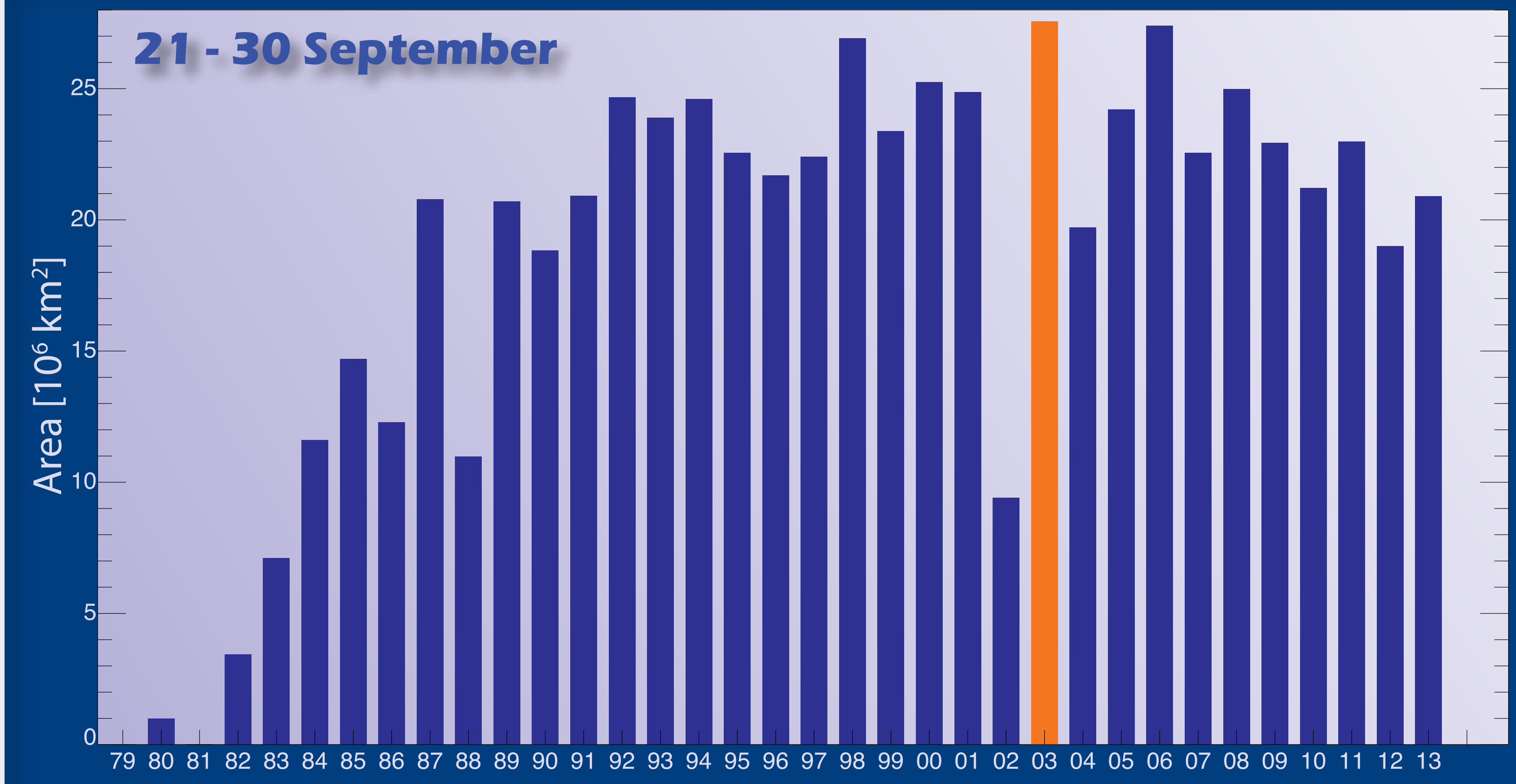
Antarctic Ozone Bulletin

No 3/2013



Daily ozone hole area averaged over the last ten days of September. Typically, this is the time period when the ozone hole reaches its maximum extent. This quantity has been calculated for every year since 1979 until present. The ozone hole areas have been calculated at the Netherlands Meteorological Institute based on data from the Multi-Sensor Reanalysis (1979-2008) and data from GOME-2 (2009-present). The plot has been produced at WMO. More details are found on page 65.

WMO OMM

14 October 2013

Global Atmosphere Watch

GAW

Executive Summary

The area of the ozone hole reached a maximum of 24.0 million km^2 on 16 September according to OMI data from NASA. This is more than in 2012 and 2010, but less than in 2011. Data from KNMI, based on GOME-2, show that the ozone hole area averaged over the ten last days of September was 20.9 million km^2. This is more than in 2012 but less than in 2010 and 2011. The ozone mass deficit averaged over the same period was 19.59 megatonnes. This is more than in 2010 and 2012 but less than in 2011. Average ozone hole area and mass deficit for other time periods will be reported in later issues as they become available.

The daily minimum temperatures at the 50 hPa level have been below the 1979-2012 average since early April. From mid June until early September the minimum temperature was well below the long term mean. From 9 to 13 August the minimum temperature was below the 1979-2012 minimum for those dates. The same also happened on 14 September. From mid September the minimum temperature has increased and is near the long term mean at the end of September. The minimum temperature has been below the NAT threshold since 8 May.

The average temperature over the 60-90°S region was below the long-term (1979-2012) mean from April until late August. On 11 August it dipped below the 1979-2012 minimum. From mid August the mean temperature has increased somewhat, and since mid September it is above the long-term mean.

Since the onset of NAT temperatures in early May the NAT area has been close to or above the long-term average. The NAT area reached a peak of 26.3 million km^2 on 19 July. Since early June 2013 the NAT area has been close to or a bit smaller than in 2011 but larger than in 2010 and 2012 on most days. As of 28 September the NAT area is 3.1 million km^2 larger than the long-term mean.

Since the onset of PSCs in early May until mid July the NAT volume was close to or above the 1979-2012 average. From mid July until mid August the NAT volume was somewhat smaller than the long-term mean. After that it has been oscillating around the long-term mean. The NAT volume has been significantly larger in 2013 than in 2010 and 2012 and it was similar to the volume seen in 2011 until late August. During September it has been significantly smaller than in 2011.

During May, June and most of July the 45-day mean of the heat flux was lower than or close to the 1979-2012 average. In August the heat flux oscillated around the long term mean. The heat flux was smaller in 2013 than in the most recent years on most days until mid August. In September the heat flux was larger than the long-term average, indicating that the vortex was more disturbed than usual.

At the 46.4 hPa level (altitude of ~18.5-19.5 km) hydrochloric acid (HCl) is now reforming after having been entirely depleted earlier in the season. There are still substantial amounts of ClO (active chlorine) present in the polar vortex, so ozone depletion is still going on.

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

As the temperatures rise the ozone depletion rate will slow down. It is still too early to give a definitive statement about the degree of ozone loss that will occur this year. Data available until now indicates that the ozone hole is larger in 2013 than in 2012 and possibly also 2010, but smaller than the one of 2011.

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

Introduction

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

The amount of water vapour in the stratosphere is very low, only 5 out of one million air molecules are water molecules. This means that under normal conditions there are no clouds in the stratosphere. However, when the temperature drops below -78°C, clouds that consist of a mixture of water and nitric acid start to form. These clouds are called PSCs of type I. On the surface of particles in the cloud, chemical reactions occur that transform passive and innocuous halogen compounds (e.g. HCl and HBr) into so-called active chlorine and bromine species (e.g. ClO and BrO). These active forms of chlorine and bromine cause rapid ozone loss in sun-lit conditions through catalytic cycles where one molecule of ClO can destroy thousands of ozone molecules before it is passivated through the reaction with nitrogen dioxide (NO_2).

When temperatures drop below -85°C, clouds that consist of pure water ice will form. These ice clouds are called PSCs of type II. Particles in both cloud types can grow so large that they no longer float in the air but fall out of the stratosphere. In doing so they bring nitric acid with them. Nitric acid is a reservoir that liberates NO_2 under sunlit conditions. If NO_2 is physically removed from the stratosphere (a process called denitrification), active chlorine and bromine can destroy many more ozone molecules before they are passivated. The formation of ice clouds will lead to more severe ozone loss than that caused by PSC type I alone since halogen species are more effectively activated on the surfaces of the larger ice particles.

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

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

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

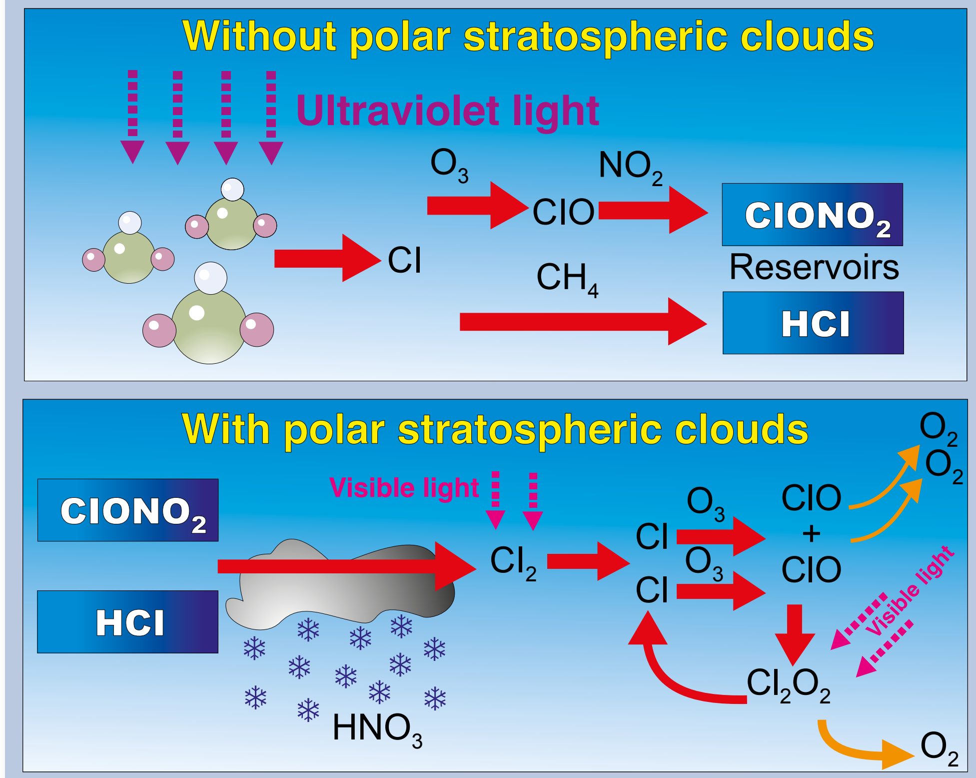


Figure 1. Diagram showing the effect of polar stratospheric clouds on ozone loss. The upper panel shows the situation when there are no polar stratospheric clouds. Ozone depletion takes place only in the gas phase (homogeneous chemistry). The lower panel shows the situation when there are polar stratospheric 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

Minimum temperatures

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

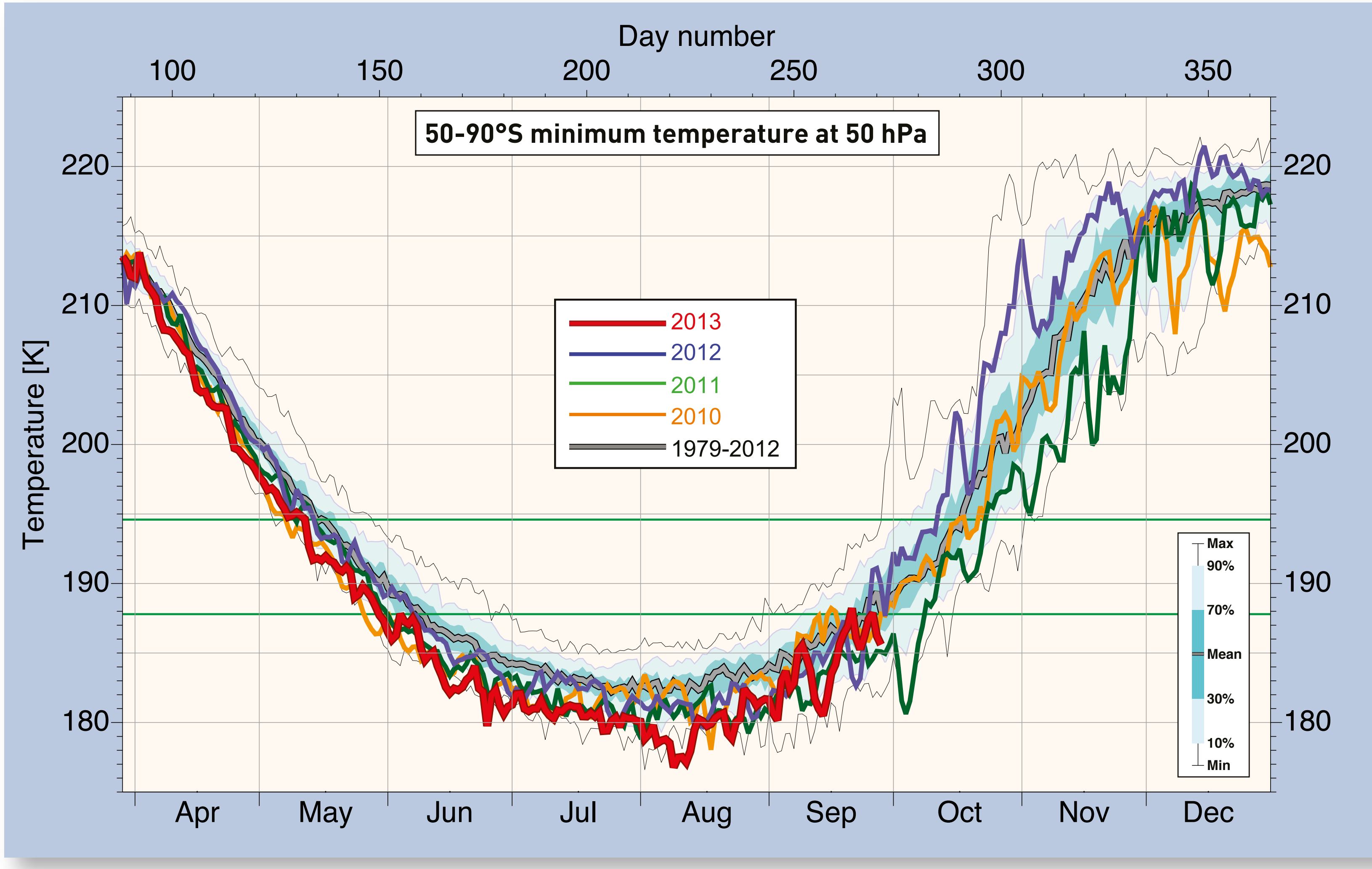


Figure 2. Time series of daily minimum temperatures at the 50 hPa isobaric level south of 50°S. The red curve shows 2013 (until 28 September). The blue line shows 2012, the green line 2011 and the orange line 2010. The average of the 1979-2012 period is shown for comparison in grey. The thin black lines represent the highest and lowest daily minimum temperatures in the 1979-2012 time period. The light blue-green shaded area represents the 10th and 90th percentile values and the dark blue-green shaded area the 30th and 70th percentiles. The two horizontal green lines at 195 and 188 K show the thresholds for formation of PSCs of type I and type II, respectively. The plot is made at WMO based on data downloaded from the Ozonewatch web site at NASA, which are based on data from NOAA/NCEP.

Mean temperatures

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

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

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

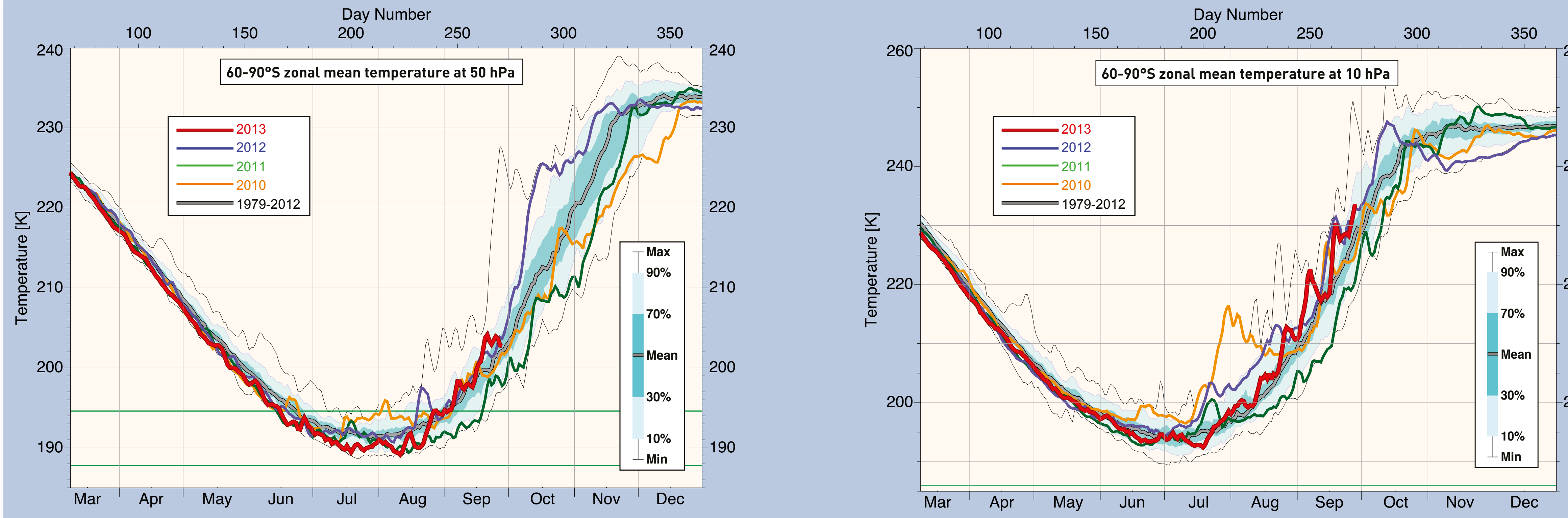


Figure 3. Time series of temperature averaged over the region south of 60°S at the 50 hPa level (left) and at 10 hPa (right). The red curve shows 2013 (until 28 September). The blue, green and orange curves represent 2012, 2011 and 2010, respectively. The average of the 1979-2012 period is shown for comparison in grey. The two thin black lines show the maximum and minimum average temperature for during the 1979-2012 time period for each date. The light blue-green shaded area represents the 10th and 90th percentile values and the dark blue-green shaded area the 30th and 70th percentiles. The plot is made at WMO based on data downloaded from the Ozonewatch web site at NASA, which are based on data from NOAA/NCEP.

PSC Area

Since 21 June, temperatures low enough for nitric acid trihydrate (NAT or PSC type I) formation have covered an area of more than 20 million square kilometres at the 460 K isentropic level (Figure 4). Since the onset of NAT temperatures in early May the NAT area has been close to or above the long-term average. The NAT area reached a peak of 26.3 million km^2 on 19 July. Since early June 2013 the NAT area has been close to or a bit smaller than in 2011 but larger than in 2010 and 2012 on most days. As of 28 September the NAT area is 3.1 million km^2 larger than the long-term mean.

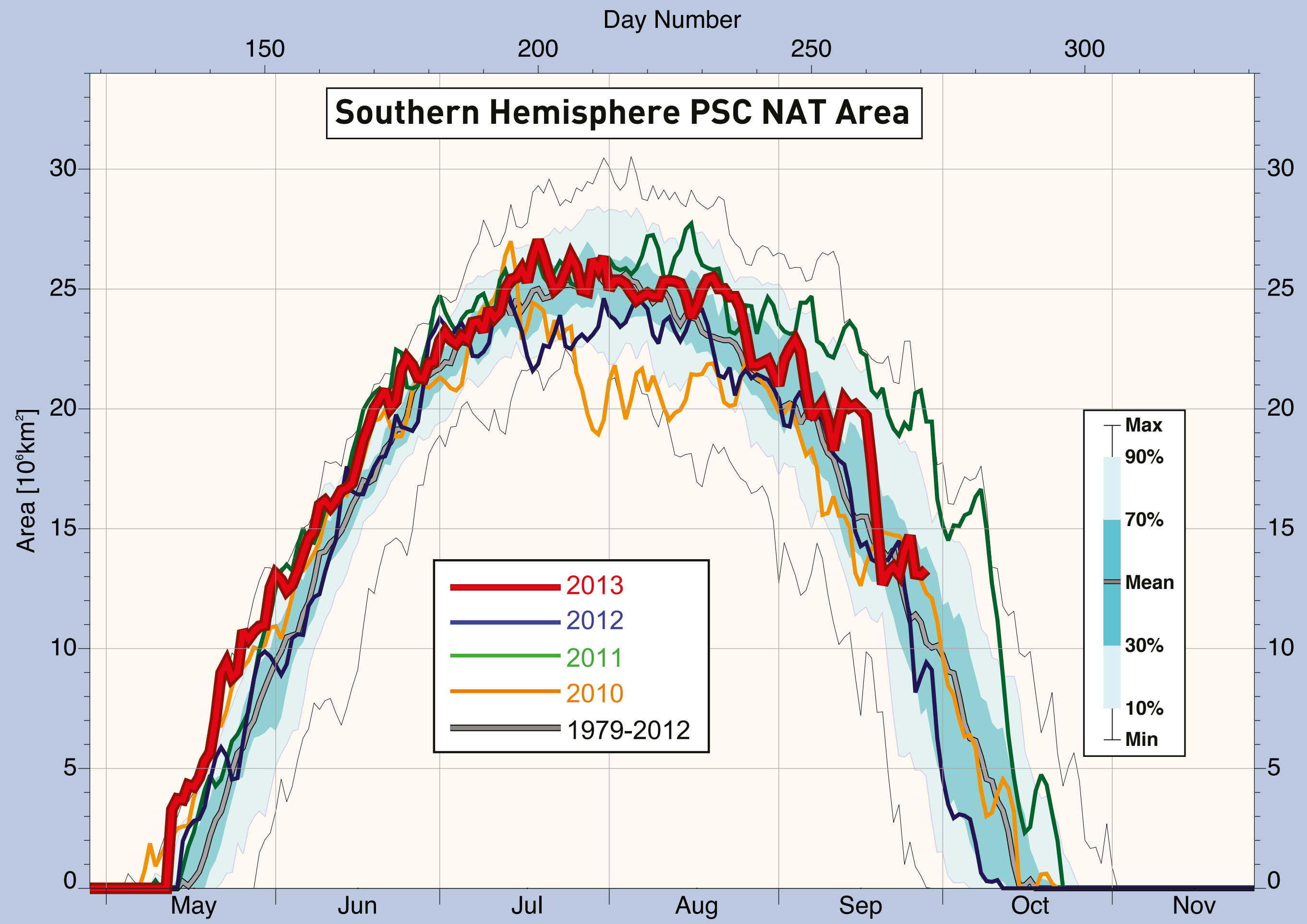


Figure 4. Time series of the area of the region where temperatures are low enough for the formation of nitric acid trihydrate (NAT or PSCs of type I) at the 460 K isentropic level. The red curve shows 2013 (until 28 September). The blue, green and orange curves represent 2012, 2011 and 2010, respectively. The average of the 1979-2012 period is shown for comparison in grey. The two thin black lines show the maximum and minimum PSC area during the 1979-2012 time period for each date. The light blue-green shaded area represents the 10th and 90th percentile values and the dark blue-green shaded area the 30th and 70th percentiles. The plot is made at WMO based on data downloaded from the Ozonewatch web site at NASA, which are based on data from NOAA/NCEP.

PSC Volume

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

The area or volume with temperatures low enough for the existence of PSCs is directly linked to the amount of ozone loss that will occur later in the season, but the degree of ozone loss depends also on other factors, such as the amount of water vapour and HNO_3. In the previous issue of the Bulletin is was argued that the near-average magnitude of the NAT area and the NAT volume in 2013 gave reason to foresee that ozone depletion later in the season would be close to average in comparison to recent years. A forecast based solely on the temperature conditions and hence NAT area and NAT volume indicated that the amount of ozone loss in 2013 would be larger than in 2010 and 2012, and probably similar to that experienced in 2011. The first ozone hole statistics, covering the 21-30 September time period mostly confirms this prediction as described on page 65.

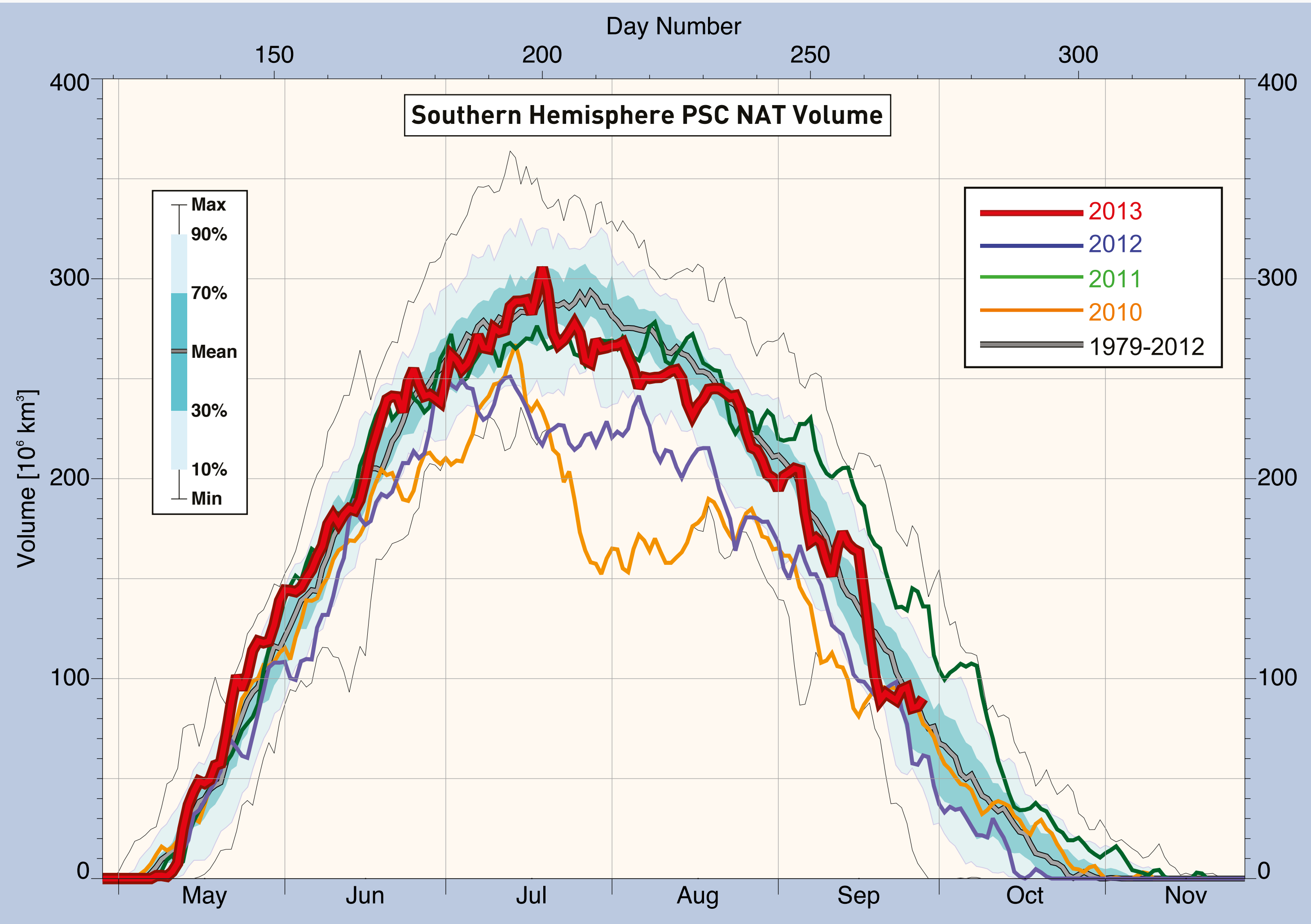


Figure 5. Time series of the volume of the region where temperatures are low enough for the formation of nitric acid trihydrate (NAT or PSCs of type I). The red curve shows 2013 (until 28 September). The blue, green and orange curves represent 2012, 2011 and 2010, respectively. The average of the 1979-2012 period is shown for comparison in grey. The two thin black lines show the maximum and minimum PSC area during the 1979-2012 time period for each date. The light blue-green shaded area represents the 10th and 90th percentile values and the dark blue-green shaded area the 30th and 70th percentiles. The plot is made at WMO based on data downloaded from the Ozonewatch web site at NASA, which are based on data from NOAA/NCEP.

Vortex stability

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

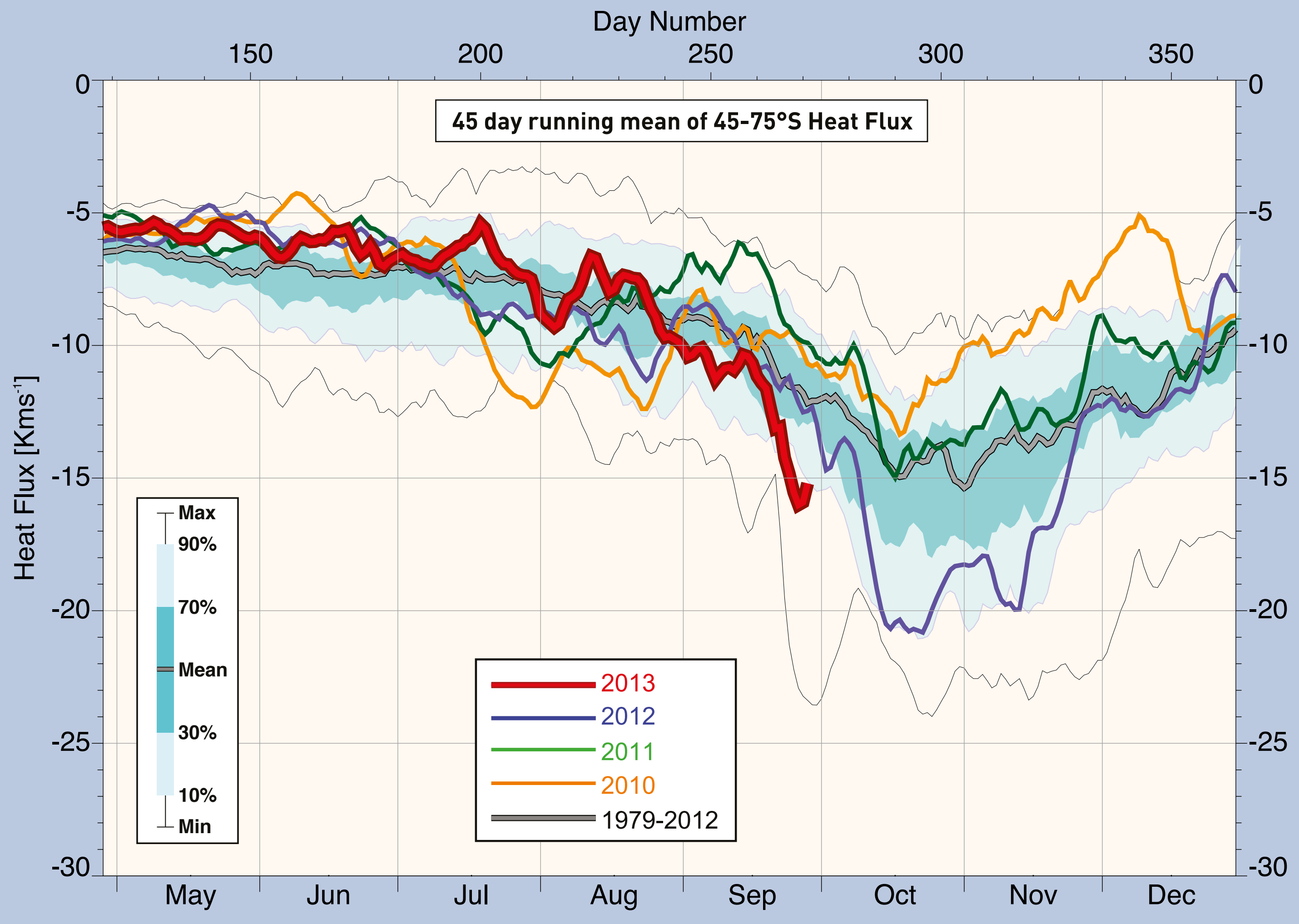


Figure 6. Time series of the meridional heat flux averaged over the 45-75°S region. The red curve shows data for 2013 (updated until 28 September). Please note that a large negative number means a large heat flux. Values closer to zero means a small heat flux. The plot is made at WMO and based on data downloaded from the Ozonewatch web site at NASA, which are based on data from NOAA/NCEP.

Ozone observations

Satellite observations

The sun is now back all over Antarctica and minimum ozone columns were reached at the end of September. Figure 7 shows minimum ozone columns as measured by the GOME-2 instrument on board MetOp in comparison with data for recent years back to 2006 (SCIAMACHY and GOME-2). In early to mid October the minimum columns were above average for the time of the year in comparison to the seven most recent years. Minimum ozone columns are now around 150 DU. The minimum reached around 26 September was just below 120 DU. OMI data from NASA also reached the minimum on 26 September with 118 DU.

Figure 8 shows satellite maps from OMI for 6 October for the years 2006 - 2013. One can see that ozone depletion on 6 October 2013 covers a larger area than in 2012, about the same area as in 2010 but less than in many of the other years show here, such as 2006 and 2011.

