MAUSAM, **62**, 4 (October 2011), 577-584

551.510.534.3 (99)

Ozone hole over poles : Current status

S. L. JAIN

Radio & Atmospheric Sciences Division, National Physical Laboratory, New Delhi - 110 012, India

e mail : sljain@nplindia.ernet.in

सार – समतापमंडल में ओज़ोन की उपस्थिति हमारी जननीग्रह, पृथ्वी पर जीवन की रक्षा के लिए अत्यंत महत्वपूर्ण है। ओज़ोन हमारे लिए एक छाते की तरह कार्य करती है जो सूर्य से आ रही हानिकारक पराबैंगनी विकिरणों से हमारी रक्षा करती है। सामान्यतः ClOx और NOx द्वारा ओज़ोन के कैटालिटिक ह्रास और विशेषकर वसंत ऋतु के दौरान एंटार्कटिक पर ओज़ोन छिद्र परिघटना ने ओज़ोन और वायुमंडल के अन्य घटकों पर नजर रखने के लिए दिलचस्पी को जाग्रत किया है। भूमंडलीय ओज़ोन कॉलम का नियमित रूप से मानीटरन करने के लिए उपग्रह अत्यंत उपयोगी साधन साबित हुए हैं। उपग्रह के विभिन्न प्लेटफॉमों का उपयोग करते हुए उत्तरी और दक्षिणी ध्रुवों पर ओज़ोन छिद्र के अध्ययन के लिए ओज़ोन आँकड़ो का विश्लेषण किया गया है। एंटार्कटिक स्थित मैत्री में भी ओज़ोन के माप लिए गए। उपग्रह से प्राप्त हुए आँकड़ों से यह पता चलता है कि अंतर्राष्ट्रीय स्तर पर किए गए प्रयासों के कारण ओजोन छिद्र में कुछ भरपाई ओज़ोन छिद्र के लिए मुख्यरूप से उत्तरदायी CFCs के कम उपयोग से हुई है। किन्तु फिर भी ओज़ोन छिद्र की भरपाई के बारे में अभी निष्कर्ष स्वरूप कुछ नहीं कह सकते हैं। अभी उपलब्ध सूचनाओं के आधार पर ओज़ोन छिद्र की वर्तमान स्थिति के बारे में विस्तार से विवेचन किया गया है।

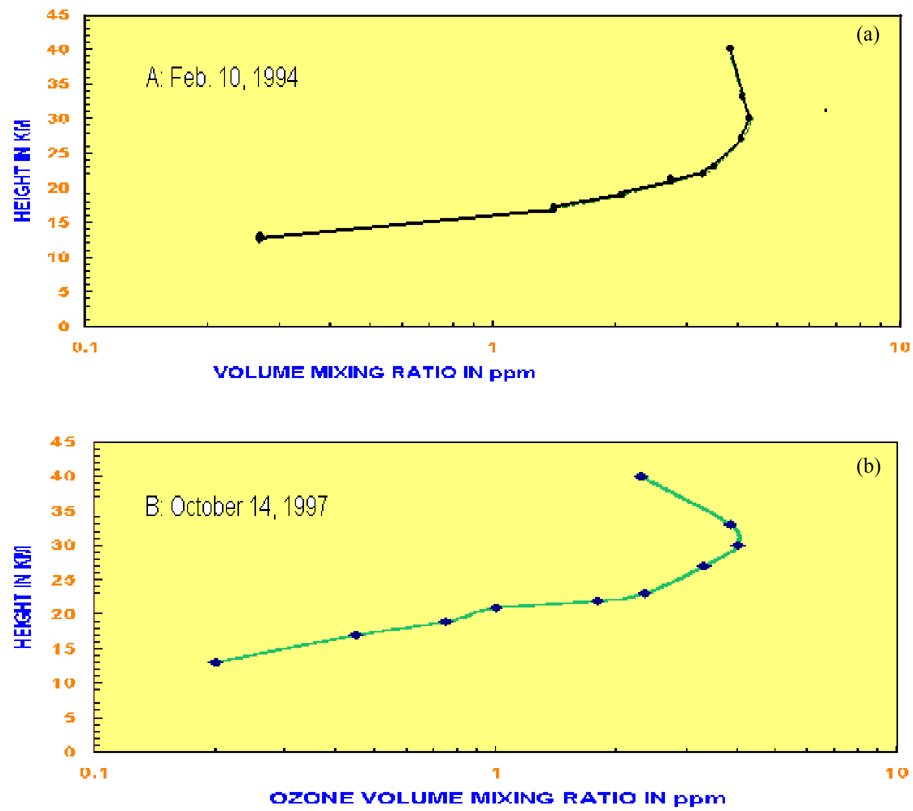
ABSTRACT. The ozone in the stratosphere is of great importance for very survival of life on the mother planet the Earth. Ozone acts as an umbrella and protects us from the harmful ultraviolet radiations coming from the Sun. The catalytic destruction of ozone by ClOx & NOx in general and ozone hole phenomenon over Antarctica during spring time in particular has generated unprecedented interest in monitoring of ozone and other trace constituents in the atmosphere. The satellites have proved to be an important tool to monitor the global ozone column on regular basis. The ozone data using various satellite platforms has been analyzed for the ozone hole studies over north and south poles. Also Ozone measurements were carried out at Maitri, Antarctica. The satellite data indicates that some recovery of ozone hole as a result of international efforts in reduction of use of CFCs which are the main culprit for ozone hole. However, it will be too early to conclude about ozone hole recovery. In the present communication current status of ozone hole will be discussed in detail.

