Atmospheric Research 169 (2016) 523–538

Contents lists available at ScienceDirect

Atmospheric Research

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

Numerical modeling of an intense precipitation event and its associated lightning activity over northern Greece

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ARTICLE INFO

Article history:
Received 31 January 2015
Received in revised form 24 June 2015
Accepted 26 June 2015
Available online 2 July 2015

Keywords:
WRF numerical model
Intense precipitation
Neighborhood based verification
Lightning Potential Index
Topography
SRTM

ABSTRACT

This study investigates an intense precipitation event and its lightning activity that affected northern Greece and primarily Thessaloniki on 15 July 2014. The precipitation measurement of 98.5 mm in 15 h at the Aristotle University of Thessaloniki set a new absolute record maximum. The thermodynamic analysis indicated that the event took place in an environment that could support deep thunderstorm activity. The development of this intense event was associated with significant low-level convergence and upper-level divergence even before its triggering and a positive vertical gradient of relative vorticity advection. The high resolution (1.667 km × 1.667 km) non-hydrostatic WRF-ARW numerical weather prediction model was used to simulate this intense precipitation event, while the Lightning Potential Index was utilized to calculate the potential for lightning activity. Sensitivity experiments suggested that although the strong synoptic forcing assumed primary role in the occurrence of intense precipitation and lightning activity, their spatiotemporal variability was affected by topography. The application of the very fine resolution topography of NASA Shuttle Radar Topographic Mission improved the simulated precipitation and the calculated lightning potential.

1. Introduction

On 15 July 2014, Thessaloniki and Chalkidiki in northern Greece (Fig. 1) were affected by strong precipitation, which caused significant problems, including flood and damages to both infrastructure and cultivations in the city of Thessaloniki and the surrounding regions. The meteorological station of the Department of Meteorology and Climatology of the Aristotle University of Thessaloniki (AUTH), which is located near the city center, measured 98.5 mm of rain from 21:00 UTC on 14 July to 12:00 UTC on 15 July 2014. Almost all of the total rain amount (98.4 mm) was collected after 00:00 UTC, while the maximum rate reached 41.0 mm in 3 h. The station of the Hellenic National Meteorological Service (HNMS) at the airport of Thessaloniki (LGTS) recorded 61 mm of rain between 00:00 UTC and 12:00 UTC on 15 July. The measurement of AUTH is a record maximum, exceeding the previous absolute maximum of 98 mm (Anagnostopoulou and Tolika, 2012), which was observed in 24 November 1985. Similarly, the measurement of LGTS exceeded the maximum daily value of 60.2 mm, which appeared in the climatology of Kornaros (1999) for July 1959–1997. The fact that the mean annual precipitation is 449.6 mm at AUTH (Anagnostopoulou and Tolika, 2012) and 448.7 mm at LGTS (Kornaros, 1999) further exhibits the severity of the event.

Previous intense precipitation events that affected Greece have been investigated through both observational and/or modeling studies (e.g., Kallos and Pytharoulis, 2005; Kotroni et al., 1997, 1999; Lagouvardos et al., 1996; Papadopoulos, 2001). Such case studies offer a unique testbed for the investigation of the performance and tuning of modern numerical weather prediction models in extreme conditions. Kotroni et al. (1997) have shown that convergence zones promote summer storm activity in Greece, but, under weak synoptic flow. Lagouvardos et al. (1996) and Kotroni et al. (1999) have pointed out the role of orographic lifting in the eastern mainland of Greece in inducing heavy precipitation and floods.

Lightning activity was associated with the event of July 2014 and affected the entire region of Thermaikos Gulf and most of Chalkidiki. Lightning discharges are among the most impressive physical phenomena, but also highly lethal. They pose a serious threat to the physical environment because they are associated with wildfires, industrial accidents and power failures (Nie et al., 2008; Peterson et al., 2010; Renni et al., 2010), while they are equally dangerous to humans (Ashley and Gilson, 2009; Rakov and Uman, 2003). A football player died during training in Greece in November 2014, because of a cloud-to-ground lightning strike. Papagiannaki et al. (2013) reported 20 deaths due to lightning strikes in Greece from 2001 to 2011.

During the last years, the availability of modern lightning detection systems (e.g., ATD, LINET, WWLLN, ZEUS) has resulted to an increased interest in their study, prediction and use. A number of studies have recently appeared in the literature, investigating their statistical characteristics, their relationship with topography, terrain slope and vegetation in the Mediterranean basin and Greece (e.g., Defer et al., 2005; Katsanos et al., 2009; Kotroni and Lagouvardos, 2008; Mazarakis

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http://dx.doi.org/10.1016/j.atmosres.2015.06.019

