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Evaluation of extreme ozone events over the Iberian Peninsula from Brewer spectrophotometers in the 2000s

D. Mateos [a,*], M. Antón [a], G. Sáenz [a], M. Bañón [b], J.M. Vilaplana [c], J.A. García [a]

[a] Departamento de Física, Avda. de Elvas s/n, Badajoz CP 06006, Spain
[b] Departamento de Producción, Agencia Estatal de Meteorología, Madrid, Spain
[c] Departamento de la Tierra, Teledetección y Atmósfera, Estación de Sondeos Atmosférico El Arenosillo, INTA, Huelva, Spain

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ABSTRACT

The analysis of extreme events is an essential key in the research of the atmospheric ozone due to their importance in biological and radiative effects. Total ozone column (TOC) databases from five ground-based sites equipped with a Brewer spectrometer are used to evaluate extreme ozone events along the Iberian Peninsula for the period 2002–2012. The monthly standard deviation is proved as a reliable metric to identify extreme cases. A total of 465 events (days) are classified as extremes events. For the database used, 2011 presents 32 events with very low TOC values (miniholes), while 2010 is the year with the maximum number (51) of events with very high TOC values (minihighs). The weight of the miniholes (minihighs) over the ozone annual mean can achieve values over the 4% (8%). The relationship between global dynamical features and ozone extreme events is also addressed in this study. Double tropopause events have explained in 2002 and 2004 up to the half of minihole events, while the North Atlantic Oscillation (NAO) negative phase is the condition prevalent in the majority of the minihighs in the entire period. These global characteristics are verified in the analysis of a case study (February–March 2004) exhibiting two periods with double tropopause events and a change in the sign of the NAO index with the consequent change in the tropopause pressure.

1. Introduction

Interesting cases for the atmospheric ozone studies are those days which present very low or very high total ozone column (TOC) values known as miniholes and minihighs, respectively. Their importance lies on the role played by ozone on global weather and climate (e.g., Kiehl et al., 1999). Furthermore, their effects over the radiative levels of ultraviolet solar radiation at the surface are relevant (e.g., Antón et al., 2008; Rieder et al., 2010; De Miguel et al., 2010). These periods with the extreme values of TOC are, in general, followed by a fast and local recovery after few days. Short term, even day-to-day, variations in TOC can produce very large differences with respect to climatologic values. The extreme cases of TOC are synoptic-scale regions where TOC is below/above a certain threshold. Concerning the ozone extreme event formation, Koch et al. (2005) found meridional transport as the key in this process, but also the vertical uplift can present a certain influence (Barriopedro et al., 2010). The formation of so-called miniholes is mainly due to transport in the lower stratosphere of a tropical air mass with low ozone and low potential vorticity (PV) while polar air (with low ozone and high PV) is transported at upper levels. The superimposition of these motions can lead to a regional reduction of the ozone content. The formation of minihighs is caused by a different horizontal transport. Polar air masses with high ozone and PV arrive in the lower stratosphere and tropical air masses (low PV and high ozone) are transported in the upper stratosphere (e.g., Mengistu Tsidu et al., 2013). Both extreme phenomena are related to PV anomalies which are correlated with ozone anomalies. Barriopedro et al. (2010) showed that 50% of ozone miniholes in Europe occur simultaneously with conditions of atmospheric blocking.

Because of the relevance of ozone extreme events, the main aim of this study is to analyze the temporal and spatial occurrences of these events over the Iberian Peninsula in 2000s decade (2002–2012). The weight of these events on the annual mean is investigated. In particular, miniholes and minihighs affecting the whole Iberian Peninsula are studied in detail. Thus, the connection of these extreme events with dynamical features such as double tropopause cases and daily North Atlantic index is analyzed, contributing to understand the mechanisms involved in their formation.

This paper characterizes extreme ozone events over a mid-latitude belt by means of ground-based stations and not using satellite data. Furthermore, the dynamical characteristics obtained from reanalysis database are not usually linked to ground-based records.

* Corresponding author at: Departamento de Física, Universidad de Extremadura, Avda. Elvas s/n, Badajoz 06010, Spain. Tel.: +34 924289300x89122.
E-mail address: davidmv@unex.es (D. Mateos).

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To our knowledge, this study presents the first collection of extreme ozone events using the five Brewer spectrometers placed in the Iberian Peninsula for the 2000s decade (2002–2012).

2. Database

2.1. Description of the database

Five Brewer spectrometers placed along the Iberian Peninsula (see Table 1) are used in this study. These instruments make up the Spanish Brewer network, which is managed by the Spanish Meteorological Agency (AEMET). Daily values of TOC are recorded by the five Brewer spectrometers with an uncertainty <1% (e.g., Antón et al., 2010). The TOC data quality provided by the Spanish Brewer Network is ensured due to the periodic checks and tests (see also, Antón et al., 2010; Mateos et al., 2015). To minimize the error source of considering different time periods in the databases, only the common period 2002–2012 is analyzed in this study.