Key words – Ozone, Stratosphere, Chlorofluorocarbon, Ultraviolet radiations, Polar stratospheric clouds.

1. Introduction

Ozone is one of the most important constituent in atmosphere and in spite of its low concentration, a few ppmv in mixing ratio, it plays an important role not only in the chemistry of this region but also it affects climate and biological activity. Ozone in the stratosphere is very important as it acts as a shield for the Earth and protects life from harmful UV-B radiation coming from the sun. However, the ozone in the troposphere is a greenhouse gas, trapping the long wave radiation in 9.6 µm band and thus affecting the energy budget of the earth – atmosphere system. The amount of ozone over any particular place depends not only on photochemical balance, but also on the stratospheric climate, the winds that disperse the ozone. The stratosphere itself is dependent on ozone for its existence. The energy absorbed by ozone in the course of creation and destruction of its layer warms the surrounding atmosphere creating temperature inversion. This inverted layer, which is the stratosphere, is very resistant to vertical movements of air and acts as a cap on the turbulent weather processes in the troposphere below (Dennis, 1994).

The reporting of catalytic depletion of ozone by ClO_x and NO_x by Johnston, (1971) in general and ozone hole over Antarctica in particular by Farman *et al*. (1985) has generated an unprecedented surge of interest in the scientific community in monitoring of ozone. It has now been established that the cause of very low ozone in Antarctic spring is due to the presence of CFCs and Polar Stratospheric Clouds (PSCs) that forms polar vortex. Very low temperature during winter leads to the formation of polar stratospheric clouds (PSCs) Manney *et al*., (1996). The heterogeneous chemical reactions take place on the surface of polar stratospheric clouds,



Figs. 1(a&b). Vertical profiles of ozone using Laser Hetrodyne system at Maitri (a) Normal period and (b) Ozone hole period

which are responsible for the ozone hole phenomenon during spring time over Antarctica [Manney *et al.*(1996)]. Warm ozone-laden air from the mid latitudes cannot get in, so the temperature inside the vortex plunges even lower. More and more ice-crystal clouds form in the freezing air, triggering even greater ozone losses. After the discovery of ozone hole and innovative research efforts, it become clear that at very low temperature (<-80° C) in the lowest stratosphere, chemical reactions were taking place which needed the presence of liquid or ice particles either as ice or nitric acid trihydrate, or other mixture. They lead to the conversion of chlorine compounds, which normally are present as HCl and $ClONO_2$ in the stratosphere. Normally these gases do not react with ozone. However, in the presence of ice particles, HCl and Chlorine Nitrate are converted into Cl_2 and HNO_3, and if UV-Solar radiation is available then Cl_2 is converted into Cl atoms, which next react with ozone to form ClO. Thereafter, a new chemical scheme, involving Cl_2O_2 as intermediate, comes into action which destroys ozone very efficiently [Crutzen (1998).

