

Synoptic, Dynamic Analysis and Numerical Simulations of Extreme Flood Cases in Pieria Region [†]

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Abstract: The synoptic and dynamic characteristics of three extreme precipitation events over the area of Pieria are analyzed. The objective of this study is to identify similarities in structure, intensity and behavior of the synoptic patterns that were responsible for the extreme precipitation over the examined area. Precipitation-derived data from weather radar images were also used to identify the intensity and extent of the events. The high-resolution non-hydrostatic WRF-ARW numerical weather prediction model was also used to simulate these intense precipitation events. Results indicated analogous synoptic conditions in all three cases suggesting the strong synoptic forcing of the events in extreme precipitation over the area. The model was able to capture these events adequately, even though discrepancies occurred regarding the intensity and the location of the precipitation maxima.



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1. Introduction

Pieria in Central Macedonia is an area frequently affected by extreme weather phenomena such as severe storms, frosts and floods. That was one of the main reasons to choose Pieria region to conduct the “Agroray” project (entitled “Development of a forecasting system and geographical indicators for agriculture”). The “Agroray” project aims at developing an integrated information system for farmers with high-spatial-resolution local weather forecasting, adapted to the needs of each crop and the particular climatic and topographical characteristics of the area. Via the “Agroray” project, a high-resolution NWP system is being developed for the area, based on the non-hydrostatic WRF model, that produces operational forecasts. Accurate forecasting of weather conditions implies direct economic benefits for agriculture through improved production efficiency, as well as reduced costs of fertilization, irrigation, energy needs and pesticides. More about the “Agroray” project can be found at [1].

This study aims to understand and analyze the synoptic mechanisms that are responsible for producing heavy rainfall over the area. Similarities in structure, intensity and behavior of synoptic patterns are identified and numerical simulations of the events are performed.

Several observational and/or modeling studies of heavy precipitation events have been carried out over the Greek area by [2–7]. Extreme precipitation events offer a unique context for investigating the performance of numerical weather prediction models.

2. Data and Methodology

This study uses upper air weather charts taken from the University of Wyoming “<http://weather.uwyo.edu>, accessed on 3 March 2023” and surface analysis retrieved from the U.K. Met Office “https://www.wetter3.de/archiv_ukmet_dt.html, accessed on 3 March 2023”. Daily surface observations from all available automatic weather stations that have been operating in the area for the last 15 years were also collected and analyzed. Weather radar data were obtained from the C-band (5 cm) weather radar made by 3D s.a. “<http://www.3dsa.gr>, accessed on 4 March 2023”, which is located on Mount Filyro (40.672° N, 23.014° E) northeast of Thessaloniki. The cell tracker TITAN [8] was used for obtaining storm characteristics and the amount of precipitation using the Marshall–Palmer relationship (constant values $a = 200$, $b = 1.3$) after calibration by the Greek Agricultural Insurance Organization [9]. Finally, numerical simulations of these extreme precipitation events were produced by the non-hydrostatic WRF-ARW (v4.3.3) weather prediction model [10,11]. Three model domains using telescoping nesting (one way) that covers Europe at 9 km grid spacing, Greece at 3 km and the area of interest at 1 km (Figure 1) were used. The NCEP/GDAS (National Centers for Environmental Prediction/Global Data Assimilation System) analyses at 6 h intervals and $0.25^\circ \times 0.25^\circ$ lat-lon resolution were used as initial and boundary conditions for the coarse domain in the numerical simulations.

