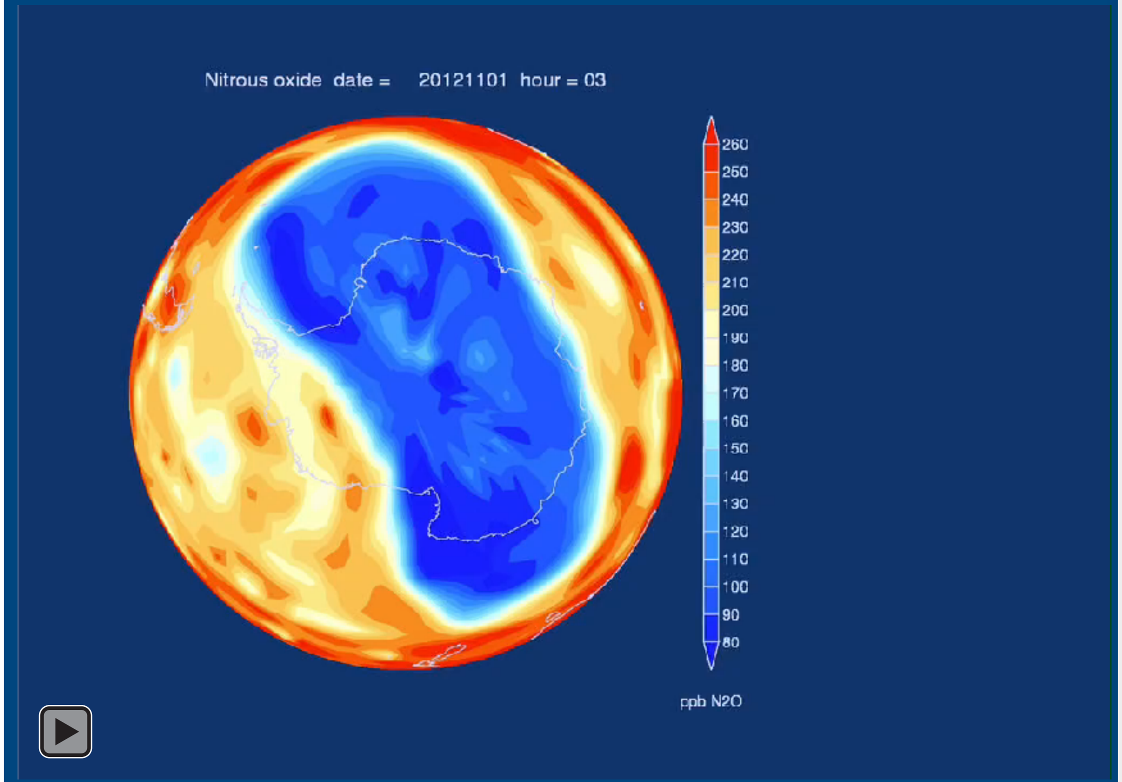
Antarctic Ozone Bulletin

No 6/2012



Animation of nitrous oxide at 68 hPa from 1 to 29 November. Due to subsidence inside the vortex and the fact that the mixing ratio of N_2O decreases with altitude in the stratosphere, N_2O is a good inert tracer for vortex air. One can see that the vortex splits in two around 8-10 November. Two new pockets of vortex air are shredded off the vortex around 17 to 18 November. Finally, a fairly large pocket of vortex air is teared off the main vortex around 25-26 November. The N_2O data come from the Bascoe data assimilation model which is run as a part of the MACC-II project. The movie runs once, but can be restarted with the control panel just underneath the movie.
More information can be found here: http://macc.aeronomie.be/4_NRT_products/3_Models_setup/

WMO OMM
10 December 2012
Global Atmosphere Watch
GAW

Executive Summary

The daily minimum temperatures at the 50 hPa level were close to or below the 1979-2011 average from April to late September. In July and August the minimum temperature was below the long term mean but still relatively warm compared to the most recent years. In September and October the minimum temperature increased more rapidly than the average, and from early October it has been above the long term mean and, on certain days, near the long term maximum.

The average temperature over the 60-90°S region was quite close to or below the long-term mean until the middle of August. During the latter half of August a minor warming led to a temperature increase of approx. 5 K. Towards the end of August the temperature decreased again, but during September the polar cap mean temperature at 50 hPa was near or above the average for the season. From late September the zonal mean temperature increased rapidly and on certain days it has been more than 10K warmer than the long term mean. On some days in October the 50 hPa mean temperature was even above the long term (1979-2011) maximum.

Since the onset of NAT temperatures in mid May the NAT area was close to or above the 1979-2011 average until early July. The NAT area reached a peak above 25 million km^2 on 12 July. Then the NAT area stayed well below the 1979-2011 average until it was back close to the long term mean in late August. During most of September it was close to or somewhat below the long-term average. In October the PSC area dropped rapidly and reached zero on the 11th.

From the onset of PSCs in mid May, the NAT volume was close to or below the 1979-2011 average throughout the winter. From early July until the end of the winter, the PSC volume was significantly lower than the long-term mean and also near and even below the 1979-2011 minimum on some days. By 22 October the PSC volume had dropped to zero.

During May and June the 45-day mean of the heat flux was lower than or close to the 1979-2011 average. From early July, the heat flux increased somewhat and remained larger than the 1979-2011 average until late August. In September it was oscillating around the average. From late September and through October the heat flux increased rapidly and remained significantly larger than the long-term mean until late November. In late November and early December it has been close to the long term average.

During the first half of August, the area increased more slowly than at the same time in many of the recent years. However, from mid August the increase more or less followed the same development as in 2011. From early September, the ozone hole area levelled off but increased a bit again after the middle of September. Starting early October, the ozone hole area dropped rapidly until it reached zero on 10 November.

Measurements with ground based instruments and with balloon sondes show that ozone depletion has passed through its maximum for the season and that most sites now show ozone amounts typical of mid-latitude conditions. In this issue data are reported from the following stations: Arrival Heights, Belgrano, Dôme Concordia, Dumont d'Urville, Davis, Halley, Macquarie Island, Marambio, Mirny, Neumayer, Novolazarevskaya, Río Gallegos, Rothera, South Pole, Syowa, Ushuaia, Vernadsky, Vostok and Zhongshan.

The unusually small ozone hole area and ozone mass deficit in 2012 are partly due to relatively warm temperatures leading to a modest amount of polar stratospheric clouds. In addition, the vortex has been perturbed, and there has been transport of ozone-rich air from lower latitudes on top of the vortex. Ozone depletion has been quite substantial over the 14-20 km altitude range, but higher up the ozone concentration has been higher than usual. Several ozonesonde profiles have been observed where there is massive depletion in the 14-20 km height range, yet the total column is well above the 220 DU threshold, which is taken as a criterion for classifying a site as affected by the ozone hole. This means that some regions which are affected by substantial ozone loss nonetheless are counted as being outside of the ozone hole.

Around 7-9 November the polar vortex split in two. This phenomenon can be seen in satellite and model data for several parameters, such as ozone, hydrochloric acid and nitrous oxide. This vortex split led to a relatively early breakdown of the polar vortex and led to a displacement of vortex air towards middle latitudes. This again caused enlarged clear-sky UV indices over the ocean between Antarctica and Africa around 1 to 10 November. The vortex split is visualised in the animation on the cover page.

The ozone hole season is now nearly over. A final issue with an overview of the 2012 ozone hole will be published in late February 2013.

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). See **Figure 1** on the next page for details.

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.

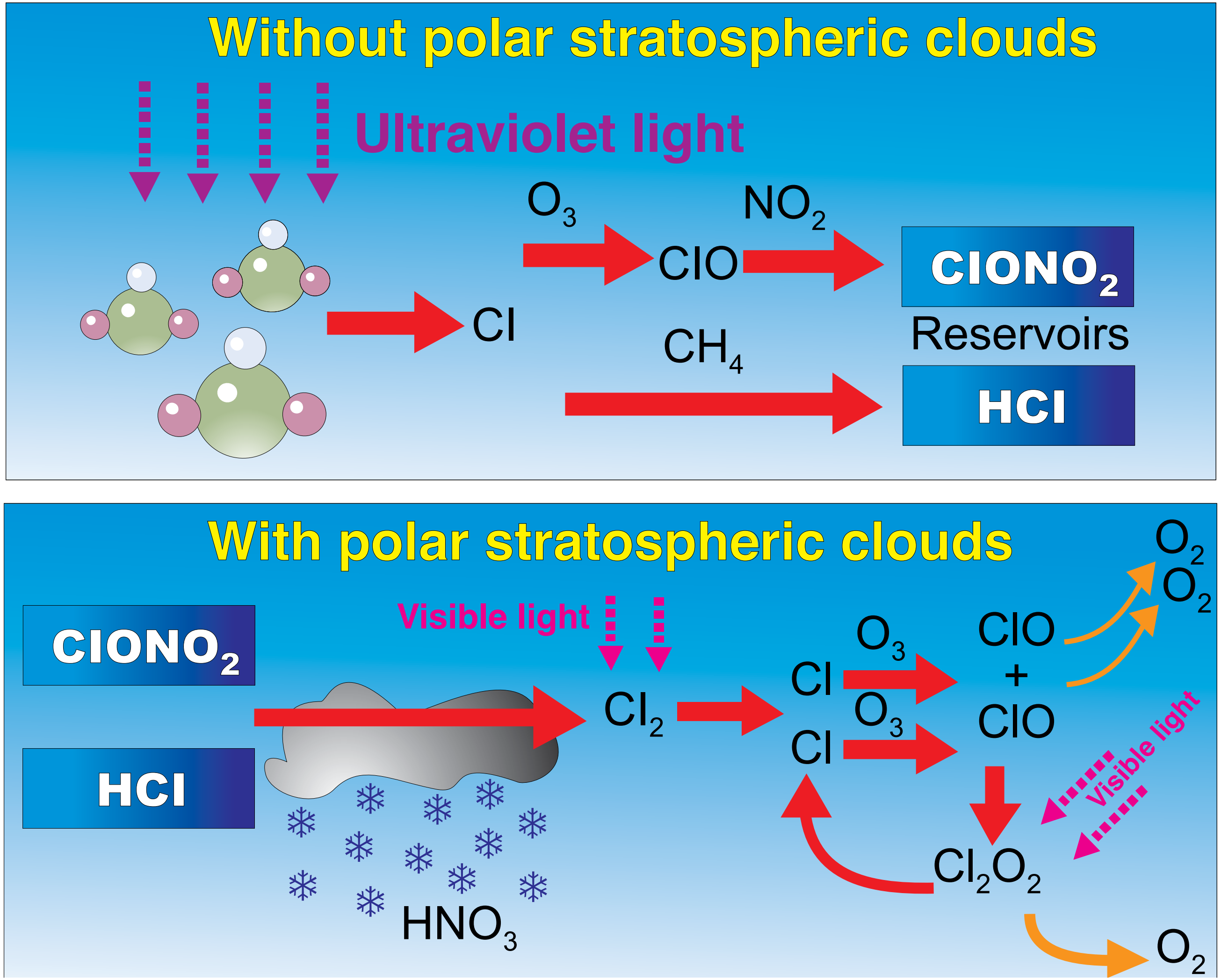


Figure 1. Diagram showing the effect of polar stratospheric clouds on ozone loss. The upper panel shows the situation when there are no polar stratospheric clouds. Ozone depletion takes place only in the gas phase (homogeneous chemistry). The lower panel shows the situation when there are polar stratospheric clouds present. The reservoir gases hydrochloric acid and chlorine nitrate react with each other on the surface of the PSC particles through a red-ox reaction and liberate elementary chlorine (Cl_2). Elementary chlorine is easily photolysed by sunlight and forms atomic chlorine, which reacts fast with ozone to form chlorine monoxide (ClO, active chlorine) and oxygen (O_2). ClO dimerises and forms Cl_2O_2, which is easily photolysed, liberating atomic chlorine again. Due to this catalytic cycle, one atom of Cl can destroy thousands of ozone molecules before it is passivated through reaction with NO_2, methane or other substances. This explains why a few ppb of chlorine can destroy several ppm of ozone. In addition, PSC particles can grow large enough to sediment, thereby removing HNO_3 from the stratosphere. This means that there will be limited amounts of NO_2 present to quench the active chlorine, and the ozone depleting process can continue for several weeks. The diagram has been made by Finn Bjørklid, Norwegian Institute for Air Research (NILU).

Meteorological conditions

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 mid May and below the PSC type II threshold of -85°C from early June, as shown in **Figure 2**. This figure also shows that the daily minimum temperatures at the 50 hPa level were close to or below the 1979-2011 average from April to late September. In July and August the minimum temperature was below the long term mean but still relatively warm compared to the most recent years. In September and October the minimum temperature increased more rapidly than the average, and from early October it has been above the long term mean and, on certain days, near the long term maximum.

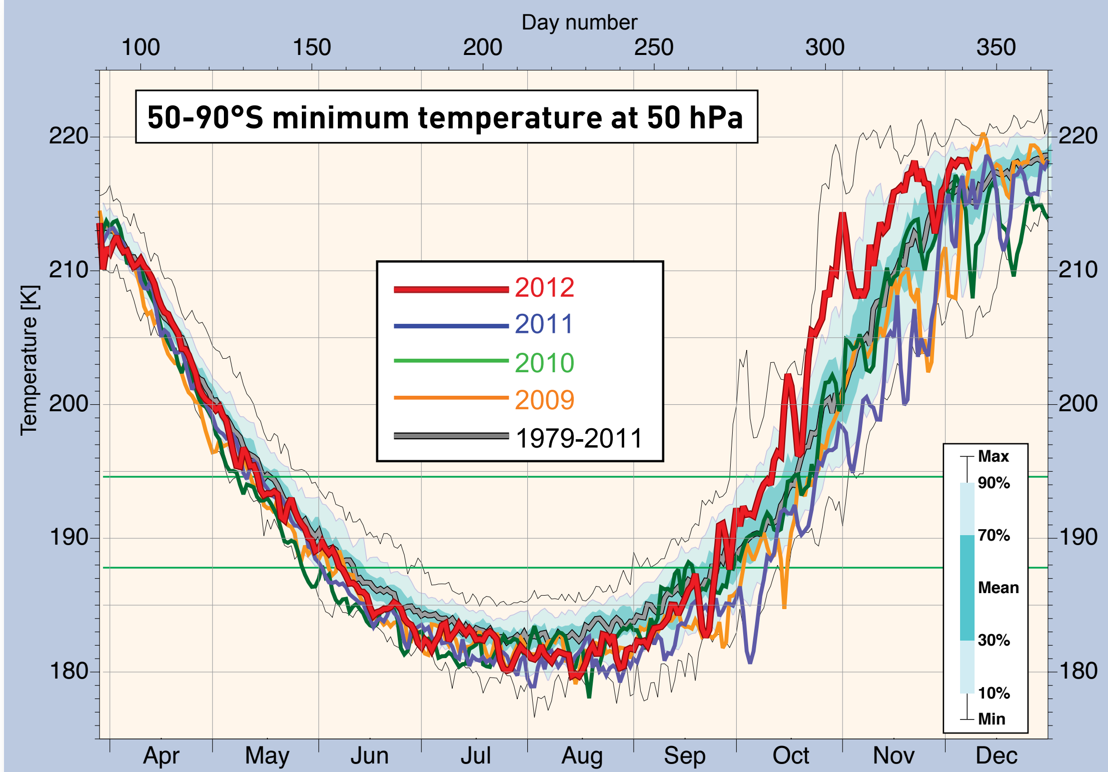


Figure 2. Time series of daily minimum temperatures at the 50 hPa isobaric level south of 50°S. The red curve shows 2012 (until 7 December). The blue line shows 2011, the green line 2010 and the orange line 2009. The average of the 1979-2011 period is shown for comparison in grey. The thin black lines represent the highest and lowest daily minimum temperatures in the 1979-2011 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 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 quite close to or below the long-term mean until the middle of August. During the latter half of August a minor warming led to a temperature increase of approx. 5 K. Towards the end of August the temperature decreased again, but during September the polar cap mean temperature at 50 hPa was near or above the average for the season. From late September the zonal mean temperature increased rapidly and on certain days it has been more than 10K warmer than the long term mean. On some days in October the 50 hPa mean temperature was even above the long term maximum.

At 10 hPa (**Figure 3**, right panel), the 60-90°S mean temperature was below or near the long term mean until the end of June. After that the mean temperature rose more or less gradually and on most days from the latter half of July it was above the 90th percentile (which

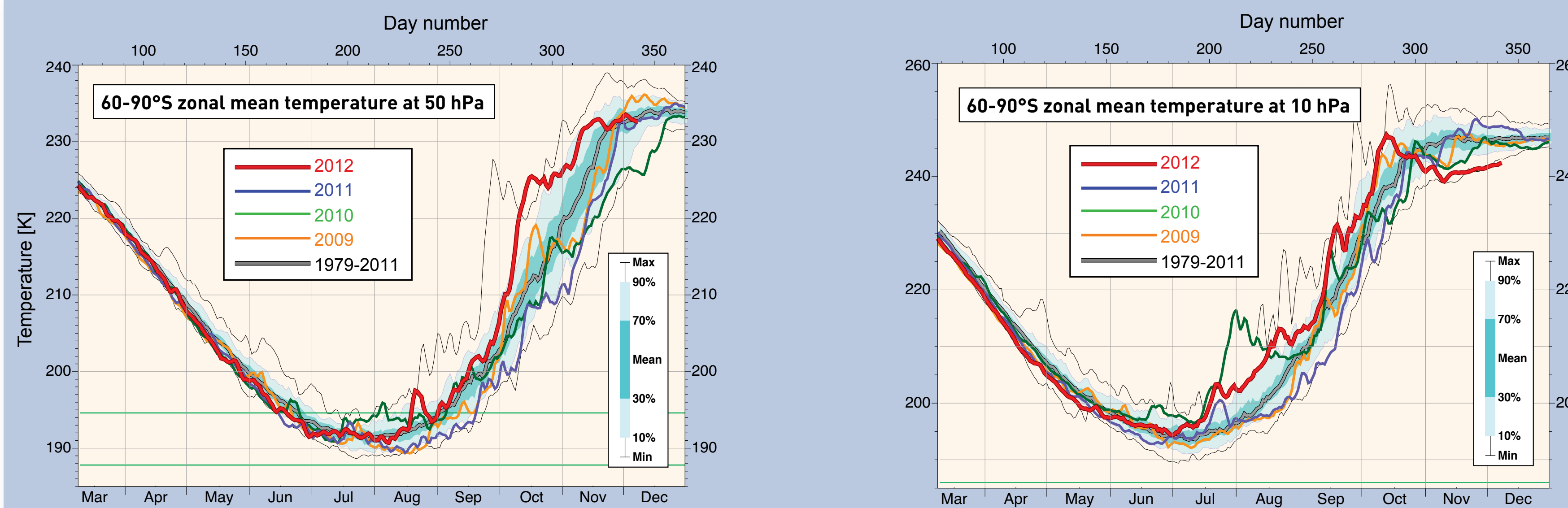


Figure 3. Time series of temperature averaged over the region south of 60°S at the 50 hPa level (left) and at 10 hPa (right). The red curve shows 2012 (until 7 December). The blue, green and orange curves represent 2011, 2010 and 2009, respectively. The average of the 1979-2011 period is shown for comparison in grey. The two thin black lines show the maximum and minimum average temperature for during the 1979-2011 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.

means that 90% of the winters during the 1979-2011 time period have been colder during this time of the year at 10 hPa). In late August the 10 hPa temperature stabilised and even decreased a bit but was still well above the long-term mean. In September and October the temperature increased and was higher than the long-term average. On some days in September and October the 10 hPa temperature was even above the long term (1979-2011) maximum.

PSC Area

Since the end of 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 4**). Since the onset of NAT temperatures in mid May the NAT area was close to or above the 1979-2011 average until early July. The NAT area reached a peak above 25 million km^2 on 12 July. Then the NAT area stayed well below the 1979-2011 average until late August, but in September it was close to or somewhat below the long-term average. In October the PSC area dropped rapidly and reached zero on the 11th.

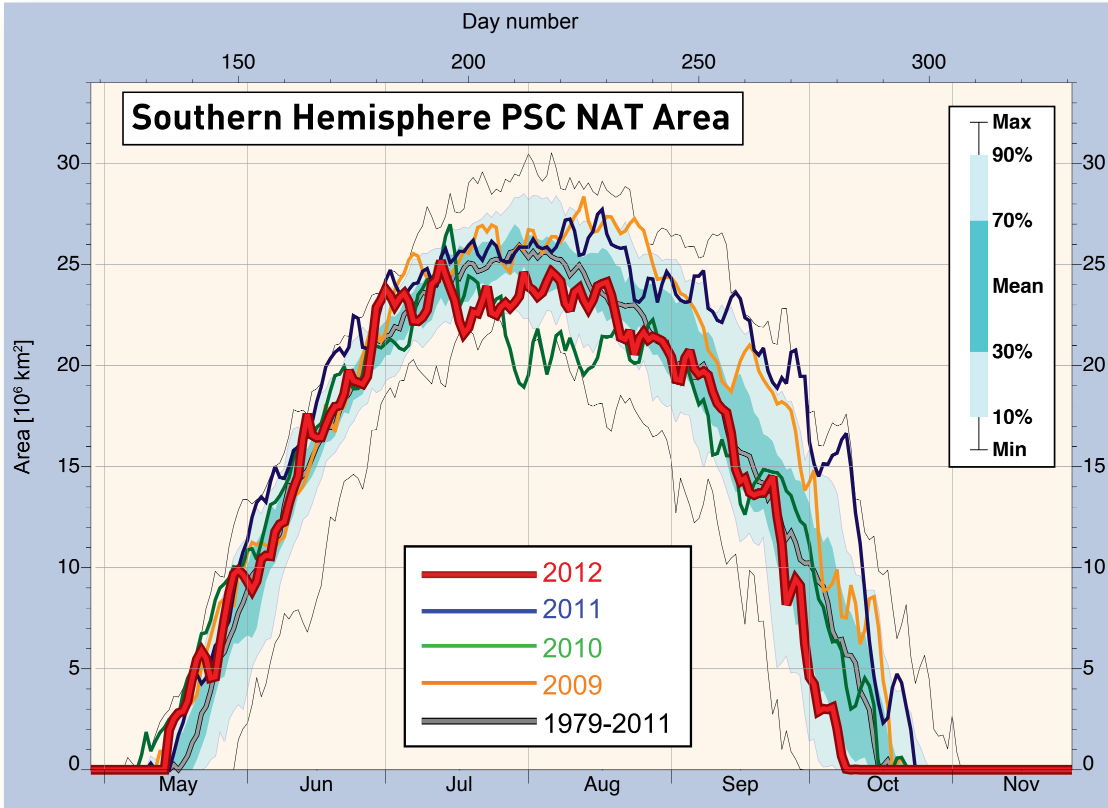


Figure 4. Time series of the area of the region where temperatures are low enough for the formation of nitric acid trihydrate (NAT or PSCs of type I) at the 460 K isentropic level. The red curve shows 2012 (until 7 December). The blue, green and orange curves represent 2011, 2010 and 2009, respectively. The average of the 1979-2011 period is shown for comparison in grey. The two thin black lines show the maximum and minimum PSC area during the 1979-2011 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 2012 is shown in **Figure 5** in comparison to recent winters and long-term statistics. From the onset of PSCs in mid May, the NAT volume was close to or below the 1979-2011 average throughout the winter. From early July until the end of the winter, the PSC volume was significantly lower than the long-term mean and also near and even below the 1979-2011 minimum on some days. By 22 October the PSC volume had dropped to zero. 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. The relatively small NAT area and NAT volume from early July can partly explain the modest size of the 2012 ozone hole.

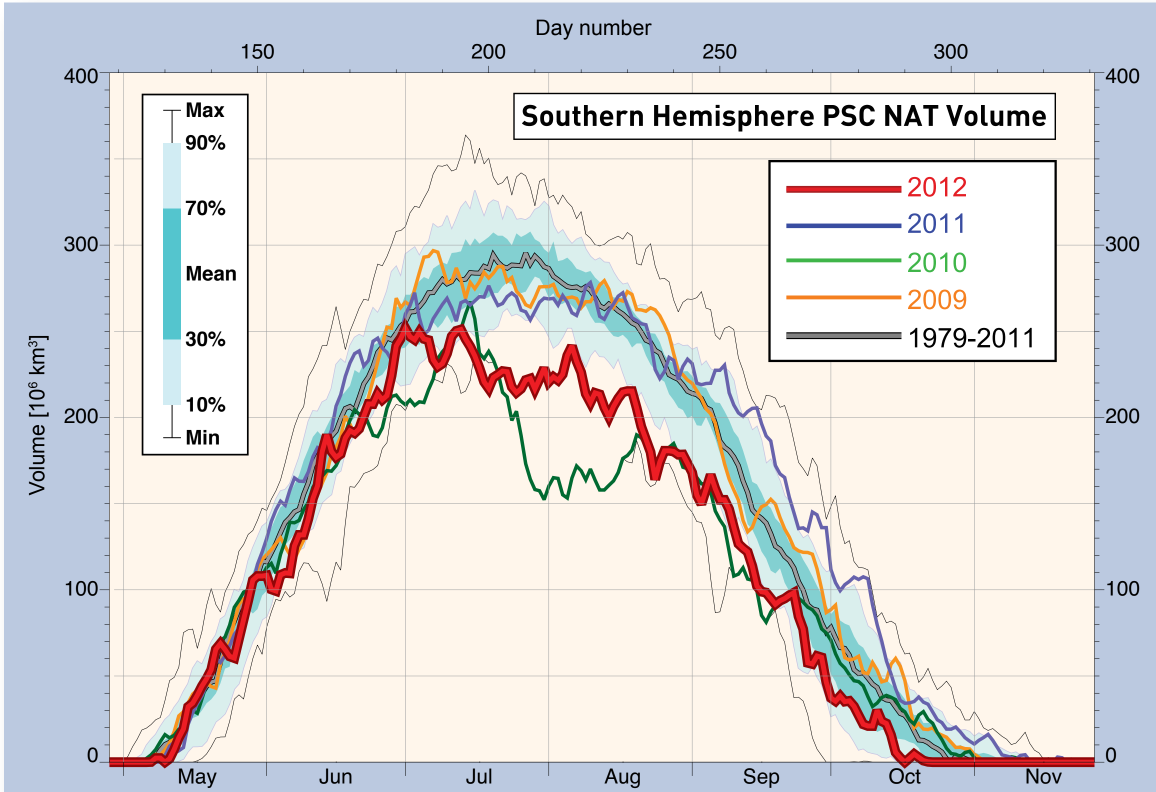


Figure 5. Time series of the volume of the region where temperatures are low enough for the formation of nitric acid trihydrate (NAT or PSCs of type I). The red curve shows 2012 (until 7 December). The blue, green and orange curves represent 2011, 2010 and 2009, respectively. The average of the 1979-2011 period is shown for comparison in grey. The two thin black lines show the maximum and minimum PSC area during the 1979-2011 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.

Vortex stability

The longitudinally averaged heat flux between 45°S and 75°S is an indication of how much the stratosphere is disturbed. The development of the heat flux is shown in **Figure 6.** During May and June the 45-day mean of the heat flux was lower than or close to the 1979-2011 average. From early July, the heat flux increased somewhat and remained larger than the 1979-2011 average until late August. In September it was oscillating around the average. From late September and through October the heat flux increased rapidly and remained significantly larger than the long-term mean until late November. In late November and early December it has been close to the long term average.

