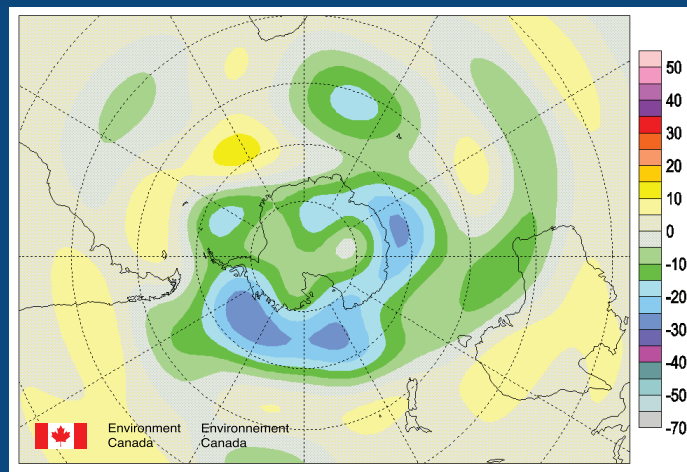
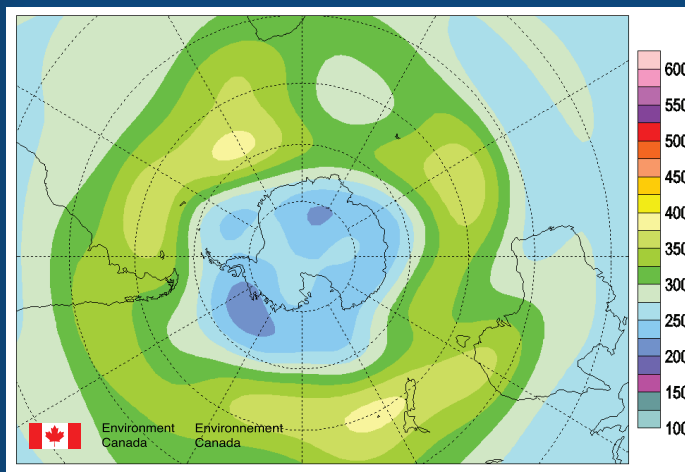


# Antarctic Ozone Bulletin

No 1/2011



Maps of Southern Hemisphere total ozone in Dobson Units (left) and its deviation in percent from the 1978-1988 mean (right). These maps are made at the WMO World Ozone and Ultraviolet Radiation Data Centre (WOUDC), hosted by Environment Canada. The maps are based on a combination of various satellite data sources and ground based observations. It can be seen that certain parts of the vortex already suffer an ozone loss in the 25-30% range. This early in the season it is the regions near the vortex edge that have experienced most ozone loss. As the sun comes back after the polar night, the negative deviations will grow larger and extend into the centre of the vortex.



Global Atmosphere Watch

19 August 2011



# Executive Summary

The daily minimum temperatures at the 50hPa level and south of 50°S have been below the 1979-2010 average since April.

The average temperature over the 60-90°S region was quite close to or below the long-term mean until the middle of July. A minor warming event in the middle of July led to temperatures rising above the long-term mean for some days. During August the 60-90°S mean temperature has decreased and is now well below the long term average.

Since the onset of NAT temperatures on 10 May the NAT area has been above the 1979-2010 average during the whole winter. The NAT area reached peaks above 27 million km<sup>2</sup> on a couple of occasions in August.

The longitudinally averaged heat flux between 45°S and 75°S is an indication of how much the stratosphere is disturbed. From April to early July the 45-day mean of the heat flux was lower than or close to the 1979-2010 average. In early July, the heat flux increased somewhat in conjunction with the minor stratospheric warming event and remained larger than the 1979-2010 average until early August. The last few days the heat flux has been smaller than the long-term average. This means that the vortex has been relatively stable so far this year and more stable than in 2010.

At the altitude of ~18km the vortex is now almost entirely depleted of hydrochloric acid (HCl), one of the reservoir gases that can be transformed to active chlorine. The polar vortex was somewhat less depleted of HCl in 2008 and

2010, as compared to 2009 and 2011. The area affected by HCl removal is somewhat larger in 2011 than in the previous years.

In the sunlit collar along the vortex edge there are regions with 1.5-1.8ppbv of active chlorine (chlorine monoxide, ClO), and ozone depletion has just started. The maximum mixing ratio of ClO is somewhat lower than in 2008 and 2009 but larger than in 2010 at the same date.

Satellite observations show that the area where total ozone is less than 220DU ("ozone hole area") is normal compared to recent years. In mid-August, the ozone hole area is larger than in 2008 and 2010 but smaller than in 2009. However, the onset of ozone depletion varies considerably from one year to the next, depending on the position of the polar vortex and availability of daylight after the polar night.

Measurements with ground based instruments and with balloon sondes show first signs of ozone depletion at some sites located close to the vortex edge. In this issue data are reported from the following stations: Arrival Heights, Dôme Concordia, Dumont d'Urville, Marambio, Neumayer, Rothera, Syowa and Vernadsky.

As the sun returns to Antarctica after the polar night, it is expected that ozone destruction will speed up. It is still too early to give a definitive statement about the development of this year's ozone hole and the degree of ozone loss that will occur. This will, to a large extent, depend on the meteorological conditions. However, the temperature

## Executive summary

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conditions and the extent of polar stratospheric clouds so far this year indicate that the degree of ozone loss will be about average in comparison to the ozone holes of the last decade.

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

## Introduction

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

The amount of water vapour in the stratosphere is very low, only 5 out of one million air molecules are water molecules. This means that under normal conditions there are no clouds in the stratosphere. However, when the temperature drops below  $-78^{\circ}\text{C}$ , 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.  $\text{HCl}$  and  $\text{HBr}$ ) into so-called active chlorine and bromine species (e.g.  $\text{ClO}$  and  $\text{BrO}$ ). These active forms of chlorine and bromine cause rapid ozone loss in sun-lit conditions through catalytic cycles where one molecule of  $\text{ClO}$  can destroy thousands of ozone molecules before it is passivated through the reaction with nitrogen dioxide ( $\text{NO}_2$ ).

When temperatures drop below  $-85^{\circ}\text{C}$ , 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  $\text{NO}_2$  under sunlit conditions. If  $\text{NO}_2$  is physically removed from the stratosphere (a process called denitrification), active chlorine

and bromine can destroy many more ozone molecules before they are passivated. The formation of ice clouds will lead to more severe ozone loss than that caused by PSC type I alone since halogen species are more effectively activated on the surfaces of the larger ice particles.

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

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

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

# Meteorological conditions

## Temperatures

Meteorological data from the National Center for Environmental Prediction (NCEP) in Maryland, USA, show that stratospheric temperatures over Antarctica have been below the PSC type I threshold of  $-78^{\circ}\text{C}$  since early May and below the PSC type II threshold of  $-85^{\circ}\text{C}$  since early June, as shown in Figure 1. This figure also shows that the daily minimum temperatures at the 50 hPa level have been below the 1979-2010 average since April. In July and August the temperatures have been below those observed

at the same dates in 2009 and 2010.

