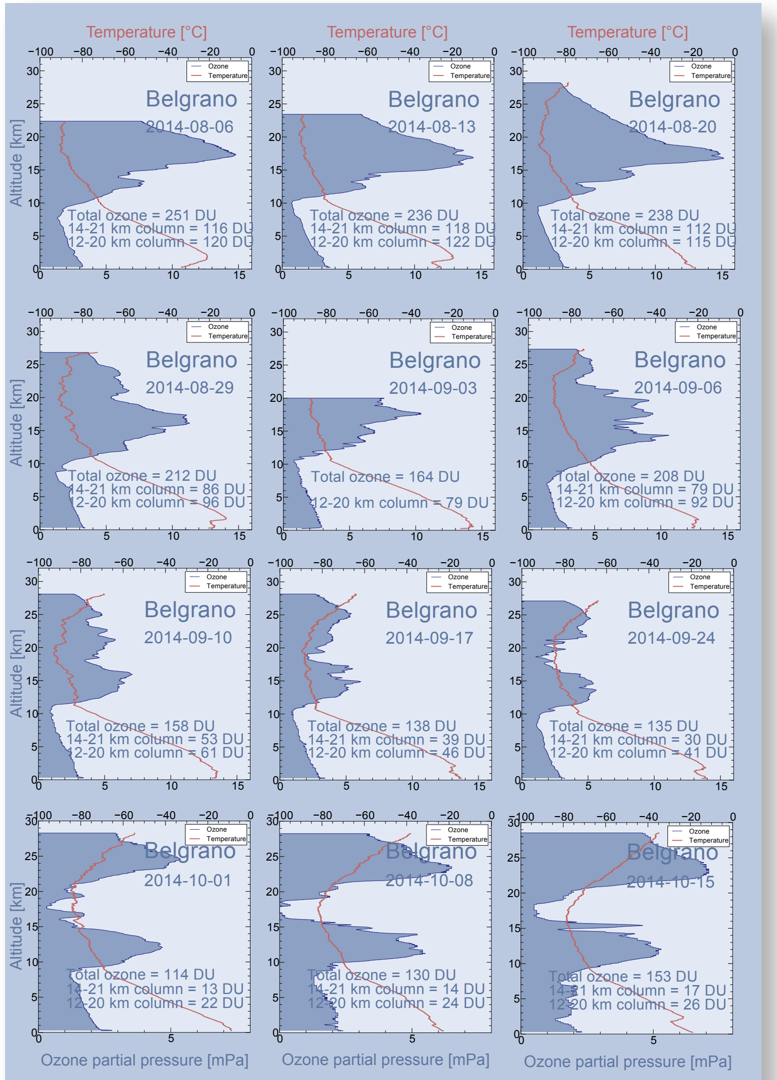


Figure 12. Ozonesonde profiles measured at Belgrano from 6 August to 15 October 2014. One can see that ozone in the 14-21 km altitude range has been drastically reduced from the end of August and into September and especially in October.

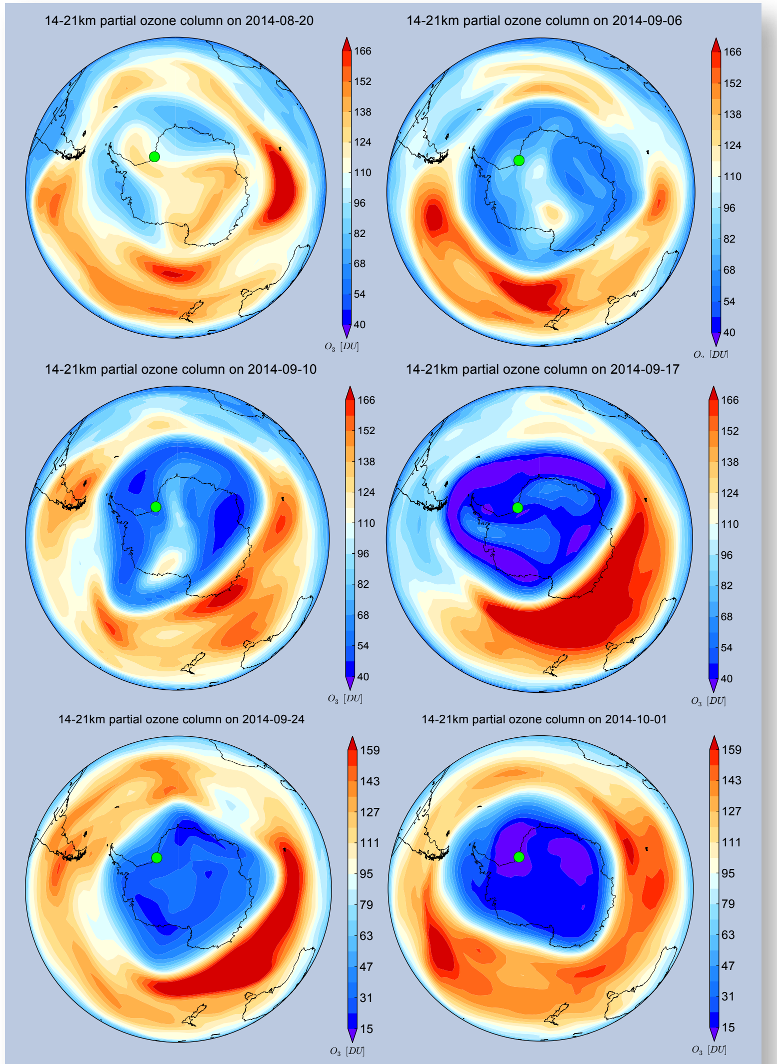


Figure 13. Ozone partial column between 14 and 21 km from the BASCOE data assimilation model at IASB. The column is calculated between the levels 41 and 62 in the BASCOE model. These levels correspond to 32.6 and 114.7 hPa, which again correspond to approx. 13.9 and 21.2 km, respectively. This model assimilates data from the Microwave Limb Sounder (MLS) on board AURA. The location of the Belgrano station is marked with a green circle. Please note that the lower end of the colour scale has been reduced to 15 DU on the two lower plots since ozone has been depleted throughout the vortex during the latter half of September.

Bureau of Meteorology observer Gavin Heatherington-Tait launching an ozonesonde from Davis. Photo: Australian Bureau of Meteorology.

From the Australian GAW site Davis (68.58°S, 77.47°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 with support from the Chinese Academy of Meteorological Sciences. **Figure 14** shows ozone profiles measured between 3 September and 15 October. The 3 September profile shows some ozone "bite-outs" and total ozone is just below 220 DU. By 24 September ozone is significantly depleted over the whole 15-20 km altitude range. The situation is similar on 1 October. On 15 October there is almost complete ozone destruction between 15 and 16 km. Total ozone deduced from the sonde is 183 DU on 15 October, the lowest so far this season at Davis. The temporal development of the 12-20 km partial ozone column deduced from the soundings is shown in **Figure 15**. The decline has been steady and the 15 October profile shows the lowest value observed this season. Maps of the 14-21 km partial ozone column as calculated by the BASCOE data assimilation model are shown in **Figure 16**. These maps show that the station is inside the vortex on both 24 September and 1 October, although it is closer to the vortex edge on 1 October.

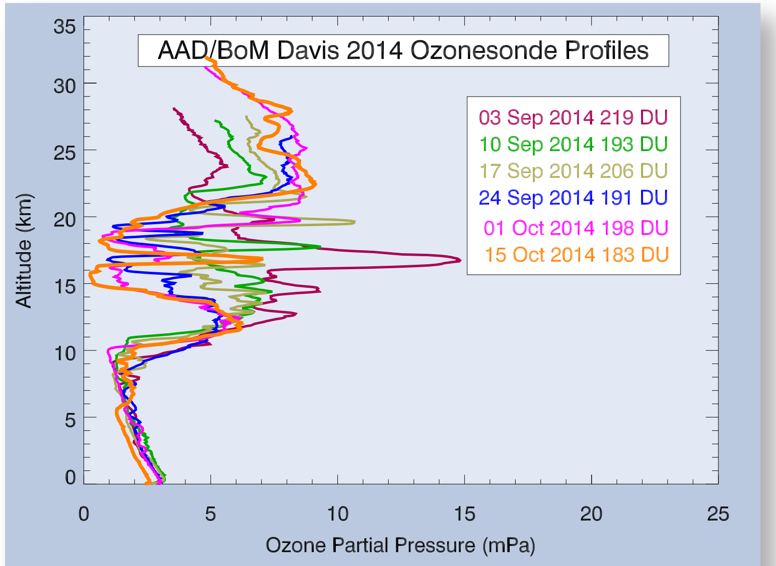


Figure 14. Ozonesonde profiles measured at Davis between 3 and 24 September 2014. The plot has been provided by Matt Tully, Australian Bureau of Meteorology.

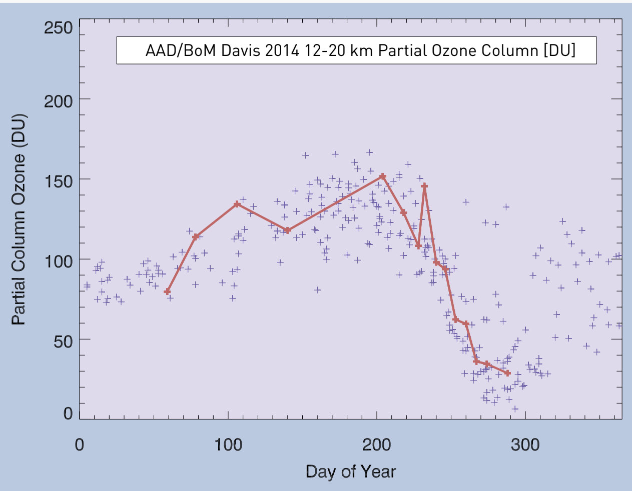


Figure 15. Partial ozone columns between 12 and 20 km from soundings at Davis. The thick red curve shows the data from 2014. The blue crosses show all data from 2003-2013. The plot has been provided by Matt Tully, Australian Bureau of Meteorology.

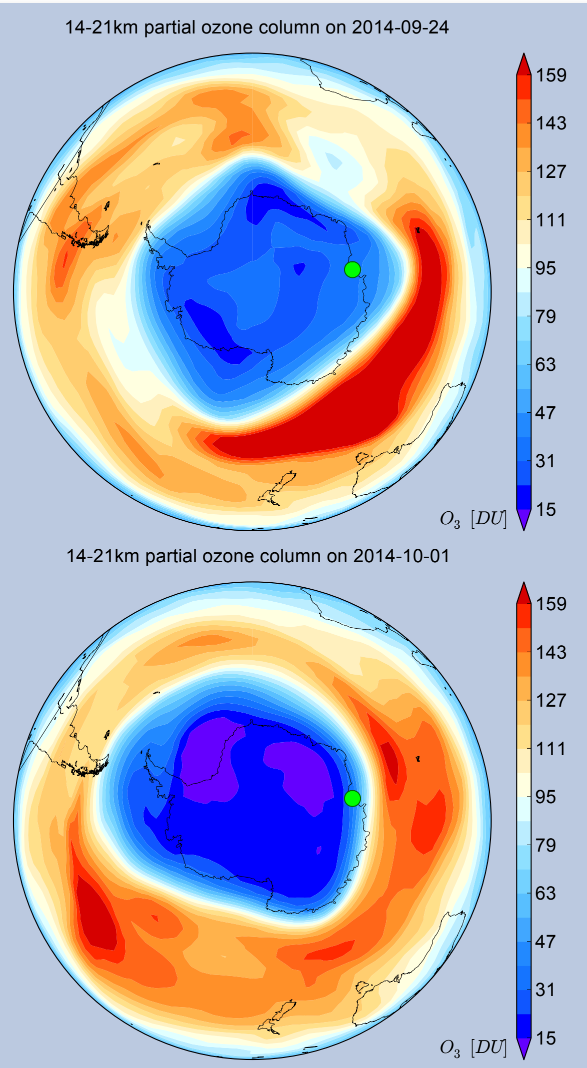


Figure 16. The partial ozone column between 14 and 21 km from the BASCOE data assimilation model at IASB. Maps are shown for 24 September and 1 October. On 24 September the station is deeper inside the vortex than on 1 October. In both cases the 14-21 km column is low (38 DU on 24 Sept. and 46 DU on 1 Oct.) The BASCOE model assimilates data from the Microwave Limb Sounder (MLS) on board AURA. The location of Davis station is marked with a green circle.

The twin buildings at Dôme Concordia. Photo: Marco Maggiore.

Total ozone is measured with a SAOZ spectrometer at the French/Italian GAW/NDACC station at Dôme Concordia (75.0998870°S, 123.333487°E, 3250 masl) on the Antarctic ice cap. The measurements started up again on 9 August after the polar night. **Figure 17** shows the 2014 measurements in comparison with data from the two previous years as well as some long term statistics. The maps in **Figure 18** show the 14-21 km partial ozone column on 13 September when total ozone was the highest observed this season and on 1 October when total ozone was the lowest so far.

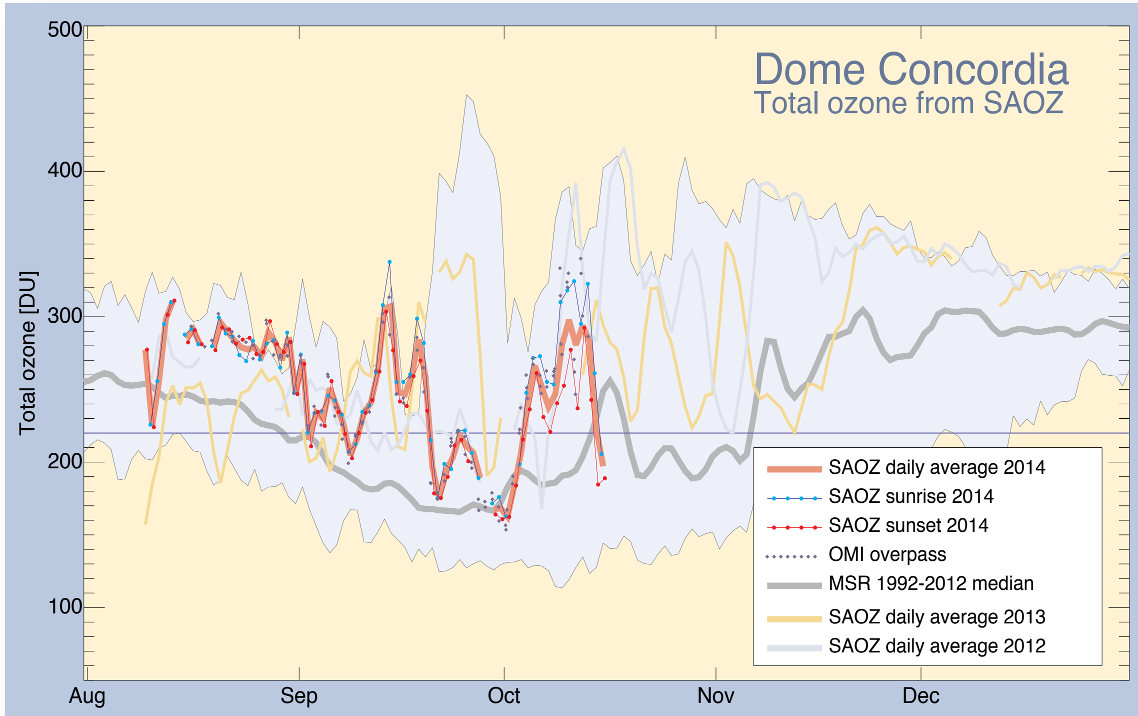


Figure 17. Time series of daily mean total ozone in 2014, in comparison to earlier years, as measured by a SAOZ spectrometer at Dôme Concordia.

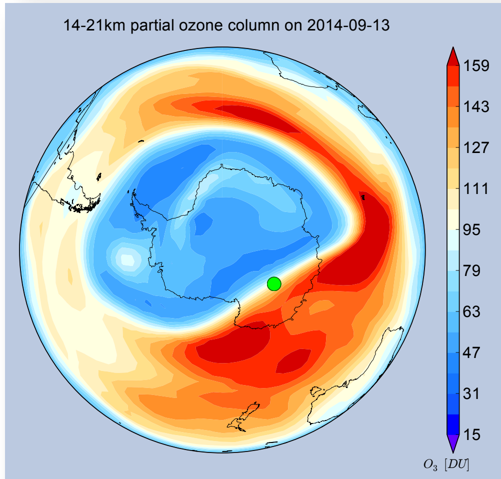


Figure 18. BASCOE maps of the 14-21 km partial ozone column on 13 September and on 1 October. From the figure one can see that Dôme Concordia is located under the vortex on 13 September. Total ozone on that day was around 300 DU. On 1 October the station is well inside the polar vortex and total ozone is around 160 DU .

Aerial view of the Dumont d'Urville station.

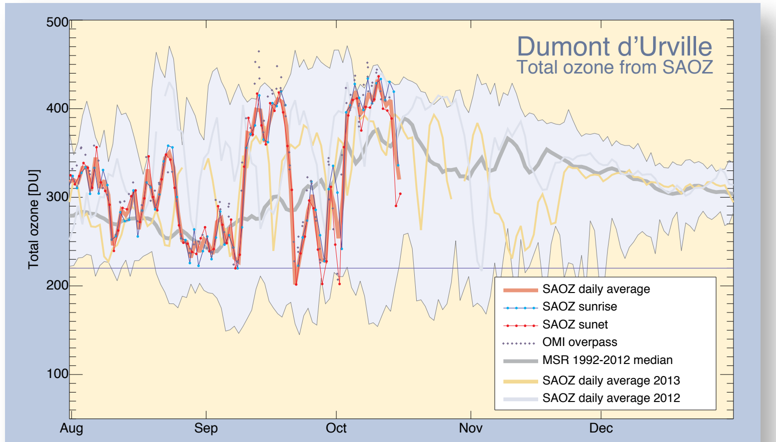


Figure 19. Time series of daily mean total ozone in 2014, in comparison to earlier years, as measured by a SAOZ spectrometer at Dumont d'Urville.