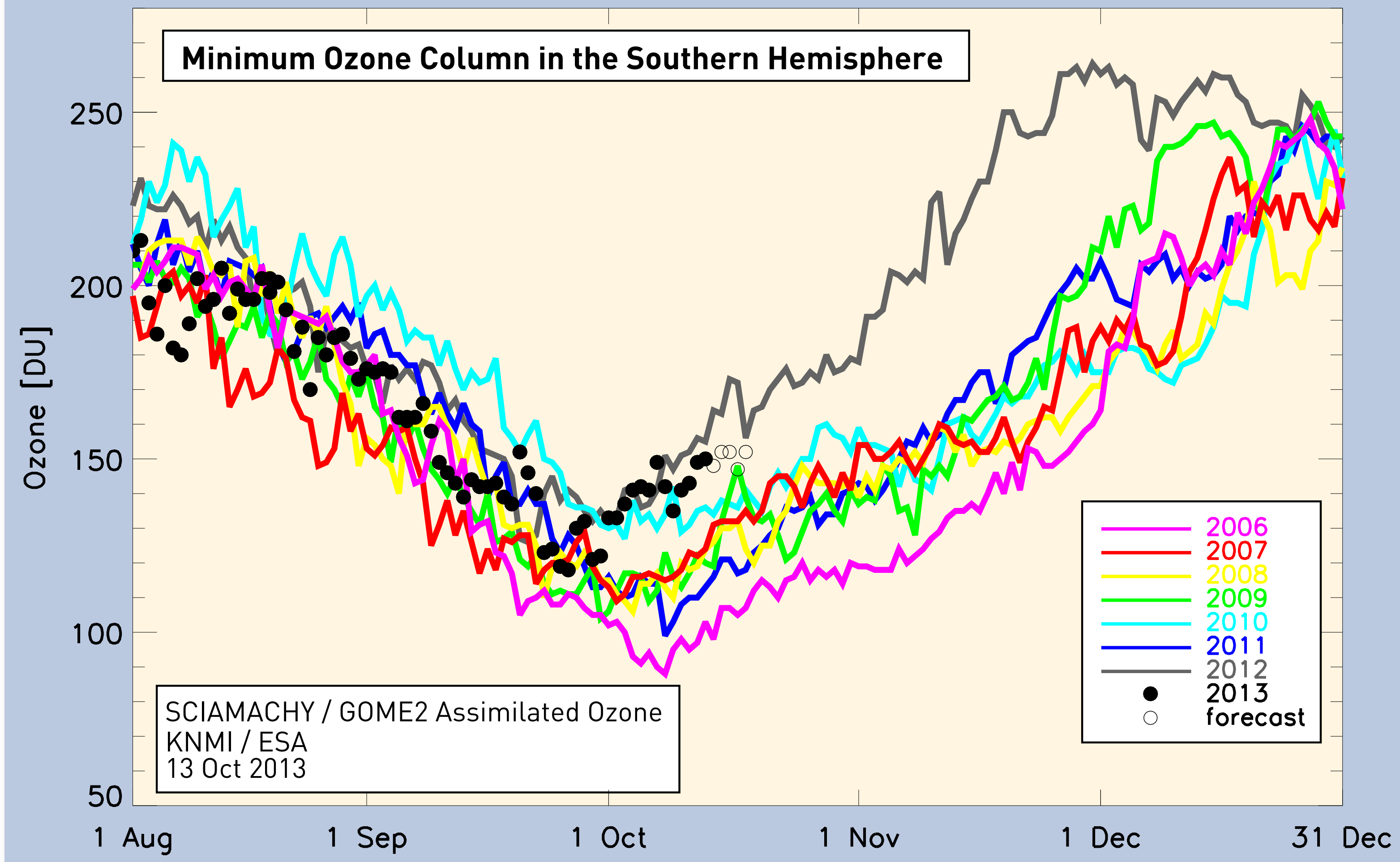


Figure 7. Daily minimum total ozone columns in the Southern Hemisphere as observed by GOME-2, and in the past by SCIAMACHY. The black dots show the GOME-2 observations for 2013 as of 20 August. The data now show minimum ozone columns around 200 DU. The forecast for the next few days show minimum ozone columns around 180 DU (open circles on the plot). The figure is adapted from a plot provided by the Netherlands Meteorological Institute (KNMI).

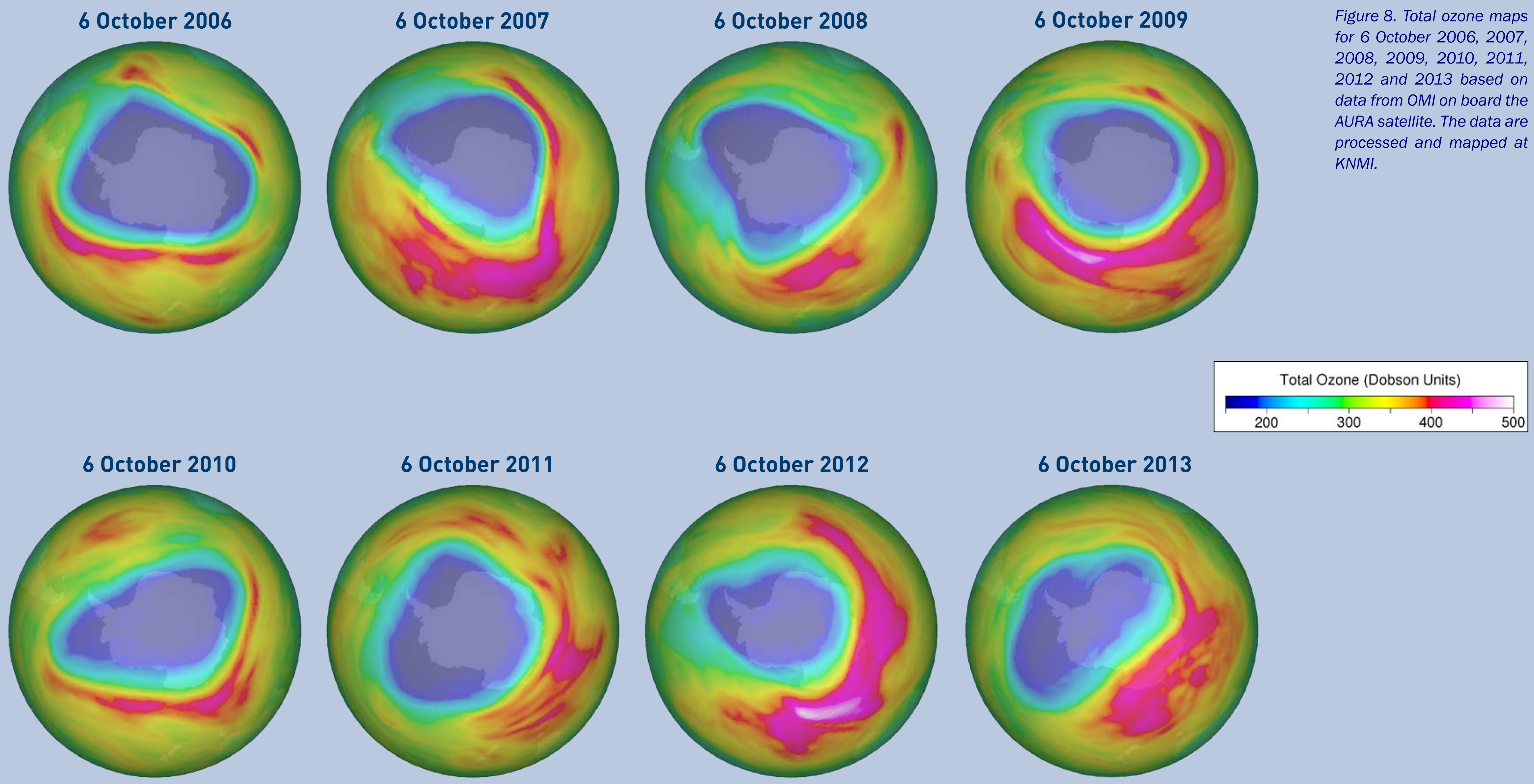


Figure 8. Total ozone maps for 6 October 2006, 2007, 2008, 2009, 2010, 2011, 2012 and 2013 based on data from OMI on board the AURA satellite. The data are processed and mapped at KNMI.

Ground-based and balloon observations

Ozone depletion peaked around 1 October and the Antarctic ozone layer is slowly recovering. Many stations still report substantial ozone loss, depending on where they are located with respect to the vortex edge.

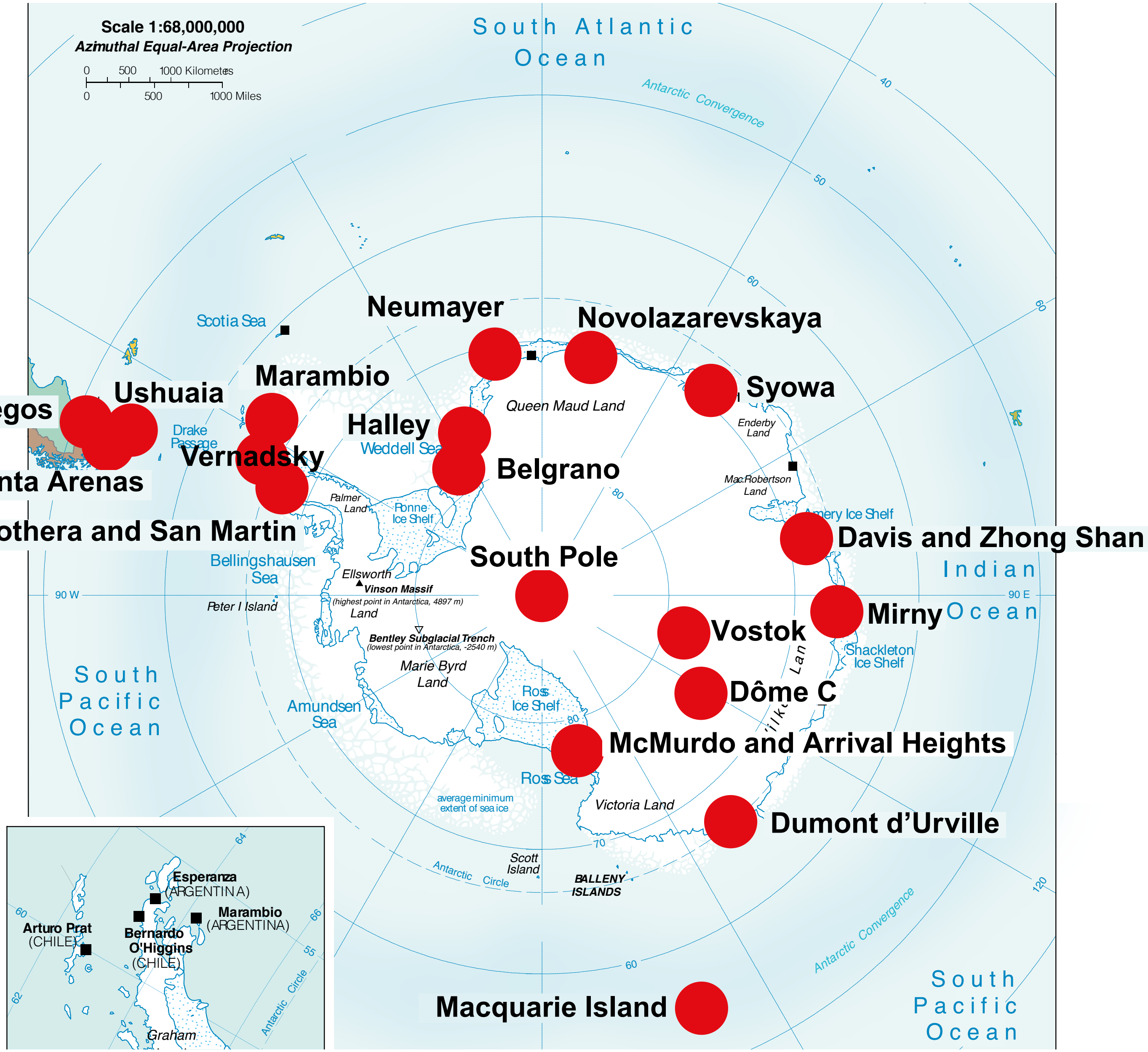
In this issue there is data from Arrival Heights, Belgrano, Davis, Dôme Concordia, Dumont d'Urville, Halley, Macquarie Island, Marambio, Mirny, Neumayer, Novolazarevskaya, Río Gallegos, Rothera, South Pole, Syowa, Ushuaia, Vernadsky, Vostok, and Zhong Shan. This constitutes all the stations carrying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

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

Station Statistics. Lowest ozone values observed at Antarctic stations between 1 Aug and 7 Oct.

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	151 DU (16.9 and 19.9)			23 (24.8 to 5.10) [2]
Belgrano	138 DU [2] (2.10)	131 DU (2.10)	22 DU (2.10)	29 [2] (1.8 to 5.10)
Davis	185 DU [2] (26.9)	190 DU (24.9)		3 [2] (1.8 to 7.10)
Dôme C	170 DU (8.8)			13 (2.8 to 30.9)
Dumont d'Urville	228 DU (6.9)			0
Halley	127 DU (23.9) and 106 DU[4] (23.9)			59 (3.8 to 10.10)[4]
Marambio	163 DU (15.9, 17.9, 30.9)	162 DU (28.9)	41 DU (25.9)	36 (10.8 to 6.10)
Mirny	213 DU (30.8)			3 (1.8 to 6.10)
Neumayer	153 DU [2] (22.9)	154 DU (23.9)	21 DU (1.10)	31 (2.8 to 3.10) [2]
Novolazarevskaya	157 DU (6.10)			36 (15.8 to 6.10)
Rothera	124 DU [4] (29.9)			52 (1.8 to 10.10) [4]
South Pole	135 DU[2] (30.9)	124DU (29.9)	24 DU (29.9)	13 [2,3] (24.9 to 6.10)
Syowa	161 DU (25.9)	176 DU (23.9)	36 DU (27.9)	17 (15.8 to 10.10)
Ushuaia	214 DU (16.9)	194 DU (17.9)	65 DU (17.9)	3 (1.8 to 30.9) [1]
Vernadsky	152 DU (15.9)			47 (1.8 to 11.10)
Vostok	149 DU (28.9)			16 (6.9 to 30.9)
Zhong Shan	178 DU (29.8)			6 (1.8 to 30.9)
Minimum	**124 DU**	**124 DU**	**21 DU**	

[1] From ozonesonde data.
[2] From OMI overpass data.
[3] First measurement after the polar night starting on 24 September.
[4] From SAOZ NRT data.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South Atlantic Ocean
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Syowa
Marambio
Ushuaia
Río Gallegos
Drake Passage
Halley
Weddell Sea
Queen Maud Land
Enderby Land
Vernadsky
Belgrano
Punta Arenas
Mac.Robertson Land
Palmer Land
Ronne Ice Shelf
Amery Ice Shelf
Rothera and San Martin
Davis and Zhong Shan
Bellingshausen Sea
South Pole
Indian Ocean
Ellsworth Land
Vinson Massif
(highest point in Antarctica, 4897 m)
Peter I Island
90 W
90 E
Mirny
Vostok
Bentley Subglacial Trench
(lowest point in Antarctica, -2540 m)
Shackleton Ice Shelf
Marie Byrd Land
South Pacific Ocean
Ross Ice Shelf
Dôme C
Amundsen Sea
McMurdo and Arrival Heights
Ross Sea
average minimum extent of sea ice
Victoria Land
Dumont d'Urville
Scott Island
Antarctic Circle
BALLENY ISLANDS
Esperanza (ARGENTINA)
Marambio (ARGENTINA)
Arturo Prat (CHILE)
Bernardo O'Higgins (CHILE)
Graham
Macquarie Island
South Pacific Ocean

Arrival Heights

The NIWA Observatory at Arrival Heights. Photo: NIWA.

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

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

At Arrival Heights there are also a UV/Visible spectrometer and an FTIR instrument. A suite of species are measured with these instruments and data for 2013 together with data from earlier years are shown on Page 16 (**Figure 11**). See the figure caption for more details on those measurements.

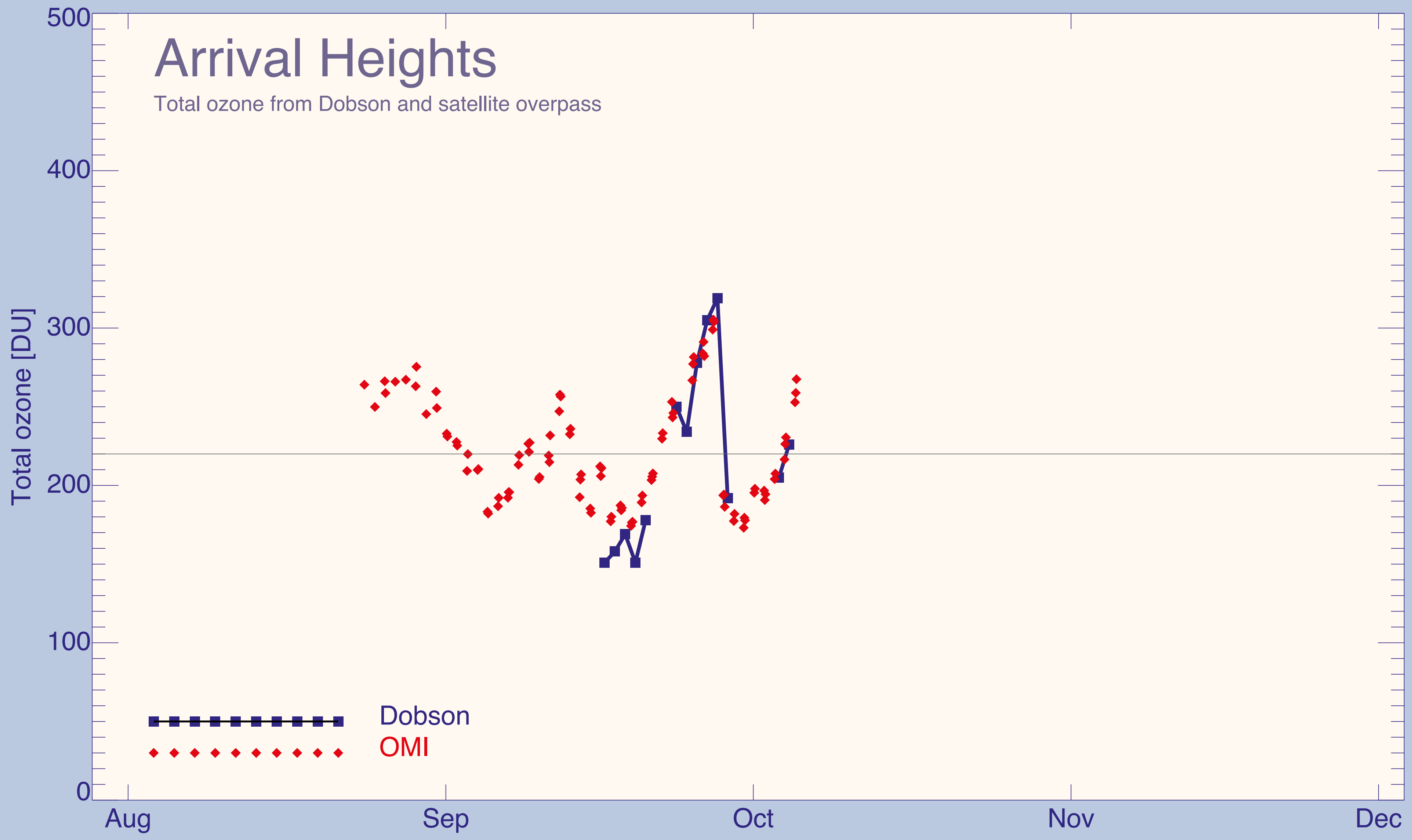


Figure 9. Time series of total ozone from the Arrival Heights Dobson spectrophotometer and satellite overpasses by OMI on board the AURA satellite. Dobson data have been provided by New Zealand's National Institute for Water and Air Research (NIWA). Satellite overpass data have been downloaded from the TEMIS web site. The plot is produced at WMO.

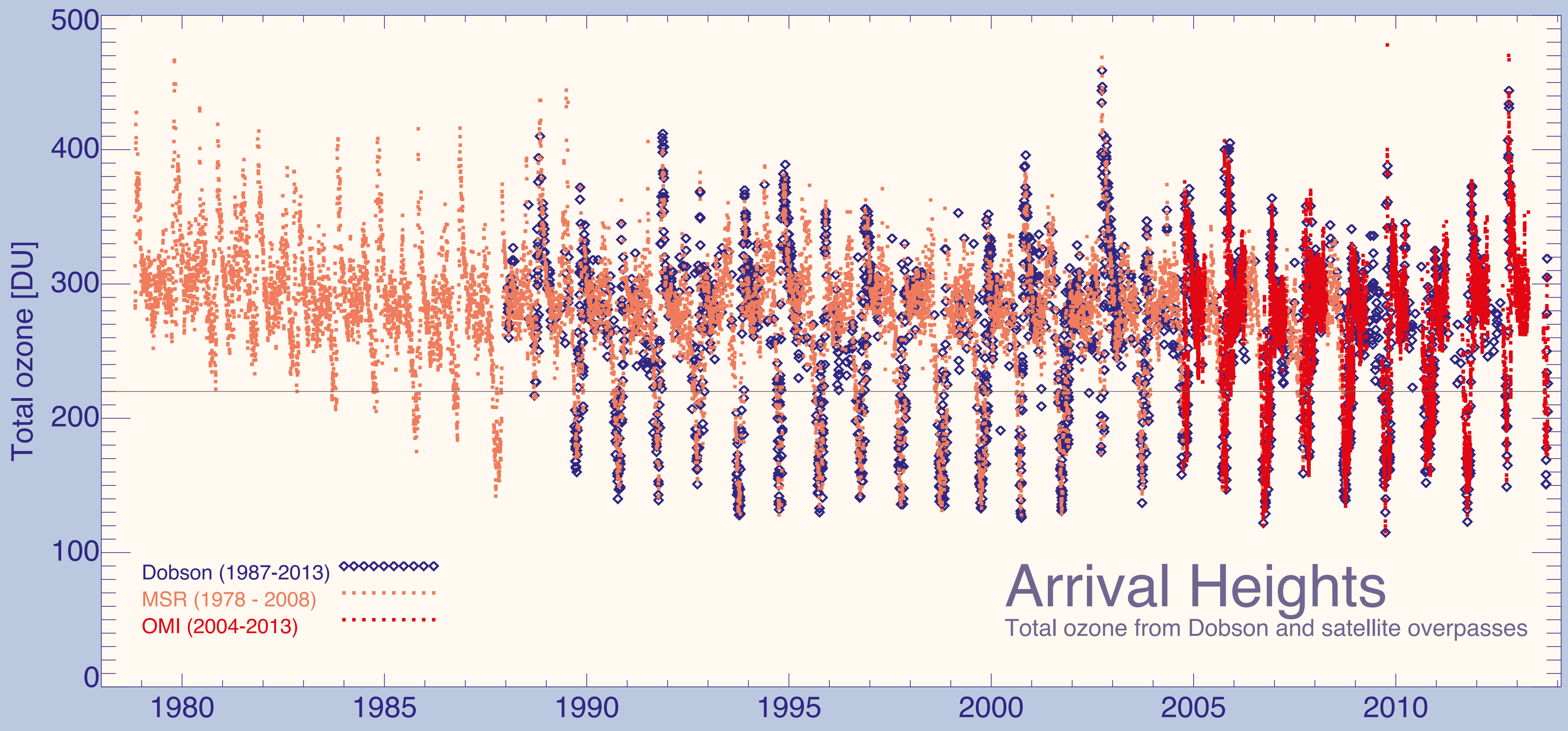


Figure 10. Time series of total ozone from the Arrival Heights Dobson spectrophotometer and satellite overpasses by OMI on board the AURA satellite (2004 - present) and satellite overpass data from the Multi-Sensor Reanalysis data set (1978 - 2008).

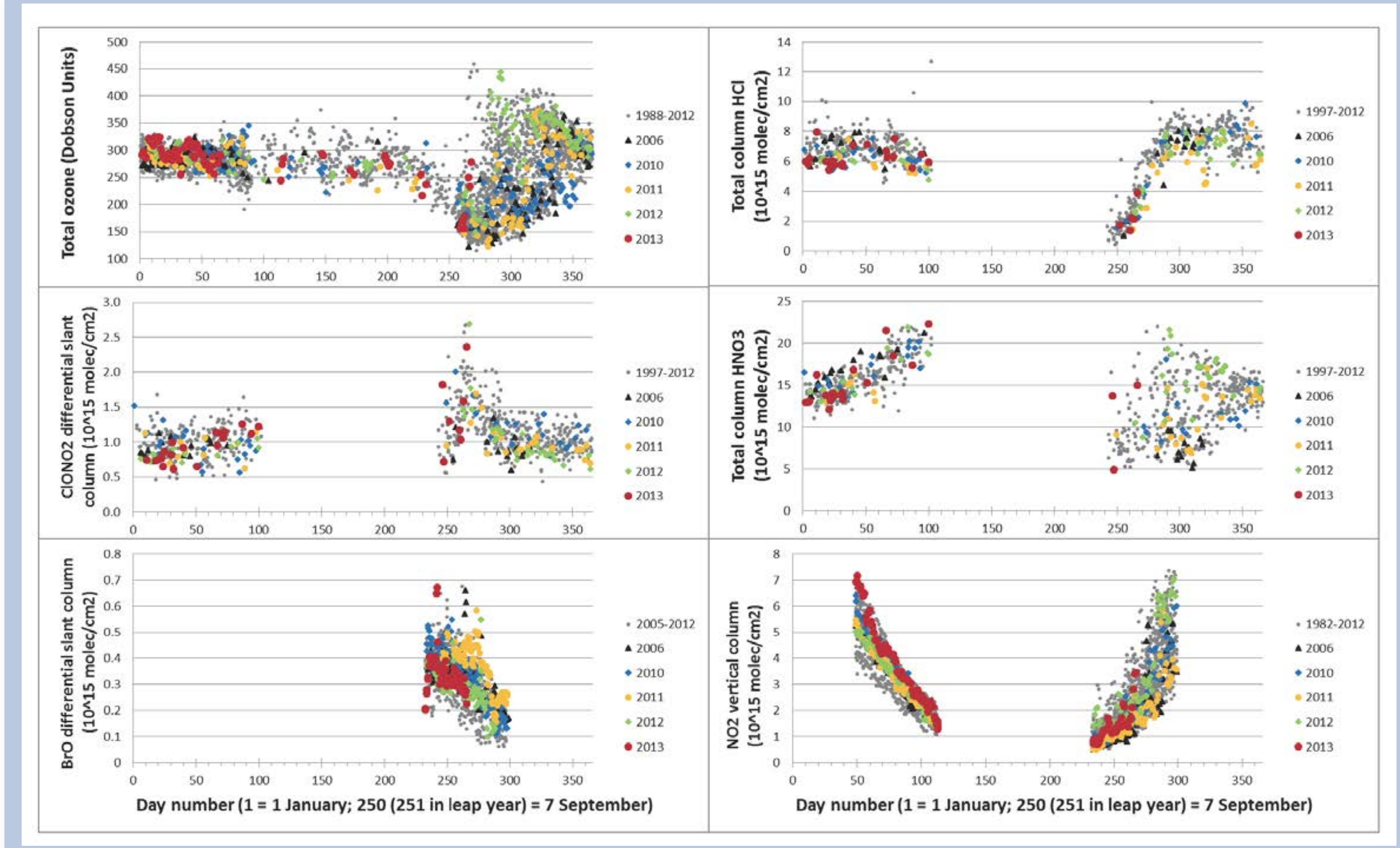


Figure 11. Time series of various parameters relevant to ozone depletion from ground-based instruments at Arrival Heights (77.8°S, 166.7°E): Total ozone measurements are from a Dobson spectrophotometer; HCl, $ClONO_2$ and HNO_3 measurements are from a Bruker Fourier Transform spectrometer; BrO and NO_2 measurements are from a zenith viewing DOAS spectrometer. The graphs show selected recent years; 2006, 2010, 2011, 2012 and 2013. The small grey dots show all the data from the beginning of the time series until 2012 in order to show the range of values for each parameter. The upper left panel shows total ozone. The middle panel to left shows the differential slant column of chlorine nitrate ($ClONO_2$), one of the reservoir gases that liberate active chlorine through reactions on PSCs. The lower left panel shows the differential slant column of bromine monoxide (BrO). This molecule takes part in one the catalytic cycles that destroy ozone. The upper right panel shows the total column of hydrochloric acid (HCl), also a reservoir gas that liberates active chlorine by reactions on PSCs. One can see that the HCl column is very low when the measurements start up around day 250 (7 September). As the stratosphere heats up after the winter and the PSCs evaporate the amount of HCl recovers. The middle panel to the right shows the total column of nitric acid (HNO_3). When the stratosphere cools and PSCs start to form in May, the amount of HNO_3 in the gas phase goes down. As the stratosphere heats up again in the spring the PSCs evaporate and HNO_3 goes back into the gas phase. The lower panel to the right shows the vertical column of NO_2. One can see the annual cycle with a maximum of NO_2 during summer and a gradual decline as the sun descends in the sky. After the polar night NO_2 comes gradually back. The Dobson measurements are carried out within WMO's Global Atmosphere Watch Programme and the other measurements shown here are done as part of NDACC (Network for the Detection of Atmospheric Composition Change).

Ozonesonde launch at Belgrano.

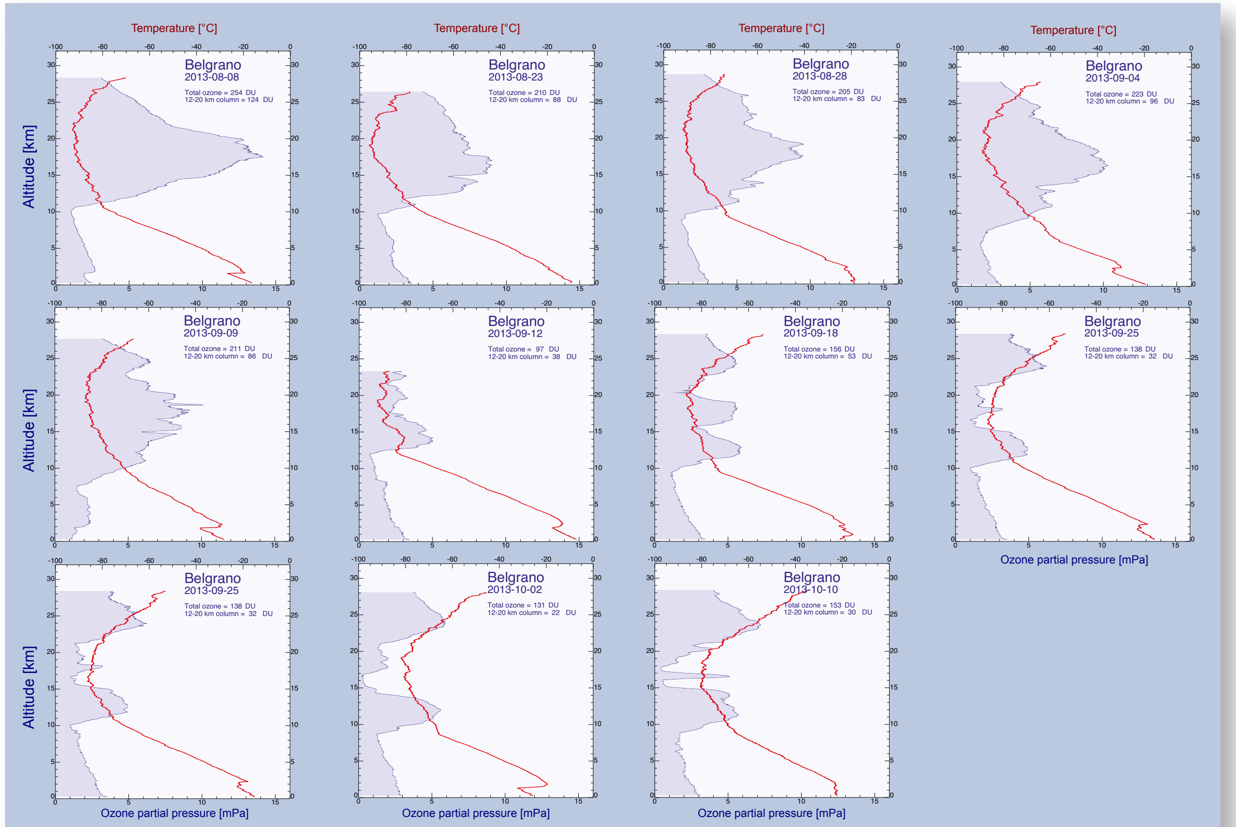


Figure 12. Ozonesonde profiles measured at Belgrano from 8 August until 10 October 2013.

The vertical distribution of ozone is measured at the Argentine GAW station Belgrano (77.8740°S, 34.6264°W, 202 masl) with electrochemical ozonesondes. Two sondes were launched in July, three in August six in September, and two so far in October. The profiles measured in August, September and October are shown in **Figure 12**. The profiles measured on 10 and 24 July are quite similar to the one of 8 August. The profiles from 12 September onward show clear signs of significant ozone depletion. The 2 October profile has a 12-20 km partial ozone column of 22 DU, one of the lowest detected at any station in Antarctica so far this year. The 10 October profile also shows significant ozone depletion in the 15-20 km altitude range. In **Figure 13** total ozone derived from ozonesondes is compared to total ozone from OMI overpass data. Satellite data do not start until 25 August after the polar night. On 25 and 26 August total ozone was less than 220 DU. Then the column rose to approx. 250 DU before making a dive, crossing the 220 DU threshold on 10 September. Since then and until now (6 October) total ozone has remained well below the 220 DU threshold. Total ozone has been below the 220 threshold on 29 days between 25 August and 6 October.

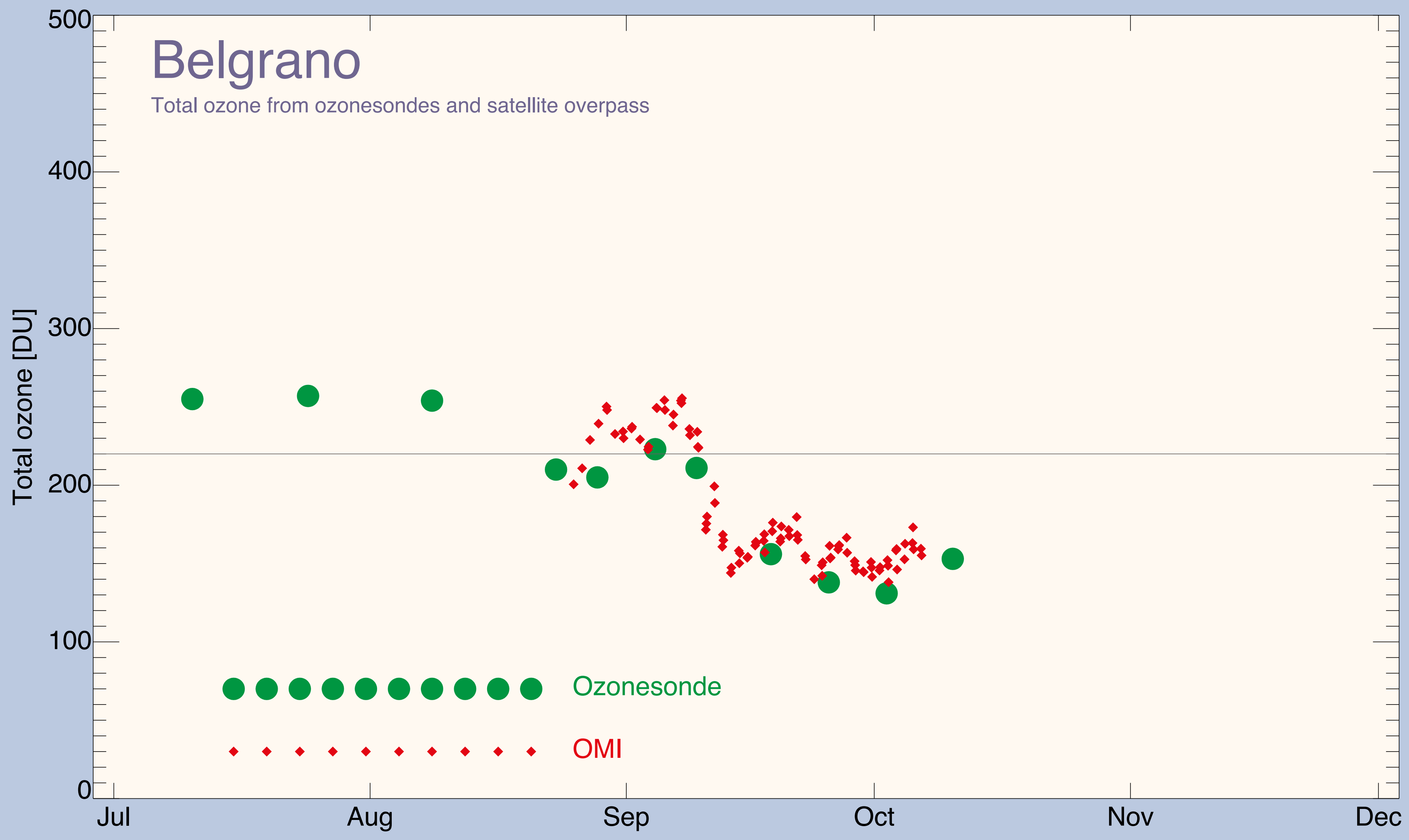


Figure 13. Total ozone columns from soundings at Belgrano (green circles). The red diamonds show data from the OMI satellite instrument. The plot is made at WMO based on sonde data from INTA and the Meteorological Service of Argentina. The OMI overpass data have been downloaded from the TEMIS web page at KNMI.

