

Episodios extremos de bajo contenido de ozono en la región sub-ártica de Keflavik

Extreme low ozone episodes over the sub-Arctic region of Keflavik

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Received: 22 June 2009

Accepted: 25 September 2009

RESUMEN

En el presente trabajo se realiza un estudio sobre los episodios extremos con bajo contenido en ozono observados desde la estación de Keflavik (Islandia) durante los meses de invierno y primavera entre los años 1992 y 2005. Para la identificación de estos episodios se han utilizado los perfiles verticales de ozono realizados desde la estación, clasificando los mismos de acuerdo a distintos parámetros. Con objeto de identificar los mecanismos dinámicos y químicos responsables de estos episodios, se han analizado las retrotrayectorias isentrópicas para esos días en distintos niveles de la baja estratosfera. Se han identificado dos tipos de episodios extremos: el tipo A, caracterizado por valores bajos de ozono desde la tropopausa hasta los 22 km; y el tipo B, con una distribución vertical de ozono en la baja estratosfera en forma laminada. Los resultados del estudio indican que los mecanismos responsables de cada tipo de perfil varían en función de la posición relativa de la estación respecto al vórtice polar.

Palabras clave: Mini-agujero de ozono; perfiles verticales de ozono; retro-trayectorias isentrópicas; baja estratosfera.

ABSTRACT

The present work presents a study of the anomalous low ozone events observed over Keflavik (Iceland) during the winter and spring months from 1992 to 2005 years. Ozone profiles from balloons sounding carried out from Keflavik were used to identify the extreme ozone events and to classify them according to different parameters. Ten days backward trajectories at different isentropic levels in the lower stratosphere have been employed to investigate the dynamical and chemical processes involved. Two types of extreme low ozone events have been found: type A, characterized by low ozone content from the tropopause up to 22 km; and type B, associated to laminated ozone structures in the lower stratosphere. Results indicate that the mechanisms responsible for each type of profile vary depending on the position of the station with respect to the polar vortex.

Key words: Ozone mini-hole; ozonesondes; isentropic back trajectories; lower stratosphere

SUMMARY: 1. Introduction. 2. Data source and methodology. 3. Results. 4. Summary and conclusions. 5. Acknowledgements. 6. References

1. INTRODUCTION

During winter and spring is very often to observe at middle and high latitudes of both hemispheres a rapid decrease in total ozone. These events are known in the literature as ozone mini-holes due to their relative small horizontal scale as compared with the wider ozone polar hole (Newman et al., 1988). During the last decade the number of publications on this subject has increased. A climatology of ozone mini-holes over the North Hemisphere based on Nimbus-7 TOMS satellite data has been elaborated by James (1998a) and for the South Hemisphere by James (1998b). Others studies have found a relation between the phase of the North Atlantic Oscillation and the frequency of the mini-holes events (Orsolini and Limpasuvan, 2001). These works have demonstrated that the ozone mini-hole events are mainly cause by dynamical mechanisms rather than chemical processes.

The purpose of the present study is to analyse the causes of the formation of the low extreme ozone events observed and study the influence of the position of the station with respect the polar vortex on the mechanisms involved.

The paper is structured as follows: Section 2 presents an overview of the data used and the methodology employed. Then, Section 3 presents a classification of the low ozone events observed and analyses the potential mechanisms, which could explain them. Finally, Section 4 summarizes the mechanisms suggested to be responsible for the low ozone events.

2. DATA SOURCE AND METHODOLOGY

2.1. Ozone profiles

The data used in this study are in situ vertical profiles of ozone partial pressure, temperature, ambient pressure and humidity from the sub-Arctic region of Keflavik (Iceland) carried out by INTA (Instituto Nacional de Técnica Aeroespacial) and IMO (Icelandic Meteorological Office). The period of measurements is focus on winter/spring months, when the largest variability of ozone on interannual and longer timescales occurs. During this period ozonesondes are the best source of information of the vertical ozone distribution, as the measurements are not depended on the sunlight. Data presented are based on ozonesondes from December 1991 to March 2005. Vertical ozone profiles have been carried out with a frequency about once or twice a week. The ozonesondes used are of electrochemical concentration cell (ECC) type from the Science Pump Corporation and ENSCI Corporation. The sonde was interfaced to a meteorological radiosonde (RS80 from Vaisala) for pressure, temperature and humidity data. All the system is flown on a balloon (TX-1200) filled with helium. A TSC-1 ozonozzer/test unit (manufactured by Science Pump Corporation) was used for the calibration and preparation of son-

des according to the recommendations given by Komhyr (1986). The accuracy of ECC sondes is estimated to be about $\pm 5\%$ in the stratosphere and about 10% in the troposphere.