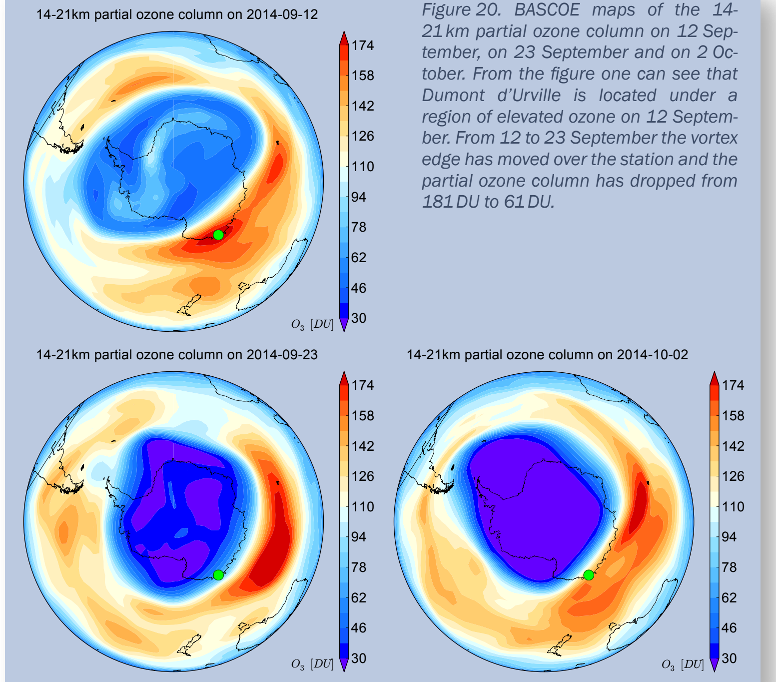


Figure 20. BASCOE maps of the 14-21 km partial ozone column on 12 September, on 23 September and on 2 October. From the figure one can see that Dumont d'Urville is located under a region of elevated ozone on 12 September. From 12 to 23 September the vortex edge has moved over the station and the partial ozone column has dropped from 181 DU to 61 DU.

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. **Figure 19** shows the progression of daily averaged ozone together with sunrise and sunset values. The daily average value is calculated as the mean of the total ozone values at sunrise and sunset. On some days, when the vortex edge is over the station, the difference between the sunrise and sunset values can reach several tens of DU. On 12-13 September total ozone went above 400 DU as seen in **Figure 19**. The upper BASCOE map of the 14-21 km partial ozone column (**Figure 20**) shows that Dumont d'Urville on 12 September is located outside the polar vortex and in a region with elevated amounts of ozone.

Ozone soundings carried out between 2 August and 2 October are shown in **Figure 21**. These ozone profiles show clearly how the profile changes when the vortex moves over the station. On 12 September the station is well outside the vortex and the profile is a typical middle latitude profile and total ozone is 463 DU. On 23 September the station is at the vortex edge and total ozone has dropped to 279 DU. The 14-21 km column is 46 DU, which is a sign of substantial ozone depletion. On 2 October the station is again under the vortex edge and the 14-21 km partial ozone column is 100 DU. However, around 16 km there is a "bite-out", so the station is not entirely outside of the vortex at all levels.

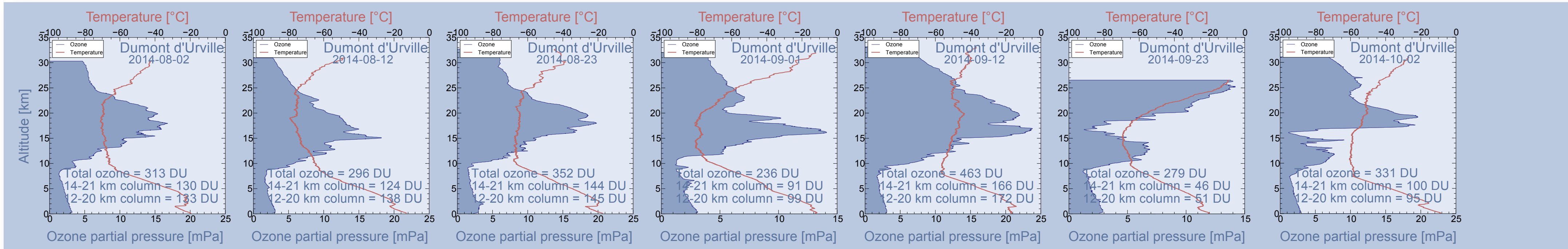


Figure 21. Ozone soundings performed at Dumont d'Urville between 2 August and 23 September. Please note that the abscissa scale has been changed on the 23 September plot since there is much less ozone than on the other dates. On 23 September one can see a large "bite-out" of ozone centred around 17 km.

Halley

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 and the first measurement after the polar winter was carried out on 28 August. The Dobson observations are shown on the next page in **Figure 22**. It can be seen that with the total ozone values have oscillated around the 1992-2012 median.

In early 2013 a SAOZ spectrometer was put into service at Halley. The SAOZ instrument measures the scattered light from zenith around sunrise and sunset. This allows for measurements at higher solar zenith angles, which leads to a longer measurement season. In 2014 the SAOZ measurements started up again on 26 August after the polar winter with a total ozone value of 200 DU. After that total ozone has been below the 220 DU threshold on most days. On 18 September total ozone dropped to 129 DU, which is below the 1992-2012 minimum deduced from the MSR data set. From 30 September until 5 October, total ozone varied between 111 and 114 DU, which is lower than the 1992-2012 minima from the MSR data set. The SAOZ data are somewhat lower than the Dobson data and since the data are preliminary they should be used with caution. **Figure 23** shows the SAOZ total ozone time series at Halley for 2014 together with long term statistics (1992-2012) and OMI overpass data.

The new Halley Research station (Halley VI). Photo: Jonathan Shanklin, British Antarctic Survey. More information about the new Halley Station can be found at: http://en.wikipedia.org/wiki/Halley_Research_Station

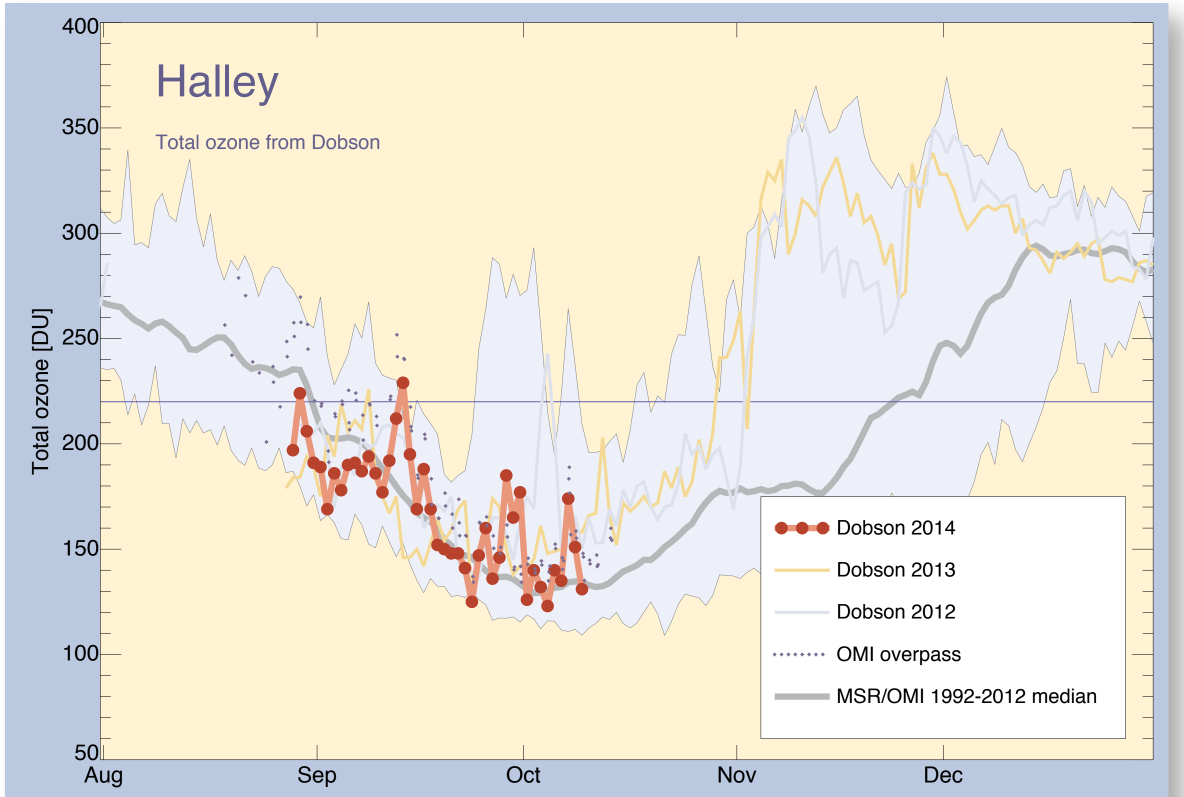


Figure 22. Time series of daily mean total ozone in 2014, as measured by a Dobson spectrophotometer at Halley. The thick grey line shows the median ozone column for the 1992-2012 time period based on MSR data from KNMI. The grey shaded area shows historical maxima and minima calculated for the 1992-2012 time period. The plot is produced at WMO based on data downloaded from WOUDC, from Jonathan Shanklin's Antarctic web site at British Antarctic Survey and from the TEMIS web site at KNMI.

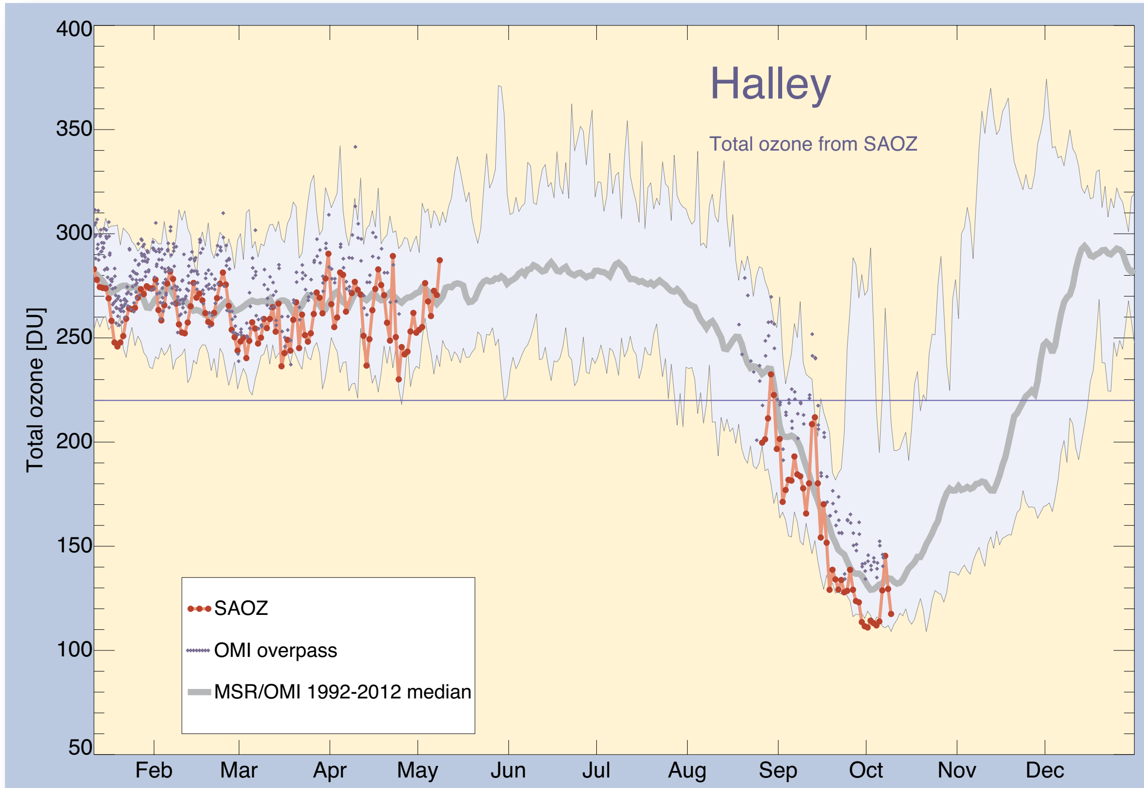


Figure 23. Time series of total ozone in 2014, as measured by a newly deployed SAOZ spectrometer at Halley starting in late January 2013. The pink line with dark red circles shows the daily average ozone column. The blue diamonds show the OMI overpass data. The plot is produced at WMO based on data downloaded from Jonathan Shanklin's Antarctic web site at British Antarctic Survey.

Aerial view of the French research station at the Kerguelen Islands

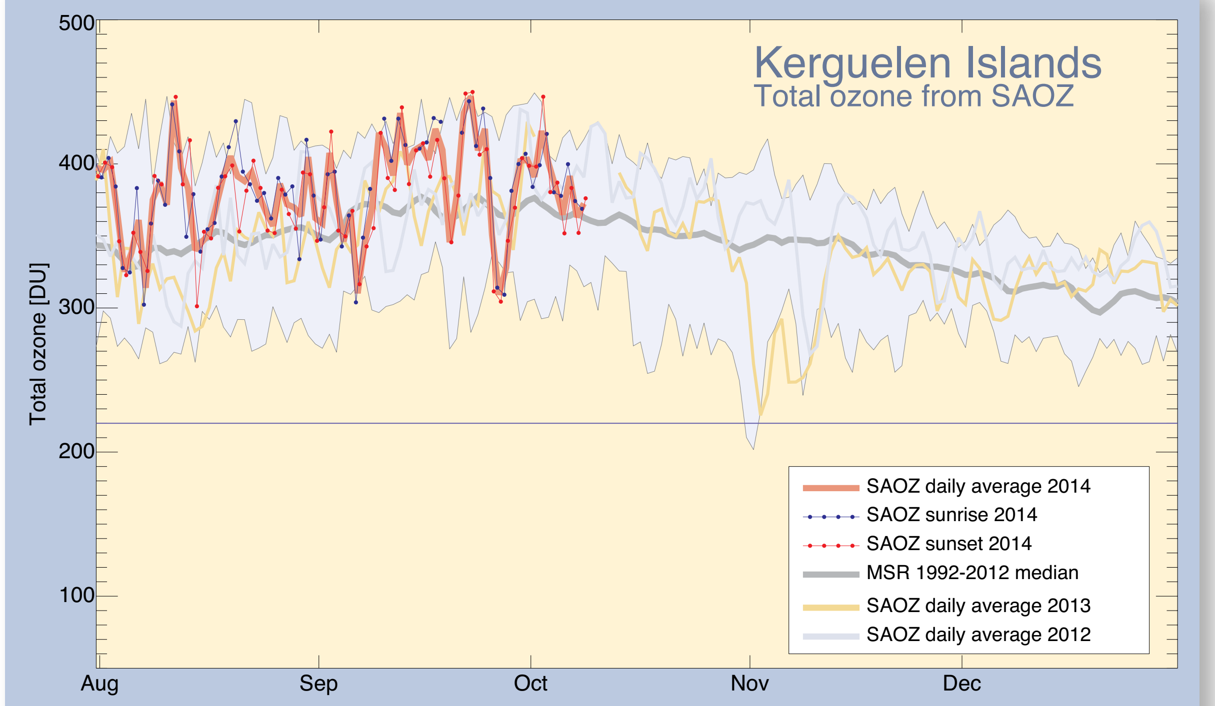


Figure 24. Total ozone above Kerguelen Islands from August 2014. The small blue and red circles show SAOZ morning and evening total ozone values, respectively. Observations from 2102 and 2013 are also shown. The plot shows the 2 November 2013 episode when the south polar vortex passed over the Kerguelen Islands giving rise to unusually low total ozone values just above 200 DU. After moving away for a couple of days the vortex came back on 6-9 November.

The Kerguelen Islands, also known as the Desolation Islands, are a group of islands in the southern Indian Ocean constituting one of the two emerged parts of the mostly submerged Kerguelen Plateau. Among the most isolated places on Earth, they are more than 3,300 km away from the nearest populated location. The islands, along with Adélie Land, the Crozet Islands and the Amsterdam and Saint Paul Islands are part of the French Southern and Antarctic Lands and are administered as a separate district. There are no indigenous inhabitants, but France maintains a permanent presence of 50 to 100 engineers and researchers.

At Kerguelen Islands there is a GAW/NDACC station (49.35°S, 70.28°E, 29 masl) equipped with a SAOZ spectrometer. Usually, Kerguelen is well outside the polar vortex, but on rare occasions the vortex might pass over the islands. The SAOZ ozone observations for 2014 are shown in **Figure 24** together with data from 2012 and 2013.

Macquarie Island

Dobson observations taken by Bureau of Meteorology observer Craig George at Macquarie Island. Photo: BoM.

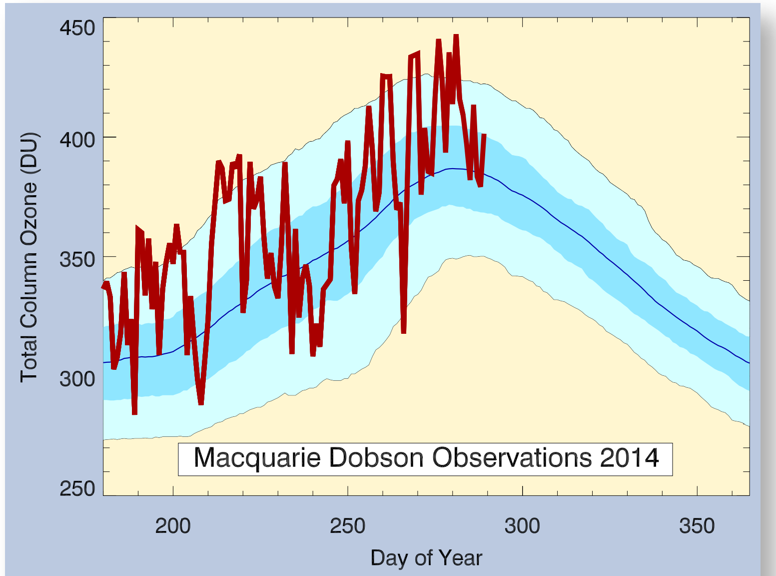


Figure 25. Dobson observations carried out at Macquarie Island in 2014 in comparison with long term (1987-2013) statistics.

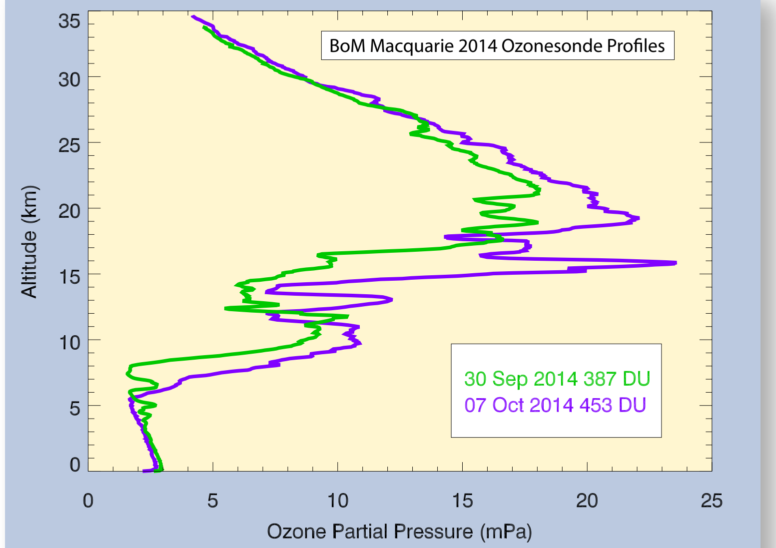


Figure 26. Ozone profiles over Macquarie Island measured with electrochemical ozonesondes.

The GAW/NDACC station Macquarie Island is located at 54.499531°S and 158.937170°E. Dobson observations of total ozone have been made there since 1957.