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

From the Australian GAW site Davis (68.5767°S, 77.9695°E, 15 masl) ozonesondes are launched weekly. The measurement programme is run in partnership by the Australian Bureau of Meteorology and the Australian Antarctic Division. **Figure 14** shows ozone profiles measured between 13 August and 8 October. The profile of 24 September displays a large ozone "bite-out" between 17 and 20 km altitude and gives a total column of 190 DU. This is in clear contrast to the 17 September profile, which shows a total column of 362 DU. On 1 October one can a again see a large "bite-out" in the vertical ozone distribution, and at 15-16 km altitude ozone depletion is even more advanced than on 24 September. However, there is a layer of ozone rich air around 17-18 km and the total column estimated from

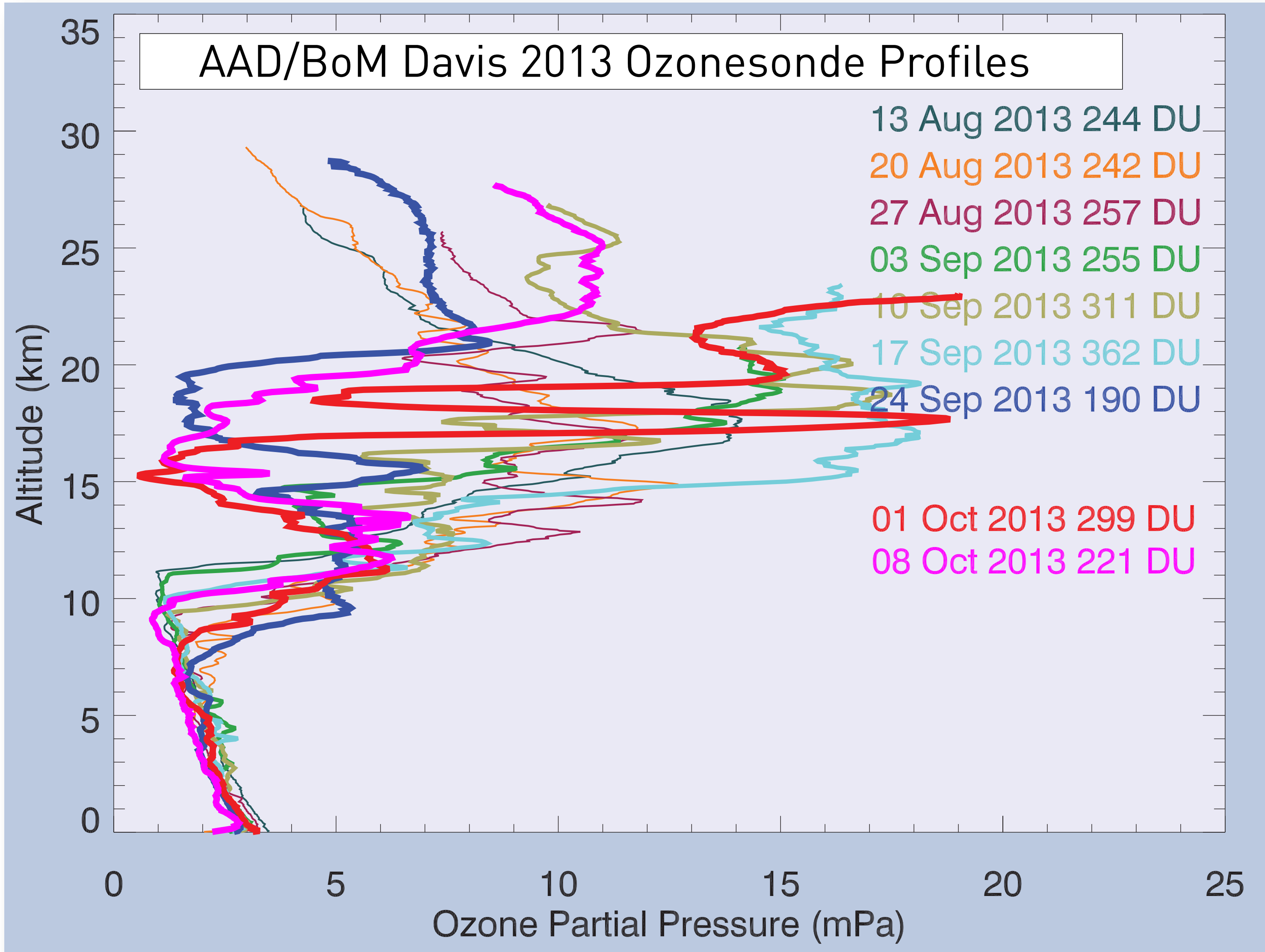


Figure 14. Ozonesonde profiles measured at Davis between 13 August and 24 September 2013.

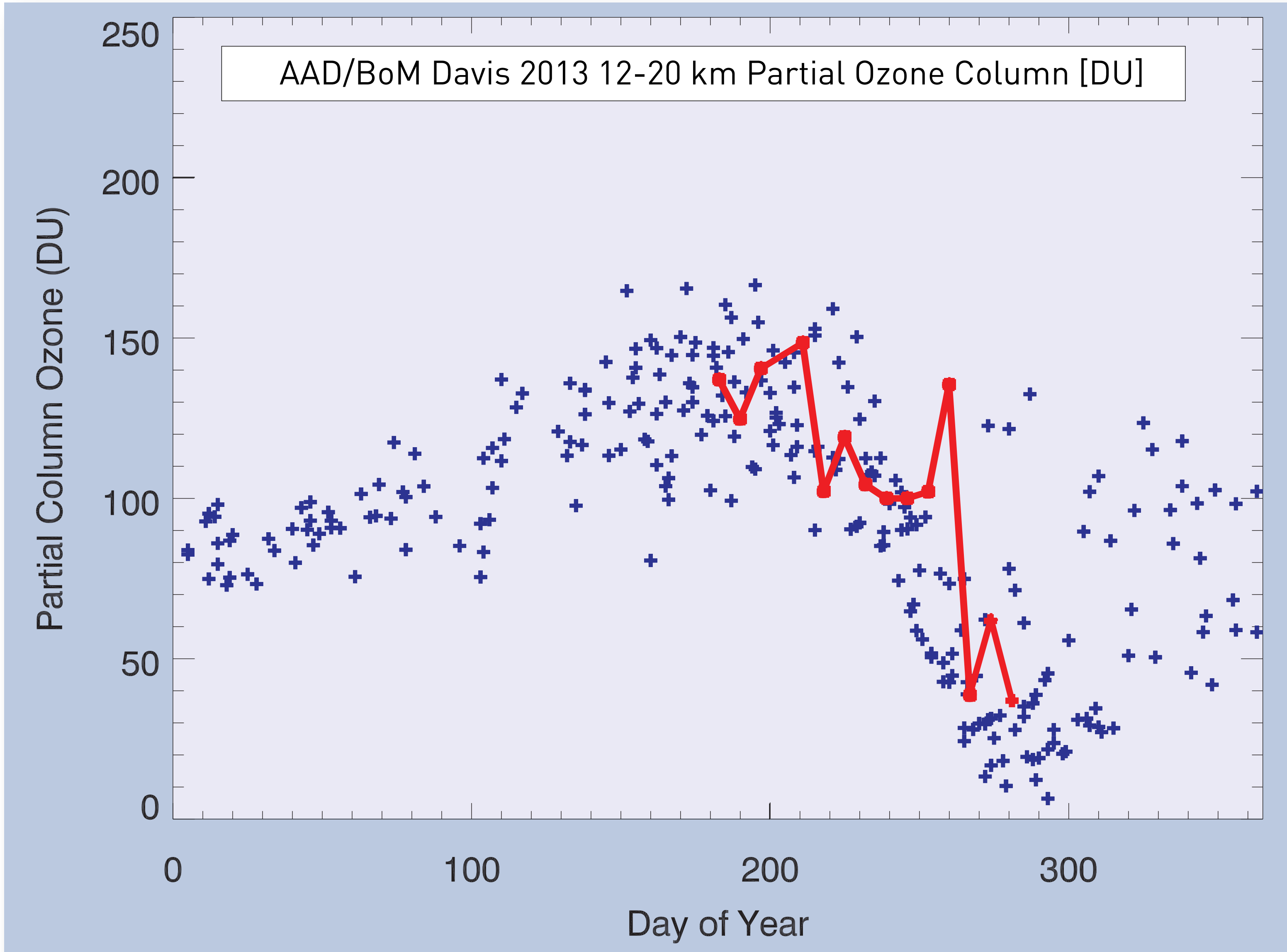


Figure 15. Partial ozone columns between 12 and 20 km from soundings at Davis. The thick red curve shows the data from 2013. The blue crosses show all data from 2003-2012. The plot has been provided by Matt Tully, Australian Bureau of Meteorology.

the sonde profile is 299 DU. The ozone profile observed on 8 October has the typical signature of an ozone hole profile with a large "bite-out" from 15-19 km. However, the layers above are quite rich in ozone so that the total column is just above the 220 DU threshold. Partial ozone columns from 12-20 km are shown in **Figure 15**. This plot shows the development in 2013 (thick red curve) in comparison to earlier years (2003-2012). It shows that the development so far in 2013 follows the pattern of earlier years with the exception of the ozone rich profile of 17 September. The rate of decrease in the 12 to 20 km partial column between mid-August and mid-October is comparable to previous years.

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

The development of total ozone above Davis, as observed by the OMI instrument on board the AURA satellite is shown in **Figure 17** together with total ozone calculated from ozonesonde profiles.

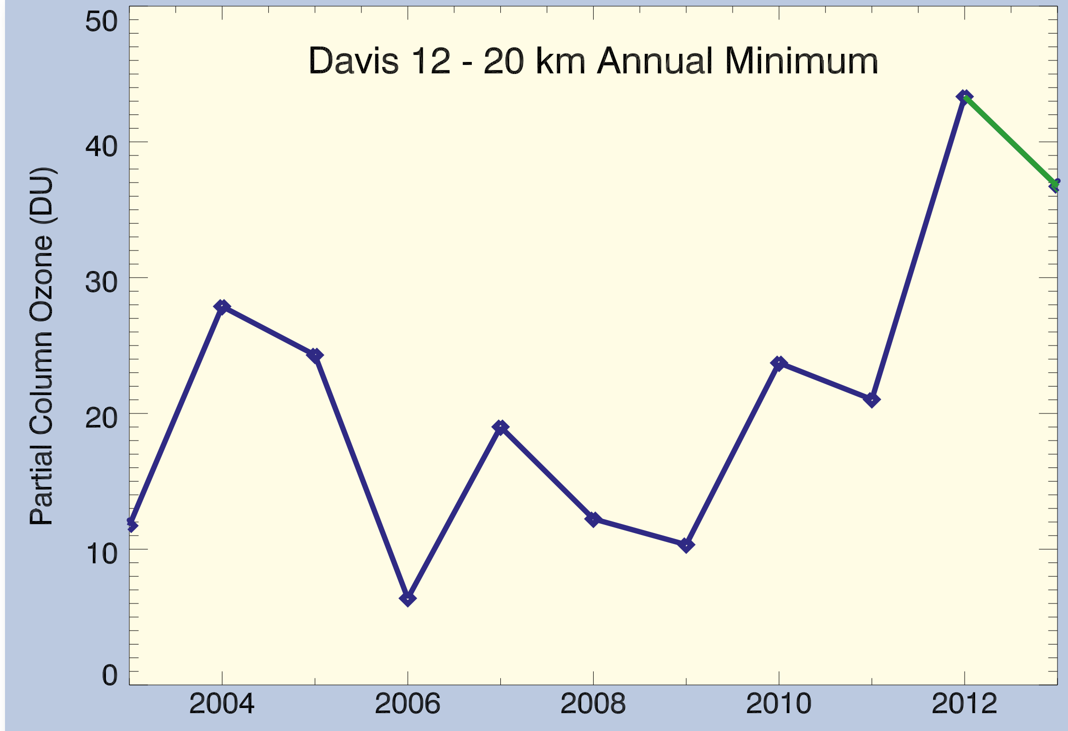


Figure 16.Seasonal minima of the 12-20 km partial ozone profile. The plot has been provided by the Australian Bureau of Meteorology.

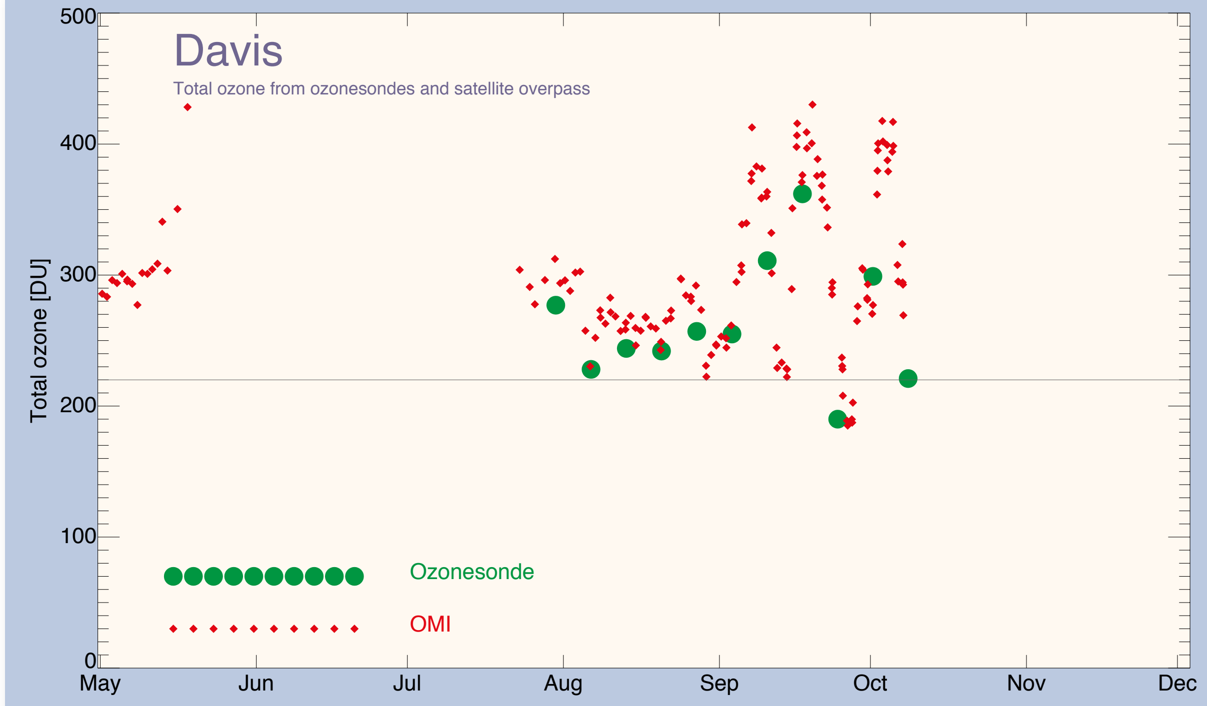


Figure 17.Total ozone columns from soundings at Davis (green circles). The red diamonds show data from the OMI satellite instrument. The plot is made at WMO based on sonde data from the Australian Bureau of Meteorology and the Australian Antarctic Division. The OMI overpass data have been downloaded from the TEMIS web page at KNMI.

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

Total ozone is measured with a SAOZ spectrometer at the French/Italian GAW/NDACC station at Dôme Concordia (75.0998870°S, 123.333487°E, 3250 masl) on the Antarctic ice cap. The measurements started up again on 2 August after the polar night. During August total ozone varied between 170 and 312 DU. From 1 to 26 September total ozone dropped from 250 DU to 199 DU.

So far this season total ozone has been below the 220 DU threshold on eight days. From 7 September onward daily average ozone has not dipped below 220 DU. Figure 18 on the next page shows the 2013 measurements in comparison to earlier years.

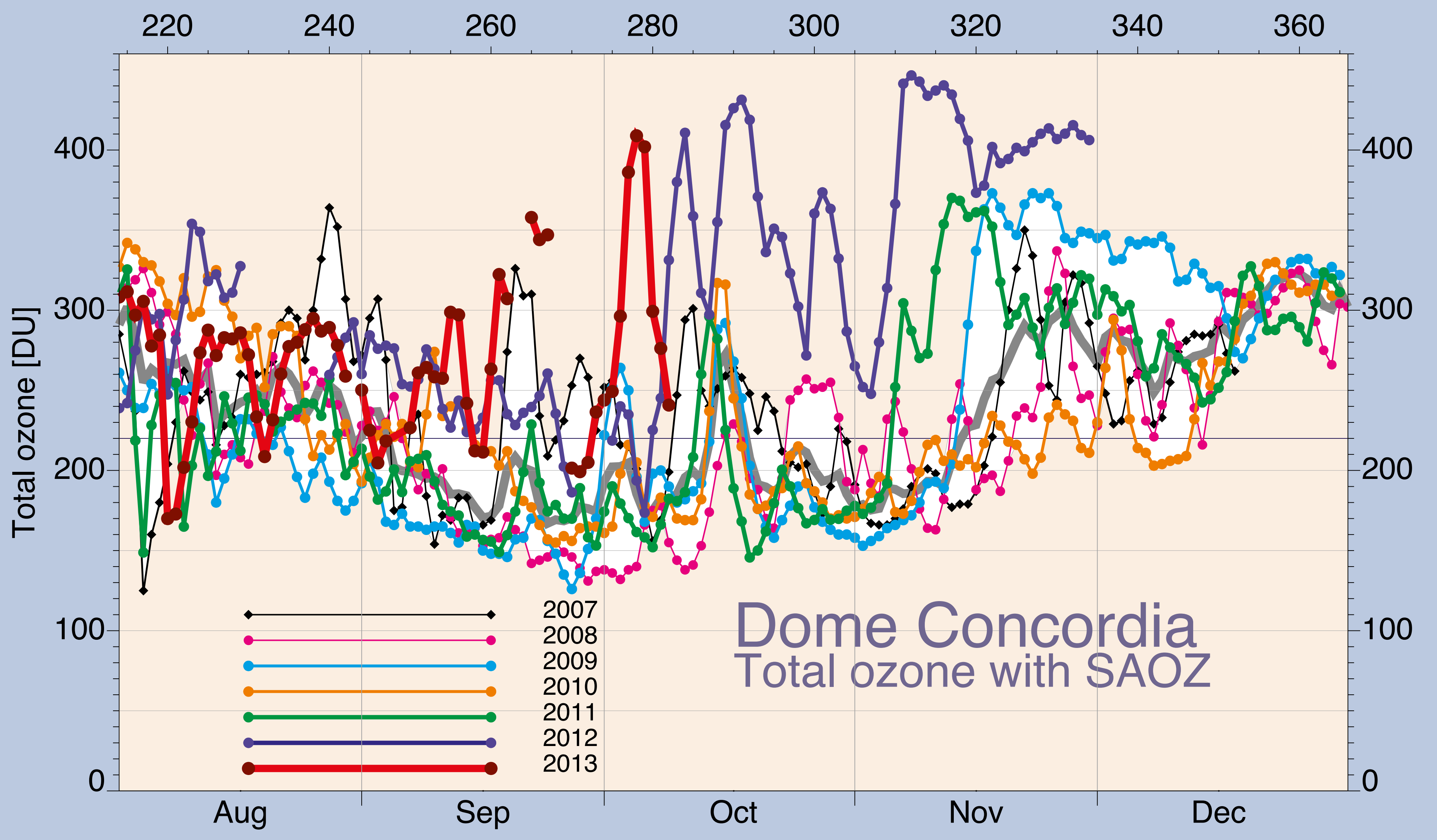


Figure 18. Time series of total ozone measured with the SAOZ spectrometer at Dôme Concordia on the Antarctic ice cap until 9 October. The thick grey curve is the 2007-2010 average. The white shaded area gives the range from minimum to maximum values for each day during the 2007-2010 time period. The measurements are carried out in the framework of the Network for the Detection of Atmospheric Composition Change (NDACC). The plot is produced at WMO based on data downloaded from the SAOZ web site at CNRS.

Dumont d'Urville

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 until 5 October daily averaged total ozone has varied between 228 DU and 399 DU.

Figure 19 shows the progression of daily averaged ozone. The most striking is the large day-to-day variability, as the polar vortex moves back and forth above the station. The daily average value is calculated as the mean of the total ozone values at sunrise and sunset. On some days the difference between the sunrise and sunset values can reach several tens of DU. It might also happen that the station is inside the ozone hole at sunrise and outside at sunset or vice versa, but the daily mean is above the 220 DU threshold. This has happened on two days so far this season.

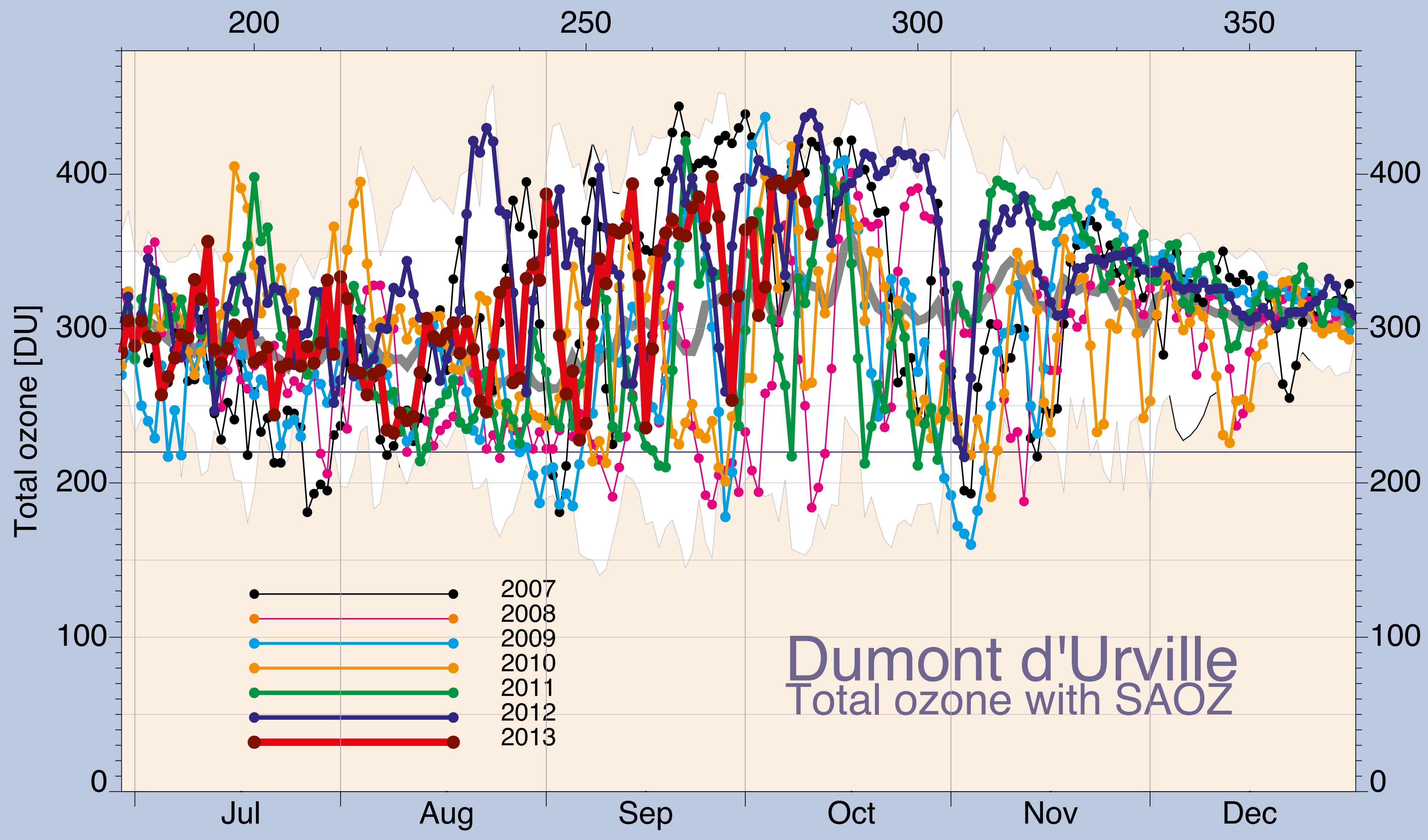
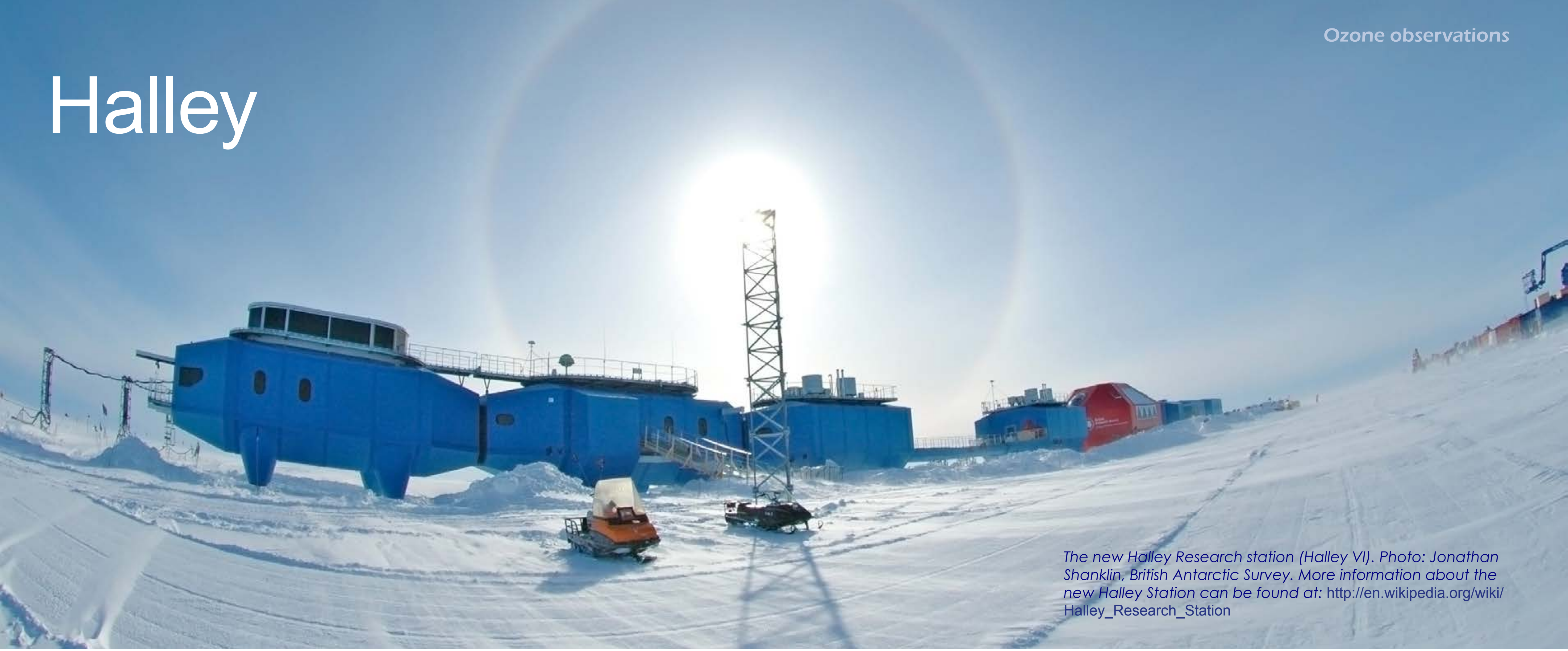


Figure 19. Time series of daily mean total ozone in 2013, in comparison to earlier years, as measured by a SAOZ spectrometer at Dumont d'Urville. The plot is updated until 11 October 2013. The plot is produced at WMO based on data downloaded from the SAOZ web site at CNRS.

Halley



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

Total ozone has been measured with a Dobson spectrophotometer at the UK GAW station Halley (75.6052°S, 26.2100°W, 33 masl) since 1957. Due to its high latitude the measurement season starts in late August. In 2013 the measurements started up again on 27 August after the polar winter with a total ozone value of 188 DU. From then until 10 October, total ozone has been below the 220 DU threshold on all days except two. **Figure 20** shows the total ozone time series at Halley for the most recent years together with long term statistics (1957-2012). On 23 September total ozone dropped to 127 DU, the lowest value observed at any station so far this year with a Dobson spectrophotometer. In early 2013 a SAOZ spectrometer was put into service at Halley. The SAOZ measures the scattered light from zenith around sunrise and sunset. This allows for measurements at higher solar zenith angles and this leads to a longer measurement season with 24 more days in the autumn and starting 24 days earlier in the spring. The SAOZ also measures the total column of NO_2. During the time period when there are NAT PSCs, NO_2 is removed from the gas phase and bound up in the PSCs as HNO_3.

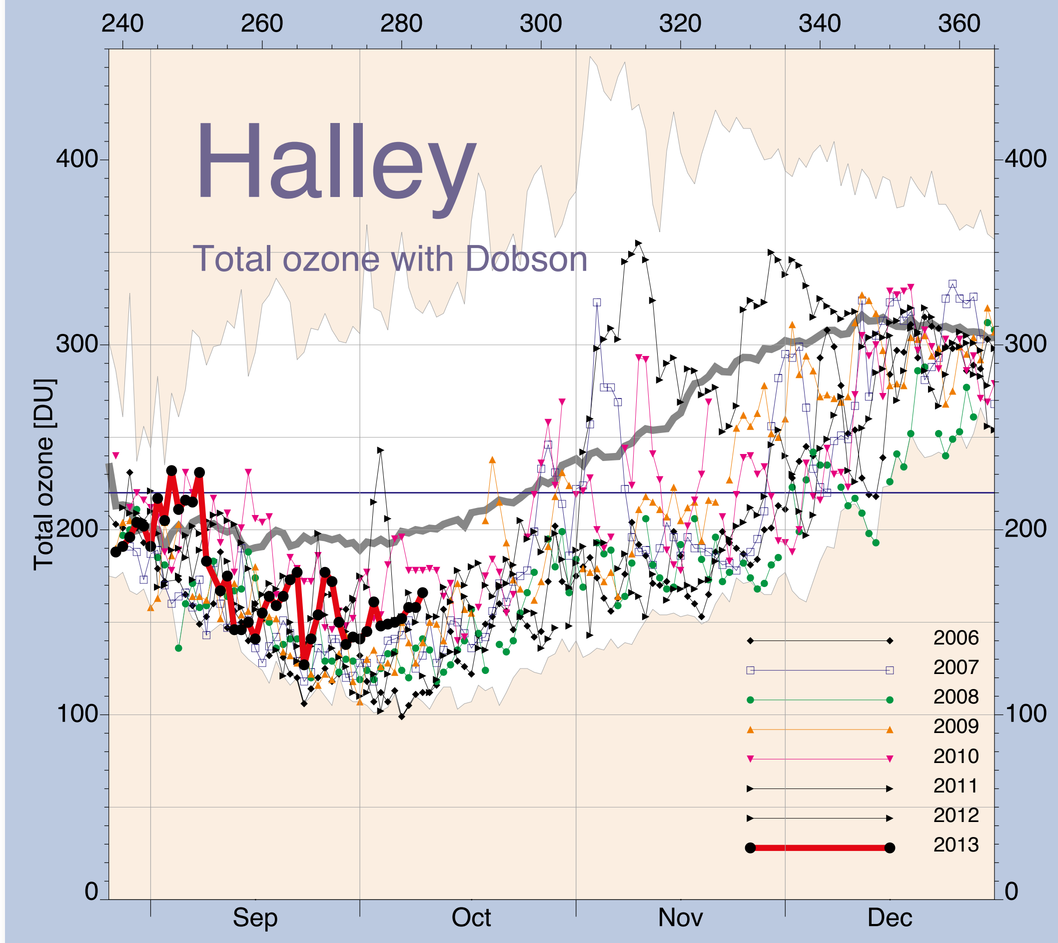


Figure 20. Time series of daily mean total ozone in 2013, as measured by a Dobson spectrophotometer at Halley. The thick grey line shows the average ozone column for the 1957-2012 time period. The white shaded area shows historical maxima and minima calculated for the 1957-2012 time period. The plot is produced at WMO based on data downloaded from WOUDC and from Jonathan Shanklin's Antarctic web site at British Antarctic Survey.

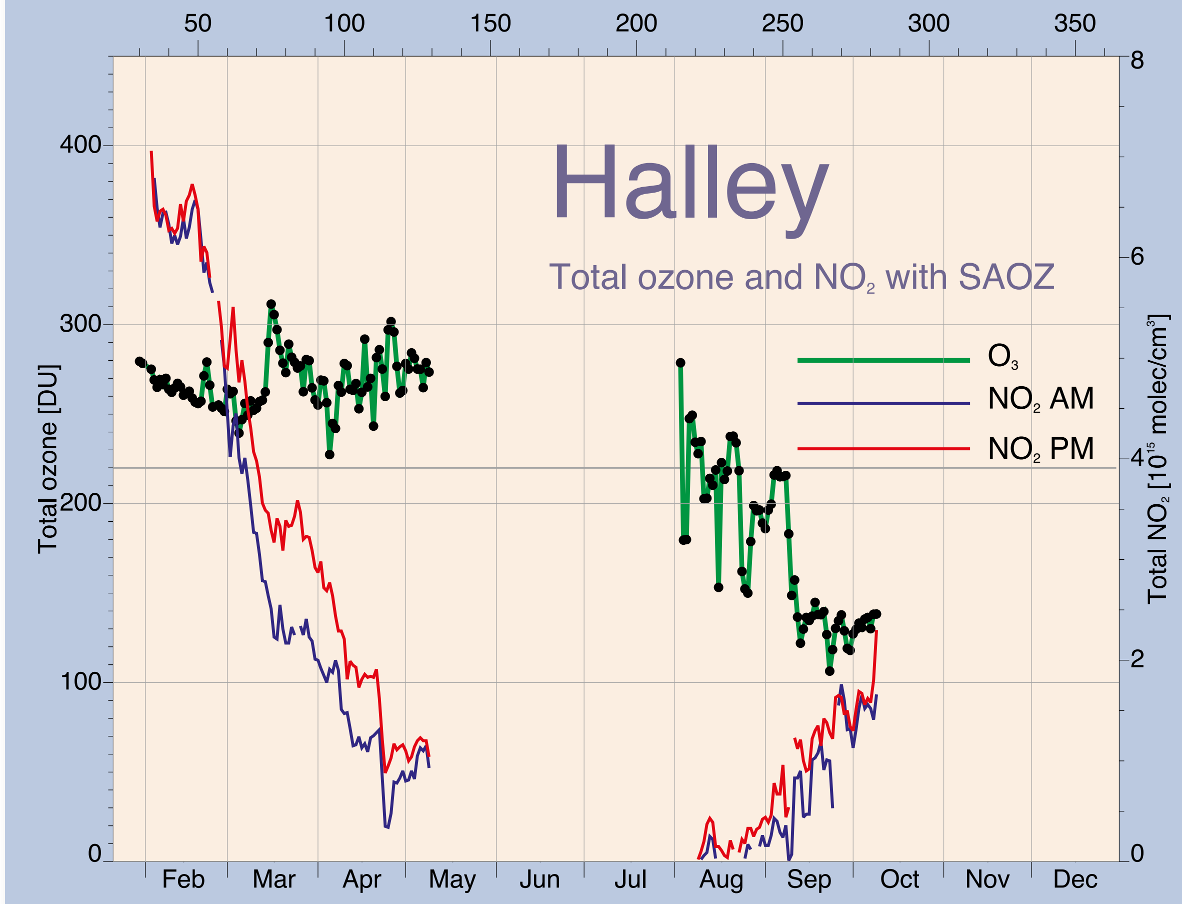


Figure 21. Time series of total ozone and NO_2 in 2013, as measured by a newly deployed SAOZ spectrometer at Halley starting in late January 2013. The green line shows the daily average ozone column. The blue line shows the NO_2 column at sunrise and the red line shows total NO_2 at sunset. It can be seen that in August the NO_2 column is very small, showing that the stratosphere above Halley is denoxified. During September the NO_2 column has increased gradually and in early October the increase gets more rapid. The plot is produced at WMO based on data downloaded from Jonathan Shanklin's Antarctic web site at British Antarctic Survey.