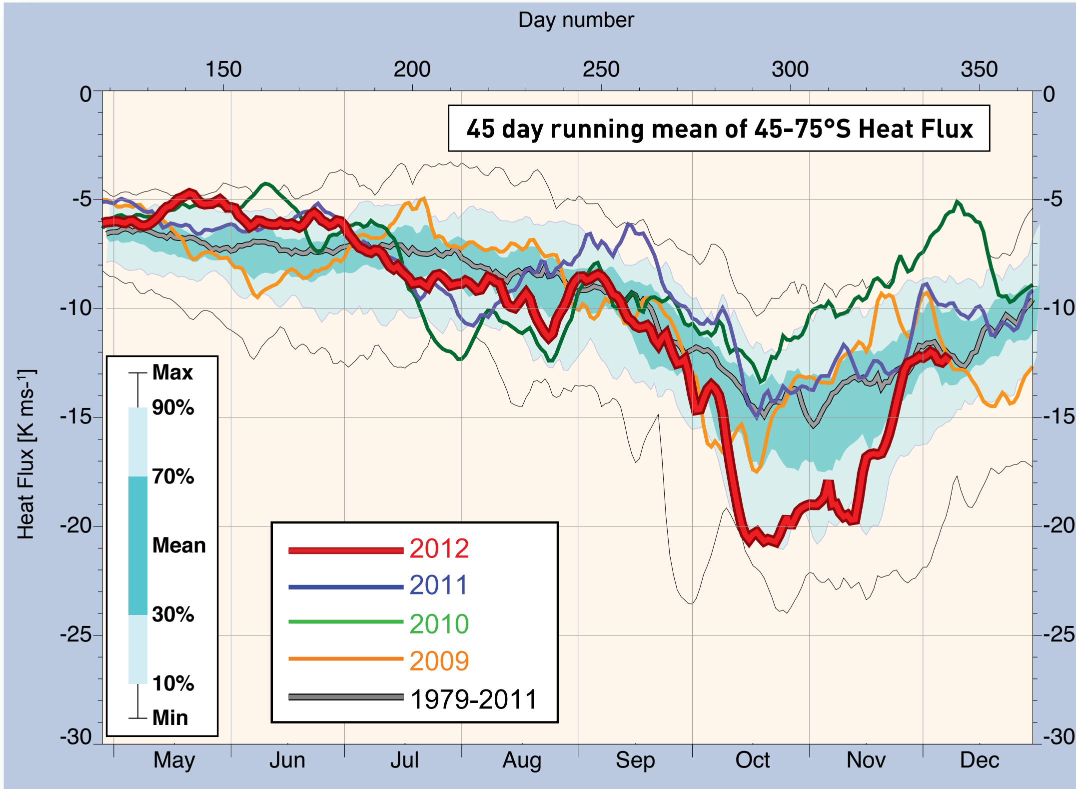


Figure 6. Time series of the meridional heat flux averaged over the 45-75°S region. The red curve shows data for 2012 (updated until 7 December). Please note that a large negative number means a large heat flux. Values closer to zero means a small heat flux. The plot is made at WMO based on data downloaded from the Ozonewatch web site at NASA, which are based on data from NOAA/NCEP.

Ozone observations

Satellite observations

All of Antarctica is now exposed to sunlight, ozone destruction has ceased and the polar vortex has dissipated. **Figure 7** shows minimum ozone columns as measured by the GOME-2 instrument on board MetOp-A in comparison with data for recent years back to 2005 (SCIAMACHY and GOME-2). In the middle of August the minimum columns were about average for the time of the year in comparison to the seven most recent years. After that the minimum columns have been relatively large in comparison to the other years shown here. The minimum ozone columns have increased through October and November. The lowest value seen so far this year is 126 DU on 21 September.

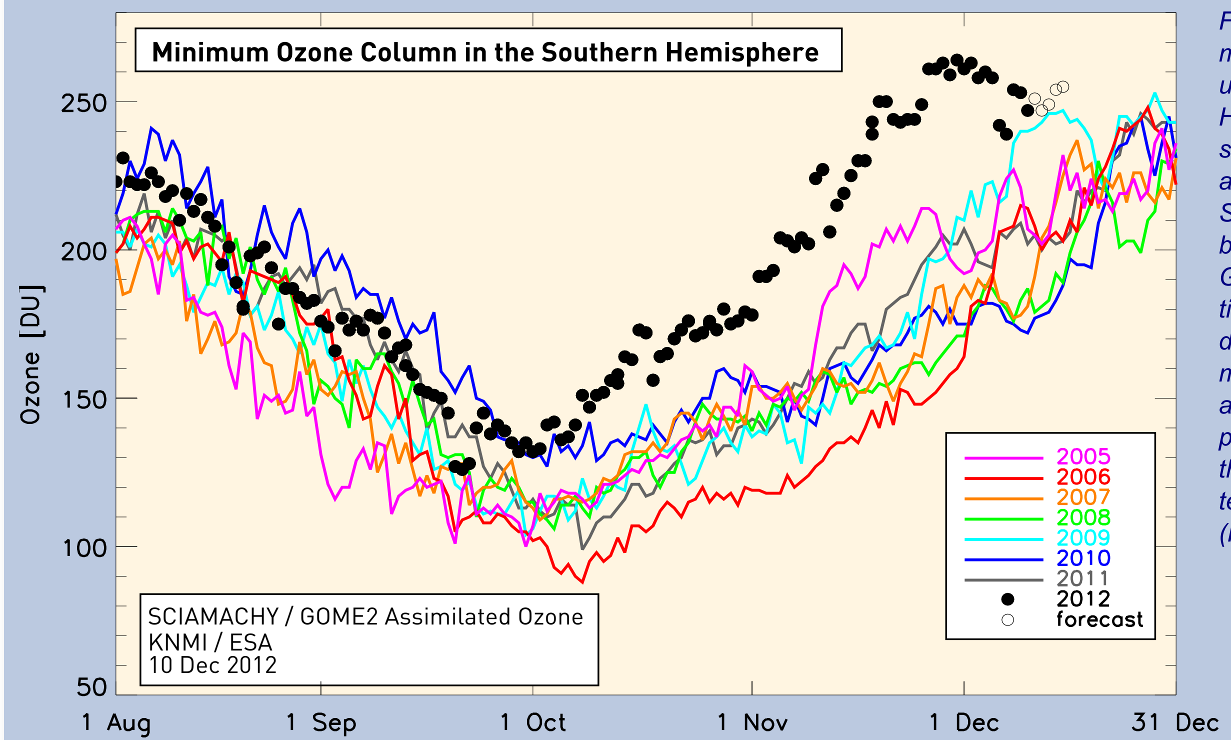


Figure 7. Daily minimum total ozone columns in the Southern Hemisphere as observed by GOME-2, and in the past by SCIAMACHY. The black dots show the GOME-2 observations for 2012. The data now show minimum ozone columns around 260 DU. The plot is provided by the Netherlands Meteorological Institute (KNMI).

Figure 8 shows satellite maps from GOME-2 for 7 November for the years 2006 - 2012. For this time of the year, the 2012 ozone hole is clearly the smallest among the years shown here. One can also see that the ozone hole has taken on a shape of the figure eight. This is at the beginning of the vortex split episode shown in the animation on the cover page.

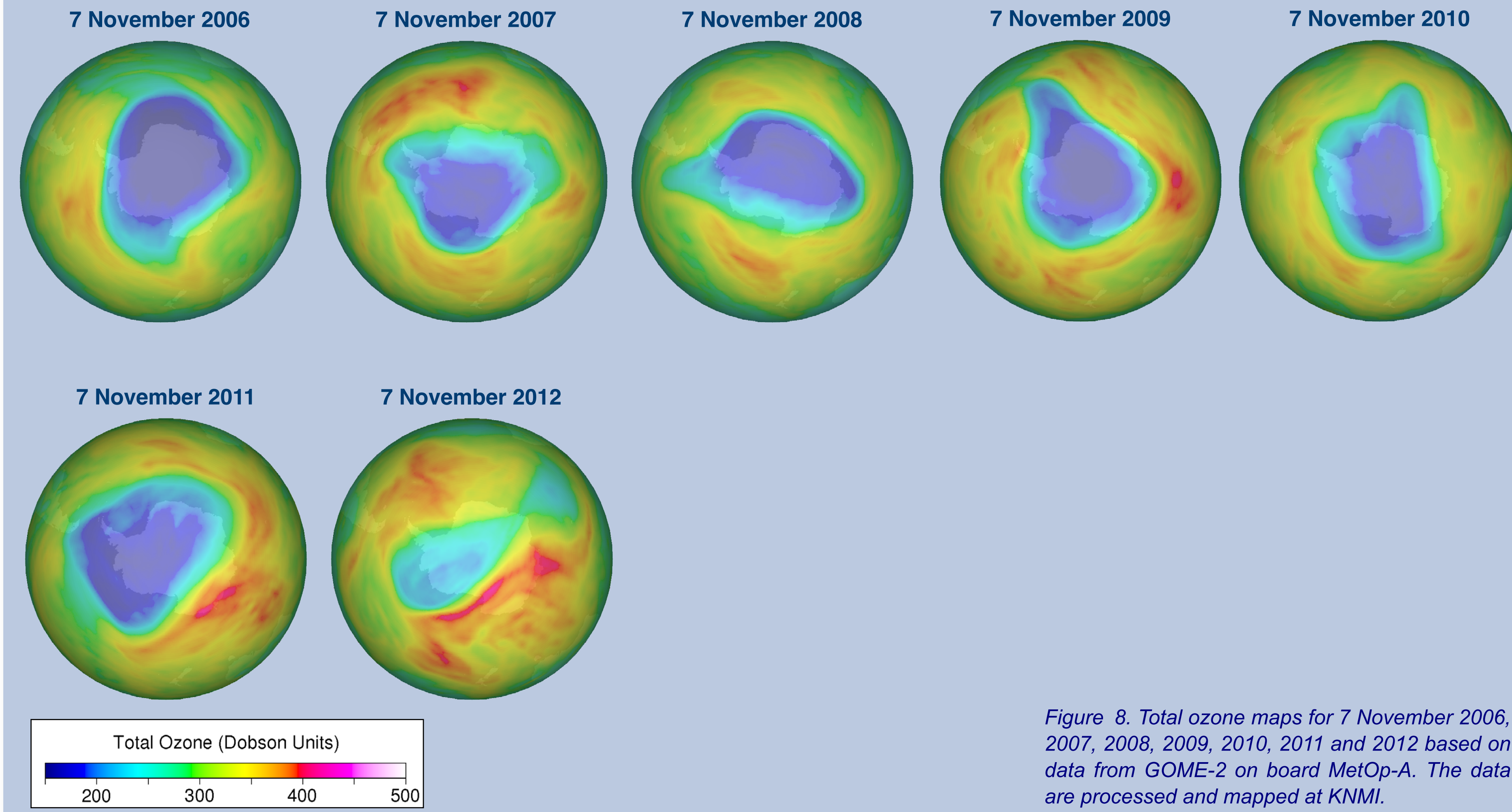


Figure 8. Total ozone maps for 7 November 2006, 2007, 2008, 2009, 2010, 2011 and 2012 based on data from GOME-2 on board MetOp-A. The data are processed and mapped at KNMI.

Ground-based and balloon observations

All the stations are now reporting data and are presented in this issue. On the next page is a map showing 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 is also indicated for each station. For stations with a limited number of data points, as compared to daily data, the calculation is done with OMI satellite overpass data.

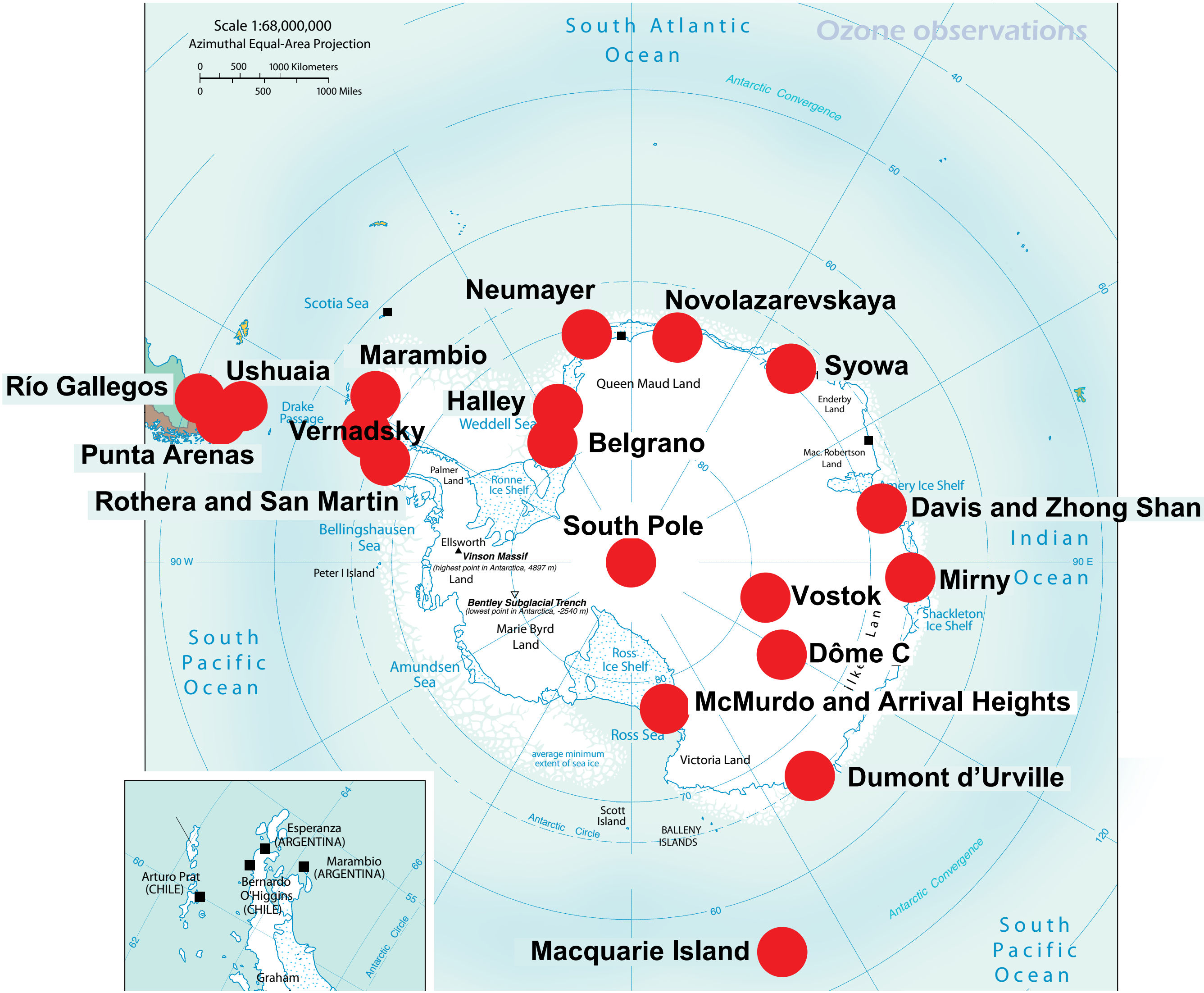
Station Statistics. Lowest ozone values observed at Antarctic stations

Station name	Lowest Total Ozone (Dobson, Brewer, SAOZ, filter)	Lowest Total Ozone from Sonde	Lowest 12-20 km partial column	# of days with total ozone below 220 DU
Arrival Heights	149 DU (27.9)			11
Belgrano	137 DU [2] (21.9)	122 DU (26.9)	17 DU (26.9)	52 [2]
Davis	209 DU [2] (4.10)	220 DU (13.9)		4 [2]
Dôme C	174 DU (5.10)			5
Dumont d'Urville	243 DU (12.7)			2
Halley	133 DU (23.9)			62
Marambio	142 DU (8.10)	154 DU (22.9)	39 DU (22.9, 10.10)	36
Mirny	224 DU (11.9)			0
Neumayer	156 DU [2] (18.9)	141 DU (8.9)	23 DU (11.10)	50 [2]
Novolazarevskaya	160 DU [1] (19.9)			48
Rothera	132 DU (8.10)			40
South Pole	139 DU[2] (5-6.10)	136 DU (5.10)	19 DU (12.10)	26 [3]
Syowa	176 DU (23.9)	191 DU (23.9)	39 DU (23.9)	38
Ushuaia	195 DU [2] (22.9)	169 DU (22.9)	46 DU (22.9)	2
Vernadsky	150 DU (21.9)			30
Vostok	151 DU (26.9)			33
Zhong Shan	193 DU (4.10)			6
Minimum	**132 DU**	**122 DU**	**17 DU**	

[1] From satellite overpass data. This is the lowest OMI observation over Novolazarevskaya on that day.

[2] From OMI overpass data.

[3] First measurement after the polar night starting on 24 September.


Ozone observations
Scale 1:68,000,000
Azimuthal Equal-Area Projection
South Atlantic Ocean
Neumayer
Novolazarevskaya
Syowa
Marambio
Ushuaia
Río Gallegos
Punta Arenas
Halley
Vernadsky
Belgrano
Rothera and San Martin
South Pole
Davis and Zhong Shan
Mirny
Vostok
Dôme C
McMurdo and Arrival Heights
Dumont d'Urville
Macquarie Island
Queen Maud Land
Enderby Land
Mac. Robertson Land
Weddell Sea
Scotia Sea
Drake Passage
Bellingshausen Sea
Amundsen Sea
Ross Sea
Ross Ice Shelf
Ronne Ice Shelf
Shackleton Ice Shelf
Marie Byrd Land
Victoria Land
Vinson Massif
Bentley Subglacial Trench
Indian Ocean
South Pacific Ocean
Antarctic Convergence
Antarctic Circle
Esperanza (ARGENTINA)
Marambio (ARGENTINA)
Bernardo O'Higgins (CHILE)
Arturo Prat (CHILE)

Arrival Heights

The New Zealand GAW/NDACC station at 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 17 September. On that day, total ozone was 202 DU. Total ozone was above the 220 DU threshold on two days after the measurements started (20 and 21 September), otherwise it was under this threshold until 4 October. The minimum total ozone value observed so far this year is 181 DU on 26 September. From 8 October the station has been outside the ozone hole and total ozone has varied between 264 DU on 14 October to 444 DU on 18 October. In November, total ozone has varied between approx. 250 DU and approx. 400 DU.

Time series of total column ozone for the years 2006 until 2012 (up to date as of 1 December) are shown in **Figure 9** together with long term statistics.

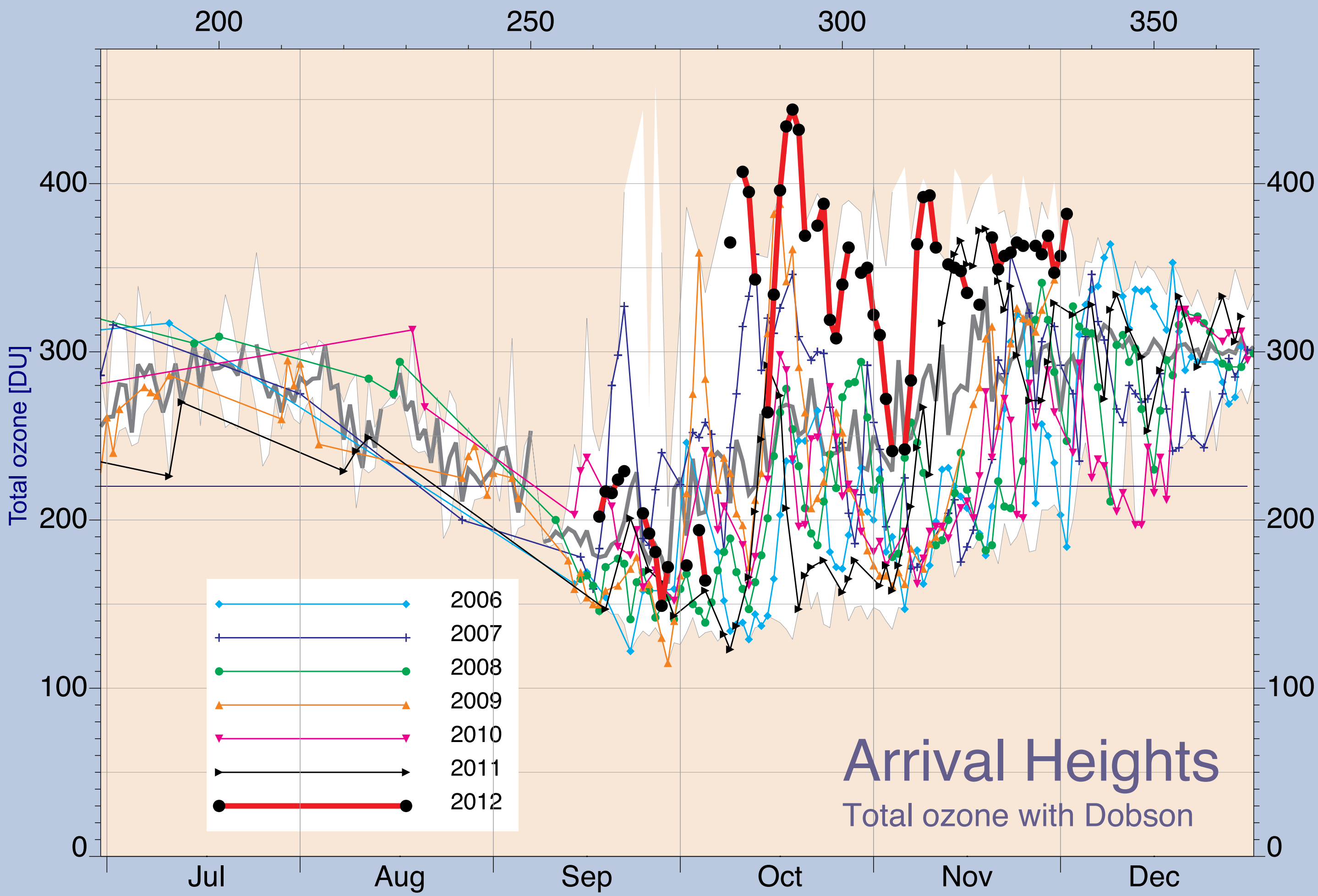
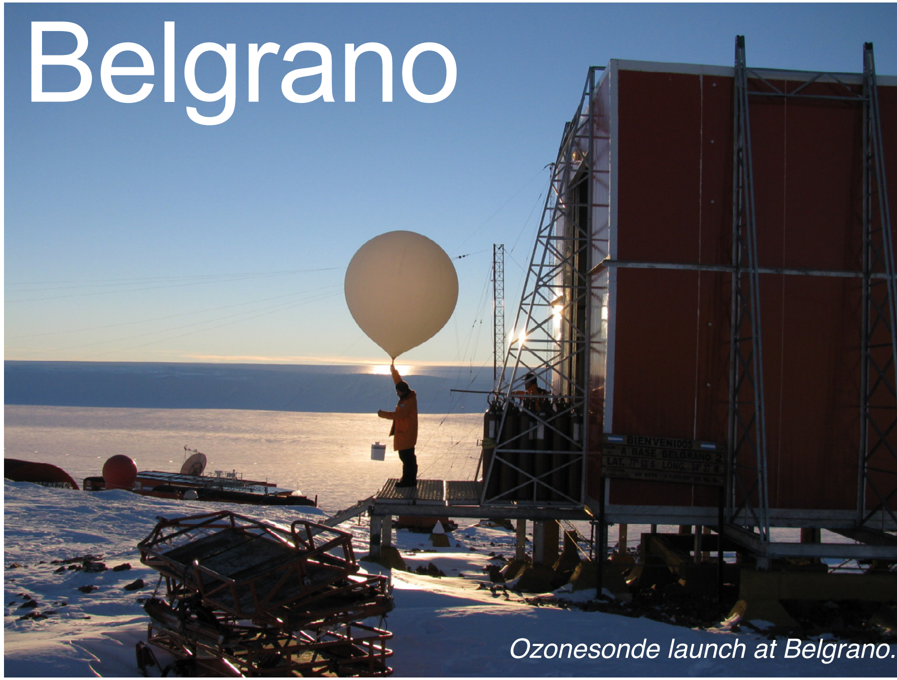


Figure 9.Time series of total ozone measured at the New Zealand station Arrival Heights. Data from 2006 until 2012 (until 1 December) are shown. The white shaded region represents the range from maximum to minimum values measured during the time period from 1988 to 2011. The thick grey line is the average value for the same time period.

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. **Figure 10** shows the nine soundings carried out from 24 August to 11 October. It can be seen that the both the total column as well as the 12-20 km column dropped considerably from 24 August

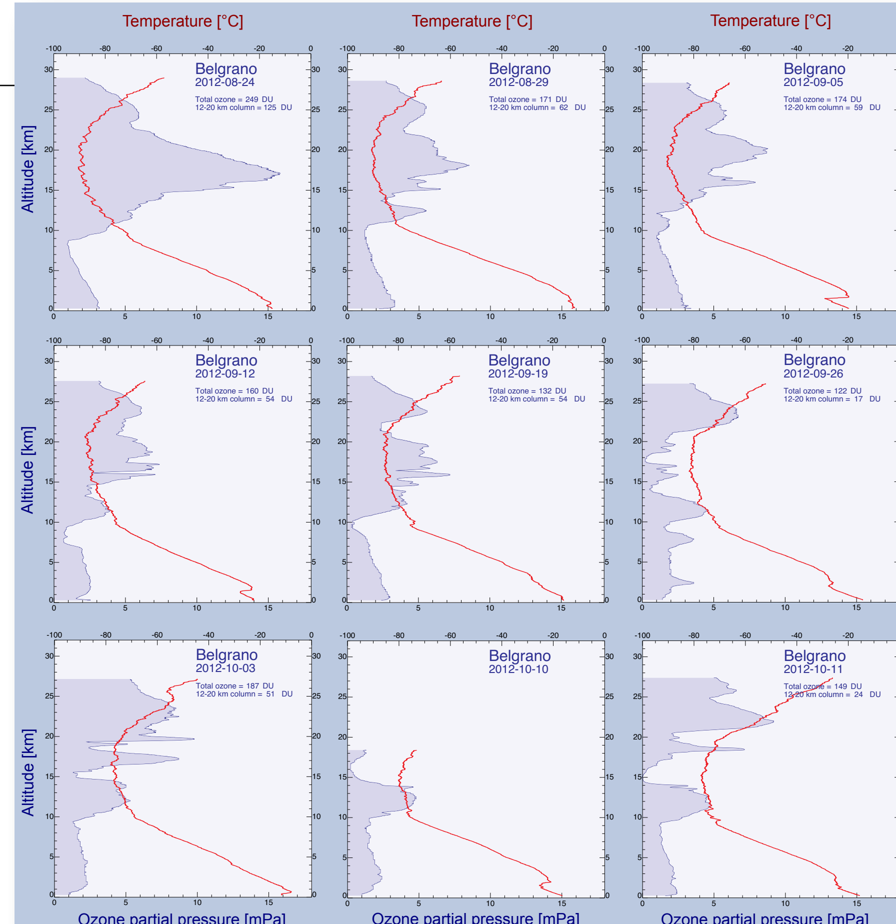


Figure 10. Ozonesonde observations at the GAW station Belgrano carried out from 24 August to 11 October. The plots are made at WMO based on data received from INTA, Spain.

to 3 October. It can be seen that there is substantial depletion in the 21-23 km height range in the profiles from 12 and 19 September. The profile measured on 26 September shows massive ozone depletion over the 14 to 21 km height range. The 12-20 km partial ozone column is 17 DU, which is the lowest measured at any station so far this year. The sounding of 10 October suffered an early balloon burst, but one can see the large degree (almost complete) of ozone depletion at around 16-17 km altitude. Because of the early balloon burst on 10 October a new sonde was launched the following day. That profile shows complete destruction of ozone at 15 km, as well as a big bite-out around 20 km. The soundings carried out from 17 October to 28 November are shown in **Figure 11**. In late October and early November there is still massive ozone depletion over the 15-20 km altitude range, although the 12-20 km partial profile is not as low as it was on 26 September. The profiles of 7 and 14 November show signatures of ozone depletion. The 28 November profile shows the influence of ozone rich air at around 20 km altitude, although ozone is still quite low just below 15 km.

The GOME-2 maps shown in **Figure 12** show that Belgrano was influenced by relatively ozone rich air on 24 August and by ozone poor air 5 days later. Overpass data from the OMI instrument on board the AURA satellite confirm this decrease although the total ozone values show some disagreement. The figure also shows that Belgrano was inside the ozone hole on 19 and 26 September. **Figure 13** shows maps from the MLS satellite instrument and from a MACC-II model run that shows that Belgrano was in a region of very poor ozone at the 55 hPa level. The figure shows that Belgrano was inside a region where the ozone mole fraction was less than 0.1 ppm at the 55 hPa

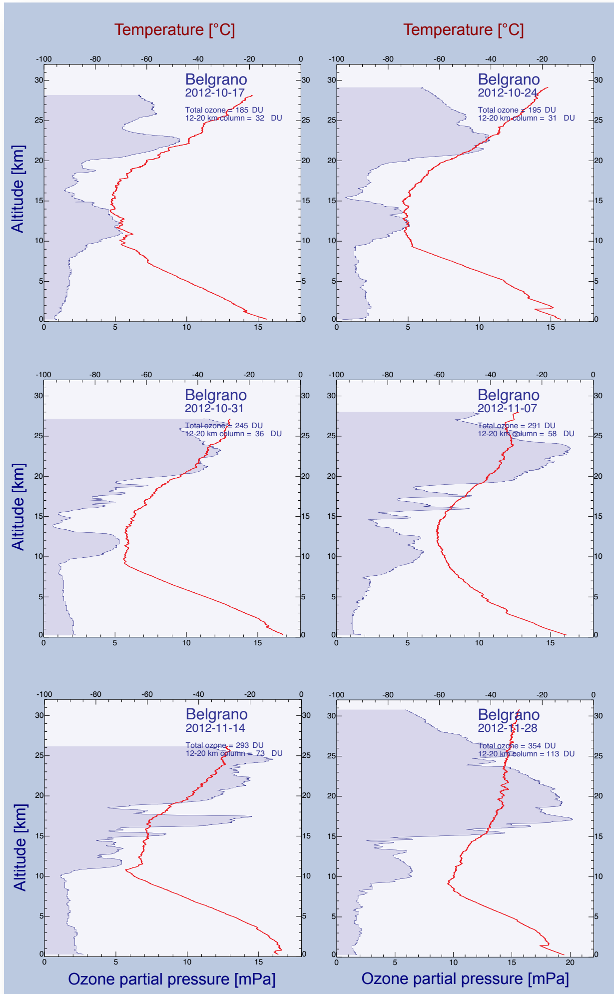


Figure 11. Ozonesonde observations at the GAW station Belgrano carried out from 17 October until 28 November. The plots are made at WMO based on data received from INTA, Spain. Please note that the abscissa scale is different on the 28 November plot as there is more ozone around 20 km.