The plot (**Figure 25**) shows daily total ozone values in August, September and early October 2014 (red line) compared to the 1987-2013 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. One can see that total ozone was unusually high and above the 90th percentile line in early October.

Ozonesondes are launched at Macquarie approximately once per week. **Figure 26** shows profiles from flights launched on 30 September and 7 October. None of these profiles shows any signs of ozone depletion.

Seals and emperor penguins at Macquarie Island.

Marambio

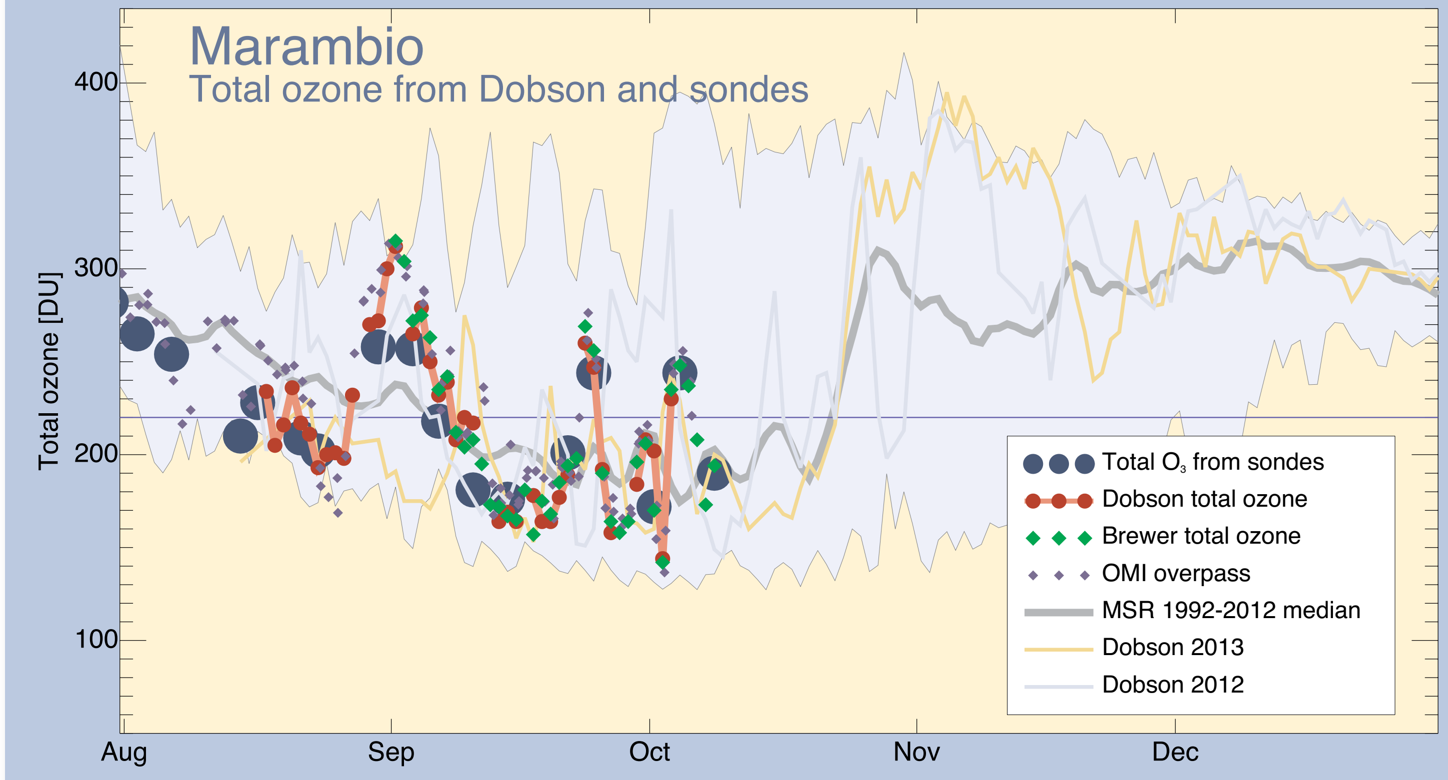


Figure 27. Total ozone over Marambio as measured by a Dobson spectrophotometer (orange line with red dots) and by ozonesondes (large blue dots). For comparison satellite over pass data from OMI are also shown (small violet diamonds). The median and maximum and minimum values from satellite measurements for the 1992-2012 period are shown to put current data into context.

Total ozone is measured at the Argentine GAW station Marambio (64.2°S, 56.6°W) both with a Brewer MkIII instrument and with a Dobson instrument. The Dobson and Brewer data are reported daily to WMO's Global Telecommunication System (GTS) in CREX format since 19 August. Except for a period in late August and early September, total ozone has been below the 1992-2012 median derived from the MSR data set. The Dobson observations for 2014 are shown in **Figure 27** together with satellite overpass data and Dobson data from 2012 and 2013. Total ozone derived from ozonesondes is also shown. Long term statistics based on the MSR data set is shown for comparison.

Partial column ozone over the 14-21 km altitude range is shown in **Figure 28** for two selected dates: 4 October when total ozone was above relatively high and on 11 October when total ozone dropped to 169 DU. One can see that Marambio was

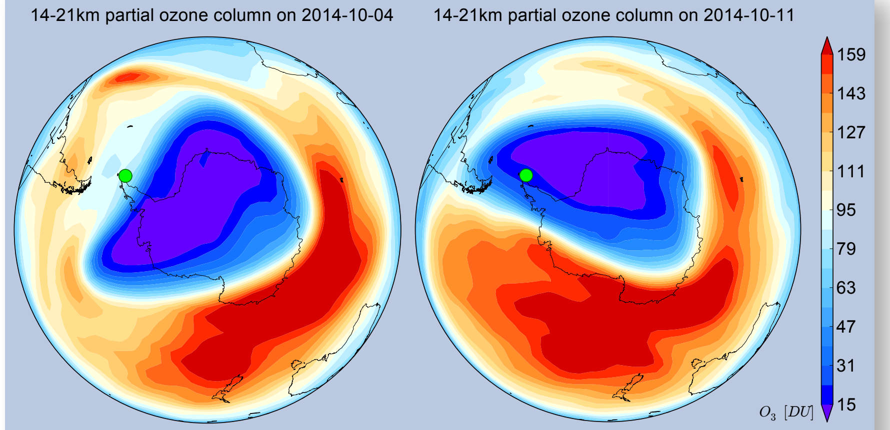


Figure 28. The partial ozone column between 14 and 21 km from the BASCOE data assimilation model at IASB. The dates have been chosen to coincide with ozone soundings (see next page). This model assimilates data from the Microwave Limb Sounder (MLS) on board AURA. The location of Marambio station is marked with a green circle.

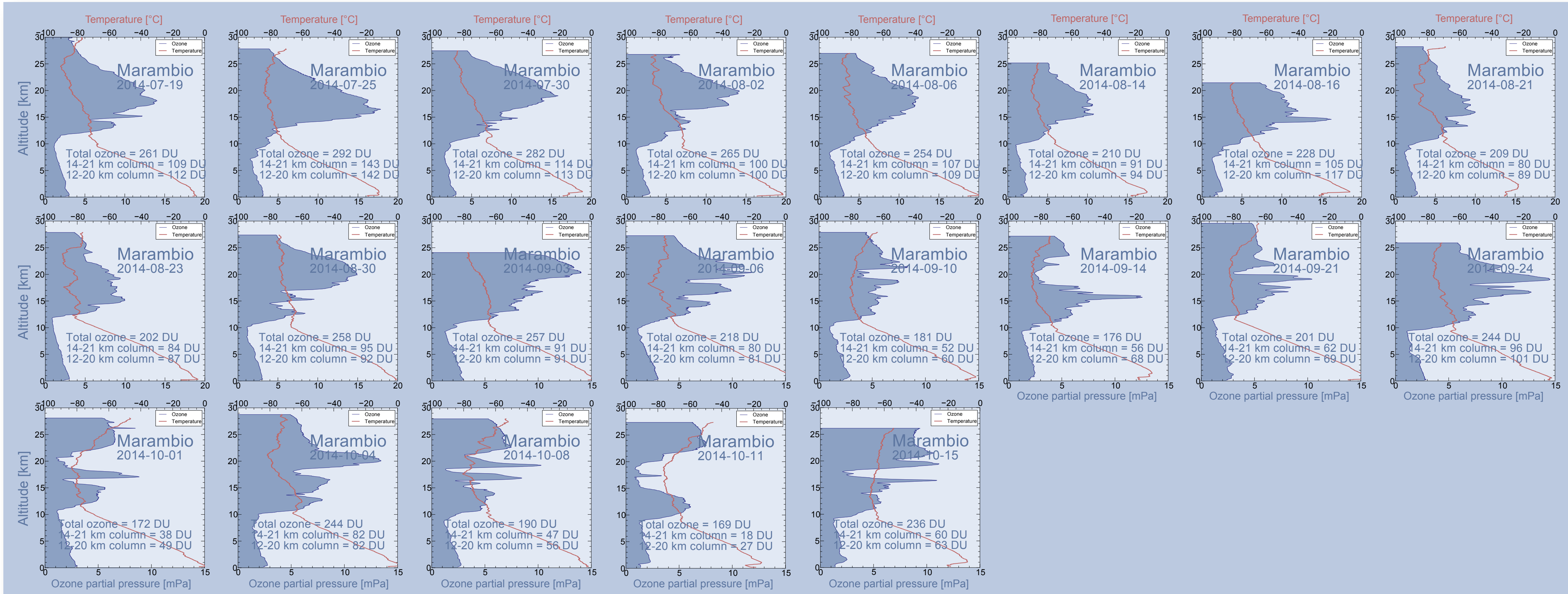


Figure 29. Ozone profiles measured with electrochemical ozonesondes launched from the Argentinian GAW station Marambio from 19 July to 11 October 2014. Ozone depletion has progressed since the previous Bulletin and the 14-21 km partial column dropped from 80 DU on 6 September to 38 DU on 1 October.

well outside the vortex on 1 September and in a region of depleted ozone on the 19th of September.

Ozone profiles are observed with ozonesondes at Marambio. Soundings are carried out approx. twice per week. Seven ozonesondes were launched in June, seven in July, seven in August, six in September, and four so far in October. The September profiles, with the exception of 24 September (see **Figure 29**) show clear signs of ozone destruction around 14-21 km altitude and display total columns well below 220 DU.

Three of the four October profiles show clear signs of ozone depletion. On 11 October the 14-21 km column deduced from the ozonesonde profile is down to 18 DU, the lowest measured at Marambio so far this season.

At the Russian GAW station Mirny (66.558270°S, 93.001017°E) total ozone is measured with a filter instrument (M-124). The observations for 2014 are shown together with data for the previous two years in Figure 30. Overpass data from the OMI instrument are shown for comparison. 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. It can be seen that total ozone was unusually low during the first three weeks of August. The maximum total ozone value observed so far was 313 DU on 12 September and the minimum so far was 178 DU on 6 September. The maps in Figure 31 shows the 14-21 km partial ozone column extracted from output from the BASCOE data assimilation model. On 6 September the station is located well inside the polar vortex and the 14-21 km partial ozone column is 64 DU. Six days later the station is just outside the vortex and total ozone is 313 DU with a partial column of 107 DU.

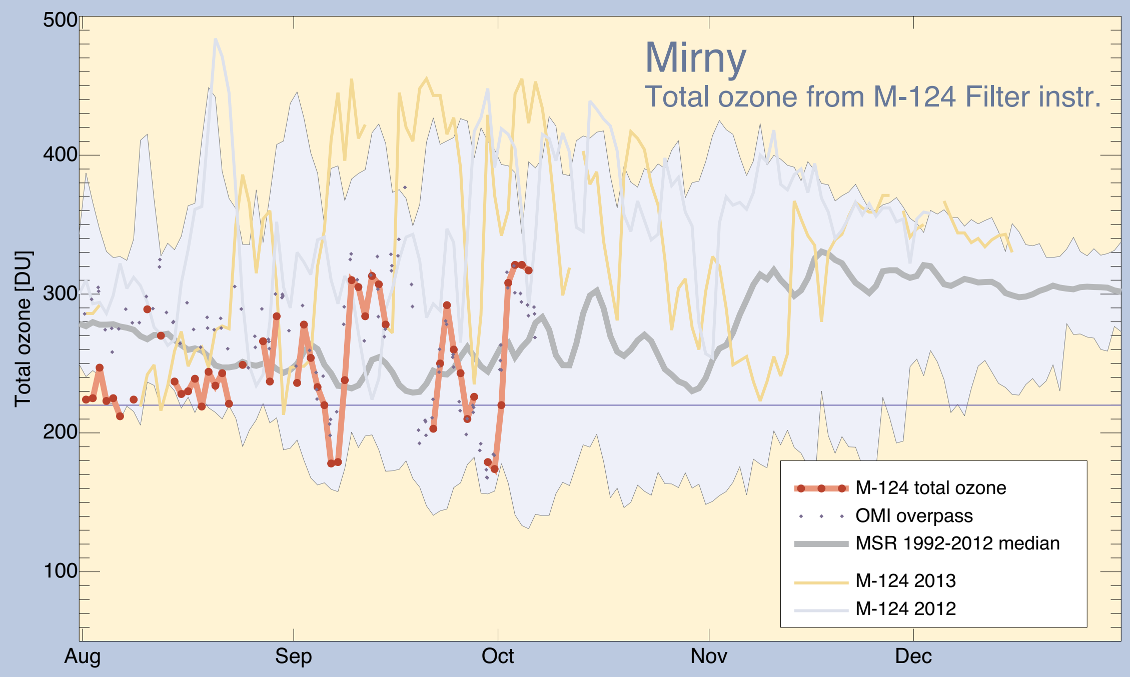


Figure 30. Total ozone above Mirny as measured by a M-124 filter instrument and by the OMI instrument on board the AURA satellite.

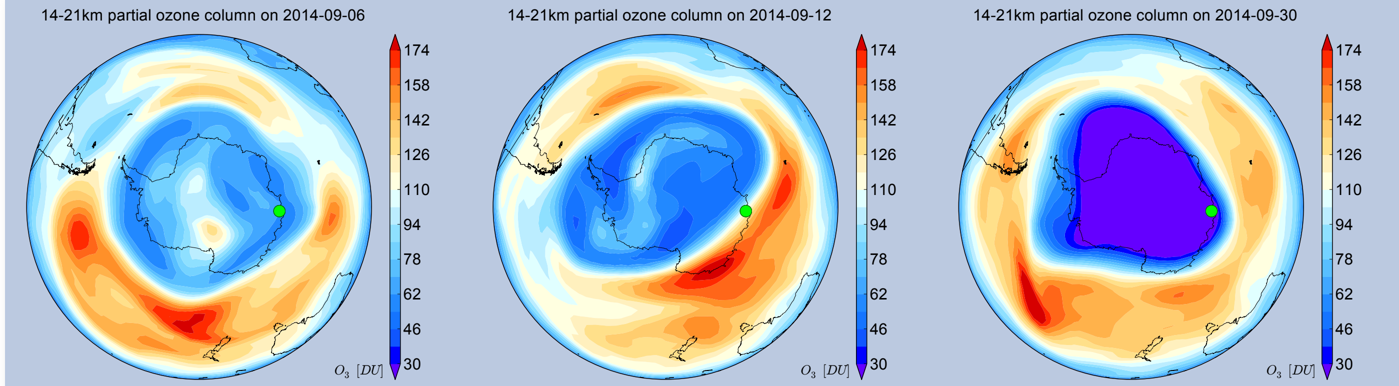


Figure 31. 14-21 km partial ozone column from the BASCOE data assimilation model for 6 and 12 September 2014. The position of Mirny is indicated with a green circle. On 6 September the 14-21 km partial ozone column was 64 DU and on 12 September it was 107 DU.

Neumayer

The vertical distribution of ozone is measured with ozonesondes from the German GAW/NDACC station at Neumayer (70.666°S, 8.266°W). Seventeen sondes have been launched since 18 July, as shown on the next page in **Figure 32**. On 20 August, total ozone was inferior to 220 DU for the first time this season. The ozone depletion has progressed gradually during August and September and the most depleted profile, both in the 14-21 km column and the total column, was measured on 24 September. Maps of the 14-21 km partial ozone column from the BASCOE data assimilation model is shown in **Figure 33** (next page). Here one can clearly see that Neumayer is inside a region with ozone rich air on 5 August. This is the date that shows the largest total and partial column ozone from the ozonesonde data. On 27 August the ozonesonde profile shows that ozone depletion has set in. This is confirmed by the BASCOE data where on can see that Neumayer is in an ozone poor region. The smallest 14-21 km partial column observed so far this season was on 15 October with 9.3 DU. This is lowest measured anywhere this season.

The Neumayer III station. Photo: AWI

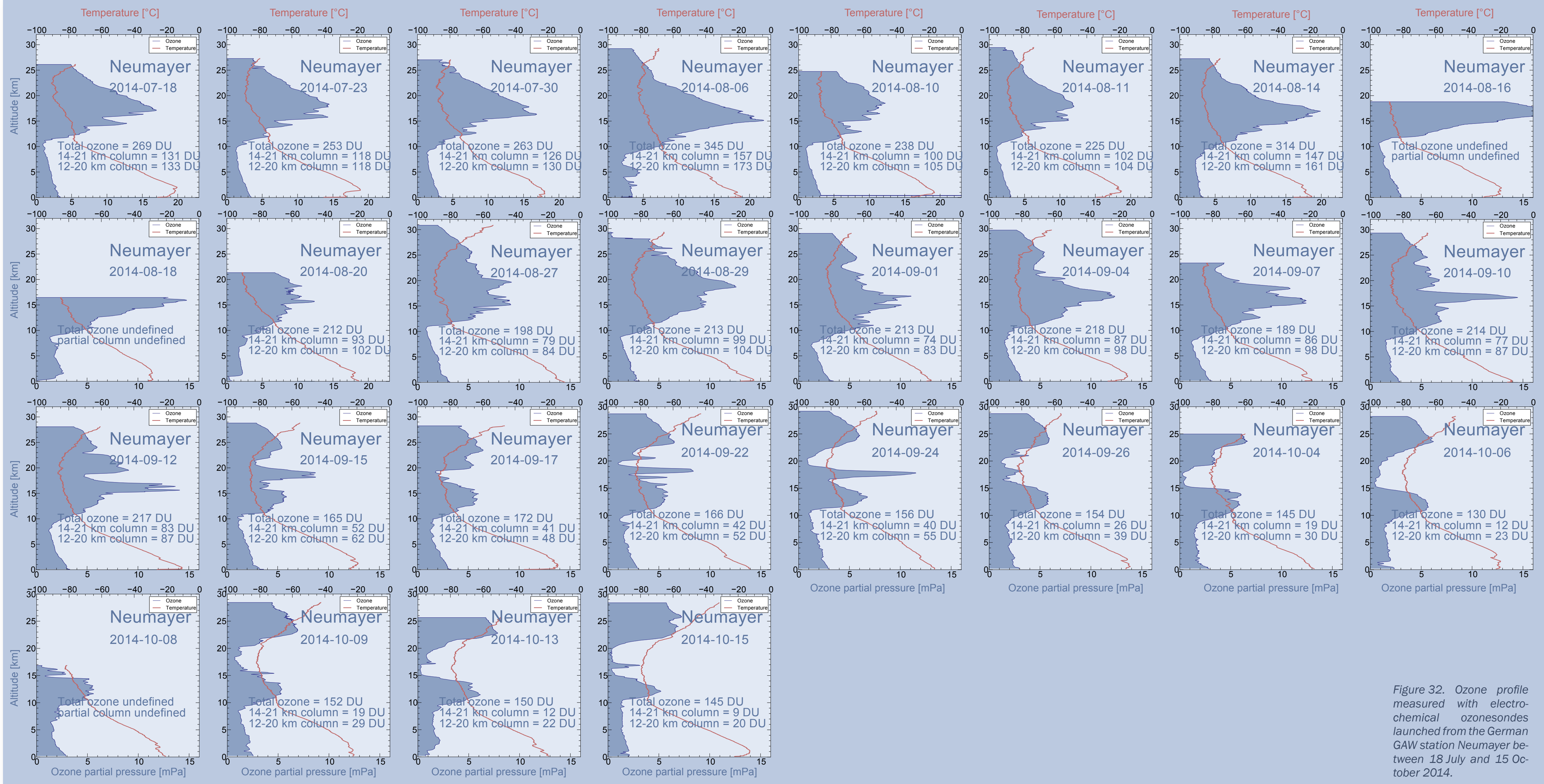


Figure 32. Ozone profile measured with electrochemical ozonesondes launched from the German GAW station Neumayer between 18 July and 15 October 2014.

