Atmósfera 20(2), 215-221 (2007)

Differences in the monthly evolution of the Antarctic ozone hole size

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Received September 28, 2004; accepted September 28, 2006

RESUMEN

En el presente trabajo estudiamos la evolución del área del hoyo de ozono (AHO) con la finalidad de contribuir al entendimiento de su evolución de largo plazo, así como al origen de las discrepancias entre el área modelada y la observada. Utilizamos los promedios mensuales del AHO para los meses de septiembre, octubre y noviembre, durante los años 1982-2003, y separamos cada serie mensual en dos componentes: la lineal y la residual. La componente residual para los meses de octubre y noviembre muestra una tendencia a decrecer después de 1997, mientras que la componente residual de septiembre no muestra tal comportamiento. Es decir que el AHO durante septiembre evoluciona diferente, en relación a los otros meses. Por lo tanto, de acuerdo a nuestros resultados, concluimos que es posible hacer un refinamiento a los análisis obtenidos previamente con base a promedios anuales para el AHO.

ABSTRACT

We study here the evolution of the ozone hole size (OHS) with the aim of contributing to understand the long term evolution and the origin of the discrepancies between modeled and observed size. Using the September, October and November monthly average data of the OHS, for the years 1982-2003, we separate the series into two components: a linear and a residual one. The residual OHS components for October-November, shows a tendency to decrease after 1997, whereas the residual component of September does not show a clear decrease. The OHS during September evolve different, in relation to the other months. Therefore, the earlier results for the OHS analysis obtained with an annual approach may be refined.

Keywords: Ozone hole, Antarctic, ozone depletion, ozone recovery

1. Introduction

Conventionally, it is considered that there is an ozone hole when de ozone abundance is ≤ 220 Dobson Units (DU) (1 DU=0.001 atm cm) in a specific locality. The main cause of this reduction is ascribed to anthropogenic activity (WMO, 2003; Huck *et al*., 2005). However, it was originally suggested that the existence of the hole could be explained on the basis of solar cycles, or purely atmospheric dynamics, though such hypothesis became very soon inconsistent with observational features of the Antarctic ozone hole (Seinfeld and Pandis, 1998). Nevertheless, according to WMO (2003, section 3.4.3.5), the modeling studies indicate a possible influence of the solar cycle on high-latitude temperatures (60-90° S) and, in consequence on the OHS, because the ozone destruction processes are sensitive to the stratospheric temperature. However, any effect is still too uncertain to quantify and remains somewhat speculative.

In addition, it is also well known that the total ozone abundance is affected by natural phenomena; for example, the following natural causes has been identified: the solar cycle of ultraviolet radiation, volcanic eruptions, inter-annual temperature changes, atmospheric dynamics, energetic solar protons events, galactic cosmic rays, and the relativistic electron precipitation (Jackman *et al*., 1996 and references therein).

According to WMO (2003), the OHS varies from one year to another, and it is not yet possible to say whether the area of the ozone hole has reached its maximum. Also, WMO (2003 section 3.5.3.1) reports that the coincidence of results in relation to the predicted OHS of some models as the GISS, E39/C and CSR/NIES may be interpreted in terms of a slight under-prediction. This sub-estimation in the OHS indicates that errors in modeling the ozone hole size perhaps have important implications to the Antarctic OHS with respect to the relative importance of the ozone transport, photo-chemistry and the radiative processes, assuming that the underlying physics of the models is correct.

Therefore, in order to contribute to the understanding of the evolution and the origin of such discrepancies between models and observations, we examine here the long-term OHS behavior. With this goal in mind, we analyze the monthly average of the Antarctic OHS, for the months of September, October, and November, in the period 1982 to 2003, as reported by the National Oceanic and Atmospheric Administration (NOAA) National Weather Services Climate Prediction Center for the years 1982 to 2003 (Southern Hemisphere winter summary 2003, Figures 4b-4c, available at http://www.cpc.ncep.noaa.gov/products/stratosphere/winter_bulletins/sh_03/index.html.