The tropopause characteristics have been calculated from ERA-Interim reanalysis data produced by the European Centre for Medium-Range Weather Forecasts (ECMWF) (see, e.g., Simmons et al., 2007). We have chosen ERA-Interim reanalysis because it has 60 levels of vertical resolution more than other known reanalysis. Events with a double tropopause (2TRO) are also identified with the usual thermal definition, as stated by the World Meteorological Organization (WMO, 1957). From lapse rate ($\Gamma = -\partial T/\partial z$), the tropopause is defined "as the lowest level at which the lapse rate decreases to 2 ° C/km or less, provided also the average lapse rate between this level and all higher levels within 2 km does not exceed 2 ° C/km. If above the first tropopause, the average lapse rate between any level and all higher levels within 1 km exceeds 3 °C/km then a second tropopause is defined by the same criterion as under the first tropopause. This tropopuase may be either within or above the 1 km layer." When these conditions are satisfied double tropopause events are located (e.g., Castanheira et al., 2012) and the pressure and height of the first and second tropopauses are calculated using the methodology proposed by Reichler et al. (2003) and the hydrostatic equation (Birner, 2010).

From the same source of reanalysis data, the daily values of the North Atlantic oscillation (NAO) index are evaluated following the same procedures described by Mateos et al. (2015).

2.2. Comparison of Brewer and ERA-Interim TOC data

The accuracy of the ERA-Interim ozone database is already proved in other regions and planetary scale (e.g., Dragani, 2011). For the analyzed area (Iberian Peninsula) and time period (2002–2012), a comparison between daily TOC ground-based and ERA-Interim data is carried out. Table 2 summarizes the obtained results using the five ground-based stations. ERA-Interim reproduces the ground-based data with high accuracy showing a root mean square error below 5% and a well-determined linear correlation between both databases. Hence, the reliability of the ground-based measurements is proved and, in addition, ERA-Interim data are an adequate tool to investigate some of the phenomena involved in the formation of extreme ozone events.

Table 1
Geographical locations of the five sites used in this study for the period 2002–2012.

Site	Coordinates	Data coverage 2002–2012 (%)
A Coruña (COR)	43.33°N, 8.42°W, 58 m a.s.l	2884 (72%)
Zaragoza (ZGZ)	41.01°N, 1.01°W, 260 m a.s.l.	3277 (82%)
Madrid (MAD)	40.45°N, 3.72°W, 664 m a.s.l.	2849 (71%)
Murcia (MUR)	38.03°N, 1.17°W, 61 m a.s.l.	3344 (83%)
El Arenosillo (ARE)	37.10°N, 6.73°W, 41 m a.s.l.	3155 (79%)

Table 2
Statistics of the Brewer and ERA-Interim TOC data. Legend: n (number of data), mbe (mean bias error), rmse (root mean square error), i_{agree} (index of agreement), and linear fit $y = a + bx$ (b: slope, a: intercept, and r: correlation coefficient). Methods adopted from Willmott (1982).

Variable	Value
n	16102
mbe	−2.7%
rmse	4.5%
i_{agree}	0.95
b	0.90
a	22.1
r	0.94

3. Identification of extreme ozone events

Fig. 1a shows the annual cycle of TOC at the five ground-based sites in the period 2002–2012. A latitudinal S-N increasing gradient can be observed, being more evident in the maximum TOC values. For instance, during the first 6 months of the year, the difference between Northern (A Coruña and Zaragoza) and Southern (Murcia and El Arenosillo) areas can be over 20 DU. The absolute differences among the five sites drastically diminished during fall season. This S-N increasing gradient of TOC values is also observed in Portugal by Antón et al. (2011a, 2011b). In the last decade, monthly TOC maxima over the Iberian Peninsula reach 360 DU in April while the minima are around 280 DU in October. Fig. 1b shows the standard deviation (σ) of the monthly climatological values for the five sites. High variability is observed in the averages in winter, spring, and autumn, while the values during summer are very stable (σ below 20 DU).

There is a big discrepancy about the definition of the threshold to identify extreme events in literature. Fixed values for the threshold (300, 225, or 220 DU) were proposed by several authors (e.g., McCormack and Hood, 1997; Petzoldt, 1999; Bojkov and Balis, 2001), while a difference between 70 or 80 DU with respect to the monthly and the annual averages were used by other studies (e.g., James, 1998; Krzyscin, 2002; Iwao and Hirooka, 2006). Other studies applied a time-dependent filter based on the standard deviation (Koch et al., 2005; Antón et al., 2007, 2008; Martínez-Lozano et al., 2011; Sola and Lorente, 2011). Finally, Rieder et al. (2011) pointed out the non-Gaussian behavior of the TOC and used a Pareto distribution in the analysis of extreme events at 5 ground-based stations in Central Europe.

As was shown in Fig. 1, there are differences over the five sites; hence, it is evident that the criterion of selecting miniholes and minihighs should be site dependent. Hence, a monthly criterion for selecting extreme events over each site is applied in this study. Each monthly database has been investigated in terms of the distribution analysis. The monthly values of the skewness and kurtosis are presented in Fig. 2. Overall, most of the months comply with the criteria of a normal distribution being both magnitudes close to zero (±0.5). Several months present a larger concentration of values than the normal distribution. However, most of the TOC ranges in each month can be interpreted by a normal distribution when analyzing quartiles and CDF plots. Therefore, the properties of the normal distribution can be assumed in the identification of the ozone extreme events. In this sense, about 95.45% of the values lie within twice the standard deviation (2σ) for a normal distribution. Hence, 2σ over the 12-month data sets seems to be an appropriate choice to identify ozone extreme cases. This threshold was already selected in literature by, e.g., Antón et al.