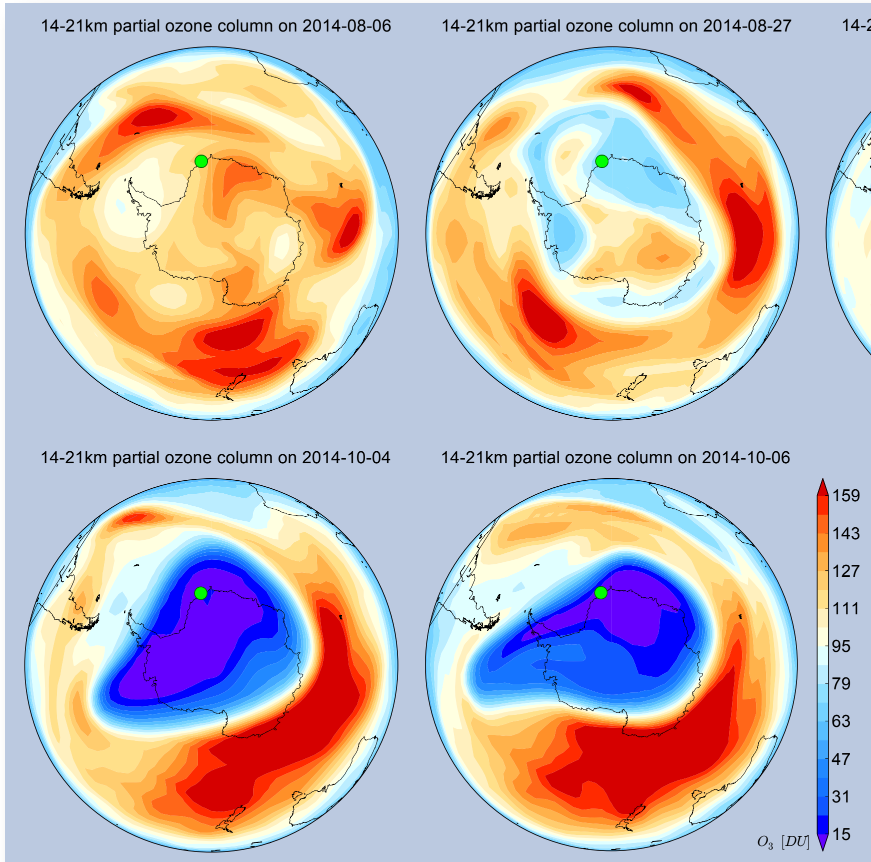


Figure 33. 14-21 km partial ozone column from the BASCOE data assimilation model on 6 and 27 August, on 15, 17 and 26 September, and on 4 and 6 October, 2014. The position of Neumayer is indicated with a green circle. One can see the progressive development of ozone depletion. The colour scale is the same on all the plots.

Novolazarevskaya

At the Russian GAW station Novolazarevskaya (70.776739°S, 11.822138°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. In late September and early October total ozone is around 150 DU and quite close to the 1992-2012 median. **Figure 34** shows the M-124 filter data together with OMI overpass data.

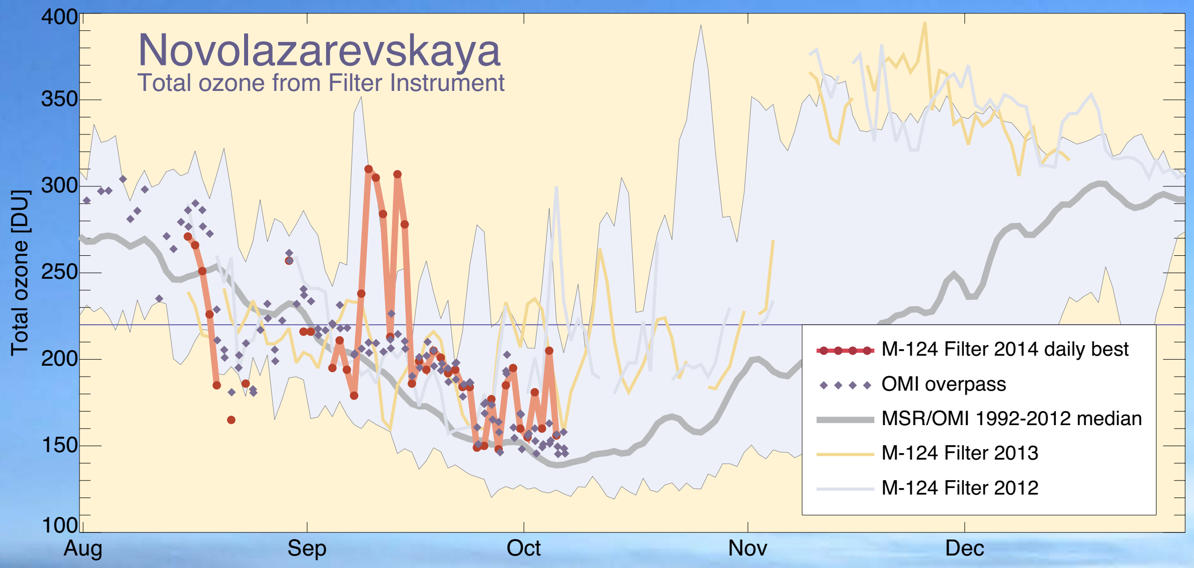


Figure 34. Total ozone is measured at Novolazarevskaya with an M-124 filter instrument. Together with the 2014 data one can see data from 2012 and 2013 as well as OMI overpass data. Long term statistics is shown for comparison. The light grey-blue shaded region shows the maximum and minimum values between 1992 and 2012 based on the MSR data set.

The approach to the Rothera Research Station. Photo: Beth Simmons.

At the British GAW/NDACC station Rothera (67.5695°S, 68.1250°W) total ozone is measured with a SAOZ spectrometer. The data are up to date as of 20 September. Since the station is close to the polar circle, observations can be carried out around the year. Total ozone was oscillating between 240 and 360 DU in June. In July, total ozone dipped under 220 DU on three days (17, 26 and 27 July). On 6 and 7 August total ozone dropped below 220 DU before going back up to near 270 DU on 9 August. On 23 August total ozone dropped to 131 DU. Total ozone then increased as the vortex went away and on 1 September total ozone was 292 DU. Then the vortex came back and ozone dropped again and reached 181 DU on 8 September. With the exception of two days total ozone has been below the 220 DU threshold during all of September and so far in October. On 1 October total ozone was 139 DU. **Figure 35** shows the 2014 data in comparison to earlier years and long term statistics.

Figure 36 shows maps of the ozone partial column between 14 and 21 km on 23 August, on 1 September and on 1 October. Rothera is indicated with a green circle. It can be seen that on 23 August the station is influenced by air masses with ozone depleted air and nine days later the vortex has moved away from the station. By 1 October ozone depletion has progressed substantially and the station is inside the vortex. The 14-21 km partial ozone column is 30 DU on that day.

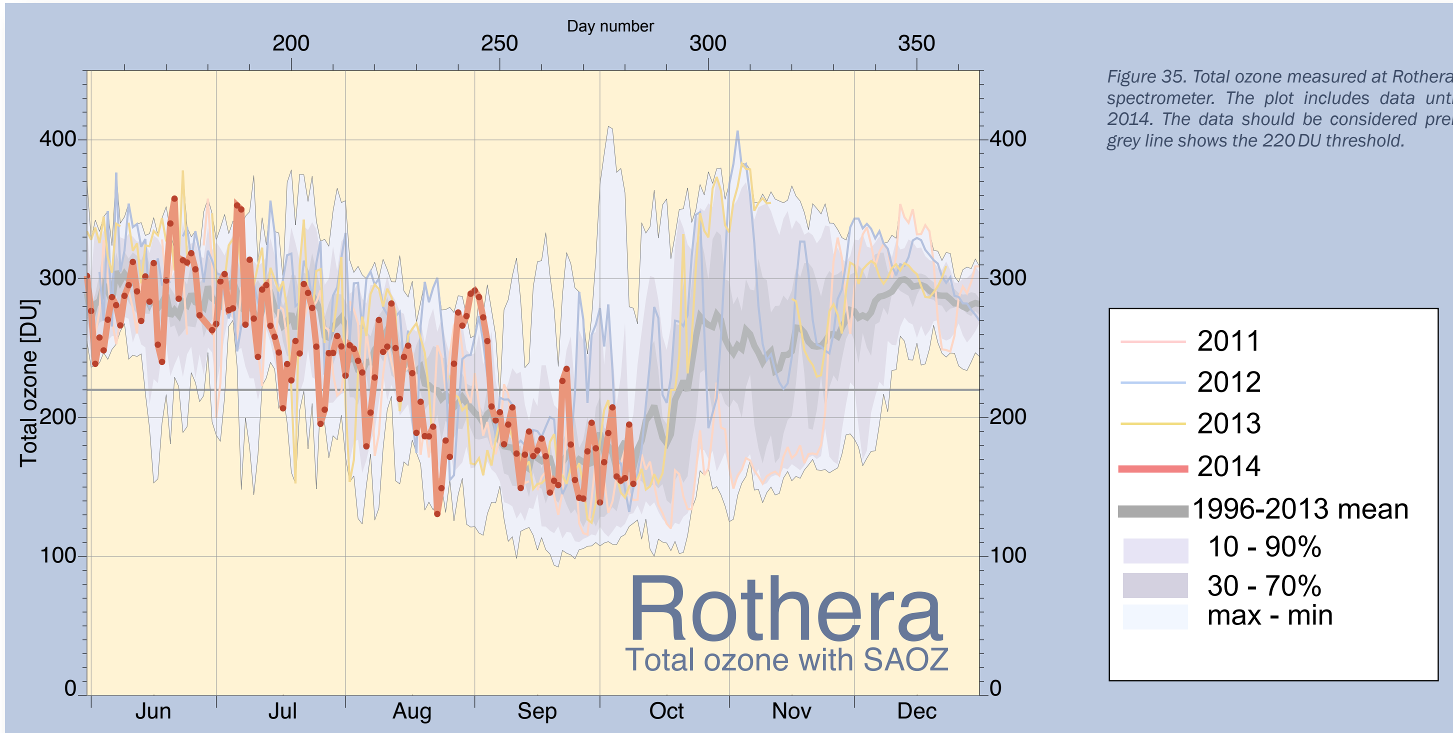


Figure 35. Total ozone measured at Rothera with a SAOZ spectrometer. The plot includes data until 1 October 2014. The data should be considered preliminary. The grey line shows the 220 DU threshold.

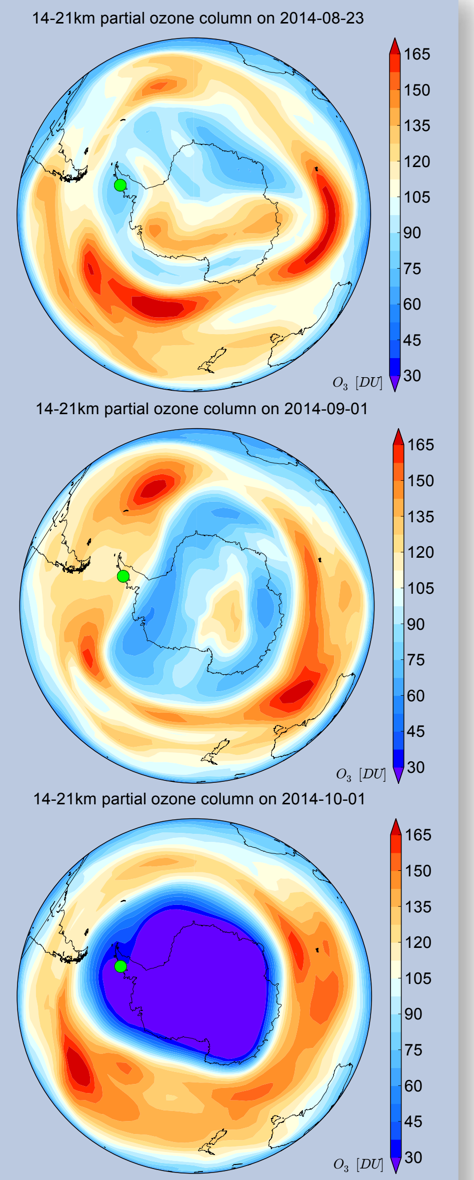


Figure 36. Maps of the ozone 14-21 km partial column as calculated by the BASCOE data assimilation model. The location of Rothera is shown with a green circle. On 23 August the station is influenced by ozone poor air masses with total ozone of 131 DU. On 1 September the station is outside of the vortex and on 1 October it is back inside the vortex and the 14-21 km partial column is 30 DU.

Ozonesonde launch at the South Pole. Photo: NOAA

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 37** shows the soundings between 8 August and 16 October. The profiles measured during August don't show any signs of ozone depletion. The profiles measured on 1 and 6 September, however, show first signs of ozone being destroyed. On 11 September one can clearly see that ozone depletion has started with a large "ozone" bite-out centred around 20 km. From 11 to 23 September one can see a gradual decline in the amount of ozone. The 14-21 km partial ozone column measured on 8 October (13 DU) is among the lowest measured so far at any station this year. Ozone is still low on 12 and 16 October with total ozone at well below 220 DU. The 12-20 km column on 16 October is the lowest measured at the South Pole this year and one has to go back to 2011 in order to find a lower value for this partial column.

Figure 38 shows maps of the 14-21 km partial ozone column, and one can see the development between 26 August and 8 October.

Temperatures remain cold in the stratosphere and on 11 September the temperature was -89.7°C at 18.9 km. On 26 September the lowest temperature was -84.3°C at 17.0 km

Total ozone is measured with a Brewer spectrophotometer operated

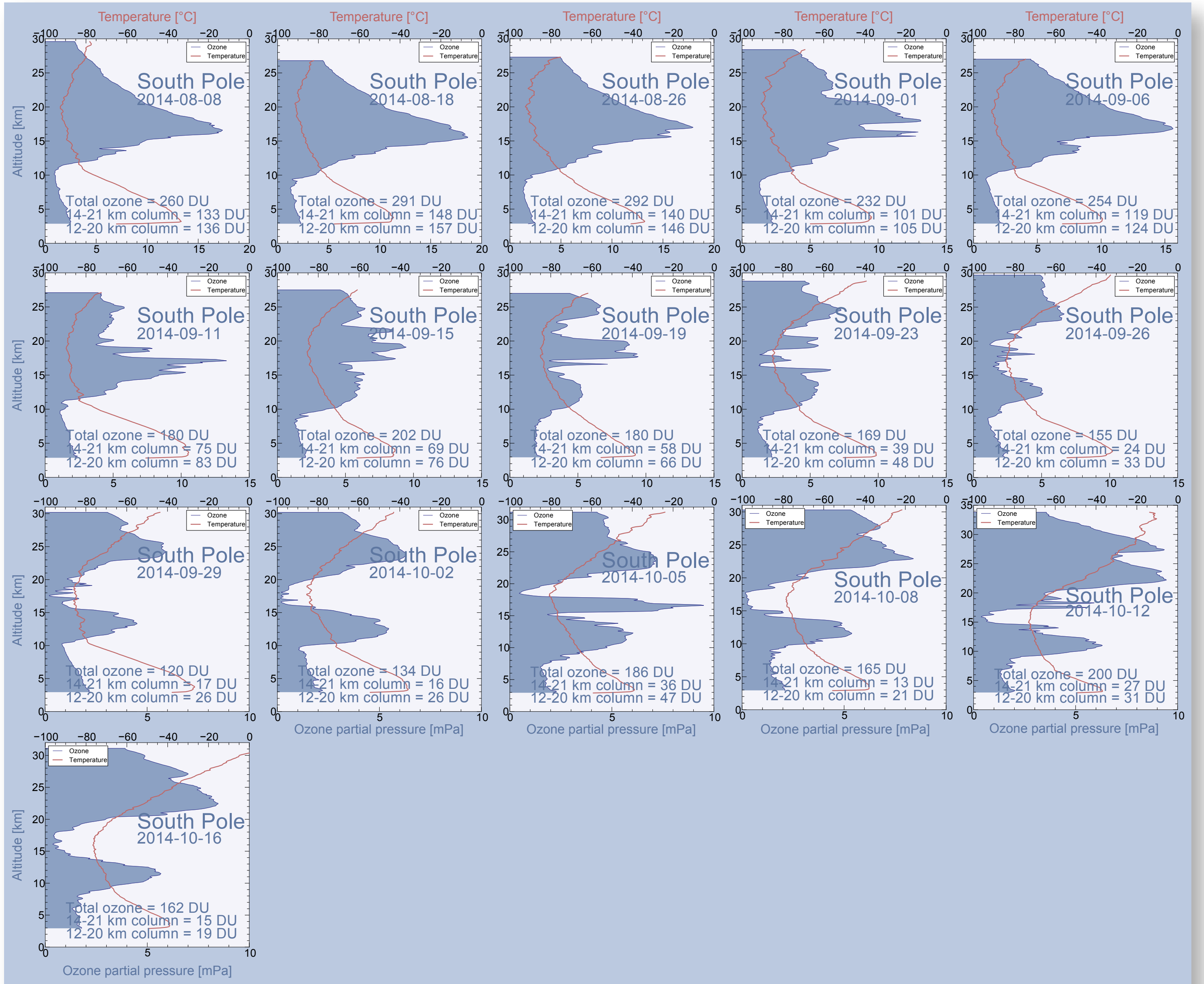


Figure 37. Ozonesonde profiles measured at the South Pole from 8 August until 16 October 2014.