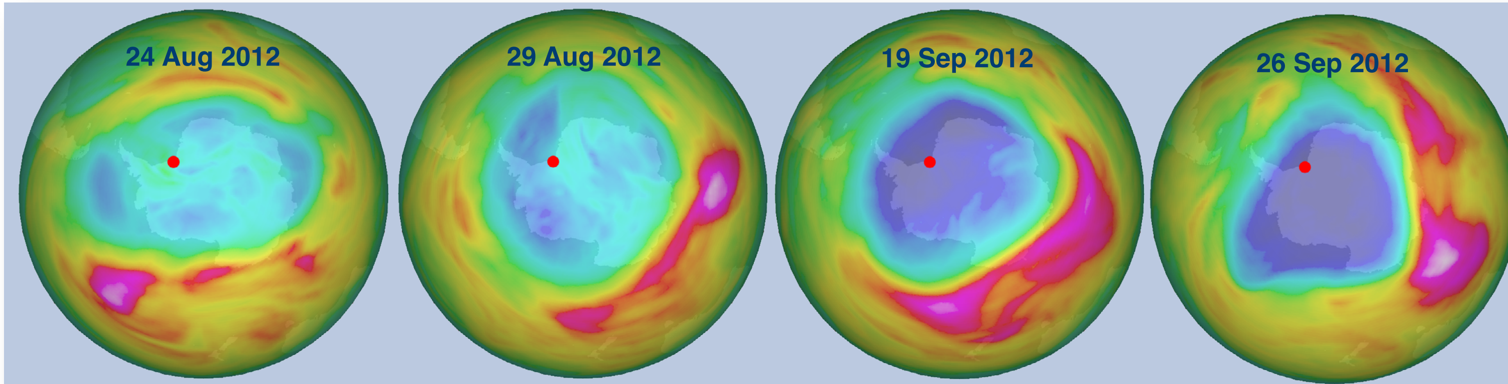


Figure 12. Total ozone from the GOME-2 instrument on 24 and 29 August and 19 and 26 September. The position of Belgrano is marked with a red circle. The plots are downloaded from the TEMIS web site (http://www.temis.nl)

level. This level corresponds to the 17-18 km region in the profile from 26 September, and which shows the largest “bite-out” of the ozone profile.

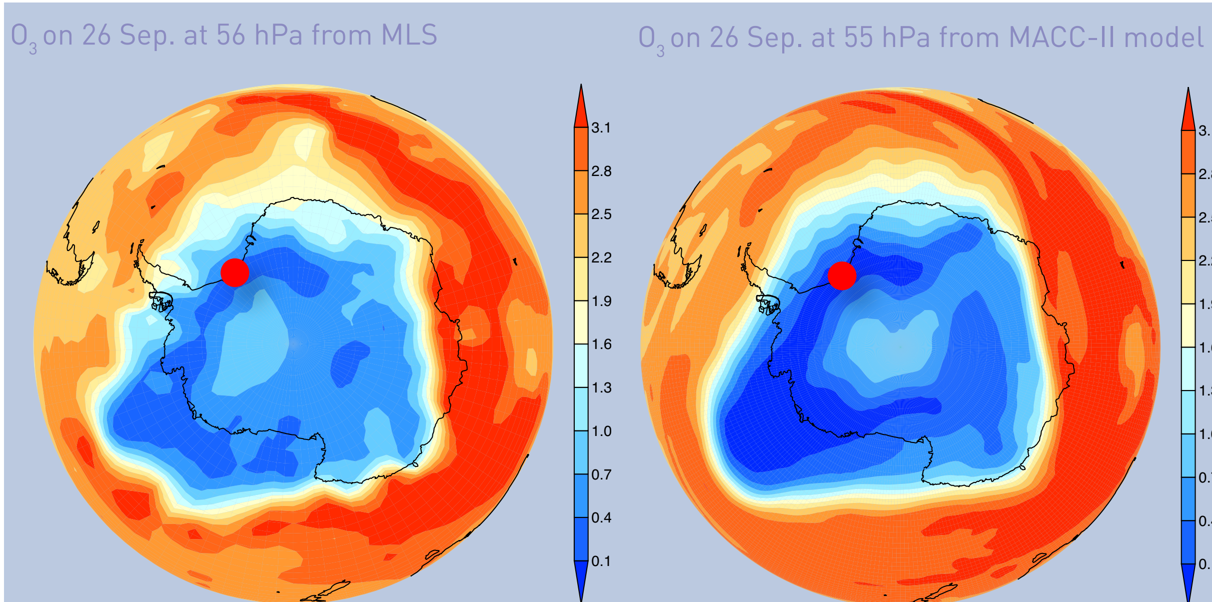


Figure 13. Ozone mole fraction at 56 hPa from the MLS instrument on the AURA satellite and at 55 hPa from the MACC-II model. This shows that Belgrano is located in a region where the ozone mole fraction is below 0.1 ppm (according to the model) at this level. The MLS data show somewhat higher mole fractions inside the vortex, but the regions with most ozone depletion look very similar in the two cases.

Davis

Ozonesonde launch at Davis.

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. **Figure 14** shows ozone profiles measured between 18 October and 5 November. The profiles of 18 and 26 October show substantial ozone depletion over the 14-20 km altitude range, whereas the profiles of 31 October and 5 November display a much larger 14-20 km partial ozone column, characteristic of an outside vortex situation.

Figure 15 shows the time series of the 12-20 km partial ozone column calculated from ozonesonde measurements performed from 2003 until present. During September, the partial column has dropped, but is close to the maximum, observed during the last decade (2003-2011). In October, the 12-20 km column has been considerably higher than

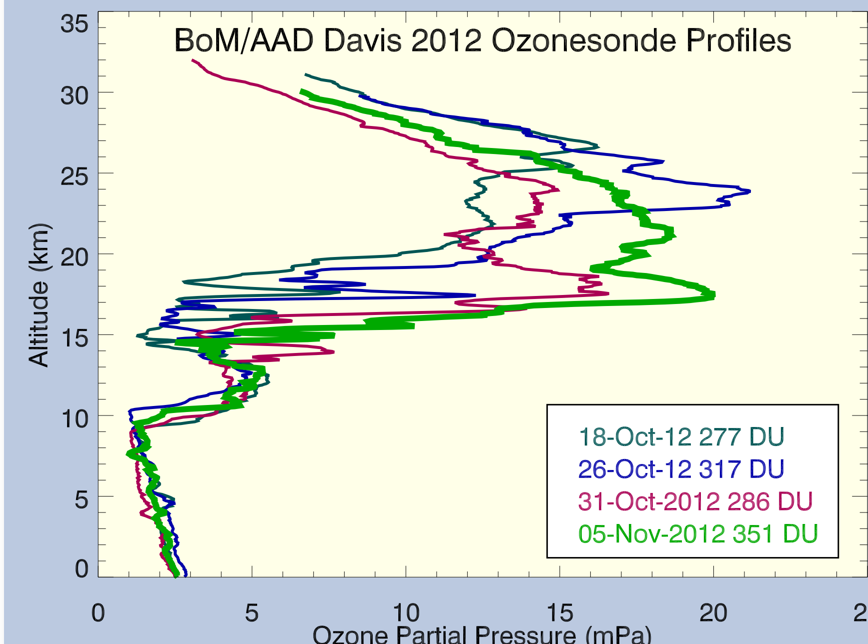


Figure 14. Ozonesonde observations at the Australian GAW station Davis. The plot has been provided by Matt Tully, Australian Bureau of Meteorology.

that observed from 2003-2011, and two soundings show record high values. On 18 and 26 October the two lowest values of the 12-20 km column in 2012 were observed. After that the 12-20 km column has increased considerably.

Another illustration of the unusual conditions in 2012 is shown in **Figure 16**, which shows the minimum 12-20 km ozone column for each year since 2003. It can be seen that in 2012 this minimum is much higher than in any of the other years since 2003.

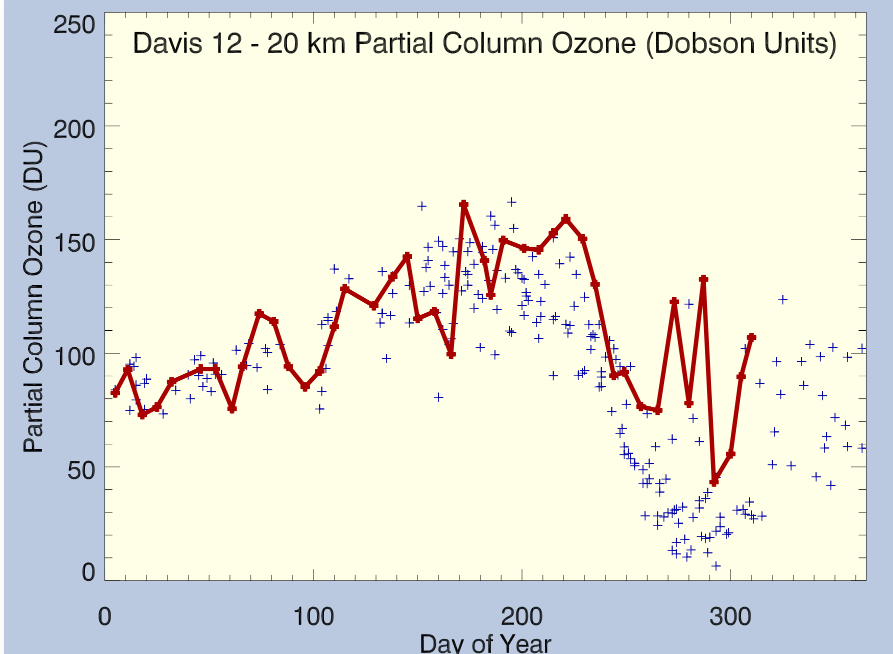


Figure 15. Partial ozone columns between 12 and 20 km from soundings at Davis. The thick red curve shows the data from 2012. The blue crosses show all data from 2003-2011. The plot has been provided by Matt Tully, Australian Bureau of Meteorology.

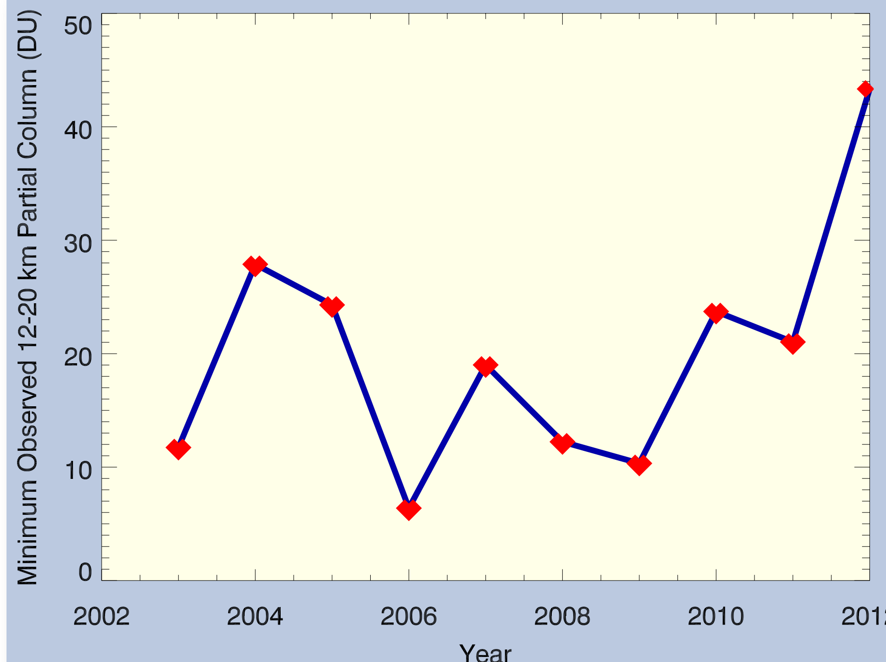


Figure 16. Annual minimum partial ozone columns between 12 and 20 km from soundings at Davis. For each year the sounding showing the minimum partial column over the 12-20 km height range is chosen. The plot has been provided by Matt Tully, Australian Bureau of Meteorology.

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 after the polar night on 1 August. During August total ozone varied between 239 and 354 DU. In September total ozone dropped from 284 DU on 1 September to 186 DU on 26 September. **Figure 17** shows the time series of total ozone measured at Dôme Concordia until 29 November. Daily averaged total ozone was below the 220 DU threshold on a few days in late September and then again in early October. The minimum daily average so far was measured on 5 October (174 DU). After 5 October, total ozone has been above the 220 DU threshold, and reached a temporary maximum of 431 DU on 17 October. After that, total ozone dropped to about 250 DU before a rapid increase to more than 400 DU. The SAOZ data are preliminary, so they should be used with caution.

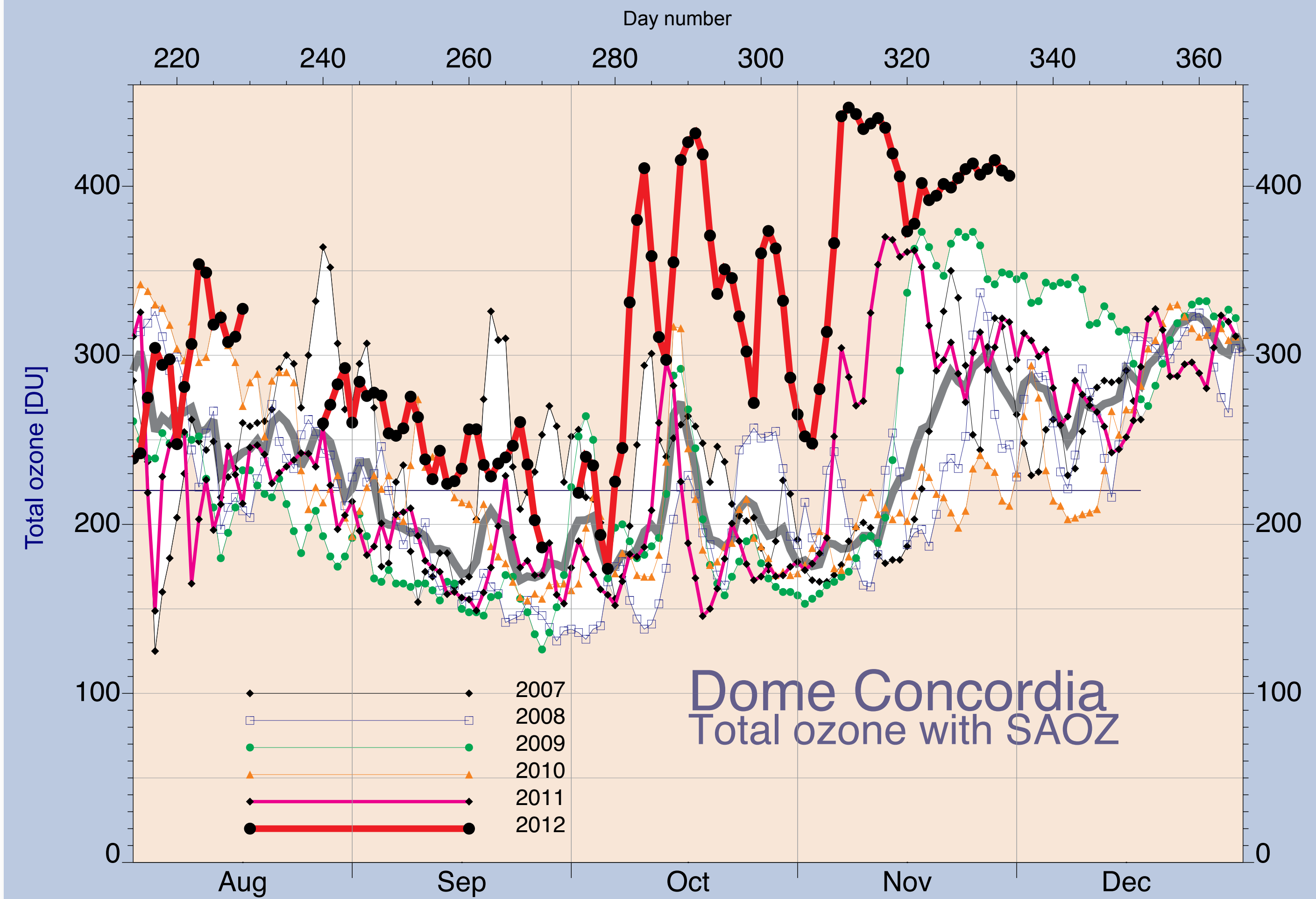


Figure 17. Time series of total ozone measured with the SAOZ spectrometer at Dôme Concordia on the Antarctic ice cap until 29 November. The plot is produced at WMO based on data downloaded from the SAOZ web site at CNRS.

Dumont d'Urville

Panorama photo showing a 360° view of the Dumont d'Urville station.

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 daily averaged total ozone has varied between 255 DU and 455 DU. Figure 18 shows the progression of daily averaged ozone until 2 December. 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. Daily averaged total ozone has by late November dipped below the threshold of 220 DU only on two days (1 and 2 November). On most days total ozone has been larger than the 1988-2011 average.

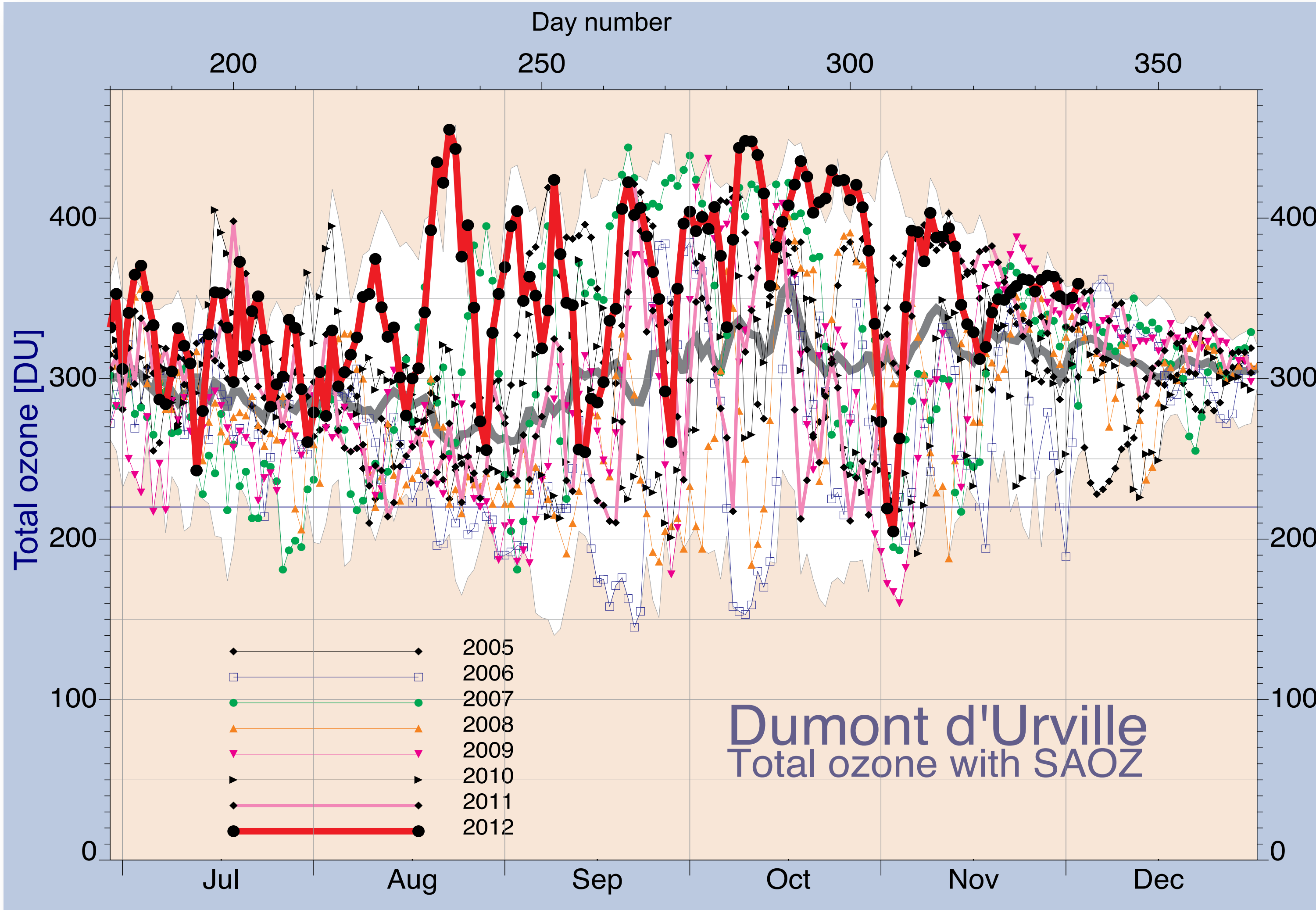


Figure 18. Time series of daily mean total ozone in 2012, in comparison to earlier years, as measured by a SAOZ spectrometer at Dumont d’Urville. The thick grey line represents the average for the 1988-2011 time period. The plot is produced at WMO based on data downloaded from the SAOZ web site at CNRS.

Halley

Total ozone is measured with a Dobson spectrophotometer at the UK GAW station Halley (75.58°S, 26.71°W). The measurements started up again on 27 August after the polar winter. **Figure 19** shows the total ozone time series at Halley for the most recent years together with long term statistics (1957-2011). From 27 to 29 August total ozone was above 220 DU, but from 30 August total ozone dropped below this threshold and remained there until 31 October, with the exception of one day (3 October), when total ozone rose to 240 DU. The lowest total ozone value observed so far this year is 133 DU, measured on 23 September.[1] Halley has experienced 62 days with total ozone below 220 DU in 2012, the highest number seen

[1] Personal communication from Jonathan Shanklin after a recent revision of the observations.

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 at any of the stations reported here.

Figure 20 shows the average total ozone column for the month of October from 1956 until 2012. It can be seen that the October mean in 2012 is larger than in 2011, yet smaller than in 2002, 2004 and 2010. The Halley time series is particularly valuable since it allows us to put the current observations into the long term perspective.

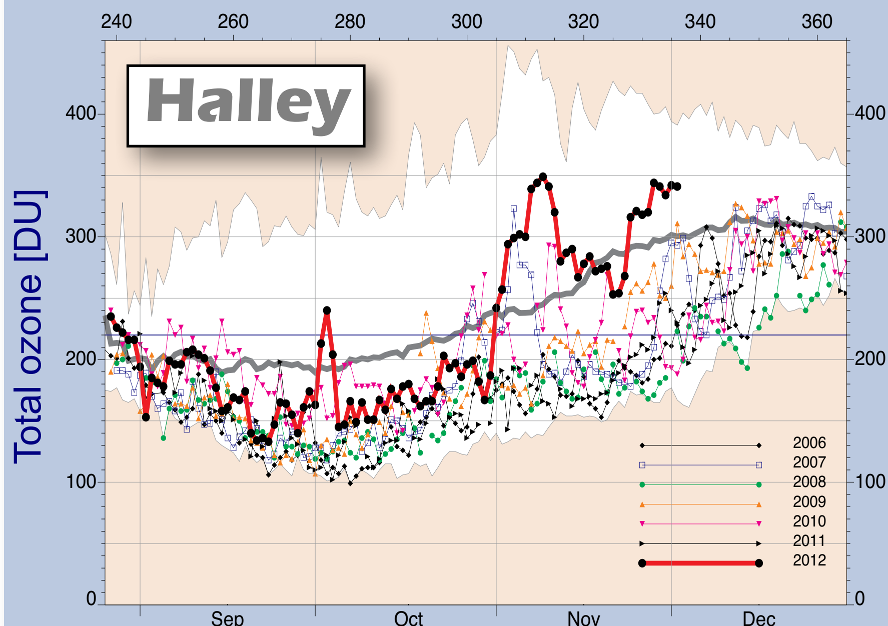


Figure 19. Time series of daily mean total ozone in 2012, as measured by a Dobson spectrophotometer at Halley. The thick grey line shows the average ozone column for the 1957-2011 time period. The white shaded area shows historical maxima and minima calculated for the 1957-2011 time period. The plot is produced at WMO based on data downloaded from WOUDC and from Jonathan Shanklin's Antarctic web site at British Antarctic Survey.

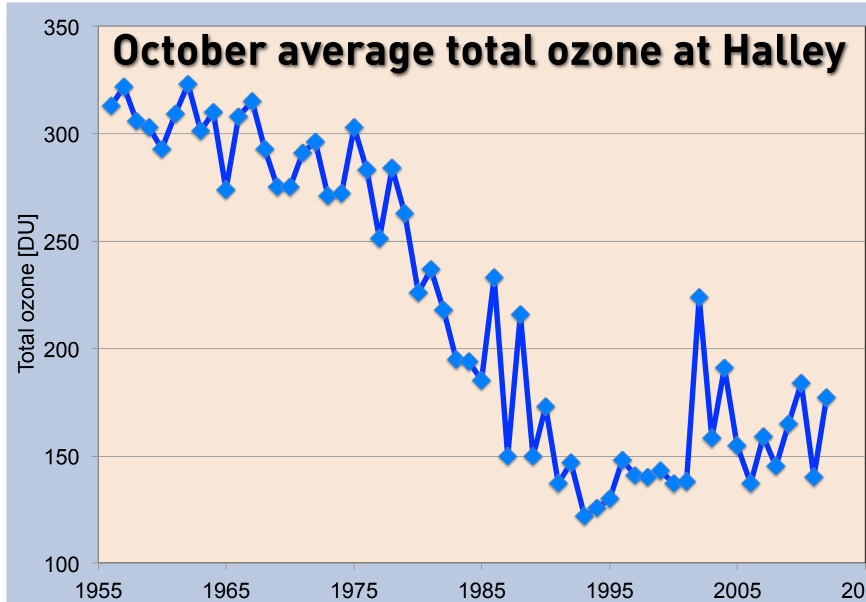


Figure 20. Total ozone averaged over the month of October for every year from 1956 to 2012. The plot is produced at WMO based on data downloaded from WOUDC and from Jonathan Shanklin's Antarctic web site at British Antarctic Survey.

Macquarie Island

Ozonesonde launched by Bureau of Meteorology observer Ashleigh Wilson at Macquarie Island. Photo: Leon Hamilton.

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.

Matt Tully of the Australian Bureau of Meteorology has sent the following report:

Although Macquarie Island lies outside the ozone hole itself, very low values of total ozone are often observed in springtime when the hole is in close proximity.