However, planetary waves work against CFC-induced ozone destruction. These vast pressure waves influence ozone destruction in several ways and can have relevant impact on the size and stability of the massive jet stream encircling Antarctica called the "Antarctic vortex" [Newman (1986); Chandra and McPeters (1986)]. Ozone have been found to be strongly affected by the dynamical behavior of the polar vortex Carswell *et al*. (1998). When the strength of planetary waves picks, they exert a force on the vortex, which blow it apart. As the vortex breaks down, the surrounding warm, ozone-rich air mix with the air over Antarctica, raising ozone concentrations above the threshold for ozone hole Newman (2002). The day-to-day size of the ozone hole is really controlled by the fine details of weather and needs more attention.

The satellite data from NASA [http://www.theozonehole.com/arcticozone.htm] have been used for the study of current status of the ozone hole over Antarctica as well as over Arctic. Also a highly sophisticated and hand held microprocessor based sun photometer, *i.e.*, MICROTOP-II, has been used to measure total ozone, water vapour, optical depth etc. at Maitri, Indian Antarctica research station during the year 1997-1998 and 2002-2003. In the present communication the current scenario of ozone hole over polar regions is discussed in detail.

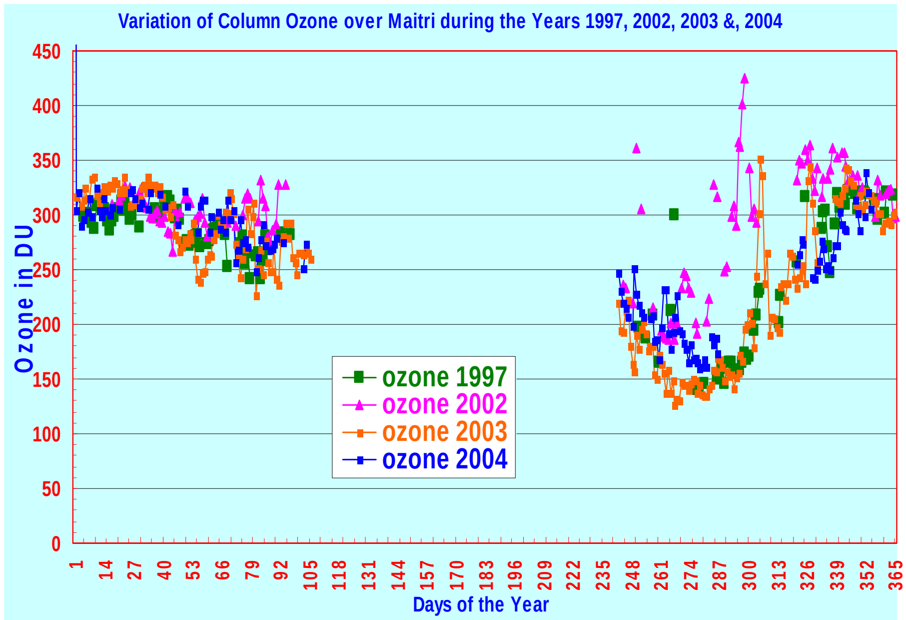


Fig. 2. The variation of Column Ozone during 1997 and 2002-2004 at Maitri, Antarctica

2. Experimental setup

2.1. *The MICROTOP-II*

The MICROTOP-II is a five channels hand held microprocessor based sun photometer with a full field of view of 2.5°. The instrument has five optical collimators aligned to aim in the same direction. A narrow-band interference filter and a photodiode suitable for the particular wavelength range are fitted with every channel. All the channels face directly the solar disc simultaneously when the image of the sun is centred at the cross hairs of the sun target. When the radiation captured by the collimators falls onto the photodiodes, it produces an electrical current proportional to the received radiant power, which is amplified and converted into digital form in a high resolution A/D converter. Signals are processed in a series of 20 conversions per second. Out of the five channels at 300, 305, 312, 940 and 1020 nm, the first three filter channels are used to derive atmospheric total ozone column and other two for water vapour (Jain, 2001).