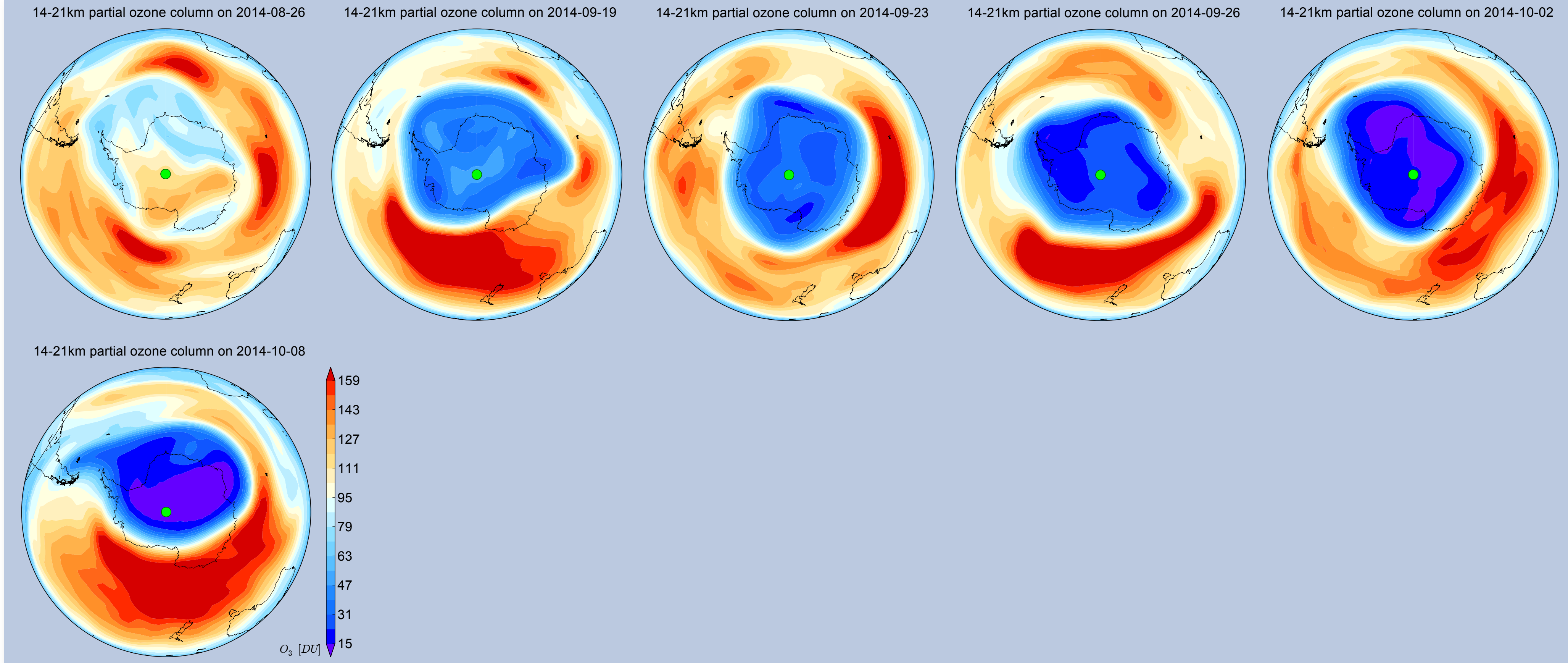


Figure 38. Maps of the 14-21 km partial ozone column on the same dates as some selected ozone soundings: 26 August, 19, 23 and 26 September and 2 and 8 October, based on output from the BASCOE data assimilation model. The green circle shows the location of the South Pole station. On the 26th of August one can see that ozone depletion does not affect the South Pole to any large extent yet. On 19 September ozone depletion is clearly visible, but there are regions to the north that are slightly more depleted than the South Pole. Only four days later one can see that ozone depletion has progressed further and on 8 October the South Pole is inside the most depleted region with less than 15 DU of partial column. The maps have been produced at WMO based on data downloaded from the IASB FTP server.

by Environment Canada and NOAA and that belongs to Environment Canada. This instrument was installed at the South Pole in February 2008. The measurements will started up again in early October after the polar night. NOAA also operates a Dobson spectrophotometer at the South Pole and these measurements have been ongoing since 1961. Due to the late sunrise at the South Pole after the winter the Dobson and Brewer data will be reported in forthcoming issues of the Bulletin.

Ozonesonde launch at Syowa. Photo: JMA.

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 21 August after the winter. The total ozone value measured with the Dobson spectrophotometer on that day showed 211 DU. The Dobson measurements are shown in Figure 39. One can see that on most days the total ozone is well below the 220 DU threshold.

Ozone profiles are measured at Syowa with ozonesondes. So far, twelve soundings have been carried out. (Figure 40). The ozonesonde launched on 21 August gives a total ozone column of 251 DU, which corresponds quite well with the OMI overpass value of 246 DU. The ozonesonde launched on 10 September shows reduced ozone around 20 km and the 14-21 km partial ozone column has dropped to 71 DU. All the profiles measured after 14 September show a clear ozone "bite-out" around 20 km and the 14-21 km partial ozone column shows a steady downward trend and reached 18 DU on 6 October. After that, as seen in the soundings of 11 and 16 October, ozone is returning slowly, but the station still experience ozone hole conditions. On 16 October, total ozone is 244 DU as estimated from the sonde profile. Yet, the 14-21 km partial ozone column is 38 DU, which is a clear sign of ozone depletion and one can also see the large ozone "bite-out" between 15 and 20 km. This is yet another example where total ozone surpassed the 220 DU threshold, and still, when looking at the ozone profile one can determine that one is inside the ozone hole.

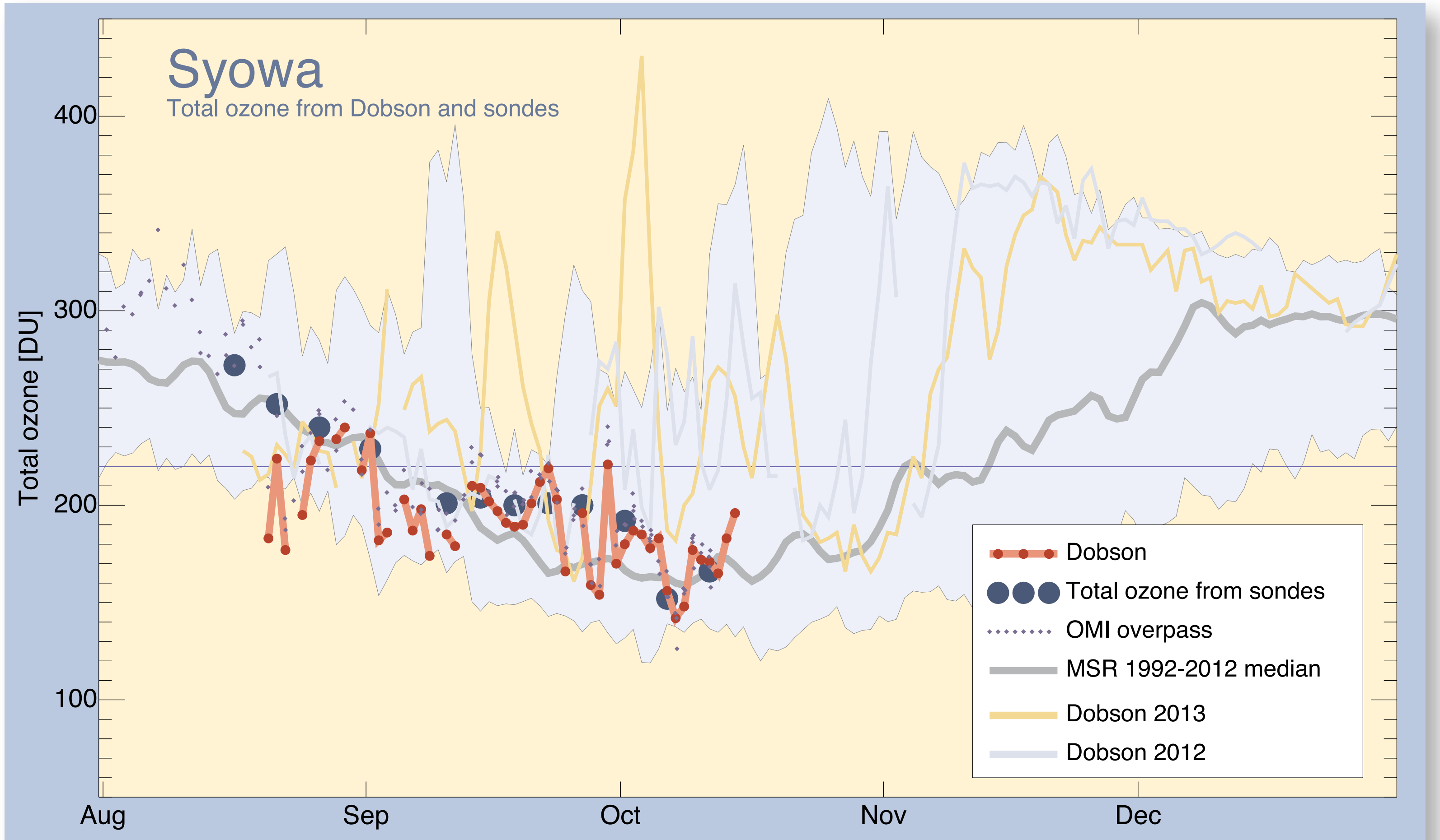


Figure 39. Dobson measurements from Syowa. Data from the current year and the two previous years are shown. For comparison total ozone from OMI overpass data are also shown (small blue diamonds) as well as total ozone calculated from ozonesondes (orange circles).

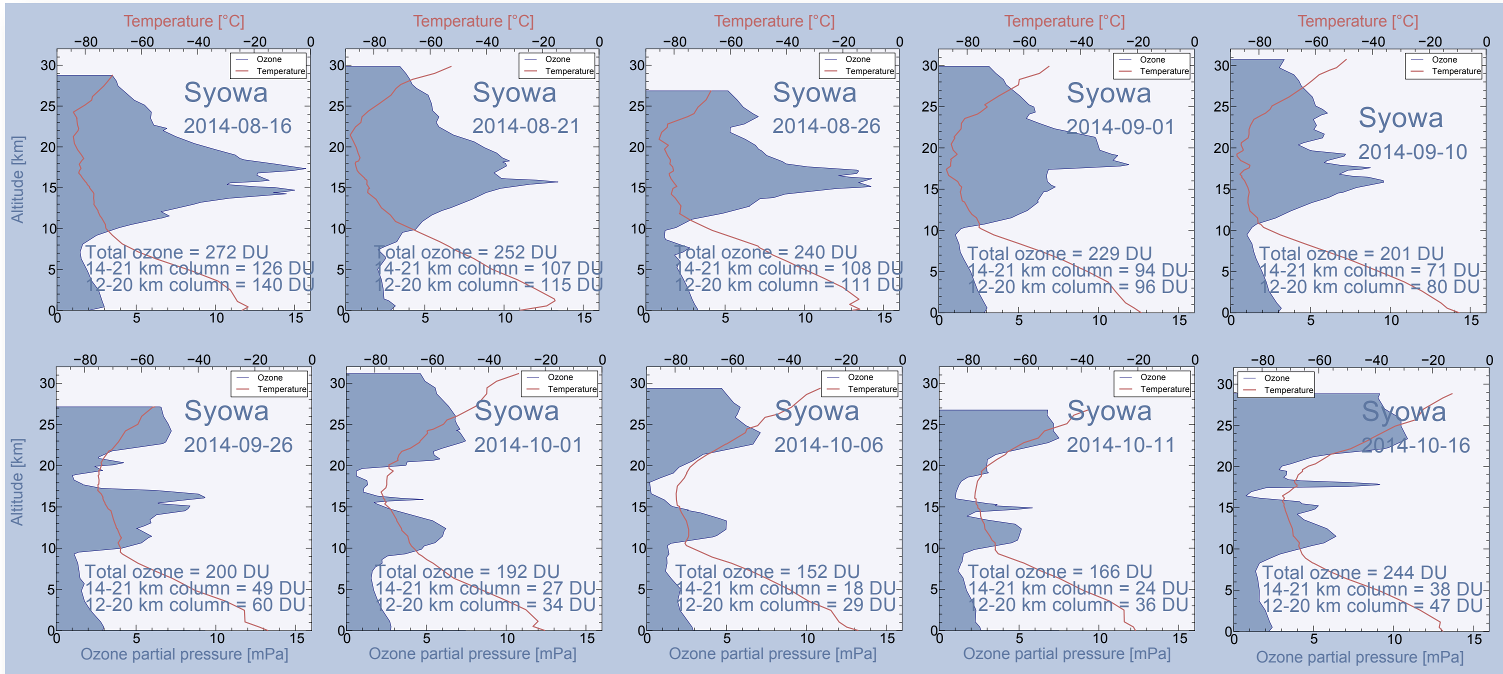


Figure 40. Ozonesonde observations at Syowa from 16 August until 16 October.

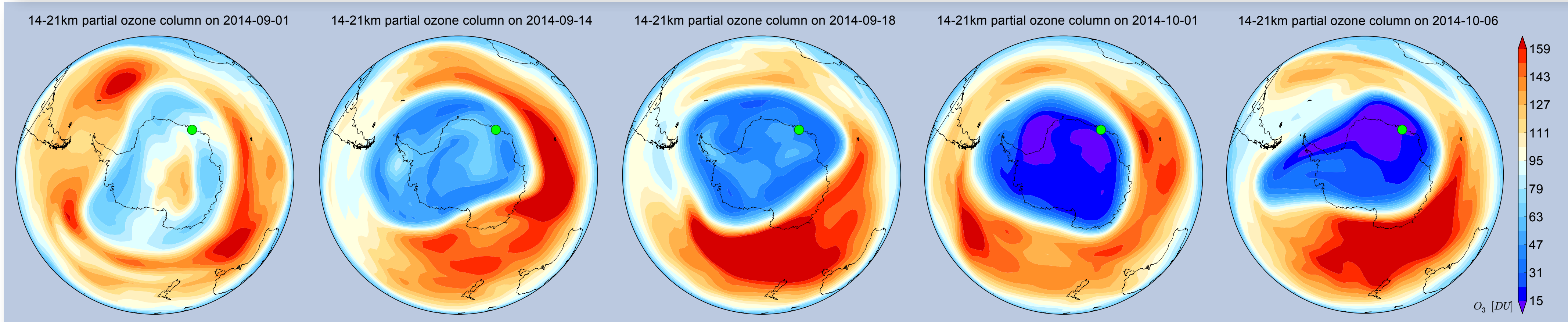


Figure 41. Maps of the 14-21 km partial ozone column from 1, 14, and 18 September and 1 and 6 October, based on output from the BASCOE data assimilation model. The green circle shows the location of Syowa station. These maps show that Syowa was inside the vortex on all five dates and they also show the gradual decrease of ozone inside the polar vortex in general and at Syowa in particular. The maps have been produced at WMO based on data downloaded from the IASB FTP server.

Ushuaia

Ozonesonde launch at Ushuaia. Photo: SMN.

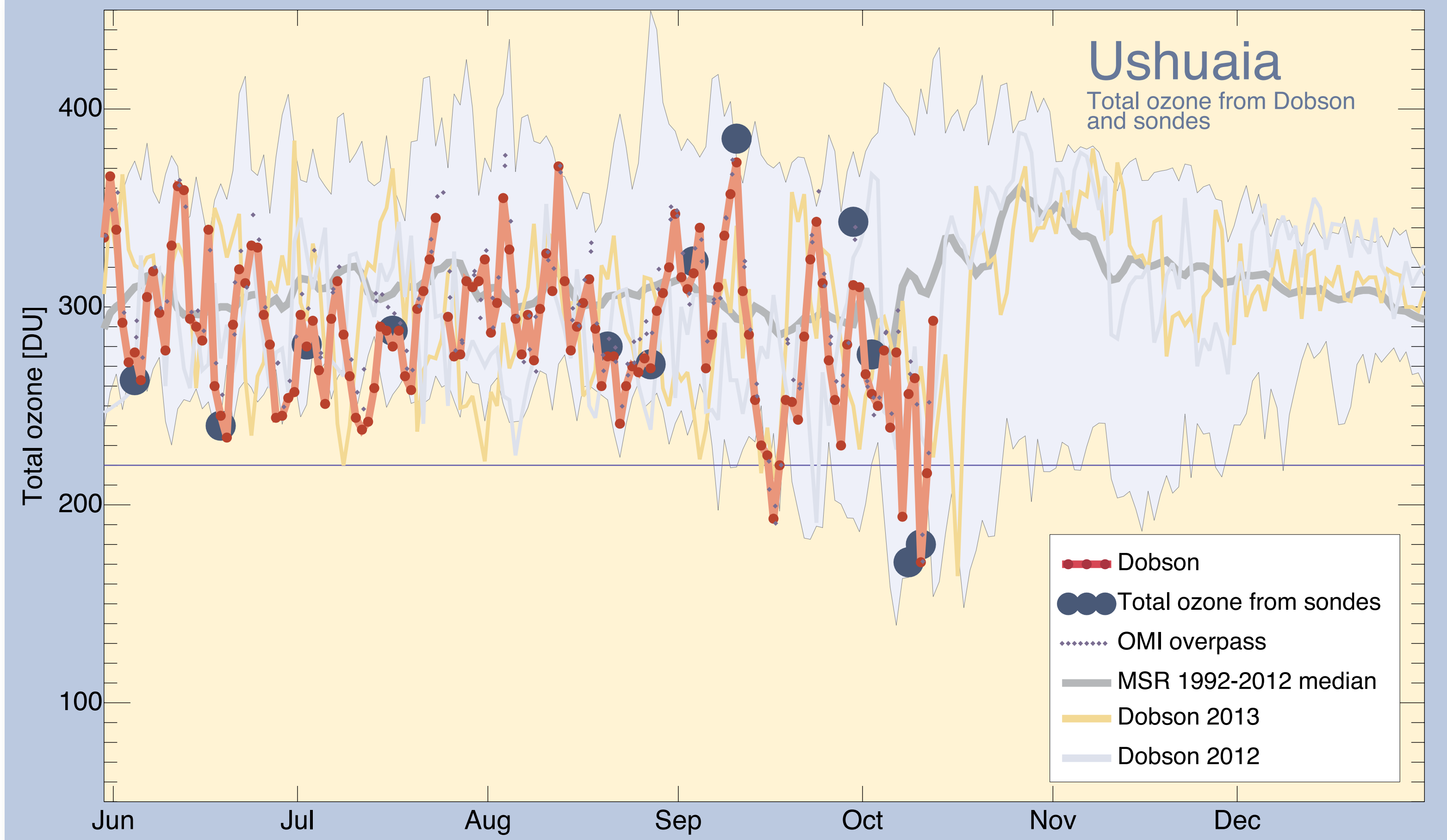
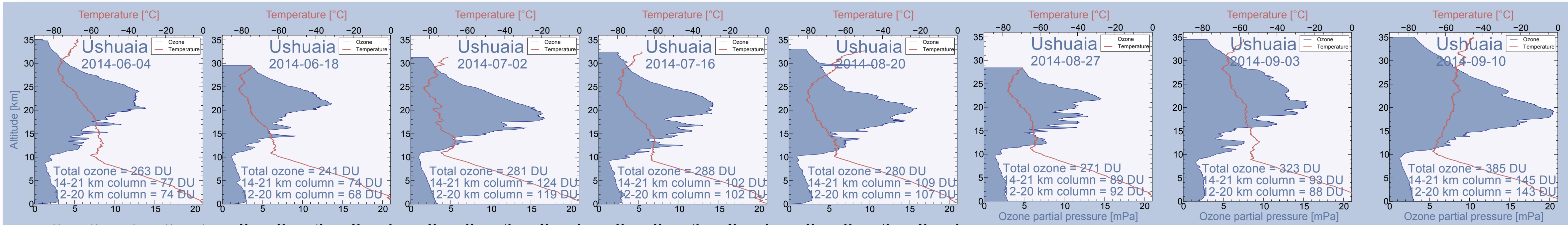


Figure 42. Total ozone over Ushuaia in 2014. The orange circles show total ozone deduced from ozone balloon soundings, the red curve with dark red dots shows the Dobson observations (until 12 October) and the blue diamonds show OMI overpass data (until 6 October). The thick grey line shows the median total ozone value for each day based on MSR and TM3 data for the 1992-2012 time period. The light grey shaded area shows the range of total ozone values over the same time period.