In 2012 however, the ozone hole has had minimal influence at Macquarie in September compared to recent years, in part due to the vortex being displaced off the pole towards South America for much of the time. This can be seen in **Figure 21**, which shows that the minimum total ozone in September 2012

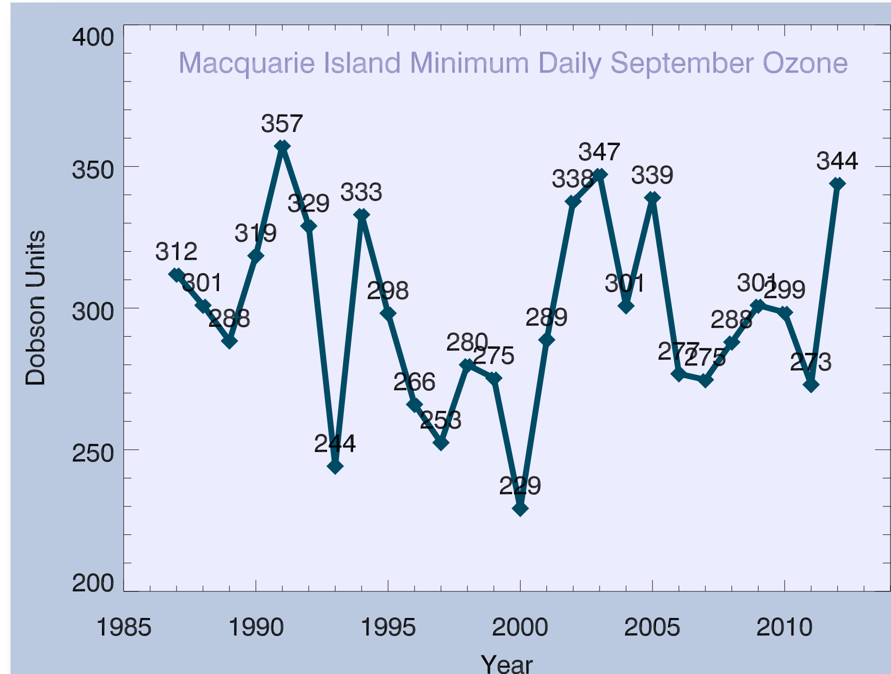


Figure 21. Time series of the minimum daily ozone recorded in September at Macquarie Island each year since 1987. The plot has been provided by Matt Tully of the Australian Bureau of Meteorology

was 344 DU, the highest value since 2003, and 1991 before that.

Throughout October total ozone values were either average or above average, however more recently some lower values have been recorded on the 2nd and 3rd November (338 DU) and on the 7th (335 DU). This can be seen in **Figure 22**.

Figure 23 shows ozone sonde profiles carried out between 16 October and 6 November. All these profiles are more or less characteristic of mid-latitude air masses, and there is no clear sign of ozone depletion.

Satellite imagery (see **Figure 24**) suggests the ozone hole become highly elongated in early November, with one loop of the figure-of-8 shape at around 150 degrees East longitude, affecting Macquarie Island. One can see from the figure that Macquarie Island is at the edge of the ozone hole.

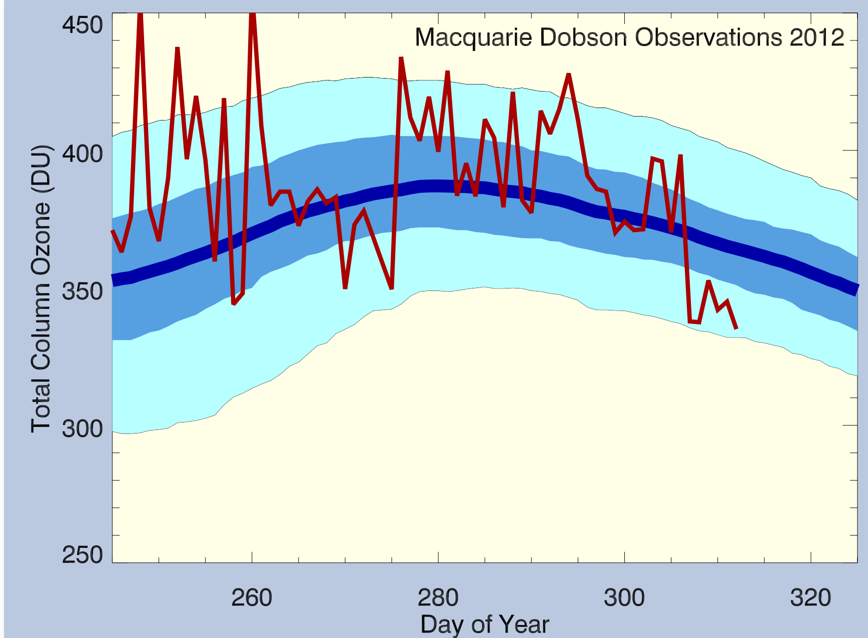


Figure 22. Daily average total ozone measured by the Dobson instrument in September and October 2012 (red line), compared to the 1986-2011 mean (blue line) and the 10th-90th and 30th-70th percentile ranges (light blue and dark blue bands respectively). The plot has been provided by Matt Tully of the Australian Bureau of Meteorology.

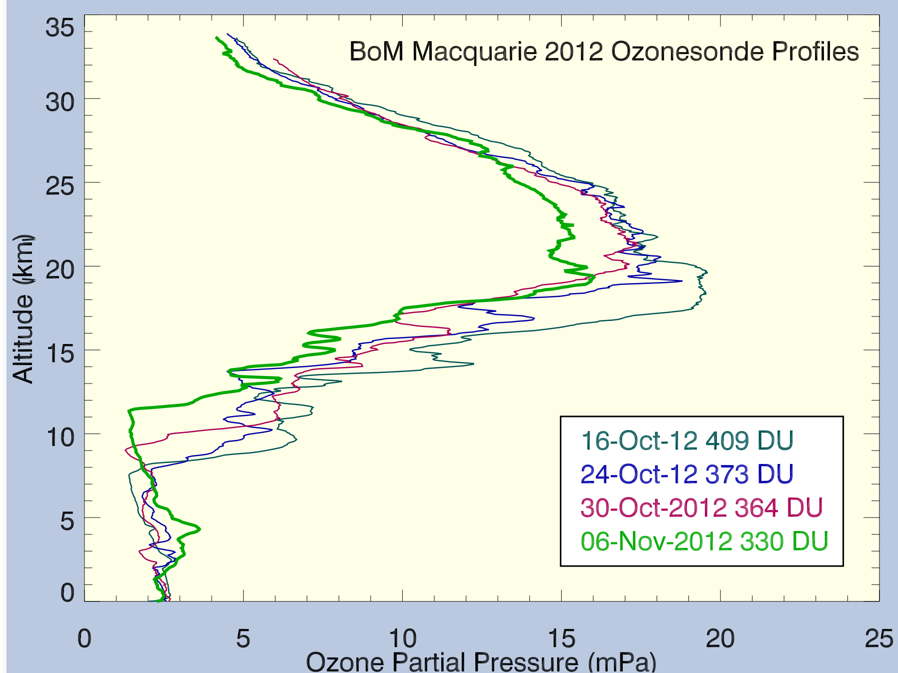


Figure 23. Ozone profiles recorded from 16 October to 6 November 2012 at Macquarie Island. The plot has been provided by Matt Tully of the Australian Bureau of Meteorology.

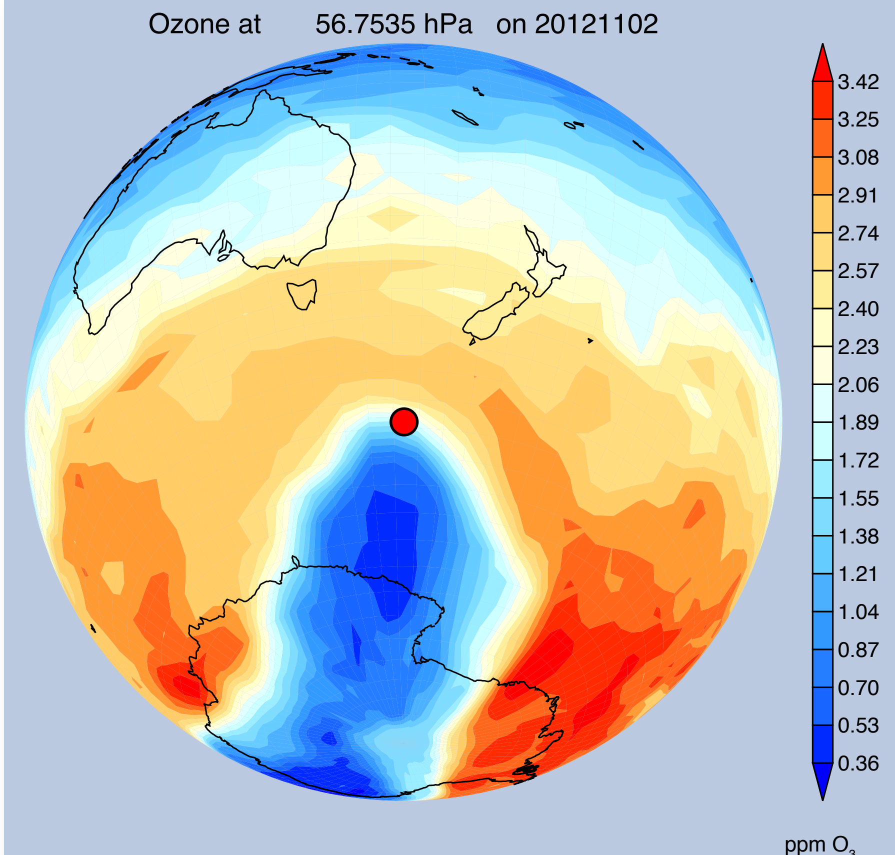
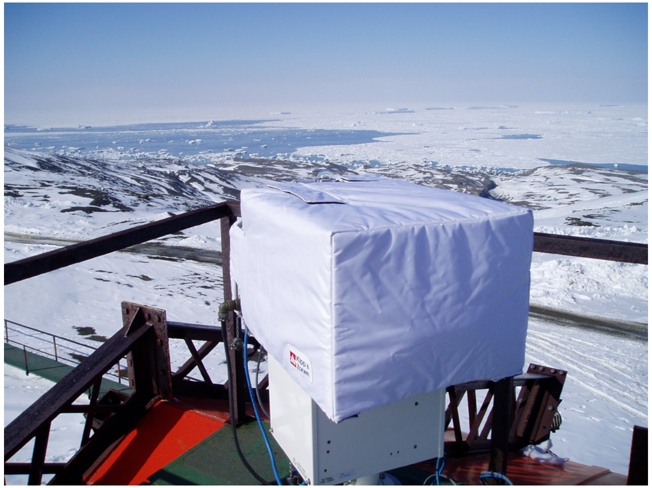


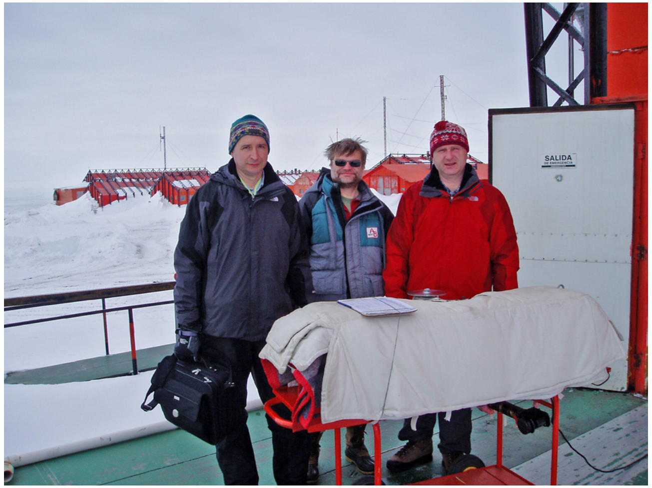
Figure 24. Ozone mixing ratio on the 56.8 hPa pressure surface. The position of Macquarie Island is marked with a red circle. The plot has been made at WMO with input data from the Bascoe model in the MACC-II project. This model assimilates ozone data, as well as other parameters from the MLS instrument on the Aura satellite.

Marambio

Panorama photo showing a 360° view of the Marambio station.



The Brewer spectrophotometer MARK III No. 199, Marambio Antarctic Station – yearly inspection. Photo: Michal Janouch.



Research group from CHMI, Ing. Martin Staněk, RNDr., Michal Janouch, Ph.D and Ing. Ladislav Sieger, CSc. from CTU.

Total ozone is observed at the Argentine GAW station Marambio (64.2°S, 56.6°W) with a Dobson and Brewer MkIII spectrophotometer. The measurements started up after the winter on 10 August. Ozone profiles are observed with ozonesondes. Soundings are carried out once to twice per week. Six ozonesondes were launched in June, six in July, nine in August and nine in September. Eight sondes were launched in October and five in November. The lowest total ozone value observed so far this year with the Brewer instrument was 142 DU on 8 October (see **Figure 25**). With the ozonesonde one deduces a total ozone column of 154 DU on 22 September (**Figure 26**). During the same time period the 12-20 km partial ozone column dropped from about 140 DU to 39 DU on 22 September, i.e. a reduction of 72%. Also on 10 October the 12-20 km partial column was 39 DU. The Marambio time series is characterised by rapid changes as the station is located near the edge of the polar vortex. From 8 to 14 October, total ozone increased from 142 to 296 DU before it dropped to 198 DU on 17 October. After some days of high ozone after 17 October, total ozone dropped below 220 DU again for a couple of days in late October. During November, total ozone has been well above the 220 DU threshold.

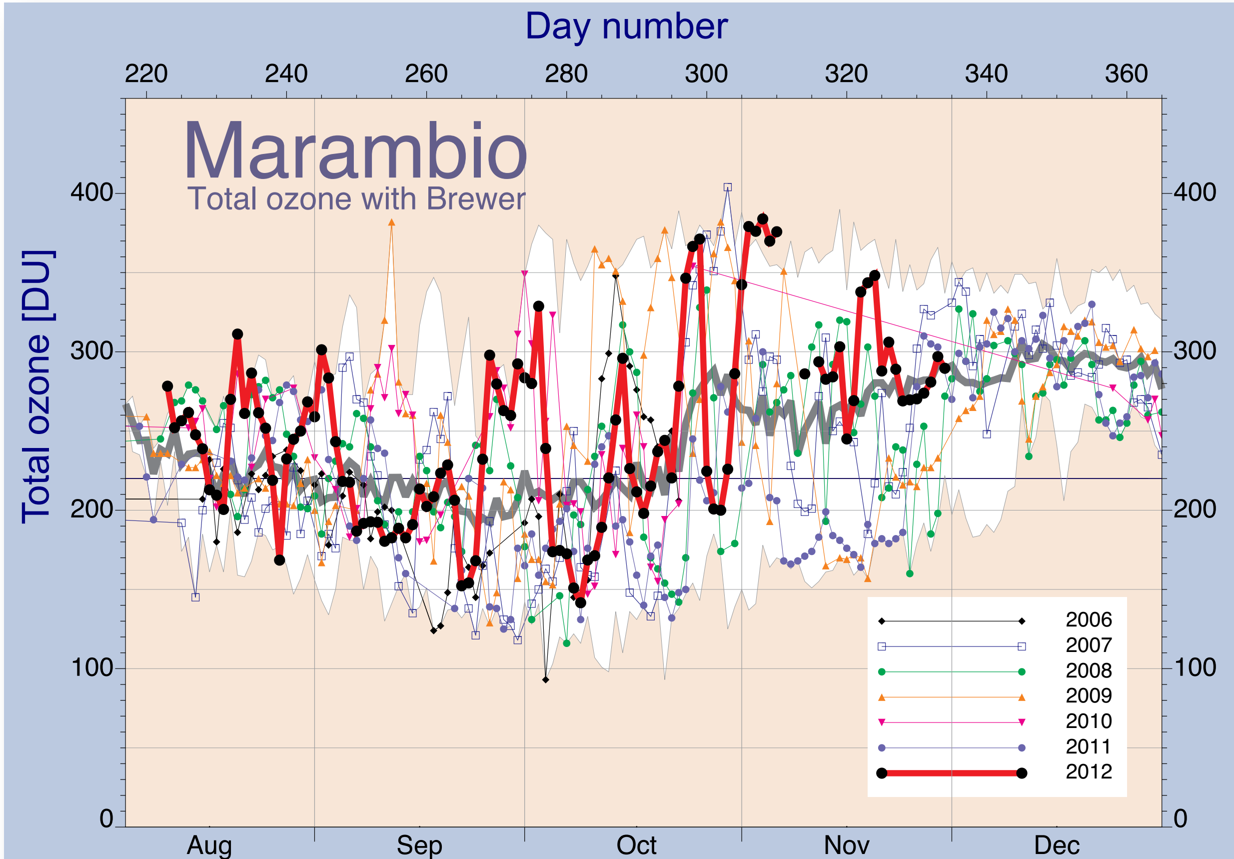


Figure 25. Total ozone over Marambio as measured by Dobson and Brewer spectrophotometers. The plot is up to date until 12 November. The thick grey curve represents the long-term mean (1987-2011) and the white shaded area represents the historical maxima and minima for the same time period. The plot is produced at WMO based on Dobson data from WOUDC and Brewer data for 2012 submitted by Instituto Antarctico Argentino and the Czech Hydrometeorological Institute.

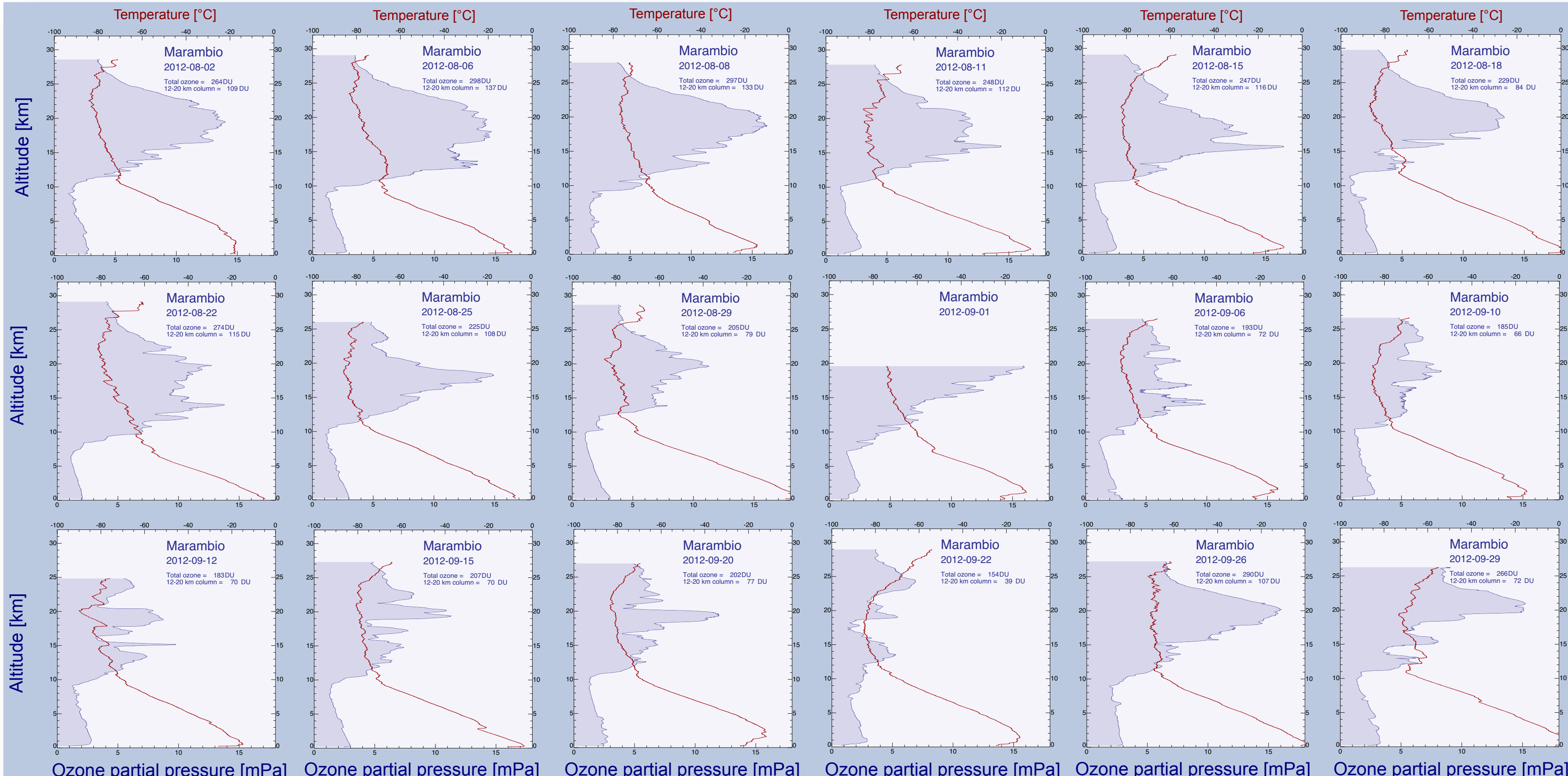


Figure 26. Ozone profiles measured with electrochemical ozonesonde launched from the Argentine GAW station Marambio from 2 August to 29 September. The plots are produced at WMO with data submitted by the National Meteorological Service of Argentina.

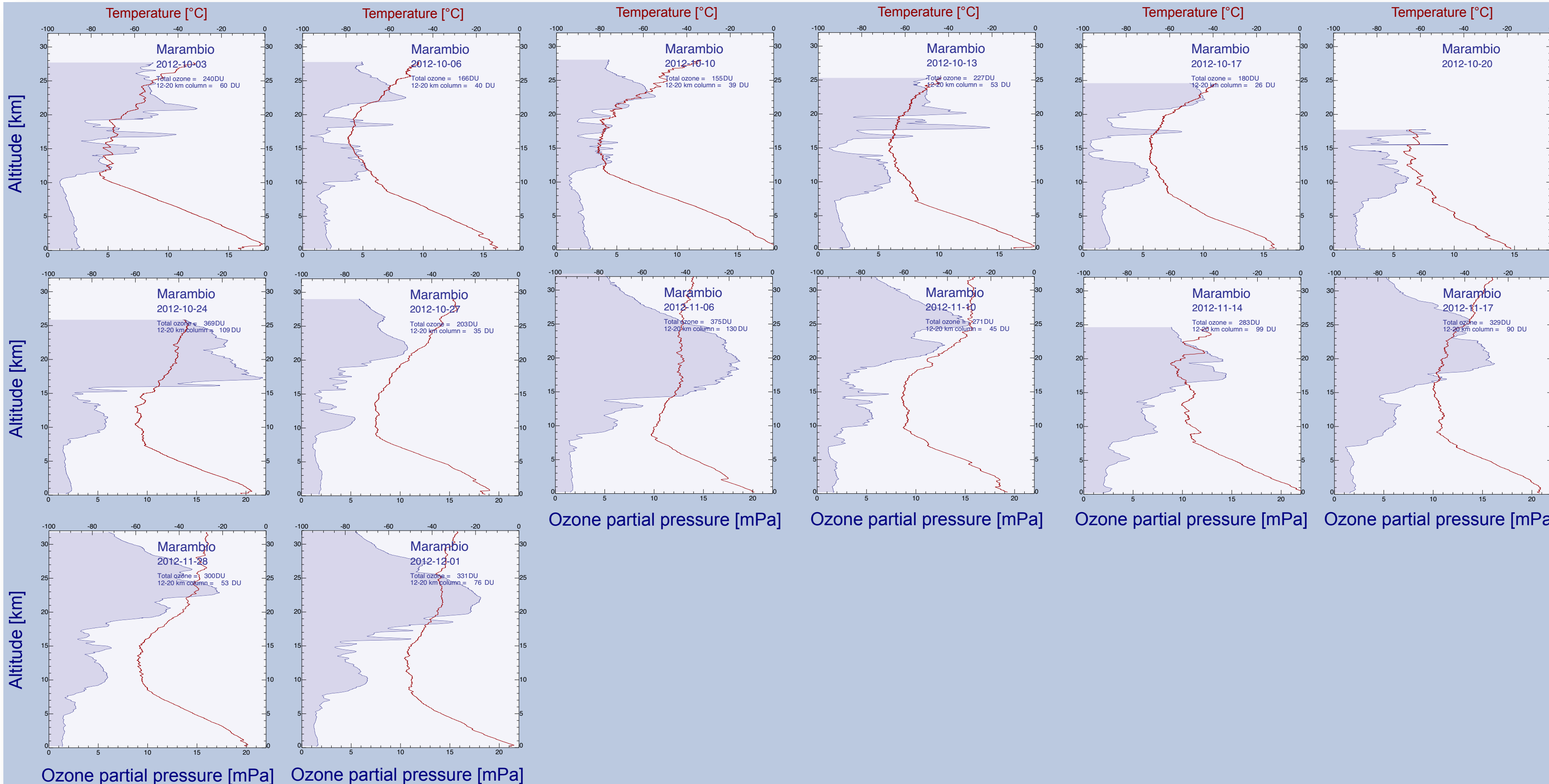


Figure 27. Ozone profiles measured with electrochemical ozonesonde launched from the Argentine GAW station Marambio from 3 October to 1 December. Please note that the ozone partial pressure scale is different on the last plots (from 24 Oct). The plots are produced at WMO with data submitted by the National Meteorological Service of Argentina.

Mirny

The Russian GAW station Mirny.

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 of the Arctic and Antarctic Research Institute, St. Petersburg, and are up to date as of 2 December. During August total ozone varied quite a lot with a maximum of 484 DU on 19 August and a minimum of 234 DU on 25 August. In September total ozone varied between 224 (11 Sep) and 448 DU (28 Sep). In October total ozone varied between 439 DU on 13 October and 254 DU on 31 October. In November total ozone has varied between 418 DU (9 November) and 322 DU (29 November). The minimum observed so far this season was 224 DU on 11 September. The values obtained with the filter instrument agree quite well with satellite overpass data from OMI on board the AURA satellite. So far in 2012, i.e. until 2 December, total ozone at Mirny has not been below the threshold of 220 DU.

Neumayer

Preparing an ozonesonde for launch at the Neumayer station.

The vertical distribution of ozone is measured with ozonesondes from the German GAW/NDACC station at Neumayer (70.65°S, 8.26°W). Sondes were launched on 1, 10 15, 18, 22, 26 and 31 August. These sounding are shown in **Figure 28** together with the first two soundings of September. The sounding of 3 September shows clear signs of ozone depletion with a total ozone column of 200 DU and a 12-20 km partial ozone of 76 DU, down from 130 DU on 31 August.

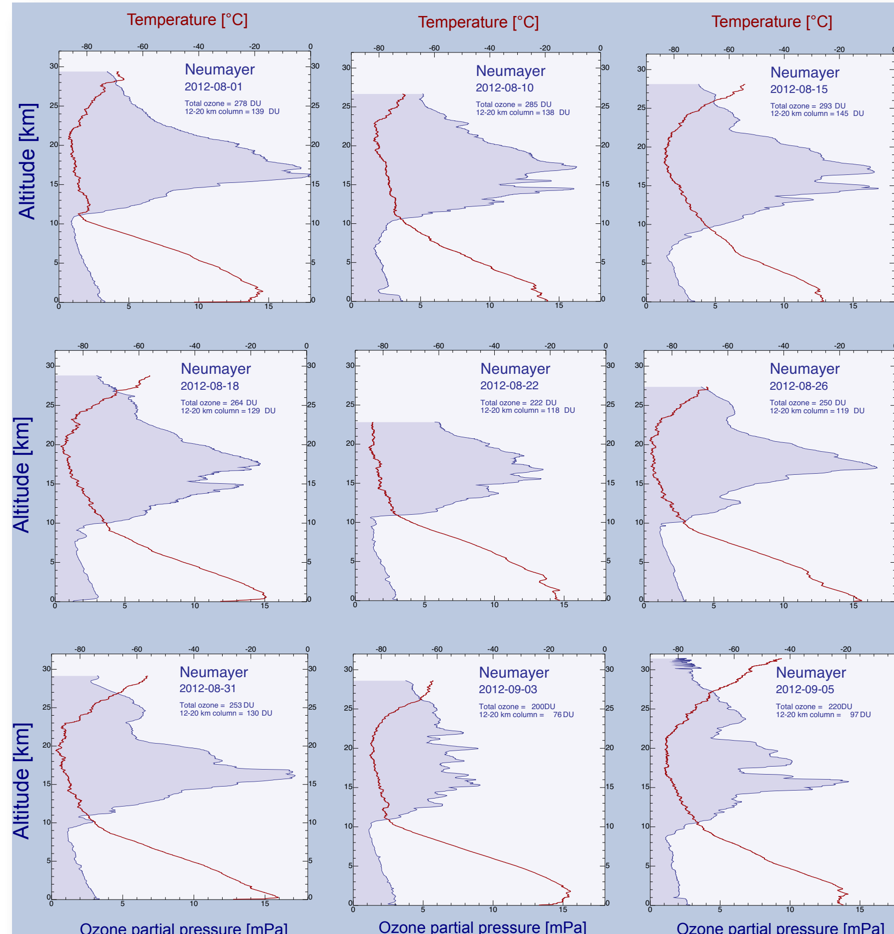


Figure 28. Ozone profiles measured with electrochemical ozonesonde launched from the German GAW station Neumayer from 1 August to 5 September 2012. It can be seen how the 12-20 km partial ozone column is coming down towards the end of August and into the beginning of September.

