TRACK ANALYSIS OF CYCLONES RELATED TO TORNADOES OVER WESTERN GREECE

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ABSTRACT

Extreme weather phenomena, posing a significant threat to public health, causing injuries and even more fatalities, have been considered of high concern by the scientific community so that to mitigate the impacts and contribute to the adaptation and resilience of the society. Tornadoes and waterspouts have been characterized as the most violent of all small-scale natural phenomena. They are associated with extremely high winds, inside and around the tornado's funnel, causing extended damage and in many cases loss of life.

The goal of this study is to examine the cyclonic tracks associated to the incidence of tornadoes over western Greece, within the cold period of the year, from 2000 to 2012. The Laboratory of Climatology and Atmospheric Environment (LACAE, http://lacae.geol.uoa.gr) of the University of Athens has undertaken a systematic effort in recording tornadoes, waterspouts, and funnel clouds in Greece since 2007. LACAE developed in 2009 an open-ended online tornado report database web system (http://tornado.geol.uoa.gr), contributing to the compilation of a climatology of these extreme weather events. All database's records have been assembled as photographs, videos, eyewitness reports, literature reports and synoptic reports by the HNMS. Each tornado event is linked with a cyclone track close to the time of its appearance. The cyclone tracks are derived from the Melbourne University cyclone finding and tracking scheme (MS algorithm) applied to the mean sea level pressure (MSLP) reanalysis data sets of the ERA-Interim Project on a 0.5° x 0.5° regular longitude/latitude grid.

The findings of the cyclone track analysis revealed specific patterns of cyclogenesis that favour tornadogenesis over western coastal regions of Greece. More specifically, the maximum frequency of cyclogenesis is highlighted mainly over the northern parts of Italy, during autumn. Regarding the winter season, the maximum frequency of cyclogenesis is spotted over the southern and western parts of Italy. The autumn cyclone density of 2.9 cyclones per deg. lat^2 was found against 2 cyclones per deg lat^{2}during winter.

Keywords: tornadoes, cyclones, tracks, ECMWF, ERA-Interim, Greece

1. Introduction

The Laboratory of Climatology and Atmospheric Environment (LACAE) has started a systematic effort documenting severe weather phenomena and their impacts over Greece since 2007. Thus, an extensive database, consisted of tornadoes, waterspouts and funnel cloud activities from 1795 to 2014 has been developed, accompanied by their impacts (e.g. fatalities, injuries, damages). Based on this database, an updated climatology of tornadoes and waterspouts was suggested by Matsangouras *et al*. (2014), verifying previous climatological studies by Nastos and Matsangouras (2010), and Sioutas (2011), regarding spatial and temporal tornadic activity within the 20th century and 2000-2009, respectively.

Climatological studies based on historical and recent (2000-2012) tornadoes activities over Greece, revealed that western Greece is the most vulnerable region for tornado development (Sioutas, 2011; Matsangouras *et al*., 2014). In particular, Sioutas (2011) based on 10 years of data (2000–2009), suggested a mean annual number of 1.1 tornadoes per unit area of 10^4 km^2 for Greece. Matsangouras *et al*. (2014) based on 13 years data (2000-2012), presented that Greece is experiencing an annual mean of more than 10 tornadoes, while the maximum tornado frequency is evident over the western Greece, indicating an annual mean of 5.1 tornadoes. A research study based on an objective synoptic classification of tornadic days over the western Greece during 1953-2012 period, showed that tornadoes occur under the influence of specific synoptic types (Matsangouras *et al*., 2013). Nastos and Matsangouras (2014) based on National Centers for Environmental Prediction– National Center for Atmospheric Research (NCEP–NCAR) reanalysis data sets, showed that a SW surface flow is the main characteristic of daily composite mean of synoptic conditions for tornado days within the autumn and winter seasons, as the centre of low pressure system is identified near the Gulf of Taranto. Moreover, tornadoes were associated with synoptic features, thus, 48% of tornadoes within autumn occurred in pre- frontal weather conditions (cold fronts) and 27% appeared after the passage of the cold front (Nastos and Matsangouras, 2014).

The aim of this study is to examine the cyclonic tracks associated with the incidence of tornadoes over western Greece, within the cold period of the year, from 2000 to 2012, in order to identify specific regions of cyclogenesis that favour tornado development. The outline of the paper is as follows: Section 2 presents the data source and the methodology that we adopted. Results and discussion are illustrated in Section 3. Finally, Section 4 summarizes our findings and conclusions.

2. Methodology and data

2.1. LACAE tornado database

The LACAE tornado database includes more than 235 tornadic events (tornadoes, waterspouts and funnel cloud) that occurred over the western Greece from January 1, 2000 to December 31, 2012.