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.

Total ozone is measured with a Dobson spectrophotometer and the measurement from June 2014 until now are shown in Figure 42 together with OMI overpass data and total ozone derived from ozonesondes. One can see the excellent agreement between total ozone from the Dobson measurement and the total ozone derived from the ozonesondes.

Ozone profiles are measured with electrochemical ozonesondes approximately twice per month from June until the end of the ozone hole season. The ozonesonde data for 2014 are shown in Figure 43. One can see that on 16 September, when the edge of the ozone hole passed over the station, the 12-20 km partial ozone column is substantially lower than for the other soundings. This can also be seen in the BASCOE maps of partial column ozone in Figure 44 where the situation on 16 September is compared to the one on 10 September. On the 29th of September the observed ozone profile is typical of mid latitudes and the total ozone column derived from the sonde is 343 DU. The BASCOE map in Figure 44 also shows that Ushuaia was well outside of the ozone hole region. On 7 and 10 October the vortex passes over the station again as seen from the ozonesonde profiles in Figure 43 and on the BASCOE map in Figure 44. In Figure 45 is shown a map of potential vorticity that also demonstrates that Ushuaia on 7 October was well inside the polar vortex.



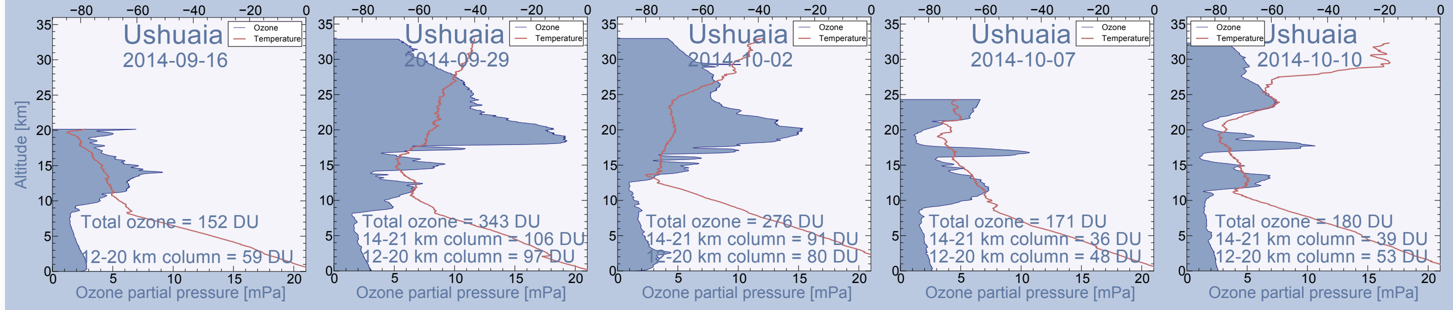


Figure 43. Ozonesonde profiles measured at Ushuaia from 4 June to 16 September 2014. The sounding of 16 September burst too early for the total column to be calculated reliably.

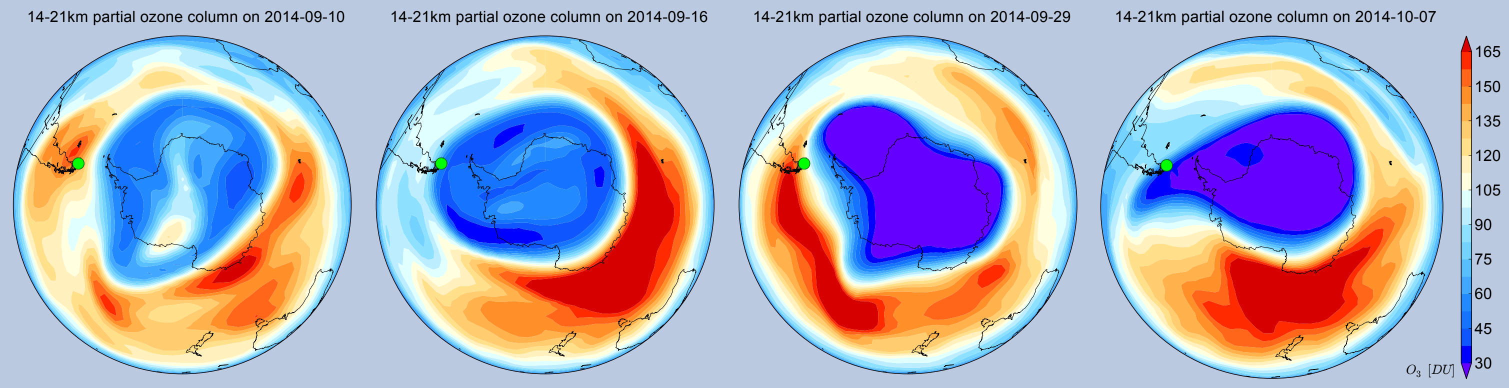


Figure 44. Maps of the 14-21 km partial ozone profile from the BASCOE data assimilation model. On 10 September Ushuaia is well outside of the polar vortex and ozone is elevated with a partial column of 143 DU. On 16 September Ushuaia is on the edge of the vortex and the 14-21 km partial column has dropped to 52 DU. On the 29 September Ushuaia is well outside the vortex and even in a region of relatively ozone rich air masses. On 7 October the vortex is back over the station and the partial ozone column is down to 36 DU, the lowest observed at Ushuaia this season.

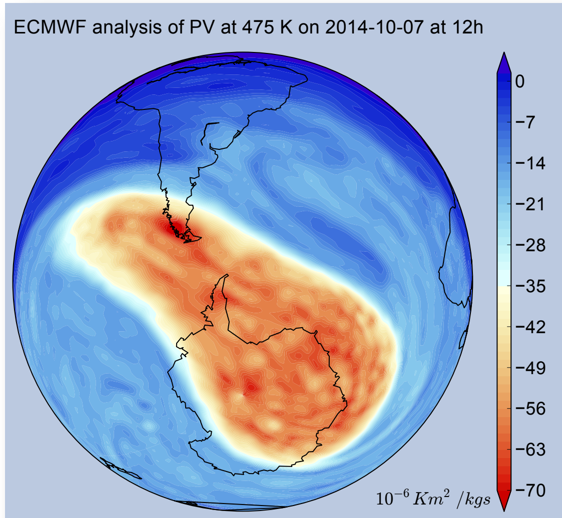


Figure 45. Map of potential vorticity at the isentropic level of 475 K on 7 October. This map shows clearly that Ushuaia is well inside the polar vortex and even in a region where the absolute value of PV is high. The data come from the European Centre for Medium Range Weather Forecasts (ECMWF) and have been provided by the Norwegian Institute for Air Research (NILU) through a project funded by the European Space Agency. The extraction from the grib2 format is done at NILU and the plot is made at WMO.

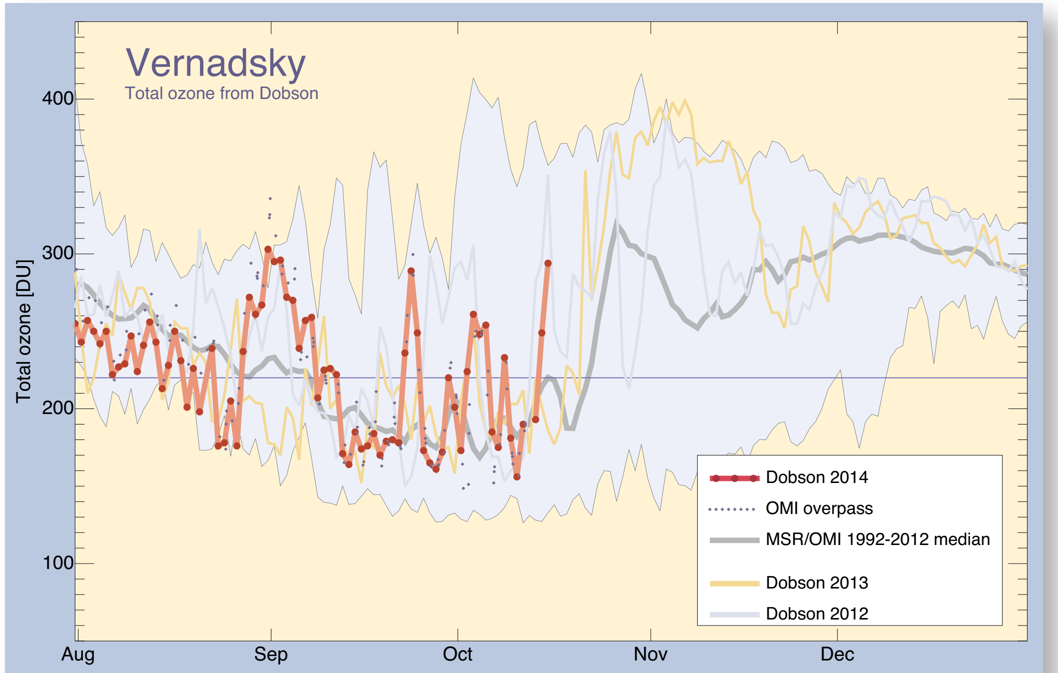


Figure 46. Total ozone over Vernadsky in 2014. The red line with dark red dots shows the Dobson observations (until 11 October) and the small blue diamonds show OMI overpass data (until 9 October). The grey line shows the 1992-2012 median. It can be seen that total ozone varies with the position of the station with respect to the vortex edge.

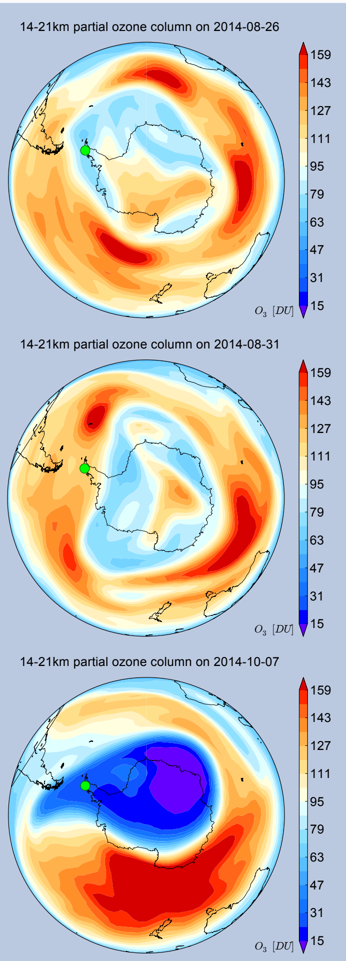


Figure 47. Maps of the 14-21 km partial ozone column on three selected dates based on output from the BASCOE data assimilation model. The green circle shows the location of Vernadsky station. On the 26th of August, Vernadsky was located inside the ozone depleted vortex and the partial column was 75 DU. On the 31st of August the station was well outside of the vortex and the 14-21 km partial column was 123 DU. On the 7th of October the vortex was back and the 14-21 km column had dropped to 29 DU. The maps have been produced at WMO based on data downloaded from the IASB FTP server.

Vernadsky station (65.15°S, 64.16°W) is run by the National Antarctic Scientific Centre of Ukraine. The data are processed by the British Antarctic Survey. Total ozone observations have been carried out here since mid 1957. Total ozone is measured with a Dobson spectrophotometer. Observations recommenced after the polar night on 21 July, with initial results around 230-250 DU. In August total ozone values oscillated between 176 (23 Aug) and 303 DU (31 Aug). In September total ozone varied between 296 DU (2 Sep) and 161 DU (27 Sep). In October the ozone column has so far varied between 261 DU (3 October) and 156 DU (10 October), which is the lowest value observed so far this season. The Dobson observations and OMI overpass data for 2014 are shown in **Figure 46** together with long term statistics (1992-2012). It can be seen from the figure that total ozone in August was low in comparison with the long term statistics. On three days total ozone was lower than the 1992-2012 minima for those dates. Then the vortex moved away from the station and total ozone increased to 303 DU on 31 August. The polar vortex came back over the station a few days later and on 13 September total ozone was 164 DU. The maps in **Figure 47** show the 14-21 km partial ozone column from the BASCOE model, and one can see how the ozone depleted vortex moves back and forth over the station. One can also see the general vortex-wide progress of ozone depletion from 26 August to 7 October.

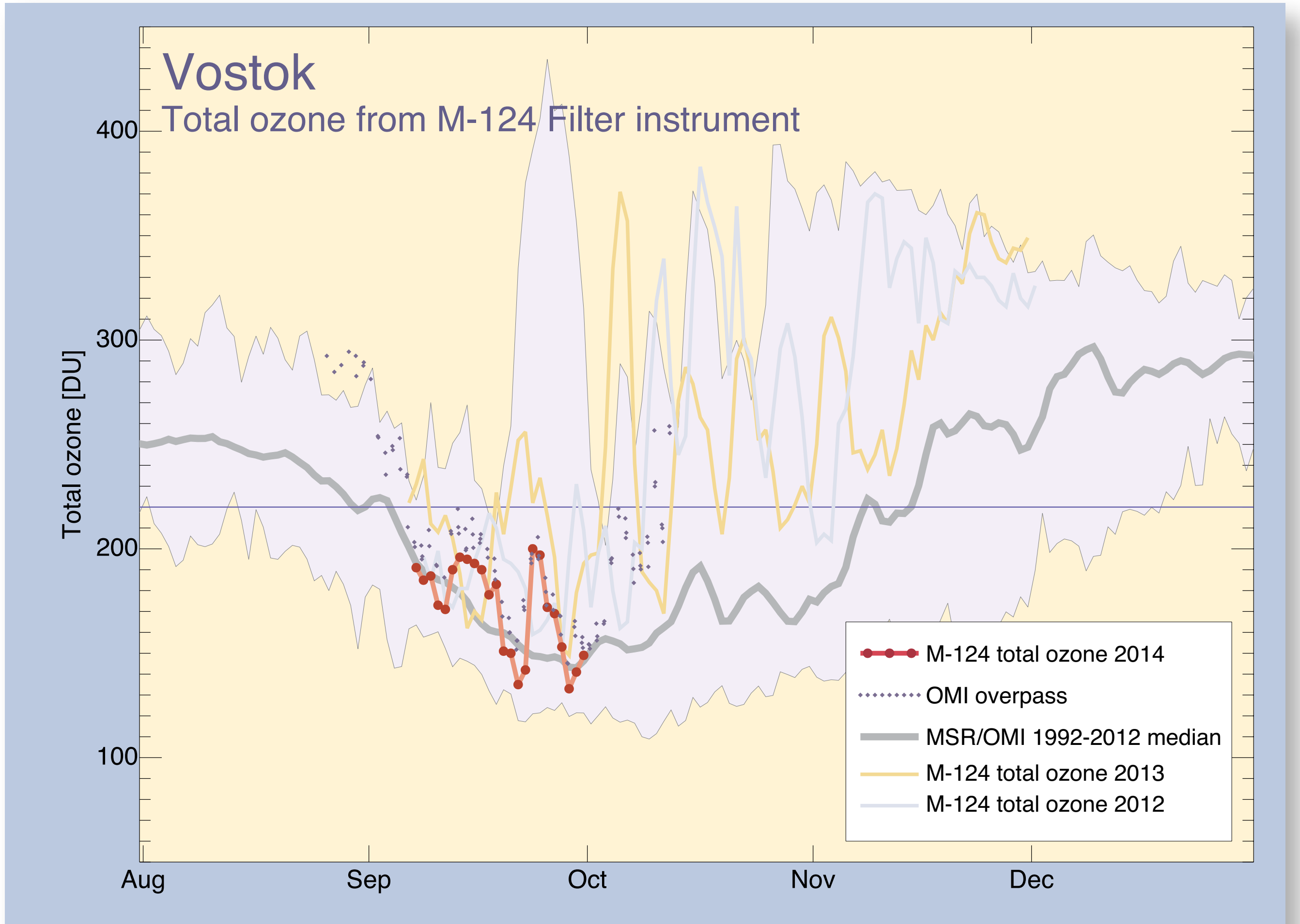


Figure 48. Total ozone observations carried out at the Vostok ice drilling site in 2014 with an M-124 filter instrument compared to satellite overpass data from OMI. Also shown is statistics for the 1992-2012 time period. The thick grey curve shows the median total ozone column for this time period. The grey shaded area shows the range of values for the 1992-2012 time period. The observations made in 2012 and 2013 are also shown.

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 September until 31 October are currently available. During this time period, total ozone was below the 220 DU threshold on 25 days. The minimum in September was 149 DU measured on the 28th. The minimum in October was 169 DU, measured on the 11th. **Figure 70** shows the M-124 data of September and October 2013 together with satellite overpass data from the OMI instrument on board the AURA satellite (until 23 November). One can see that with a few exceptions total ozone has been above, and often well above, the long term median.

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 2014, the observations started up on 5 September after the polar night. The total ozone value on that day was 173 DU. After that, total ozone has varied between 135 DU (27 Sep) and 244 DU (23 Sep and 3 Oct). The station is often close to the vortex edge, and this can lead to large changes in total ozone. **Figure 49** shows the Brewer measurements (red curve) compared to OMI overpass data (blue diamonds) until 16 October. Long term statistics for the 1992-2012 time period is also shown.

Figure 50 shows the partial ozone column from the BASCOE model on 27 September, when ozone was low and on 3 October, when ozone was relatively high. According to the BASCOE data the 14-21 km ozone column was 29 DU on 27 September and 55 DU on 3 October. Both values are typical of ozone hole conditions, but the station was closer to the vortex edge on 3 October. This is an example of a situation where total ozone is superior to 220 DU, yet there is substantial ozone depletion in the 14-21 km altitude range.