2.2. Isentropic back trajectories

The tool used to obtain information about the origin of the air masses arriving to the station has been the 10-day backward isentropic trajectories. These trajectories were obtained by NILU (Norsk Institutt for Luftforskning) data base and calculated by DMI (Danish Meteorological Institute) using Knudsen et al. (1996) algorithm. In particular, the levels analysed are between 380 K and 550 K that correspond to the altitudes from 12 and 25 km, respectively. The calculations are based on temperature and wind fields from the ECMWF operational analysis available every 6 hours.

The trajectories have been classified in three classes according to the maximum and minimum latitude during the 10-day trajectory. If the minimum latitude along the trajectory is less than 32°N , the trajectory is considered of *subtropical origin*; if maximum latitude is less than 75°N and minimum latitude is greater than 32°N , the trajectory is *from mid-latitudes*; and if maximum trajectory is north of 75°N , it is considered *polar*.

2.3. Methodology

The location of Keflavik station with respect to the polar vortex is highly variable. These particular conditions make the station very interesting for studying polar vortex processes related to the ozone layer. Therefore, the first step has been to determine the relative position of the station with respect to the polar vortex. Although there are several methods to determinate the edge of the polar vortex, in this work, the position of the polar vortex and its boundaries has been calculated for each day from 1 January to 31 March during the period study using the method of Nash et al. (1996). Potential vorticity from ECMWF truncated to T106 horizontal resolution ($1.125^\circ \times 1.125^\circ$) at the isentropic level of 475 K has been used. Occasionally, position of the station with respect to the vortex varies with altitude due to its vertical structure. The isentropic level of 475 K has been chosen for the study as it represents a mean level of the low stratosphere where the maximum ozone concentration is observed. Each day was classified in three groups according to the position of the station with respect to the polar vortex: *inside*, *outside* and *at the edge* of the polar vortex). The statistical analysis of the position of the Keflavik with respect to the polar vortex shows that the station was situated *outside* of the polar vortex most of the time, with an occurrence frequency of 64 %; *at the edge* and *inside* the vortex, the station was located the 20% and 16% of the time, respectively.

The high variability of the ozone at the station during the winter months, partly due to the variability of the position of the station with respect to the polar vortex, has led to study the low extreme events for each of the three groups of days. In this way, low ozone episodes have been considered when the ozone concentration was

less than the mean value minus one standard deviation corresponding for its group at the isentropic level of 475 K.

3. RESULTS

3.1. Cases *outside* of the polar vortex

A total of ten cases of low ozone content have been observed when the station was outside of the polar vortex. For each event, standardized anomalies of total ozone column and tropopause height have been calculated. Three different types of profiles have been established (Fig. 1):

- A. This type is characterised by a low ozone concentration (below the mean minus one standard deviation) from the troposphere up to the lower stratosphere (around 23 km).
- B. The low ozone concentrations are observed from 15-20 km, whereas the values for the rest of the profile are between the mean and one standard deviation.
- C. Only anomalous ozone values (below the mean minus one standard deviation) are observed around the layer of 475 K (22 Km).

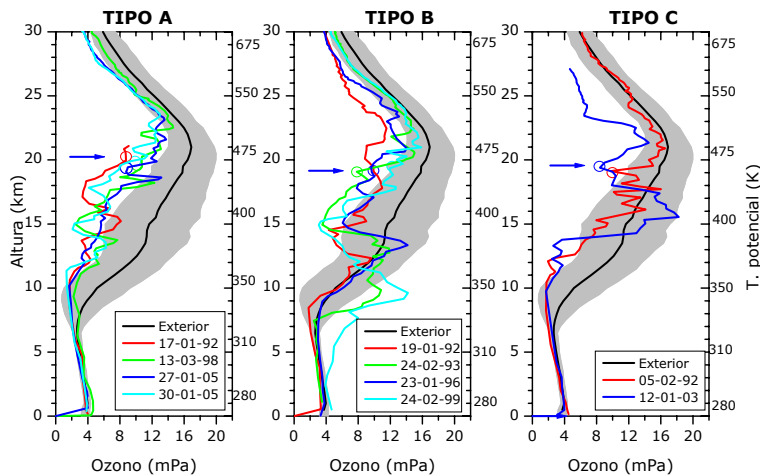


Figure 1. Vertical ozone distributions for the three types of low extreme ozone events when station was *outside* of the polar vortex. The black line in each panel represents the mean ozone distribution outside of the vortex and shaded areas one standard deviation.