Figure 29 shows soundings carried out from 8 September to 6 October. The September profiles show clearly the progression of ozone depletion with 12-20 km partial ozone columns down to 35 DU (24 September and 6 October). The sounding performed on 28 September shows a large "bite-out" of ozone over the 15-20 km height range. **Figure 30** (next page) shows profiles measured from 8 October to 5 December. Ozone depletion continued during early October, and the 12-20 km partial column reached a minimum so far this year for this station with 23 DU on 11 October. After that, the partial column stayed relatively low until early November. On 6 November the partial column suddenly increased to 122 DU. After that the ozone profile has varied a lot as the vortex moved back and forth over the station. Satellite overpass data show that total ozone over Neumayer has been under the 220 DU threshold on fifty days during the 2012 ozone hole season.

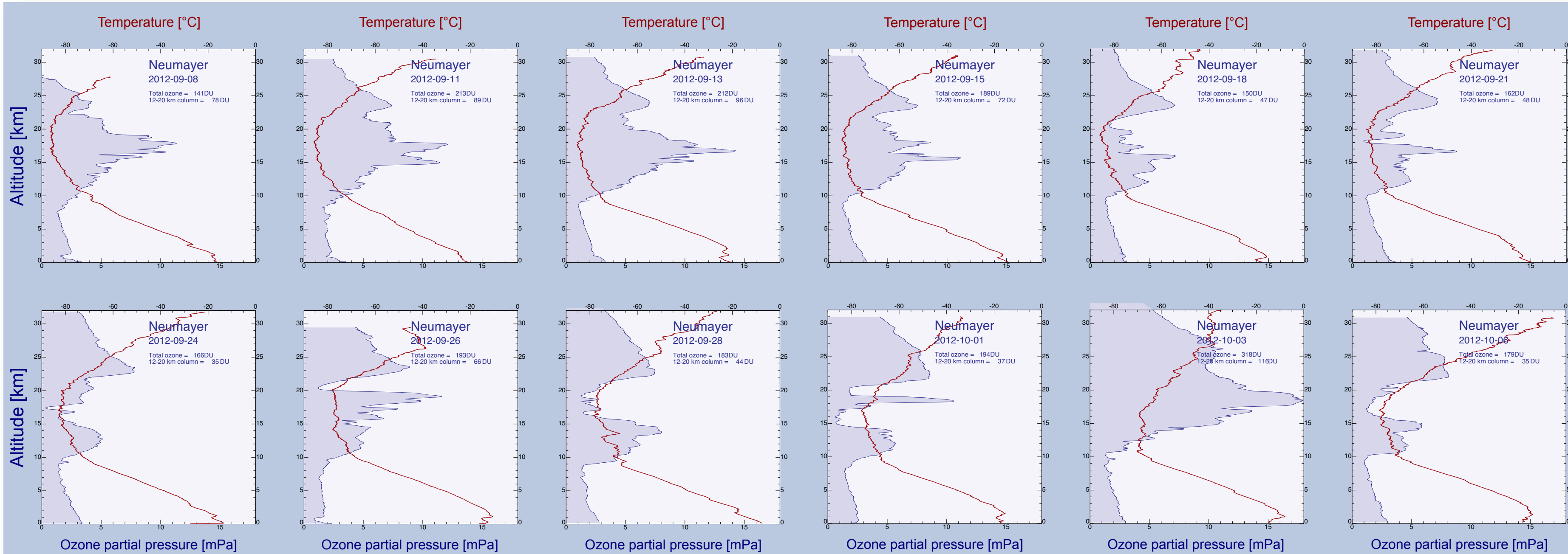


Figure 29. Ozone profiles measured with electrochemical ozonesonde launched from the German GAW station Neumayer from 8 September until 6 October 2012. Ozone depletion is now well under way as can be seen from 12-20 km partial ozone columns well below 100 DU. The plots in this and the previous figure are produced at WMO based on data sent directly from the Neumayer station.

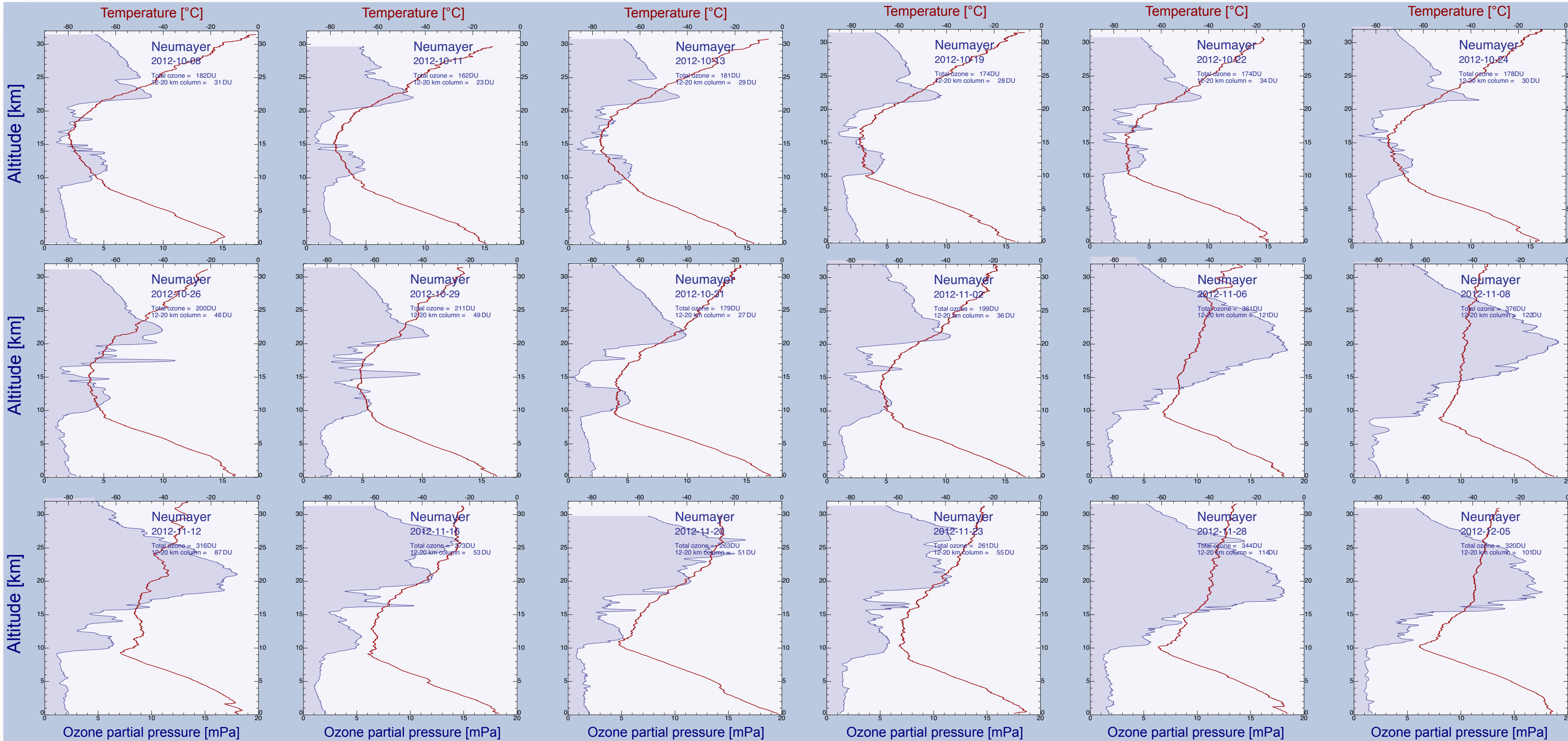


Figure 30. Ozone profiles measured with electrochemical ozonesonde launched from the German GAW station Neumayer from 8 October until 5 December 2012. The plots are produced at WMO based on data sent directly from the Neumayer station. The lowest 12-20 km partial ozone column this season was measured on 11 October with 23 DU. The 12-20 km partial column was still small at the end of October with 27 DU. On 6 and 8 November Neumayer is clearly outside the ozone hole. On 12, 16, 20 and 23 November the profile shows clear signs of ozone depletion again. The profiles of 28 November and 5 December are typical of an outside vortex situation.

The ozone hole above Neumayer III Station, Antarctica

Kathrin Höppner (Air chemist of the overwintering crew 2012), Thomas Schmidt (Meteorologist of the overwintering crew 2012), Gert König-Langlo (Scientific manager of the Meteorology Observatory of Neumayer III Station), Contact: gert.koenig-langlo@awi.de, kathrin.hoeppner@dlr.de

The 2012 ozone hole season has started for the entire Antarctica and the overwintering crew at the Neumayer III Station (Photo 1) now performs in addition to the daily radiosonde releases also ozone soundings up to 3 times a week (up from 1 per week). The data are available in near-real time (NRT) and are submitted to the GAW-World Ozone and Ultraviolet Radiation Data Centre (WOUDC) and to the WMO Global Telecommunication System (GTS), in future to the WMO Information System (WIS). Neumayer III acts as a global GAW station and is additionally included in the NDACC and BSRN networks.

Three to seven days prior to the sonde release the ozonesonde (using currently ECC 6A sensors mounted on Vaisala RS92 radiosondes) is prepared following standard operating procedures developed by the GAW Programme. On the day of release the sonde is again thoroughly tested including e.g. comparison with a calibration sensor, measurement of background sensor current and sensor response test (see Photo 2). The sondes are launched from the roof of the building (Photo

Photo 1: The German Antarctic Research Station Neumayer III at the Ekström Shelf Ice in the north-eastern Weddell Sea (70°40'S, 08°16'W) started routine operation in 2009. The building is situated on a platform above the snow surface integrating scientific research (meteorology, air chemistry and geophysics), operational and accommodation facilities in one building, and it is connected to a garage in the snow. The red hall located at the center of the roof is the platform for launching weather balloons. The picture was taken during polar night in June 2012. © Kathrin Höppner.

Photo 2: Preparation of an electrochemical ozone sonde (in the foreground) in the ozone laboratory of Neumayer III station. The calibration unit (in the background) is used to make different performance tests prior to the release. © Kathrin Höppner.

1) even during adverse wind conditions up to about 30-35 knots (see Photos 3 and 4).

The ozone profiles obtained from the last five releases at Neumayer III between 29 August and 08 September, 2012 are shown in **Figure 31**. The stratospheric ozone depletion between 15 and 20 km has started, and further decline in ozone concentration is expected.

Photo 3: The balloon launching hall located on the roof of the Neumayer III building. Copyright Kathrin Höppner.

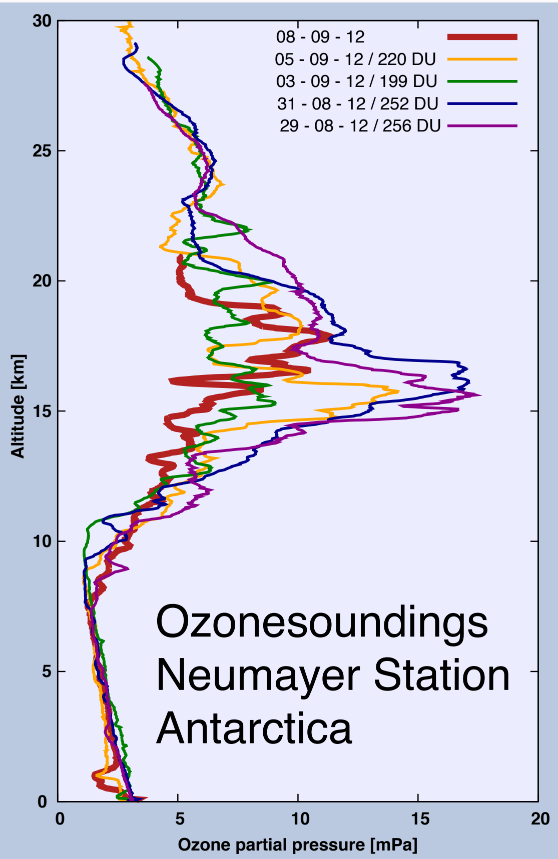


Figure 31. Ozone profiles measured with electrochemical ozonesondes at the Neumayer III station on 29, 31 August, 03, 05 and 08 September, 2012. Also indicated is the total ozone amount (in Dobson units) of each release. Due to the low burst height on 08 September the total ozone amount was not calculated for this release.

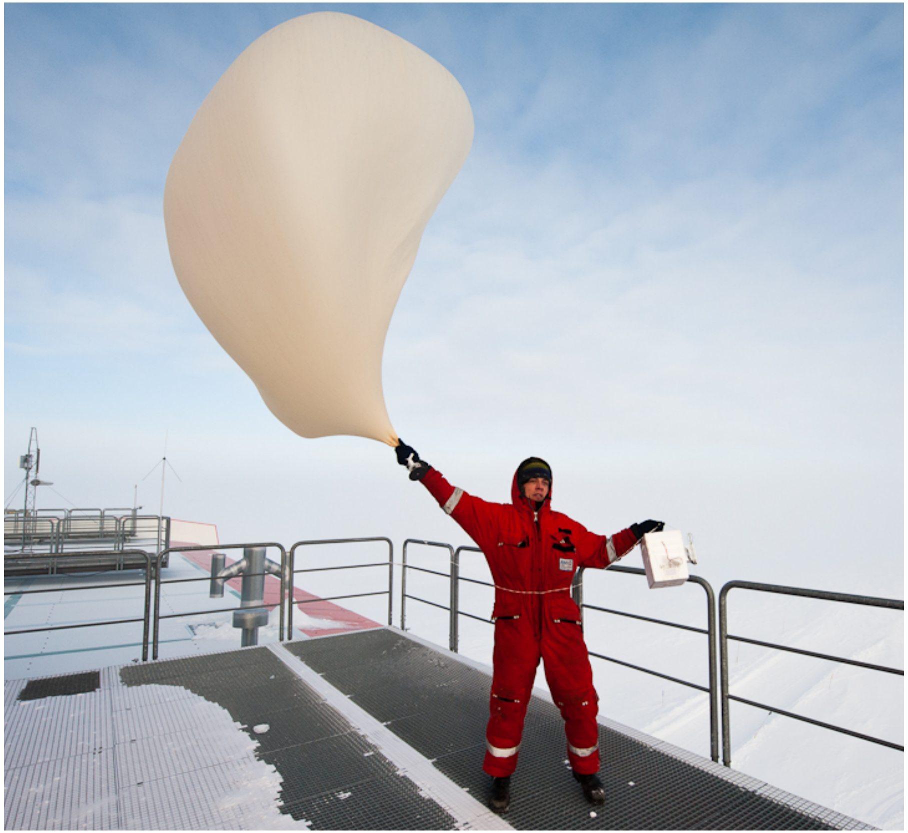


Photo 4: Thomas Schmidt, meteorologist of this year's overwintering crew, launching an ozonesonde from the roof of the Neumayer III station during stormy weather conditions on 5 September, 2012. © Stefan Christmann.

The observed total ozone for these five profile measurements is in the typical range of about 200 to 250 Dobson units (DU) as expected at the beginning of the ozone hole season. Compared to the long-term average it is sometimes even slightly higher (see **Figure 32**).

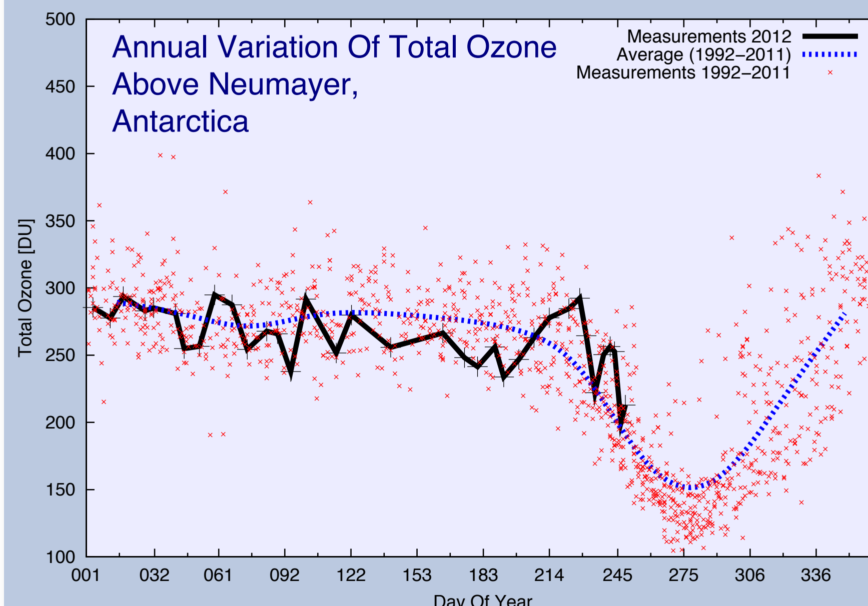


Figure 32. Annual variation of total ozone (in Dobson units) above Neumayer III station (shown in black). The blue dotted line shows the average over 1992-2011, the red crosses dedicate all measurements from 1992-2011.

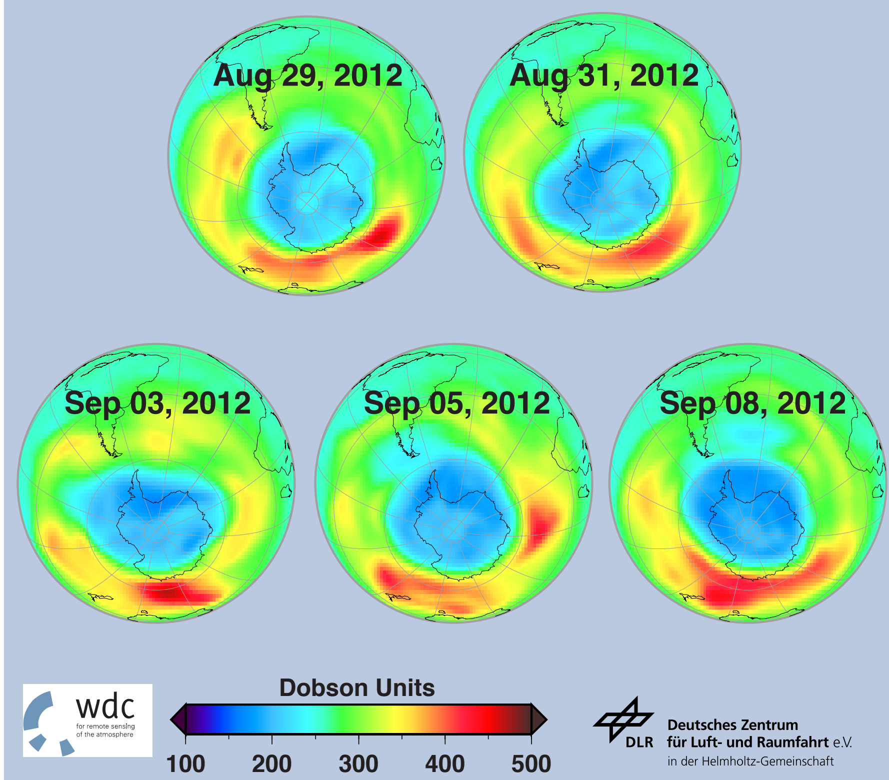


Figure 33. Sequence of total ozone maps from 29 August to 08 September, 2012 based on data from the GOME-2 instrument aboard the MetOp-A satellite. Shown are assimilated data using the ROSE/DLR model. Data are available at the WMO World Data Center for Remote Sensing of the Atmosphere (WDC-RSAT).

Satellite based measurements of ozone vertical column density (**Figure 33**) derived from the ROSE/DLR model based on GOME-2 data also indicate low values in the range of 200 to 250 DU over Neumayer during the same time period.

From 1985 to 1992 regular ozone soundings have been performed at the German Georg Forster Station (70°46'S, 11°41'E). In 1992, this ozone sounding programme was moved to the Neumayer II Station (70°39'S, 8°15'W), which is located at the same latitude 750 km further west. Since February 2009 the programme is ongoing at the Neumayer III station built 6 km south of the Neumayer II Station. The results of all three stations can be regarded as one time series, as shown in **Figure 34**.

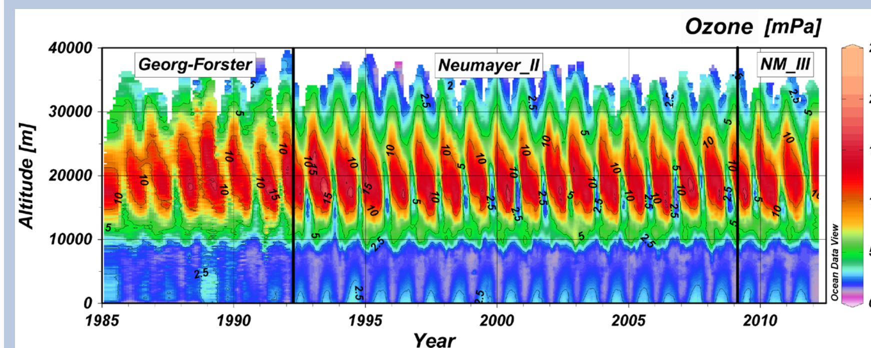


Figure 34. Time-height sections of ozone partial pressure above Georg Forster Station (1985-1992), Neumayer II Station (1992-2009) and Neumayer III Station (2009-2011). Clearly seen is the typical annual variation in the stratospheric ozone.

Within the last 20 years the seasonal averaged ozone partial pressure at 70 hPa shows a remarkable trend during Antarctic spring (September - November). In close correlation to this ozone depletion the stratospheric temperatures are decreasing. During Antarctic autumn (January - March) no comparable trends are observed (see **Figure 35**).

Neumayer III is committed to continue the research and monitoring programmes designed to document changes in the chemical composition of the atmosphere that are attributable to anthropogenic activities. Of special importance are the long-term ozone profile measurements contributing to the investigation of the Antarctic ozone hole and documenting its predicted recovery.

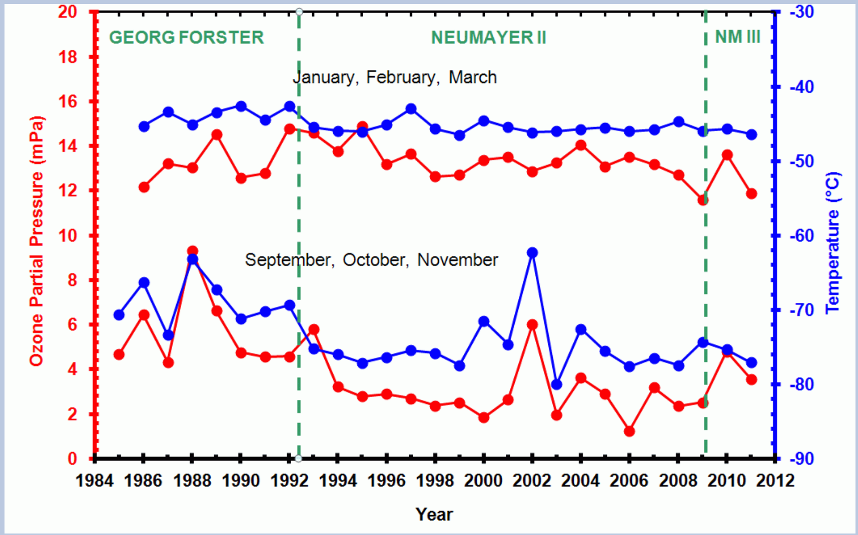


Figure 35.Figure 9: Time series of the seasonally averaged stratospheric parameters at 70 hPa. Shown is the coupled time series of Georg Forster Station (1985-1992), Neumayer II Station (1992-2009) and Neumayer III Station (2009-2011).

References

Gert König-Langlo and Bernd Loose, 2007. The Meteorological Observatory at Neumayer Stations (GvN and NM-II) Antarctica. Polarforschung 76 (1-2), 25-38.

Meteorology Observatory of Neumayer III Station: http://www.awi.de/en/infrastructure/stations/neumayer_station/observatories/meteorological_observatory/

World Data Center for Remote Sensing of the Atmosphere (WDC-RSAT), the most recent data center in the WMO-WDC family: http://wdc.dlr.de

Novolazarevskaya

At the Russian GAW station Novolazarevskaya (70.776739°S, 11.822138°E) total ozone is measured with a filter instrument. The data are submitted by Elena Sibir of the Arctic and Antarctic Research Institute, St. Petersburg. The measurements started on 14 August and are up to date until 2 December. From 21-23 August, total ozone was under the 220 DU threshold with a minimum of 192 DU on 21 August. From 3 September, total ozone was below the 220 DU threshold, with a minimum of 157 DU on 19 September. OMI satellite overpass data show that the station has remained inside the ozone hole most of September, with a minimum ozone column of 160 DU on 19 September, in good agreement with the ground based observations . In October total ozone varied between 180 (on the 12th) and 300 DU (on the 4th). In November total ozone varied between 220 DU on the 2nd and 382 DU on the 18th. Total ozone has been below the 220 DU threshold on 48 days during the 2012 ozone hole season.

An overview of the Novolazarevskaya station. Photo: Maks Kupec.

Río Gallegos

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

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 NO_2. 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 the scientists at the station.

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

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September 2012

As a part of systematic observation of ozone layer in southern Patagonia, total ozone column taken with SAOZ spectrometer and stratospheric ozone vertical profiles (14-45 km) with lidar were measured in the Río Gallegos NDACC Station.

The total ozone columns over Río Gallegos present typical fluctuation around mean values for this time of the year. On September 6 (day of year 250), the ozone hole pass over Río Gallegos station, and total ozone column drops to 260 DU (**Figure 36**). These ground based ozone column measurements were taken with SAOZ and each single point in the figure corresponds to the average of sunrise and sunset daily measurement.

During the first days of September, four ozone vertical profiles were measured with the Differential Absorption Lidar operative at OAPA. In average, the integration time of each lidar experiment was around 3 hour. The measured stratospheric ozone profiles are presented in

Figure 36. The approximation of polar vortex to vertical of Río Gallegos produces reduction of ozone profile in the middle stratosphere (profile Sep 3) clearly visible in comparison with typical ozone profile on Sep. 1. Reductions in all altitudes are observed in the ozone profile measured on September 6, when ozone hole reach the vertical of Río Gallegos, as confirmed by OMI/AURA satellite image (**Figure 38**). Rapid recovery of total ozone happens after this day as a consequence of the polar vortex movement away from the station. **Figure 38** shows the sequence of images of the total ozone column measured by the OMI instrument aboard the AURA platform.

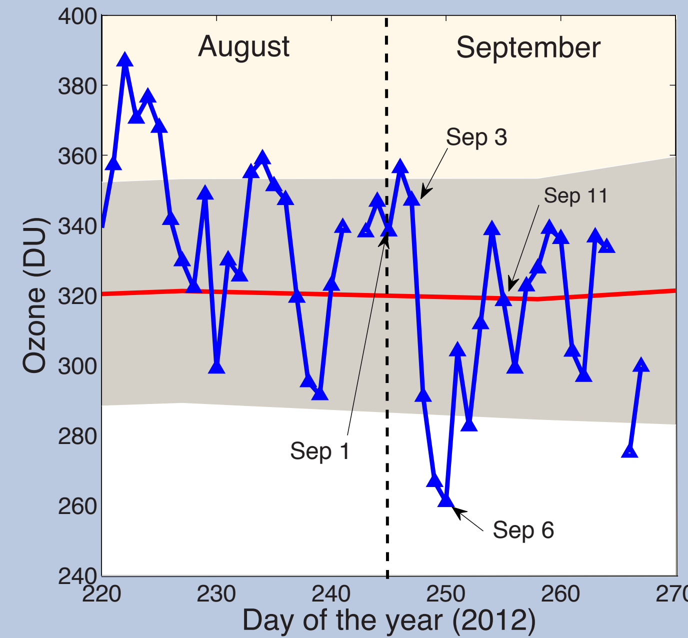

Figure 36. Evolution of the total ozone column over Río Gallegos. Measurements were taken with SAOZ spectrometer. Each point corresponds to the mean of daily sunrise and sunset observations.