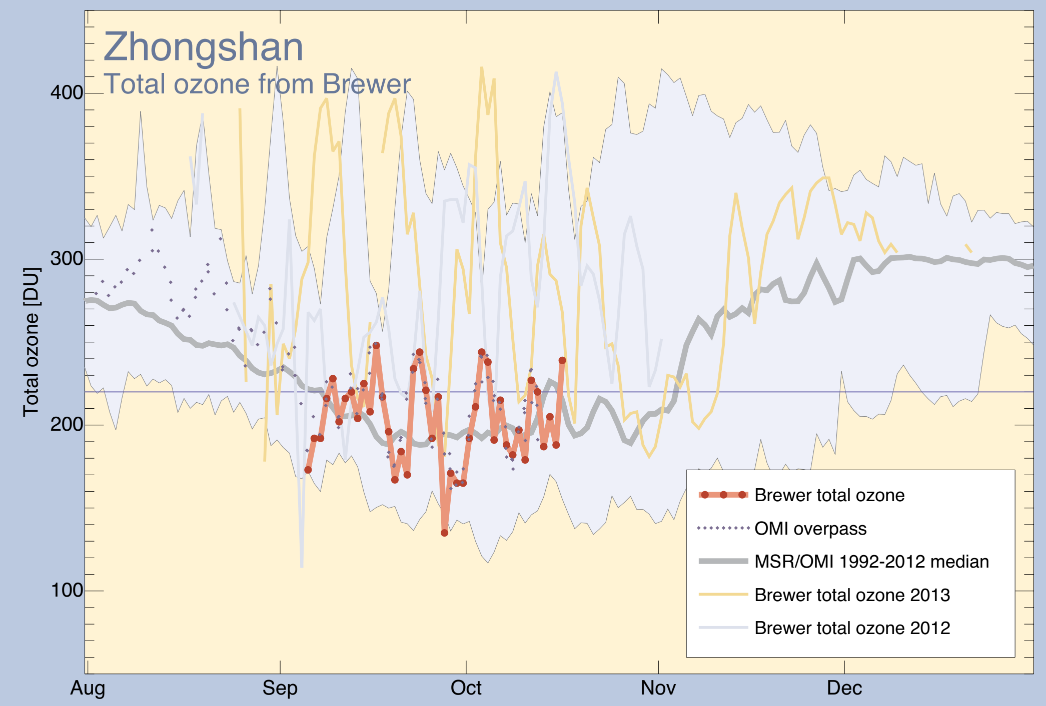


Figure 49. Total ozone observations carried out at Zhong Shan in 2014 with a Brewer instrument compared to satellite overpass data from OMI.

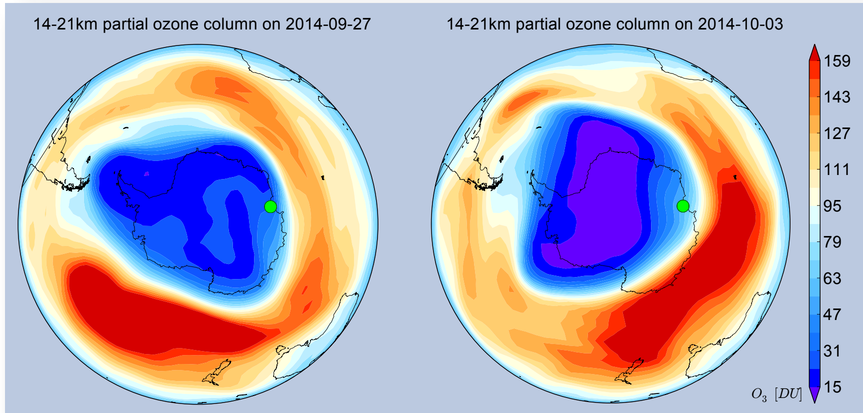


Figure 50. Maps of the 14-21 km partial ozone column on two selected dates based on output from the BASCOE data assimilation model. The green circle shows the location of Zhongshan station. On the 27th of September, Zhongshan was located inside the ozone depleted vortex and the partial column was 29 DU. On the 3rd of October the station was closer to the vortex edge and the partial column was 55 DU. This is still a sign of ozone depletion. The maps have been produced at WMO based on data downloaded from the IASB FTP server.

Chemical activation of the vortex

Satellite observations

The chemical activation of the south polar vortex has passed its maximum and there are just small amounts of active chlorine left. This also means that ozone depletion has come to a halt. As seen on page 5, daily minimum values of ozone have gone through a minimum and are on the way back up again.

Figure 51 (upper row) shows the extent of removal of hydrochloric acid (HCl), which is one of the reservoirs for active chlorine, on 4 October 2014, and on the same date for the four previous years, 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 has now recovered inside the polar vortex. Removal of HCl is an indicator of chemical activation of the vortex and return of HCl is an indicator of deactivation. It can be seen that in 2011 the vortex was still somewhat depleted of HCl on this date.

Another indicator of vortex activation is the amount of chlorine monoxide (ClO). It should be noted, however, that ClO dimerises and forms $(ClO)_2$ 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 $(ClO)_2$, which is not observed by Aura-MLS. **Figure 51** (lower row) shows the mixing ratio of ClO on the same dates as above. One can see that there is still an area with somewhat elevated ClO that forms an incomplete collar along the vortex edge. It can be seen from the figure that there is more ClO in 2014 than in 2012 and 2013, but less than in 2011.

Figure 52 (upper row) shows the amount of nitric acid (HNO_3) in the polar vortex. Removal of gaseous HNO_3 is an indication that this compound is condensated in the form of polar stratospheric clouds (nitric acid trihydrate, $HNO_3 \cdot 3H_2O$). It can be seen from the figure that the degree of HNO_3 removal is more or less similar for all the five years shown here, but again 2011 stands out as HNO3 depleted over a larger area than the other years shown here.

Figure 52 (lower row) shows the mixing ratio of ozone at the 46.4 hPa level. A collar of enhanced ozone can be seen just outside the polar vortex. Inside the polar vortex one can see that ozone depletion now affects the entire vortex. On 4 October 2014, the ozone depleted area is larger than in 2010, 2012 and 2013, but smaller than in 2011.

Figure 53 (next page) shows results from the BASCOE data assimilation model for the level of 46 hPa. This model assimilates data from the MLS instrument on the AURA satellite. The figure shows the temporal development of three species over the time period from 1 July until 11 October. One can see how hydrochloric acid (upper row) is being depleted as it is being converted on the PSC particles. Extensive conversion of HCl has already taken place by 1 July, and by 1 August essentially the whole vortex is entirely devoid of HCl. Between 8 and 23 September, HCl has partly recovered as the amounts of polar stratospheric clouds has been reduced. On 1 October there is just a small area left with depleted HCl and by 11 October HCl is completely recovered.

The middle row shows the sum of ClO and Cl_2O_2. This is an indication of the total amount of active chlorine. ClO dimerises in darkness, but is rapidly cracked in the presence of daylight. On 1 July there is elevated amounts active chlorine inside the vortex and the concentration increases gradually as the processing on the PSCs continues. From 22 August to 8 September the maximum concentration of active chlorine has gone down a bit, but the vortex is more evenly filled with active chlorine on 8 September. From 8 to 23 September the amount of active chlorine is reduced significantly, but there is still active chlorine remaining and that continues to destroy ozone. By 1 October the amount of active chlorine is greatly reduced and on 11 October there is no active chlorine left.

The mixing ratio of ozone (lower row) shows quite a dramatic development over the course of the time period shown here. One 1 July there is yet no sign of ozone depletion. By 22 August, and even more so by 8 September, one can see a clear reduction in the ozone mixing ratio at 46 hPa. Through September the ozone destruction continues and large areas of the vortex have less than 0.5 ppm of ozone. The maximum depletion is reached around 1 October. From 1 to 11 October one can see that the ozone depleted region is shrinking, but there are still large areas with very low ozone. The Belgian Institute for Space Aeronomy (BIRA-IASB) is in charge of the monitoring and evaluation

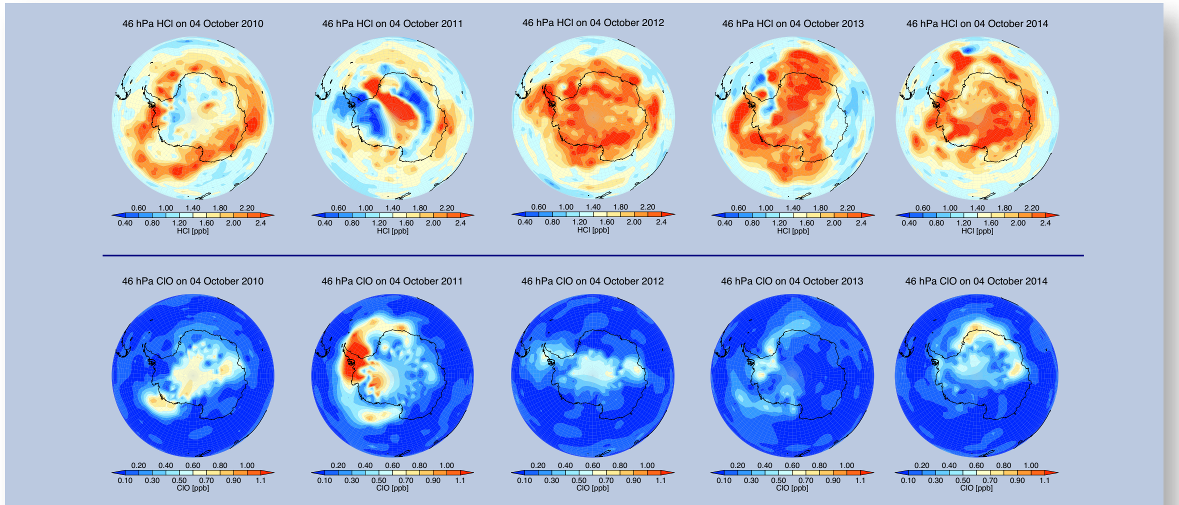


Figure 51. Upper row: Mixing ratio of HCl on 4 October of 2010, 2011, 2012, 2013 and 2014 at the isobaric level of 46.4 hPa (~18.5 - 19.5 km). Lower row: Mixing ratio of ClO on the same four dates as above. The data have been interpolated and mapped at WMO. The data are from the Aura-MLS satellite instrument and downloaded from NASA's Mirador data server.

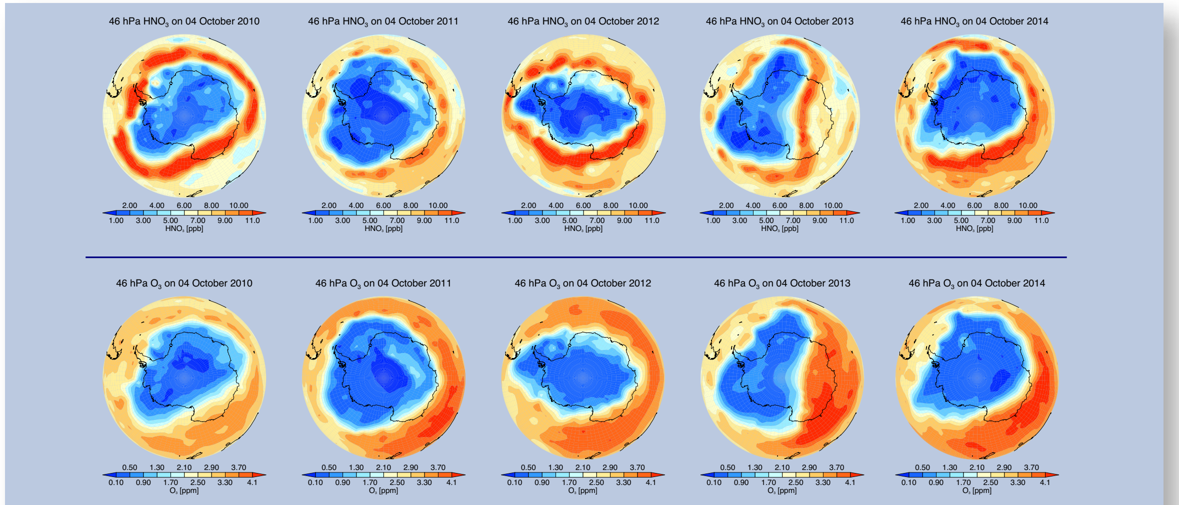


Figure 52. Upper row: Mixing ratio of nitric acid (HNO_3) on 21 September of 2010, 2011, 2012, 2013 and 2014 at the 46 hPa level. Lower row: Mixing ratio of ozone (O_3) on the same four dates as above. The maps are made at WMO and based on data from the Aura-MLS satellite instrument downloaded from the Mirador data service at NASA.

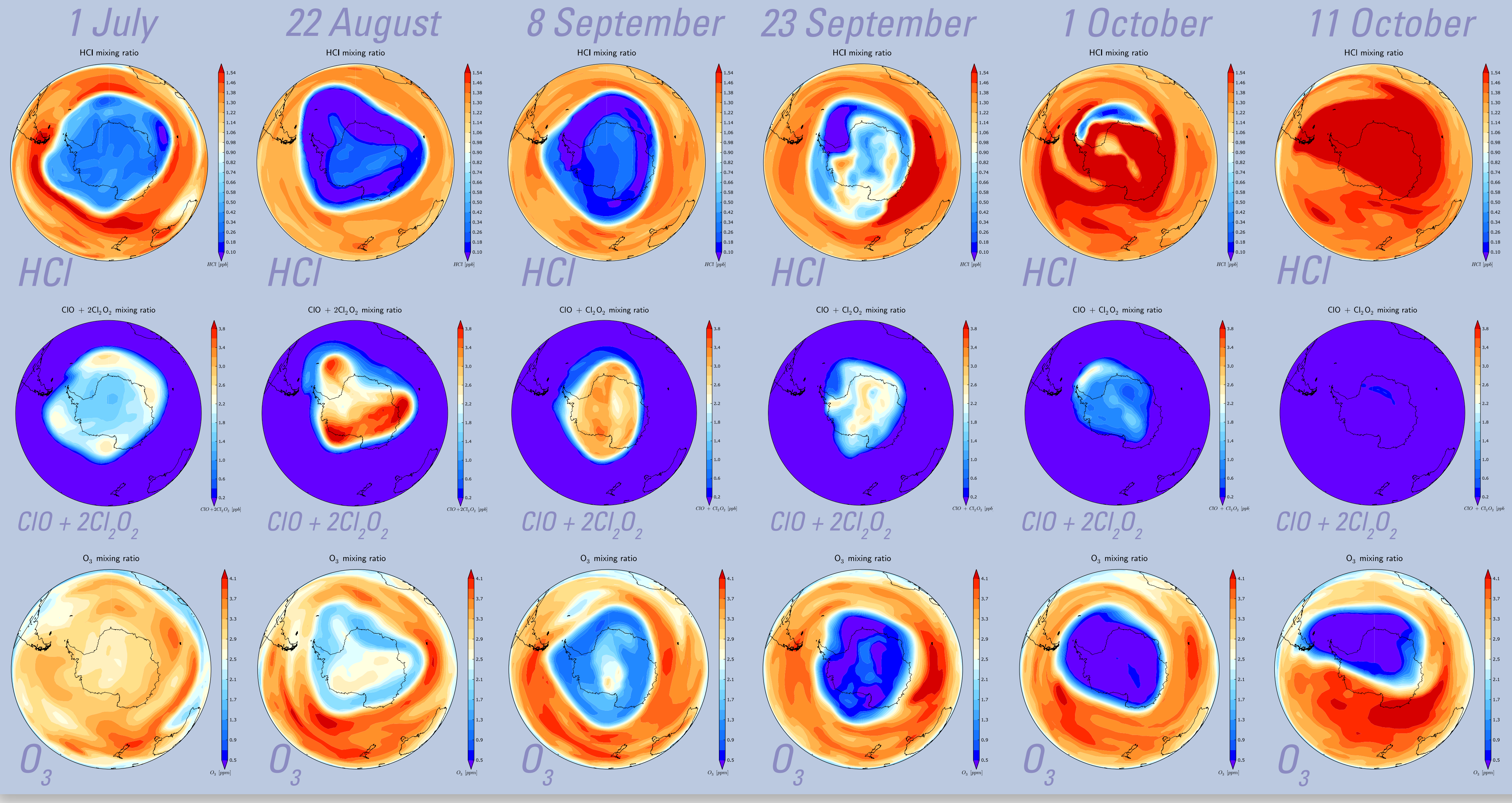


Figure 53. Results from the BASCOE data assimilation model at the level of 46 hPa. This model is run as part of the MACC-II project, which is funded by the European Commission and coordinated by ECMWF. The upper row shows the mixing ratio of hydrochloric acid, the middle row shows the sum of active chlorine and its dimer (ClO + $2Cl_2O_2$), and the lower row shows the mixing ratio of ozone. All three rows show the temporal development from 1 July to 11 October with intermediate frames shown for 22 August, 8 and 23 September, and 1 October. Please note that the projection used for these maps is not the same as the one used for the maps in the two preceding figures.

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 assimilates 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: O_3, H_2O, HNO_3, HCl, ClO, HOCl and N_2O. 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

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 from the GOME-2 instrument on Metop (and SCIAMACHY on Envisat in the past) is shown in Figure 54. During the first half of August, the area increased more slowly than at the same time in many of the recent years. However, during the last half of August and the first couple of weeks of September it increased at about the same rate as in recent years. Figure 55 shows the ozone hole area as deduced from the OMI satellite instrument. Also here it can be seen that the 2014 ozone hole was having a slightly later start than in the other years shown here but that during August the ozone hole area caught up with that seen in recent years. The ozone hole area reached a maximum so far this year on 11 September with 24.06 million square kilometres. That is close to the maximum reached in 2013 (23.77 million km^2).