Figure 2 shows temperatures averaged over the  $60\text{--}90^{\circ}\text{S}$  region at 10 and 50 hPa. It can be seen from the figure that the average temperature has been quite close to or below the long-term mean until the middle of July. A minor warming event in the middle of July led to temperatures rising above the long-term mean for some days. During August the  $60\text{--}90^{\circ}\text{S}$  mean temperature has decreased and is now well below the long term average. The mean temperature over the  $55\text{--}75^{\circ}\text{S}$  region has behaved quite similarly to the temperature averaged over the  $60\text{--}90^{\circ}\text{S}$

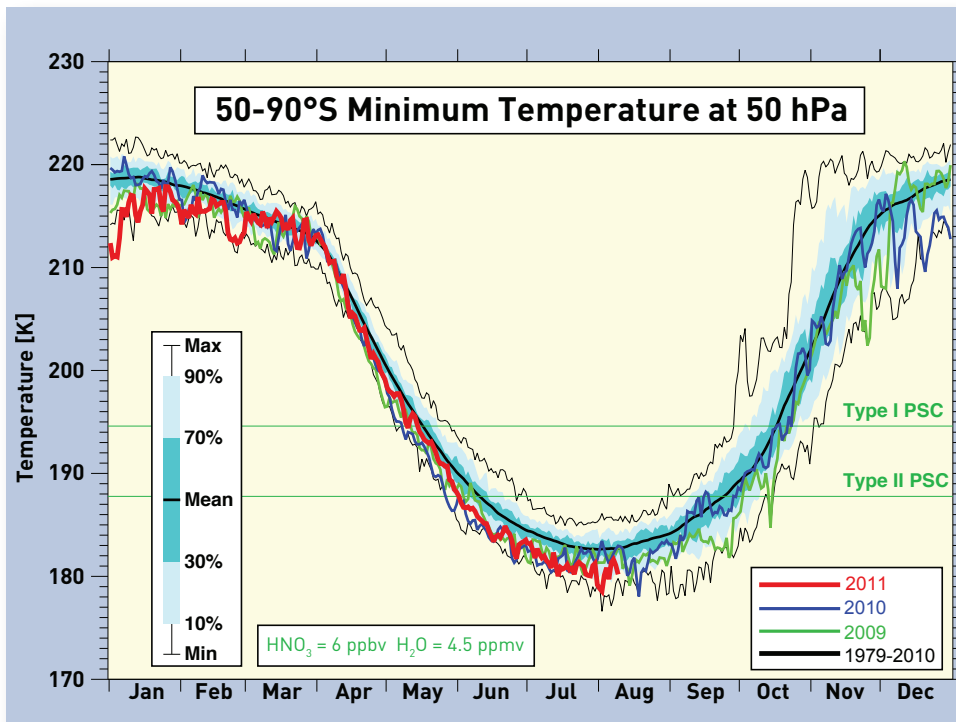


Figure 1. Time series of daily minimum temperatures at the 50 hPa isobaric level south of  $50^{\circ}\text{S}$ . The red curve shows 2011 (until 9 August). The blue line shows 2010 and the green line 2009. The average of the 1979-2010 period is shown for comparison in black. The thin black lines represent the highest and lowest daily minimum temperatures in the 1979-2010 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 adapted from a plot downloaded from the Ozonewatch web site at NASA and based on data from NOAA/NCEP. The original plot was made by P. Newman (NASA), E. Nash (SSAI) and S. Pawson (NASA).

## Meteorological conditions

region at all levels from 10 to 150 hPa.

### PSC Area and Volume

Since the beginning of July, temperatures low enough for nitric acid trihydrate (NAT or PSC type I) formation have covered an area of more than 24 million square kilometres at the 460K isentropic level (Figure 3). Since the onset of NAT temperatures on 10 May the NAT area has been above the 1979-2010 average during the whole winter. The

NAT area reached peaks above 27 million km<sup>2</sup> on a couple of occasions in August. During August the NAT area has stayed between the 70th and 90th percentile, which means that the NAT area has been smaller than in 2011 during 70-90% of all winters since 1979 for this time of the season.

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.

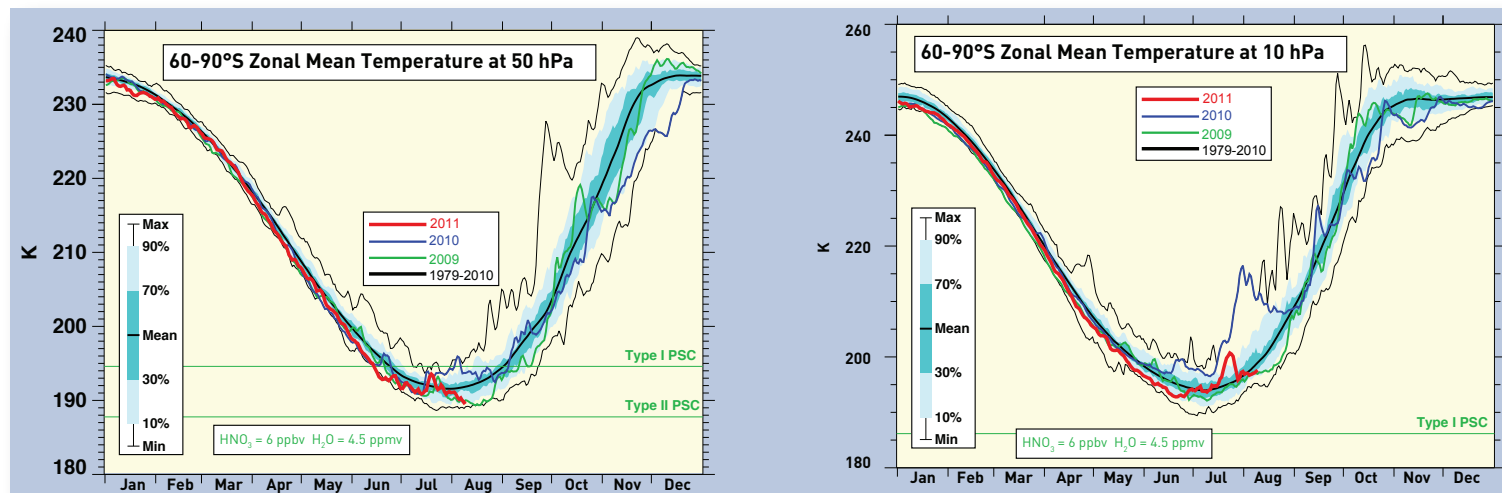


Figure 2. Time series of temperature averaged over the region south of 60°S at the 50hPa level (left) and at 10hPa (right). The red curve shows 2011 (until 9 August). The blue and green curves represent 2010 and 2009, respectively. The average of the 1979-2010 period is shown for comparison in black. The two thin black lines show the maximum and minimum average temperature for during the 1979-2010 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 adapted from a plot downloaded from the OzoneWatch web site at NASA and based on data from NOAA/NCEP. The original plot was made by P. Newman (NASA), E. Nash (SSAI) and C. Long (NOAA).

## Meteorological conditions

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 2011 is shown in Figure 4 in comparison to recent winters and long-term statistics. Since the onset of PSCs in early May, the NAT volume was above or close to the 1979-2010 average until early July. After that it levelled off and remained below the long-term mean until early August. The last couple of weeks the NAT volume has been above the long-term average.

