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Anomalous mesospheric ozone variability is not a precursor to earthquakes: A case study in Greece

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ABSTRACT

Very recently, it has been found that intense anomalies of the mesospheric ozone occur a few days before major earthquakes. This paper explores the credibility of this finding in the case of the last two major earthquakes in Greece. Indeed, the study of the mesospheric ozone vertical distribution showed that unusual anomalies occurred a few days before these two earthquakes. However, at time periods with no significant seismicity the same unusual changes in the mesospheric ozone vertical distribution were observed. Consequently, significant temporal changes of the mesospheric ozone can not be considered as precursors for upcoming significant seismic activity.

1. Introduction

In the recent past, some studies have reported the possible relationship of various atmospheric changes before and after an earthquake. For example, several researchers using ground-based, in-situ and satellite observations suggested a close connection of the occurrence of significant earthquakes with changes in the lithosphere (electrical precursory signals formed due to point defects), ionosphere, surface air temperature, atmospheric total ozone and (eg Lazaridou et al., 1985; Amani et al., 2014).

However, other studies have argued about the lack of statistical significance of such a connection. For example, Efstathiou (2012) studied total ozone anomalous fluctuations in the time window between 14 days before and after the eight major earthquakes of the 2001–2010 period, in Greece, suggesting that total ozone observations could not be considered as a precursor tool for major earthquake events. Similar results with what Efstathiou (2012) mentioned, were reported by Dologlou (2013). Also, Varotsos et al. (2017a) investigated again five major earthquakes happened in Greece (on dates: 26/7/2001, 14/8/2003, 8/1/2006, 14/2/2008 and 17/11/2015) looking for possible unusual fluctuations in aerosol optical depth and total ozone in the time window between 25 days before, and 14 days after each of these seismic events. The main result obtained by Varotsos et al. (2017a) was that there was no statistically significant abnormal change around the earthquake date.

Very recently, Phanikumar et al. (2018) investigating the case of the Indian Subcontinent to Nepal Gorkha earthquakes that occurred between April and May 2015, reported strong anomalous variations of mesospheric ozone (accompanied by very low frequency-VLF sub-ionospheric anomalies) prior to April 25, 2015 earthquake and its biggest aftershock in May 12, 2015.

In the present paper, motivated from the above-mentioned finding of Phanikumar et al. (2018), we investigate the validity of this finding in the case of Greece, focusing on the two last two major seismic events that took place in Greece on June 16, 2013 (Mw = 6.0) and June 12, 2017 (Mw = 6.4).

2. Data and analysis

For the above-mentioned purposes of this study we used daily mesospheric ozone data (over the Greek area: 35 °N - 41°N and 21°E - 26°E, at the altitude range: 50-155 Km, for June 2008–2017) as derived from SABER (Sounding of the Atmosphere using Broadband Emission Radiometry) observations (Smith et al., 2013; Mlynczak et al., 2013). SABER is one of the leading instruments on board TIMED (Thermosphere, Ionosphere, Mesosphere Energetics, and Dynamics) satellite that measures chemical species such as ozone in the upper atmosphere. Ozone measurements are carried out on two different spectral channels; one at 9.6 μm and the other at 1.27 μm. In the present study, we used the ozone retrieved from the 9.6 μm spectral channel during the evolution of earthquake events (http://saber.gats-inc.com/).

The information on the earthquakes studied in this analysis was

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obtained from the Geo-Dynamic Institute of the National Observatory of Athens (GI-NOA) and the United States Geological Survey (USGS). The first event (June 16, 2013) had epicentre: (34.35 °N, 24.99 °E), depth: 12 Km and magnitude: 6.0. The second event (June 12, 2017) had epicentre: (38.85 °N, 26.33 °E), depth: 10 Km and magnitude: 6.4.

The non-parametric goodness-of-fit Kolmogorov-Smirnov (KS) test and chi-square test were applied to the daily ozone values, in order to examine the null hypothesis (H_0), namely: the data is derived from the Gaussian distribution versus alternate hypothesis (H_1), i.e. at least one value does not match the Gaussian distribution. The general steps for conducting the KS test are: 1) to create an empirical cumulative distribution function $F_n(x)$ for the set of data being considered (where n is the sample size), 2) to determine the cumulative distribution function $F_o(x)$ of a defined distribution, 3) to plot the two distributions together, 4) to measure the largest vertical distance between the two graphs by calculating the test statistic $D_n = \sup_{|x|<\infty}|F_n(x) - F_o(x)|$, 5) to compare the statistical result of test D_n with the critical value obtained by Kolmogorov (1933). The distribution function of $\sqrt{n}\cdot D_n$ uniformly converges to the Kolmogorov distribution function $K(S)$ as $n \to \infty$ (Bolshev and Smirnov, 1983). If D_n is greater than the critical value, the null hypothesis is rejected. It is worthy of note that the Kolmogorov test is recommended to be used with Bolshev's correction (Lemeshko et al., 2010) i.e. $S_k = \sqrt{n}D_n + \frac{1}{6\sqrt{n}}$, where

$$D_n = \max(D_n^+, D_n^-),\ D_n^+ = \max_{1\le i\le n}\left\{\frac{i}{n} - F_o(x_i)\right\}, D_n^o = \max_{1\le i\le n}\left\{F_o(x_i) - \frac{i-1}{n}\right\}$$

and $x_1 \le x_2 \le \ldots \le x_n$ is the sample sorted in increasing order.

