6th European Conference on Severe Storms (ECSS 2011) , 3 - 7 October 2011, Palma de Mallorca, Balearic Islands, Spain

NUMERICAL SIMULATIONS OF INTENSE PRECIPITATION IN MADEIRA ISLAND USING THE MESO-NH MODEL

Flavio Tiago do Couto[1,2], Rui Salgado[1,2], Maria João Costa[1,2]

[1]*Physics Department, University of Évora, Romão Ramalho, 59, 7000, Évora – Portugal*
[2]*Geophysics Centre of Évora, University of Évora, Romão Ramalho, 59, 7000, Évora – Portugal*
(couto.ft@gmail.com; rsal@uevora.pt; mjcosta@uevora.pt)

(Dated: 26 August 2011)

I. INTRODUCTION

Extreme orographic precipitation events are a common cause of natural hazards such as flash floods, landslides, and avalanches in mountainous regions (Roe, 2005), and may be caused by different mechanisms. Situated in the Subtropical Atlantic Ocean (32º 45' N and 17º 00'W), Figure 1, the Madeira Island is the largest island of the Madeira Archipelago, with surface area of 737 km^2, a length of 58 km, a 23 km width and a maximum altitude of 1861m (Pico Ruivo), consisting of a barrier elongated in the east-west direction (Prada et al., 2009) and presenting favorable conditions for generation or intensification of orographic precipitation, sometimes responsible by high records and several social-economical damages. During the winter 2009/2010, some events of heavy precipitation were observed in Madeira Island, mainly in high regions, as occurred on 22 December 2009, when intense rainfall was responsible for economic damages in isolated points of the island. On the other hand, in the last years, the use of high-resolution simulations are becoming a common tool for diagnosis and prognosis of intense precipitation events around the world. Therefore, this study aims at analyzing the main aspects associated to the generation/enhancement of precipitation in Madeira Island, verifying the model's ability for the diagnostic of intense precipitation in a region where the orographic effects are predominant.

FIG. 1: Location of Madeira Island. Source: Google Earth.

II. CASE STUDY, DATA AND METHODS

From the extreme events identified during the winter 2009/2010, the case of heavy rainfall that occurred on 22 December 2009 has been chosen as the case study to analyze in this paper, using rain gauges data and numerical simulations. The precipitation data was provided by the Portuguese Meteorological Institute (*Instituto de Meteorologia – IM*), while the MESOscale Non-Hydrostatic Model (MESO-NH; Lafore et al., 1998) was utilized to simulate the evolution of the atmosphere, in particular of some meteorological variables such as accumulated precipitation (mm), wind components (m/s), relative humidity (%), temperature (°C), mixing ratio for water vapor (g/kg) and cloud droplets (g/kg) (Pinty and Jabouille, 1998; Lascaux et al., 2006), cloud fraction, and Convective Available Potential Energy (CAPE) (J/kg). The MESO-NH model was run making use of the nesting grid technique, and configured for 3 horizontal domains (resolutions of 9, 3 and 1 km) and 45 vertical levels (see Figure 2 for depiction of the horizontal domains). Convective parameterization was applied in the outer domains (9 and 3 km); only explicit precipitation was active in the 1 km resolution domain. The simulation was integrated for 54 h, starting on 21 December at 00UTC, with initial and boundary conditions updated every 6 hours and obtained from the European Centre for Medium-Range Weather Forecasts (ECMWF) analyses.

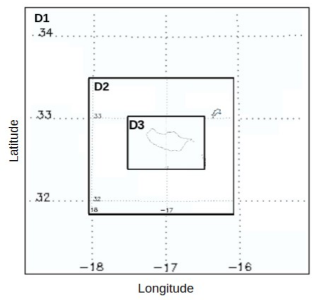

FIG. 2: Horizontal domains used for simulation with grid spacing of 9 km (D1), 3 km (D2) and 1 km (D3).

III. RESULTS AND CONCLUSIONS

The distribution of hourly precipitation in four surface stations for 22 December 2009 (Figure 3) shows that the largest accumulated values occurred in the late afternoon and early evening, around 20 UTC. However, in Areeiro station, there was precipitation since 10 UTC, which intensified throughout the afternoon reaching a maximum of 47.3 mm at 20 UTC. In the other stations the maxima were also observed around 20 UTC, but with values lower than those observed in Areeiro, with a maximum of 17.7 mm in Caniçal station and 15 mm in Santana station. The highest value of accumulated precipitation in 24 hour was registered in Areeiro station (127,7 mm).