2.2. *Laser heterodyne system*

A high resolution Laser Heterodyne system with 1 GHz acousto-optical spectrometer as backend was designed and developed at National Physical Laboratory, New Delhi for study of vertical profiles of various trace species including ozone profiles at Maitri, Antarctica during normal as well as ozone hole conditions (Jain, 1996). The Laser Heterodyne System has been successfully operated at Maitri (70° 46' S, 11° 44' E) an Indian Antarctic station during 13th, 14th and 16th Indian Antarctic Expedition to obtain ozone line spectra at 1043.1775 cm^{-1} with an ultra high spectral resolution. The line spectra thus obtained with high spectral resolution in turn has been used to get vertical profiles of ozone in the atmosphere using inversion technique developed at NPL for Antarctic conditions (Jain, 1987). A guess profile of uniform mixing ratio of 3 ppm has been used for the retrieval. The system was operated during ozone hole period also. The typical retrieved profiles during normal period and during ozone hole period are shown in Figs. 1 (a) & (b) respectively. The ozone was found to be depleting during ozone hole period from 3 per cent to 68 per cent in the height range of 13 to 40 km (Jain, 2008).

3. Results and discussion

3.1. *Microtop - II data at Maitri, Antarctica*

The variation of total ozone from January to December for the years 1997, 2002, 2003 and 2004 measured using MICROTOP–II at Maitri, Antarctica is shown in Fig. 2. The maximum ozone up to 320- 340 DU has been recorded in the months of January and February in all the years. The gap in the figure is due to non-

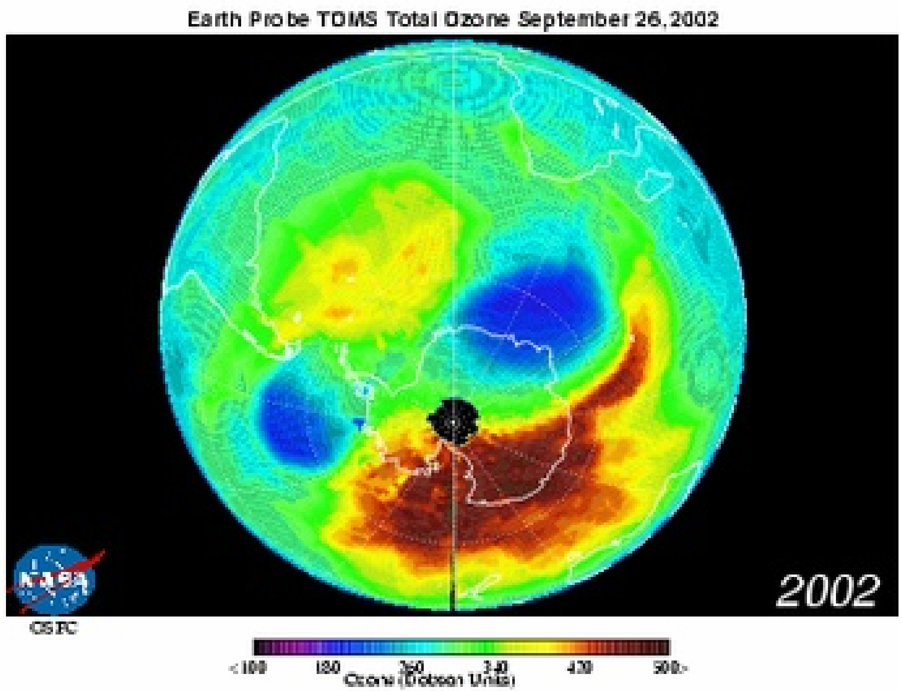


Fig. 3. Satellite imagery of the ozone hole (http://toms.gsfc.nasa.gov) over Antarctica on 26 September 2002

availability of data during polar night. The minimum value of total ozone in the range 126 to 185 were observes during the last week of September or the first week of October and found to be fluctuating on year to year basis depending on the meteorological conditions over Maitri. The observation suggests that the ozone hole in the year 2002 was not as deeper as in the year 2003. The observation also reveals the early recovery of ozone hole in the year 2002 as compared to other observational years as depicted in Fig. 2. The ozone depletion was started from 1^{st} September, 2002 onwards. Exceptionally high values up to 361DU of total ozone column were observed during ozone hole period during 7^{th} and 8^{th} September, 2002. Ozone hole started recovering around 23^{rd} September, 2002, however, some exceptional variations were also observed during recovery period of ozone hole as shown in Fig. 2.