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

The GAW/NDACC station Macquarie Island is located at 54.499531°S and 158.937170°E. It is about 2000 km from the southeast coast of Australia and about 1500 km from the Antarctic coastline. Dobson observations of total ozone have been made there since 1957.

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

Dobson observations at Macquarie can be seen in comparison with OMI overpass data in **Figure 23**.

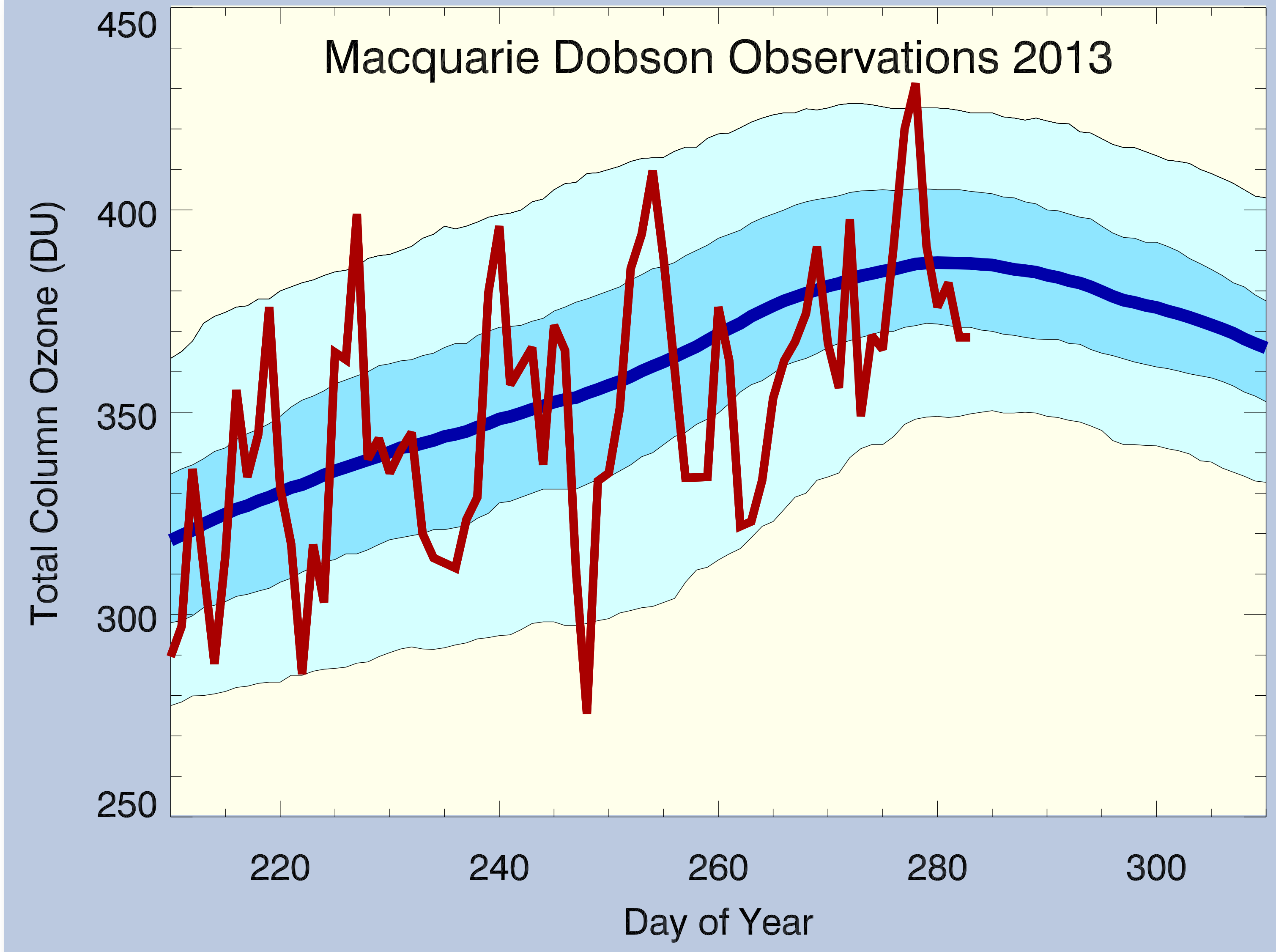


Figure 22. Dobson observations carried out at Macquarie Island in 2013 (until 10 October, day 283) in comparison with long term (1987-2012) statistics.

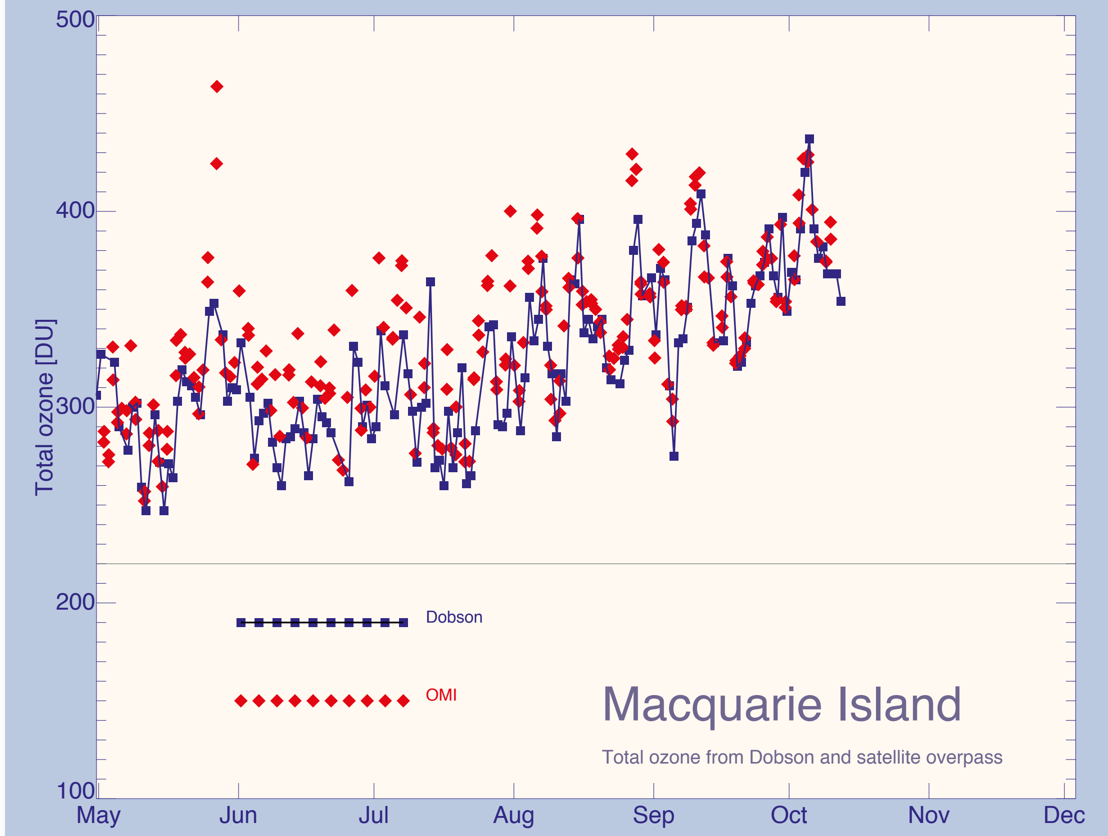


Figure 23. Comparison of Dobson observations and OMI satellite overpass data starting from May 2013 until 10 October.

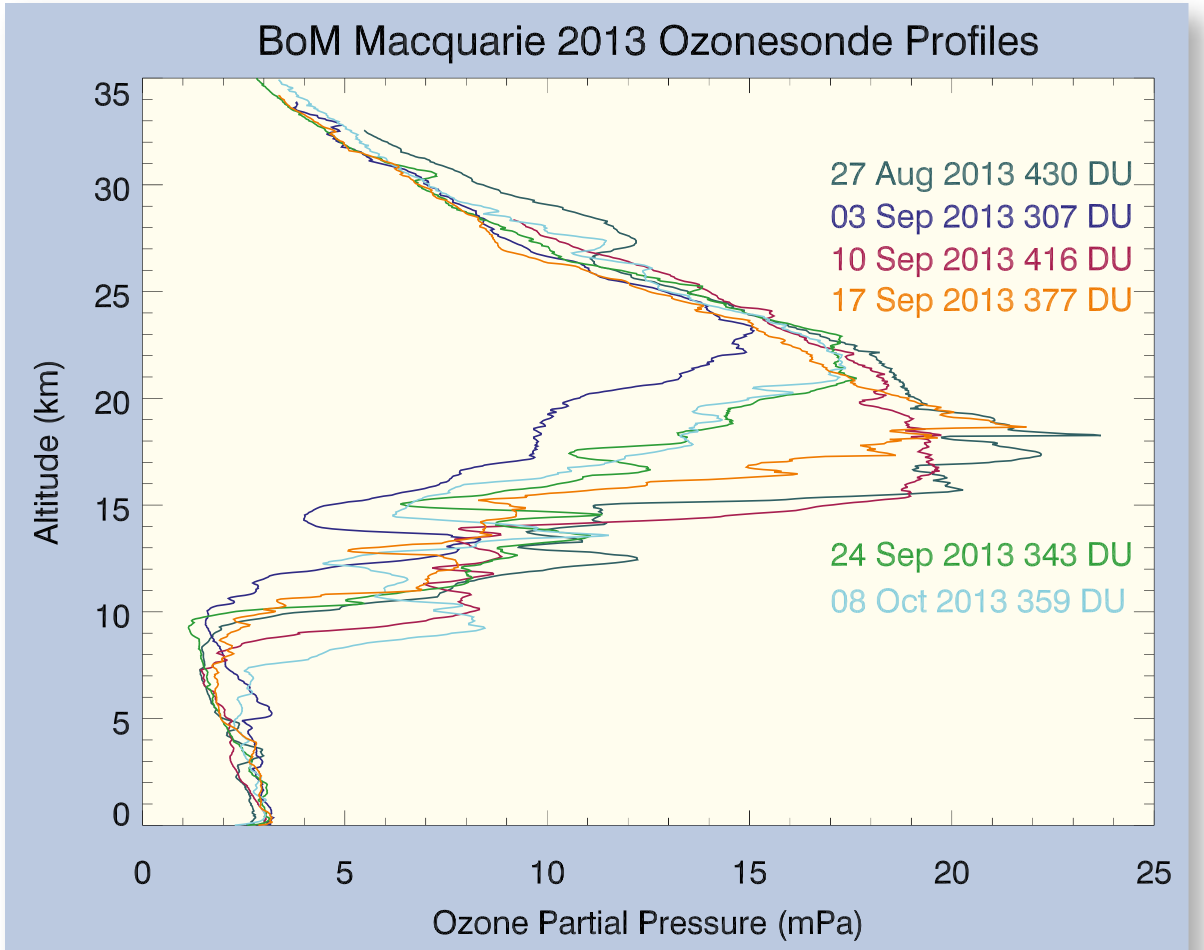


Figure 24. Ozone profiles over Macquarie Island measured with electrochemical ozonesondes.

Ozonesondes are launched at Macquarie once per week. Some selected profiles observed since late August 2013 are shown in **Figure 24**. Several profiles shows a deficit of ozone around 15 km altitude, in particular the profile of 3 September.

The full time series of Macquarie Dobson data is shown in **Figure 25** (next page). Except for a gap in the early 1960s this station has measured total ozone continuously since 1957. Such long time series are very valuable and it is important that they are continued so that we can see the expected ozone recovery in the long term perspective.

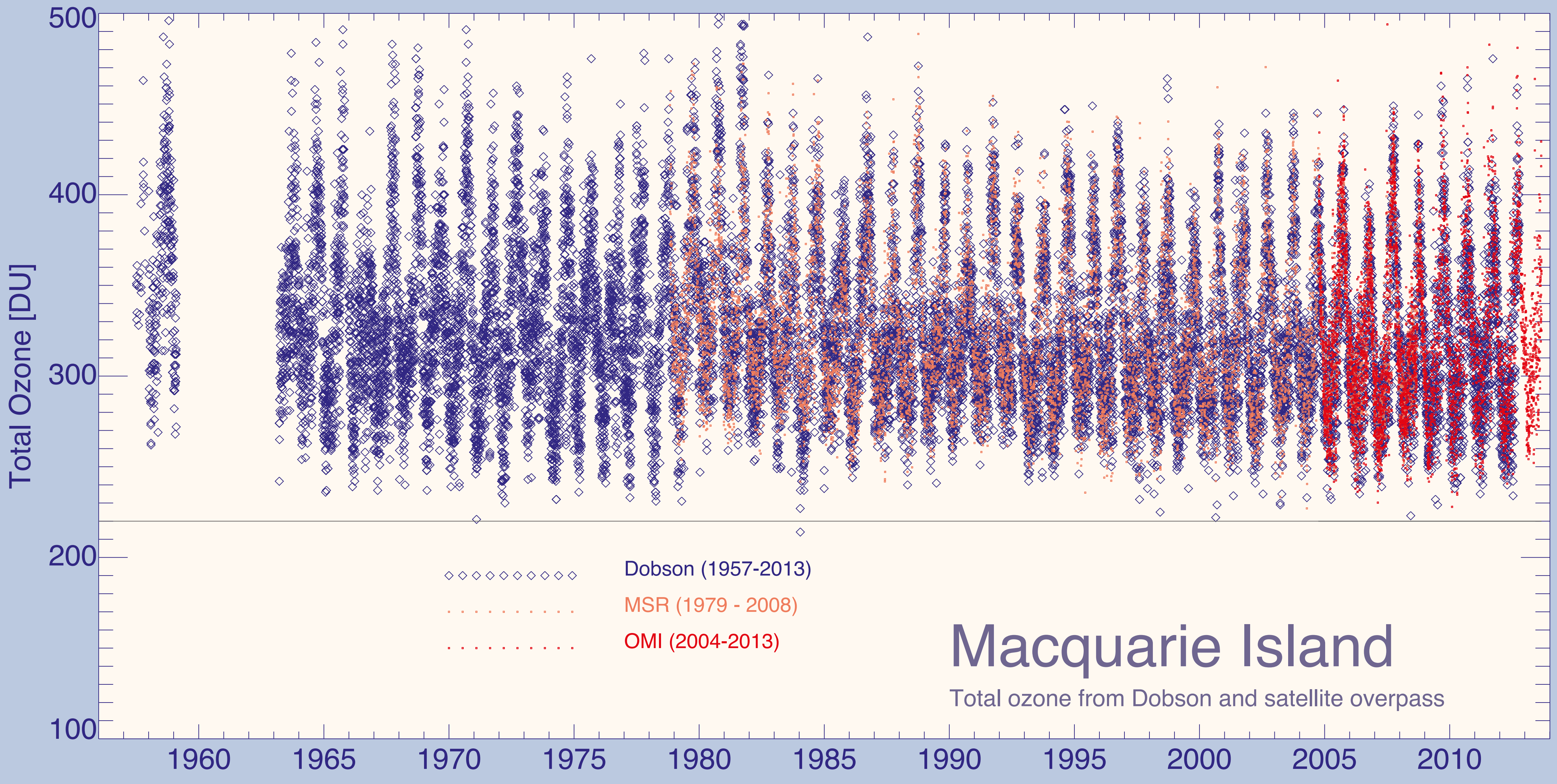
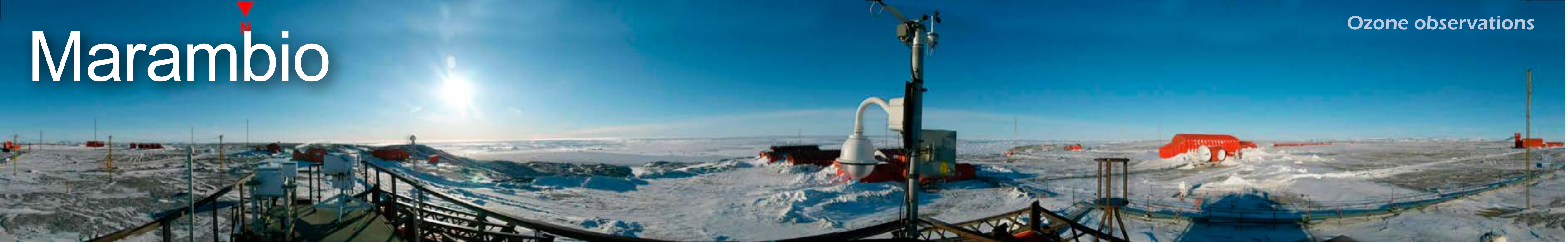


Figure 25. Total ozone over Macquarie Island from 1957 until now (31 August 2013) measured with Dobson spectrophotometer (blue dots) compared to satellite overpass data. The orange dots show data from KNMI's Multi-Sensor Reanalysis (1979-2008) and the red dots show OMI overpass data (2004 until now).

Marambio



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

An ozone map based on data from the BASCOE data assimilation model (**Figure 27**) shows that Marambio was inside the ozone hole on 28 September.

Total ozone is measured at Marambio with a Brewer MkIII instrument. The Brewer measurements have been carried out since February 2010. In 2013 the measurements started up after the winter on 10 August. From that date until 6 October total ozone has varied between 305 DU (12 August) and 163 DU (15, 17 and 30 September). Total ozone has been below the 220 DU threshold on 36 days so far this season. The Brewer measurements, together with OMI overpass data and total ozone deduced from ozone soundings are shown in **Figure 28**. At Marambio, total ozone is also measured with a Dobson spectrophotometer. Those measurements started in August 1987. The entire Dobson time series together with OMI and MSR overpass data can be seen in **Figure 29**.

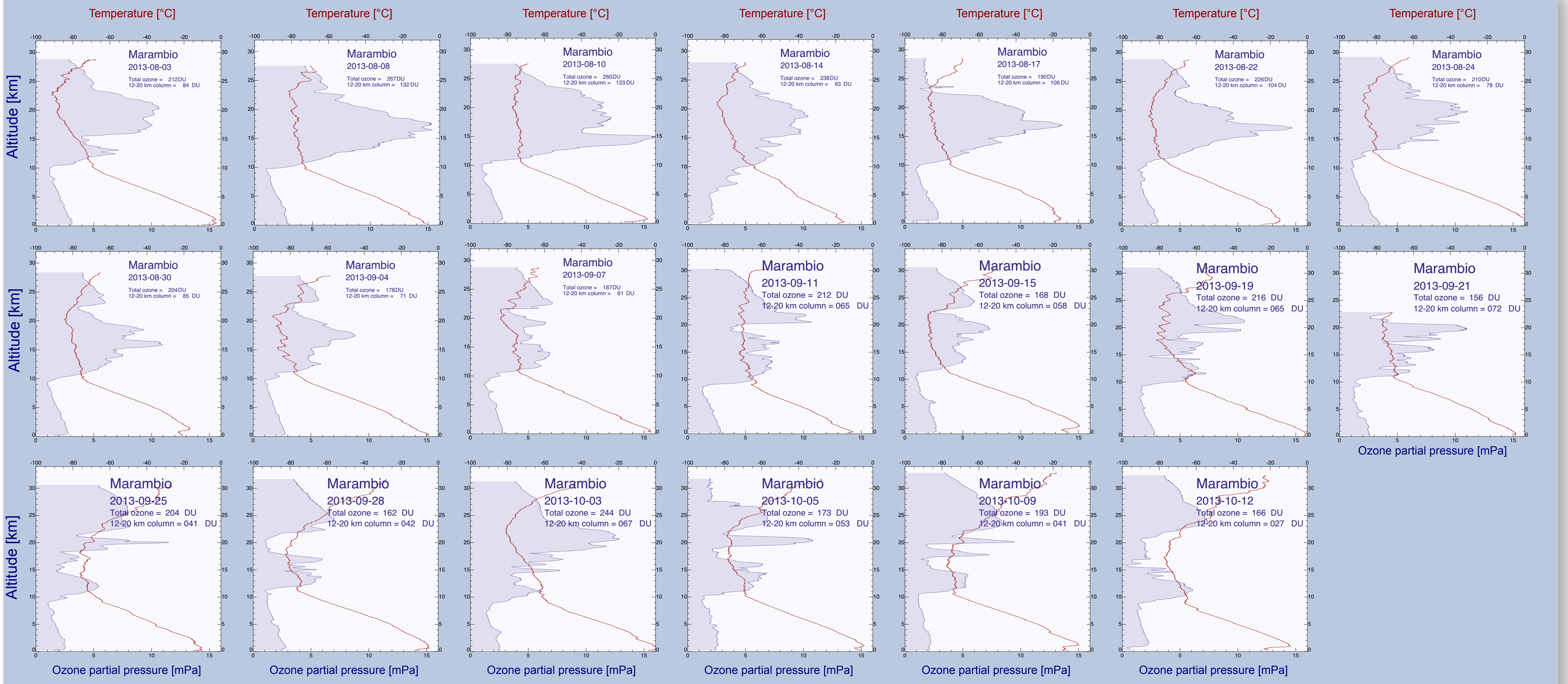


Figure 26. Ozone profile measured with electrochemical ozonesonde launched from the Argentinian GAW station Marambio from 3 August to 12 October. Some of the profiles show a "bite-out" at around 13-15 km altitude, and also around 22 km. The 21 September sonde experienced a balloon burst already at 23 km, so the total ozone deduced from that sounding is not reliable.

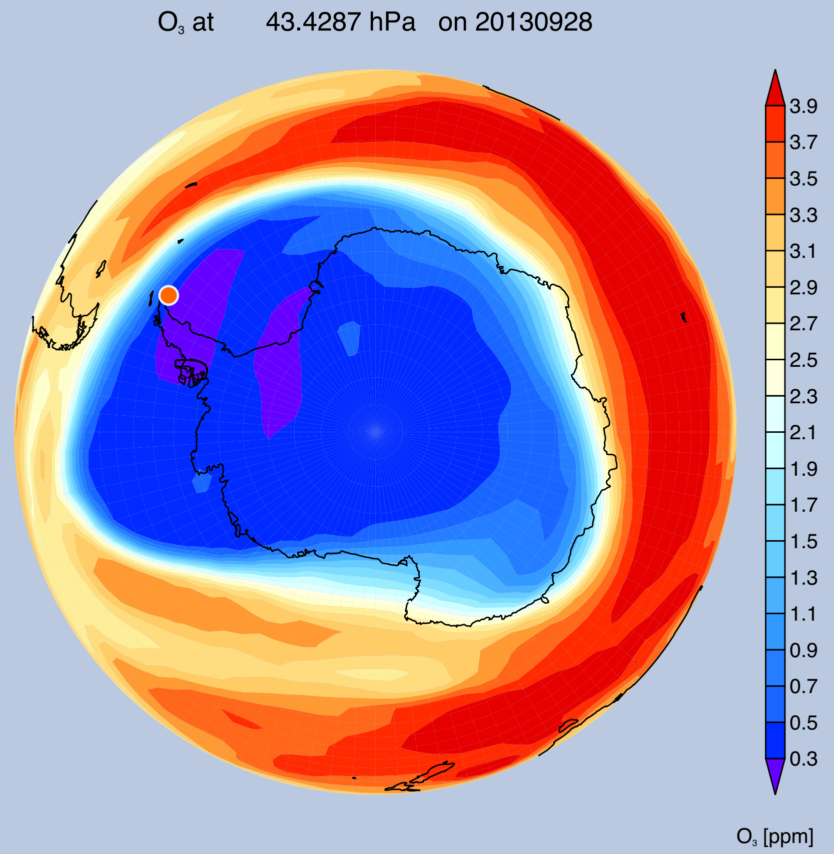


Figure 27. Assimilated ozone on 28 September 2013 at 43.4 hPa. The position of Marambio is indicated with a red circle. The data is calculated with the BASCOE model, which uses data from the MLS instrument on AURA. The plot shows that Marambio was affected by low ozone mixing ratios at that level on this day.

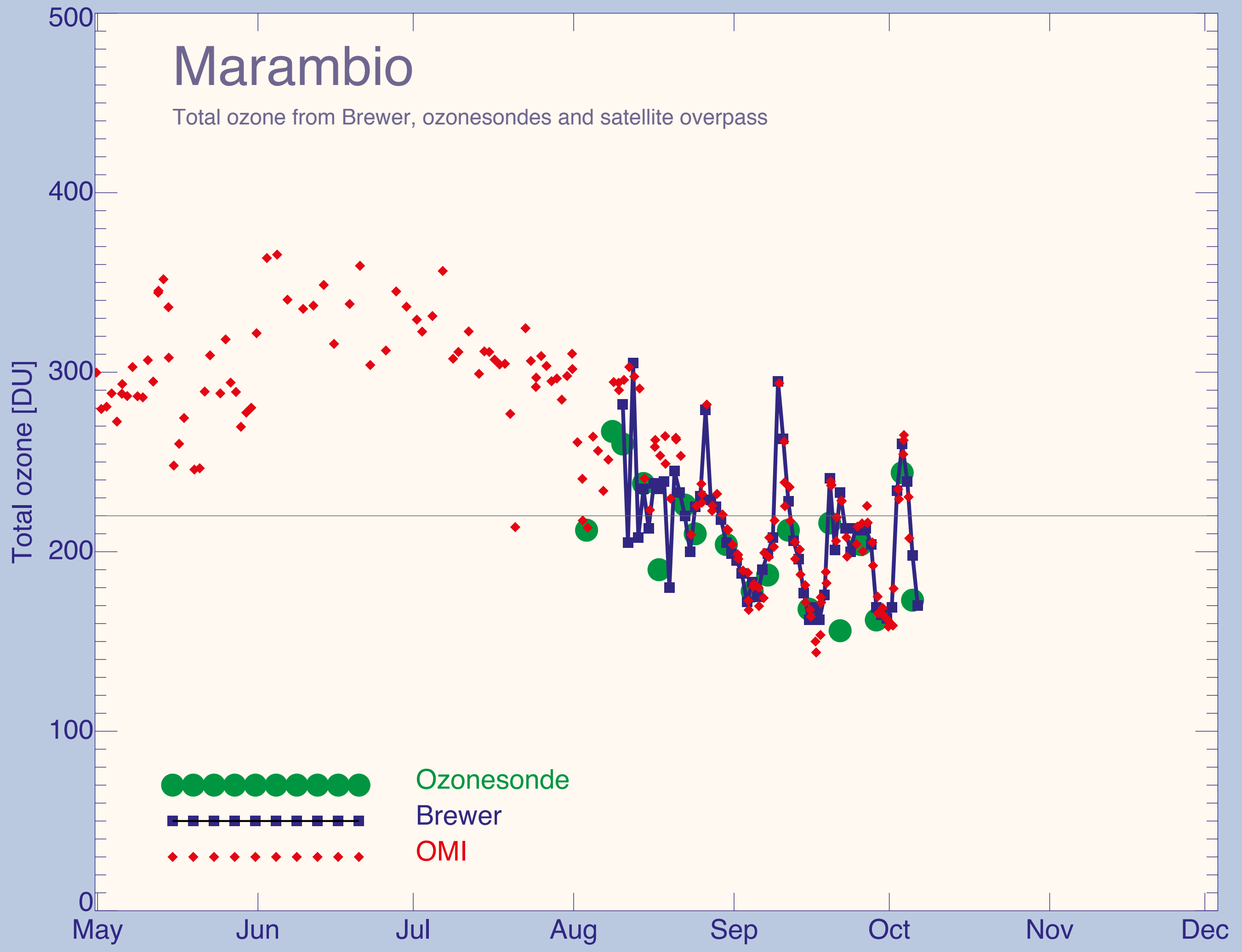


Figure 28. Total ozone over Marambio as measured by ozonesondes (green circles), Brewer spectrophotometer (blue line and squares) and by the OMI satellite instrument on board AURA.

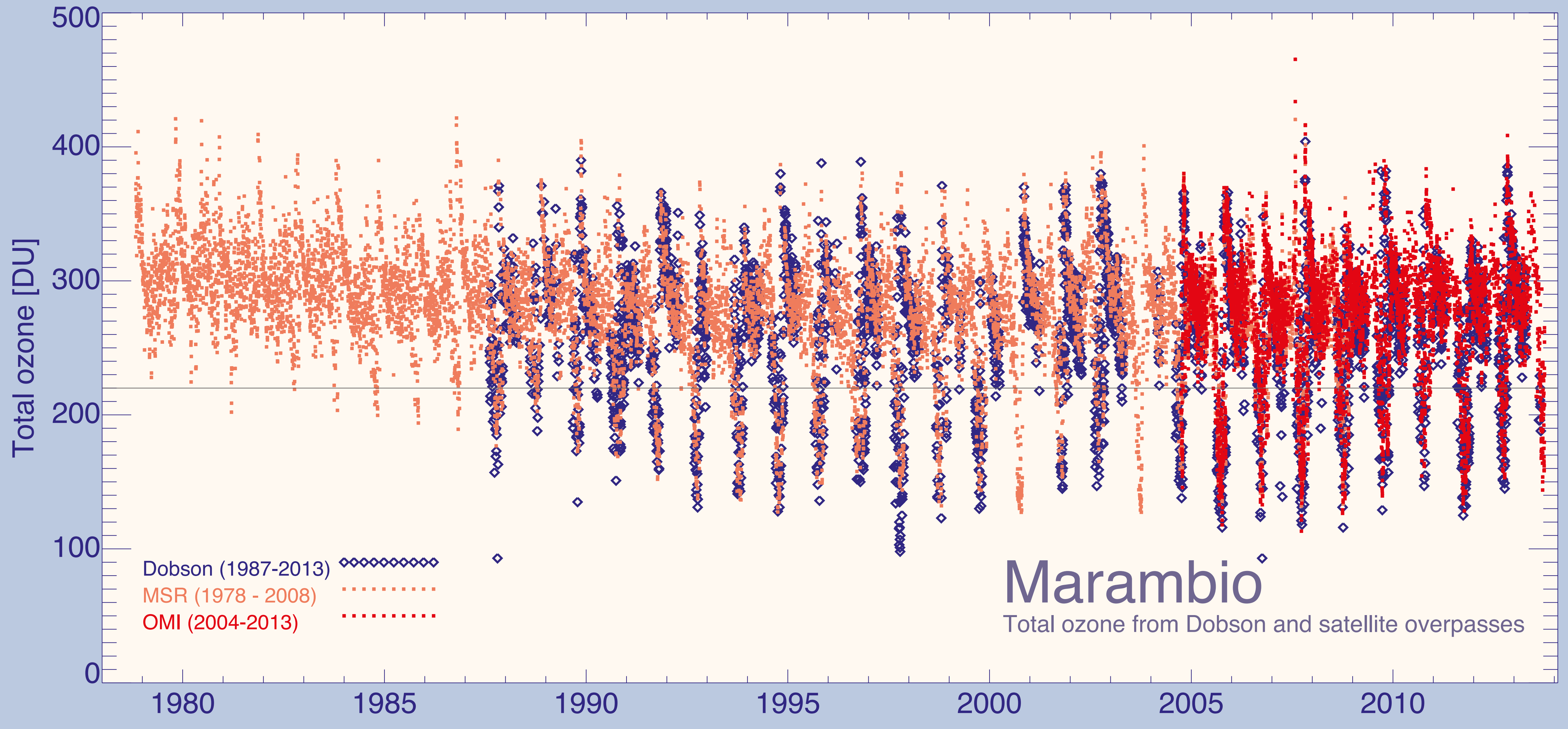


Figure 29. Total ozone over Marambio from Dobson spectrophotometer (blue diamonds), from the OMI satellite instrument on board AURA (red squares) and from the MSR data set calculated by KNMI from various satellite instruments.

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 and Vladimir Radionov of the Arctic and Antarctic Research Institute, St. Petersburg. The measurements started up again after the polar night on 1 August and are up to date as of 6 October. The maximum total ozone value observed so far was 455 DU on 9 and 20 September and 4 October. The minimum so far was 213 DU on 30 August. The maps in **Figure 30** (next page) shows total ozone observed by MLS on the AURA satellite. On 9 August the station is inside the polar vortex and total ozone derived from the map is around 220 DU. On the 20th of September the station is outside the vortex and one can see that it is influenced by ozone rich air masses. Total ozone derived from the MLS map is around 310-320 DU. The ground-based data are shown together with OMI satellite overpass data in **Figure 31**.

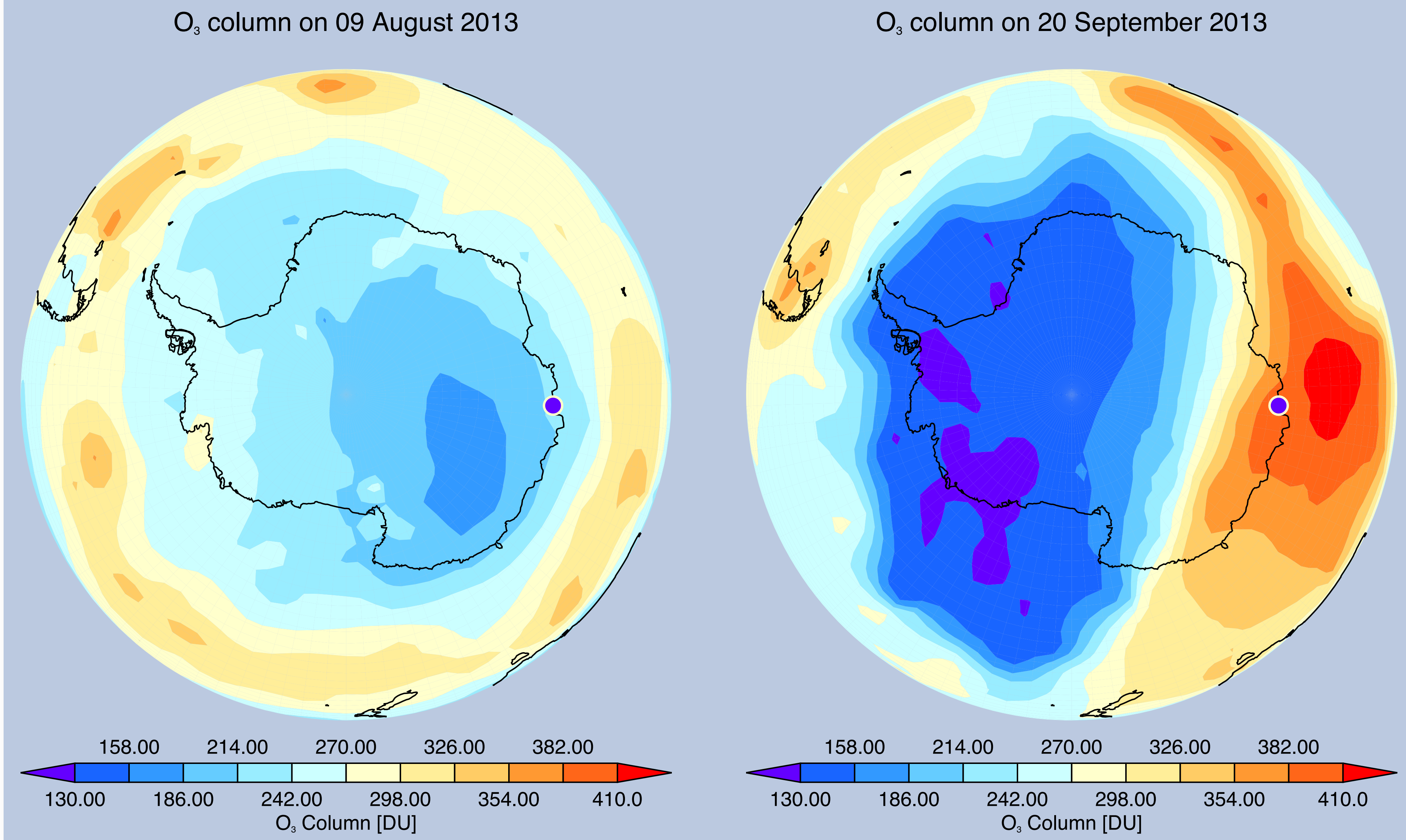


Figure 30.Total ozone observed by MLS on Aura. The position of Mirny is shown with a blue circle. The plots are produced at WMO based on data downloaded from NASA's GES-DISC.