A detailed description and study about the causes associated with each type of ozone profile is presented:

Type A:

This type of profile is known in the bibliography as ozone mini- holes (Newman et al., 1988). These episodes are characterized by low ozone concentration in a synoptic-scale region for a short period of time (1-5 days). Many studies have demonstrated they are mainly caused by dynamical process by transport of poor-ozone air mass from the tropics to higher latitudes by planetary wave activity or, connected with strong adiabatic uplifting of the tropopause height. However in some occasions due to adiabatic ascent of air masses, stratospheric temperatures drops below the threshold for formation of Polar Stratospheric Clouds (PSCs), leading to an additional ozone reduction due to chemical processes (Rood et al., 1992).

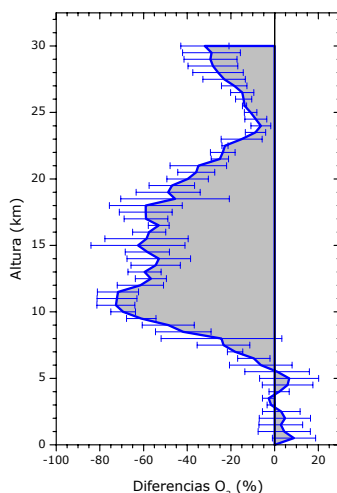


Figure 2. Mean difference of ozone (%) with respect to the mean ozone profile outside of the vortex. Horizontal bars represent one standard deviation.

Even though these episodes occur irregularly and during short periods, they exert influence on the total ozone content. In order to assess the magnitude of the ozone destruction, for each episode, the differences with respect to the vertical mean profile outside of the polar vortex have been calculated. Mean differences and the standard deviations for all cases are shown in Fig. 2. Results indicate that the vertical ozone distributions during these events present a significant ozone reduction from the tropopause to up 20 km ranging from 40 to 70%.

Isentropic backward trajectories have been calculated for each episode on the isentropic levels of 380 K, 435 K, 475 K and 550 K. The results show that at lower levels the transport from subtropical latitudes where the mean ozone concentration is lower than at subarctic areas is responsible of the ozone reduction at these levels. On the other hand, at higher levels, trajectories indicate a midlatitude origin, and in some cases polar origin (Fig. 3).

Temperature and pressure along the trajectories have been analysed for these days. In all cases, during the last four days before air masses arrive to the station, it was observed an adiabatic ascent and a decrease of temperatures leading to a formation of local quasi-stationary polar stratospheric clouds (PSCs). An exceptional

case is the day 17th January 1992. The seventh day before the masses arrived, the temperature was below the threshold for PSC formation (triangles over the trajectories indicate temperatures below -78°C) that could produces an additional ozone destruction due to chemical processes. In fact, the lowest ozone value of the study period was registered this day with only 185 DU, and it is considered a typical referent ozone mini-hole event.