The observation at Maitri showed recovery around 24 - 25 September 2002, the early recovery of ozone hole in last week of September in 2002 can be explained by Varotsos [Kondratyev and Varotsos (2000); Varotsos (2002)] findings. Varotsos, 2002 have performed a Fourier analysis of the 10 hPa height and the temperature time series at the high latitude of the southern hemisphere. He found that extremely large amplitude of planetary waves were present which broke up Antarctic ozone hole into two holes (http://toms.gsfc.nasa.gov) on 24-25 September, 2002 as seen in Fig. 3. After the breakup, the polar vortex reforms and subsequently disappeared very early. NASA press release (NASA/NOAA, 2002) also represented the prevalence of strong planetary waves in Antarctica. The vortex break up and disappearance have been attributed to the occurrence of a major sudden stratospheric warming in Antarctica due to the occurrence of very strong planetary waves.

The Maitri Station is situated in the fringe region of the vortex. The observed abrupt high total ozone on 7^{th}, 8^{th} September and also during recovery period from 23^{rd} September onwards as shown in Fig. 2 may be attributed to the planetary wave phenomenon. The planetary wave phenomenon forces the ozone rich air masses from mid latitude to polar latitude region and the rapid displacement of the polar vortex from a roughly symmetric circulation about the pole to a circulation that is offset from the pole, which leads to the stratospheric sudden warming for a short period over the fringe region of the vortex. If the strengths of these waves is high enough then this forces the ozone reach air mass inside the polar vortex and sudden increase in the total ozone may takes place [Brinksma *et al.* (1998); Schoeberl *et al.* (1989); Kirchoffs *et al.* (1997); Lee *et al.* (2001)].

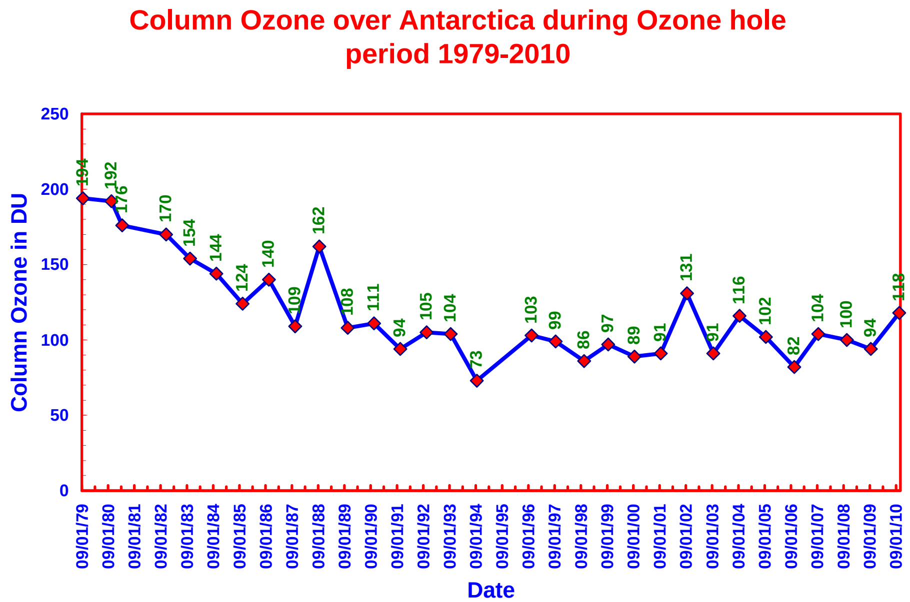


Fig. 4. Variation of minimum column ozone over Antarctica during ozone hole period 1979-2010