2. Data and analysis

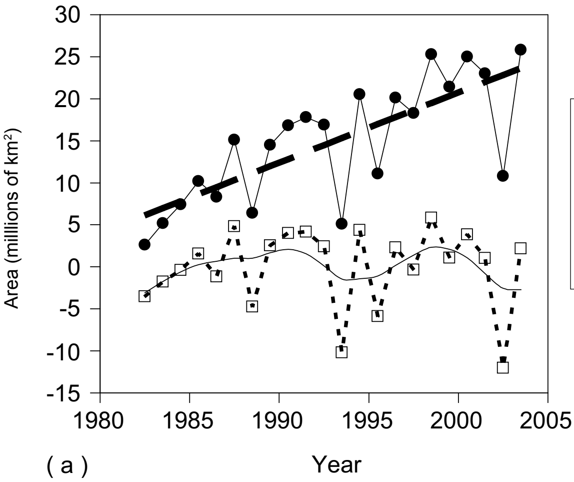
The data series used in this work are computed on the basis of measurements of SBUV on Nimbus-7 and SBUV/2 instruments on board of the NOAA Polar Orbiting Satellites. A description of the data sources is available in NOAA-Winter Summary 2003, and for a discussion on the limitations and uncertainties of SBUV and SBUV/2 measurements the WMO (2003, Chapter 4, Appendix 4A) may be consulted.

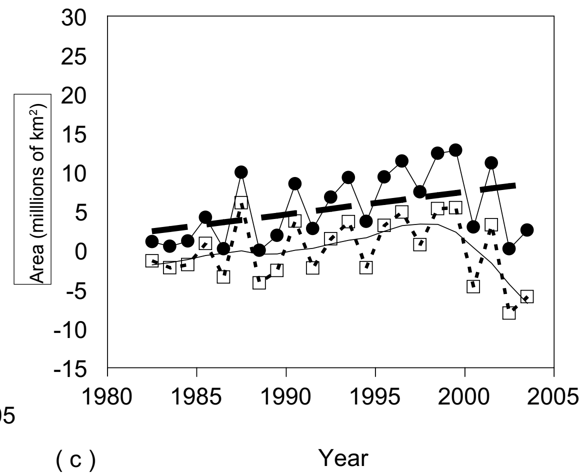
In first instance, the OHS has an increasing tendency from 1982 to the present, as we can observe in Figure 1. However, as the principal cause for the Antarctic ozone depletion is ascribed to anthropogenic contamination with chlorine and bromine compounds, we expect a modification in the tendency of the OHS in the latest years, because the EESC index (Effective Equivalent Stratospheric Chlorine, which estimates the ozone destructiveness of contamination loading in the stratosphere) reached its maximum value in 1997 (WMO 2003), following a consistent decrease since then. Therefore, a change in the tendency of the OHS that overlaps the EESC decrease is highly probable. In this work we identify such a modification in the OHS tendency during the last years.

In order to find a deviation from the main tendency we compute a decomposition of the monthly average data series, for each of the analyzed months: September, October and November (Fig. 1). We employ an additive model to decompose the series; the following expression applies to our analysis:

$$Y_i = L_i + C_i + e_i \tag{1}$$

Where Y_i describes the monthly average data of the OHS for the year i; $L_i = a + b_i$ is a linear trend of data and $(C_i + e_i)$ represents a residual component plus a random error commonly named "noise" (e_i), for the year i. Typically L_i is a line determined by least squares, with minimum dispersion with respect to the total points.





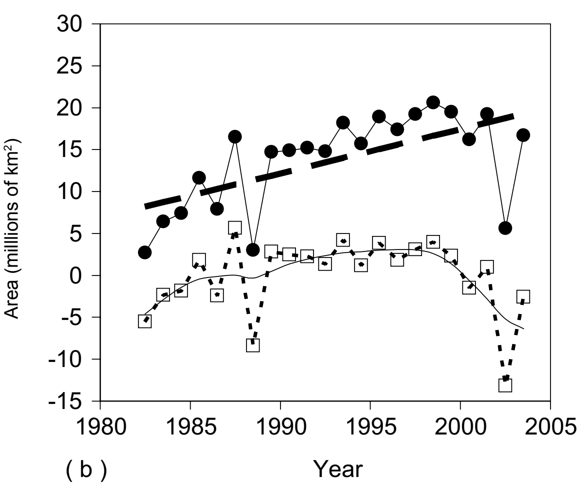


Fig. 1. Decomposition of the OHS data for the months of September a), October b) and November c), during the period 1982-2003. The dotted line represents the OHS data as it is reported by NOAA in Winter Summary 2003. The squared pointed line $(C_i + e_i)$ is the result of subtracting the linear tendency (illustrated as a dashed line) from the original data (dotted line), and the continous line illustrates the Hodrick-Prescott Filter (HPF) smoothing over the $(C_i + e_i)$ which estimates the C_i component in each case.

To estimate the values of the residual component (without the noise), we apply the Hodrick-Prescott filter (HPF) (Hodrick and Prescott, 1997) with λ = 3, over the ($C_i + e_i$) data in order to smooth the series. Assuming that the random "noise" (e_i) has zero average, the resulting component estimates the residual C_i.