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  $\text{HNO}_3$ . Based upon the historical meteorological record it is expected that the extent of the region with temperatures below the NAT threshold will level off and begin to decrease now as the sun rises over Antarctica, whereas the vortex will gradually increase in

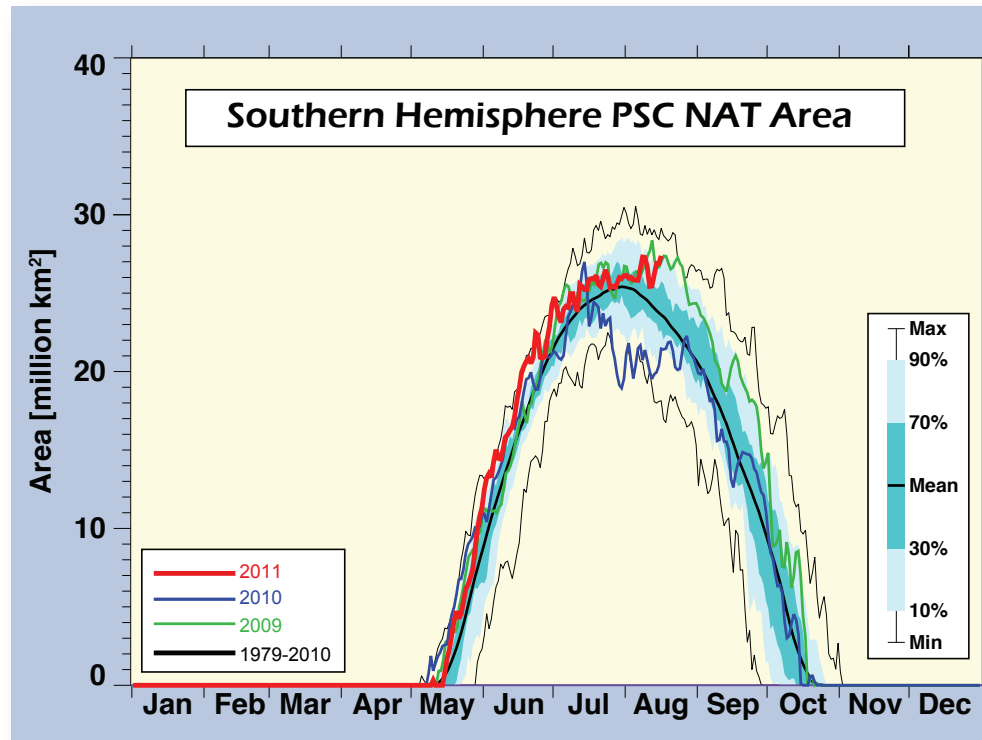


Figure 3. Time series of the area of the region where temperatures are low enough for the formation of nitric acid trihydrate (NAT or PSCs of type I) at the 460K isentropic level. The red curve shows 2011 (until 17 August). The blue and green curves represent 2010 and 2009, respectively. The average of the 1979-2010 period is shown for comparison in black. The two thin black lines show the maximum and minimum PSC area during the 1979-2010 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 adapted from plots downloaded from the Ozonewatch web site at NASA and based on data from NOAA/NCEP.



## Meteorological conditions

size throughout most of August.

### Vortex stability

The longitudinally averaged heat flux between 45°S and 75°S is an indication of how much the stratosphere is disturbed. From April to early July the 45-day mean of the heat flux was lower than or close to the 1979-2010

average. In early July, the heat flux increased somewhat in conjunction with the minor stratospheric warming event and remained larger than the 1979-2010 average until early August. The last few days the heat flux has been smaller than the long-term average. This means that the vortex has been relatively stable so far this year and more stable than in 2010.

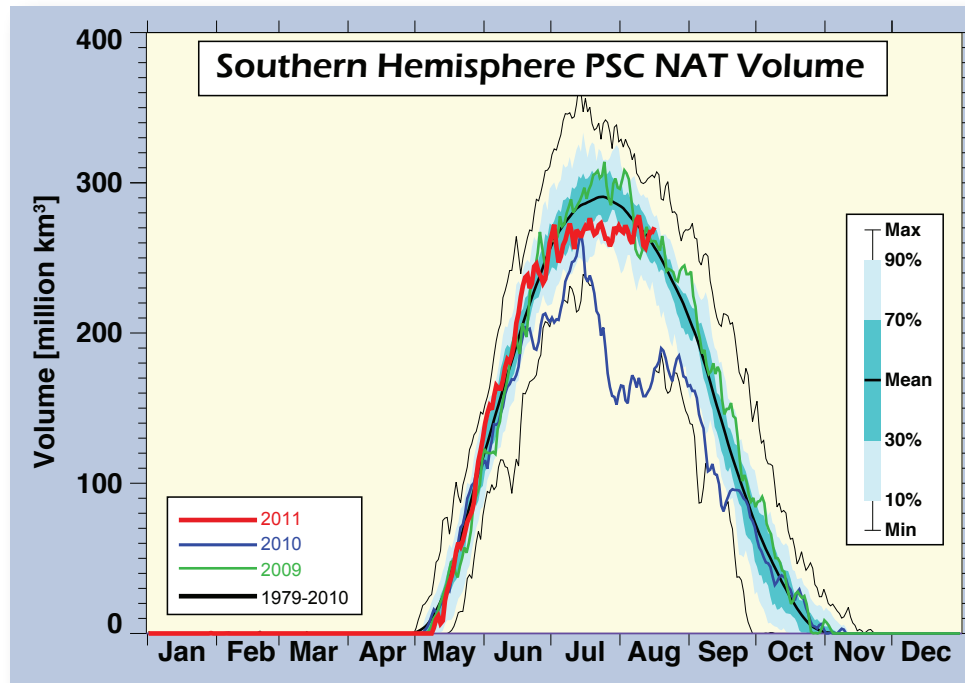


Figure 4. Time series of the volume of the region where temperatures are low enough for the formation of nitric acid trihydrate (NAT or PSCs of type I). The red curve shows 2011 (until 17 August). The blue and green curves represent 2010 and 2009, respectively. The average of the 1979-2010 period is shown for comparison in black. The two thin black lines show the maximum and minimum PSC area during the 1979-2010 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 adapted from plots downloaded from the Ozonewatch web site at NASA and based on data from NOAA/NCEP.