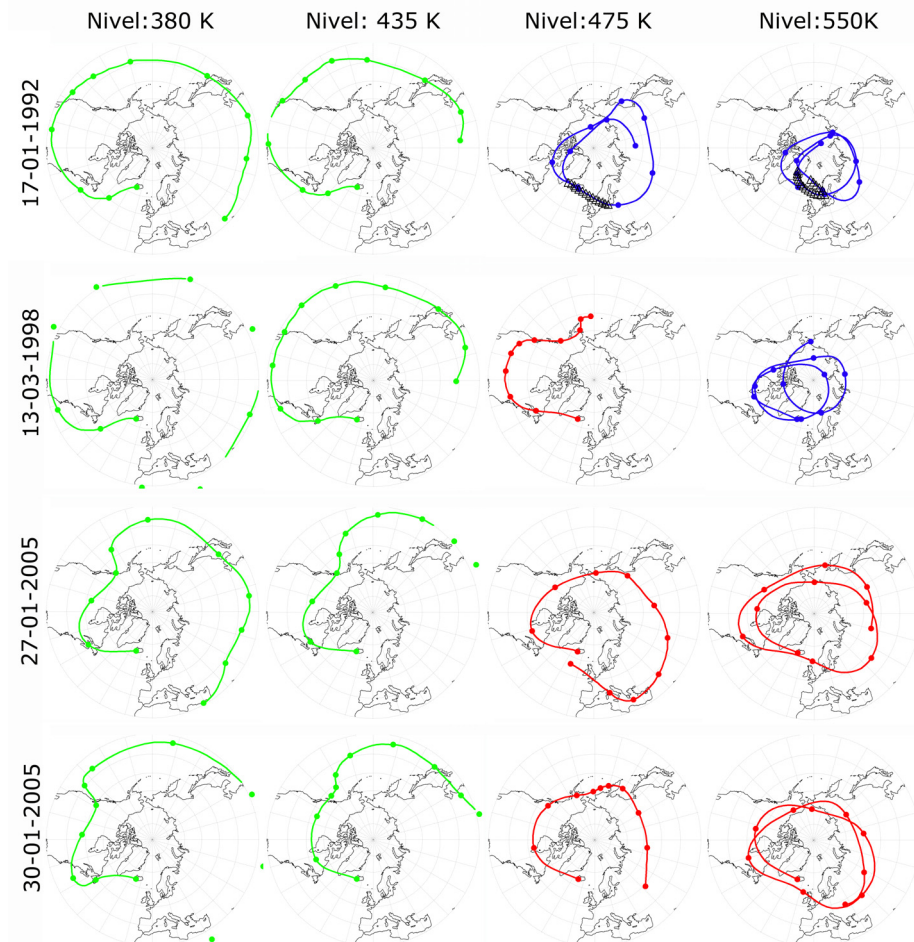


Figure 3. Ten-day back trajectories for the low extreme events (type A) with the station *outside* of the polar vortex. Each point represents the daily position of the mass.

Type B:

This class of ozone profile is characterized by irregular vertical ozone structures in the lower stratosphere with maximum and minimum values within a vertical extension of a few hundreds of meters. These structures are known in the literature as “laminae” or layering (Appenzeller and Holton, 1997). The first theory about its formation was described by (Dobson, 1973) suggesting that they are created by

stratospheric-tropospheric exchange near the subtropical jet-stream. Later, Reid and Vaughan (1991) proposed another mechanism based on advection of air from different origin and by exchange of air from in and out of the polar vortex. Sometimes several laminated structures can be observed in a profile as it has been the case in our profiles.

Ten-day isentropic back trajectories were analyzed for each event. The results show that these structures were originated from advection of air masses from different origin at the levels where the maximum and minimum in ozone were observed. Trajectories at 350 K, where the maximum in ozone occurs, have been considered coming from mid-latitudes. On the other hand, at the levels where the minimum in ozone appears (380 and 400 K), the origin of the air masses is subtropical.

Type C:

This type of profile presents similar characteristics to type A, but the integrated ozone column does not reach such low ozone values to be considered type A. The vertical ozone distributions are lower than their standard deviation from 5 km up to 14 km.

The back isentropic trajectories for these events show that only at 350 K the air masses come from subtropic latitudes, while at higher levels the trajectories are from midlatitudes and polar. On these days the low ozone values are associated with transport of ozone from subtropic latitudes at the tropopause.

3.2. Cases at the edge of the polar vortex

When the station was at the edge of the polar vortex five extreme low ozone episodes were registered. Three of them present characteristics of the type A described previously and two events were considered with type B profile.

Type A:

The analyses of the back trajectories show that the ozone mini-hole events observed in this type of profile when the station is at the edge of the vortex are associated to adiabatic vertical transport of air masses coming from midlatitudes at the level of 380 K, instead of subtropics areas as it was found when the station was outside of the polar vortex.. At higher levels, (475 and 550 K) air masses from polar latitudes with temperatures below the threshold of PSCs are responsible for the extremely low ozone values observed.

Type B:

Laminated structures are found around 475 K, and also for the case of 10th January 1996, a second structure at a lower level, typical of a secondary maximum, can be observed. The origins of the back trajectories for these days are midlatitudes for the levels lower than 435 K and polar at the levels of 475 and 550 K.

3.3. Cases inside of the polar vortex

Even though the mean annual frequency of the station inside of the polar vortex is only about 15%, four extreme low ozone episodes have been identified. Three of them are considered type A, and the other as type B.