Technically, the HPF is a two-sided linear filter that computes the smoothed series S_i of Y_i by minimizing the variance of Y_i around S_i, subject to a penalty that constrains the second difference of S_i. That is, the HP filter chooses S_i to minimize Z, where:

$$Z = \sum_{i=1}^{T-1} (Y_i - S_i)^2 + \lambda \sum_{i=2}^{T-1} ((S_{i+1} - S_i) - (S_i - S_{i-1}))^2 \quad (2)$$

The penalty parameter λ, in equation (2), controls the smoothness of the series S_i. The larger the λ, the smoother the S_i. As $\lambda \rightarrow \infty$, S_i approaches a linear trend. T is the end of the estimation sample.

Our results show a cyclical behavior in the residual component, perceptible only during September. During October and November the residual component does not follow exactly the same pattern, showing a tendency to remain faraway with respect to the corresponding linear trend, as it can be seen from Figure 1.

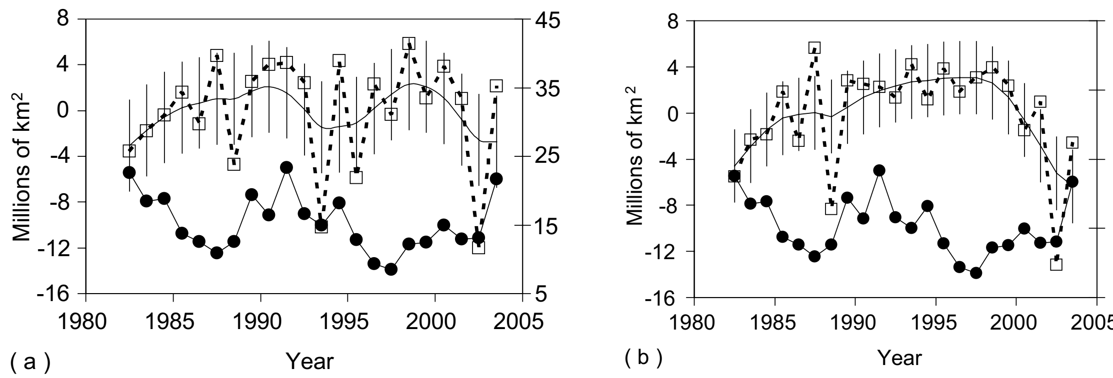
Looking for a characteristic time of variation of some process which may affect the OHS in a cyclical way, we compare the residual component of September with the annual mean of geomagnetic activity index AP (available at Geomagnestic Indices: http://web.dmi.dk/fsweb//projects/wdcc1/indices.html, since the geomagnetic activity variation is in the same range as the observed variation in the residual component for OHS-September. The contrast of the residual component of the OHS, with the annual mean of AP, are plotted for each month in Figure 2. The error bars correspond to the standard error in the smoothing.

3. Discussion

According to the smoothed residual component of the OHS data for the months of October and November of the studied period, the OHS has a sustained tendency to diminish after 1997 (Fig. 2). Taking into account the error bars, the probability that the real values follow a decreasing tendency is shown in Table I. As we can observe, the probability was rising in the last years and it is up to 93% since 2002.

Table I. Analysis taking in account error bars.

Year	September		October		November	
	Residual value according the smoothing ($\times 10^6$ km^2)	Probability that the real value falls below the linear tendency	Residual value according the smothing ($\times 10^6$ km^2)	Probability that the real value falls below the linear tendency	Residual value according the smothing ($\times 10^6$ km^2)	Probability hat the real value falls below the linear tendency
2000	1.1	39%	–0.6	58%	0.4	45%
2001	–0.8	58	–2.8	82	–1.6	71
2002	–2.6	74	–5.2	95	–4.3	93
2003	–2.7	75	–6.3	98	–6.7	99
	Error bars magnitude: 3.97×10^6 km^2		Error bars magnitude: 3.15×10^6 km^2		Error bars magnitude: 2.99×10^6 km^2	



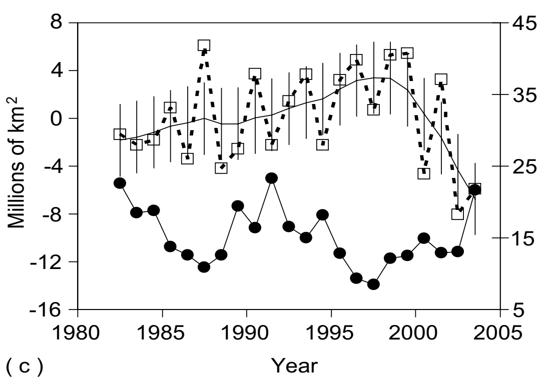


Fig. 2. Comparison of the residual component of the OHS for the months of a) September, b) October and c) November, with the annual mean of the geomagnetic activity index (AP) during the period 1982-2003. The dashed squared line corresponds to the residual component, the continuous line corresponds to the residual smooth using a HPF with the $\lambda = 3$, and the dotted line represents the annual mean of geomagnetic activity index, in each case.