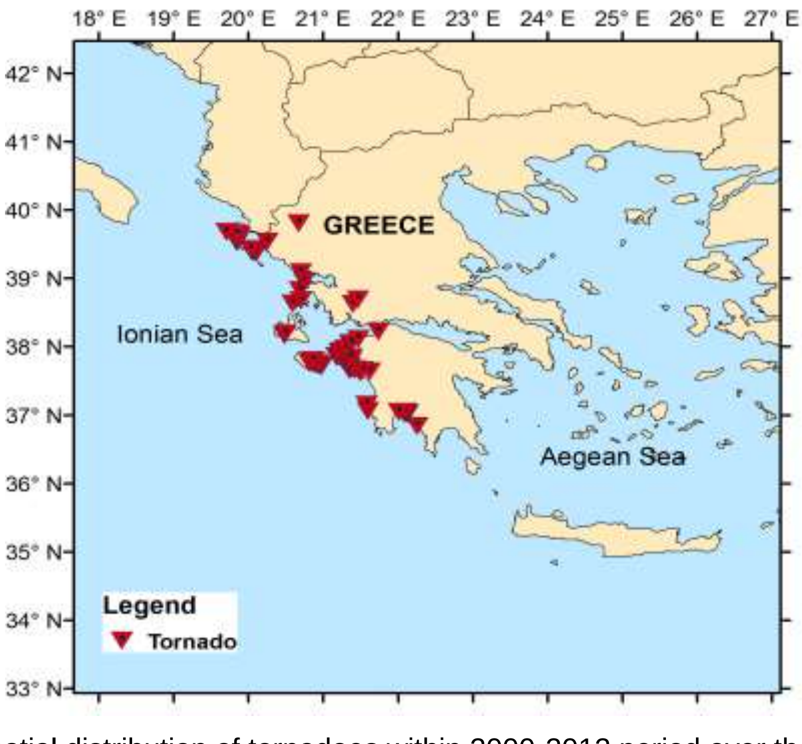

Figure 1: Spatial distribution of tornadoes within 2000-2012 period over the western Greece based on LACAE's database.

Figure 1 shows that tornadoes are more prominent over specific sub geographical regions along western Greece. Moreover, it is evident that tornado maximum frequency appears over NW Peloponnese, the northern Ionian Sea (central and southern parts of Corfu Island), the central Ionian Sea (Zante island) and southern Peloponnese (Messinian Gulf). Previous studies regarding tornado activity over the western Greece showed that tornadoes are favored during the autumn season followed by the winter (Matsangouras *et al*. 2014) and the majority of tornadoes are associated with synoptic frontal features (Nastos and Matsangouras, 2014). Based on these results, our analysis concerns tornadoes that verify the following selection criteria: a) tornadoes that occurred during the cold period of the year (autumn and winter season), b) their time of occurrence is known with ± 1 h accuracy and c) they are related to frontal synoptic features. Thus, a total of 41 tornadoes has been taken into consideration and catalogued in 38 individual days, as there were days with multiple events.

2.2. Cyclone tracking algorithm

The cyclone identification and tracking were performed by the algorithm developed at the Melbourne University (the MS algorithm; see Murray and Simmonds, 1991). One of the most important advantages of the MS algorithm lies in its spatially continuous representation of MSLP field, using both pressure and surface geostrophic relative vorticity fields. The algorithm has been widely employed for both southern and northern hemisphere, and has demonstrated its reliability and efficiency in capturing the weather patterns and synoptic climatology of the transient activity and providing objective climatologies, while it has also proved to be a powerful tool in the analysis of cyclone case studies (e.g., Pinto *et al*., 2005; Kouroutzoglou *et al*., 2014). Specifically for the Mediterranean, the algorithm was found to be capable of identifying cyclones in a range of locations and with different characteristics (e.g., Flocas *et al*. 2010).

ERA-Interim (Dee *et al*., 2011) 6-hourly reanalysis data sets of mean sea-level pressure (MSLP) on a 0.5° × 0.5° regular latitude–longitude grid from the European Centre for Medium-Range Weather Forecasts (ECMWF), were implemented as input to the MS algorithm, resulting in cyclonic tracks with 6 hour steps. Tornadoes were associated to synoptic features (frontal activity) based on UK Met Office analysis and related to MS algorithm cyclone tracking analysis results. Geographical Information System (GIS) software was used to visualize MS algorithm tracking results from the time of cyclonegeneis until the time of tornadogenesis.

3. Results

The findings of the cyclone track analysis revealed specific seasonal spatial distribution of cyclogenesis that favor tornadogenesis over western coastal regions of Greece within the 2000-2012 period. Figure 2, summarizes these findings, for autumn (left) and winter (right) season. During the autumn season (Figure 2, left graph) the maximum frequency of cyclogenesis is evident, mainly over the central and northern parts of Italy (mainland and northern Adriatic Sea). However, the cyclone density of 2.9 cyclones per deg. lat^2 was depicted over a significant area, bounded from the Gulf of Taranto to the central Ionian Sea(not shown), suggesting cyclones' persistence over that area. On the contrary, the spatial distribution of cyclogenesis during the winter season (Figure 2, right graph) shows that the maximum frequency is depicted over the southern parts of Italy and between the Corsica and Italy region (western parts of Italy). Winter cyclone density shows maximum values of 2 cyclones per deg. lat^2 only close (NE) to the Gulf of Taranto (not shown).