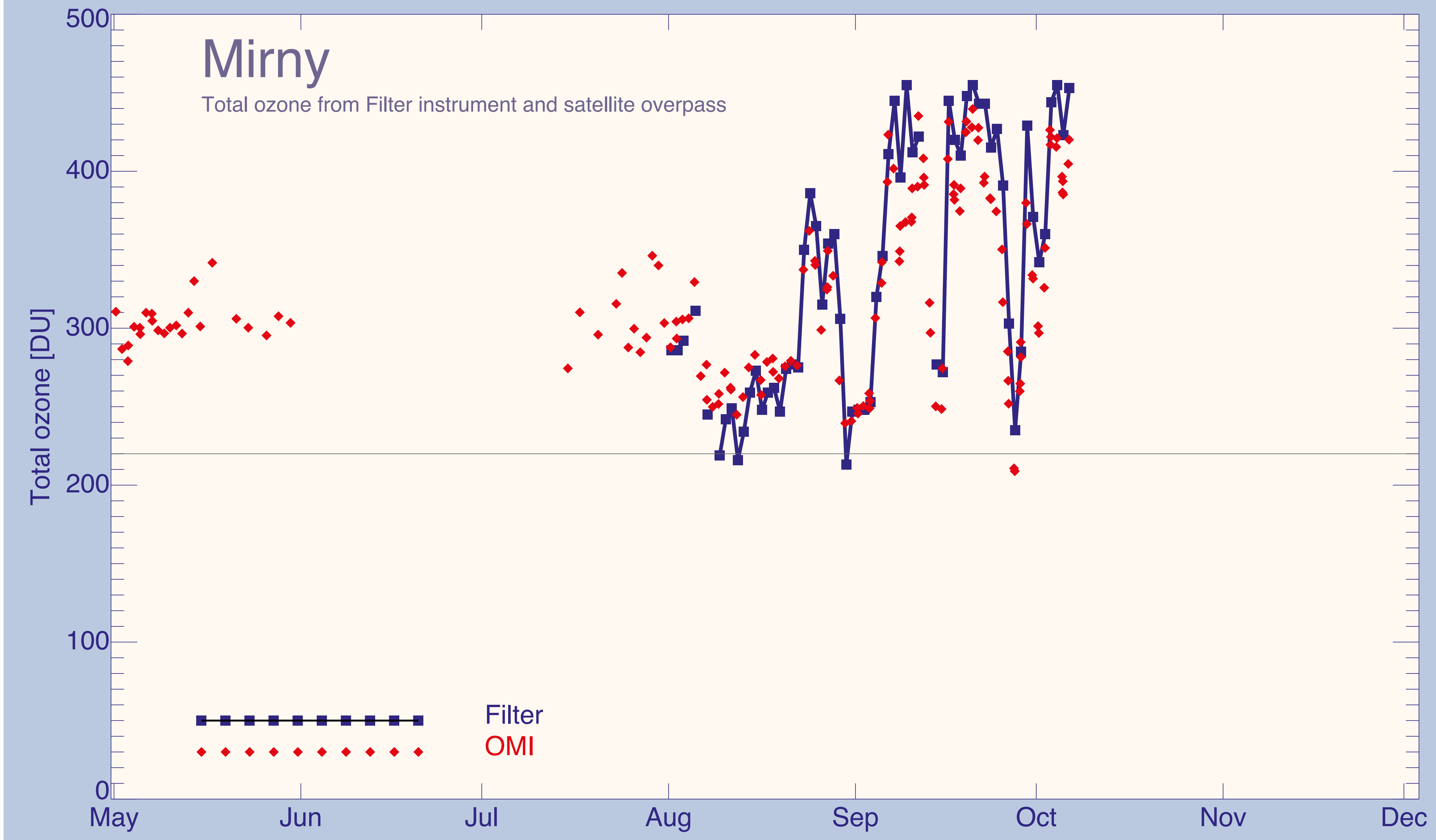
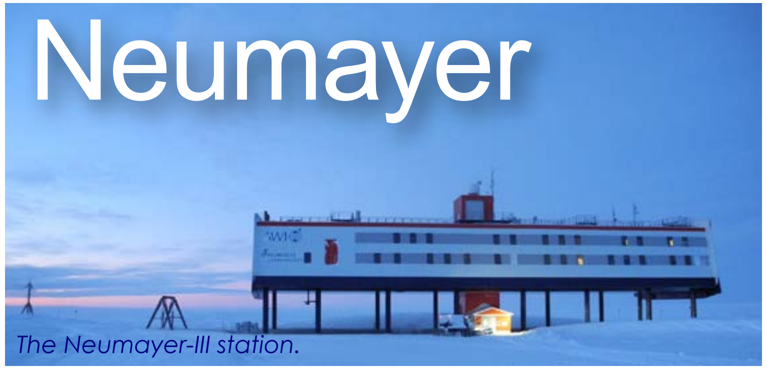


Figure 31. Total ozone above Mirny as measured by a M-124 filter instrument and by the OMI instrument on board the AURA satellite.

Neumayer



The Neumayer-III station.

The vertical distribution of ozone is measured with ozonesondes from the German GAW/NDACC station at Neumayer (70.666°S, 8.266°W). Sondes were launched on 1, 7 13, 21, 24 and 27 August, on 3, 6, 14, 16, 19, 23 and 28 September, and on 1, 5, 7 and 11 October as shown in **Figure 32**. The profile of 13 August shows a 12-20 km partial ozone column of 95 DU. By 1 October this partial column has dropped to 21 DU, the lowest 12-20 km columns measured so far in 2013 at any station in Antarctica. The ozone mixing ratio at 79.4 hPa (approx. 16 km) from the BASCOE model is shown for four different dates in **Figure 33**. On 7 August there is no sign of ozone depletion. This can be seen both from the ozonesonde profile and from the BASCOE data (about 1.9 ppm ozone above Neumayer). On 13 August one can see from the sonde profile that ozone is reduced at several levels. This is also clear from the BASCOE map with around 1.2 ppm at 79 hPa above Neumayer. On 21 August Neumayer seems somewhat less affected by ozone loss than on the 13th, which is also visible from the BASCOE map (1.5-1.6 ppm ozone above Neumayer).

On 27 August, the ozone profile shows that ozone partial pressure at 16 km has dropped from approx. 16 mPa on

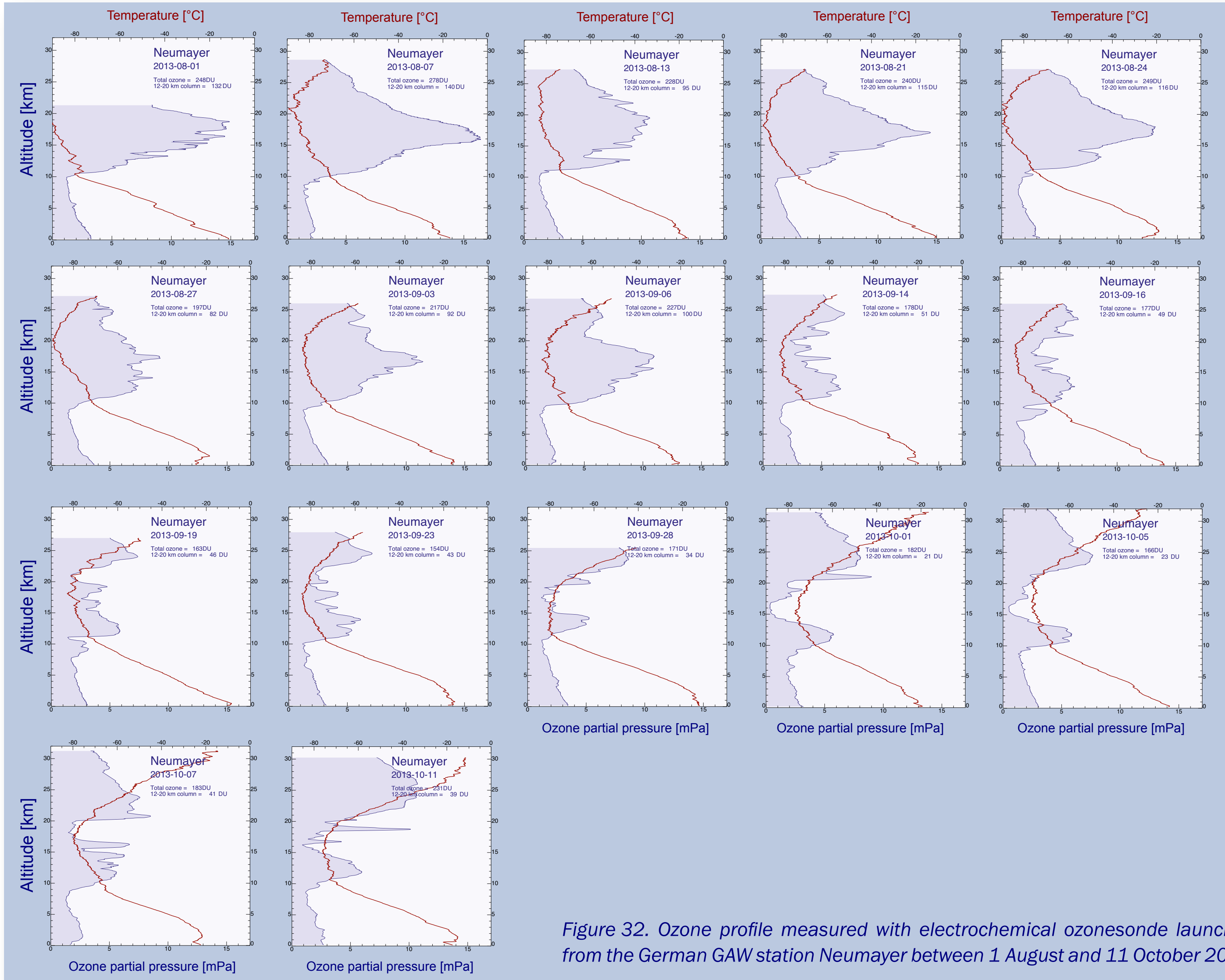


Figure 32. Ozone profile measured with electrochemical ozonesonde launched from the German GAW station Neumayer between 1 August and 11 October 2013.

7 August to approx. 7 mPa. This drop in ozone is also reflected in the BASCOE data at this level (below 0.9 ppm). The ozone profiles observed on 3 and 6 September show a bit less depletion than on 27 August, but total ozone is close to the 220 DU threshold and there are quite visible ozone "bite-outs", especially around 20-22 km. From 14 September onward all the profiles show a large degree of ozone depletion. The last map (lower right) in **Figure 33** shows that Neumayer is situated in a region with low ozone mixing ratios on 23 September.

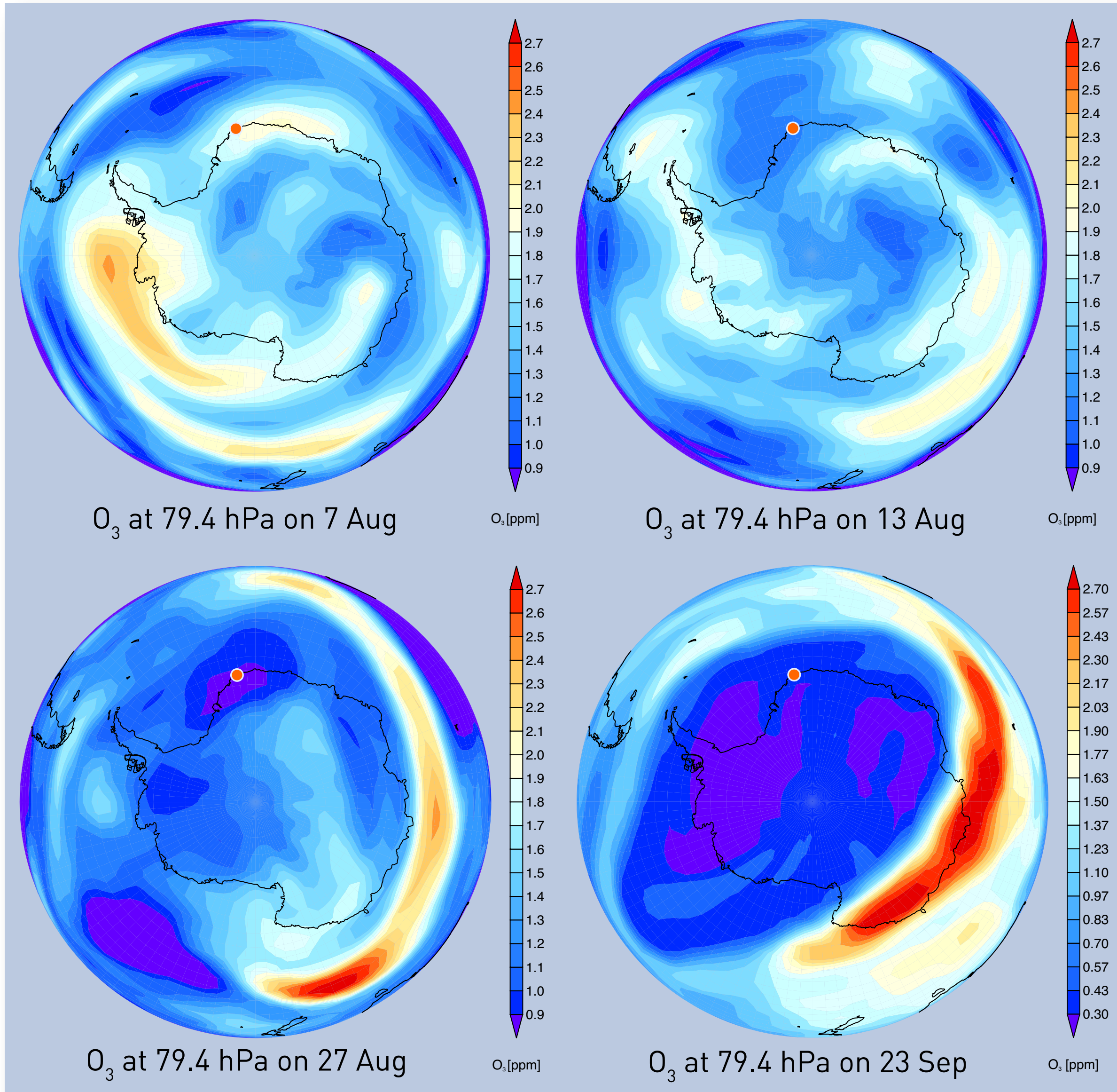


Figure 33. Ozone mixing ratio at 79.4 hPa on 7 August (upper left), on 13 August (upper right), on 27 August (lower left) and on 23 September (lower right) from the BASCOE model. This model assimilates observations measured by MLS on AURA. The coloured circle shows the location of Neumayer station. Please note that the lower end of the colour scale has been changed from 0.9 to 0.3 ppm on the last plot. The model data have been downloaded from the BASCOE ftp server and plotted at WMO.

Novolazarevskaya

At the Russian GAW station Novolazarevskaya (70.776739°S, 11.822138°E) total ozone is measured with an M-124 filter instrument. The data are submitted by Elena Sibir and Vladimir Radionov of the Arctic and Antarctic Research Institute, St. Petersburg. The measurements started on 15 August and are up to date until 6 October. During this time period total ozone has varied between 160 (12 and 25 Sep) and 241 DU (20 Aug). Total ozone has been below the 220 DU threshold on 36 days so far this season.

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

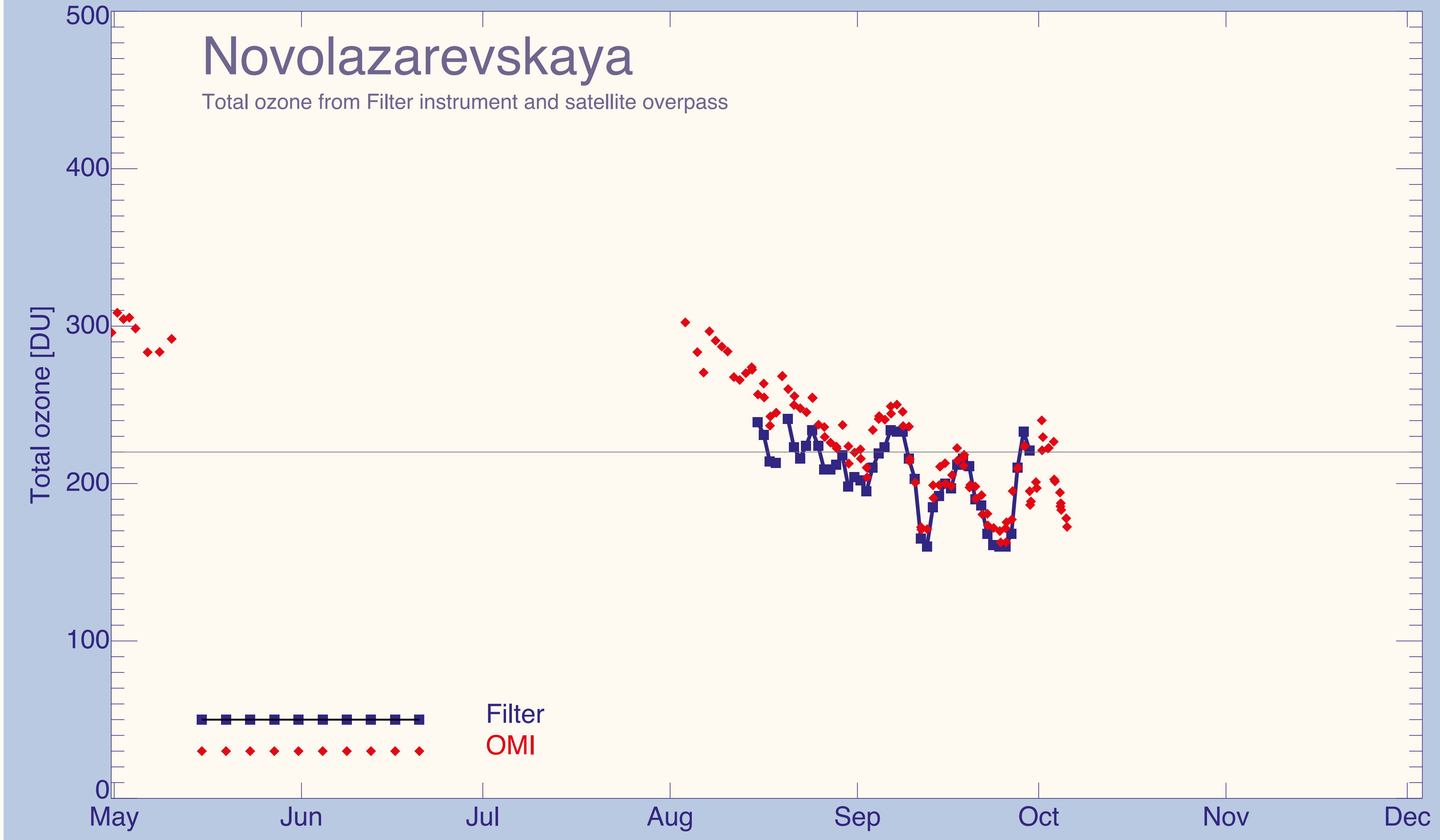


Figure 34.Total ozone above Novolazarevskaya as measured by a M-124 filter instrument and by the OMI instrument on board the AURA satellite.

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 scientists at the station.

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

J. Salvador, E. Wolfram, F. Orte, R. D’Elia, D. Bulnes, E. Quel
email contact jacosalvador@gmail.com

Total ozone evolution during August - September 2013

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

The total ozone columns over Río Gallegos present typical fluctuations around mean values for this time of the year. The development of the polar vortex around Antarctica is a natural barrier that avoids the ozone rich air transported from the equatorial zone to reach the pole. This produces the pile-up of ozone rich air in the equatorial side of the polar vortex. This situation was observed on 21 August 2013 (**Figure 35**) when the total ozone column over the station was around 400 DU, approximately 60 DU above the mean value for this month.

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

On September 17 (day of year 260), the ozone hole passed over the Río Gallegos station, and total the ozone column dropped to 274 DU (**Figure 35**). 29 August and 17 September were the only two days with total a ozone column below one standard deviation of the ozone climatologic monthly mean value (1978-2009).

During the August - September period, several ozone vertical profiles were measured with the Differential Absorption Lidar operative at OAPA. On average, the integration time of each lidar experiment was around 3 hours. Selected stratospheric ozone profiles are presented in **Figure 36** in correspondence with the days of interest.

Higher total ozone columns registered on 21 August are produced by air of elevated ozone contents in the lower stratosphere, below 21 km as can be seen from the DIAL ozone profile on this day (**Figure 36**). The proximity of the polar vortex to the zenith line of Río Gallegos produces a reduction of the ozone content in the middle stratosphere (profiles of 29 Aug. and 17 Sep.; **Figure 36**). The reduction zones are clearly visible in comparison with the September climatologic ozone profile.

OMPS satellite images confirm the position of ozone hole over Río Gallegos (**Figure 37**). Rapid recovery of total ozone happens after this day as a consequence of the polar vortex movement away from the station.

Figure 37 shows the sequence of images of total ozone column measured by OMPS instrument aboard the NPP platform corresponding to the ozone profiles shown in **Figure 36**.

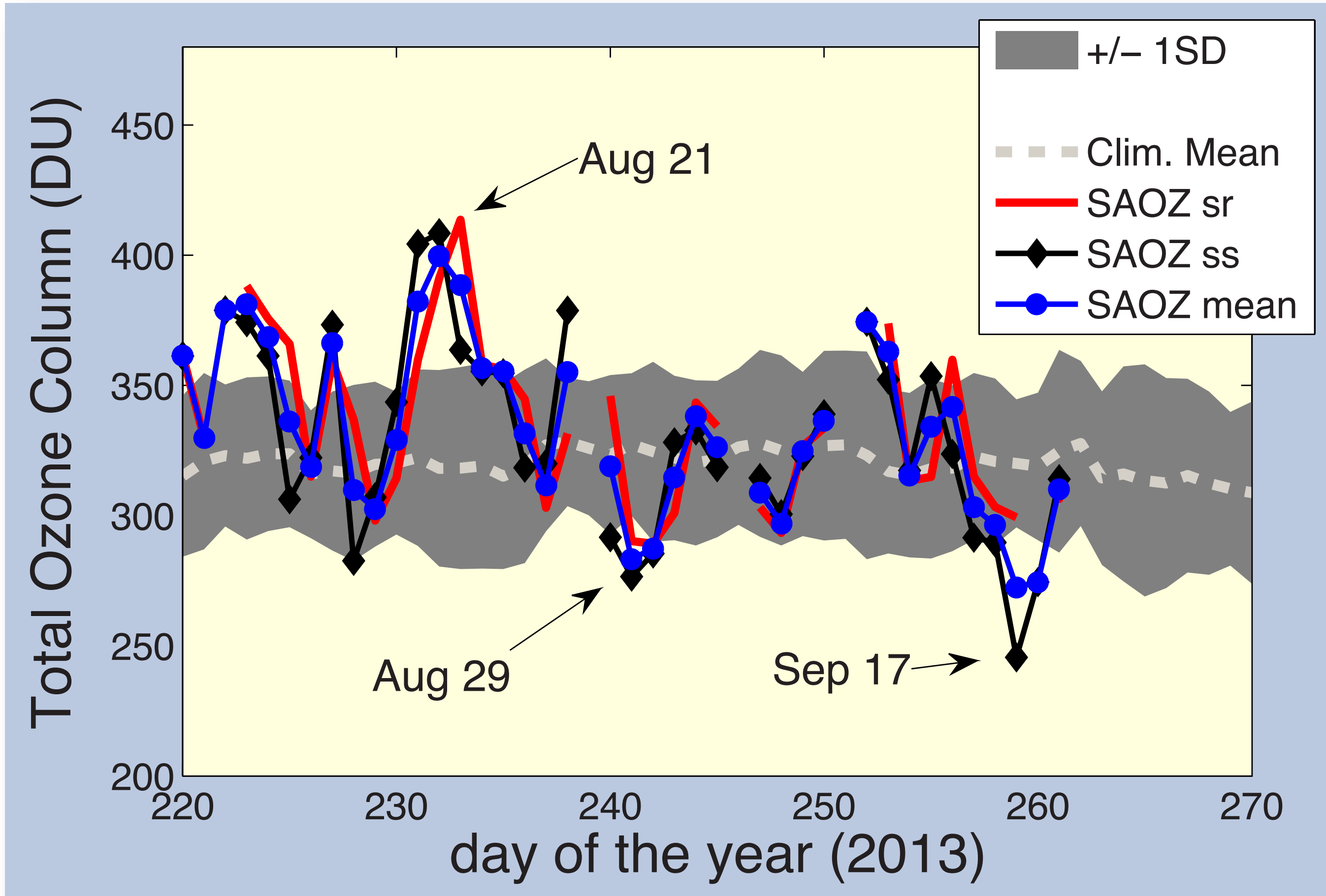


Figure 35. Evolution of the total ozone column over Río Gallegos. Ground based measurements were taken with SAOZ spectrometer. "SAOZ sr" corresponds to sunrise measurement; "SAOZ ss" corresponds to sunset measurement; "SAOZ mean" corresponds to the daily mean of two measurements.

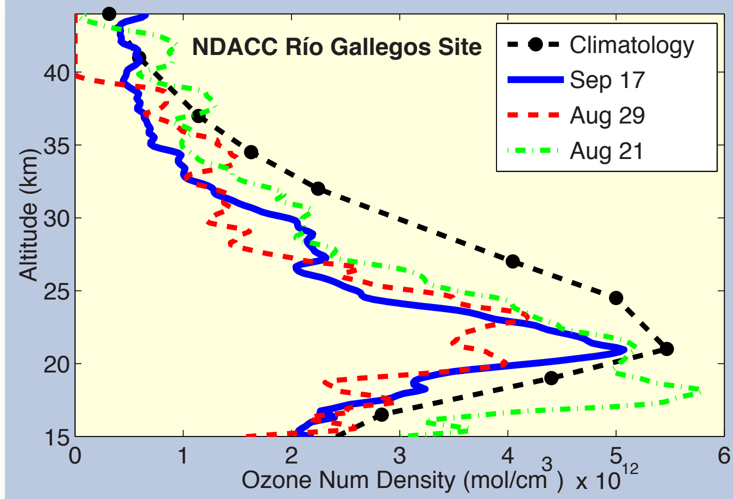


Figure 36. DIAL stratospheric ozone profiles measured on August 21 (dashed dotted green line), August 29 (dashed red line) and September 17 (blue line) in Río Gallegos site. Fortuin & Kelder September climatologic profile for latitude belt (45-55 °S)(black dashed line).

The overpass of poor ozone air for these days induce a slight increase in UV levels at the ground. Measurements of UV radiation with a GUV 541 moderate narrowband multi-filter radiometer reach moderate UV indices (around 3-3.5).

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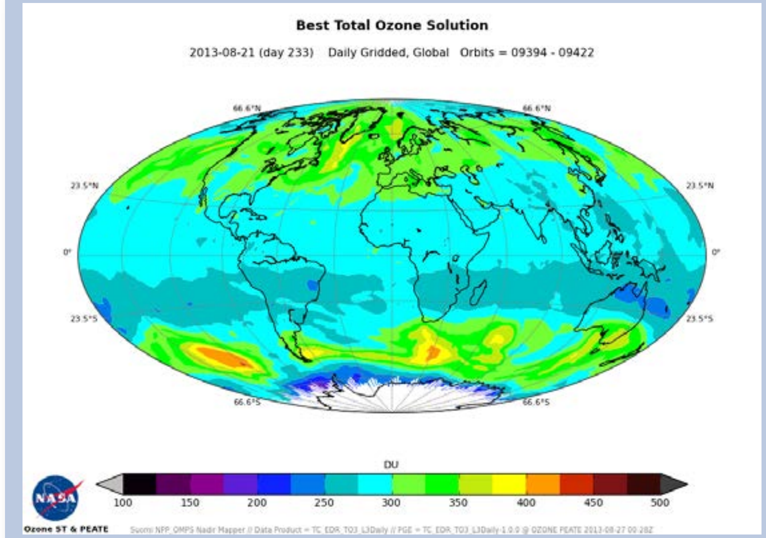
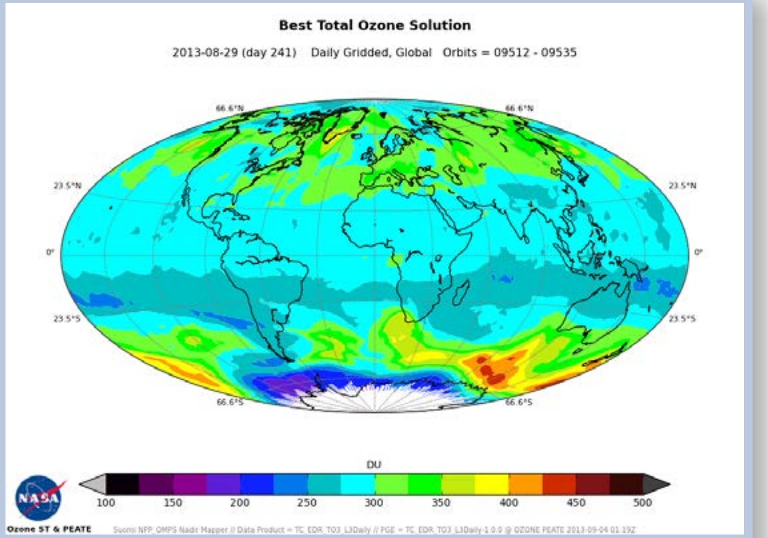




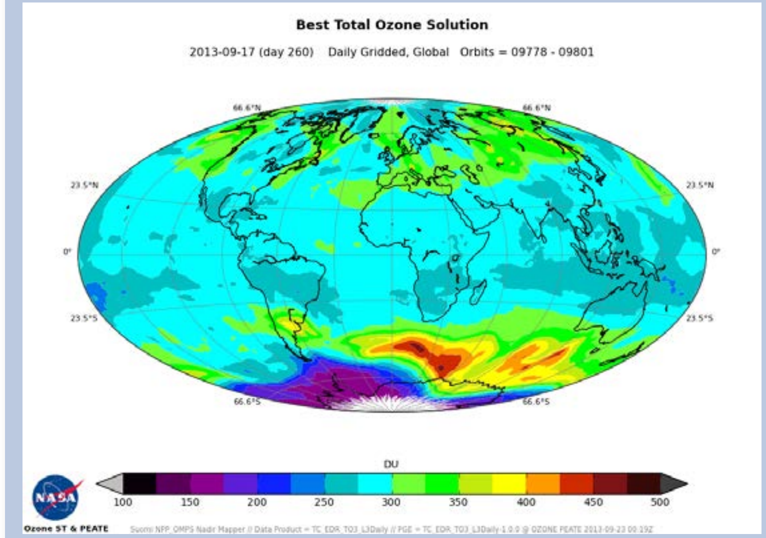


Figure 37. Total ozone from the Ozone Mapper and Profiler Suite (OMPS). OMPS is one of five new instruments flying aboard NASA's Suomi National Polar-orbiting Partnership satellite (NPP), which was launched on Oct. 28, 2011. Suomi NPP is the result of a partnership between NASA, the National Oceanic and Atmospheric Administration and the Department of Defence. The Rio Gallegos station is near the southern tip of the South American continent.

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, observations can be carried out around the year. Total ozone was oscillating between 300 and 380 DU in June. On 2 August total ozone dropped to 154 DU before going back up to near 300 DU on 8 August. After that total ozone oscillated between 124 and 296 DU until the end of August. From 27 August onward total ozone has been below (mostly well below) the 220 DU threshold. **Figure 38** shows the 2013 data in comparison to earlier years and long term statistics. **Figure 39** (next page) shows a map of total ozone from MLS on 2 and 8 August as well as 15 September, where Rothera is indicated with a red circle. It can be seen that on 2 August the station is influenced by air masses with ozone depleted air, on the 8th it was on the outer edge of the vortex and on the 23rd it was well inside the vortex with a total ozone column of around 160 DU. Total ozone has been below the 220 DU threshold on 52 days so far in 2013 (1 August to 10 October).

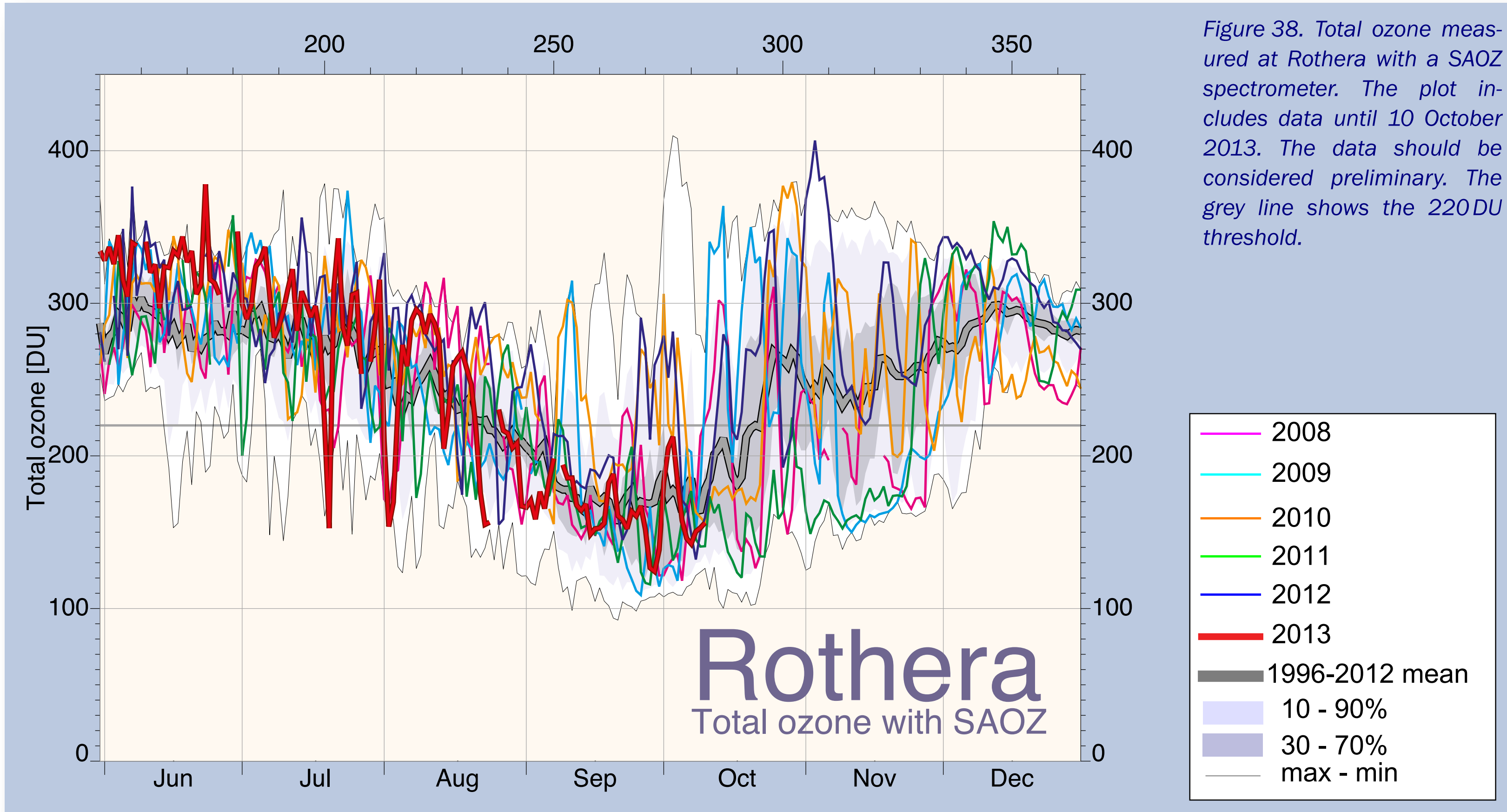


Figure 38. Total ozone measured at Rothera with a SAOZ spectrometer. The plot includes data until 10 October 2013. The data should be considered preliminary. The grey line shows the 220 DU threshold.