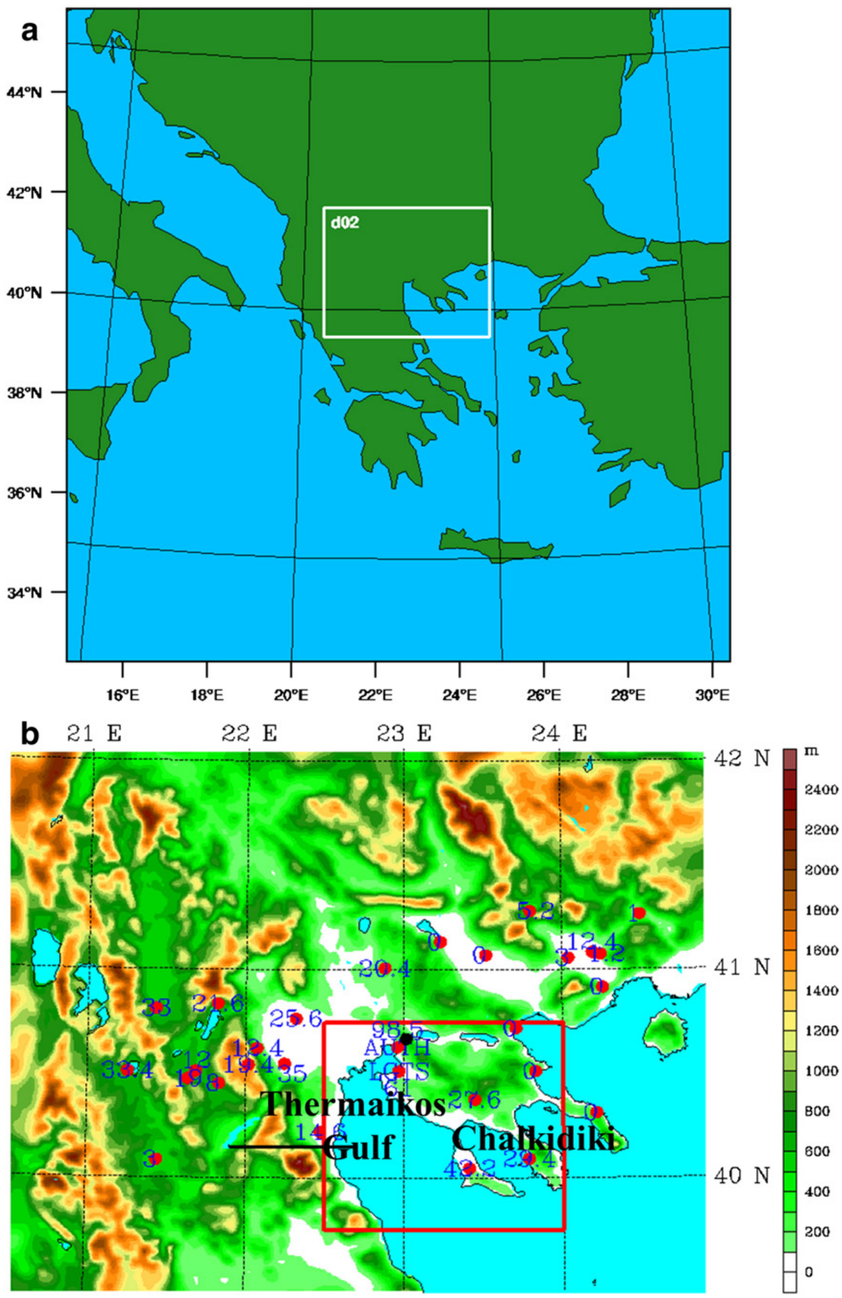

Fig. 1. (a) The two nests (D01, D02) used by WRF-ARW in the numerical experiments and (b) the topography of the inner domain and the locations of the available stations. In panel (b): i) the square indicates the region of interest (39.75°N–40.75°N, 22.5°E–24.0°E), ii) the numbers depict the observed 24 h accumulated precipitation (mm) from 18:00 UTC on 14 July to 18:00 UTC on 15 July 2014, iii) the black bullet indicates the location of the weather radar at Filyro, and iv) the black line depicts the area of the vertical section of Fig. 14.

et al., 2008; Nastos et al., 2014). Papadopoulos et al. (2005) developed a technique for the assimilation of lightning observations for a regional numerical weather prediction model, in order to improve the convective precipitation in the Mediterranean. Papadopoulos et al. (2009) successfully applied this methodology to represent the precipitation during a flood event. Fierro et al. (2012) assimilated total lightning data into the Weather Research and Forecasting (WRF) numerical model during the 24 May 2011 Oklahoma tornado outbreak and significantly improved the representation of convection at both the analysis and forecasts. More recently, Lynn et al. (2015) used the WRF model and the dynamic lightning model of Lynn et al. (2012), in four case studies with different convective regimes over the U.S.A., and showed that the assimilation of observed lightning improved the spatial distribution and intensity of forecast lightning.

A number of indices have been proposed in order to predict the lightning activity and not only the probability or severity of convection, based either on statistical methods or simplifications of the lightning physics (e.g., Bright et al., 2005; Dahl et al., 2011a,b; Lynn et al., 2012; Mazany et al., 2002; McGaul et al., 2009; Price and Rind, 1992; Yair et al., 2010). These indices may be calculated using radiosonde data, radar measurements or numerical weather predictions. The lack of lightning data prevented the use and validation of such techniques in Greece until recently (Giannaros et al., 2015; Pytharoulis et al., 2012; Yair et al., 2010).

The intense precipitation event of July 2014 and its associated lightning activity offered the motivation and the chance to test the performance of the state-of-the-art WRF numerical weather prediction model along with the Lightning Potential Index (LPI) of Yair et al.