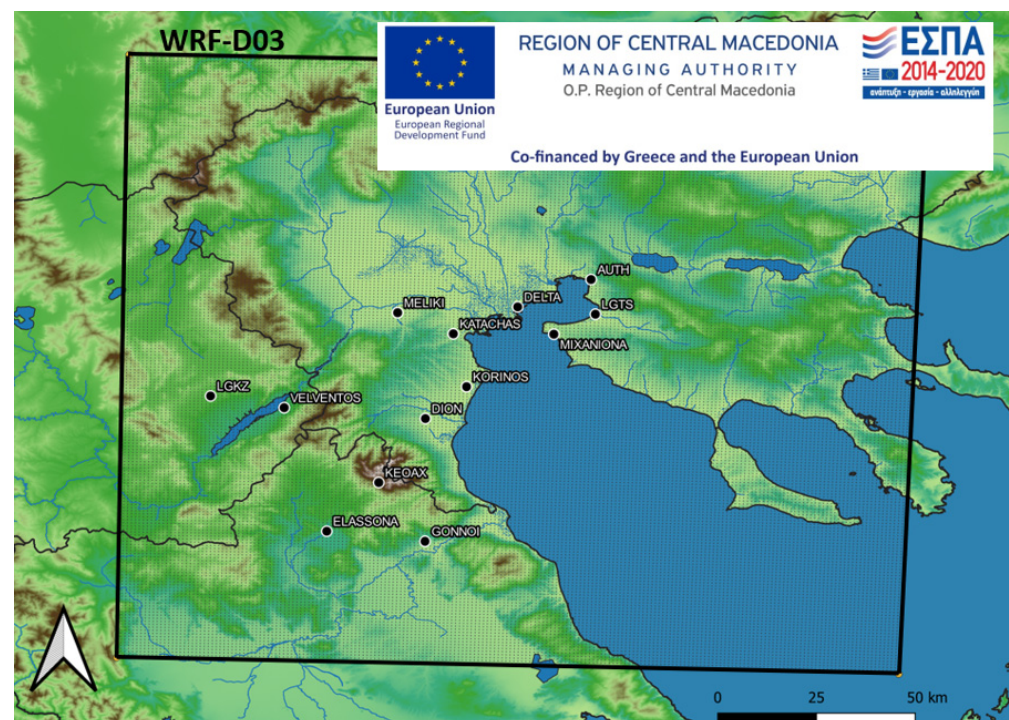


Figure 1. Area covered by Domain 3 (D03) used by the WRF-ARW in the numerical simulations.

The WSM6 scheme was utilized for the representation of microphysical processes and the RRTMG scheme for the treatment of longwave and shortwave radiation. The Mellor–Yamada–Janjic scheme was employed for the boundary layer and the Monin–Obukhov (Eta similarity) theory for the surface layer. Soil physics were represented by the NOAH model while deep and shallow convection was parametrized by the Kain–Fritsch scheme only in the outer domain. The USGS land cover dataset was utilized for the representation of land use in the model.

With the above model setup, four different experiments were performed using different vertical model levels. In the levs39-eta experiment the model used 39 sigma levels (up to 50 hPa) with increased resolution in the boundary layer. The levs50-wrf experiment utilized the default hybrid vertical coordinate (HVC) which is terrain-following near the ground and becomes isobaric at a user-predefined level. Here 50 vertical levels were chosen while the thickness of the lower layer (between surface and 1st model level) was set at 50 m. The levs50-wrfs experiment was similar to levs50-wrf except for the thickness of the lower layer which was set at 20 m and a higher resolution in the lower troposphere. In the levs80-wrf experiment, 80 vertical model levels were deployed with the default thickness of the lower layer (at 50 m).

3. Results

To analyze the amount of precipitation over the area, three distinct heavy precipitation events were chosen for this study from the daily surface observations database. These episodes took place on 12–13 March 2016, 15–17 November 2017 and 24–25 March 2018, respectively. The accumulated amount of precipitation recorded by the available automatic weather stations in the area is presented in Table 1. As observed from Table 1, precipitation exhibited significant spatial variability over the area as a result of both synoptic forcing conditions and local topographic features.

Table 1. Accumulated amount of precipitation (mm) recorded during the 48 h period by the automatic weather stations for the three episodes.

