Atmospheric Research 208 (2018) 148–155

Contents lists available at ScienceDirect

Atmospheric Research

journal homepage: www.elsevier.com/locate/atmosres

Numerical modeling analysis of the mesoscale environment conducive to two tornado events using the COSMO.Gr model over Greece

E. Avgoustoglou[a,*], I.T. Matsangouras[a,b], I. Pytharoulis[c], N. Kamperakis[a,b], M. Mylonas[b], P.T. Nastos[b], H.W. Bluestein[d]

[a] Hellenic National Meteorological Service, Athens, Greece
[b] Laboratory of Climatology & Atmospheric Environment, Faculty of Geology & Geoenvironment, University of Athens, University Campus, Greece
[c] Department of Meteorology and Climatology, School of Geology, Aristotle University of Thessaloniki, Thessaloniki, Greece
[d] School of Meteorology, University of Oklahoma, Norman, OK, USA

ARTICLE INFO

Keywords:
Tornadoes
Greece
COSMO.GR model
Numerical study

ABSTRACT

The COnsortium for Small-scale MOdeling (COSMO) was formed in October 1998, and its general goal is to develop, improve and maintain a non-hydrostatic limited-area atmospheric model. The COSMO model has been designed both for operational numerical weather prediction (NWP) as well as various scientific applications on the meso-β and meso-γ scale. Two tornado case studies were selected to investigate the ability of COSMO model to depict the characteristics of severe convective weather, which favoured the development of the associated storms.

The first tornado (TR01) occurred, close to Ag. Ilias village, 8 Km north-western of Aitoliko city over western Greece on February 7, 2013, while the second tornado (TR02) was developed close to Palio Katramio village, 8 Km southern from Xanthi city over northern Greece on November 25, 2015. Although both tornadoes had a short lifetime, they caused significant damages. The COSMO.GR atmospheric model was initialized with analysis from the European Centre for Medium-Range Weather Forecasts (ECMWF). The resulting numerical products with spatial resolution of 0.02° (~ 2 km) over the geographical domain of Greece depicted very well the severe convective conditions close to tornadoes formation. The Energy Helicity Index (EHI) diagnostic variable in both numerical simulations showed a gradual increase of values closing to the location and time of the tornado-genesis. Similar to EHI, the storm relative helicity (SRH) spatio-temporal analysis followed a gradual increase prior to the tornadogenesis events and was reduced after them.

1. Introduction

Tornadoes are considered among the most intense and catastrophic weather phenomena globally as parts of severe convective storms not limited to any specific geographical location (Fujita, 1973). Regarding their climatology in Europe, several publications during the last two decades indicate the occurrence of tornadoes in many European countries. In particular, Simeonov et al. (2013) presented the first tornado climatology for Bulgaria, Rauhala et al. (2012) constructed the first tornado climatology for Finland based on 298 tornado reports between 1796 and 2007. Gianfreda et al. (2005), documented tornadoes that occurred in southern Apulia, southeastern Italy, Antonescu and Bell (2015), presented the first tornado climatology for Romania, Kahraman and Markowski (2014) developed a tornado climatology for Turkey. Antonescu et al. (2016) presented a synthesis of tornadic climatology across Europe between 1800 and 2014. However, Groenemeijer and Kühne (2014), stated the strong underreporting in the Mediterranean region and Eastern Europe. Over the central and eastern Mediterranean significant research is in progress during the last years in terms of convection and numerical simulations dealing with the development of severe weather phenomena (e.g. Matsangouras et al., 2014a, 2014b; Miglietta and Rotunno, 2016; Miglietta et al., 2016, 2017).

