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Study of the tornado event in Greece on March 25, 2009: Synoptic analysis and numerical modeling using modified topography

I.T. Matsangouras [a,b,*], P.T. Nastos [a], I. Pytharoulis [c]

[a] Laboratory of Climatology and Atmospheric Environment, Faculty of Geology and Geoenvironment, University of Athens, University Campus GR 15784, Athens, Greece
[b] Hellenic National Meteorological Service, Hellinikon GR 16777, Athens, Greece
[c] Department of Meteorology and Climatology, School of Geology, Aristotle University of Thessaloniki, University Campus, GR 54124, Thessaloniki, Greece

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ABSTRACT

Recent research revealed that western Greece and NW Peloponnese are regions that favor prefrontal tornadic incidence. On March 25, 2009 a tornado developed approximately at 10:30 UTC near Varda village (NW Peloponnese). Tornado intensity was T4–T5 (TORRO scale) and consequently caused an economic impact of 350,000 € over the local society. The goals of this study are: (i) to analyze synoptic and remote sensing features regarding the tornado event over NW Peloponnese and (ii) to investigate the role of topography in tornadogenesis triggered under strong synoptic scale forcing over that area.

Synoptic analysis was based on the European Centre for Medium-Range Weather Forecasts (ECMWF) data sets. The analysis of daily anomaly of synoptic conditions with respect to 30 years' climatology (1981–2010), was based on the National Centers for Environmental Prediction–National Center for Atmospheric Research (NCEP–NCAR) reanalysis data sets. In addition, numerous remote sensing data sets were derived by the Hellenic National Meteorological Service (HNMS) weather station network in order to better interpret the examined tornado event.

Finally, numerical modeling was performed using the non-hydrostatic Weather Research and Forecasting model (WRF), initialized by ECMWF gridded analyses, with telescoping nested grids that allow the representation of atmospheric circulations ranging from the synoptic scale down to the meso-scale. The two numerical experiments were performed on the basis of: (a) the presence and (b) the absence of topography (landscape), so as to determine whether the occurrence of a tornado – identified by diagnostic instability indices – could be indicated by modifying topography.

The energy helicity index (EHI), the bulk Richardson number (BRN) shear, the storm-relative environmental helicity (SRH), and the maximum convective available potential energy (MCAPE, for parcels with maximum θ_e) were considered as principal diagnostic instability variables and employed in both numerical experiments. Furthermore, model verification was conducted, accompanied by analysis of the absolute vorticity budget.

Synoptic analysis revealed that the synoptic weather conditions on March 25, 2009 are in agreement with the composite synoptic climatology for tornado days over western Greece. In addition, maximum daily anomalies at the barometric levels of 500, 700, 850 and 925 hPa were found, compared to the climatology of composite mean anomalies for tornado days over western Greece. Numerical simulations revealed that the topography of NW Peloponnese did not constitute an important factor during the tornado event on March 25, 2009, based on EHI, SRH, BRN, and MCAPE analyses.

1. Introduction

Despite the general perception that tornadic storms mainly occur in the central United States (US), these extreme events are well known to appear globally and in many cases, have the ability to produce significant loss of both property and life. Climatological studies have described the spatio-temporal distribution of tornadoes around the Mediterranean Sea throughout the last decades (Dessens and Snow, 1987; Paul, 1999, 2000; Gianfreda et al., 2005; Giaiotti et al., 2007; Gayà, 2011; Kahraman and Markowski, 2014; Matsangouras et al., 2014a). A significant effort has been put forth during the last 10 years to present climatological studies on tornadoes in Greece (Nastos and Matsangouras, 2010; Matsangouras et al., 2011a; Sioutas, 2011; Matsangouras et al., 2014a) and analyze case studies of important tornado and waterspout events (Matsangouras and Nastos, 2010; Matsangouras et al., 2011b). Matsangouras et al. (2014a) based on 13 years data

* Corresponding author at: Laboratory of Climatology and Atmospheric Environment, Department of Geography and Climatology, Faculty of Geology and Geoenvironment, University of Athens, University Campus GR 15784, Athens, Greece. Tel.: +30 210 7274191.
E-mail address: john_matsa@geol.uoa.gr (I.T. Matsangouras).