Station	Dion	Katachas	Korinos
12–13 March 2016	102.0	81.6	n/a
15–17 November 2017	284.2	182.6	105.6
24–25 March 2018	105.4	61.8	28.2

The prevailing synoptic conditions over the area in all three episodes presented remarkable similarities. In the upper troposphere, at 300 hPa, a closed low is situated over the central Mediterranean while the jet stream is located south of it (not shown).

The area of interest lies at the left exit of the jet stream being associated with upward motions and upper-level divergence. In the middle troposphere, at 500 hPa, the closed low is also present over the central Mediterranean (Figure 2a,d,g). The area is affected by a strong southerly flow associated with this system. The low is also present and well organized at the 850 hPa level where the area of interest is affected by a southeast flow bringing warm moist air masses from the Aegean Sea (Figure 2b,e,h). At the surface level, a low-pressure system with its center located over south Italy is present, associated with frontal activity over the area of interest. The low-level wind pattern presents a well-established southeast to northwest flow exhibiting strong low-level convergence zones over the area (Figure 2c,f,i).

These intense precipitation events were captured by the weather radar and simulated using the WRF model. The model was able to capture these events adequately, even though discrepancies occurred regarding the intensity and the location of the precipitation maxima. A neighborhood-based technique was followed to compare the precipitation of WRF-d03 with the radar-estimated one [1]. The equitable threat score at the threshold of 10 mm/6 h, averaged for all cases at boxes with sides of 1–61 km around each grid point and 6 h periods after the model's spin-up period (first 12 h), is equal to 0.238, 0.236, 0.233 and 0.231 in levs50-wrfs, levs80-wrf, levs50-wrf and levs39-eta, respectively.

Figure 3 depicts the accumulated precipitation for 48 h (from 15 November 17 00:00 UTC to 16 November 17 23:59 UTC) estimated using the weather radar (Figure 3a) and the four different model experiments (Figure 3b–e). Most of the precipitation estimated from the radar data and simulated by all the WRF experiments appears in the western part of the domain, covering Pieria. Levs80-wrf produces smaller areas with very intense

precipitation (>200 mm/48 h, 300 mm/48 h) than the other experiments, and so it is closer to the radar data.