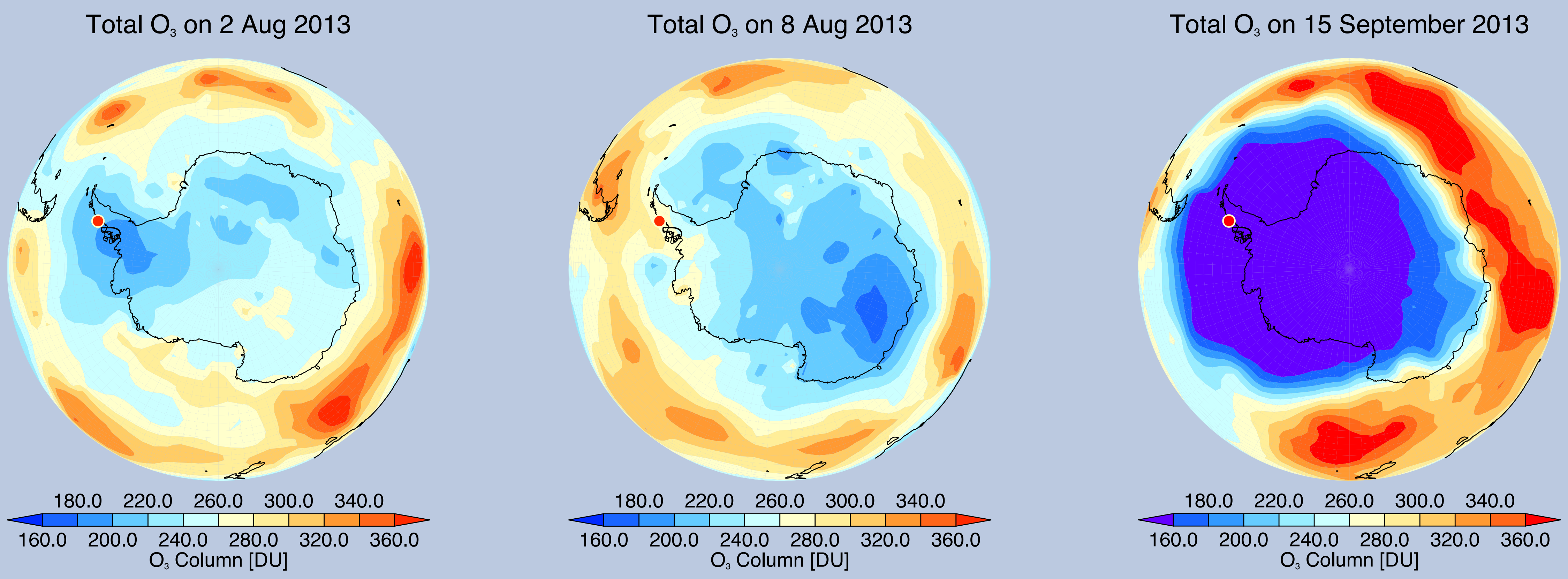


Figure 39. Maps of total ozone from MLS for 2 and 8 August, and 15 September, showing the location of Rothera. On 2 August the station is influenced by ozone poor air masses with total ozone around 200 DU. On 8 August total ozone is approx. 290 DU and on 15 September it is below 150 DU.

Ozonesonde launch at the South Pole

The vertical distribution of ozone at the GAW/NDACC South Pole station (Amundsen-Scott base) has been measured by NOAA/ESRL with electrochemical concentration cell (ECC) ozonesondes since 1986. **Figure 40** shows the four soundings between 20 July and 26 August. **Figure 41** (next page) shows soundings carried out from 1 September to 2 October. Since 7 September all the profiles show clear signs of ozone depletion. Also the profile of 26 August displays a clear ozone "bite-out" This probably stems from air masses being transported from the vortex edge region where depletion starts some weeks earlier than at the South Pole. On 29 September there is a region around 16-17 km altitude where essentially all ozone is destroyed. Total ozone values deduced from the sondes are shown together with OMI satellite overpass data in **Figure 42**. Due to the late sunrise at the South Pole after the winter the satellite data cover just a short time period.

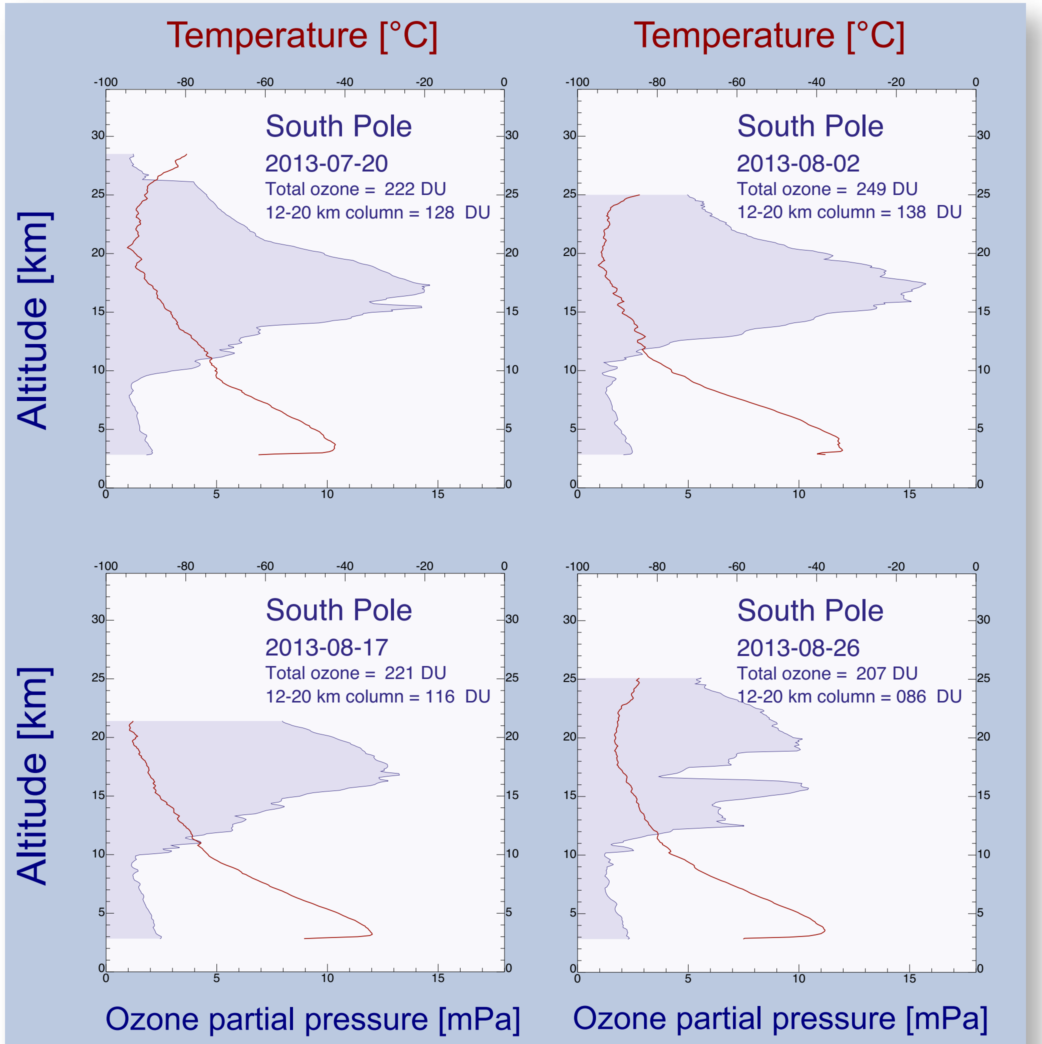


Figure 40. Ozone profiles measured with electrochemical ozonesonde launched from the US NDACC/GAW station South Pole from 20 July until 26 August 2013. The plots are produced at WMO based on data downloaded from the NOAA/ERSL/GMD ftp server.

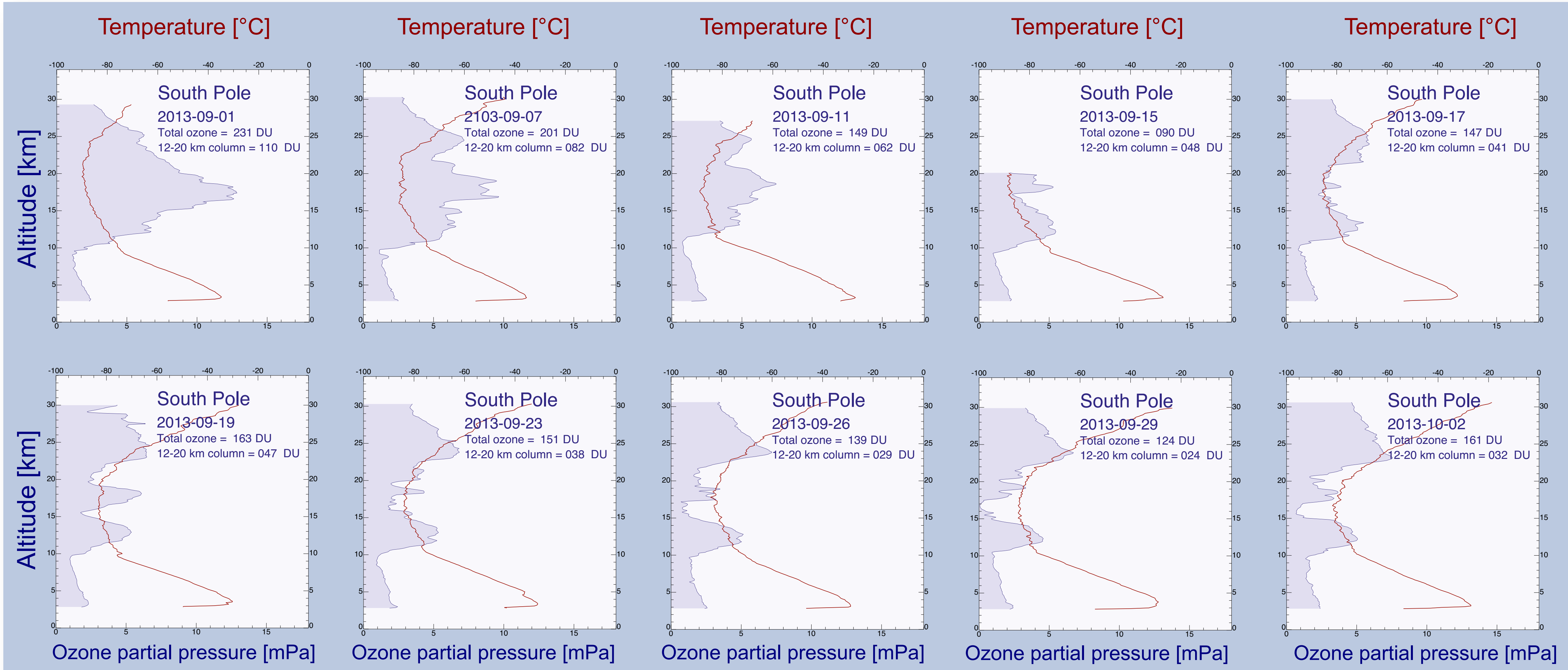


Figure 41. Ozone soundings from the South Pole station from between 1 September and 2 October. Since 7 September the 12-20 km partial column is typical of ozone hole conditions. Also the 26 August profile displays a characteristic ozone loss "bite-out", probably due to air masses advected from the vortex edge region. The plots are produced at WMO based on data downloaded from the NOAA/ERSL/GMD ftp server.

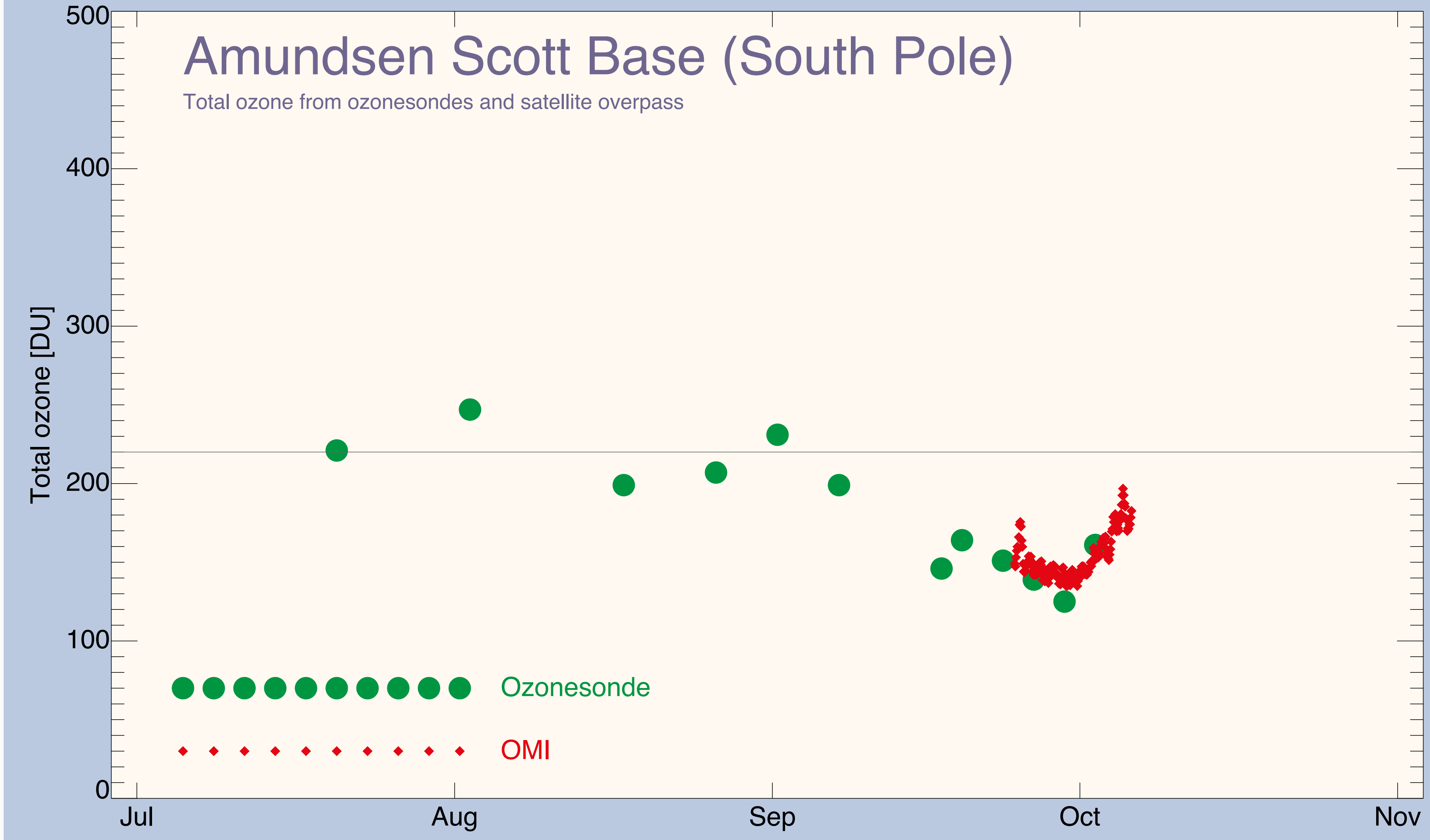


Figure 42. Total ozone above the South Pole as measured by ozonesondes (green circles) and by the OMI instrument on board the AURA satellite. Due to the late sunrise at the South Pole after the polar night, the satellite retrievals start only at 24 September.

Syowa

Ozonesonde launch at Syowa.

Total ozone is measured at the Japanese GAW station Syowa (69.006°S, 39.577°E) with a Dobson spectrophotometer. These measurements have been carried out since 1961. Measurements started up on 15 August after the winter. The total ozone value measured with the Dobson spectrophotometer on that day showed 218 DU. Between 15 and 31 August total ozone values varied between 209 DU (on the 28th) and 243 DU (on the 24th). In September total ozone varied between 161 DU (on the 25th) and 341 DU (on the 16th). From 1 to 6 October, total ozone has varied between 431 DU on the 3rd and 187 DU on the 6th. This rapid variation in total ozone shows the importance of the posi-

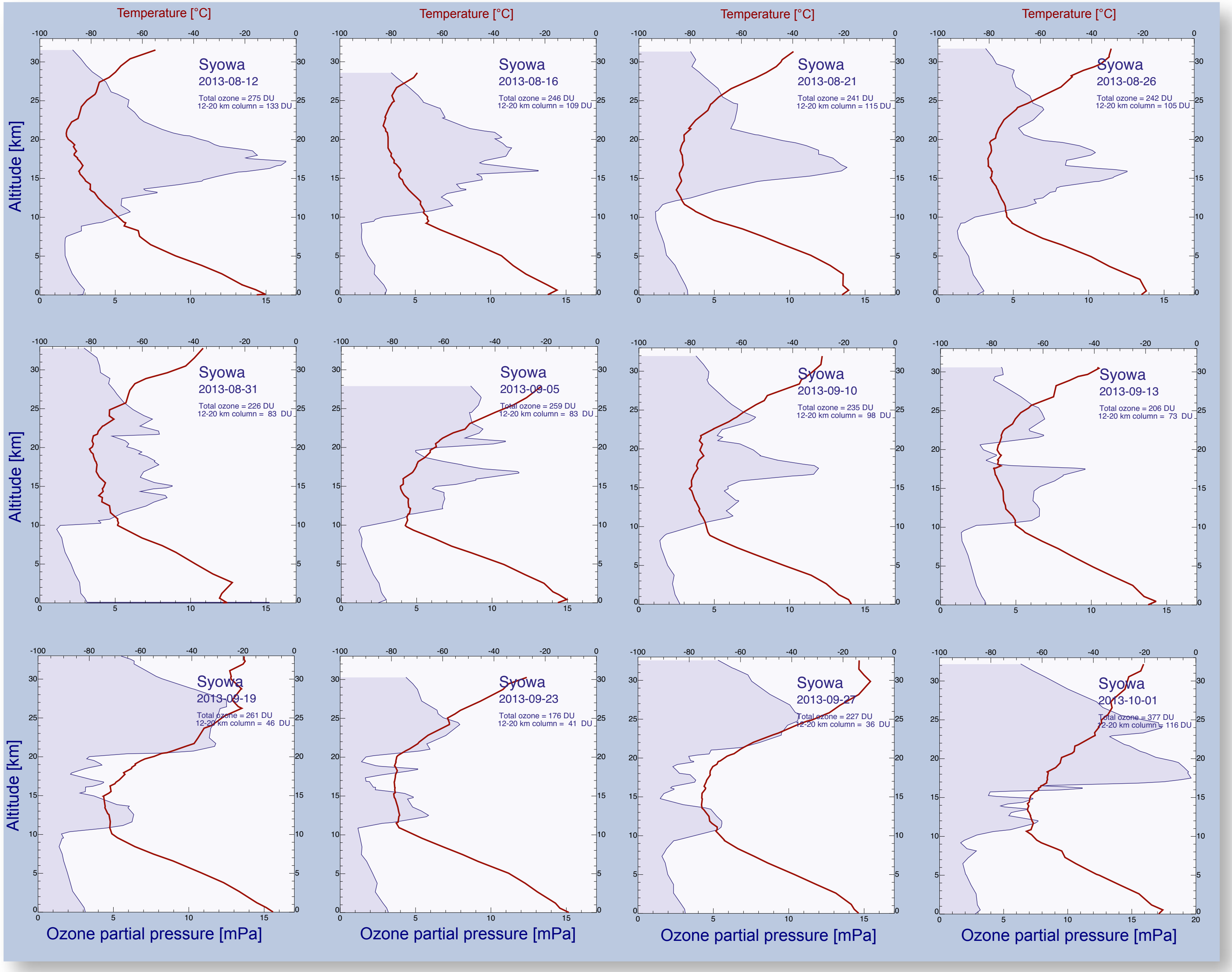


Figure 43. Ozonesonde profiles measured at Syowa from 12 August to 1 October 2013. Please note that the plot of the 1 October profile has a different abscissa range (0-20 mPa instead of 0-17 mPa).

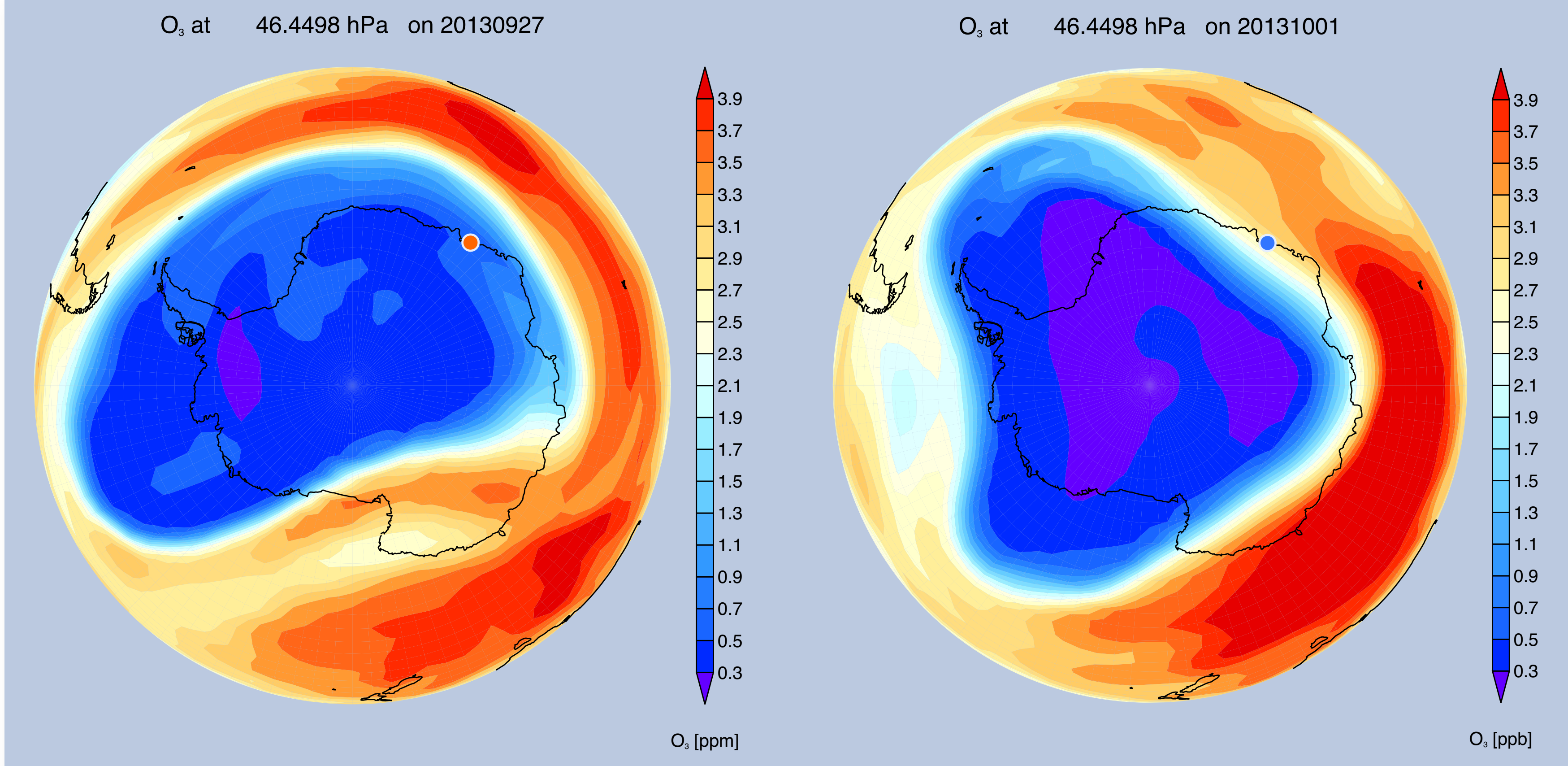


Figure 44. Maps of the ozone mixing ratio based on data from the BASCOE model on 27 September (left) and on 1 October. On 27 September Syowa is well inside the polar vortex, whereas on 1 October it is on the outer edge and influenced by airmasses outside the vortex. The coloured circle shows the location of Syowa station. The map has been produced at WMO based on data downloaded from BASCOE ftp server at IASB. The BASCOE model assimilates data from the MLS instrument on board the AURA satellite.

tion of the polar vortex with respect to the station.

Ozone profiles are measured at Syowa with ozonesondes. So far six soundings have been carried out, on 12, 16, 21, 26 and 31 August, on 5, 10, 13, 19, 23 and 27 September, and on 1 October (**Figure 43**). Several profiles show characteristic "bite-outs" of ozone, both in the 16-19 km range and also around 21 km. The profiles measured on 27 September and on 1 October show very different situations. In the first case there is substantial ozone depletion between 15 and 20 km. In the second case there is almost 20 mPa of ozone at 18-19 km altitude. Ozone mixing ratio maps for those two days at 46.45 hPa (approx. 19 km) from the BASCOE data assimilation model is shown in **Figure 44**. The map shows that Syowa is well inside the polar vortex on 27 September and just outside the vortex edge on 1 October.

Between 15 August and 6 October Syowa has experienced less that 220 DU on 12 days. As some of the ozone profiles show, there can be substantial ozone depletion in the 15-20 km altitude range, yet total ozone is above 220 DU.

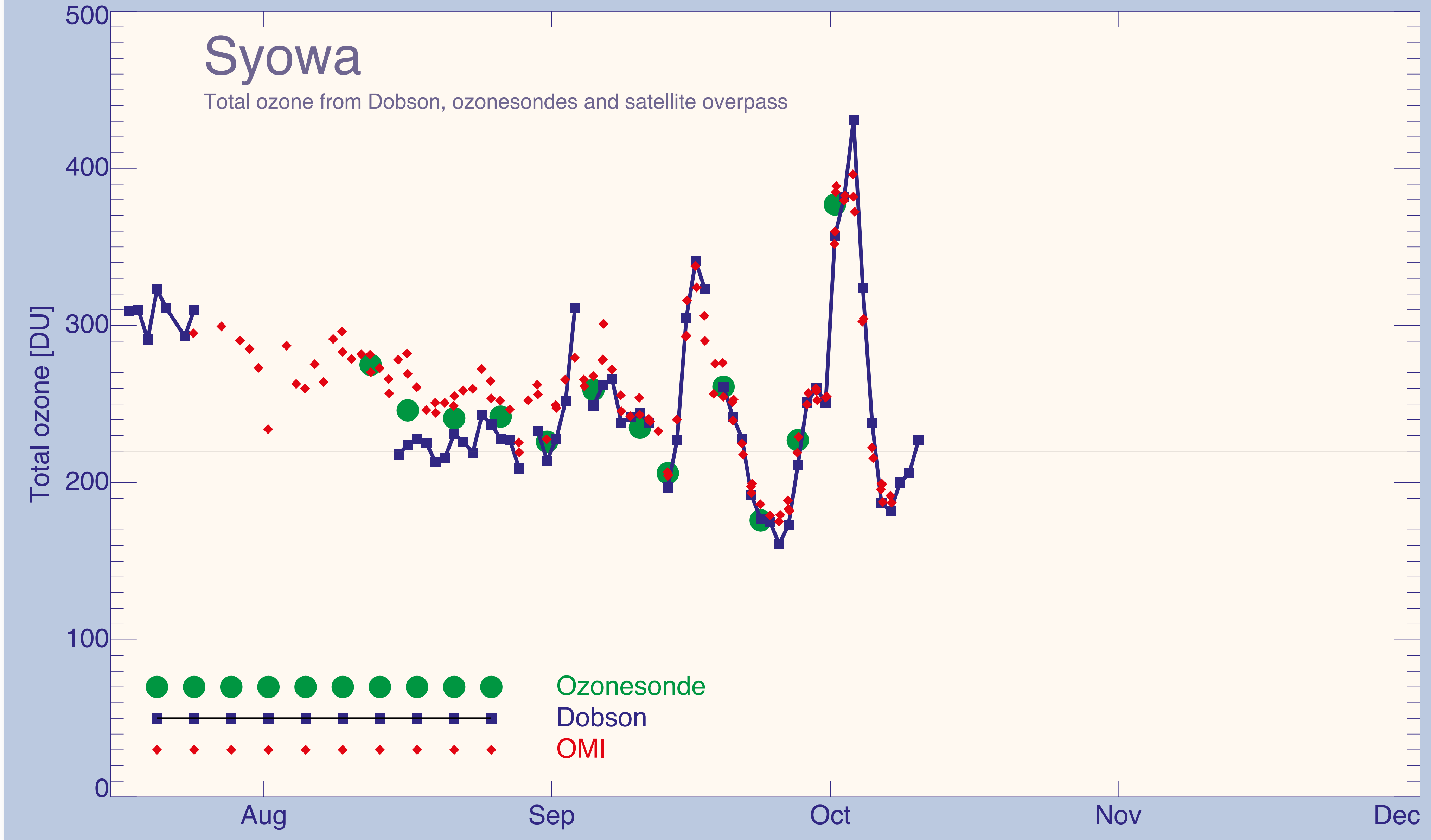


Figure 45. Total ozone observations carried out at Syowa from mid July 2013 with a Dobson spectrophotometer (blue line and squares) and with electrochemical ozonesondes (green circles). Satellite overpass data from the OMI instrument on board the AURA satellite are shown for comparison (red diamonds).

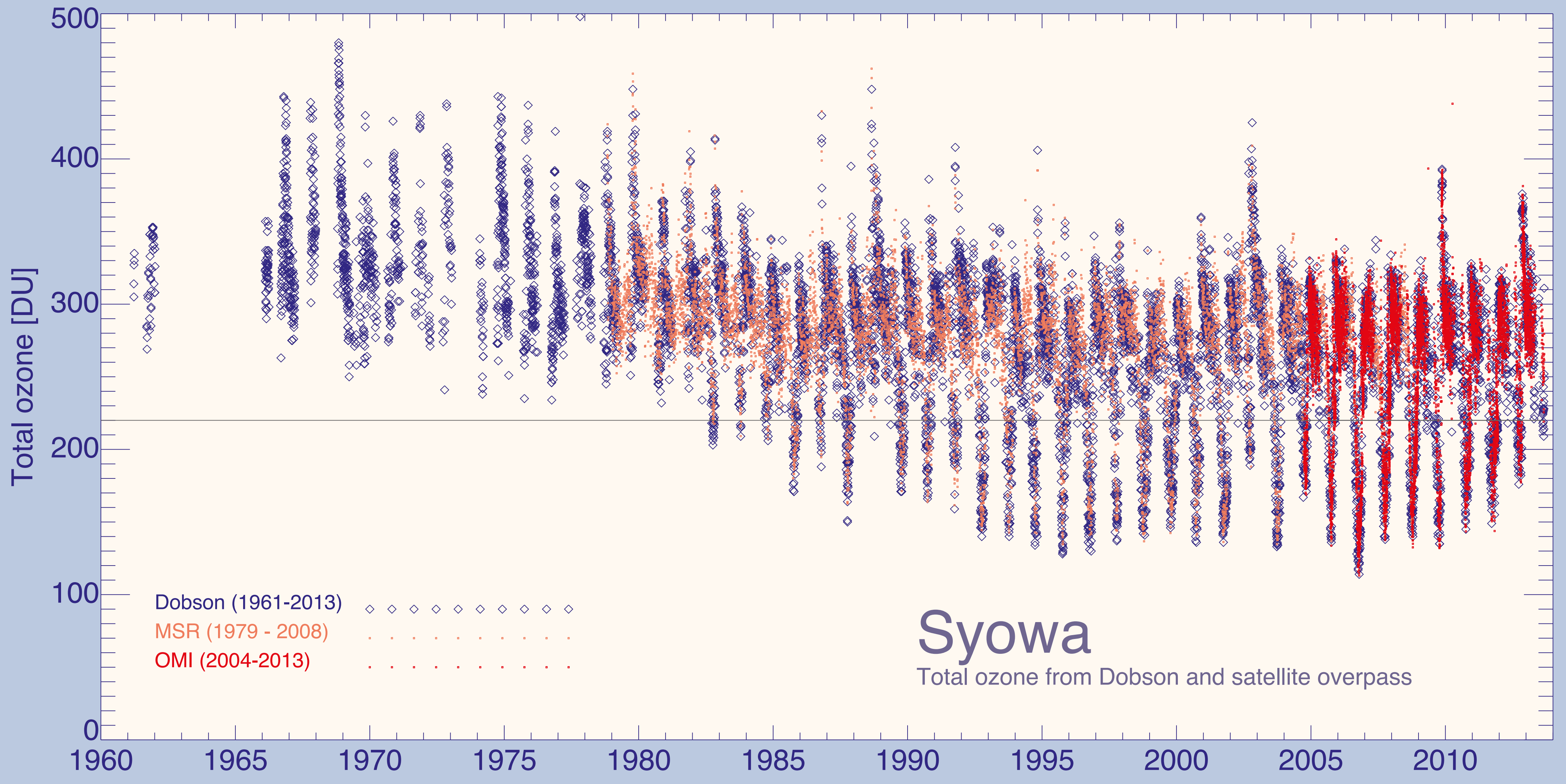


Figure 46.Total ozone observations carried out at Syowa since 1961 with Dobson instruments compared to satellite overpass data (KNMI Multi-Sensor Reanalysis from 1979 - 2008 and from OMI from 2004-2013).

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 in August and September are shown in **Figure 47**. On 21 August the ozone partial pressure is around 17 mPa at 20 km. On 4 September it has dropped to around 10 mPa and on 17 September it has dropped further to 2 mPa at about 22 km altitude. The partial ozone column between 12 and 20 km dropped from 133 to 65 DU between the two dates.

