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Analysis and hindcast simulations of an extreme rainfall event in the Mediterranean area: The Genoa 2011 case☆

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ABSTRACT

The city of Genoa, which places between the Tyrrhenian Sea and the Apennine mountains (Liguria, Italy) was rocked by severe flash floods on the 4th of November, 2011. Nearly 500 mm of rain, a third of the average annual rainfall, fell in six hours. Six people perished and millions of Euros in damages occurred. The synoptic-scale meteorological system moved across the Atlantic Ocean and into the Mediterranean generating floods that killed 5 people in Southern France, before moving over the Ligurian Sea and Genoa producing the extreme event studied here.

Cloud-permitting simulations (1 km) of the finger-like convective system responsible for the torrential event over Genoa have been performed using Advanced Research Weather and Forecasting Model (ARW-WRF, version 3.3).

Two different microphysics (WSM6 and Thompson) as well as three different convection closures (explicit, Kain–Fritsch, and Betts–Miller–Janjic) were evaluated to gain a deeper understanding of the physical processes underlying the observed heavy rain event and the model's capability to predict, in hindcast mode, its structure and evolution. The impact of forecast initialization and of model vertical discretization on hindcast results is also examined. Comparison between model hindcasts and observed fields provided by raingauge data, satellite data, and radar data show that this particular event is strongly sensitive to the details of the mesoscale initialization despite being evolved from a relatively large scale weather system. Only meso-γ details of the event were not well captured by the best setting of the ARW-WRF model and so peak hourly rainfalls were not exceptionally well reproduced. The results also show that specification of microphysical parameters suitable to these events have a positive impact on the prediction of heavy precipitation intensity values.

1. Introduction

Floods are the most dangerous meteorological hazard in the Mediterranean due to both the number of people affected and to the relatively high frequency by which human activities and goods suffer damages and losses (Llasat-Botija et al., 2007). These facts are evidenced by the noteworthiness of several historical disastrous events that have been previously studied including; the 1970 Genoa case (northern Italy) studied by Roth et al. (1996) and Siccardi (1996) among others, the 1992 Vaison-la-Romaine event (southern France; Massacand et al., 1998; Ducrocq et al., 2008), the Izmir case (west Turkey) in 1995 (Komuscu et al., 1998), and the disastrous flash flood of Bab-el-Oued in 2001 (Argence et al., 2008; Branković et al., 2008; Tripoli et al., 2005).

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Despite its generally mild climate, severe weather events are a significant part of the Mediterranean climate on both northern and southern shores. It is not uncommon to observe that the rain accumulated in one hour accounts for an entire monthly average for that location, and the rain accumulated in one day accounts for the entire yearly average (Altinbilek et al., 1997). Additionally, Barredo (2007) found that in the period 1950–2005 up to 40% of casualties have been due to flash-floods, related, at least in part, to the growing population and the expanding economic development in the region. These impacts are only expected to increase in the coming decades. Also shown in Barredo (2007), half of the major flood events from 1950 to 2005 in the European Union mainly took place in Italy, Spain and southern France causing more than 2750 fatalities with an average rate of about 50 per year. Lastly, it is now widely expected that climate change will increase the occurrence of severe rainfall events in many regions around the world including the Mediterranean (Groisman et al., 2004, 2005).

The principal meteorological pre-conditions or 'ingredients' for potentially disastrous flash floods are quite well known and were summarized by Delrieu et al. (2005). First, a deep and sustained source of heat and moisture is required and is often provided by the Mediterranean Sea in September up to mid-November as it cools from its late-summer peak heat content. The second ingredient is the convergence and lifting provided by synoptic configurations which, in the case of many Mediterranean storms, are dominated by extended troughs that advect south (easterly or westerly) flow to the coasts. The third driving factor is the presence of significant orography next to the sea which can amplify and focus low-level moisture convergence and trigger deep convective motion within the flow (Altinbilek et al., 1997).