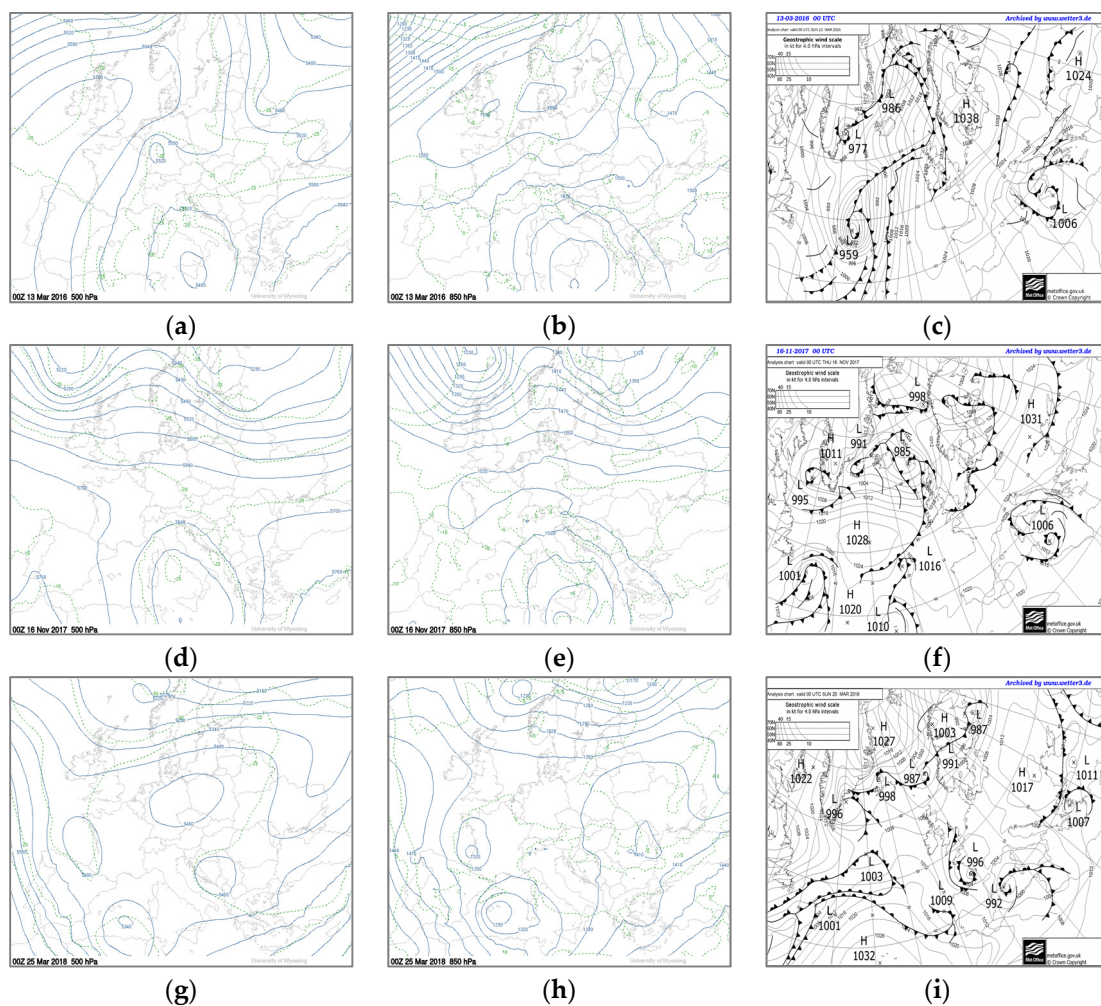


Figure 2. Geopotential height (solid lines) and temperature (dotted lines) at 00:00 UTC on 13/3/2016 for 500 hPa (a), 850 hPa (b) and sea surface pressure (c). The same for 16/11/2017 (d–f) and 25/3/2018 (g–i). (Source: University of Wyoming and U.K. Met Office).

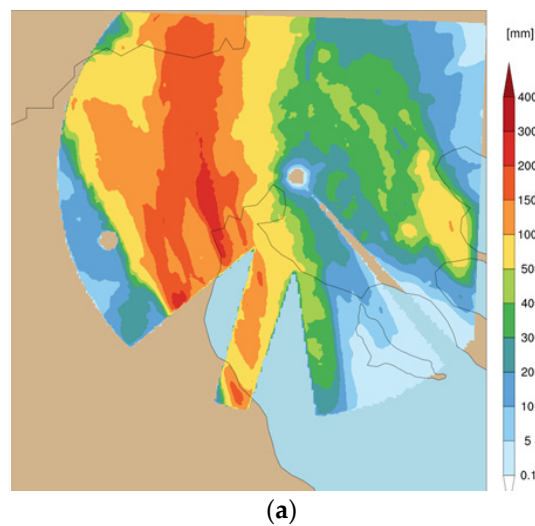


Figure 3. Cont.