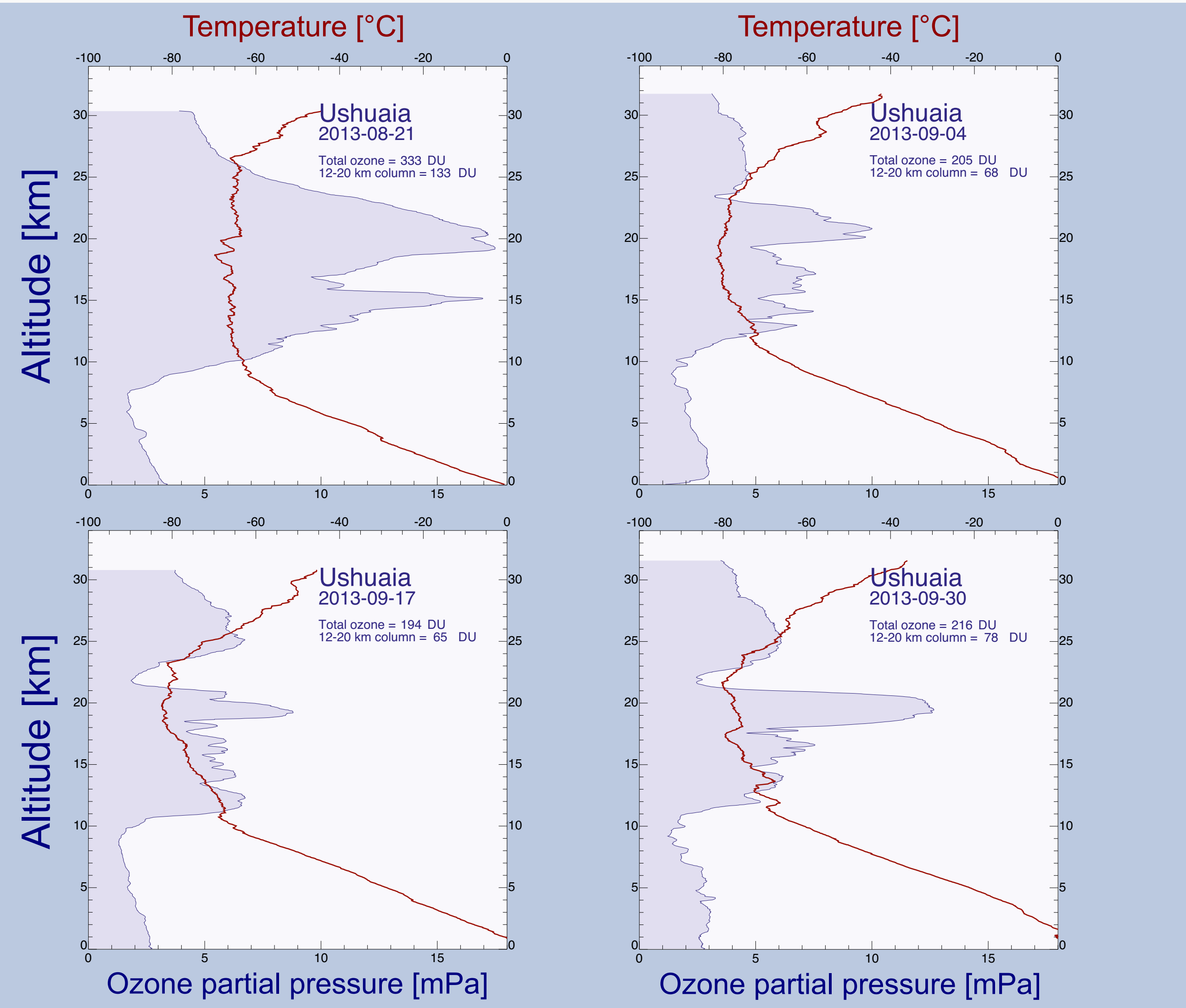


Figure 47.Ozonesonde profiles measured at the Argentine GAW station Ushuaia between 21 August and 30 September. The plots are produced at WMO based on data submitted by the National Meteorological Service of Argentina.

Figure 48 shows maps of BASCOE model calculated ozone mixing ratios for the two dates. One can see that on 21 August Ushuaia was located outside the vortex. On 17 September the station is inside the vortex. One can also see that the air masses inside the vortex in general have become much more depleted in ozone compared to 21 August. The total ozone columns derived from the sondes agree very well with columns from OMI overpass data on most days. On 21 August total ozone derived from the ozonesonde was 333 DU and from OMI it was 343 DU. On 4 September the ozone column derived from the sonde was 205 DU and from the OMI overpass it was 222 DU. On 17 September total ozone from the ozonesonde is 194 DU and from two OMI overpasses on that day the average is 238 DU. On 30 September the total ozone calculated from the sonde is 216 DU and from OMI overpass it is 241 DU.

Figure 49 on the next page show total ozone as measured by Dobson, satellite and ozonesondes since May 2013. One can see the episodes when the vortex passes close to the station resulting in a rapid dip in total ozone.

Figure 50 on the page after next shows the entire time series of MSR overpass data for Ushuaia, starting in late 1978 until 2008, the OMI overpass data from 2004 until present and the Dobson time series from September 1994 until present.

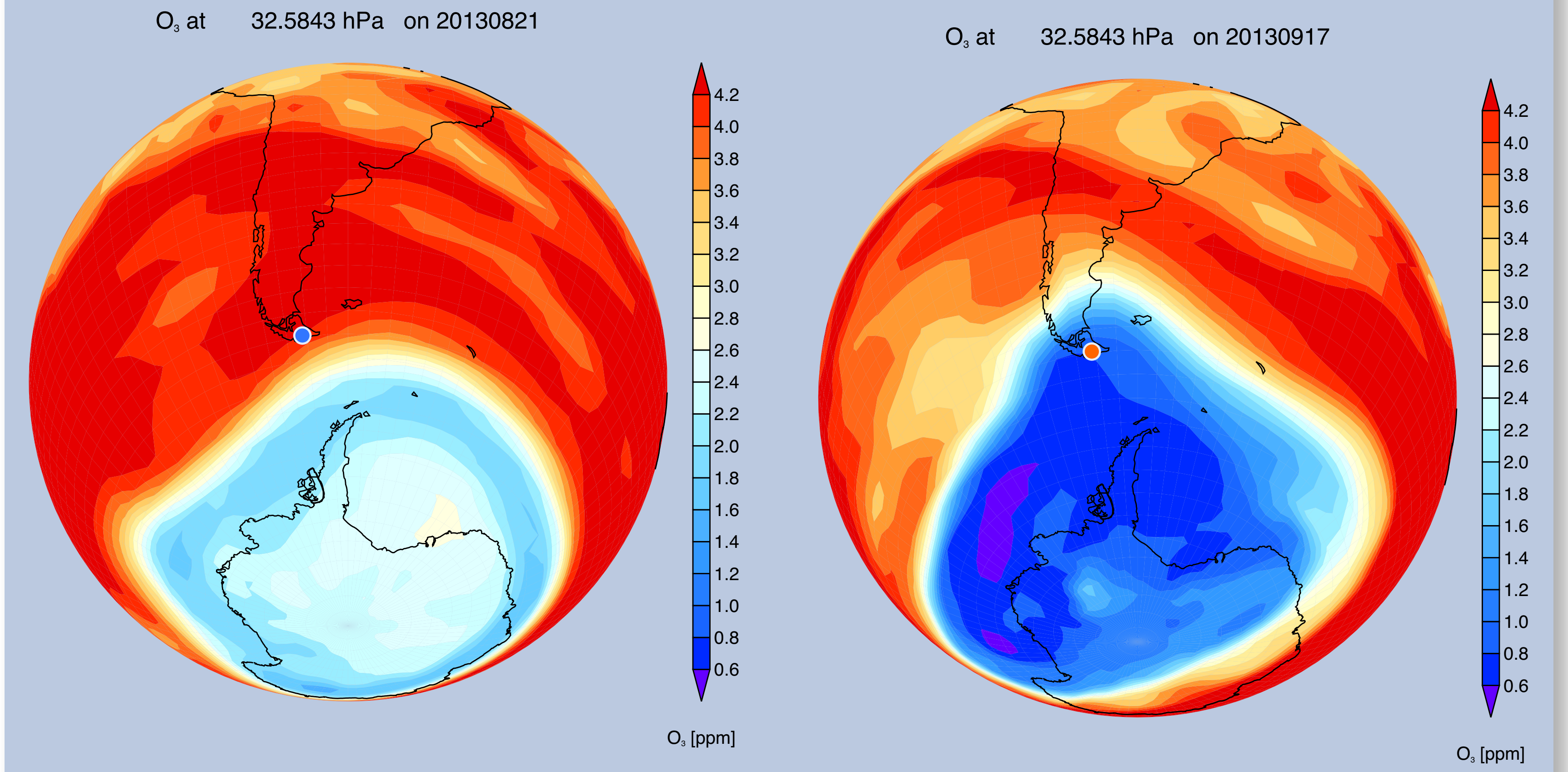


Figure 48. Ozone mixing ratio as calculated by the BASCOE data assimilation model for the dates 21 August and 17 September. This model assimilates data from the MLS instrument on AURA. The Ushuaia station is indicated with a coloured circle. In addition to the different situations for Ushuaia on these two dates one can also clearly see the progress of ozone depletion inside the polar vortex between the two dates.

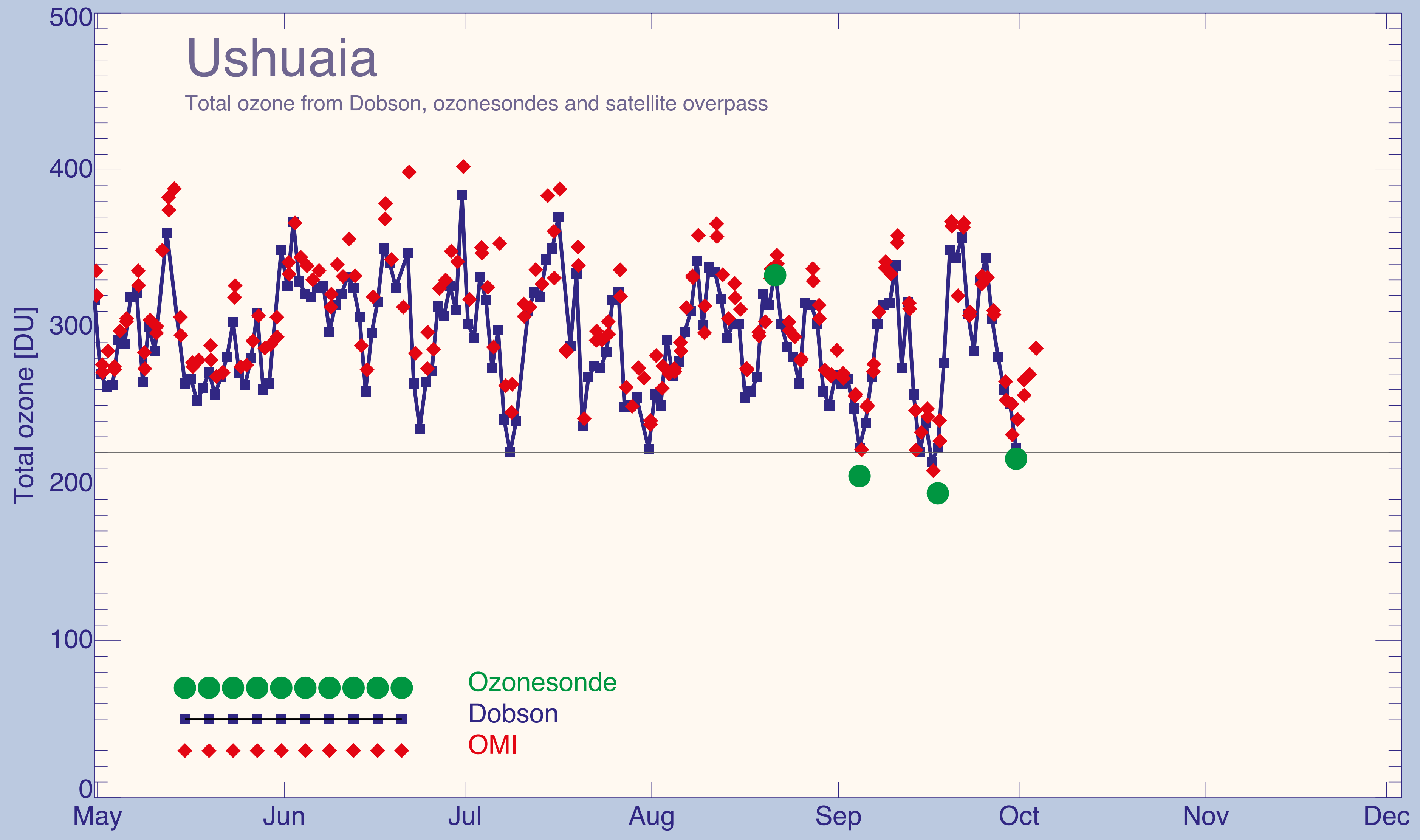


Figure 49. Total ozone over Ushuaia in 2013. The green circles show total ozone deduced from ozone balloon soundings, the blue line shows the Dobson observations (until 30 September) and the red diamonds show OMI overpass data (until 3 October).

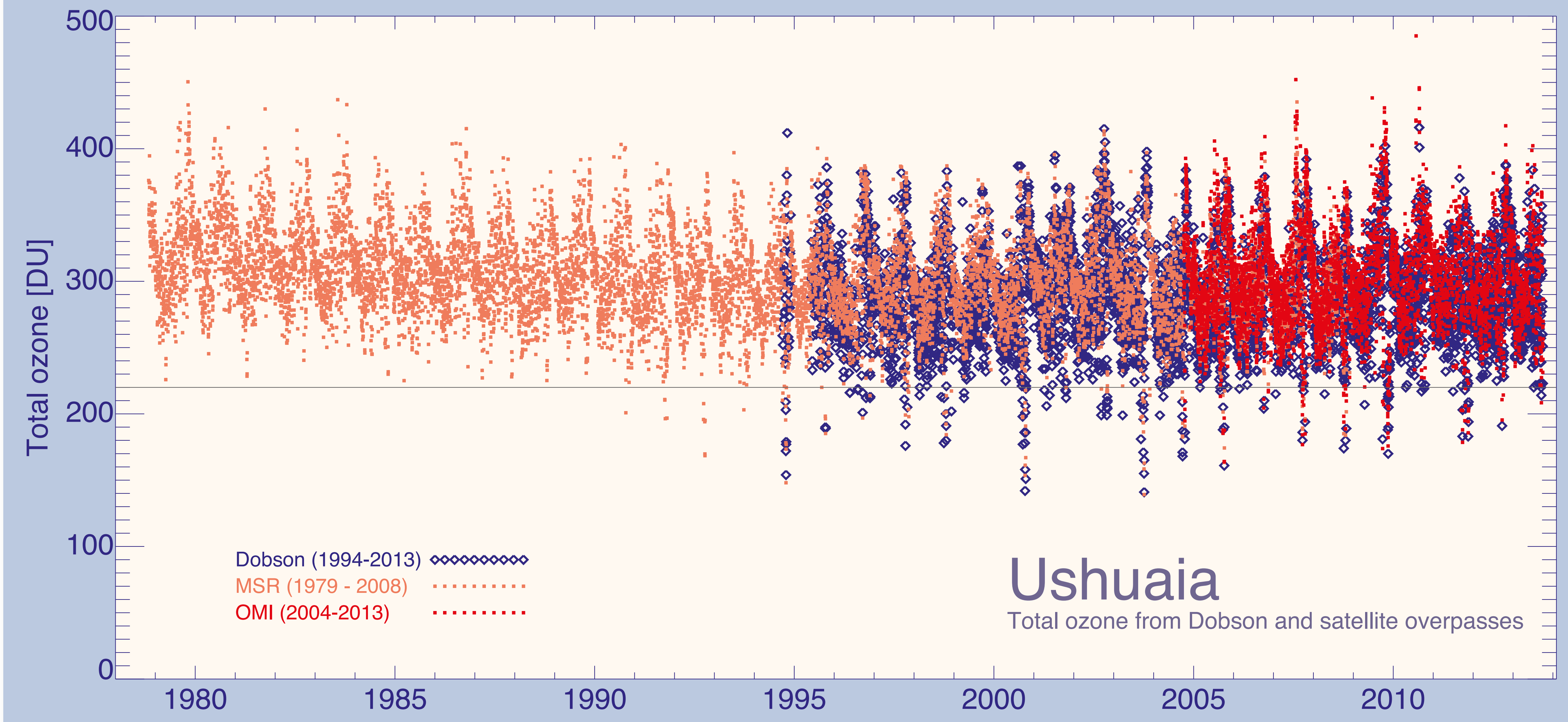


Figure 50. Total ozone observations carried out at Ushuaia with Dobson instruments compared to satellite overpass data (KNMI Multi-Sensor Reanalysis from 1979 - 2008 and from OMI from 2004-2013). One can clearly see episodes where the ozone hole has passed over Ushuaia with total ozone columns dropping as low as approx. 140 DU on some occasions.

The Vernadsky station seen from the sea.

Vernadsky station (65.2458°S, 64.2573°W) is run by the National Antarctic Scientific Centre of Ukraine. Total ozone is measured with a Dobson spectrophotometer. The data are processed by the British Antarctic Survey. Total ozone observations have been carried out here since mid 1957. Observations recommenced after the polar night on 21 July, with initial results around 270-290 DU. During August total ozone values have oscillated between 178 DU (31 Aug) and 287 DU (7 Aug). The first five days of September total ozone was well below the 220 DU threshold. The data from Vernadsky are reported to WMO's Global Telecommunication System (GTS) daily. The Dobson and OMI overpass data are shown in **Figure 51**. On the cover page is shown the entire time series at Vernadsky starting in 1957 together with satellite overpass data from KNMI's Multi-Sensor Reanalysis from 1979 to 2008 and OMI overpass data from 2004 until now.

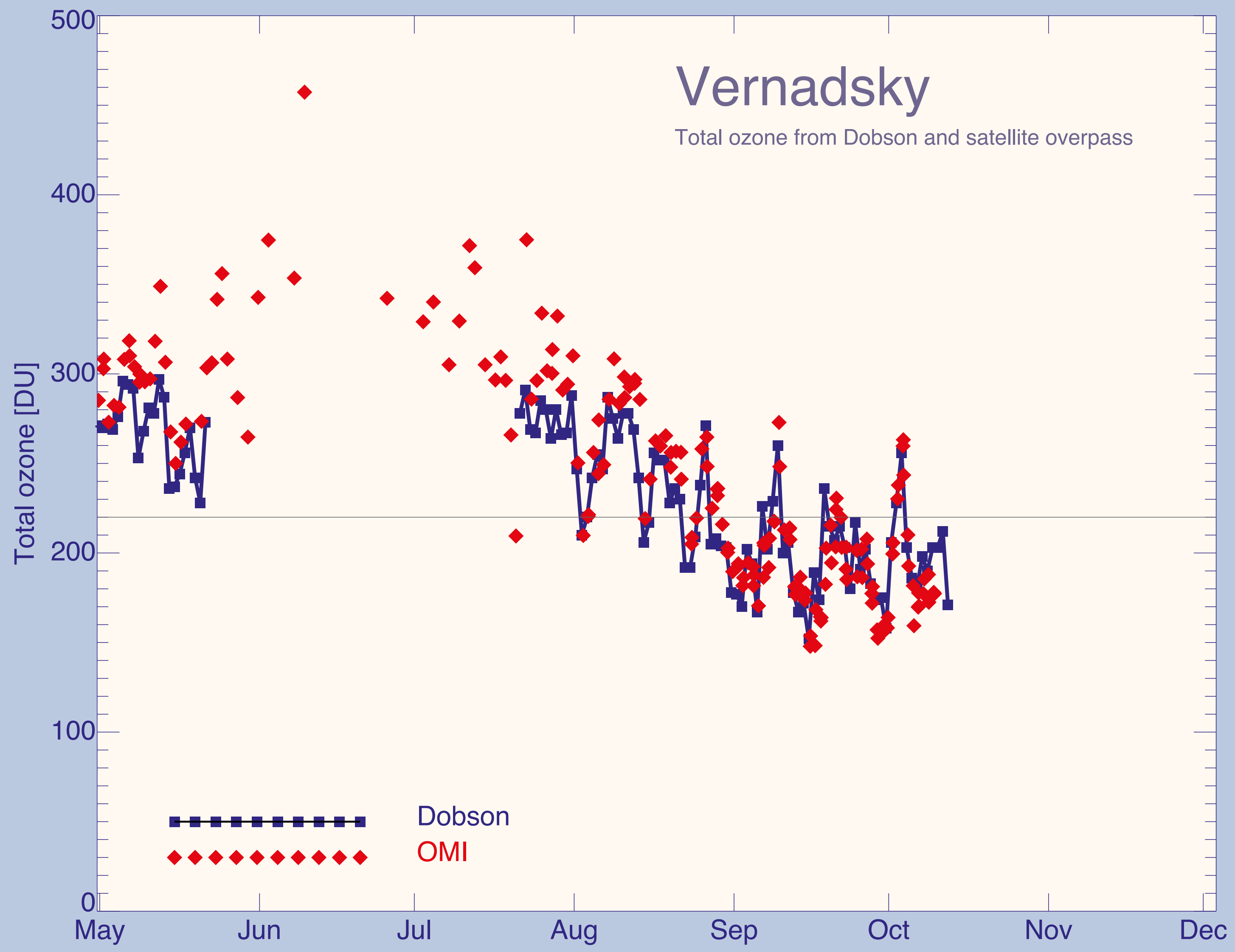


Figure 51. Total ozone over Vernadsky in 2013. The blue line shows the Dobson observations (until 11 October) and the red diamonds show OMI overpass data (until 9 October).

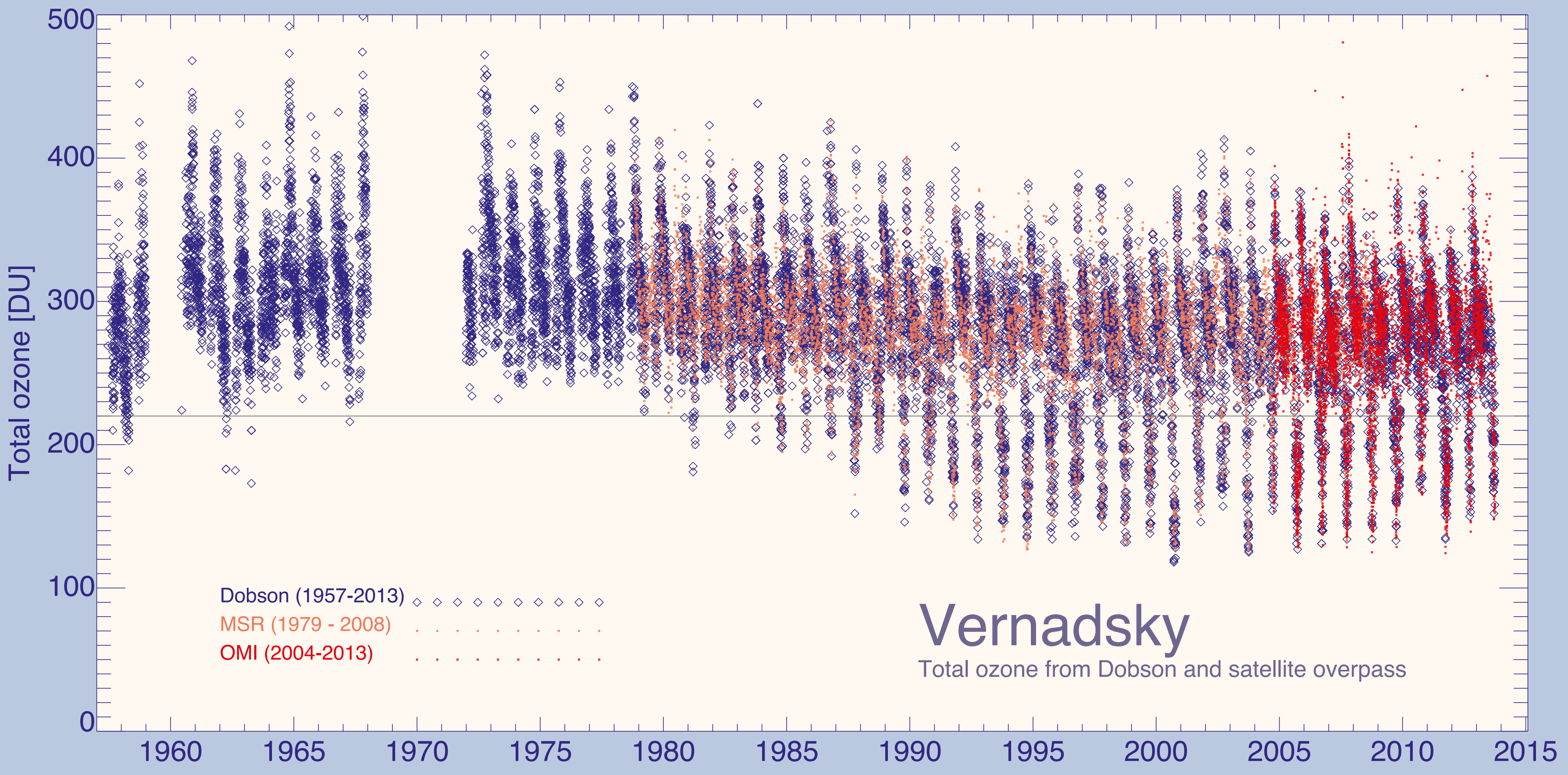


Figure 52. Total ozone measurements from the Vernadsky station. On the plot are shown the Dobson time series (blue diamonds) together with satellite overpass data from the Multi-Sensor Reanalysis (1979-2008) of the Netherlands Meteorological Institute (orange dots) and from the OMI instrument (2004-now) on board the AURA satellite (red dots). This long time series is an excellent example of the value of the long term measurements which we need to see the ozone depletion phenomenon in the long term perspective and which we need to detect ozone recovery.

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

Vostok (78.464422°S, 106.837328°E, 3448 masl) is located near the South Geomagnetic Pole, at the center of the East Antarctic ice sheet. Although this is a Russian research station, scientists from all over the world conduct research here. One of the primary projects at this site, a coordinated Russian, French and American effort, is drilling ice cores through the 3,700 m thick ice sheet. These ice cores contain climate records back to almost half a million years before present.

Total ozone is measured at Vostok with a M-124 filter instrument. Data from 6 to 30 September are currently available. During this time period, total ozone was below the 220 DU threshold on 16 days. The minimum in September was 149 DU measured on the 28th. **Figure 53** shows the M-124 data of September 2013 together with satellite overpass data from the OMI instrument on board the AURA satellite.

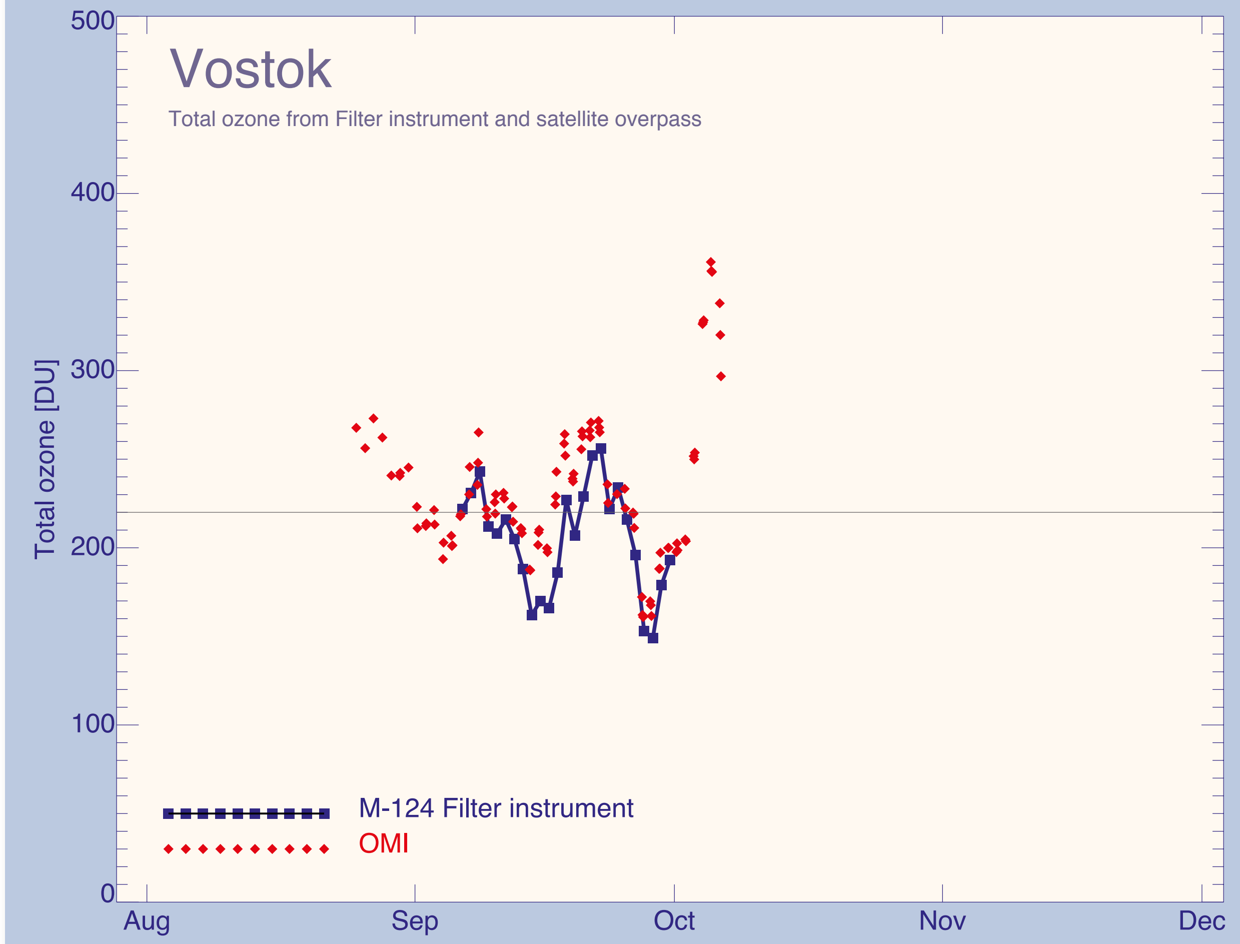
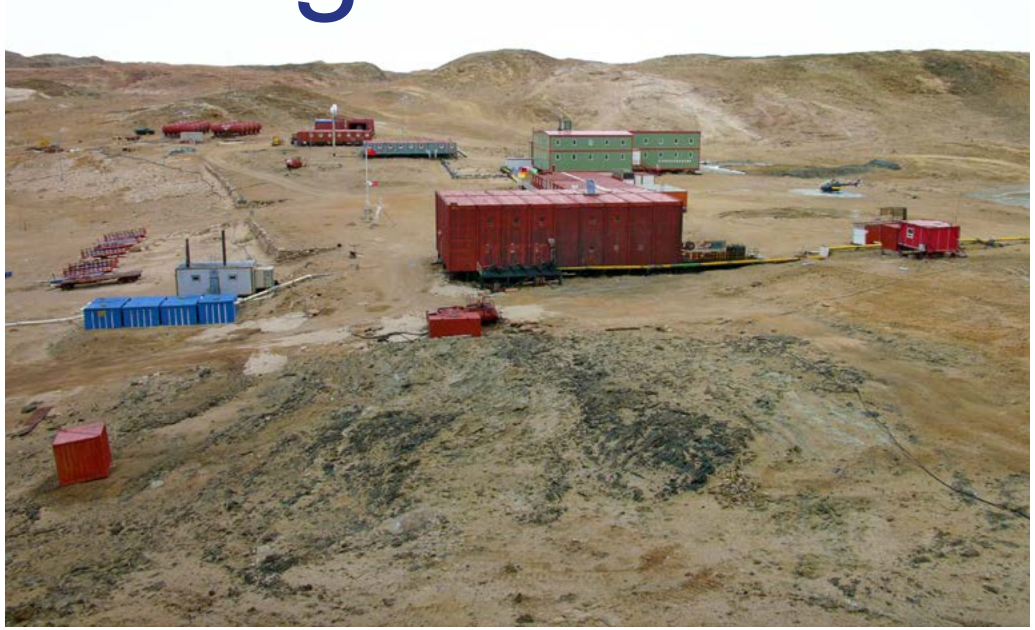


Figure 53. Total ozone observations carried out at the Vostok ice drilling site in 2013 with an M-124 filter instrument compared to satellite overpass data from OMI.

Zhong Shan



The Zhong Shan station.

At the Chinese GAW station Zhong Shan (69.3731°S, 76.3724°E) total ozone is measured with a Brewer spectrophotometer. The measurement series started in March 1993. In 2013 the observations started up on 23 August after the polar night. The first direct sun measurement was carried out on 26 August. The total ozone value on that day was 226 DU. After that, direct sun measurements have varied between 178 DU and 397 DU. The station is often close to the vortex edge, and this can lead to large changes in total ozone. Total ozone has been below the 220 DU threshold on six days so far this season. **Figure 54** shows the Brewer measurements (blue) compared to OMI overpass data (red).

The entire time series from 1993 until now together with satellite overpass data from KNMI's Multi-Sensor Reanalysis (1979-2008) and from the OMI instrument on AURA (2004-now) is shown in **Figure 55**.

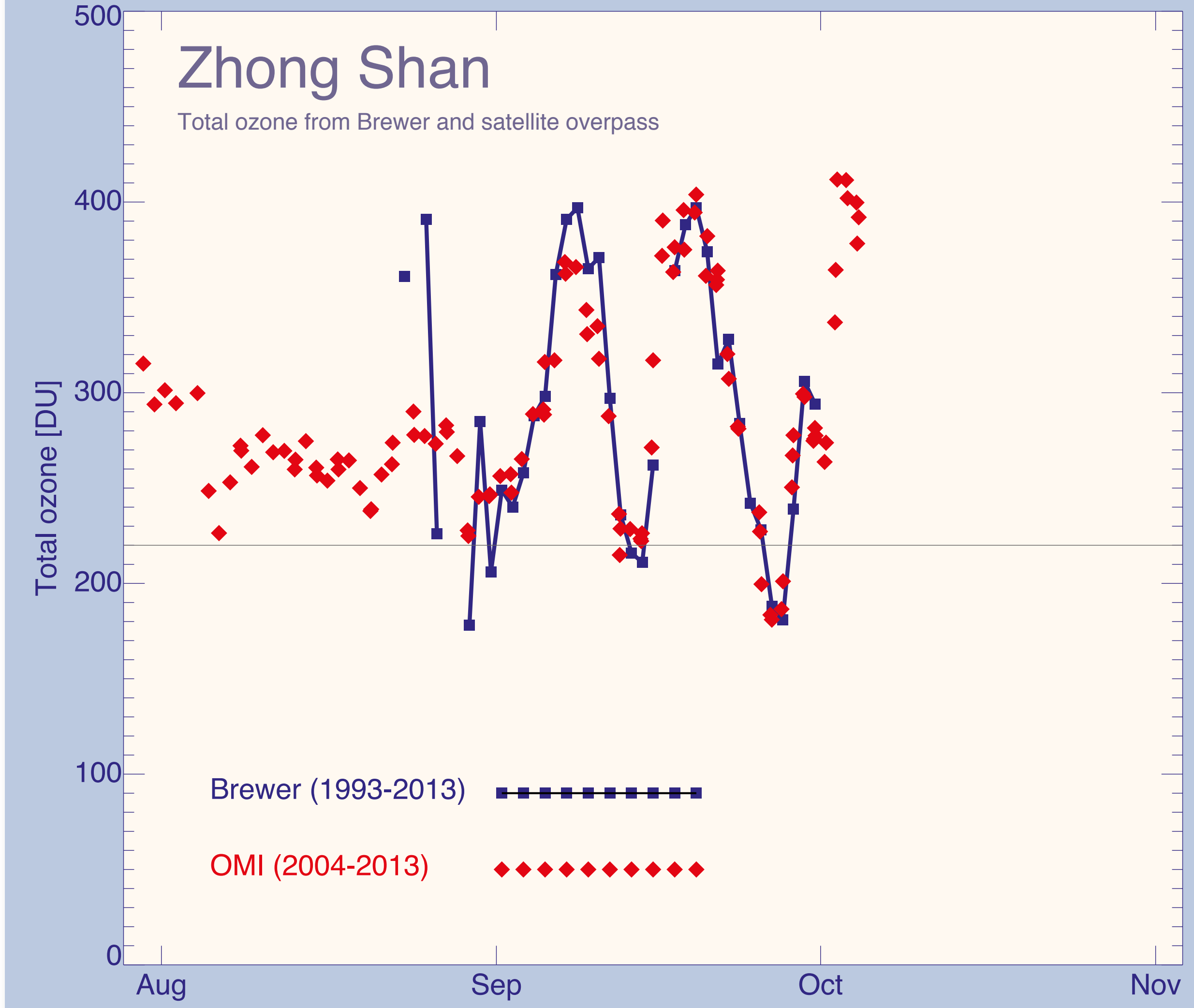


Figure 54. Total ozone observations carried out at Zhong Shan in 2013 with a Brewer instrument compared to satellite overpass data from OMI.

