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Weather forecast performances for complex orographic areas: Impact of different grid resolutions and of geographic data on heavy rainfall event simulations in Sicily

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ABSTRACT

Over the past decades, Sicily has undergone an increasing sequence of extreme weather events that have produced, besides huge damages to both environment and territory, the death of hundreds of people together with the evacuation of thousands of residents, which have permanently lost their properties.

In this framework, with this paper we have investigated the impact of different grid spacing and geographic data on the performance of forecasts over complex orographic areas. In order to test the validity of this approach we have analyzed and discussed, as case study, the heavy rainfall occurred in Sicily during the night of October 10, 2015. In just 9 h, a Mediterranean depression, centered on the Tunisian coastline, produced a violent mesoscale storm localized on the Peloritani Mountains with a maximum rain accumulation of about 200 mm. The results of these simulations were obtained using the Weather Research and Forecasting (WRF-ARW) Model, version 3.7.1, at different grid spacing values and the Two Way Nesting procedure with a sub-domain centered on the area of interest. The results highlighted that providing correct and timely forecasts of extreme weather events is a challenge that could have been efficiently and effectively countered using proper employment of high spatial resolution models.

1. Introduction and synopsis

Extreme weather events are characteristics of the Mediterranean coastal areas and often cause flash floods. During these episodes, the precipitations that occur in a few hours often exceed the rain accumulations that normally occur in several months (Altinbilek et al., 1997).

Usually, these extreme precipitations are in conjunction with intense and quasi-stationary mesoscale convective phenomena that insist on the same area for several hours (Fiori et al., 2014). Local factors such as the presence of orographic reliefs along to the coastline often determine their intensity. The geographical position and the complex orography of Sicily often cause extreme weather events (Chen and Lin, 2005; Chen and Sun, 2002). Positioned at the center of the Mediterranean Sea, the island is placed in the transition zone between the arid and dry climate of North Africa; the more temperate and humid climate of central Europe. Hence, the phenomena trigger the interactions between processes typical of middle latitudes and the tropics.

In early autumn, the Mediterranean cyclones that originate from the contrast between air masses with very different temperatures and humidity interacting with seawater high temperature (Sea Surface Temperature, SST), affect the seas surrounding Sicily. These conditions can cause extreme weather events characterized by sudden and heavy rainfalls and dangerous flash floods (Cassola et al., 2015).

From the geographic point of view, Sicily is characterized by an orography distributed in the direction of the parallel, especially in the Northern area, which is strongly exposed to the atmospheric perturbations that come from the South. In such cases, the warm and moist air coming from the Libyan Sea is often lifted over the orographic barriers, losing its humidity because of the cooling, and these modifications can cause heavy rains (Chu and Lin, 2000; Randall, 2001). This occurs especially in the autumn seasons when the sea around the island is still warm and able to transfer large amounts of humidity into the atmosphere (Giuffrida and Sansosti, 2007; Salby, 1996).

It clearly emerges that the island complex orography plays a key role in the portion of the Ionian coastline between the towns of Catania and Messina (Fig. 1).

In detail, our work covers an area where the most important

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Fig. 1. 3D Orography of the eastern coast of Sicily between Catania and Messina.

morphological structures are the massif of Mt. Etna (3330 m above sea level) and the Peloritani mountain range (max altitude is 1374 m ASL), which stretches between the Mt. Etna and the Strait of Messina for a length of approximately 65 km.

Between these mountains is the Alcantara Valley, located North of Mt. Etna, and some other smaller valleys that descend from the Peloritani Mountains following the NW-SE direction towards the sea.

Recently, extreme weather conditions have affected this area of Sicily. For example, from the tragic sequence of severe meteorological events that occurred between 2007 and 2011 in the below towns:

i) 25 October 2007, which took place at Santa Margherita, Giampilieri and Scaletta (Messina), with flash flood and precipitations of 175 mm in 2 h, against an annual average amount of 800–1000 mm;
ii) 22 November 2011 at Barcellona and Saponara (Messina) with precipitations of 351 mm in 10 h (recorded by the Castroreale weather station);
iii) 01 October 2009 at Giampilieri, a tragic and disastrous event with 37 victims.

Referencing these three events, the recovery costs of the disaster damages were estimated at about 900 million euros (Source: DRPC Sicily – Stato dei rischi del territorio Siciliano – Rischio idrogeologico: raccolta dati storici – Sicilian Territory State of Risk – Hydrogeological Risk: Historical data Record). These events, occurred during the beginning of the autumn season, did not originate from a single factor, but rather from a sum of several interacting processes at different scales not yet fully understood. Consequently, their study can represent a big chance for testing the performances of High Resolution Meteorological Models, which as of yet have not been able to effectively predict the amounts of precipitation with the required spatial and temporal accuracy (Davolio et al., 2009; Miglietta and Rotunno, 2009). Topography and land use characteristics at the respective scales strongly influences the local and regional weather and climate (Clyne and Rast, 2005; Garratt, 1993).

While the climate modeling community is performing runs typically at grid spacing of 100 km, 50 km or at most, 10 km, higher resolutions are needed for places with complex topography (Szintai et al., 2010; Schicker and Seibert, 2009; Zängl, 2007) and dynamical downscaling seems to be the way to go. The Meteorological Models local circulations accurate simulation ability will rely strongly on resolving the important terrain features over focused area. Since the terrain height depends on the grid resolution model, it is essential that the simulation uses an adequate grid size in order to resolve the terrain forcing over the analyzed area (De Meiji and Vinuesa, 2006; Clyne et al., 2007; Kalnay, 2002; Haltiner & Williams, n.d.). Merging high-resolution topography, up-to-date land uses, vegetation fraction and soil moisture and temperature are fundamental to allow models perform realistically at high resolutions, with correct atmosphere-surface interaction (Arnold et al., 2012). The aim of this paper is to understand which effects will produce an improved topographic representation obtained using different grid interval and a use of different geographic data, on the rainfall field forecast.

2. Description of the case study

The selected case study concerns a recent flood event that occurred in Messina in the early hours of 10 October 2015. In the case study, the Antillo meteorological station, which is a unit of DRPC (Dipartimento Regionale della Protezione Civile – Regional Civil Protection Department) weather stations network, recorded, from 00 to 09 UTC, a maximum precipitation accumulation of 175,4 mm. The heavy rains occurred, were the results of a mesoscale convective system developed in the Ionian Sea and powered the low atmospheric layers by the very humid Southeastern streams (Ray, 1986; Wallace and Hobbs, 2006). Another important element that triggered the violent thunderstorm was the orographic lift induced by the barrier of Nebrodi and Peloritani Mountains, together with the one induced by Mt. Etna.

The surface analysis chart at 00:00 UTC of 10 October 2015, shows a low-pressure system centered over the Central Mediterranean Sea, originating a Mediterranean cyclone, with its warm branch extended between the Southern coast of Sardinia and the Greek coast, while the cold branch was affecting the North to South, all over Tunisia. The