Regarding Greek tornadic activity numerous tornado events have caused significant disasters to several places mainly in the western and northern parts of the Greece (Nastos and Matsangouras, 2010; Matsangouras and Nastos, 2010; Matsangouras et al., 2011a; Matsangouras et al., 2014a, 2014b, 2016). Towards the better understanding of these incidents, significant research has been carried out investigating the use of diagnostic variable sets as possible forecasting tools or parameters to identify any favorable atmospheric conditions of severe convective weather or to address the overall threat of severe weather associated with convective storms, large hail, severe winds,

* Corresponding author at: Hellenic National Meteorological Service, El. Venizelou 14, Hellinicon, GR16777 Athens, Greece.
E-mail address: euri@hnms.gr (E. Avgoustoglou).

http://dx.doi.org/10.1016/j.atmosres.2017.07.022
Received 30 May 2017; Received in revised form 20 July 2017; Accepted 25 July 2017
Available online 26 July 2017
0169-8095/

tornadoes or waterspouts (e.g. Kamperakis et al., 2015; Matsangouras et al., 2017).

Matsangouras et al. (2014a), presented an updated climatology of tornadoes, waterspouts and funnel clouds over Greece based on historical and recent datasets, over the periods 1709–1999 and 2000–2012, respectively, providing a benchmark reference for further investigation, evaluation and understanding of these events in Greece. In particular, North-Western Peloponnese and Western Greece have been revealed as the most vulnerable areas for tornado development that experienced a mean annual frequency of 3 and 5 tornadoes, respectively. In parallel during the last years, there is an exceptional progress on numerical weather prediction models equipped with highly efficient computational as well as sophisticated physical schemes capable of resolving atmospheric phenomena on the 1 Km scale even in the operational forecast mode (Baldauf et al., 2011; Vionnet et al., 2016). Consequently, it comes as a formidable challenge to investigate the limits of their potential towards the diagnostic investigation of *meso* to micro-scale events like tornadoes. Towards this direction, the non-hydrostatic WRF-ARW atmospheric numerical model was utilized (at very high resolution using telescoping nests) in order to perform sensitivity experiments investigating the role of Greek topography in tornadogenesis and the ability to depict the characteristics of severe convective weather (Matsangouras et al., 2011b, 2014a, 2014b; Matsangouras et al., 2016).

This trend acted as a motivation to test the COnsortium for Small-scale MOdeling (COSMO) model, a state of the art non-hydrostatic numerical weather prediction model developed and maintained by the synonymous COSMO Consortium (www.cosmo-model.org). It was founded in 1998 and includes the National Meteorological Services of Germany, Greece, Israel, Italy, Poland, Romania, Switzerland, and Russia. Currently, COSMO model runs operationally by the consortium member services as well as numerous other National Services and Institutes worldwide both for operational and research purposes (Steppeler et al., 2003). Although the model is primarily focused and applied operationally to the meso-β and meso-γ scale, its numerical along with its physical parameterization schemes (Collaud Coen et al., 2014; Doms et al., 2011) provide a sound basis to test its ability to diagnose and forecast atmospheric phenomena beyond meso-scale and well into the miso-scale where tornadoes are categorized (Bluestein, 1992).

As a founding Member of COSMO, the Hellenic National Meteorological Service (HNMS) has built up a significant experience in the operational use of COSMO Model (denoted as COSMO.GR) in the Meso-γ scale with horizontal grid ranging from 0.06250 degrees (~7 km) over the Mediterranean and from 0.020° (~2 km) over Greece (Avgoustoglou and Papageorgiou, 2004; Avgoustoglou et al., 2006; Avgoustoglou et al., 2010; Avgoustoglou and Tzeferi, 2015).

The aim of this study is to utilize the COSMO.GR in an attempt to trace the characteristics of severe convective weather that favored the development of two severe tornadoes. Those tornadoes took place over the western Greece and the northern Greece, on February 7, 2013 and November 25, 2015, respectively. The outline of the paper is as follows: Section 2 identifies the tornado data sources and the COSMO.GR model setup. Results and discussion are given in Sections 3 and Section 4 summarizes our findings and conclusions.