In other words, at present we detect that the ozone hole has a tendency to close during October-November with at least 93% of confidence. Under the assumption that the main cause of the stratospheric ozone destruction is the anthropogenic contamination, this result agrees well with the reported decrease of the EESC after 1997 (Fig. 1b, c). However, this inference it is not valid for the month of September.

According to Figure 1a we can observe that, during September a cyclic-like behavior of the residuals is present up to now, and consequently the maximum value of OHS for this month is perhaps not reached yet. This implies an atypical alteration in at least one of the following essential factors for ozone hole formation perceptible during September: low stratospheric temperatures, high density of chlorine and bromine contaminants, stratospheric isolation, and ultraviolet solar radiation (Sinnhuber *et al*., 2003; WMO, 2003), in order to explain the different behavior.

However, the alteration is not cyclical necessarily, because taking into account the error bars of the smoothed component (Fig. 2a), we can see that the amplitude of residuals is in the same range of the error bars magnitude, therefore we do not have sufficient evidence to claim founded a cyclical behavior. On the other hand, we can affirm that the tendency of the September residuals does not diminish, as we can see in the other months (Figs. 1, 2).

Both results (for October-November and September) are in good agreement with the evolution inferred on the basis of OHS trend analysis, performed over subsets of length 5, 6, and 7 years, for the same period of analysis (Álvarez-Madrigal and Pérez-Peraza, 2005). However, at present it is not clear the existence of the quasi-cyclical pattern in the residual component for September.

The explanation of why the OHS during September follows a different behavior is not evident, perhaps is a consequence of other superimposed factors. The enhancements in the geomagnetic activity index Ap may serve as an indicator of other non typical processes that stimulate the stratospheric ozone destruction. However further research is needed in order to explain precisely, how the auroral geomagnetic activity possibly do exert a kind of modulation in the Antarctic ozone hole, perceptible only during September.

Nowadays, it is well known that the geomagnetic activity is an indicator of the level of the 11-year Solar Cycle (with a time delay of a 1-2 year approximately), and that during the Solar maximum occurs an increase in the number of energetic particles events, the so-called solar proton events (SPE). This kind of events affect the ozone destruction at stratospheric levels (Jackman *et al*., 1996).

It is well known that, under normal conditions, the interplanetary medium and the terrestrial magnetosphere shield the planet from galactic cosmic rays (GCR), which usually penetrate deep in the atmosphere, and perturb the ozone abundance in two different ways, directly, through ozone dissociation and indirectly by the NOx production at stratospheric levels (Jackman *et al*., 1996). It is important to point here that the shield is weak and the ozone destruction caused by GCR is strong at solar minimum.

Consequently, if the geomagnetic activity is intense, the ozone destruction by SPE increases and the ozone destruction by GCR decreases. On the contrary, if geomagnetic activity is weak, the ozone destruction by SPE decreases although could be increased by GCR.

According to our results, we think that the maximum ozone destruction by SPE plus GCR could be located between the maxima and the minima of the geomagnetic activity (Fig. 2a, approximately), where the contributions of the SPE in addition to GCR reach the maximum value.

We can propose only a qualitative picture, described above, as an explanation of the cyclical-like behavior in the OHS residual component, although we do not know why the phenomenon is perceptible only in September.

4. Conclusions

According to the OHS smoothed residual components for the months of October and November, the OHS has a tendency to decrease since 1997 up to the present. These results enable us to conclude that the ozone hole size is diminishing since then.

The evolution of the OHS during September is different because the residual component does not show a clearly negative tendency with respect to the increasing linear trend. Therefore, we cannot confirm if the maximum value has been reached or not during September from our analysis.

Further research is needed, in order to establish if the geomagnetic activity may exert some kind of interaction that has an effect on the stratospheric ozone hole extension, perceptible just in September in the Antarctic region. The behavior of the OHS is different in September compared with its behavior in October and November. For this reason, we think that the earlier analysis presented in the literature based on annual indices for the OHS behavior, should be refined in order to include the monthly differences.

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