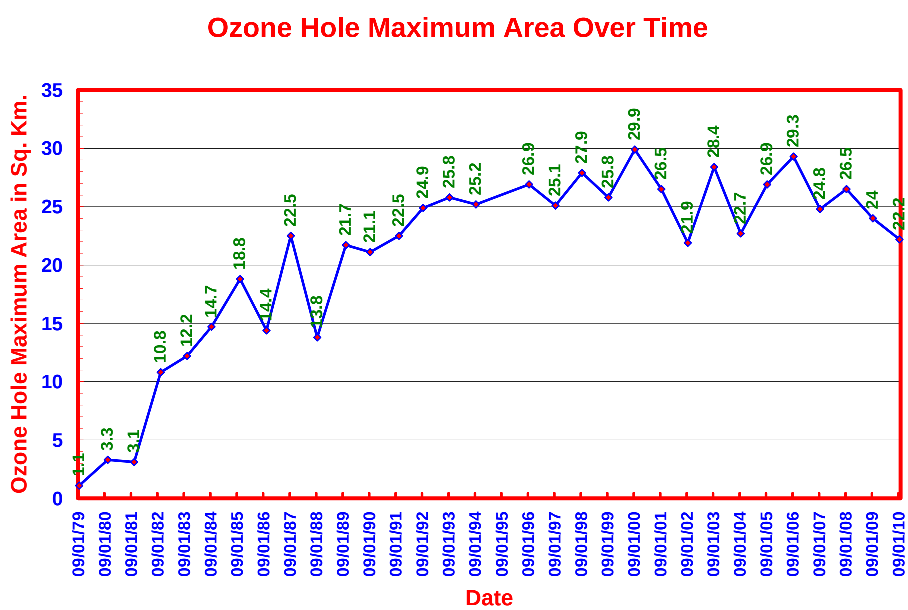


Fig. 5. Variation of maximum ozone hole area over Antarctica during the years 1979-2010

3.2. *Satellite data over Antarctica*

The variation of minimum Column Ozone over Antarctica during Ozone hole period in the years 1979-2010 observed by satellite data is depicted in Fig. 4. Also the area covered by ozone hole in the years 1979-2010 is depicted in the Fig. 5. It is observed that there is a large variation in minimum ozone values during September-October and varies between 73 DU to 194 DU and minimum value of 73 DU was observed in the year

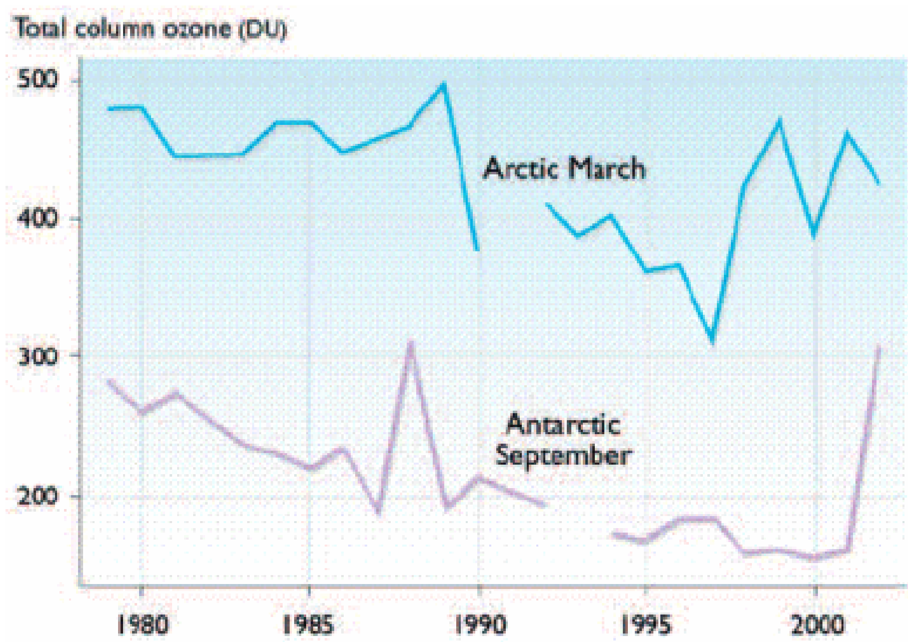


Fig. 6. Spring ozone depletion over the Antarctic and the Arctic between 1979 and 2002. *Source* : http://www.acia.uaf.edu/

1994. The maximum ozone hole area was found to be minimum in the year 1979 as 1.1 million square km and maximum was found to be 29.9 million square km in the year 2000 after which it started to decrease. During 2010 maximum ozone hole area was found to be 22.2 million square km. It is further found that the ozone hole is weakening year after year after the ban on ozone depleting chemicals with the Montreal protocol and its time to time amendments and adjustments.