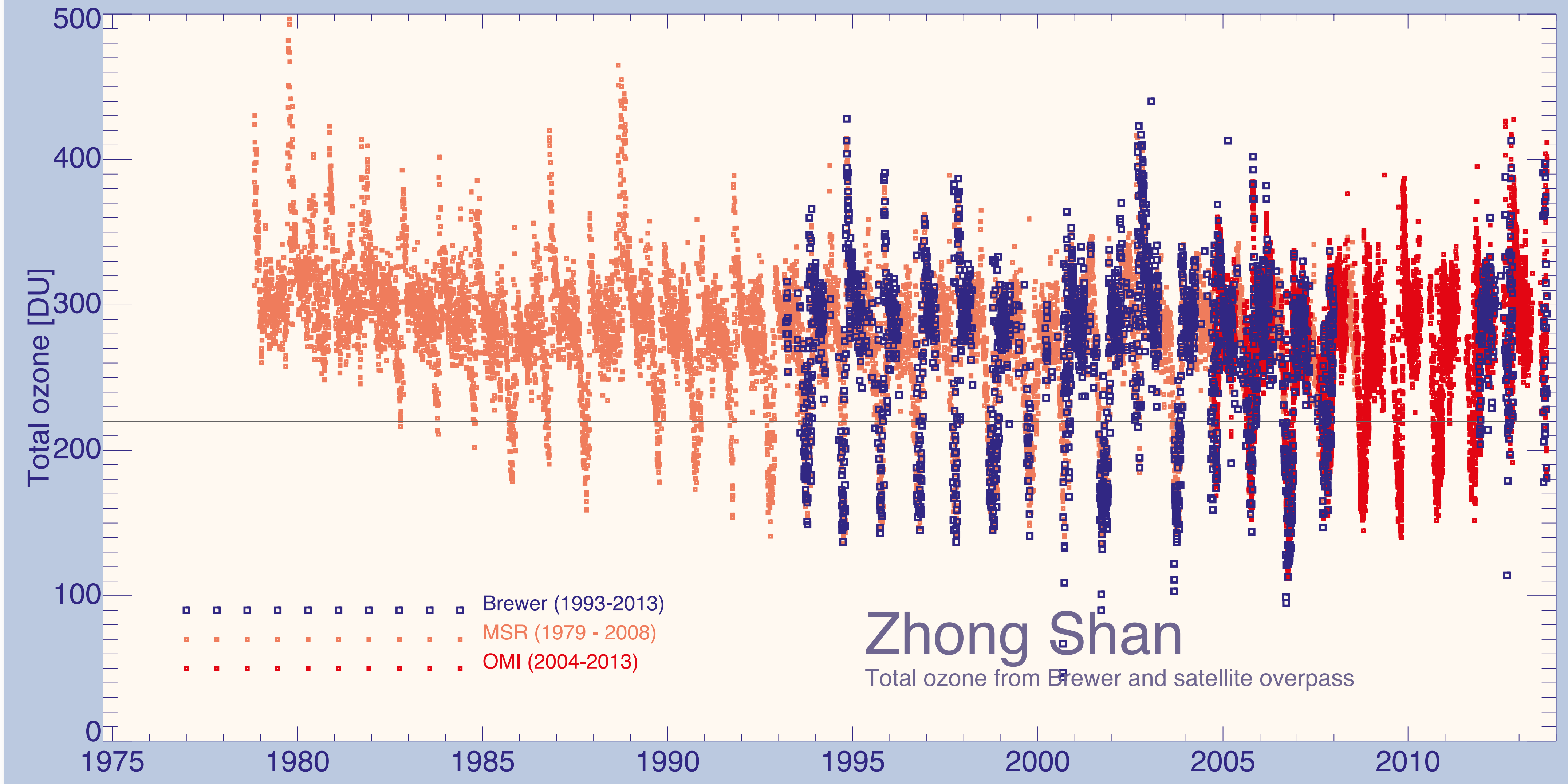


Figure 55. Total ozone observations carried out at Zhong Shan since 1993 with Brewer instruments compared to satellite overpass data (KNMI Multi-Sensor Reanalysis from 1979 - 2008) and OMI (2004-2013).

Chemical activation of the vortex

Data assimilation model results

The degree of activation in the south polar vortex is now over the peak and on the way down. The sun is back after the polar winter all over the continent and ozone depletion is still going on.

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

The BASCOE data assimilation system is run daily and assimilates the offline dataset (level-2, v3.3) retrieved from the Aura-MLS instrument. While delivered a few days later than the NRT stream, the offline dataset includes several species: O_3, H_2O, HNO_3, HCl, HOCl, ClO and N_2O. More information about the MACC project and the BASCOE model with references can be found here: http://macc.aeronomie.be/4_NRT_products/3_Models_changelogs/BASCOE.php

Figure 56 (upper row) shows the extent of removal of hydrochloric acid (HCl), which is one of the reservoirs for active chlorine, on five different dates over the course of the season (1 June, 1 July, 1 August, 2 September and 5 October) at the 46.4 hPa level. This isobaric level corresponds to an altitude of approx. 18.5 - 19.5 km inside the south polar vortex. As can be seen from the figure, HCl is somewhat depleted already on 1 June, much more depleted on 1 July and almost completely removed inside the vortex in early August and early September. On 5 October there are still some small regions that are depleted in HCl but also large area inside the vortex where HCl has reformed. Removal of HCl is an indicator of chemical activation of the vortex.

Another indicator of vortex activation is the amount of chlorine monoxide (ClO). It should be noted, however, that ClO dimerises and forms $(ClO)_2$ in darkness. The dimer is easily cracked in the presence of sunlight. ClO will therefore be present in the sunlit parts of the vortex, whereas the dark areas will be filled with $(ClO)_2$. The second row on the next page shows the mixing ratio of ClO on the same dates as above. Please note that these maps show the amount of ClO at one point in time (12 UT). They will therefore look different from the ClO maps from the MLS instrument on AURA because those maps use data from several orbits over the course of the day so that ClO typically shows up in two lobes on opposite sides of the vortex.

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

The last row shows the amount of nitric acid (HNO_3) in the polar vortex. Removal of gaseous HNO_3 is an indication that this compound is condensated in the form of polar stratospheric clouds (nitric acid trihydrate, $HNO_3 \cdot 3H_2O$). The removal of nitric acid starts when the PSC temperatures set in during May. By 1 June HNO_3 is already partially depleted inside the vortex and in early July, August and September the vortex is very low in HNO_3. In early October the PSC temperatures are almost gone and HNO_3 starts to come back to the gas phase.

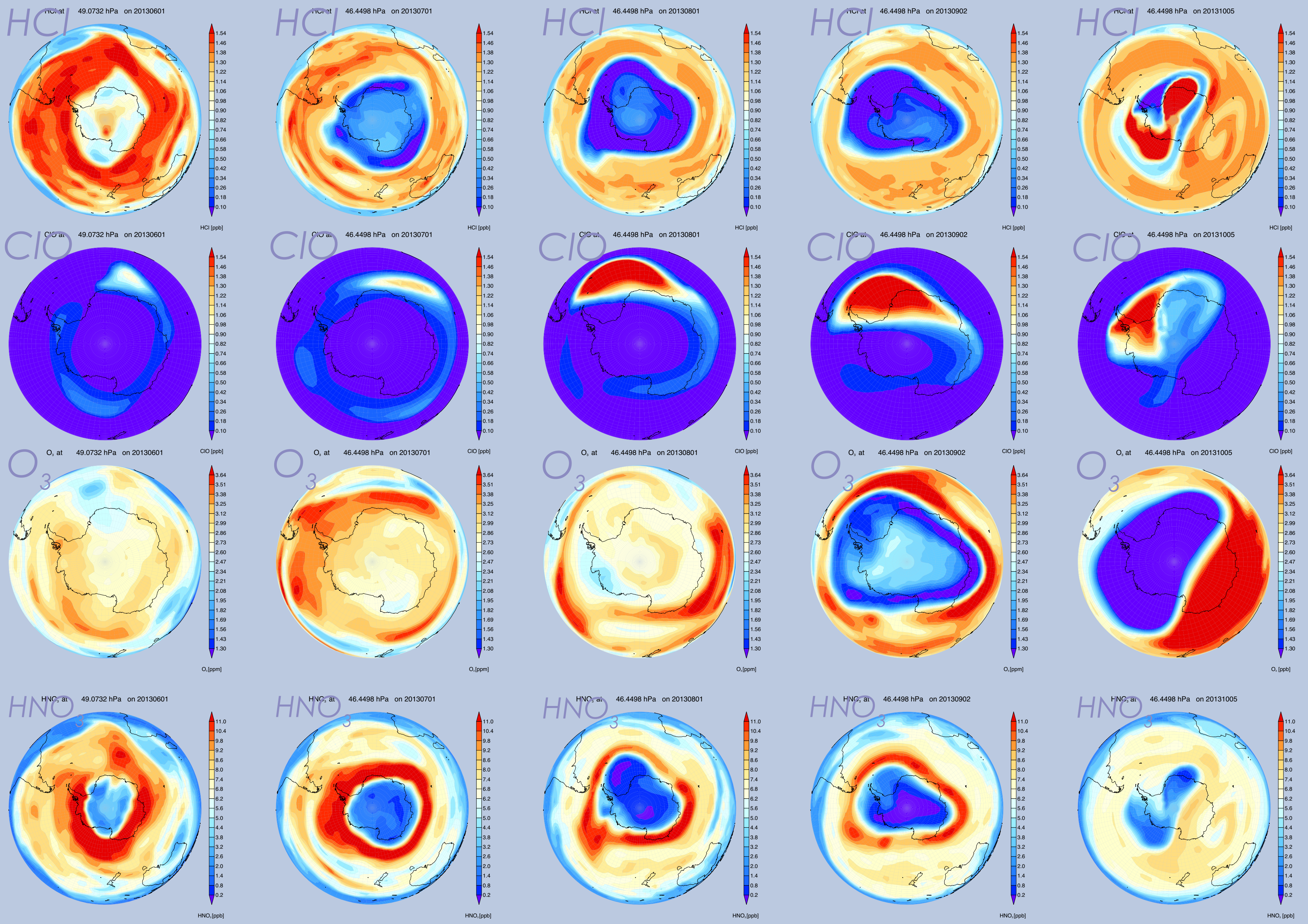


Figure 56. Results from the BASCOE data assimilation model. This model is run daily as part of the MACC-II project, which is funded by the European Commission and coordinated by ECMWF. Thanks to the assimilation of the Aura-MLS offline retrievals, BASCOE delivers analyses of ozone, ClO, H_2O, HNO_3, HCl, HOCl and N_2O with a delay of four days. These are freely available at the website of the MACC stratospheric ozone service: http://www.copernicus-stratosphere.eu

The upper row shows hydrochloric acid, the second row shows ClO, the third shows ozone and the last row shows nitric acid. All four rows show the temporal development from 1 June to 5 October with intermediate frames shown for 1 July, 1 August and 2 September. Please note that the map projection used for ozone and ClO is different than for the other two compounds. On 25 June 2013, ECMWF changed the number of levels in their model. This had as a consequence that the BASCOE data are not available on exactly the same levels before and after that date. The data for 1 June are at 49.1 hPa, whereas the other dates are given at 46.4 hPa.

Ozone hole area and mass deficit

Ozone hole area

The area of the region where total ozone is less than 220 DU ("ozone hole area") as deduced by KNMI from the GOME-2 instrument on Metop (and SCIAMACHY on Envisat in the past) is shown in **Figure 57**. During the first half of August 2013, the area increased more slowly than at the same time in many of the recent years. However, during the latter half of August it has increased faster than in 2010, 2011 and 2012. It is still too early to say anything certain about how the ozone hole area will develop over the next weeks.

Figure 58 (next page) shows the ozone hole area as deduced by NASA from the OMI satellite instrument. Here it can be seen that the 2013 ozone hole in August is increasing more rapidly than in 2010 and 2012 and similarly to 2011. The discrepancy between the KNMI and NASA figures is due to different ways of treating the areas that are still in darkness. As the sun comes back to the whole polar region the two calculations will converge.

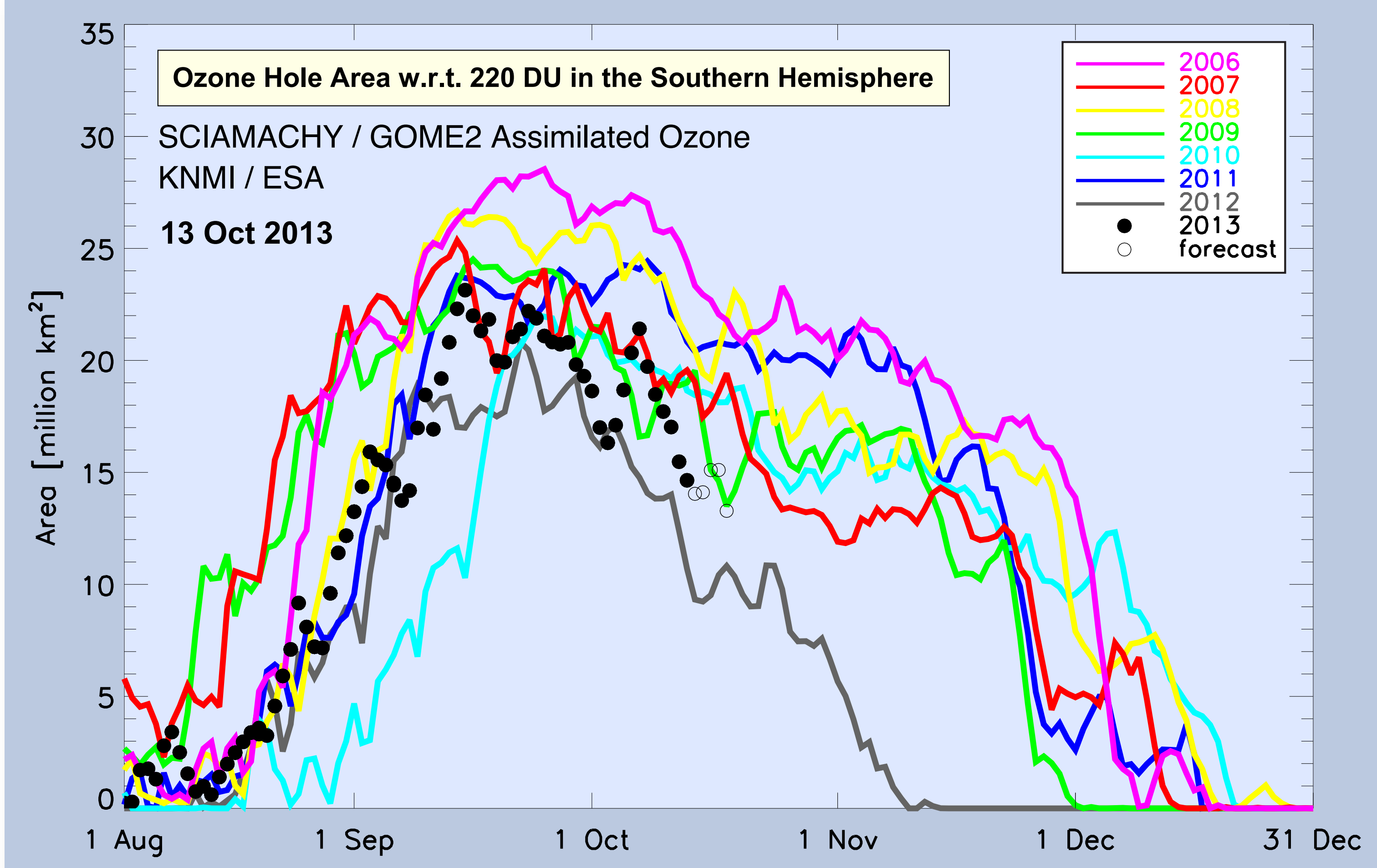


Figure 57. Ozone hole area for the years from 2006 to 2013 (black dots). The ozone hole area is the area of the region where total ozone is below 220 DU. The open circles represent a forecast for the five next days. This plot is produced by KNMI and is based on data from the GOME-2 and SCIAMACHY satellite instruments.

Ozone mass deficit

The ozone mass deficit is defined as the amount of ozone (measured in megatonnes) that has to be added to the ozone hole in order for total ozone to come up to 220 DU in those regions where it is below this threshold. The ozone mass deficit as calculated by KNMI based on GOME-2 data is shown in **Figure 59**. The same parameter as calculated by NASA from OMI data is shown in **Figure 60**.

Long term statistics

In order to assess the severity of the ozone hole one can average the ozone hole area over various representative time periods. Several time periods have been used by various investigators, and four such time periods are commonly used to calculate the average ozone hole area for the years 1979 to present based on the Multi-Sensor Reanalysis data and SCIAMACHY and GOME-2 data and calculated at KNMI. So far only the earliest time period (last ten days of September) could be calculated. The result of this analysis for 21-30 September ozone hole area is shown on the cover page.

It can be seen that the average ozone hole area over this period was larger in 2013 compared to 2012 but smaller than in 2010 and 2011. With the exception of 2002, 2004 and 2012, which all experienced unusually small ozone holes, one has to go back to 1990 to find a smaller ozone hole area for the 21 - 30 September time period.

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 61. The time period is the same as that used for the ozone hole area calculations.

Now, with the exception of 2002, 2004, 2010 and 2012, the 2013 ozone hole is the weakest ozone hole since 1991 depending on which of the metrics is considered. If one considers the last 20 ozone holes (1994-2013), 15 ozone holes have seen more ozone loss and four less ozone loss than the 2013 ozone hole.

As the season progresses it will be possible to calculate average ozone hole area and mass deficit for other time periods, the next being 7 September to 13 October.

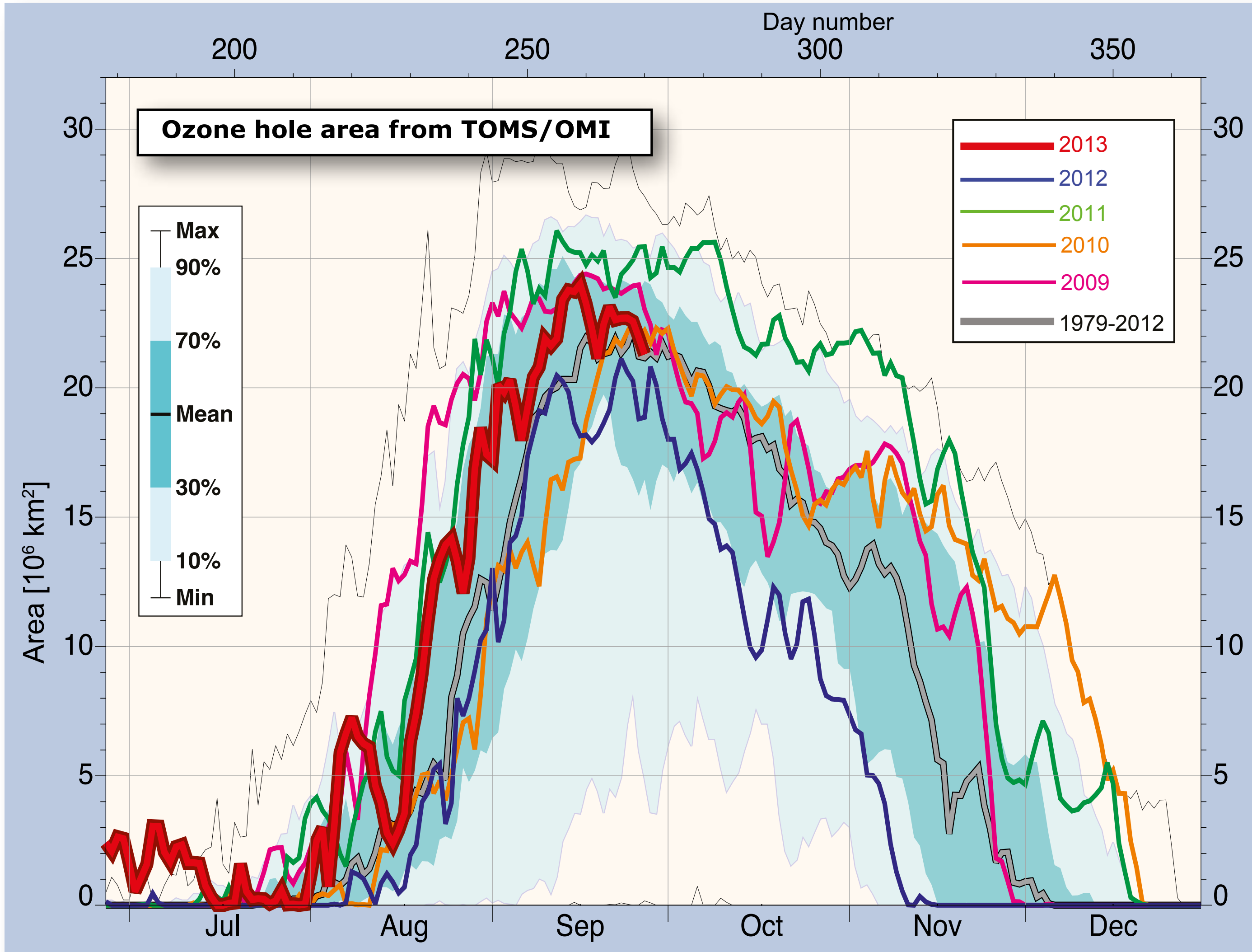


Figure 58. Area (millions of km²) where the total ozone column is less than 220 Dobson units. 2013 is showed in red (until 27 September). 2012 is shown in blue, 2011 in green, 2010 in orange and 2009 in magenta. The smooth grey line is the 1979-2012 average. The dark green-blue shaded area represents the 30th to 70th percentiles and the light green-blue shaded area represents the 10th and 90th percentiles for the time period 1979-2012. The ozone hole area reached 20.1 million km² on 2 September. 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.

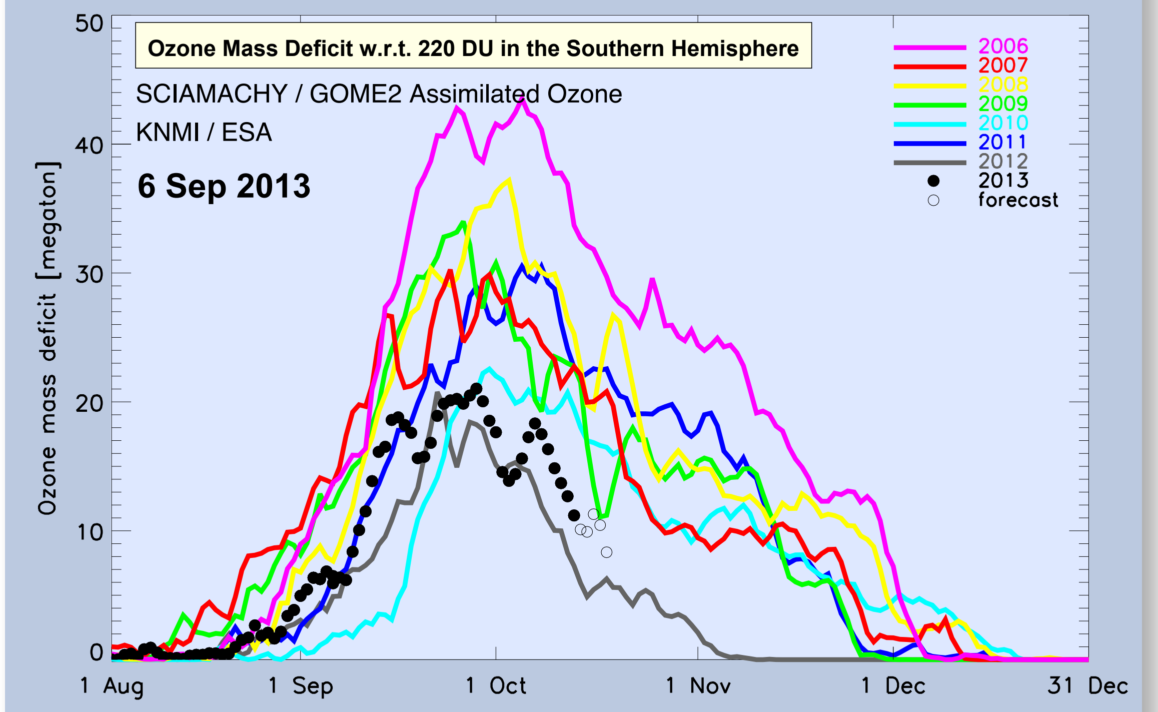


Figure 59. Ozone mass deficit (megatons) inside the Antarctic ozone hole for the years from 2006 to 2013. Data for 2013 are shown as black dots (until 13 October). The ozone mass deficit is defined as the mass of ozone that would have to be added to the ozone hole in order to bring the total ozone column up to 220 DU in those areas where total ozone is less than 220 DU. This plot is produced by KNMI and is based on data from the GOME-2 and SCIAMACHY satellite instruments.

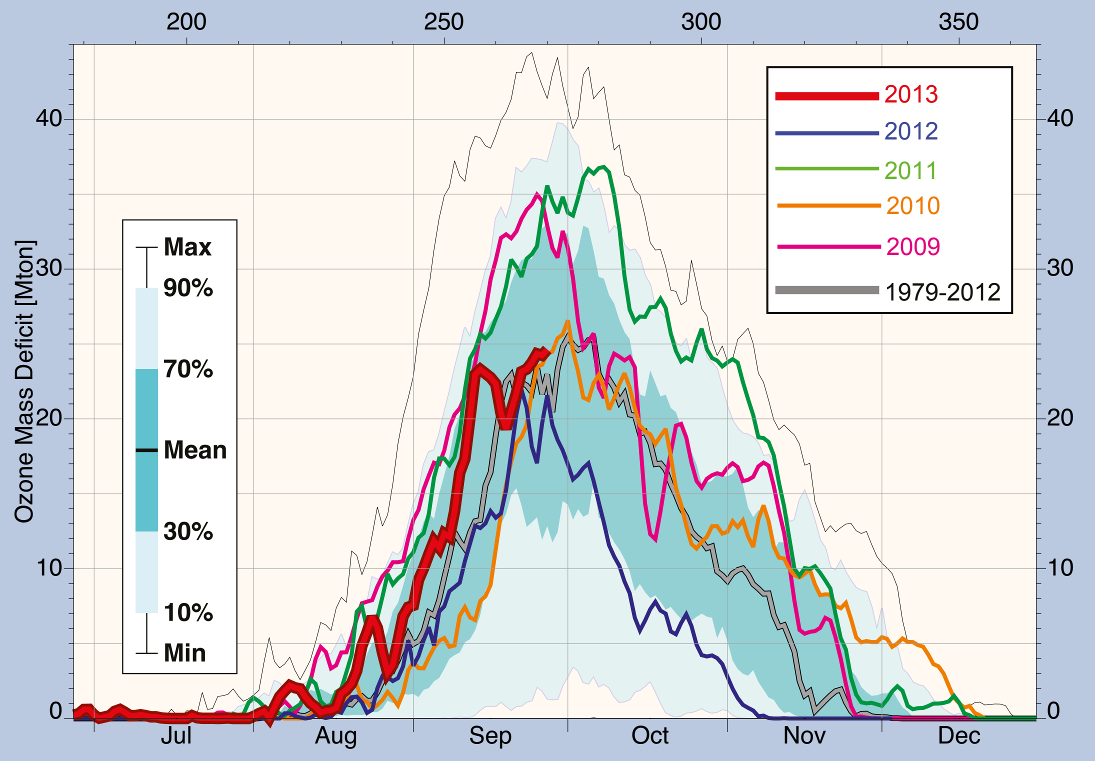


Figure 60. Ozone mass deficit (megatons) inside the Antarctic ozone hole for the years from 2009 to 2013 together with 1979-2012 statistics. Data for 2013 are shown in red (until 27 September). The ozone mass deficit is defined as the mass of ozone that would have to be added to the ozone hole in order to bring the total ozone column up to 220 DU in those areas where total ozone is less than 220 DU. The plot is made at WMO based on data downloaded from the Ozonewatch web site at NASA. The data are based on ozone observations from the OMI instrument (for recent data) and from various TOMS instruments (historical data).

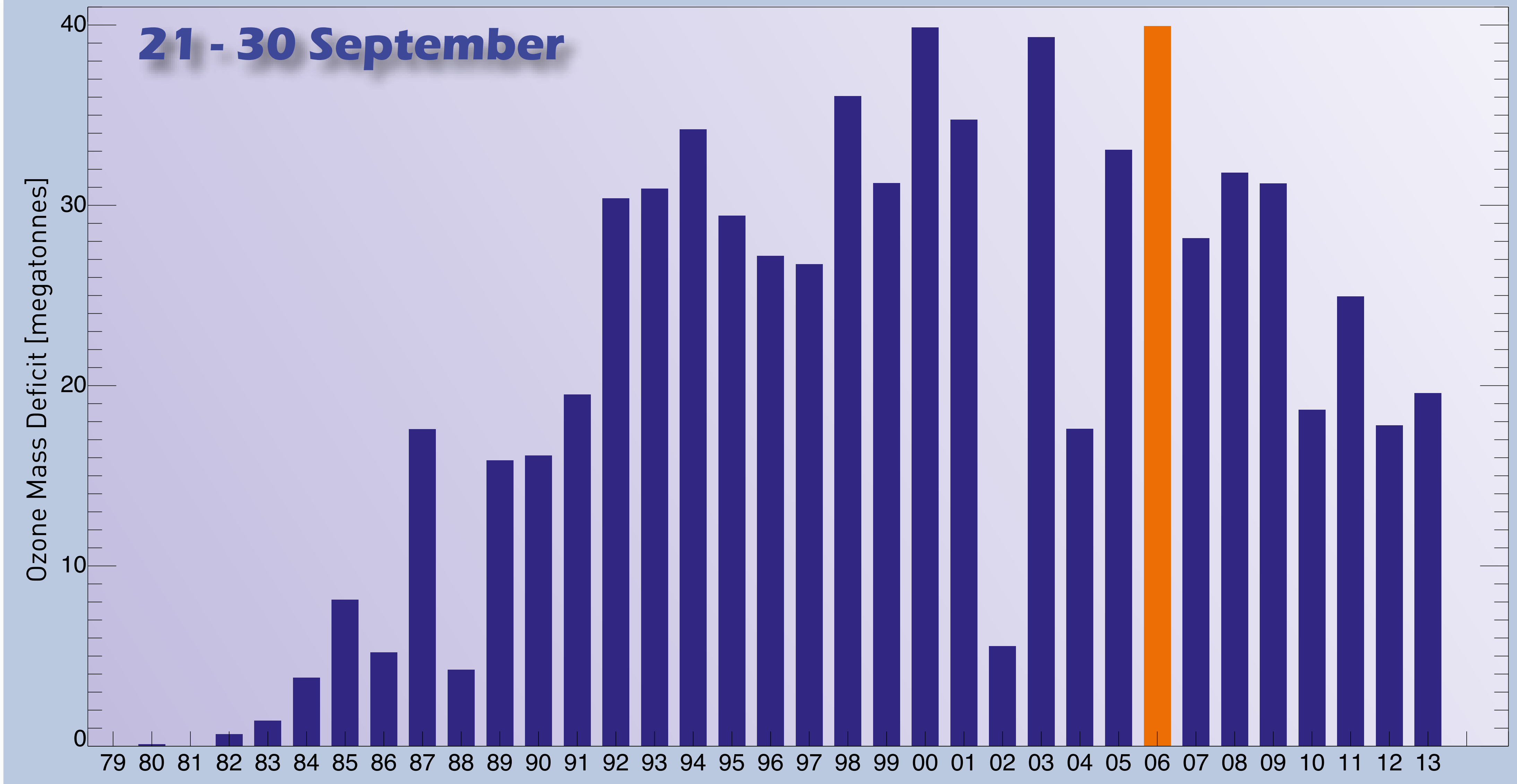


Figure 61. Average ozone mass deficit for the time period 21-30 September. The data are calculated at KNMI from the multi-sensor reanalysis (MSR) and GOME-2 data. The plot is produced at WMO.

UV radiation

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

Distribution of the bulletins

The Secretariat of the World Meteorological Organization (WMO) distributes Bulletins providing current Antarctic ozone hole conditions beginning 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, Rio Gallegos, San Martin, Ushuaia), Argentina/Finland (Marambio), Argentina/Italy/Spain (Belgrano), Australia (Macquarie Island and Davis), China/Australia (Zhong Shan), France (Dôme Concordia, Dumont d'Urville and Kerguelen Is), Germany (Neumayer), Japan (Syowa), New Zealand (Arrival Heights), Russia (Mirny, Novolazarevskaja and Vostok), Ukraine (Vernadsky), UK (Halley, Rothera), Uruguay (Salto) and USA (South Pole). More detailed information on these sites can be found at the GAWSIS web site (http://www.empa.ch/gaw/gawsis).

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

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

Potential vorticity and temperature data are provided by the European Centre for Medium Range Weather Forecasts (ECMWF) and their daily T_{106} meteorological fields are analysed and mapped by the Norwegian Institute for Air Research (NILU) Kjeller, Norway, to provide vortex extent, PSC area and extreme temperature information. Meteorological data from the US National Center for Environmental Prediction (NCEP) are also used to assess the extent of PSC temperatures and the size of the polar vortex (http://www.cpc.ncep.noaa.gov/products/stratosphere/polar/polar.shtml). NCEP meteorological analyses and climatological data for a number of parameters of relevance to ozone depletion can also be acquired through the Ozonewatch web site at NASA (http://ozonewatch.gsfc.nasa.gov/meteorology/index.html).

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

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

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

Plots of daily total ozone values compared to the long term average can be found here: http://ftpmedia.niwa.co.nz/uv/ozone/ozone_lauder.png?1234

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

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

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

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

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

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The next Antarctic Ozone Bulletin is planned for 25 October 2013.