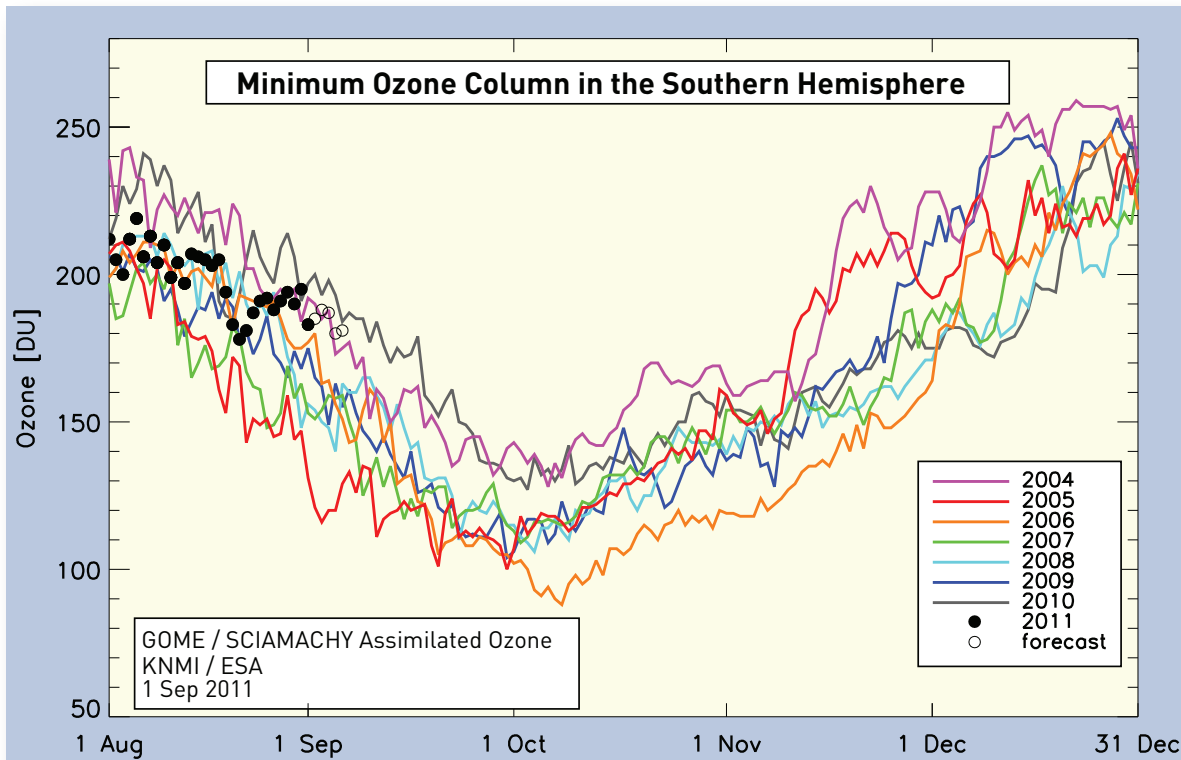
# Ozone observations

## Satellite observations

Most of Antarctica still remains under winter darkness, so the average rate of ozone loss there remains low. However, satellite data show that the depletion has just started along the vortex edge. Figure 5 shows minimum ozone columns as measured by the SCIAMACHY instrument on board ENVISAT in comparison with data for recent years back to 2004 (SCIAMACHY and GOME). Around the middle of August the minimum columns were about average

for the time of the year in comparison to the seven most recent years.

Figure 6 (next page) shows satellite maps from OMI for 17 August for the years 2006 - 2011. On 17 August 2011 one can see a hint of ozone depletion inside the polar vortex. It is evident, however, that ozone depletion was more advanced in 2007 and 2009 at this time of the season. However, an early start of the ozone depletion processes does not necessarily imply a large ozone hole later in the season.



*Figure 5. Daily minimum total ozone columns in the Southern Hemisphere as observed by GOME, and SCIAMACHY. The black dots show the SCIAMACHY observations for 2011. The data now show minimum ozone columns around 200DU. The plot is provided by the Netherlands Meteorological Institute (KNMI).*

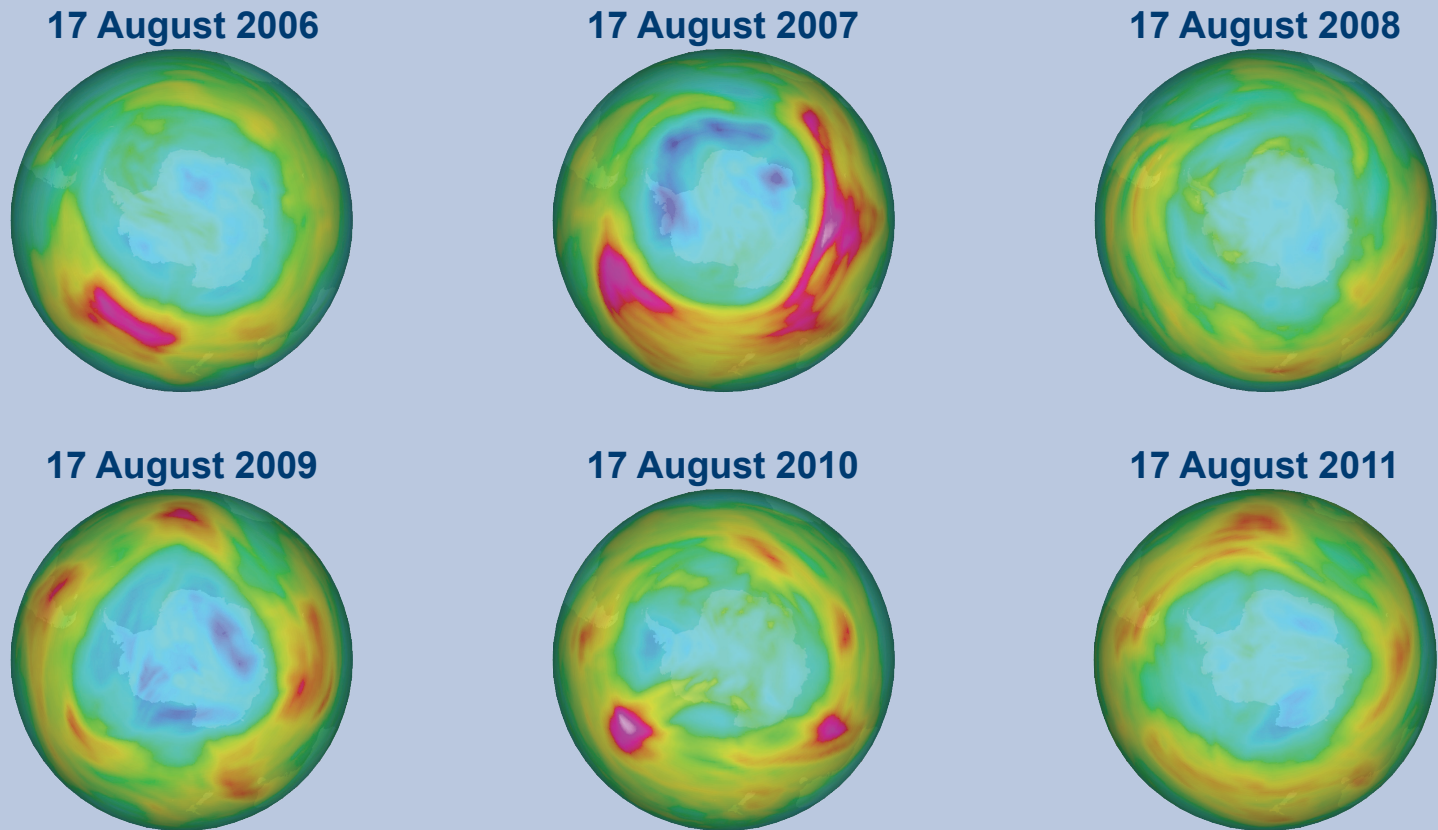
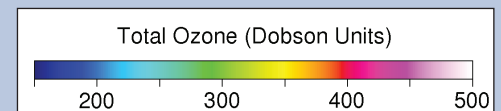


Figure 6. Total ozone maps for 17 August 2006, 2007, 2008, 2009, 2010 and 2011 based on data from OMI on board the AURA satellite. The data are processed and mapped at KNMI.



### Ground-based and balloon observations

It is still early in the ozone hole season and the degree of ozone loss is still very modest. Some stations, though, show some first signs of ozone depletion. A few stations are mentioned here. More stations will be presented in the next issues. On page 14 is a map showing the location of the stations described.

#### Arrival Heights

The GAW/NDACC station Arrival Heights (77.8°S, 166.2°E), operated by New Zealand, will start the observations after the polar night on 14 September. As soon as data are available, they will be reported here. However, a few moon measurements have been carried out on 8, 10 and 12 August and they show total ozone values in the 230-240 DU range.

#### Dôme Concordia

Total ozone is measured with a SAOZ spectrometer at the French/Italian GAW/NDACC station at Dôme Concordia (75.10°S, 123.30°E, 3250 masl) on the Antarctic ice cap. The measurements started up again after the polar night on 30 July. The first few days total ozone was around 260-310 DU, then dropped below 200 DU on 5 August. After that it has been between 200 and 280 DU. There is yet no clear sign of ozone depletion.