Very often the structures responsible for these kinds of events are quasi-stationary meso-β convective systems. In such cases it is not uncommon for intense, though often small-sized, storms to repeatedly impact the same area for several hours. In essence, new convective cells continually regenerate at approximately the same rate at which the older ones are advected away (Chappell, 1986). Regional radar and satellite imagery frequently reveal these stationary or backward regenerative systems that assume a characteristic V-shape (Delrieu et al., 2005).

The severity of these events can be tightly dependent on local factors such as upwind islands, complex coastlines and steep orography, so that even very small scale (e.g., a few kilometers) features need to be considered. To improve prediction capabilities progress must be made in understanding the mechanisms that govern the precise location of the precipitation system as well as of those that can occasionally produce uncommon amounts of precipitation (Ricard et al., 2012).

With this aim, this paper is devoted to the study of the extreme rainfall event that took place in Genoa on November 4th, 2011, by means of high-resolution numerical simulations and observational data analysis.

The original idea of numerical prediction of severe rainfall events, associated with deep moist convective processes, dates back to the fundamental studies of Lilly (1990) and Droegemeier (1997), which described possible approaches and challenges to develop numerical prediction of convective storms. Since then, many studies have demonstrated the importance of convective-scale numerical weather models (Xue et al., 2007; Done et al., 2004; Kain et al., 2006; Roberts and Lean, 2008) for research and early-warning activities. At the same time, advances in quantity, quality, and resolution of available observational data and in high-performance computing (HPC) (Xue et al., 2007) promote the use and validation of increasingly more sophisticated and computationally demanding atmospheric models.

However, many sources of uncertainty still exist and continue to play a crucial role in forecasting precipitation rate and distribution. Among them, the choices of the horizontal resolution and the associated choices of physics parameterizations for unresolved sub-grid scale processes remain as important modeling decisions (Yu and Lee, 2010). Severe weather scenarios associated with land-falling Mediterranean storms are natural laboratories for exploring high-impact hydro-meteorological events and their correlated uncertainty sources. By incorporating high-quality observational data there exists significant potential to improve modeling and prediction capabilities, to identify the root causes of such events, and to improve detection and management of those threatening phenomena (Borga et al., 2007; Delrieu et al., 2005; Llasat et al., 2003).

Specifically, in this paper, the performance of a cloud-permitting (1 km) model is assessed by the analysis of different sets of numerical simulations of the convective system responsible for the catastrophic event of November 2011 in the Liguria region. Our focus is to evaluate the sensitivity of the Advanced Research Weather and Forecasting Model (ARW-WRF, version 3.3) by the specification of cloud microphysics and methods for cumulus parameterization as well as to other model decisions such as initialization conditions and vertical model discretizations. Thus, a set of simulations combining two different microphysics (WSM6 and Thompson, described in Section 3 below) and three different cumulus convection approaches (explicit, Kain–Fritsch, and Betts–Miller–Janjic) were executed to gain a deeper understanding of the kinematic and thermodynamical processes underlying the event. The comparison of modeling findings with a host of observed meteorological fields provided by raingauge, satellite and radar data is provided. The final goal is to offer the evaluation and justification for optimal configurations of the model focused on defining a highly dependable suite for the use in ongoing forecasting operations. Section 2 provides a description of the meteorological scenario; Section 3 details the specifics of the model experiment configurations and the data used to initialize and evaluate the model; Section 4 addresses the analysis of the modeling results, and Section 5 provides some discussion and final considerations.

2. The severe weather scenario

The synoptic-scale meteorological system responsible for the Genoa flash flood event originated days before from western Atlantic Ocean and moved into the Mediterranean, where the storm re-intensified significantly due, in part, to the moisture inflow provided by an anomalously warm western Mediterranean Sea. In particular, a positive anomaly of temperature was observed in the central part of the Ligurian Sea (Rebora et al., 2013). Finally, on the 4th and 5th of November, extreme rainfall hit Provence (Southern France) and Liguria