Type A:

Analyses for the corresponding ozone mini-holes indicate that air masses for these days were mainly from polar latitudes (Fig. 4). The low ozone contents at lower levels result from the presence of high pressure at the upper troposphere in the surrounding of the polar edge, which leads to adiabatic vertical displacement of isentropic surfaces, as it has been suggested by other authors (Koch et al., 2005). At higher levels, air masses from polar regions and temperatures below -78°C were responsible for the low ozone content observed.

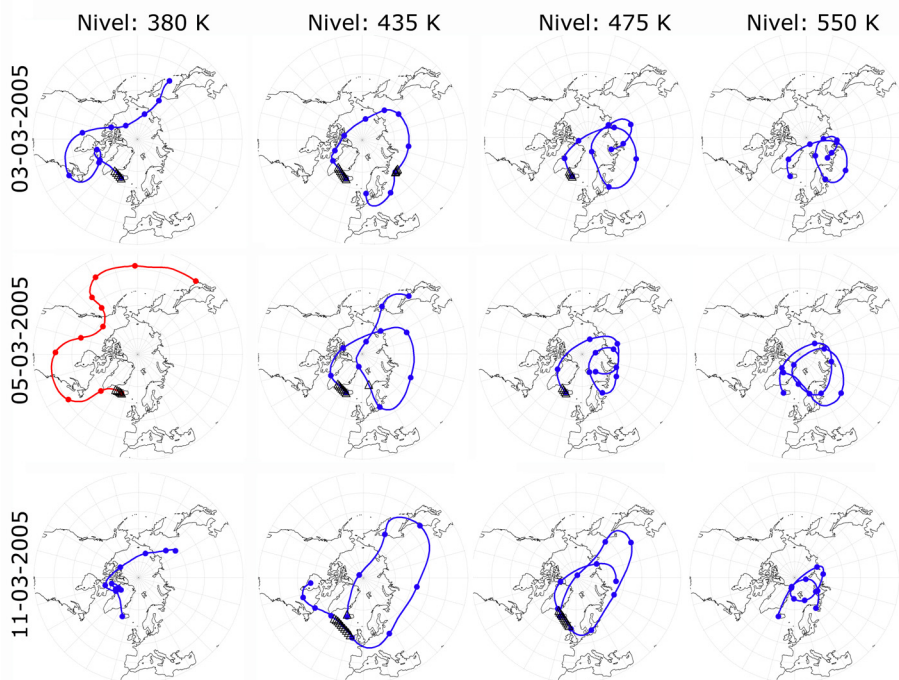


Figure 4. Ten-day back trajectories for the low extreme events (type A) with the station inside of the polar vortex.

Type B:

Laminated structures for the day 26th February 2006 are associated with transport of air masses that have been inside of the polar vortex and temperatures below the threshold for PSCs formation, leading to chemical ozone destruction.

4. SUMMARY AND CONCLUSIONS

Various mechanisms have been described in the literature as responsible for low ozone events. In order to have a better understanding about the processes responsible for these episodes observed at the subarctic station of Keflavik during winter and spring months (1992-2005), the influence of the position of the station with respect to the polar vortex has been taken into account. Three groups of events have been considered: *inside*, *edge side* and *outside* of the polar vortex.

For each group, two types of profiles with extreme low ozone content have been identified: type A, with similar characteristics to the known “ozone mini-hole”; and type B, characterized by irregular vertical structures with extreme ozone values within a vertical extension of a few hundreds of meters.

A lagrangian study for these cases shows that the mechanisms responsible for each ozone profile (type A, type B) depend on the position of the station with respect to the polar vortex:

Type A (ozone mini-holes):

1. **Outside of the polar vortex:** High tropopause and the low ozone content at the lower levels (380 and 435 K) are due to advection of air masses with subtropical origin. At higher levels, adiabatic ascent of air masses from midlatitudes could cause the low ozone values. In some cases, the decrease in temperature associated could induce additional ozone reduction due to chemical processes.
2. **Edge-side the polar vortex:** Low ozone values at lower levels are due to adiabatic ascent of air masses from midlatitudes, whereas at higher layers are produced by transport of filament structures from inside of the the vortex with low ozone content.
3. **Inside of the vortex:** Adiabatic ascent of air masses from polar and mid-latitudes at lower levels (350 and 380 K) around the edge of the vortex and chemical ozone destruction in PSCs at 475 and 550 K could explain the low ozone values.