#### Dumont d'Urville

The French GAW/NDACC station Dumont d'Urville (66.67°S, 140.02°E) is located at the polar circle, which allows for SAOZ measurements around the year. Total ozone has varied between 220 and 411 DU since 1 June with an average value of 312 DU. Dumont d'Urville is located further north than Dôme Concordia and exposed to more sunshine, hence ozone depletion is expected to set in at an earlier date. Since the beginning of August total ozone has dropped rapidly from about 350 DU to about 250 DU, and this can be seen as a sign that ozone depletion has set in.

#### Marambio

Ozone profiles are observed at the Argentine GAW station Marambio (64.2°S, 56.6°W) with ozonesondes. Soundings are carried out once to twice per week. Nine ozonesondes were launched in June, six in July and three so far in August. In some of the profiles there are first signs of ozone destruction in the 15-20 km range.

#### Neumayer

The vertical distribution of ozone is measured with ozonesondes from the German GAW/NDACC station at Neumayer (70.65°S, 8.26°W). A sonde was launched on 17 August. There is a bite-out in the ozone profile at around 17 km. Satellite data show that ozone poor air passed over the station around 16-17 August.

### Rothera

At the British GAW/NDACC station Rothera (67.57°S, 68.12°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 has been oscillating between 250 and 350 DU most of the winter. In August, ozone has dropped markedly and is now around 230-250 DU. On 8 and 9 August total ozone dropped to around 173 and 188 DU, respectively. The 2011 data are shown in Figure 7 together with data from recent years and the long term mean.

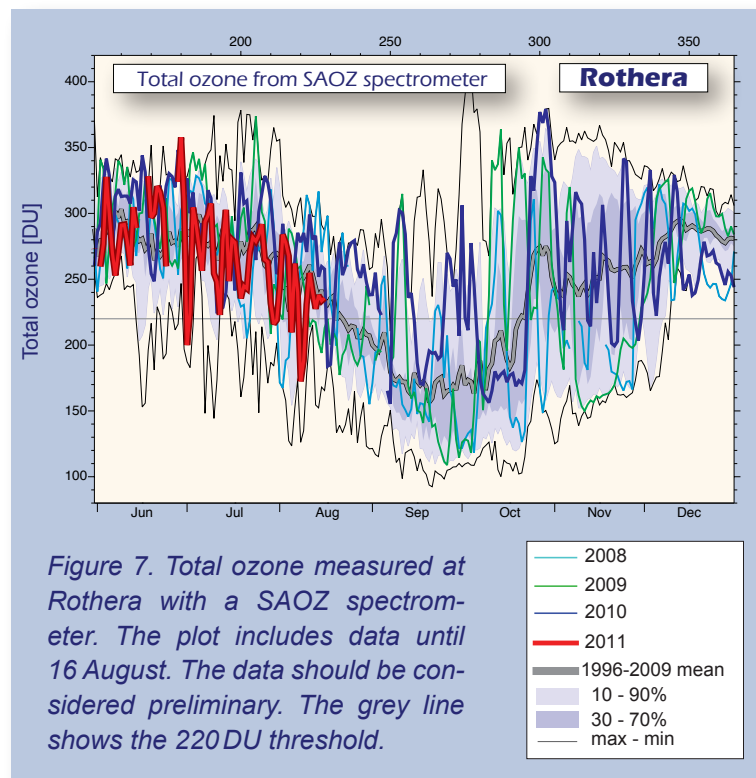
### Syowa

Total ozone is measured at the Japanese GAW station Syowa (69.0°S, 39.6°E) with a Dobson spectrophotometer. These measurements have been carried out since 1961. Measurements started up on 18 August after the winter. The total ozone value measured with the Dobson spectrophotometer on that day showed 246 DU. An ozonesonde was also launched on that day, and the profile shows a bite-out of ozone around 18-19 km.

### Vernadsky

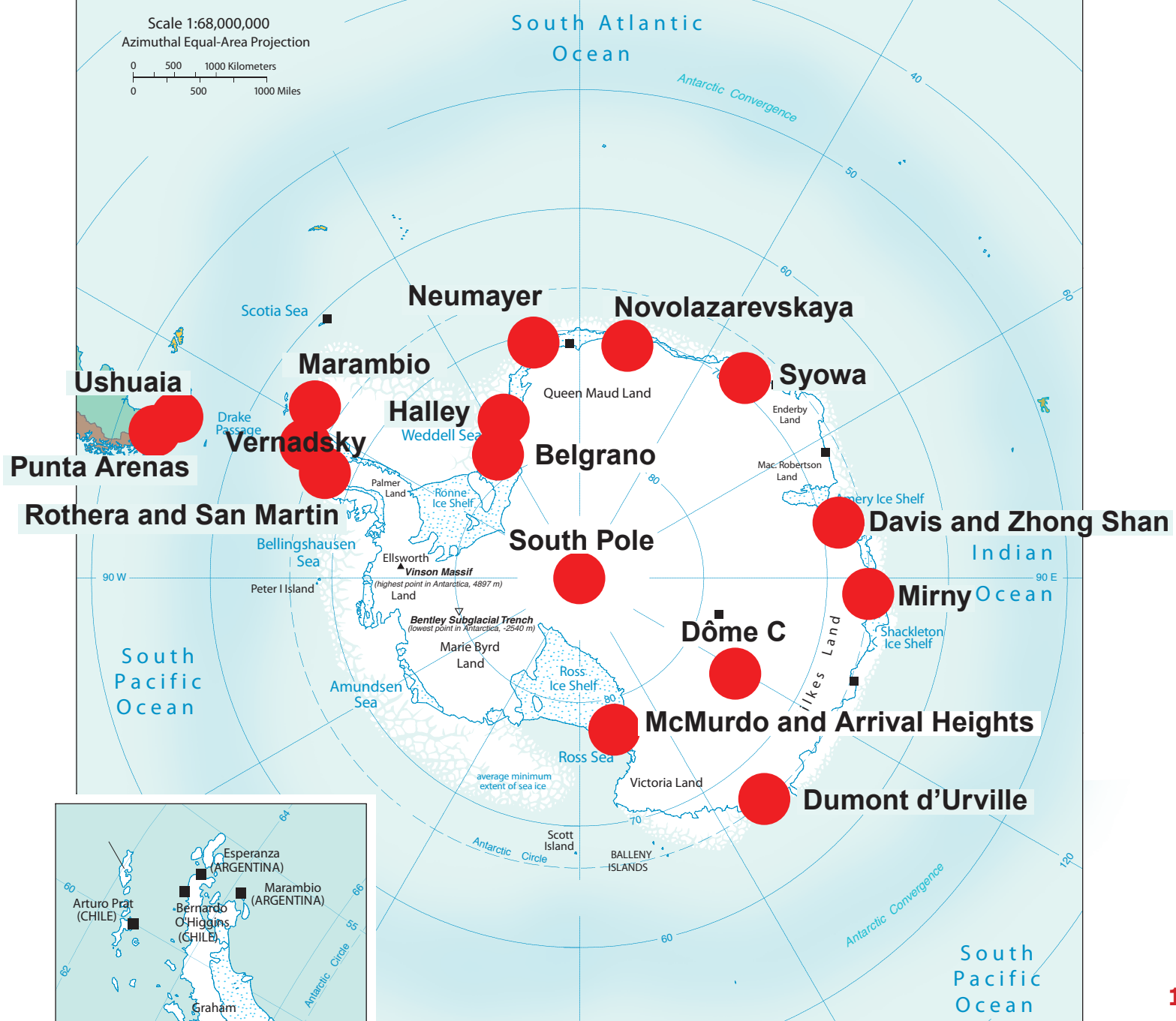
Vernadsky station (65.15°S, 64.16°W) is run by the National Antarctic Scientific Centre of Ukraine. Total ozone is measured with a Dobson spectrophotometer. Observations recommenced after the polar night on 23 July, with

initial results around 250-270 DU. During August total ozone values have dropped, reaching 221 and 207 DU on 8 and 9 August, respectively, the same days as Rothera experienced 173 and 188 DU.