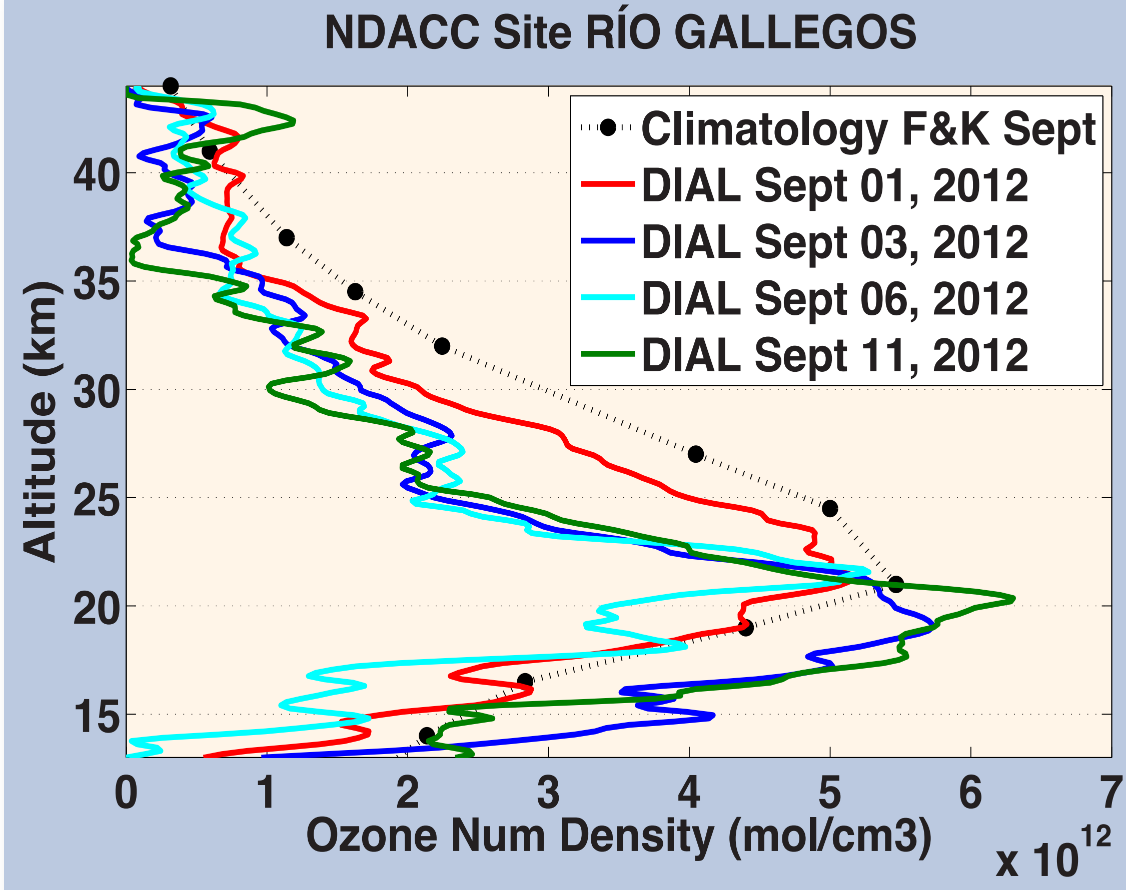

Figure 37. DIAL measurements of stratospheric ozone profile during four different days at the Río Gallegos NDACC site together with the Fortuin & Kelder climatological profile for this latitude belt (45 - 55 S).

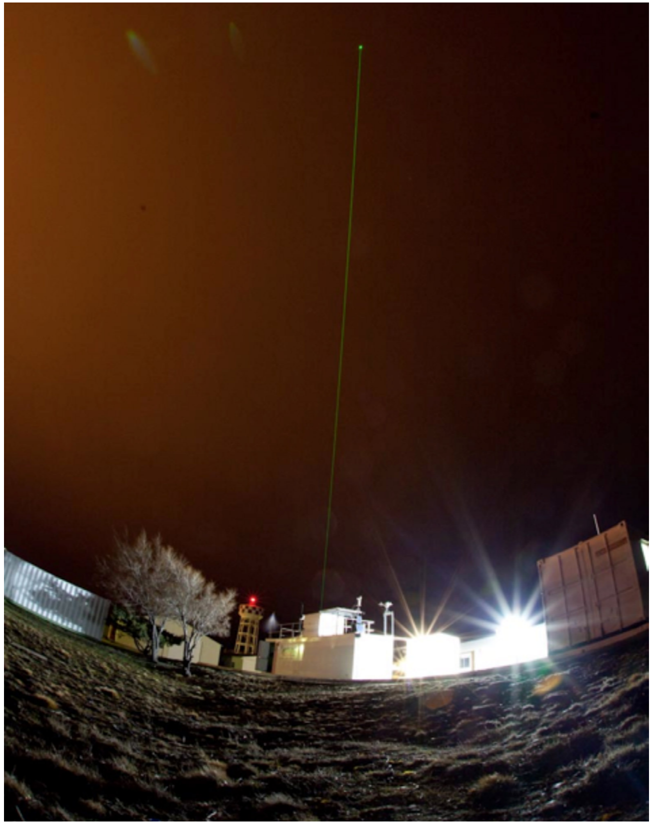

Photo 1. The differential absorption ozone lidar at Río Gallegos.

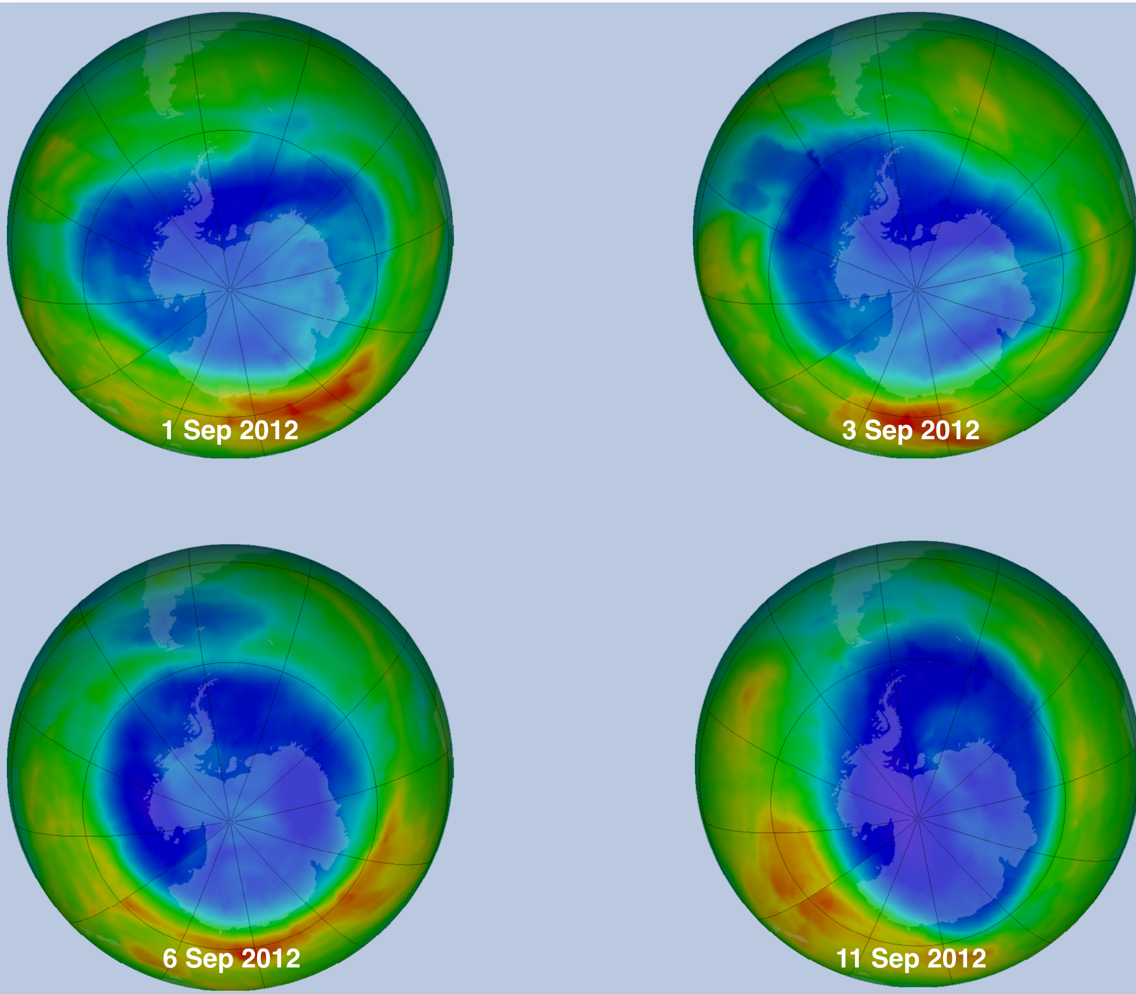

Figure 38. Sequence of ozone maps measured with the OMI satellite instrument on 1, 3, 6 and 11 September.

Rothera

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. Since the station is close to the polar circle, and the SAOZ observes with the sun near the horizon, observations can be carried out around the year. **Figure 39** shows the 2012 data (until 1 December) in comparison to earlier years and long term statistics. Total ozone was oscillating between 250 and 350 DU in June, July and early August. On 16 and 17 August total ozone dropped to 199 and 175 DU, respectively as air masses with somewhat depleted ozone passed over the station. This was the first dip under 220 DU this year. After that the 2012 time series at Rothera has been characterised by large day-to-day fluctuations as the polar vortex moves back and forth over the Antarctic Peninsula. The lowest value measured this year was 132 DU on 8 October. On forty days total ozone has been at or below 220 DU during the 2012 ozone hole season.

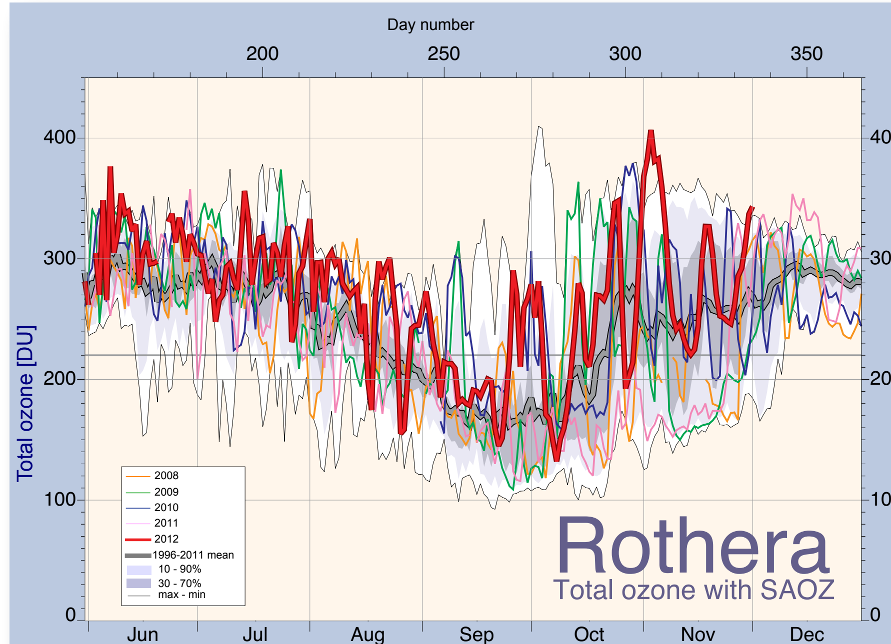

Figure 39. Total ozone measured at Rothera with a SAOZ spectrometer. The plot includes data until 1 December 2012. The grey line shows the 220 DU threshold. The plot is produced at WMO based on data obtained from Jonathan Shanklin's Antarctic web site at the British Antarctic Survey.

South Pole

Ozonesonde launch at the South Pole

The vertical distribution of ozone at the GAW/NDACC station at the South Pole (Amundsen-Scott base) has been measured by NOAA/ESRL with electrochemical concentration cell (ECC) ozonesondes since 1986.

Total ozone, as estimated from ozonesonde flights in August and until 29 September, declined from 276 to 142 DU (see **Figure 40**).

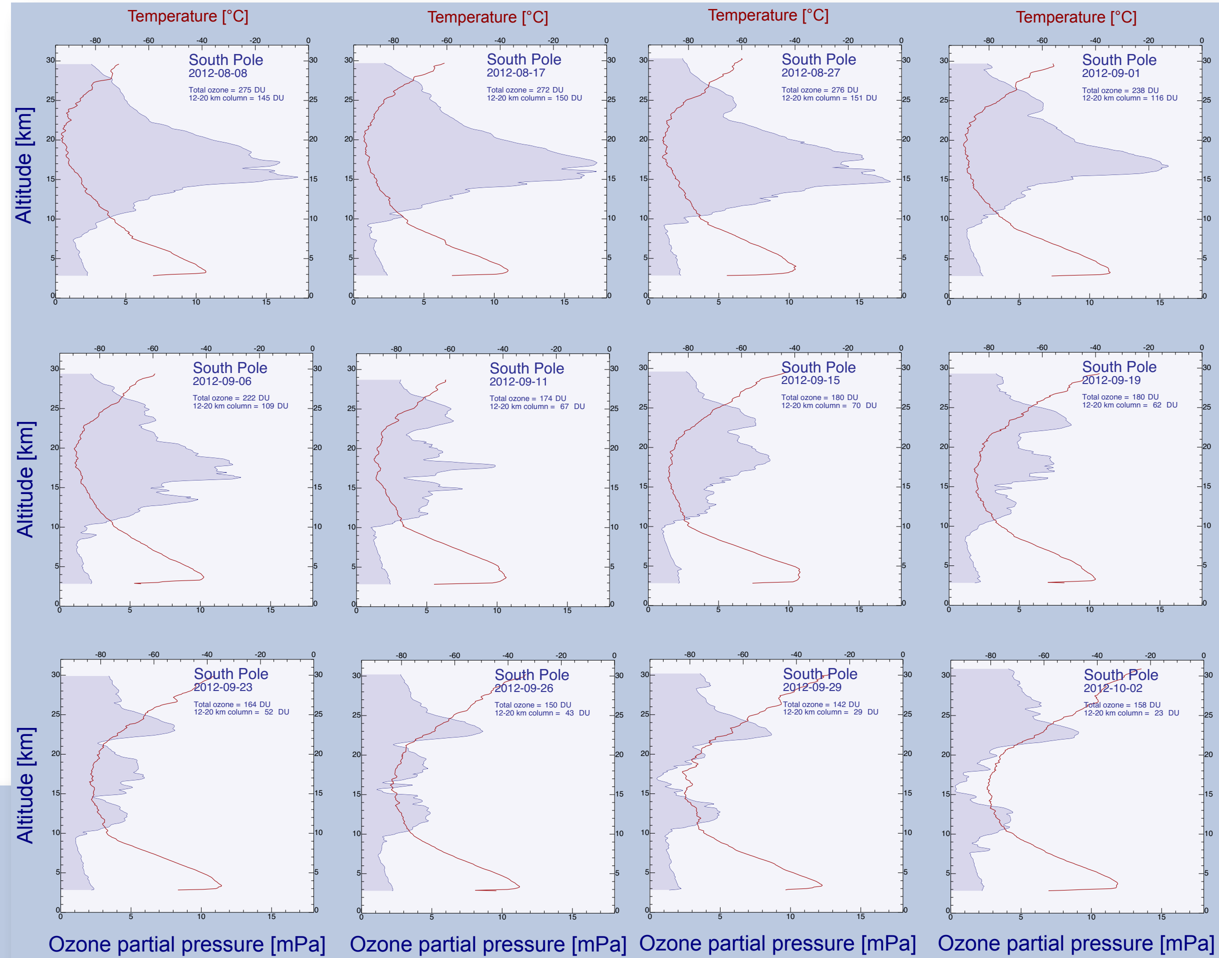

Figure 40. Ozone profiles measured with electrochemical ozonesonde launched from the US NDACC/GAW station South Pole from 8 August until 2 October 2012. It can be seen how the 12-20 km partial ozone column is coming gradually down during the first three weeks of September. The plot is produced at WMO based on data downloaded from the NOAA/ERSL/GMD ftp server.

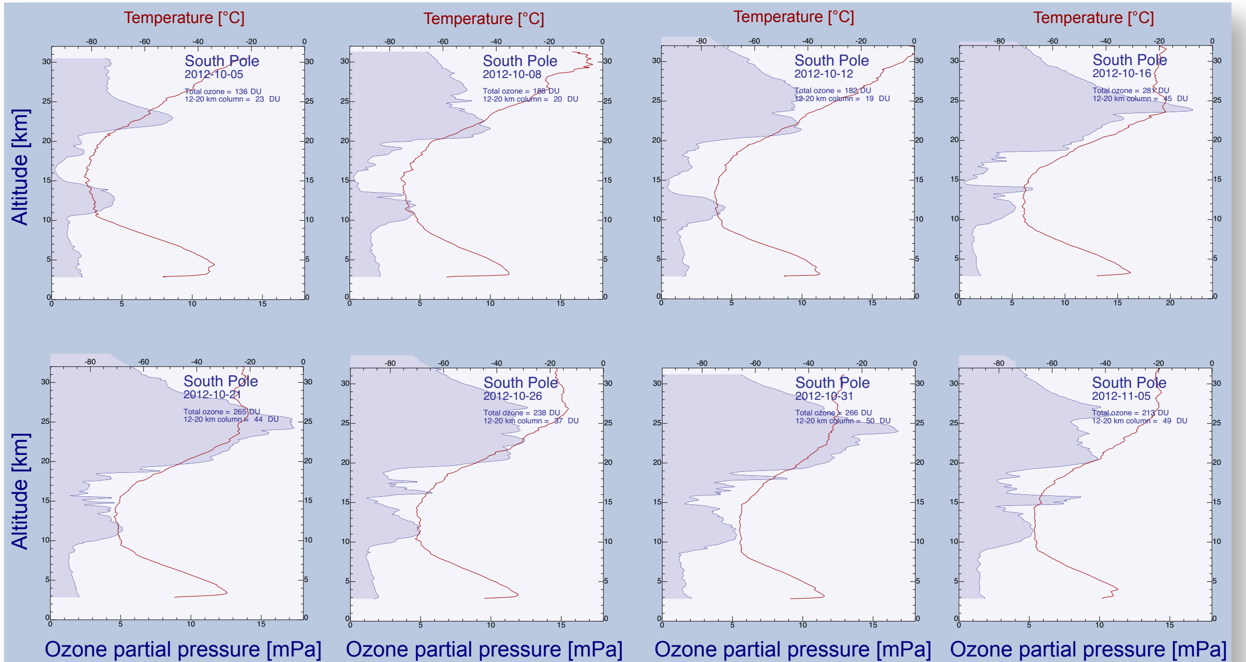

Figure 41. Ozone profiles measured with electrochemical ozonesonde launched from the US NDACC/GAW station South Pole from 5 October until 5 November 2012. It can be seen how the 12-20 km partial ozone column remains low. Please note that the scale on the abscissa is different on the plot for 16 October due to the large amount of ozone at 24 km on that day. The plots are produced at WMO based on data downloaded from the NOAA/ERSL/GMD ftp server.

In October, ozone destruction has continued and the lowest total ozone based on sonde data observed so far was reached on 5 October with 136 DU (**Figure 41**). After that total ozone has increased due to the in-flux of ozone rich air from middle latitudes. This is clearly visible in the profiles of 16 and 21 October. This phenomenon can also be observed in the profiles measured 26 and 31 October, as well as on 5 November. One can see a characteristic "bite-out" in the ozone profile between 15 and 20 km, but relatively large amounts of ozone around 25 km altitude.

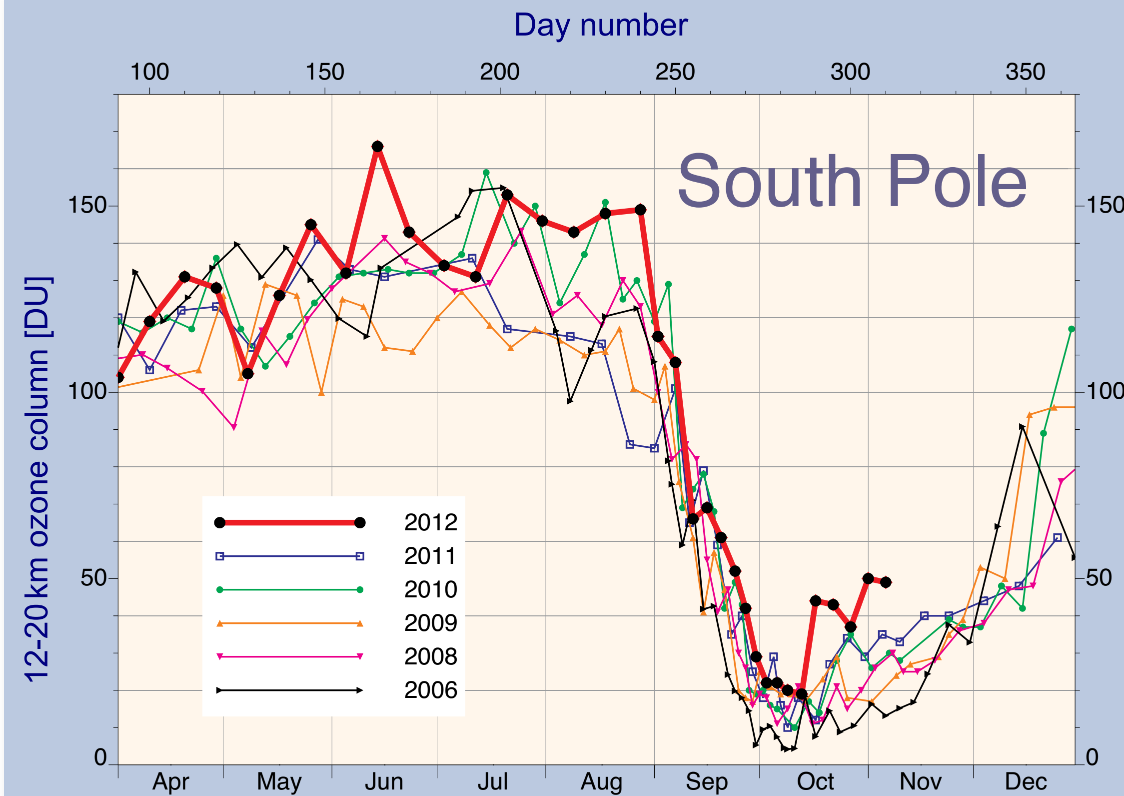

Figure 42. The 12-20 km partial ozone column (DU) based on ozonesonde measurement from the US NDACC/GAW Amundsen-Scott station at the South Pole. The plot is produced at WMO based on data published on the NOAA/ERSL/GMD ftp server. The 12-20 km partial ozone column has dropped to 20 DU as of 8 October.

The partial ozone column over the 12-20 km altitude dropped from 150 DU at the end of August to 19 DU on 12 October. This is shown in **Figure 42**. The figure shows that the 12-20 km column was stable around 140-150 DU during August, but the soundings in September showed a rapid drop in the partial ozone column. The decline has continued in October and reached a minimum so far in the season on 12 October with 19 DU. After 12 October, the 12-20 km partial column has made a jump to over 40 DU (on 16 and 21 October). **Figure 43** shows the long term development of the 12-20 km partial ozone column from 1986 until present. The largest ozone loss observed at the South Pole happened in 1993 and 2006 when the 12-20 km partial column reached 4.2 DU in both cases.

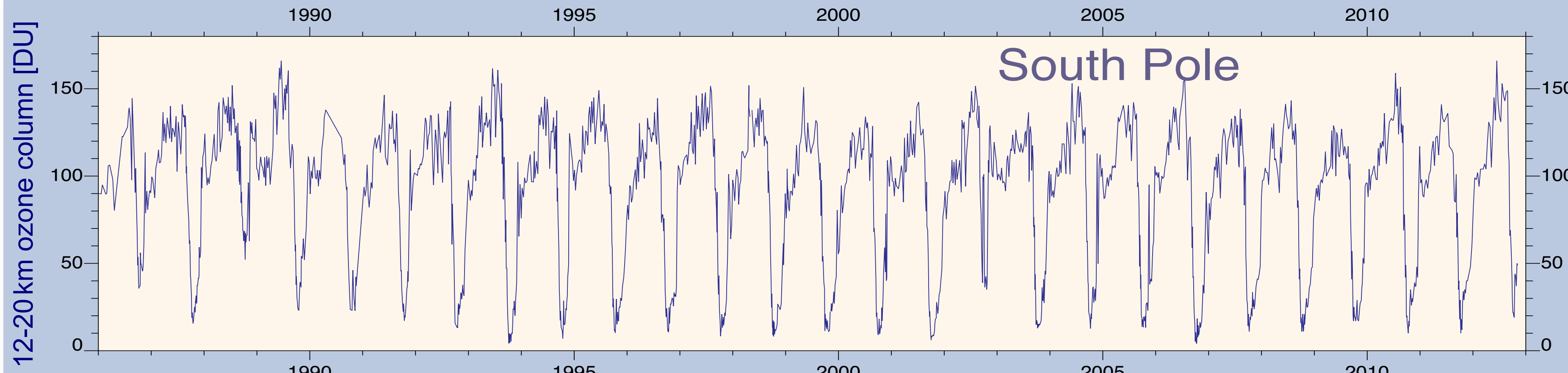

Figure 43. Time series of the 12-20 km partial ozone column deduced from ozonesonde measurements at the South Pole from 1986 until now. The recurring nature of the ozone hole is clearly seen. One can also see that 1993 and 2006 are the years when the 12-20 km partial ozone column reached the lowest values ever observed at this station, with 4.2 DU in both cases.

Total ozone is measured at the Japanese GAW station Syowa (69.0°S, 39.6°E) with a Dobson spectrophotometer. These measurements have been carried out since 1961. Measurements started up on 2 August after the winter. The total ozone value measured with the Dobson spectrophotometer on that day showed 255 DU. During August the total ozone values varied between 219 and 266 DU. During September total ozone has decreased from around 240 DU at the beginning of the month to 189 DU on 9 September. After that total ozone has varied up and down as the polar vortex moves over the station. A minimum so far this season occurred on 23 September with 176 DU. This is shown in **Figure 44**. In October total ozone was below the 220 DU threshold on the 2nd and 3rd, but then increased rapidly to above 300 DU. Towards the end of the month ozone dipped under 220 DU again. During October, total ozone was very variable with a maximum of 314 DU on the 13th and a minimum of 182 DU on the 21st. In November total ozone varied between 201 DU on 3 November and 376 DU on 9 November. In total, Syowa has experienced ozone columns less than or equal to 220 DU on 38 days during the 2012 ozone hole season.

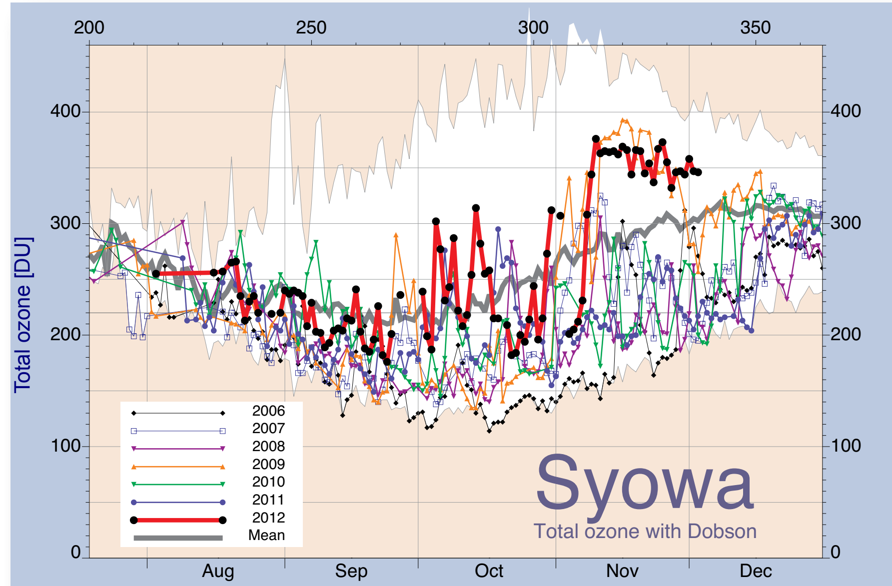

Figure 44. Time series of total ozone measured at the GAW station Syowa. The thick grey curve shows the 1961-2011 average. The data are updated until 25 November. The plot is produced at WMO based on data submitted by the Japanese Meteorological Agency.