2. Tornado data and model setup

On February 7, 2013, several tornadoes developed along western Greece, while the most intense event took place close to Agios Ilias village (21.28710E, 38.48820N), over western Greece. Hereafter this tornado case is denoted as TR01 (Fig. 1c). The tornado lasted only a few minutes and was developed between 12:30 and 12:45 UTC. TR01 had a short lifetime and it caused significant numerous damage to local properties and crops. The relatively closest meteorological station to the event (Fig. 1c) is Araxos (LGRX, at 21.41670E and 38.16670N) which is part of the meteorological stations network of Hellenic National Meteorological Service (HNMS).

From the synoptic standpoint (Fig. 2 upper panel), a relatively deep barometric low of 1000 hPa associated with frontal activity developed over the area during the day and reached the level of 995 hPa around 18 UTC at the area of TR01 during the cold front passage, while a second front was developing and reaching the Ionian Sea 6 h later. These synoptic characteristics were in agreement with the composite synoptic climatology for tornado days over western Greece (Matsangouras et al., 2014a, 2014b; Nastos and Matsangouras, 2014).

The second tornado case (hereafter denoted as TR02) formed on November 25, 2015 over Northern Greece close to Palio Katramio village, (24.91230E, 41.07320N). The event formed between 20:10 and 20:20 UTC, TR02 (Fig. 1d) lasted for a few minutes and it caused numerous damage to properties and crops over that area. The relatively closest meteorological station of HNMS to the event place was Chrysoupoli meteorological station (LGKV) located at geographical longitude and latitude respectively of (24.616E, 41.916N) (Fig. 1d).

Regarding the synoptic conditions during TR02 tornado event, Greece was under an extensive frontal activity with the warm front developing over Northern Greece (Fig. 2, lower panel). The frontal activity became temporarily stationary over the area of TR02 during the daily hours creating relatively favorable conditions for storm activity. TR02 formed in the warm frontal sector established during the night hours while the cold front was developing in the Aegean.

Both tornado events were simulated through the application of COSMO model version 5.0 used operationally at HNMS at the time. The model default parameterization was considered in order to examine in a straightforward way how the model would respond to the challenge of capturing events in the tornado level such as TR01 and TR02. Since the goal was mainly to diagnose such incidents, boundary conditions from the European Centre for Medium-Range Weather Forecasts (ECMWF) model analysis of 0.1250 (~15 km) were used in 6-h intervals. The model was initially implemented for 24-h runs over a 0.06250 (~7 km) horizontal grid of 649 × 393 points, 60 vertical levels and a 30-s time step over the wider Mediterranean area (Fig. 1a), starting at 00 UTC on the dates of the tornado events, i.e. approximately 12 and 18 h before TR01 and TR02 respectively. The output was produced in 1-h intervals and was used as initial conditions for the subsequent model runs over a finer 0.020 (~2 km) horizontal grid of 501 × 401 points, the same 60 vertical level resolution and a 10-s time step over the wider area of Greece (Fig. 1b). The results were produced in the highest possible model output time density of 15-min intervals.

Several 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 shear, the Storm-Relative Helicity (SRH) have been considered as useful tools to depict the ingredients of energy, helicity, vertical wind shear and the relationship with the buoyant energy for tornado development (Moncrieff and Green, 1972; Weisman and Klemp, 1982, 1984; Davies-Jones et al., 1990, Hart and Hart and Korotky, 1991, Droegemeier et al., 1993; Hannesen et al., 1998; Craven and Brooks, 2002; Rasmussen, 2003; Groenemeijer and Van Delden, 2007; Brooks, 2009, Matsangouras et al., 2016).

In this study, EHI and SRH were considered also as diagnostic instability variables along with convective available potential energy (CAPE) and employed in both numerical experiments (TR01 and TR02). In addition, the following meteorological variables of Mean Sea Level Pressure (MSLP), air temperature at 2 m (T2 m), dew point air temperature (Td2m), wind speed and direction at 10 m (V10 m and Dir_V10 m, respectively) were also used into the verification process with the meteorological stations nearest to as well as the geographical locations of TR01 and TR02.