Scale 1:68,000,000  
Azimuthal Equal-Area Projection

0 500 1000 Kilometers  
0 500 1000 Miles



## Chemical activation of the vortex

### Satellite observations

The south polar vortex is now activated and primed for ozone depletion. The sun is on the way back after the polar winter and ozone depletion is about to set in.

Figure 8a (upper row) shows the extent of removal of hydrochloric acid (HCl), which is one of the reservoirs for active chlorine, on the 9 of August for this year and the three previous years. As can be seen from the figure, HCl is almost completely removed inside the vortex at the 490 K isentropic level. Removal of HCl is an indicator of chemical activation of the vortex. It can be seen that the polar vortex was somewhat less depleted of HCl in 2008 and 2010, as compared to 2009 and 2011. The area affected by HCl removal is somewhat larger in 2011 than in the previous years.

Another indicator of vortex activation is the amount of chlorine monoxide (ClO). It should be noted, however, that ClO dimerises and forms  $(\text{ClO})_2$  in darkness. The dimer is easily cracked in the presence of sunlight. ClO will therefore be present in the sunlit parts of the vortex, whereas the dark areas will be filled with  $(\text{ClO})_2$ , which is not observed

by Aura-MLS. Figure 8a (lower row) shows the mixing ratio of ClO on the same dates as above. One can see an area of elevated ClO that forms a collar along the vortex edge. This collar constitutes the sunlit part of the vortex. It can be seen from the figure that the degree of activation is more or less similar except for 2010, which experienced less activation at this time of the year.

Figure 8 b (upper row) shows the amount of nitric acid ( $\text{HNO}_3$ ) in the polar vortex. Removal of gaseous  $\text{HNO}_3$  is an indication that this compound is condensed in the form of polar stratospheric clouds (nitric acid trihydrate,  $\text{HNO}_3 \cdot 3\text{H}_2\text{O}$ ). It can be seen that the degree of removal in 2011 is similar to that observed in 2008 and 2009, whereas in 2010 the removal was less severe.

Figure 8 b (lower row) shows the mixing ratio of ozone at the 490 K isentropic level. A collar of enhanced ozone can be seen just outside the polar vortex. Inside the polar vortex there is yet no clear sign of ozone depletion. In 2009, however, one can see that ozone depletion already had started on this date. This can also be seen in the next chapter on "Ozone hole area and mass deficit", where 2009 stands out as a year when the ozone depletion started earlier than usual.



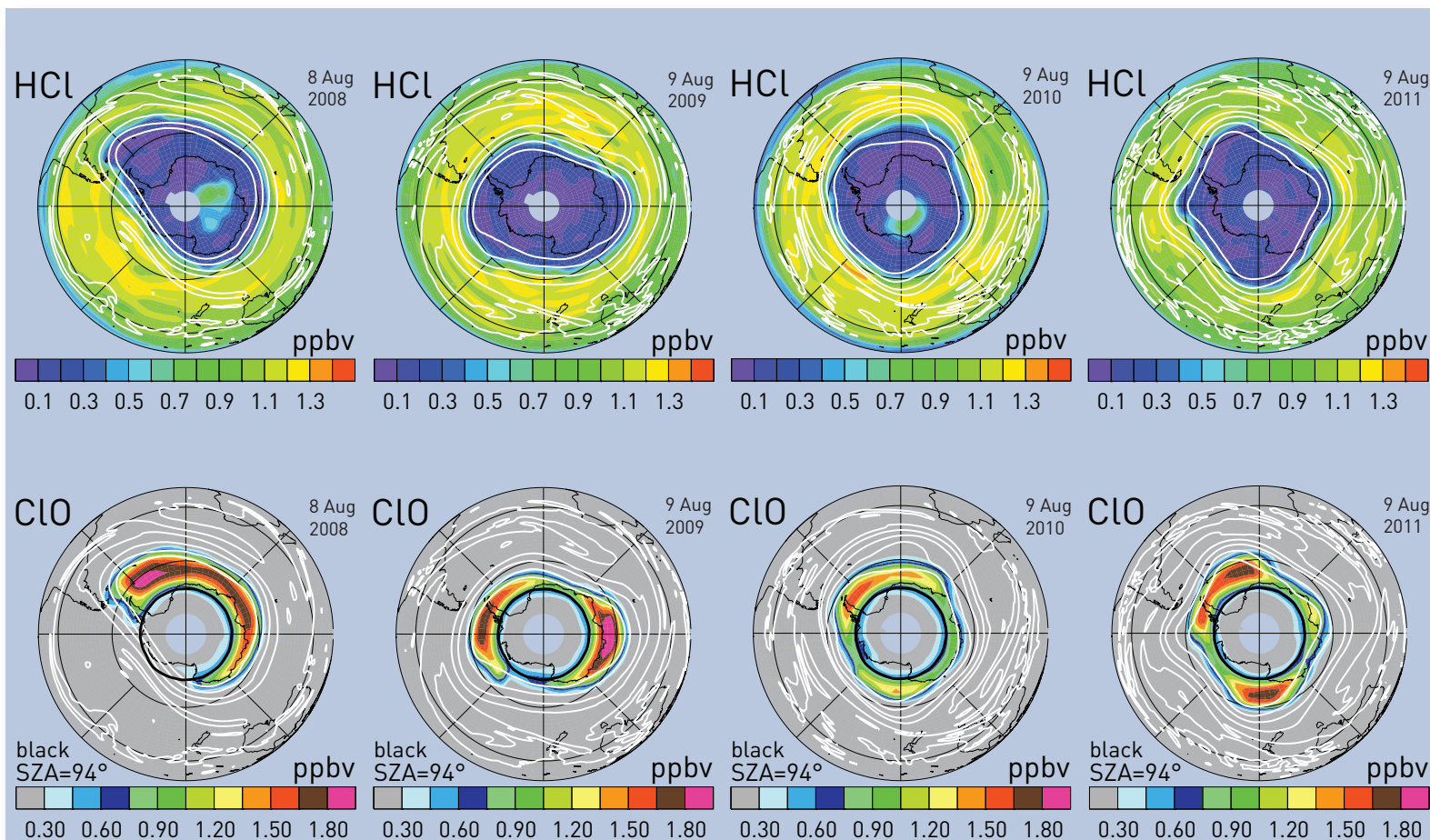


Figure 8a. Upper row: Mixing ratio of HCl on Day 221 of 2008, 2009, 2010 and 2011 at the isentropic level of 490 K (~18 km). Lower row: Mixing ratio of ClO on the same four dates as above. The white contours indicate isolines of scaled potential vorticity. The maps are made at NASA's Jet Propulsion Laboratory and based on data from the Aura-MLS satellite instrument.