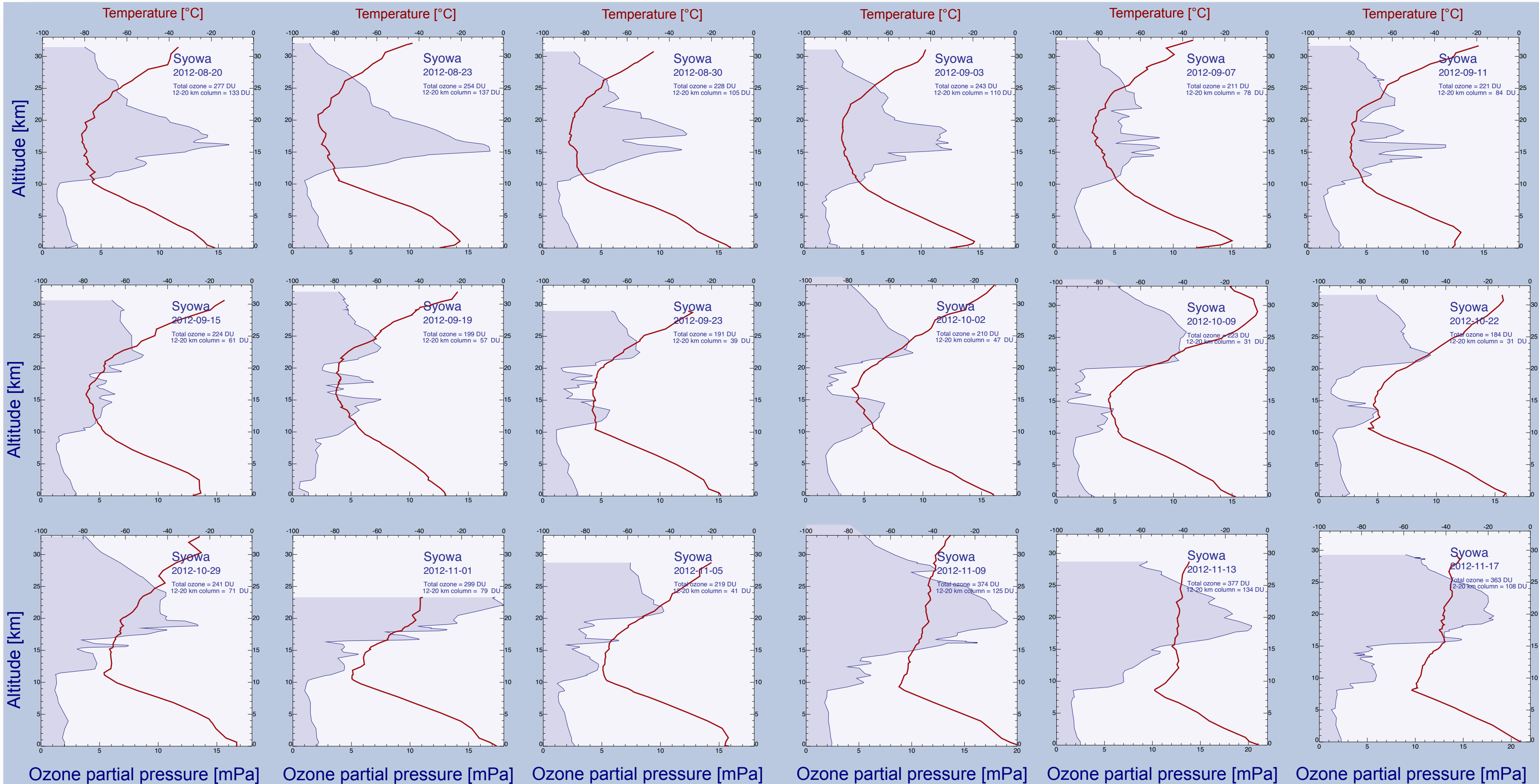

Figure 45. Ozone profiles measured with electrochemical ozonesondes launched from the Syowa station. Note that the abscissa scale is different on the last two plots. The plots are produced at WMO based on data submitted by the Japanese Meteorological Agency.

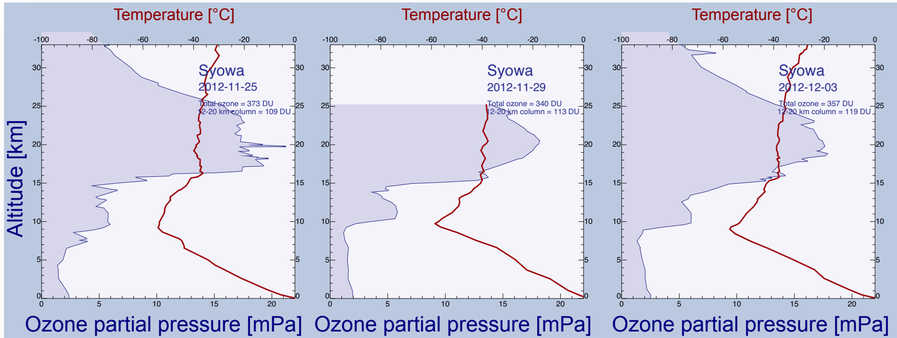

Figure 46. Ozone profiles measured with electrochemical ozonesondes launched from the Syowa station from 25 November until 3 December 2012. The plots are produced at WMO based on data submitted by the Japanese Meteorological Agency.

Ozonesondes have been launched from Syowa since the early 1960s, as well. **Figure 45** shows the ozone profiles measured from 20 August, September to 17 November. It can be seen from the figure that the 12-20 km partial column has decreased from about 130-140 DU around 20 August to 31 DU on 9 and 22 October, which are the minimum 12-20 km columns above Syowa this year. **Figure 46** shows sounding carried out from 25 November until 3 December. These profiles are characteristic of an outside of vortex situation.

Ushuaia

Ozonesonde launch at Ushuaia

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 are shown in **Figure 47**. The profile measured on 5 September shows that the station was influenced by ozone poor air with a 12-20 km partial ozone column of 76 DU. The

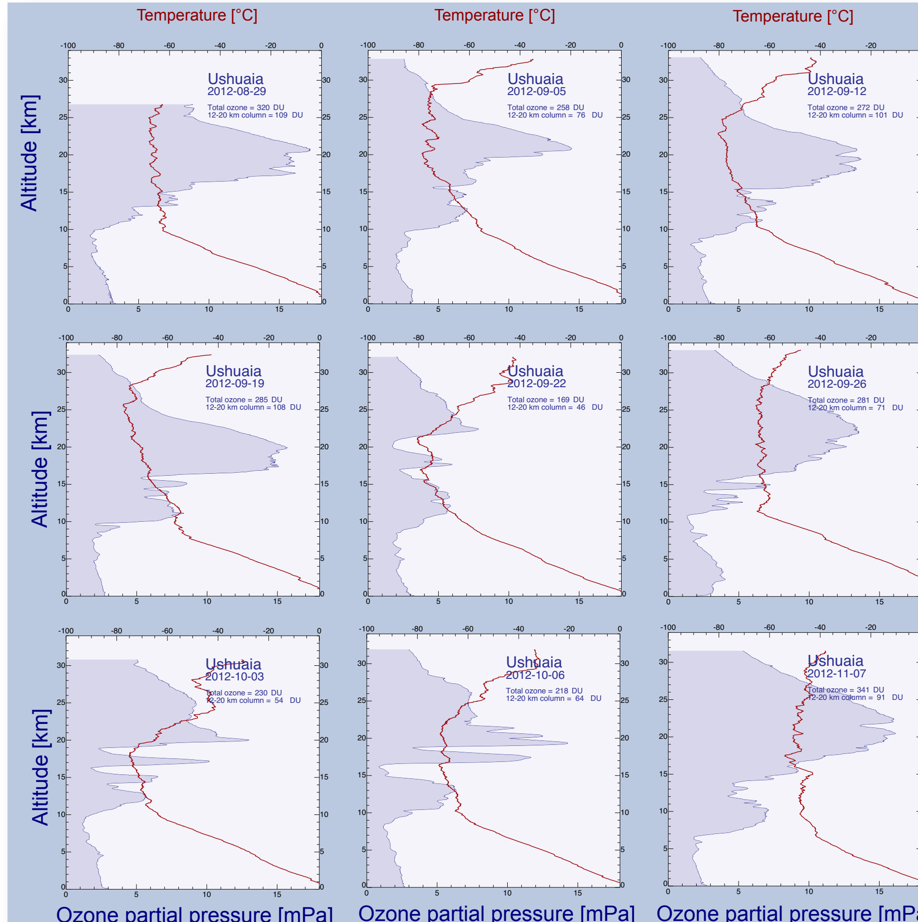

Figure 47.Ozonesonde profiles measured at the Argentine GAW station Ushuaia between 29 August and 7 November. The plots are produced at WMO based on data submitted by the National Meteorological Service of Argentina.

sounding carried out on 22 September shows clear signs of ozone depletion in the 15-21 km range. The satellite images in **Figure 48** shows that the station was under the edge of the ozone hole on this day. On 26 September, the ozone hole had again moved away from the station. The vortex came back over the station in early October and sondes were launched on the 3rd and the 6th. The timing of these launches were optimised thanks to ozone forecasts from the MACC-II project. Column ozone from MLS is shown in the lower row of **Figure 48** for the 6th of October, when Ushuaia was on the edge of the ozone hole. The ozone profile from 7 November is characteristic of mid latitude air masses, and it can also be seen from the figure that Ushuaia is well outside of the ozone hole on that day.

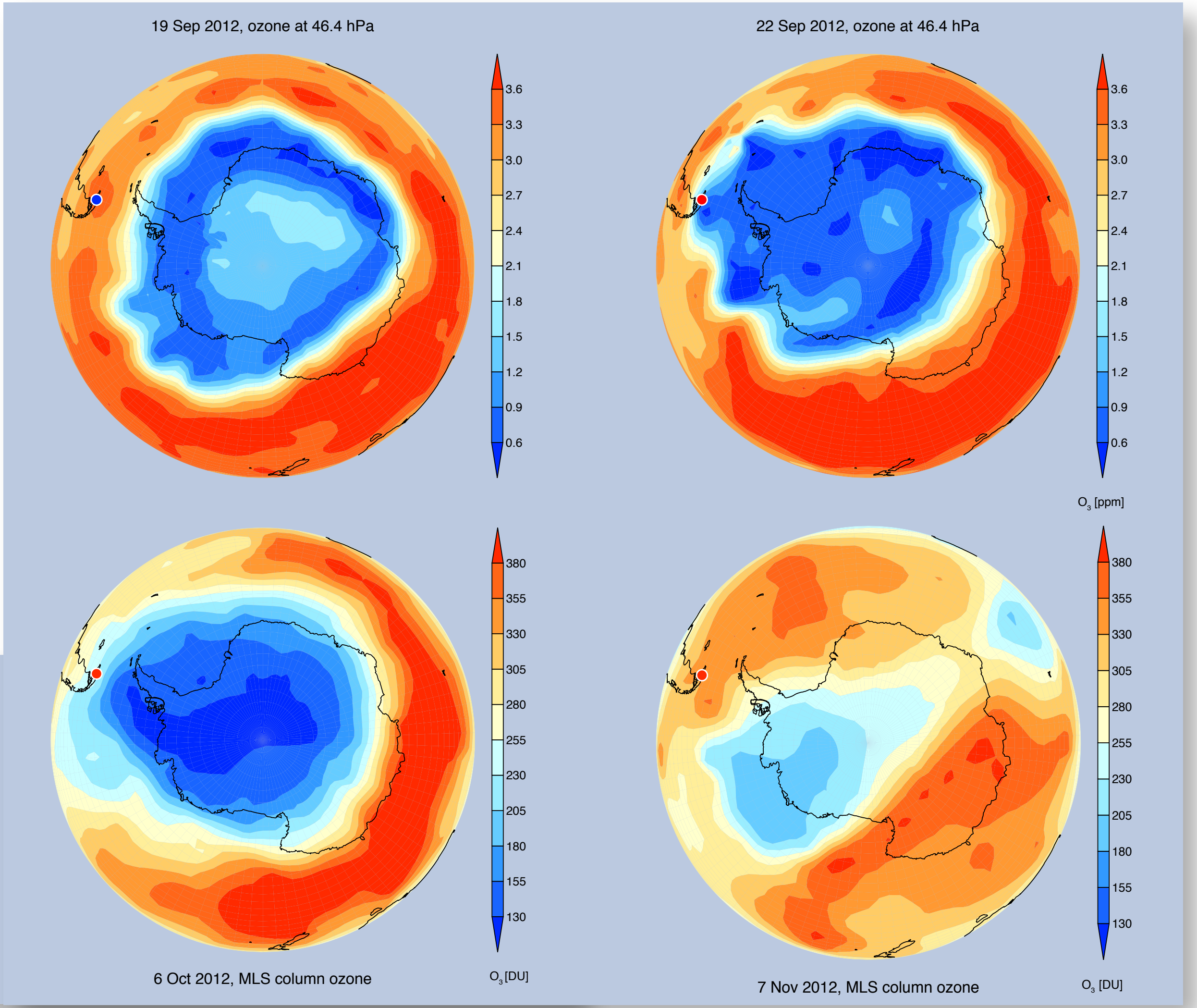

Figure 48.Upper panels: Ozone mixing ratio (ppm) at 46 hPa on 19 Sept 2012 and 22 September 2012. Lower panels: Column ozone [DU] on 6 October and 7 November. Data are from the MLS instrument on the AURA satellite. The data are downloaded from the Goddard Earth Sciences Data and Information Services Center (GES DISC) and plotted at WMO.

Vernadsky

The Vernadsky station seen from the sea. Photo: Katrin Sif.

Vernadsky station (65.2458°S, 64.2575°W) is run by the National Antarctic Scientific Centre of Ukraine. Total ozone is measured with a Dobson spectrophotometer. Observations recommenced after the polar night on 21 July, with initial results around 260-280 DU. During August total ozone values oscillated between 316 (19 Aug) and 203 DU (25 Aug). In September total ozone varied between 150 DU (21 Sep) and 299 DU (25 Sep). In October total ozone varied between 153 DU on the 7th and 379 DU on the 24th. In November, total ozone varied between 387 DU on 5 November and 255 DU on 22 and 23 November. Total ozone has been smaller than or equal to 220 DU on 30 days in during the 2012 ozone hole season.

Vostok

An overview of the Vostok station. Photo: Libor Zicha.

Vostok (78.464422°S, 106.837328°E) 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 with a filter instrument. Data from 7 September to the end of November are currently available. From 7 to 30 September, total ozone was below the 220 DU threshold on every day except on the 28th. The minimum in September was 151 DU measured on the 26th. In October, total ozone varied between 162 DU on the 4th and 383 DU on the 15th. In November, total ozone varied between 204 DU on the 2nd and 370 DU on the 8th. From 7 September until 30 November total ozone has been equal to or below the 220 DU threshold on 33 days.

Zhong Shan

The Zhong Shan station. Photo: Hannes Grobe, Alfred Wegener Institute for Polar and Marine Research.

At the Chinese GAW station Zhong Shan (69.373770°S, 76.373770°E) total ozone is measured with a Brewer spectrophotometer. The observations started up on 13 August after the polar night. The first direct sun measurement was carried out on 17 August. The total ozone value on that day was 291 DU. After that, total ozone showed a gradual decline and on 11 September it was 214 DU. Then total ozone increased and reached 276 DU on 16 September. Between 16 and 30 September total ozone has varied between 211 DU (24 September) and 358 DU (30 September). In October, total ozone varied between 193 DU (4 October) and 412 DU (14 October). In November (until the 11th) total ozone has been well above 300 DU. The station is often close to the vortex edge, and this can lead to large changes in total ozone, as a function of the location of the station relative to the vortex edge. **Figure 49** on the next page shows a long term time series, combining satellite overpass data from 1978 until now with Brewer data from 1993 until now.

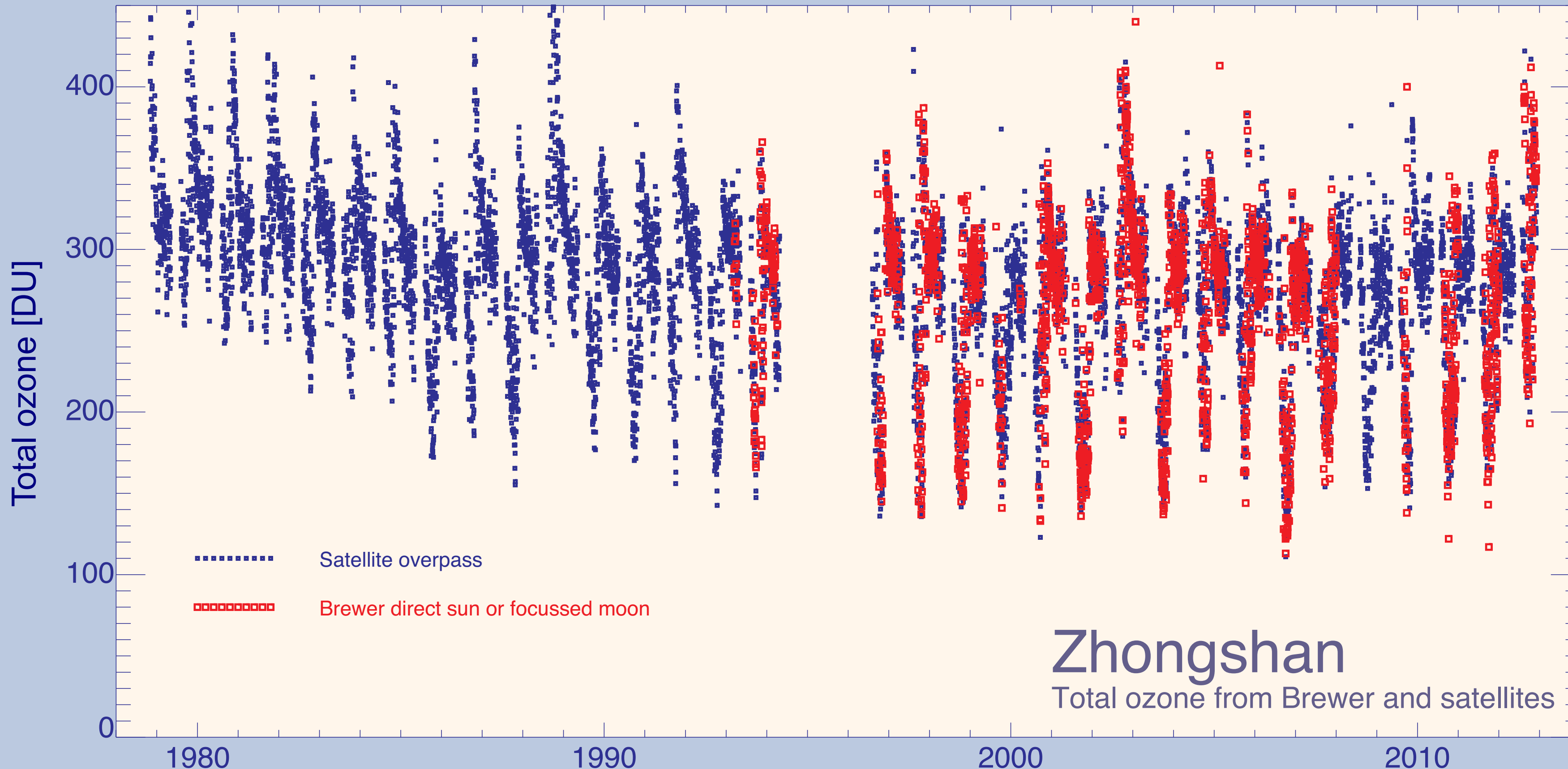

Figure 49. Time series of total ozone over Zhong Shan from 1978 until present. The blue data points are overpass data from various satellites (TOMS until end of September 2004 and OMI from 1 October 2004). The red data points are observations made with Brewer #74. Only direct sun and focussed moon measurements have been included.

Chemical activation of the vortex

Results from a data assimilation model

Data from the Bascoe model, which is part of the MACC-II project shows the breakdown of the ozone hole over the course of the month of November. The Bascoe model assimilates data on various species, such as ozone, water vapour, nitrous oxide, hydrochloric acid and nitric acid from the MLS instrument on the Aura satellite.

Figure 50 shows ozone maps for 1, 6, 11, 16, 21, 26 and 30 November as well as 5 December at the 56.7 hPa level. One can see the vortex split that took place between the 6th and the 11th. One can also see how ozone poor air is transported towards middle latitudes at the end of November and the beginning of December.

Figure 51 shows the mixing ratio of hydrochloric acid (HCl), which is one of the reservoirs for active chlorine, for the same dates and the same level as in the previous figure. Also here one can see the vortex split between the 6th and the 11th and also how vortex air is transported away from Antarctica and towards middle latitudes.

Figure 52 shows the mixing ratio of nitrous oxide (N_2O) at for the same dates and the same level as in the previous figure. Nitrous oxide is a good tracer for vortex air. Its mixing ratio is constant in the well mixed troposphere, but in the stratosphere its mixing ratio goes down with altitude due to UV photolysis. During the winter there is diabatic descent inside the polar vortex. Hence, over the course of the winter a gradient develops across the vortex boundary with significantly less N_2O inside than outside the vortex. The figure shows how the vortex splits and also how vortex air is advected towards middle latitudes. On 5 December there is still a fairly large region with vortex air around 45°S, between Africa and Antarctica.

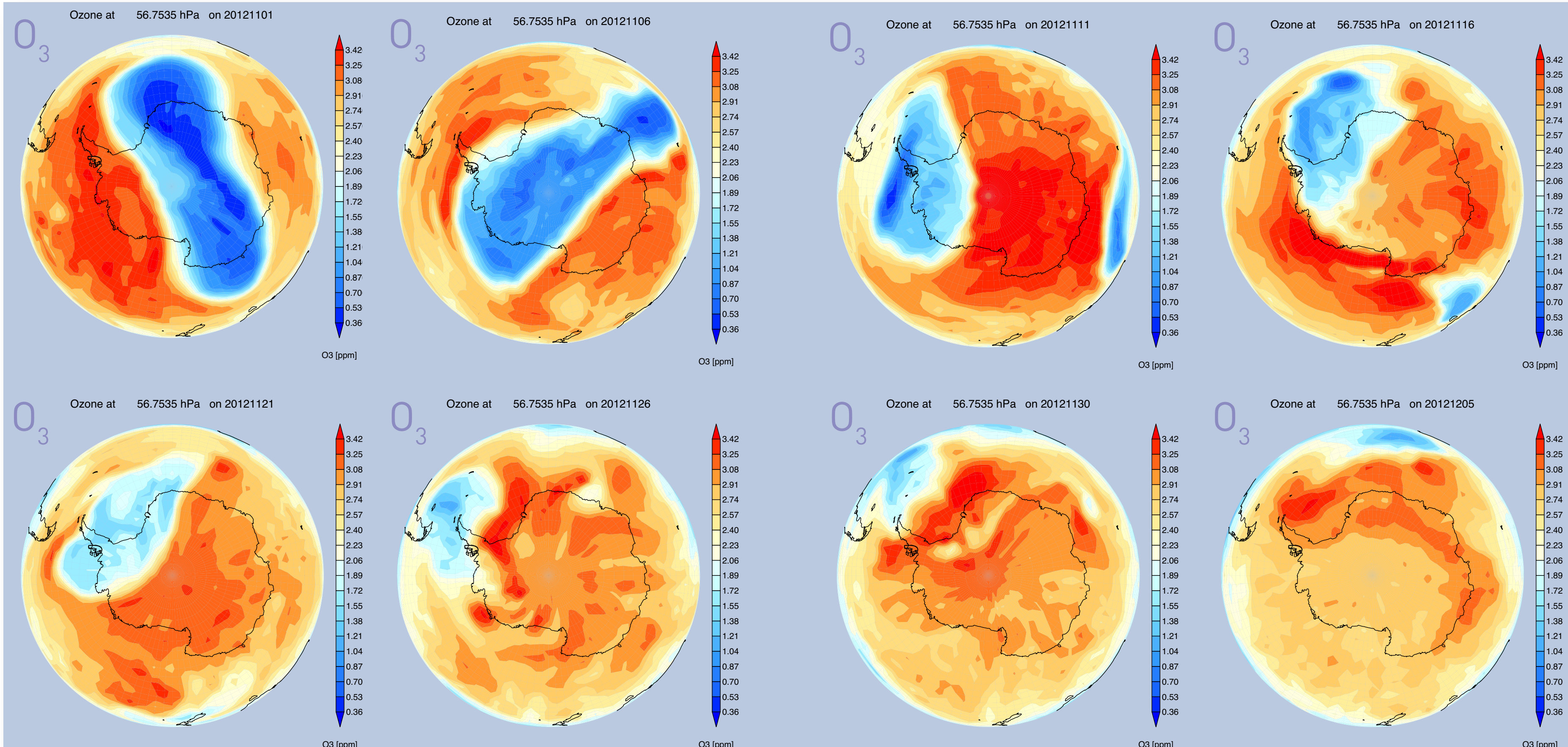

Figure 50. Mixing ratio of ozone at the 56.7 hPa level on 1, 6, 11, 16, 21, 26 and 30 November as well as 5 December 2012. One can see how the ozone hole gradually dissipates over this time span of a good month. The maps are made at WMO and based on data from the Bascoe model.

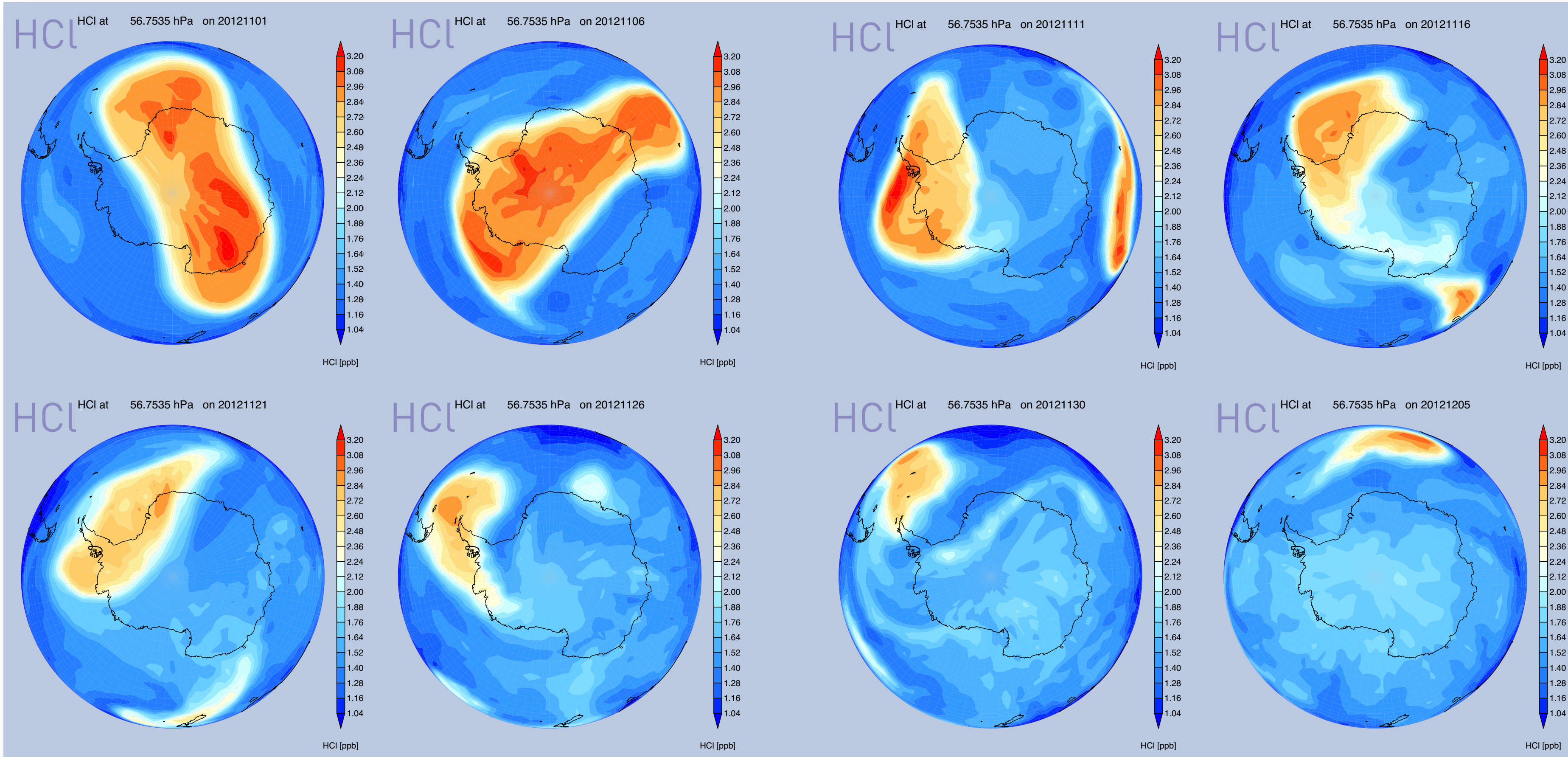

Figure 51. Upper row: Mixing ratio of HCl on 1, 6, 11, 16, 21, 26 and 30 November, as well as on 5 December. The maps are made at WMO and based on Bascoe model data from the MACC-II project.