3.3. *Ozone hole over Arctic*

Significant ozone depletion in the Arctic stratosphere also occurs in cold winters because of reactive halogen gases. The depletion, however, is much less than the depletion that now occurs in every Antarctic winter and spring. Although Arctic depletion does not generally create persistent "ozone hole"-like features in Arctic total ozone maps, depletion is observed in altitude profiles of ozone and in long-term average values of polar ozone. An Arctic Ozone Hole, if similar in size to the Antarctic Ozone Hole, could expose over 700+ million people, wildlife and plants to dangerous UV ray levels.

The Arctic winter stratosphere is generally warmer than its Antarctic counterpart. Higher temperatures reduce Polar Stratospheric Cloud (PSC) formation, which slows the conversion of reactive chlorine gases to form ClO and as a consequence, reduces the amount of ozone depletion. Furthermore, the temperature and wind conditions are much more variable in the Arctic from winter to winter and within a winter season than in the Antarctic. Large year-to-year differences occur in Arctic minimum temperatures and the duration of PSC-forming temperatures into early spring. In a few Arctic winters, minimum temperatures are not low enough for PSCs to form. These factors combine to cause ozone depletion to be variable in the Arctic from year to year, with some years having little to no ozone depletion. A significant difference exists between the Northern and Southern Hemispheres in how ozone-rich stratospheric air is transported into the polar regions from lower latitudes during fall of winter. In the northern stratosphere, the poleward and downward transport of ozone-rich air is stronger. As a result, total ozone values in the Arctic are considerably higher than in the Antarctic at the beginning of each winter season as shown in Fig. 6 (http://www.acia.uaf.edu/).

4. Conclusion

It has been observed that the year to year large variation in ozone depletion at Antarctica as well as over Arctic depends on the meteorological conditions prevailing over the polar regions. The data analysis performed gives the following conclusions, which provide a plausible observational explanation of the unusual behaviour of the ozone hole over Antarctica in year 2002. The earlier recovery of ozone hole was observed in year 2002 as compared to other years and the effect of planetary wave on the vortex and thereby the total column ozone is visible over the station situated at the fringe of the polar vortex. It is clear from the observations that the vortex breakdown due to planetary wave phenomenon can occur during ozone hole period and has a large influence on total ozone. Relatively warm air extending to the pole indicates that a polar stratospheric major warming was taking place. The observation may be useful in the study of dynamics of waves and their influence on the vortex formation, movement and breakdown.

It has also been observed that there is large fluctuation in ozone depletion at Antarctica as well as over Arctic. The ozone hole over Arctic is not as severe as that over Antarctica, due to its geographical location and being warmer than Antarctica, however an Arctic Ozone Hole, if similar in size to the Antarctic Ozone Hole, could expose over 700+ million people, wildlife and plants to dangerous UV ray levels. Also the ground based as well as satellite borne experiments show that there are indications of slow recovery of ozone hole. The ozone hole data does give an indication of the long-term trend and the measurements show that the CFC concentrations in the stratosphere are levelling off and in the lowest layer of the atmosphere, the troposphere, CFC concentrations have started to decline due to the decisions taken by international community under Montreal Protocol, its subsequent adjustments and amendments to stop the use of ozone depleting chemicals. These measurements indicate that the ozone hole is not worsening and may soon start to improve. However, this improvement is going to come very slowly and will take few decades before ozone hole recovers depending on how the CFC concentrations levels off due to their long life time.

Acknowledgement

The author wish to express his sincere gratitude to the Director, NPL and Head, RASD, for their encouragement during the progress of the work. Author thanks the Council for Scientific and Industrial Research (CSIR), India, in the emeritus scientist scheme for the financial support. Thanks are also due to National Space Science Data Center, NASA, Goddard Space Flight Center, USA, for receiving data from their web site. (http://www. science.nasa.gov/) and http://www.theozone hole.com/arcticozone.htm and also to NCAOR, Goa for providing platform to perform experiments at Maitri and financial support.