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(2000–2012), revealed that Greece is experiencing an annual mean of about 42 tornadic events, while the maximum tornado frequency is evident over NW Peloponnese (western Greece), indicating an annual mean of more than 2 tornadoes (Matsangouras et al., 2014a).

Significant research has been carried out investigating the use of diagnostic variable sets as forecasting tools or parameters to identify favorable atmospheric conditions of severe convective weather or to address the overall threat of severe weather associated with convective storms, large hail, severe winds or tornadoes, in particular. Diagnostic variables have a long history in association with forecasting severe convection (Schaefer, 1986; Johns and Doswell, 1992). Doswell and Schultz (2006) aptly stated that the value of such variables is strongly associated with their capacity to summarize in a single number some characteristics of the severe storm environment, rather than having to consider the full complexity of four-dimensional atmospheric data. Furthermore, Doswell and Schultz (2006), noted that when forecasters are calculating diagnostic variables, they are unaware of the caveats associated with the particular variable being analyzed and can be misled. In particular, diagnostic variables can be useful in assessing quantitatively the state of the lower troposphere at the time of their calculation, but their capability to alert forecasters about convective weather in the future can be quite limited, at best. Moreover, criteria are required to determine whether an index/diagnostic variable represents an effective forecast parameter. Indeed, Monteverdi et al. (2003) showed that for at least one type of severe weather forecasting (tornadoes in California), convective available potential energy (CAPE) proved to be of little value in discriminating tornado cases from non tornadic cases when tested as a forecast parameter. However, time pressure can encourage an increased use of indices/diagnostic variables by operational forecasters so as to obtain a quick "look" at the data aiming to identify hot spots to focus upon throughout nowcasting. Moreover, Michaelides et al. (2014) indicated that the development and use of instability indices have evolved into two main branches: (i) the development of the instability indices themselves and (ii) research on instability indices referring to the corresponding data acquisition. Several studies have been performed to investigate instability indices over southeastern Europe (Siedlecki, 2009), Italy (Conte et al., 2011), Greek peninsula (Dalezios and Papamanolis, 1991), Cyprus (Michalopoulou and Jacovides, 1987; Michaelides et al., 2008) and the Mediterranean (Tudurí and Ramis, 1997; Lolis, 2007; Lolis et al., 2012). The concept of ingredients for severe convective weather was introduced by Doswell (1987), Doswell et al. (1996), and Groenemeijer et al. (2011), and can be defined as an essential, but not sufficient, condition for a phenomenon to occur.

Diagnostic indices like the maximum convective available potential energy (MCAPE, for parcels with maximum θ_e), the energy helicity index (EHI), the bulk Richardson number (BRN) shear, and the storm-relative environmental helicity (SRH) (Table 1 in Matsangouras et al., 2014b) have been considered as useful tools to depict the ingredients of energy, helicity, vertical wind shear and the relationship with the buoyant energy for tornadogenesis (e.g., Moncrieff and Green, 1972; Weisman and Klemp, 1982; Droegemeier et al., 1993; Hannesen et al., 1998; Craven and Brooks, 2002; Monteverdi et al., 2003; Rasmussen, 2003; Groenemeijer and Van Delden, 2007; Brooks, 2009; Shafer et al., 2009). Tornadogenesis is a major forecast challenge in regions of complex terrain (e.g., Homar et al., 2003). Miglietta and Regano (2008) confirming the importance of even a relatively shallow orography in the development of convective cells, using WRF sensitivity experiments over a small area in Apulia (in southern Italy). Similarly, Matsangouras et al. (2014b) investigated the importance of Greek topography by using WRF simulations in western, central and northern parts of the Greek complex topography, revealing that complex topography with steep slope constituted an important factor during both tornado events on November 17, 2007 and February 12, 2010, based on EHI, SRH, BRN, and MCAPE analyses. Conversely, a plain topography, regarding the tornado event in Vlychos Bay, in the marina of Lefkada's Island on September 20, 2011, was a less important factor based on EHI, SRH, BRN, and MCAPE analyses (Matsangouras et al., 2014b).