A summary of the main processes responsible for these profiles of ozone is presented in Table 1.

	TYPE A	TYPE B
Inside of the vortex	Adiabatic ascent of masses from mid and polar latitudes (380 K), and chemical ozone destruction at 475 and 550 K.	Chemical ozone destruction.
Edge side of the vortex	Adiabatic ascent of masses from midlatitudes (380 K) and transport of filament structures from polar region at 475 K	Advection of air masses from midlatitudes and polar regions
Outside of the vortex	High tropopause, advection of air masses from subtropic areas (350, 380 K) and adiabatic ascent of masses from midlatitudes (475, 550 K)	Advection of air masses from subtropical and midlatitude areas

Table 1. Mechanisms responsible for extreme low ozone events observed at Keflavik (type A and B).

Type B

1. **Outside of the polar vortex:** laminated ozone structures are caused by advection of air masses from subtropical and midlatitudes regions at the levels where the minimum and maximum values are observed, respectively.
2. **Edge-side the polar vortex:** Isentropic advection of air masses surrounding the polar vortex leads to the formation of filament structures which are responsible for the layering profiles observed.
3. **Inside of the vortex:** Only one case has been observed and chemical ozone destruction could have given rise the structure observed at 475 K isentropic level.

5. ACKNOWLEDGEMENTS

This work has been supported by several European projects, such as EASOE, SESAME, OSDOC and THESEO. The author wants to thank to the operational team at IMO and to Manuel Gil Ojeda for his support and advices during the development of this work. The potential vorticity fields and back isentropic trajectories were provided by the Norsk Institutt for Luftforskning (NILU).

A mi profesora y amiga Elvira Zurita, por todo el cariño, ayuda y consejos que me ha dado siempre, tanto en lo profesional como en lo personal.

6. REFERENCES

- APPENZELLER, C. & J.R. HOLTON (1997). Trace filamentation in the stratosphere, a global climatology. *J. Geophys. Res.*, 102, 13555-13569.
- DOBSON, G.M.B. (1973). The laminated structure of the ozone in the atmosphere. *Quart. J. Roy. Meteor. Soc.*, 99, 599-607.
- JAMES, P.M. (1998a). A climatology of ozone mini-holes over the northern hemisphere. *Int. J. Climatol.*, 18, 1287-1303.
- JAMES, P.M. (1998b). An interhemispheric comparison of ozone mini-holes climatology. *Geophys. Res. Lett.*, 25, 301-304.
- KOCH, G., H. WERNLI, C. SCHWIERZ, J. STAEHELIN & T. PETER (2005). A composite study on the structure and formation of ozone miniholes and miniheights over central Europe, *J. Geophys. Res.*, 32, L12810, doi:10.1029/2004GL022062.
- KNUDSEN, B.M., J.M. ROSEN, N.T. KJOME & A.J. WHITTEN (1996). Comparison of analyzed stratospheric temperatures and calculated trajectories with long-duration balloon data, *J. Geophys. Res.*, 101, 19137-19145.
- KOMHYR, W.D. (1986). Operations handbook-ozone measurements to 40 km altitude with model 4A electrochemical concentration cell (ECC) ozonesondes (used with 1680 MHz radiosondes), *NOAA Tech. Memo.* ERL ARL-149, 49pp.
- NASH, E., P. NEWMAN, J. ROSENFELD & M.R. SCHOEBERL (1996). An objective determination of the polar vortex using Ertel's potential vorticity, *J. Geophys. Res.*, 101, 9471-9478.
- NEWMAN, P.A., L.R. LAIT & M.R. SCHOEBERL (1988). The morphology and meteorology of the southern hemisphere spring total ozone mini-holes. *Geophys. Res. Lett.*, 15, 923-926.
- ORSOLINI, Y.J. & V. LIMPASUVAN (2001). The North Atlantic Oscillation and the occurrences of ozone miniholes. *Geophys. Res. Lett.*, 28, 4099-4102.
- REID, S. J., & G. VAUGHAN (1991). Lamination in ozone profiles in the lower stratosphere, *Q. J. R. Meteorol. Soc.*, 117, 824-844.
- ROOD R.B., J.E. NIELSEN, R.S. STOLARSKI, A.R. DOUGLAS, J.A. KAYE & D.J. ALLEN (1992). Episodic total ozone minima and associated effects on heterogeneous chemistry and lower stratospheric transport. *J. Geophys. Res.*, 97, 7979-7996.