References

Arctic Climate Impact Assessment, 2010, "Factors affecting arctic ozone variability in the Arctic", Published : February 9, 2010, 2:55 pm, Edited: February 9, 2010, 2:55 pm http://www.acia.uaf.edu/

Brinksma, E. J., Meijer, Y. J., Connor, B. J., Manney, G. L., Bergwerff, J. W. and Swart, D. P. J., 1998, "Analysis of Record Breaking low Ozone values During the 1997 winter over NDSC - station Lauder, New Zealand", 19th ILRC, NASA, p319.

Carswell, A. I., Bird, J. C., Donovan, D. P., Duck, T. J, Pal, S. R. and Velkov, D., 1998, "Lidar measurements of stratospheric ozone at the Eureka NDSC station, 1993 to 1998", Proceedings of the 19th International Laser Radar Conference, NASA CP-1998-207671, 327-330.

Chandra, S., and McPeters, R. D., 1986, "Some observations on the role of planetary waves in determining the spring time ozone distribution in the Antarctic", *Geophys. Res. Lett*. (USA), **13**, 1224-1227.

Crutzen, P. J., 1998, "*Globale environmental Chemistry*", (ed. Mitra, A. P).

Dennis, L. Hartmann, *Global Physical Climatology*, Academic Press, San Diego, CA 1994.

Farman, J. C., Gardiner, B. G. and Shanklin, J. D., 1985, "Large losses of total ozone in Antarctica reveal seasonal ClOxNOx interaction. Nature", **315**, 207-210.

http://www.theozonehole.com/arcticozone.htm

Jain, S. L., 2001, "Monitoring of ozone, water vapour etc during the voyage to Antarctica", *Asian Journal of physics*, **10**, 3, 315-321.

Jain, S. L., 1996, "Laser heterodyne system for measurement of minor constituents of atmosphere", *J. Radio & Space Phys*., **25**, 309-317.

Jain, S. L., 1987, "Inversion technique to get vertical profiles of ozone in atmosphere using laser heterodyne system", *Indian J. Radio & Space Phys*., **16**, p324.

Jain, S. L., 2008, "Lidars for Atmospheric Probing: A Review", *Journal Óptica Pura y Aplicada*, **41**, 2, 129-133.

Johnston, H. S., 1971, "Reduction of stratospheric ozone by nitrogen oxide catalysts from SST exhaust", *Science*, **173**, 517-522.

Kirchoffs, V.W., C.A.R. Casiccia and F. Zamorano, 1997, "The Ozone Hole over Punta Arenas", *J. Geophys. Res*., **102**, 8945-8953.

Kondratyev, K. Y. and Varotsos, C., 2000, "In Atmospheric Ozone Variability: Implications for Climate Change, Human Health and Ecosystems", Springer-Praxis, Chichester, UK, p617.

Lee Adrian, Howard, M. lee, Roscoe, K., Jones, Anna E., Haynes, Peter H., Schuckburg, Emily F., Morrey, Martin W. and Pumphery, Hugh C., 2001, "The impact of the mixing properties within the Antarctic stratospheric vortex on ozone loss in spring", *J. Geophys. Res*., **106**, 3203-3211.

Manney, G. L., Froidevaux, L. and Waters, 1996, "Arctic Ozone depletion observed by UARS MLS during the 1994-95 winter", *Geophys. Res. Lett*., **23**, 1, 85-88.

Newman, P. N., 1986, "The final warming and polar vortex disappearance during the southern hemisphere spring", *Geophys. Res. Lett*. (USA), **13**, 1228-1231.

NASA/NOAA, in Ozone Hole Press release, 02-185, 30 September 2002 (http://toms.gsfc.nasa.gov).

Newman, P., 2002, Science news, NASA, (www.science.nasa.gov/.), www.ozonewatch.gsfc.nasa.gov

Schoeberl, M. R., Lait, L. R, Newman, P. N., Martin, R. L., Proffitt, M. H., Hartmann, D.L., Loewenstein, M. Podolske., J. Strahan, Anderson, J., Chan, K. P., and Gary, B., 1989, "Reconstruction of the constituent distribution and trends in the Antarctic polar vortex from ER-2 flight observations", *J. Geophys. Res*., **94**, 16815.

Varotsos, C., 2002, "The Southern Hemisphere Ozone Hole Split in 2002", *ESPR- Environ Sci & Pollut Res*., **9**, 6, 375-376.