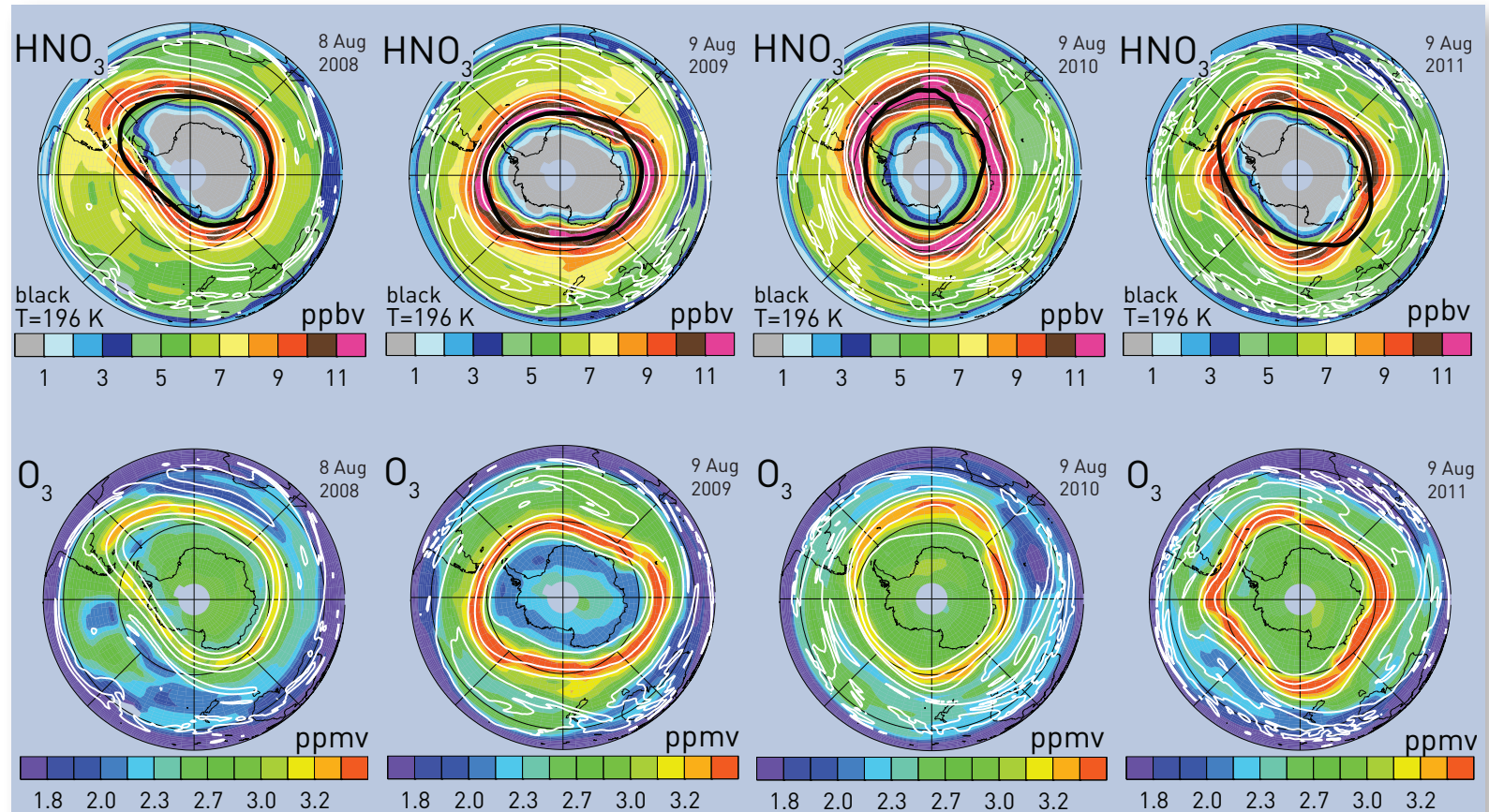


Figure 8b. Upper row: Mixing ratio of nitric acid ( $\text{HNO}_3$ ) on Day 221 of 2008, 2009, 2010 and 2011 at the isentropic level of 490 K ( $\sim 18\text{ km}$ ). Lower row: Mixing ratio of ozone ( $\text{O}_3$ ) on the same four dates as above. The white contours indicate isolines of scaled potential vorticity. The maps are made at NASA's Jet Propulsion Laboratory and based on data from the Aura-MLS satellite instrument.

## Ozone hole area and mass deficit

The area of the region where total ozone is less than 220 DU ("ozone hole area") as deduced from the SCIAMACHY instrument on Envisat is shown in Figure 9. During the first half of August, the area has increased more slowly than at the same time in many of the recent years. However, it has increased faster than in 2004 and 2010. It is still too early

to say anything certain about how the ozone hole area will develop over the next weeks.

Figure 10 (next page) shows the ozone hole area as deduced from the OMI satellite instrument. Here it can be seen that the 2011 ozone hole is having a slightly later start than in 2009 but an earlier start than in 2008 and 2010. The ozone mass deficit is still very small, so no figure is shown here. It will be reported in upcoming issues of the Bulletin.