The spatial distribution of cyclonic tracks during September showed that cyclones formed over the Gulf of Genoa, the western Mediterranean Sea and southern from the Gulf of Gabes (not shown) and propagated through northern and central Italy. During October (11 cases), the associated cyclonic tracks revealed that cyclones developed mainly over two regions, the northern Adriatic Sea and south of the Atlas Mountains region (not shown). November is the most active month (16 cases) and cyclones formed mainly over the Gulf of Genoa, the northern coast of Africa, and also the Atlantic (not shown). The main characteristic of cyclonic tracks during autumn, is a persistence over central and northern parts of Italy. On the contrary, during winter, the cyclonic tracks revealed persistence in their track steps over central, southern Italy and the eastern parts of Corsica. In particular, during December (3 cases) cyclones formed to the south of the Gulf of Genoa (close to Corsica) and propagated eastwards (not shown). In January (2 cases), cyclonic tracks originated over the western coasts of Europe (not shown). Finally, during February (5 cases), cyclones formed mainly south of the Gulf of Genoa and the western coast of France (not shown).

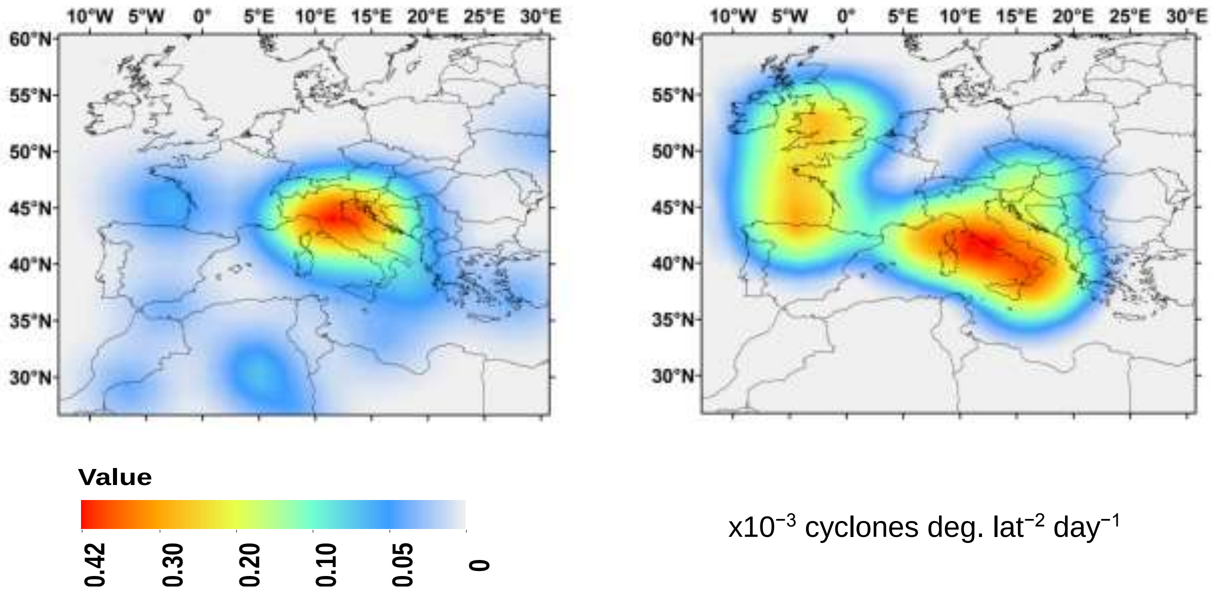

Figure 2: Mean spatial distribution of cyclogenesis frequency associated with tornadoes over the western Greece within the 2000-2012 period, for autumn (left) and winter (right) season.

4. Summary and conclusions

In this study, 41 tornado cases, as derived from LACAE database that developed over the western Greece within 2000-2012 period, were associated to specific cyclones, and their tracks were identified with the use of the MS algorithm/ The cyclone tracks analysis revealed a specific seasonal spatial distribution of cyclogenesis that favors tornadogenesis over the western coastal regions of Greece. More specifically, the maximum frequency of cyclogenesis is highlighted mainly over the northern parts of Italy during autumn. Regarding the winter season, the maximum frequency of cyclogenesis is spotted over the southern and western parts of Italy. The autumn cyclone density of 2.9 cyclones per deg. lat^2 was depicted from the Gulf of Taranto to the western Greece against 2 cyclones per deg lat^2 that appeared only close (NE) to the Gulf of Taranto during winter.

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