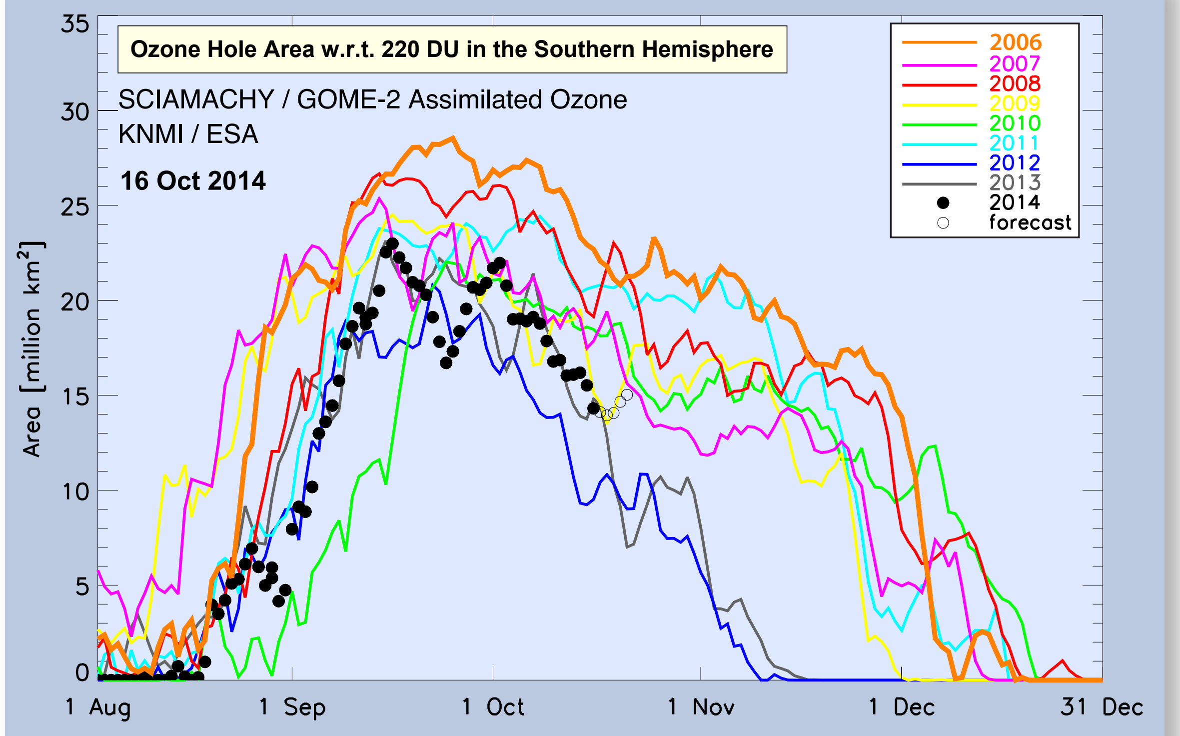


Figure 54. Ozone hole area for the years from 2006 to 2014 (black dots). The ozone hole area is the area of the region where total ozone is below 220 DU. The open circles represent a forecast for the five next days. This plot is produced by KNMI and is based on data from the GOME-2 and SCIAMACHY satellite instruments.

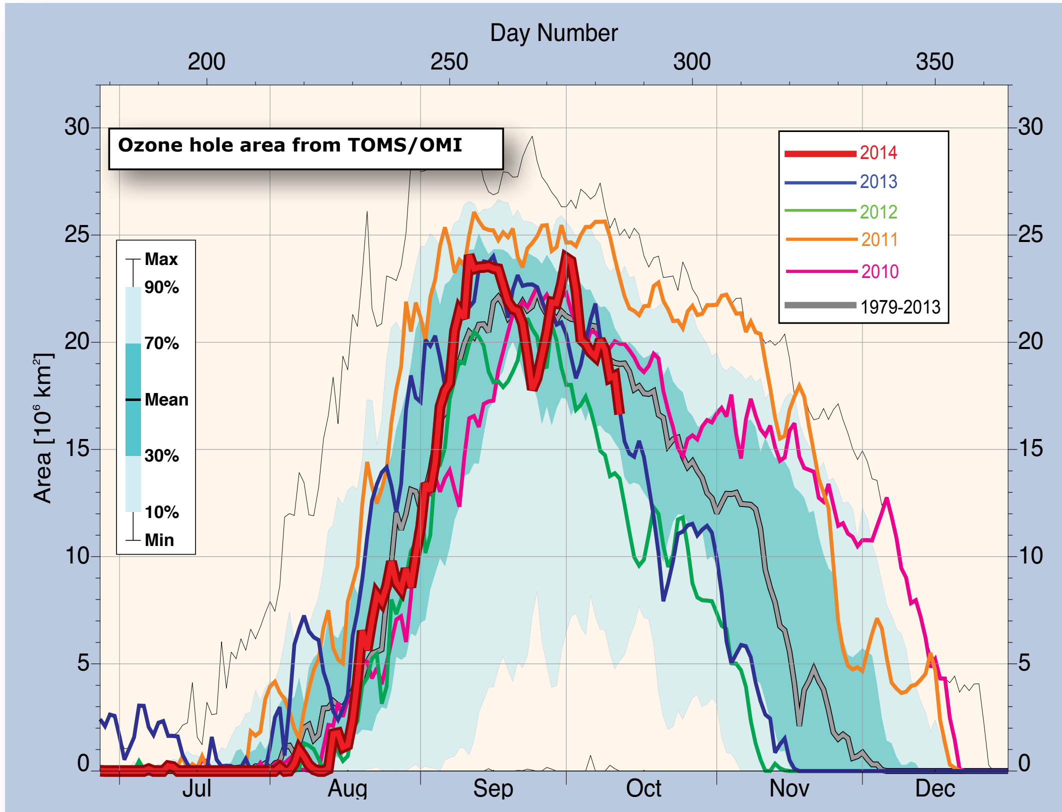


Figure 55. Area (millions of km^2) where the total ozone column is less than 220 Dobson units. 2014 is showed in red (until 12 October). 2013 is shown in blue, 2012 in green, 2011 in orange and 2010 in magenta. The smooth grey line is the 1979-2013 average. The dark green-blue shaded area represents the 30th to 70th percentiles and the light green-blue shaded area represents the 10th and 90th percentiles for the time period 1979-2013. The ozone hole area on 9 September is approx. 21.5 million km^2, a little bit above the long term average. 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.

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 56**. The same parameter as calculated by NASA from OMI data is shown in **Figure 57.** These plots show that the ozone mass deficit has developed in 2014 similarly to recent years. It seems unlikely that the 2014 mass deficit will match the one of 2011, but it looks like it will be similar to that seen in 2010, 2012 and 2013. As seen from **Figure 57** the ozone mass deficit has followed the long term mean quite closely.

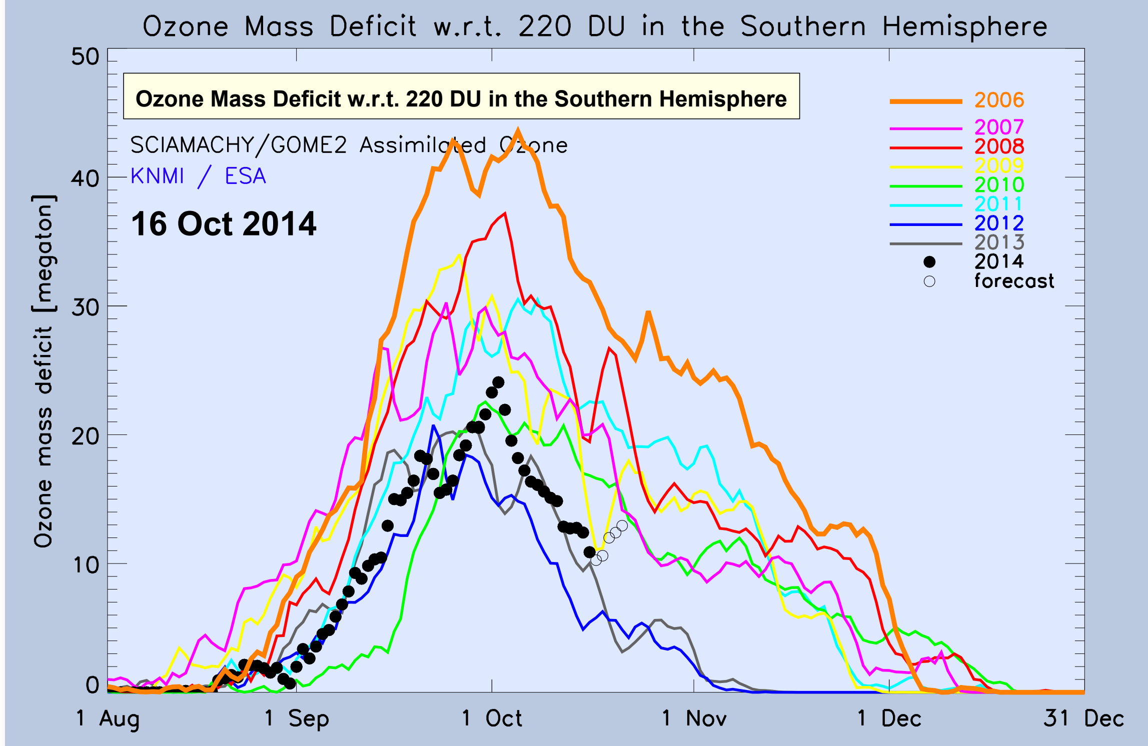


Figure 56. Ozone mass deficit for the years from 2006 to 2014 (black dots). The ozone hole area is the area of the region where total ozone is below 220 DU. The open circles represent a forecast for the five next days. This plot is produced by KNMI and is based on data from the GOME-2 and SCIAMACHY satellite instruments.

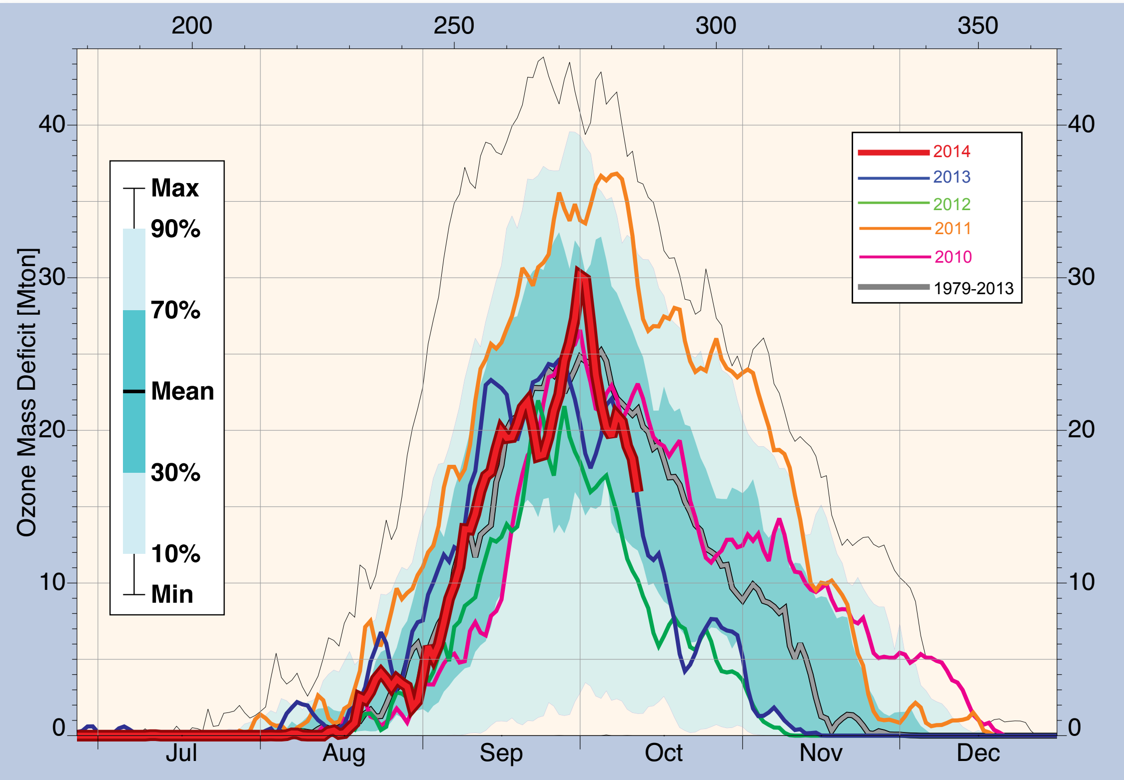


Figure 57. Ozone mass deficit (megatons) inside the Antarctic ozone hole for the years from 2010 to 2014 together with 1979-2013 statistics. Data for 2014 are shown in red (until 12 October). The ozone mass deficit is defined as the mass of ozone that would have to be added to the ozone hole in order 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).

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 the period from 7 September to 13 October) could be calculated. These results are shown in **Figure 58**. It can be seen that the average ozone hole area over the ten last days of September was smaller in 2014 compared to 2013 but a tiny little bit larger than in 2012 (19.13 vs 19.00). Otherwise one has to go back to 2002 to find an ozone hole with a smaller area and before that one has to go back to 1990 to find a smaller ozone hole area for the 21 - 30 September time period. For the time period 7 September to 13 October it can be seen from the Figure that the ozone hole area in 2014 was marginally smaller than in 2013 (19.19 vs 19.25) but larger than in 2012 and 2010.

Rather than looking at the area of the region where total ozone is below 220 DU 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 220 DU 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 59**. The time periods are the same as that used for the ozone hole area calculations. According to this metric the ozone hole of 2014 was less severe than the one in 2013 but more severe than the one in 2012. Before that one has to go back to 2004 to find a weaker ozone hole. Looking at the 7 September to 13 October time period the ozone mass deficit in 2014 was a bit smaller than in 2013 (15.42 vs 15.87) but larger than in 2012 and 2010.

In forthcoming issues of the Bulletin the statistics for other time periods will also be presented.

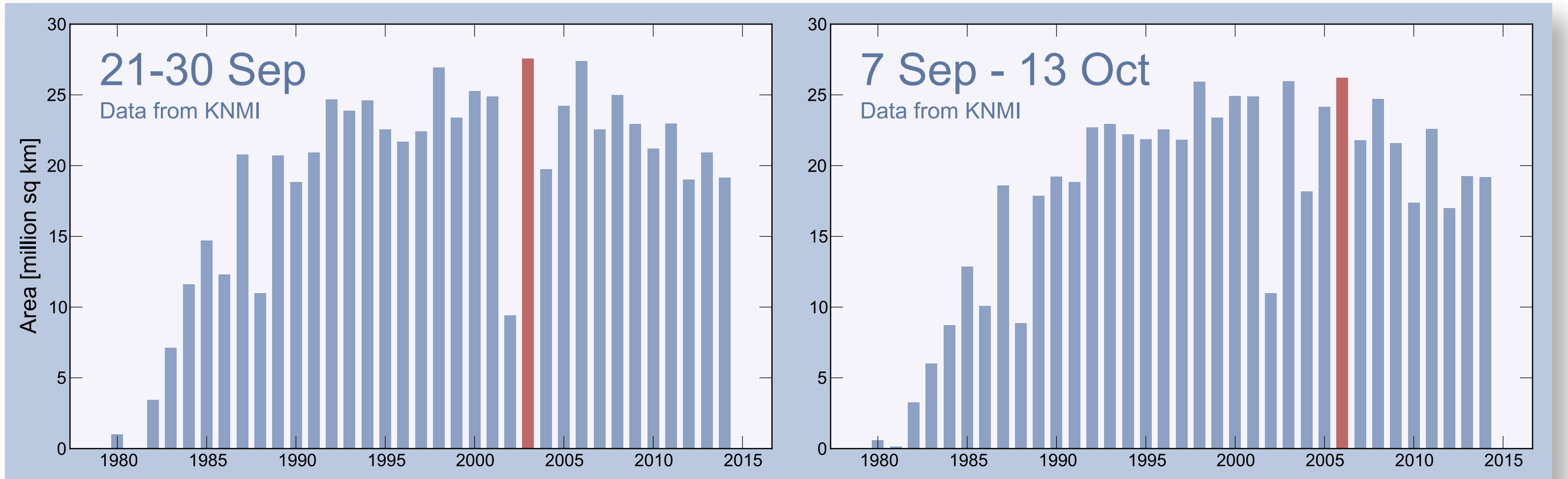


Figure 58. Area of the ozone hole for the years 1979-2014, averaged over the ten last days of September (left) and for the time period 7 September to 13 October (right). The data are calculated at KNMI from the multi-sensor reanalysis (MSR) and GOME-2 data. The plot is produced at WMO.

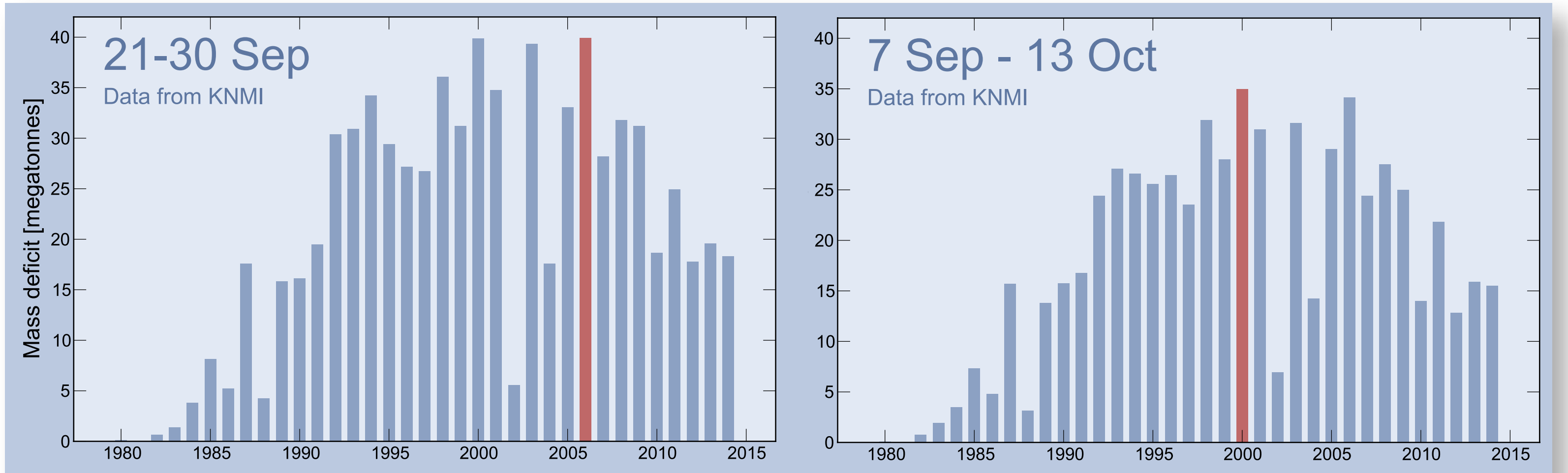


Figure 59. Ozone mass deficit averaged over the same time periods as in the previous figure. The data are calculated at KNMI from the multi-sensor reanalysis (MSR) and GOME-2 data. The plot is produced at WMO.

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 late 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 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, Davis), 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 (Artigas) and USA (South Pole). More detailed information on these sites can be found at the GAWSIS web site (http://www.empa.ch/gaw/gawsis).

Satellite ozone data are provided by NASA (http://ozonewatch.gsfc.nasa.gov), NOAA/TOVS (http://www.cpc.ncep.noaa.gov/products/stratosphere/tovsto/), NOAA/SBUV/2 (http://www.cpc.ncep.noaa.gov/products/stratosphere/sbuv2to/) and ESA/Sciamachy (http://envisat.esa.int). Satellite data on ozone, ClO, HCl and a number of other relevant parameters from the MLS instrument on the Aura satellite can be found here: http://mls.jpl.nasa.gov/plots/mls/mls_plot_locator.php and here: http://mirador.gsfc.nasa.gov/cgi-bin/mirador/presentNavigation.pl?tree=project&project=MLS

Potential vorticity and temperature data are provided by the European Centre for Medium Range Weather Forecasts (ECMWF) and their daily T_{106} 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 Corncordia and Dumont d'Urville can be found here: http://saoz.obs.uvsq.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?1234

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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