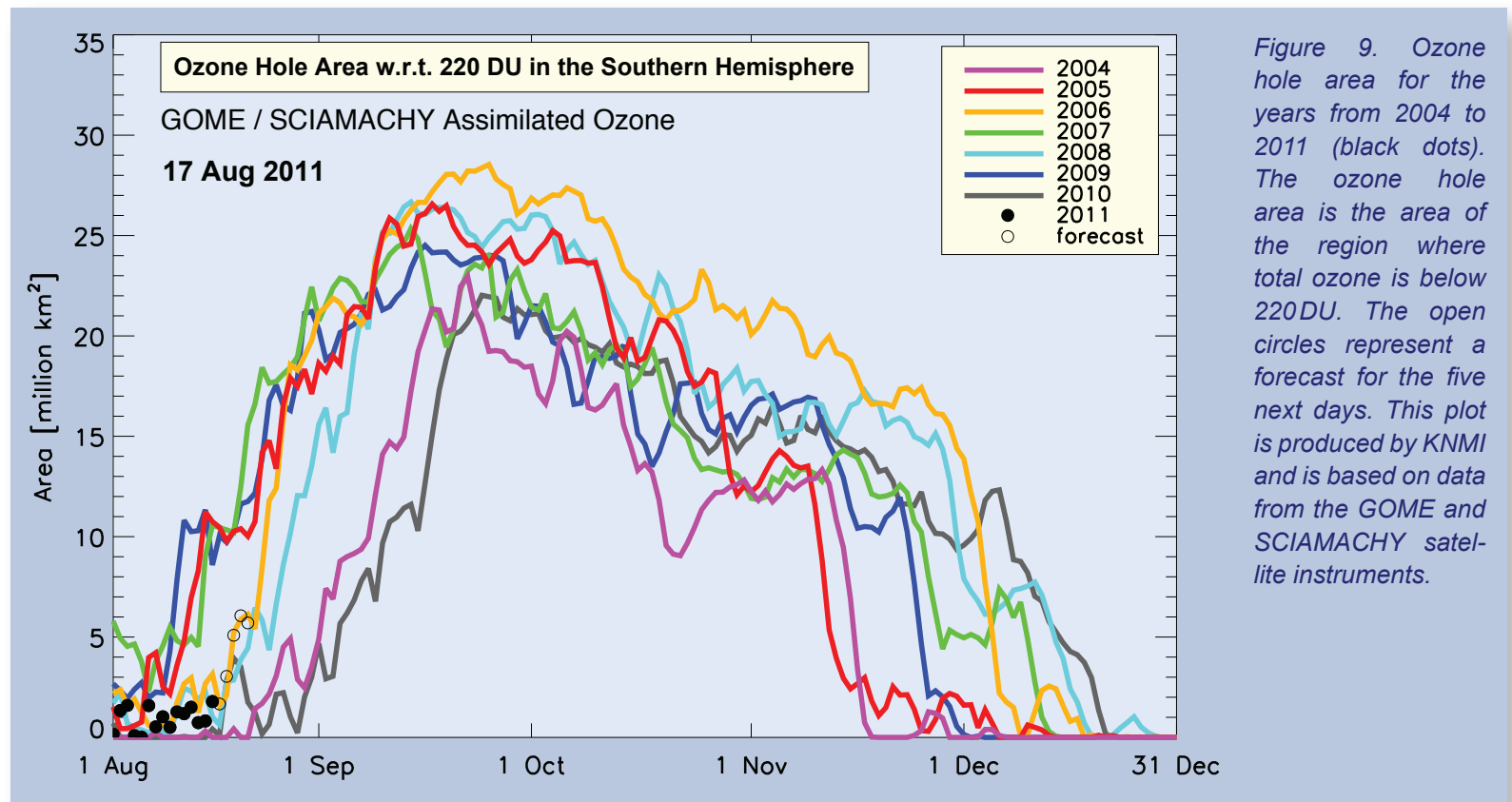


Figure 9. Ozone hole area for the years from 2004 to 2011 (black dots). The ozone hole area is the area of the region where total ozone is below 220DU. The open circles represent a forecast for the five next days. This plot is produced by KNMI and is based on data from the GOME and SCIAMACHY satellite instruments.

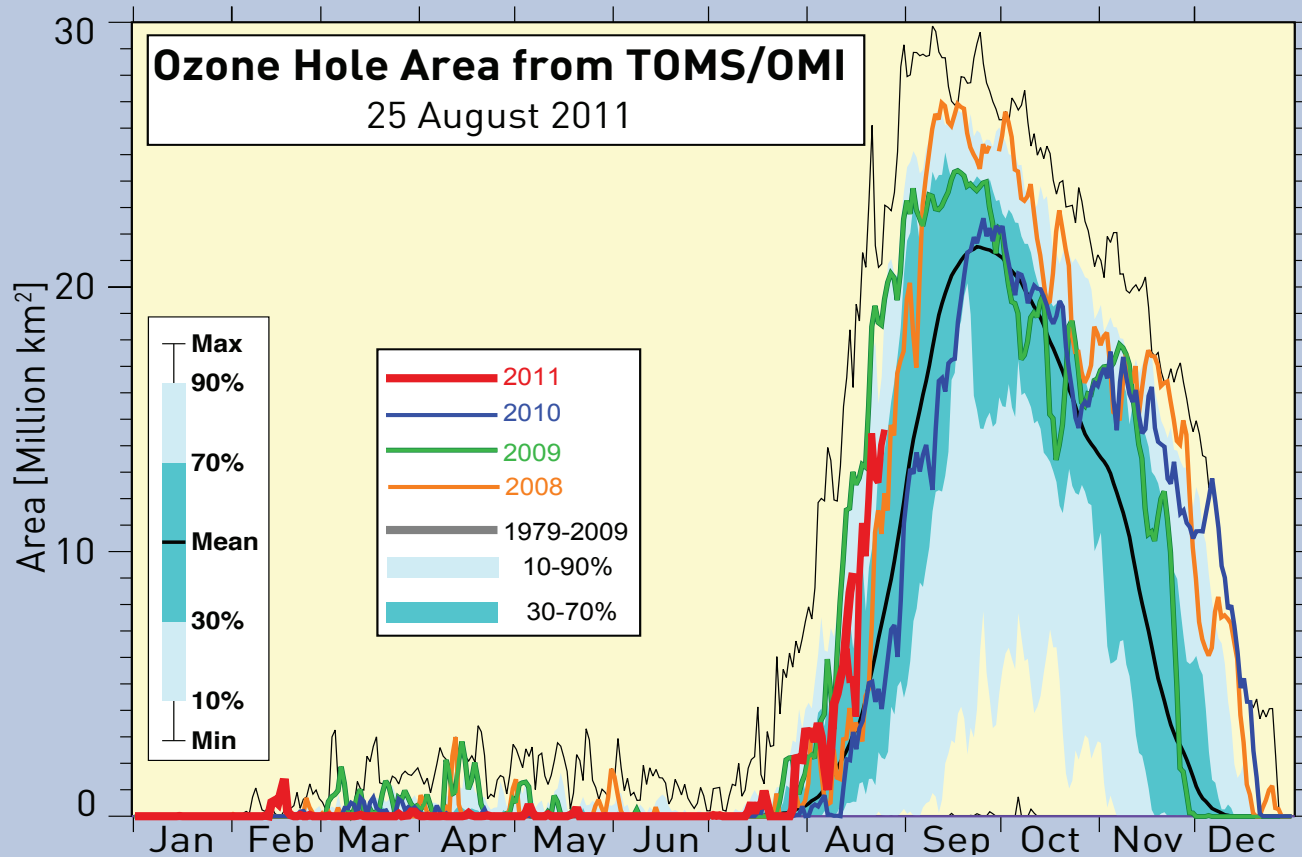


Figure 10. Area (millions of km<sup>2</sup>) where the total ozone column is less than 220 Dobson units. 2011 is shown in red (until 15 August). 2010 is shown in blue, 2009 in green and 2008 in orange. The smooth grey line is the 1979-2010 average. The dark green-blue shaded area represents the 30th to 70th percentiles and the light green-blue shaded area represents the 10th and 90th percentiles for the time period 1979-2010. The ozone hole area on 15 August is approx. 9 million km<sup>2</sup>. The plot is adapted from a plot downloaded from the NASA Ozone watch web site and is based on data from the OMI instrument on AURA and various TOMS instruments.

## UV radiation

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

## Distribution of the bulletins

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

## Acknowledgements and links

These Bulletins use provisional data from the WMO Global Atmosphere Watch (GAW) stations operated within or near Antarctica by: Argentina (Comodoro Rivadavia, San Martin, Ushuaia), Argentina/Finland (Marambio), Argentina/Italy/Spain (Belgrano), Australia (Macquarie Island and Davis), China/Australia (Zhong Shan), France (Dumont d’Urville

and Kerguelen Is), Germany (Neumayer), Japan (Syowa), New Zealand (Arrival Heights), Russia (Mirny and Novolazarevskaja), Ukraine (Vernadsky), UK (Halley, Rothera), Uruguay (Salto) and USA (McMurdo, South Pole). More detailed information on these sites can be found at the GAW SIS web site (<http://www.empa.ch/gaw/gawsis>).

Satellite ozone data are provided by NASA (<http://ozone-watch.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](http://mls.jpl.nasa.gov/plots/mls/mls_plot_locator.php).

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

SAOZ data in near-real time from the stations Dôme Concordia and Dumont d’Urville can be found here:

## Acknowledgements and links

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<http://saoz.obs.uvsq.fr/SAOZ-RT.html>

Ozone data analyses and maps are prepared by the World Ozone and UV Data Centre at Environment Canada (<http://exp-studies.tor.ec.gc.ca/cgi-bin/selectMap>), by the Royal Netherlands Meteorological Institute (<http://www.temis.nl/protocols/O3global.html>) and by the University of Bremen (<http://www.doas-bremen.de/>). UV data are provided by the U.S. National Science Foundation's (NSF) UV Monitoring Network (<http://www.biospherical.com/nsf>).

UV indices based on the SCIAMACHY instrument on Envisat can be found here: <http://www.temis.nl/uvradiation/>

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

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

The 2010 WMO/UNEP Scientific Assessment of Ozone Depletion can be found here: [http://www.wmo.int/pages/prog/arep/gaw/ozone\\_2010/ozone\\_asst\\_report.html](http://www.wmo.int/pages/prog/arep/gaw/ozone_2010/ozone_asst_report.html)

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