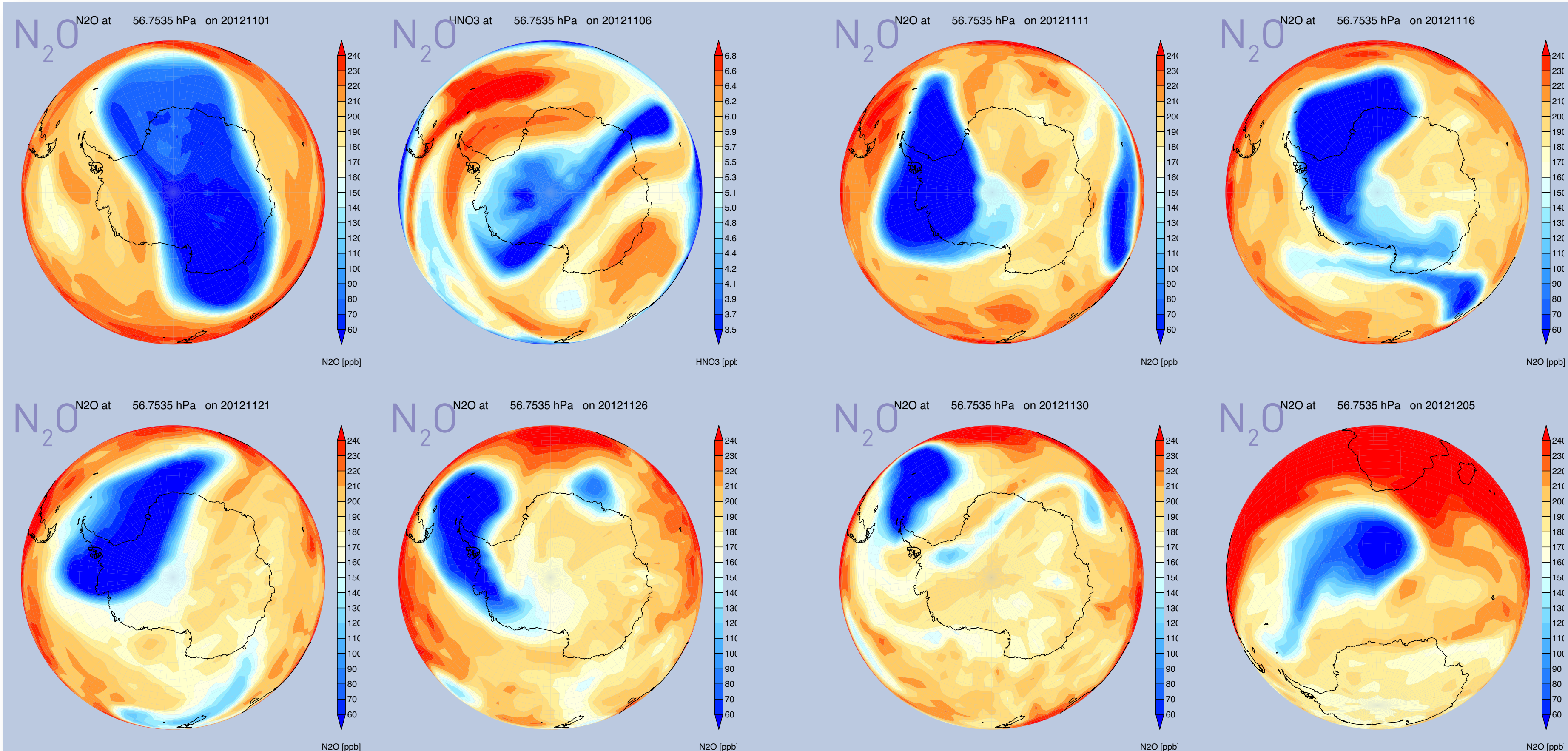

Figure 52. Mixing ratio of nitrous oxide on 1, 6, 11, 16, 21, 26 and 30 November as well as 5 December at 56.7 hPa. Please note that the last map is centred between Antarctica and South Africa. The maps are made at WMO and based on Bascoe model data from the MACC-II project.

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-A (and SCIAMACHY on Envisat in the past) is shown in **Figure 53**. During the first half of August, the area increased more slowly than at the same time in many of the recent years. However, from mid August the increase more or less followed the same development as in 2011. From early September, the ozone hole area levelled off but increased a bit again after the middle of September. Starting early October, the ozone hole area dropped rapidly until it reached zero on 10 November. Measured by this metric, the 2012 ozone hole is the weakest among the years shown here (2005 until now).

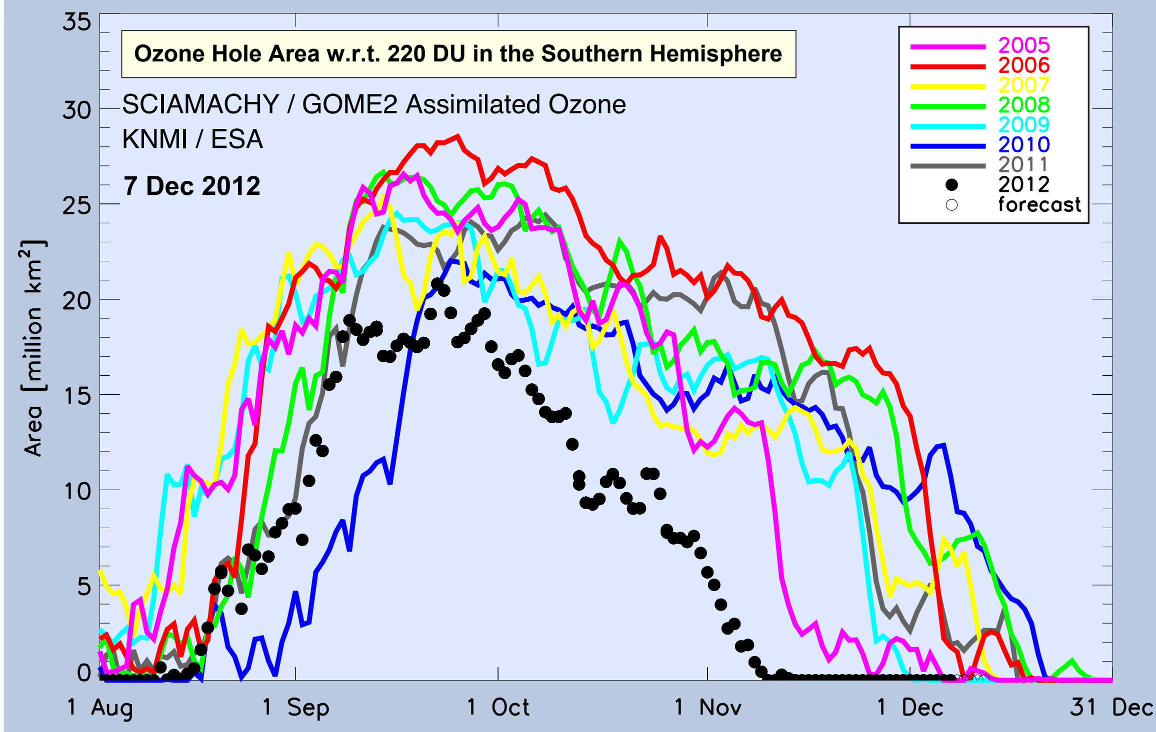

Figure 53. Ozone hole area for the years from 2005 to 2012 (black dots). The ozone hole area is the area of the region where total ozone is below 220 DU. The open circles represent a forecast for the five next days. This plot is produced by KNMI and is based on data from the GOME-2 and SCIAMACHY satellite instruments.

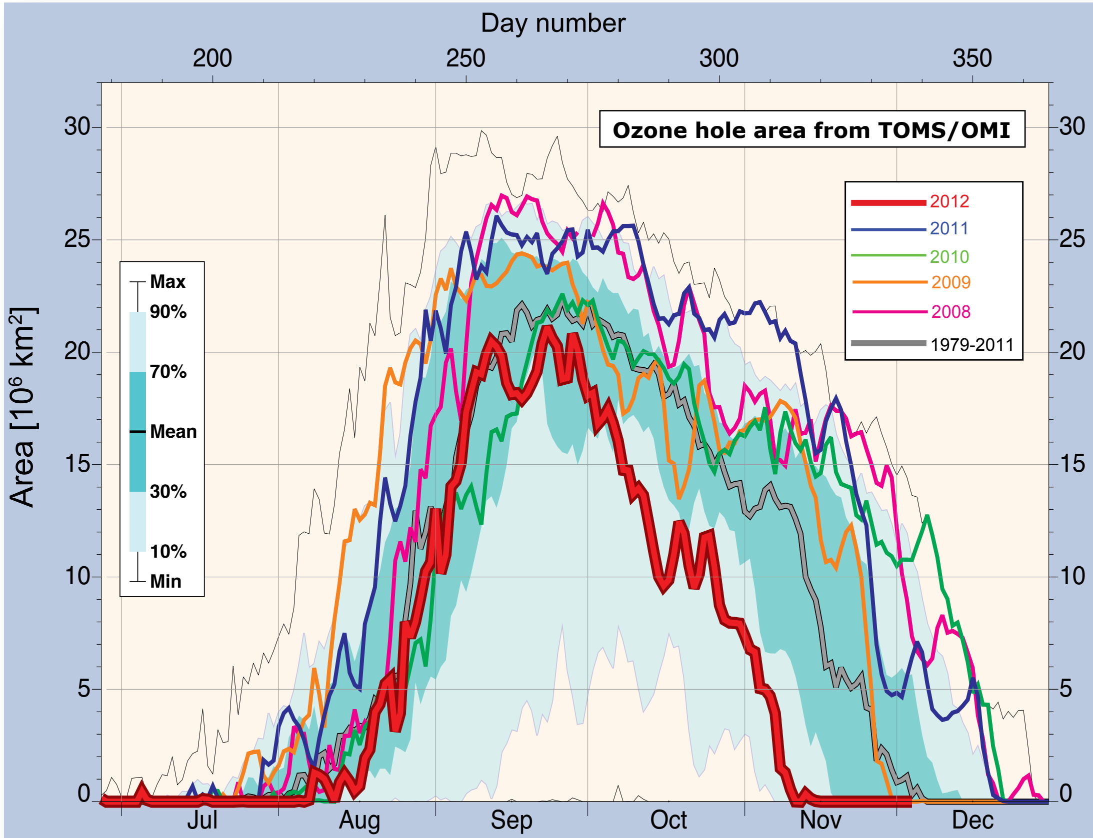

Figure 54. Area (millions of km²) where the total ozone column is less than 220 Dobson units. 2012 is showed in red (until 3 December). 2011 is shown in blue, 2010 in green, 2009 in orange and 2008 in violet. The smooth grey line is the 1979-2011 average. The dark green-blue shaded area represents the 30th to 70th percentiles and the light green-blue shaded area represents the 10th and 90th percentiles for the time period 1979-2011. 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 54 shows the ozone hole area as deduced from the OMI satellite instrument. Here it can be seen that the 2012 ozone hole had a slightly later start than in the other years shown here. From late August the ozone hole area increased rapidly and on 27 September it reached 21.6 million square kilometres, the maximum value attained in 2012. Again, as we saw on the previous figure, based on GOME-2 data, this area is smaller than at the same date both in 2011 and 2010. From the end of September, the ozone hole area decreased rapidly and reached zero by 11 November.

Ozone mass deficit

Figure 55 shows the ozone mass deficit as deduced from the OMI satellite instrument. It can be seen that the ozone mass deficit followed the development of 2010 (green curve) quite closely until late September. The ozone mass deficit reached a maximum of 22.0 megatonnes on 22 September. From the end of September, the ozone mass deficit declined rapidly and reached zero on 10 November.

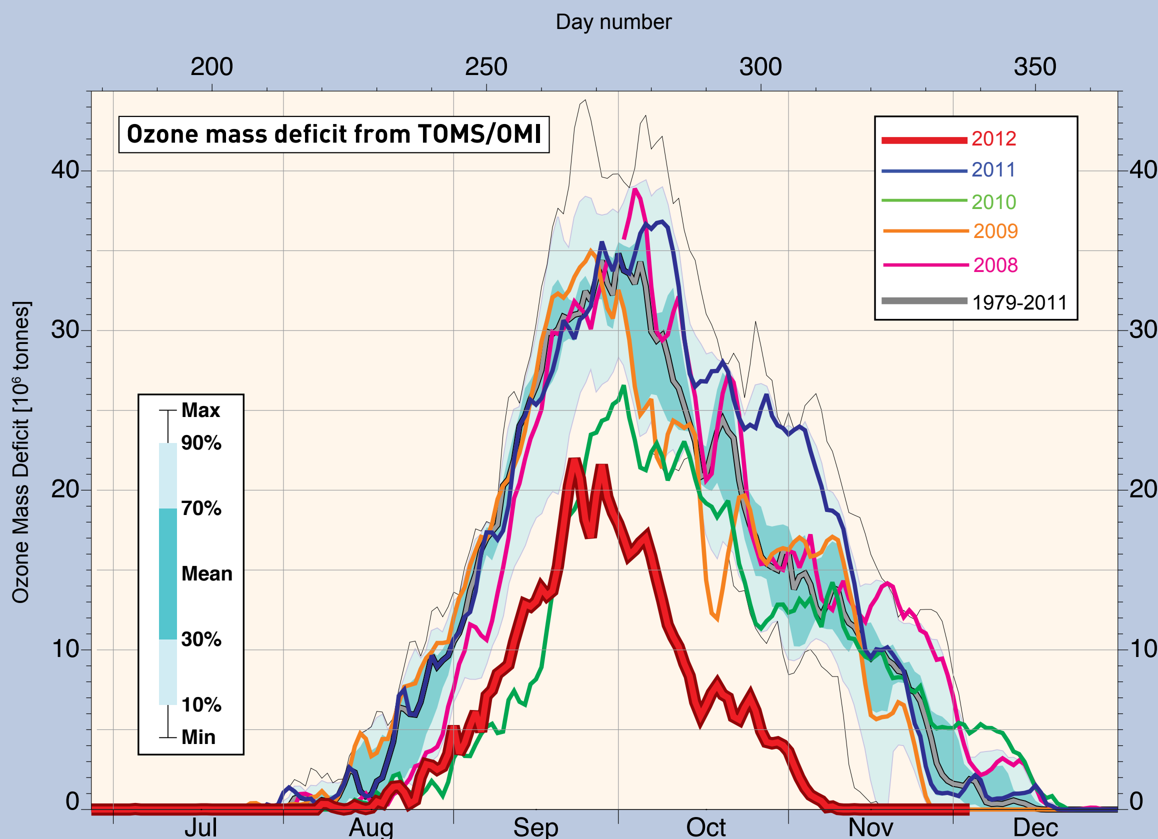

Figure 55. Ozone mass deficit (megatons) inside the Antarctic ozone hole for the years from 2008 to 2012 together with 1979-2011 statistics. Data for 2012 are shown in red (until 3 December). The ozone mass deficit is defined as the mass of ozone that would have to be added to the ozone hole in order 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.

Figure 56 shows the ozone mass deficit based on data from SCIAMACHY and more recently from GOME-2. It shows that the ozone mass deficit followed the development of the 2004 ozone hole until early October. After that the ozone mass deficit fell rapidly and by mid October it reached the same values as seen in 2002 at that time of the season. During the latter half of October and early November, the decline continued and by 10 November it reached zero.

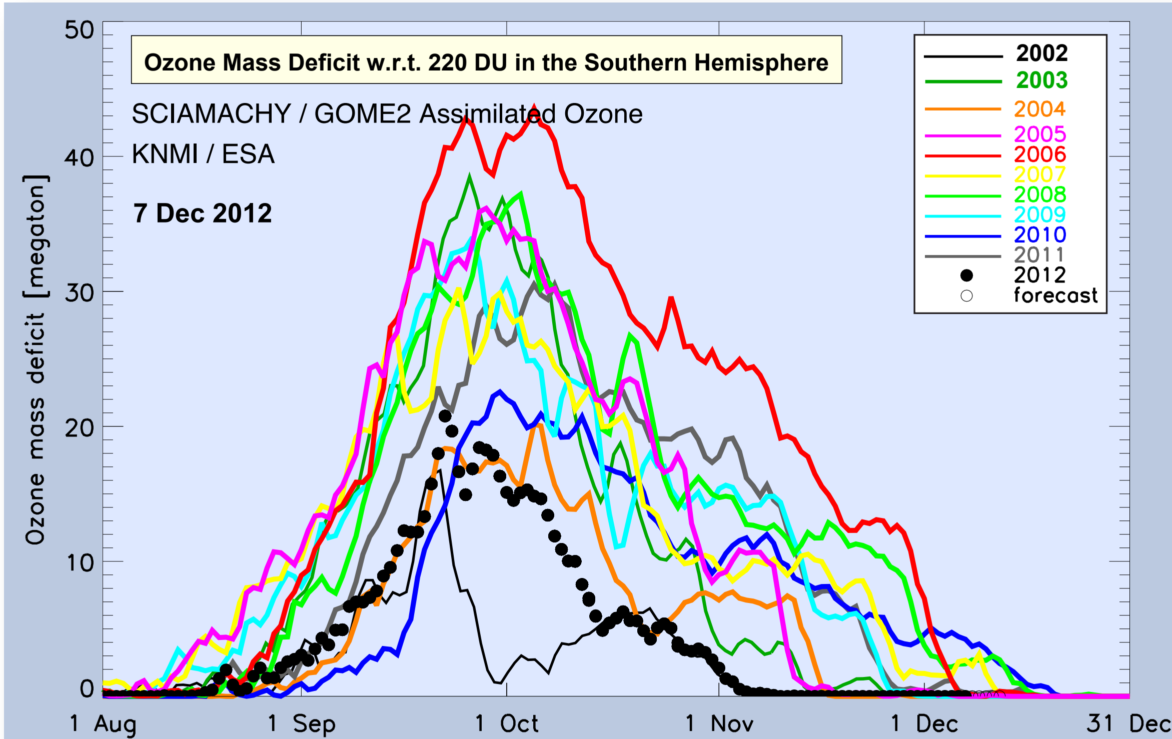

Figure 56. Ozone mass deficit (megatons) inside the Antarctic ozone hole for the years from 2002 to 2012. Data for 2012 are shown as black dots (until 7 December). The ozone mass deficit is defined as the mass of ozone that would have to be added to the ozone hole in order to bring the total ozone column 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.

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 have been chosen here to calculate the average ozone hole area for the years 1979 to 2012 based on the Multi-Sensor Reanalysis data and SCIAMACHY and GOME-2 data and calculated at KNMI. The result of this analysis is shown in **Figure 57** (next page). The first period chosen covers the last ten days of September, a period when the ozone hole usually is at its largest. This is shown in the upper left panel of the figure.

The next period chosen spans the time period from 7 September - 13 October. This period has been chosen because it covers both the period of the largest ozone hole area and the largest ozone mass deficit. The data for this period are shown in the upper right panel of the figure.

Since the date of the peak area can vary from one year to another it also makes sense to look at the period of 30 consecutive days that gives the largest average ozone hole area. This is shown in the lower left panel of **Figure 57**.

Finally, one can look at period that covers the entire period of the ozone hole. The time period from 19 July to 30 November has been chosen for this. The data for this time period are shown in the lower right panel of the figure on the next page. With the exception of 2002, when the ozone hole split in two and collapsed in September, the 2012 ozone hole is the weakest since 1988 or 1990, depending on which of the metrics is considered.

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 58**. The time periods are the same as those used for the ozone hole area calculations. Again, with the exception of 2002, the 2012 ozone hole is the weakest ozone hole since 1988 or 1990, depending on which of the metrics is considered. However, the average mass deficit over the 21-30 September period was a little bit weaker in 2004 than in 2012. In addition, The ozone hole of 2010, by some metrics, was almost as weak as the 2012 ozone hole.

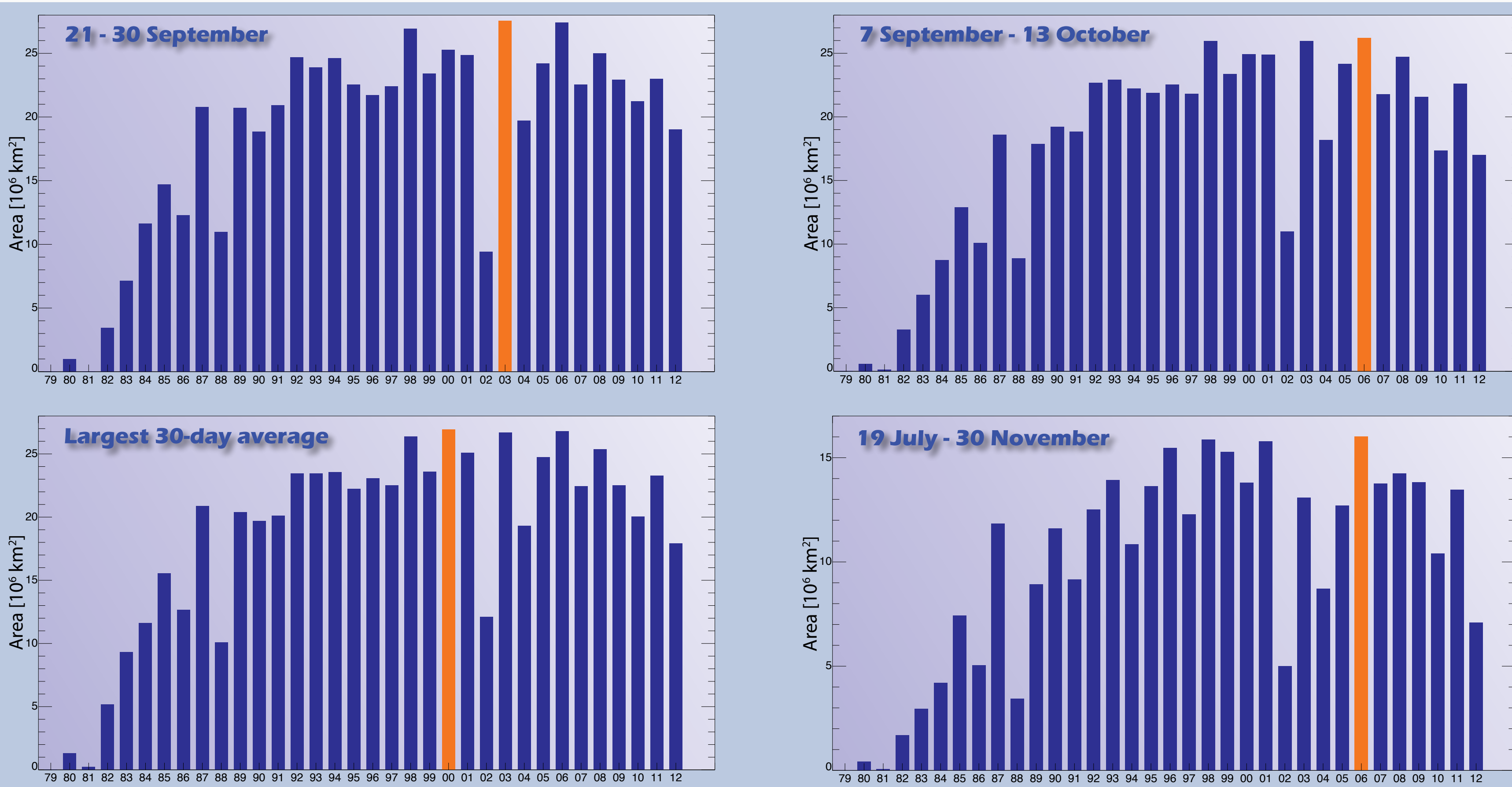

Figure 57. Average area of the ozone hole for four different time periods based on the multi-sensor reanalysis and SCIAMACHY and GOME-2 data and calculated by KNMI.

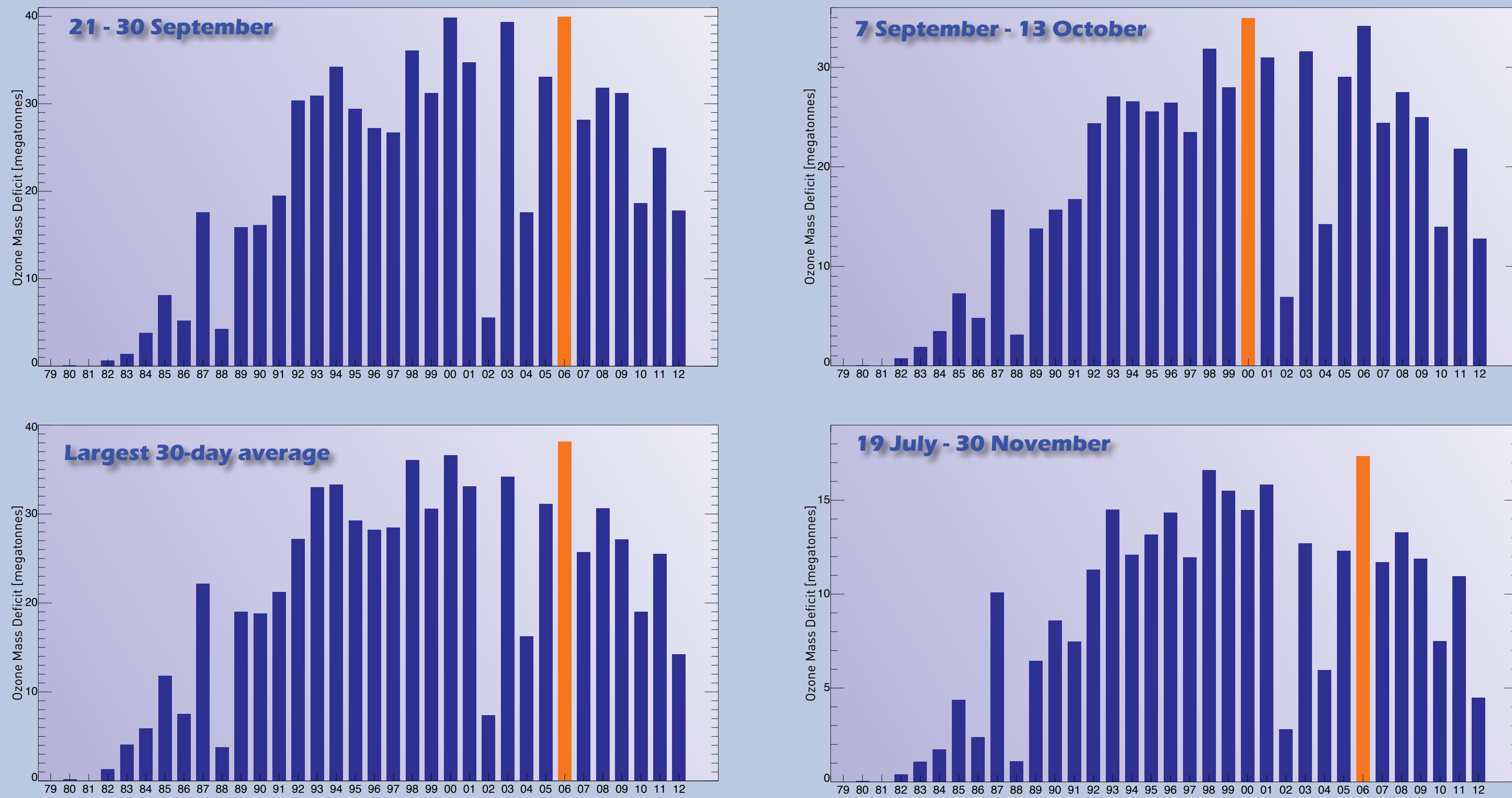

Figure 58. Average ozone mass deficit for four different time periods based on the multi-sensor reanalysis and SCIAMACHY and GOME-2 data and calculated by KNMI.

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 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, San Martin, Ushuaia), Argentina/Finland (Marambio), Argentina/Italy/Spain (Belgrano), Australia (Macquarie Island and Davis), China/Australia (Zhong Shan), France (Dumont d'Urville and Kerguelen Is), Germany (Neumayer), Japan (Syowa), New Zealand (Arrival Heights), Russia (Mirny and Novolazarevskaja), Ukraine (Vernadsky), UK (Halley, Rothera), Uruguay (Salto) and USA (McMurdo, 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.

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 data are provided by the U.S. National Science Foundation's (NSF) UV Monitoring Network (http://www.biospherical.com/nsf).

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

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, with a summary of the 2012 ozone hole season, is planned for late February 2013.