On the other hand, the chi-square test (a special case of the gamma distribution) divides the entire range of values (for the data-set under consideration) into n non-overlapping intervals of equal length and calculates the test statistic as: $X^2 = \sum_{i=1}^{n}\frac{(O_i - E_i)^2}{E_i}$, where Oi and Ei are the observed and the expected outcome frequencies, respectively, for the interval i. The expected frequency E_i is defined as: $E_i = (F(Y_u) - F(Y_l))\cdot N$ where F denotes the cumulative distribution function for the assumed distribution, Y_u = the upper limit for the interval i, Y_l is the lower limit for the interval i and N is the size of the data-set. The test statistic X^2 follows, approximately, a chi-square distribution with (n - c) degrees of freedom where n is the number of the intervals and c is the number of the estimated parameters for the assumed distribution plus one. If the resulting value X^2 is greater than the critical value $X^2_{1-a,\, n-c}$ resulting from the chi-squared distribution (for significance level α), the null hypothesis is rejected.

Both of the above described statistical tests showed that ozone values come from a normal distribution (ND) population, with a confidence level of 95%. We then considered as an anomaly any value of the ozone vertical profile (in the altitude range: 50-155 Km), located outside the interval ($\mu - 2\sigma, \mu + 2\sigma$), where μ and σ represent the ozone monthly mean and standard deviation values, respectively, in June of all years 2008–2017 (excluding year of earthquake), for the Greek area: (35 °N – 41 °N, 20 °E – 26 °E).

3. Results and discussion

We applied the statistical tool, described in section 2, focusing on the normal distribution interval ($\mu - 2\sigma, \mu + 2\sigma$). Fig. 1(a) and (b) show the vertical ozone monthly mean profile in June of all years 2008–2017 (excluding the year of the earthquake) along with the 2σ error bars, for each of the two seismic events. In addition, these figures present the daily ozone vertical profile for the time interval of 1–5 days before the earthquake. As it is seen, unusual ozone fluctuations (at 95% confidence level) appear during both seismic events, occurred in Greece. Furthermore, according to the same figures, a systematic ozone maximum appears in the 80–100 Km altitude range and the ozone vertical profile a few days before each event is completely disrupted.

However, for validation reasons, we conducted the same analysis for the June 2016 case, a random month in which no major earthquake occurred in Greece. Fig. 2(a), (b) compares the ozone monthly mean vertical profile in June of all years 2008–2017 (excluding the year 2011 and 2016, respectively) with the ozone vertical profile of particular days selected for extreme ozone values. Indeed, anomalous variations (out of the 2σ error bars) have again occurred, indicating that ozone observations can not be considered as an adequate tool for identifying previous earthquakes.

It is worth noting that the ozone vertical profile for each of the two seismic events (June 16, 2013 and June 12, 2017) revealed even more pronounced abnormal variability at altitudes outside the 50–80 Km range (i.e. in the 80–100 Km and 25–45 Km altitude, see Fig. 3). However, these ozone fluctuations were also observed in the case of the two random months (during which no large seismic event occurred), confirming once again that ozone variability could not be considered as a reliable tool for earthquake forecasting.

Therefore, it was not considered necessary to continue by analyzing VLF data, as proposed by Phanikumar et al. (2018). It appears that the analysis of Phanikumar et al. (2018) was based on evidence of only one earthquake event, without being able to support a reliable physical mechanism. In addition, there are known mechanisms that explain several fluctuations in the ozone content of the troposphere, stratosphere and mesosphere that were established since long ago, without the use of seismic parameters (e.g. Efstathiou and Varotsos, 2010, 2013; Kondratyev and Varotsos, 2001; Varotsos et al., 2013; Varotsos and Cartalis, 1991; Cracknell and Varotsos, 2011; Varotsos et al., 2017b).

The temporal variability in the ozone layer is not yet fully understood (e.g. Pancheva et al., 2003, 2014; Cracknell and Varotsos, 2007, 2011; Varotsos, 2002; Varotsos et al., 1995, 2000). In particular, the observed variability in the mesospheric ozone vertical distribution is complicated and could be attributed to several reasons considering that its life time is of the order of few secs to less than an hour (e.g. Smith et al., 2013). In this regard, few studies have associated mesospheric ozone variations with events like geomagnetic storms, solar eclipses, gravity waves, ionospheric electrodynamics, etc (Pulinets, 2009; Daae et al., 2012; Nina and Čadež, 2013; Andersson et al., 2014), which may contributed to significant fluctuations (up to even 30%) in 70–80 km altitude regions. In particular, Daae et al. (2012) employing mesospheric ozone measurements obtained by a ground-based microwave radiometer at Troll Station, Antarctica (72°S, 2.5°E, $L = 4.76$) observed a decrease of 20–70%, coincident with increased nitric oxide, between 60 km and 75 km altitude associated with energetic electron precipitation ($E > 30$ keV) during a moderate geomagnetic storm in late July 2009. They suggested that chemical changes induced by electron precipitation during moderate geomagnetic storms, can cause significant effects on the middle mesospheric ozone distribution.

It should be noted that many difficulties still exist about the understanding of the variability of the mesospheric ozone in lower/upper altitudes (where ion chemistry alone is sufficient/not sufficient to explain the observed fluctuations).

4. Conclusions

The present study was focused on the case of two major earthquakes occurred in Greece on June 16, 2013 and June 12, 2017, searching for a tool (if there is any) to identify the prior seismic signature. Studying the ozone vertical profile in the mesosphere over Greece, anomalous variations were detected few days before both these events. However, when the same analysis was repeated for the case of June 2016 and June 2011, two random months during which no large earthquake event happened, extreme ozone variations again appeared suggesting that mesospheric ozone variations could not be considered as a tool for identifying an impinging earthquake.