The objective of the present work is threefold: (i) to analyze the synoptic atmospheric conditions that triggered the tornado event over NW Peloponnese, (ii) to analyze remote sensing data (e.g., weather radar and satellite images) close to tornadogenesis and (iii) to further examine the role of topography in tornadogenesis triggered under strong synoptic scale force.

The outline of the paper is as follows: Section 2 presents an analysis of the tornado event on March 25, 2009. In Section 3, the synoptic and remote sensing features associated with the tornado event in question, are analyzed. The data sources and WRF setup are presented in Section 4 accompanied by the verification of model simulations. The model outputs with an analysis of absolute vorticity budget are also presented in Section 4. Finally, Section 5 summarizes our findings and conclusions.

2. Data and methodology

2.1. Tornado event over NW Peloponnese, on March 25, 2009

The tornado developed on March 25, 2009, at 10:33 ($\pm$2 min) UTC time (hereafter, for brevity reasons, the tornado event will be coded as TR09). TR09 was formed 2 km southwest of the Varda village (NW Peloponnese, Ilia Prefecture; Fig. 1) and propagated N-NE. TR09, with an intensity of T4–T5 of TORRO scale (Meaden, 1976; wind speed from 52 to 61 and 62 to 72 m s^{-1}, respectively), crossed the villages of Varda, Nea Manolada and dissipated at the suburb areas of Lapa village (NW Peloponnese, Achaia Prefecture; Fig. 1). It lasted 10–12 min and its path was approximately 9 to 10 km long. Sioutas (2011) showed that tornado paths from 4.7 to 9.9 km were recorded in 27.3% of the cases that occurred over Greece during 2000–2009.

Along TR09 track (Fig. 1) significant damages were recorded, illustrating its intensity, such as significant damages on buildings' roofs, greenhouse complex buildings and farms. Fig. 2 illustrates the impact of TR09 in the village of Nea Manolada on March 25, 2009. TR09 track affected the Prefectures of Ilia and Achaia (Fig. 1) with an estimated cost of 300,000 € and 50,000 €, respectively. Eye witnesses reported in several media (TV and press) that debris was flying along the tornado's path causing significant damage to their properties.

The development of high-impact weather tornadoes in the NW Peloponnese region is not uncommon. Episodes of this type are recorded almost on an annual basis and particularly a few days before the TR09 event, another tornado had occurred (March 21, 2009), in Vartholomio village (20 km SW of Varda village) causing significant damage to buildings and farms. Matsangouras et al. (2014a), showed that western Greece is an area vulnerable to tornado development, and especially NW Peloponnese that has experienced an annual mean of 2.85 tornadoes based on the 2000–2012 period. Despite such vulnerability, all recorded tornadoes did not inflict as heavy economic damage upon the area as TR09. There are three main reasons that could explain such diversity of impact: (i) firstly, several tornadoes last only a few minutes and their intensity is significantly lower, (ii) secondly, they develop over rural areas and (iii) last but not least, several waterspouts come onshore and dissipate after a short time (a combination of first and second reason).

The terrain of NW Peloponnese is characterized by low elevation over the western part and high elevation over the eastern parts. Despite the fact that the Ionian Sea is characterized by deep waters, shallow waters do exist near the NW Peloponnese coastline and in conjunction with the scattered shallow lagoons and lakes, which are usually warmed by solar irradiance during the day, they could be characterized as contributors of unstable weather environment, as they significantly increase humidity. These water surfaces are warmer than the sea and may contribute even more than the sea to destabilize the environment. Close to the TR09 formation point and at a distance of less than 2 km extends the Ionian Sea, while several large lagoons and lakes (e.g., Kotichi lagoon, Lamia lake, etc.) exist southwest in less than 3 km and northeast in about 10 km, respectively.