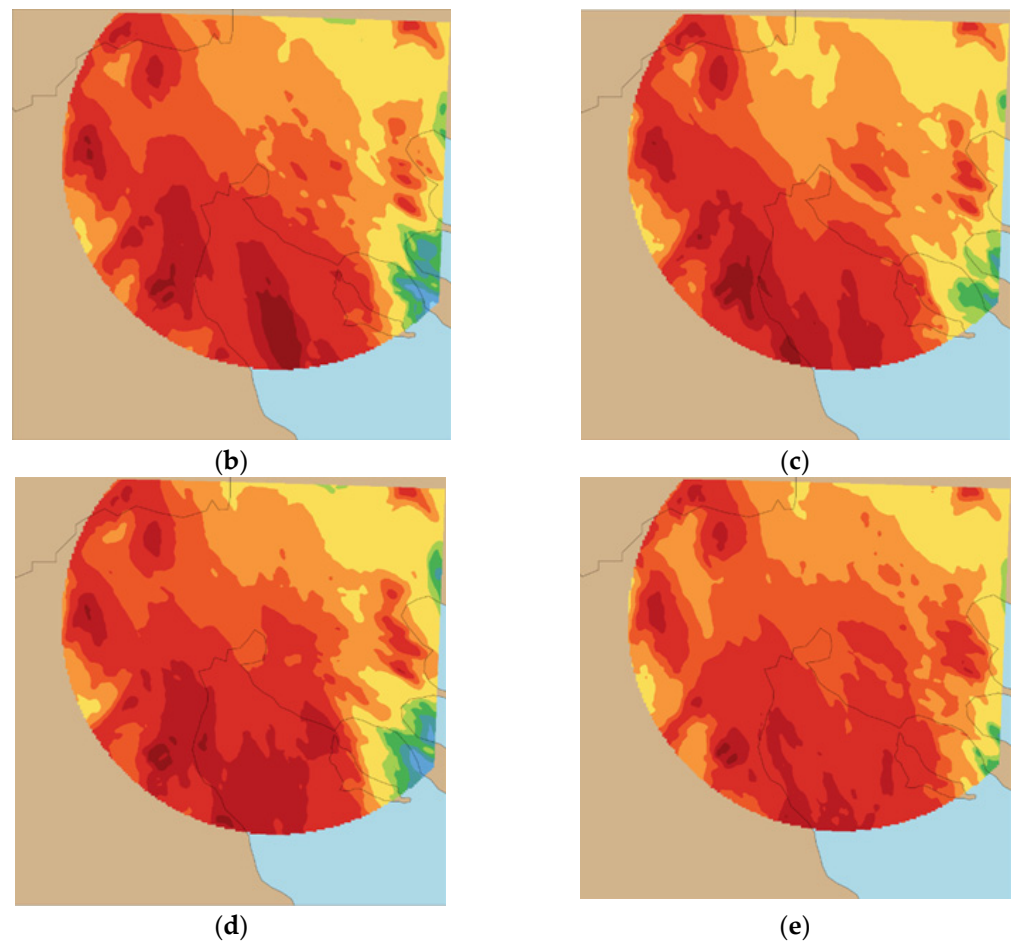


Figure 3. Accumulated precipitation in mm for 48 h from 00:00 UTC 15 November 2017 to 23:59 UTC 16 November 2017, estimated using the weather radar (a) and the four WRF experiments in D03: levs-39eta (b), levs50-wrf (c), levs50-wrfs (d) and levs80-wrf (e), initialized at 12:00 UTC 14 November 2017.

4. Conclusions

The three most intense precipitation events from the last 15 years of daily observations by the weather stations in Pieria region were identified, and the synoptic and dynamic characteristics of these events were analyzed. The synoptic and dynamic conditions that prevailed over the area in all three episodes presented significant similarities, suggesting the strong influence of dynamical forcing in such events. The synoptic conditions indicated that strong low-level convergence zones supplemented with moist inflow from the Aegean Sea and upper-level divergence zones were present resulting in these extreme precipitation events over the area. The total amount of precipitation was also captured and calculated from weather radar data, giving an overall picture of the regional distribution of rainfall over the area. Finally, using the high-resolution non-hydrostatic WRF-ARW numerical weather prediction model, the events were simulated to test the ability of the model in reproducing the intensity and distribution of precipitation. The results indicated that the WRF model was able to capture these events adequately, even though discrepancies occurred regarding the intensity and the location of the precipitation maxima. Using several model setups with different model levels revealed good overall performance of the model.

The results of this study are useful for agricultural purposes and to prevent human and property loss from extreme weather phenomena. Further research could include more sensitivity simulations in order to investigate the effect of different model setups on the model's performance.

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