From the high-resolution simulation of accumulated precipitation (Figure 4), it is possible to observe that the precipitation was located mainly over the island, while over the ocean there was no precipitation above 10 mm. In the same figure it may be verified that the highest values of accumulated precipitation (between 100 mm and 150 mm) are obtained over the central part of the island, localized mainly in the Paúl da Serra region (above 1000 m) and over the Areeiro peak (above 1500 m), corresponding thus to the highest regions of Madeira island. On the other hand, the point to point comparison between the MESO-NH simulated rainfall and the records of some of the surface meteorological stations (rain gauges), allowed to conclude that the temporal evolution of the precipitation is well represented by the model simulations (not shown here).

Weak and continuous rainfall was observed in Areeiro throughout the afternoon, in marginally unstable atmospheric conditions (low CAPE values < 250 J/kg in the morning and early afternoon). The atmosphere became less stable throughout the day, evolving to a moderately unstable atmosphere when the maximum rainfall was measured at 20 UTC, presenting a CAPE between 1000 J/kg and 1175 J/kg in the southwest of the island (Figure 5). At this time, the simulated vertical velocity shows positive nucleus (upward motion) in the south/southwest of the island with a maximum above 2.3 m/s, in the first level of the model (Figure 6), and values higher than 4.2 m/s at 850 hPa (not shown here). A southwest flow is also observed in both levels. These characteristics combined with diurnal heating and high amounts of water vapor at low level, verified by the simulation of relative humidity and water vapor mixing ratio, favored the formation of dense clouds near the surface, since the simulation of cloud droplets mixing ratio showed values between 1.5 and 2 g/kg in the highest points of the island, but not exceeding 3.5 km of altitude at 20 UTC. The simulation of cloud fraction shows low clouds mainly over the island at 12 UTC (Figure 7.a), but at 20 UTC (Figure 7.b), high clouds are also identified, however, in this case it is not possible to affirm that the seeder-feeder mechanism acted, because there is not any connection between the two cloud layers.

Finally, these aspects indicate that the precipitation observed on 22 December 2009 in Madeira's highlands started weak and continuously, mainly due to the anabatic flow created by the presence of the island. By late afternoon, due to favorable conditions this feature intensified, resulting in high accumulated rainfall over the island, confirming the relation between atmospheric hydro and thermal structure, and the local steep orography in the intensification of precipitation over Madeira. Results also confirm the ability of high resolution models to simulate heavy precipitation over isolated mountains, in this case, in Madeira Island. Similar aspects also have been verified in others events of heavy precipitation in Madeira Island.

V. REFERENCES

Lafore, J. P., J. Stein, N. Asencio, P. Bougeault, V. Ducrocq, J. Duron, C. Fischer, P. Héreil, P. Mascart, V. Masson, J. P. Pinty, J. L. Redelsperger, E. Richard, and J. Vila-Guerau de Arellano, 1998: The Meso-NH Atmospheric Simulation System. Part 1: Adiabatic Formulation and Control Simulation, *Ann. Geophys.*, **16**, 90-109.

Lascaux, F., E. Richard, and J.-P. Pinty, 2006: Numerical simulations of three MAP IOPs and the associated microphysical processes. Quart. J. Roy. Meteor. Soc., 132, 1907-1926.

Pinty, J.-P. and Jabouille, P. 1998: A mixed-phase cloud parameterization for use in a mesoscale non hydrostatic model: Simulations of a squall line and of orographic precipitation. pp. 217–220 in Proceedings of Conference on Cloud Physics, 17–21 August 1998, Everett, USA.

Prada, S., M. M. Sequeira, C. Figueira, and M. O. Silva, 2009: Fog precipitation and rainfall interception in the natural forests of Madeira island (Portugal), *Agricultural and Forest Meteorology,* **149,** 1179-1187.

Roe, G. H., 2005: Orographic Precipitation. *Annu. Rev. Earth and Planet. Sci.* **33**, 645-67.

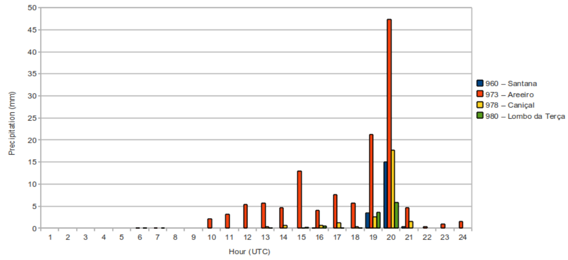

FIG. 3: Distribution of hourly precipitation (mm) in four surface stations: Santana, Areeiro, Caniçal and Lombo da Terça.

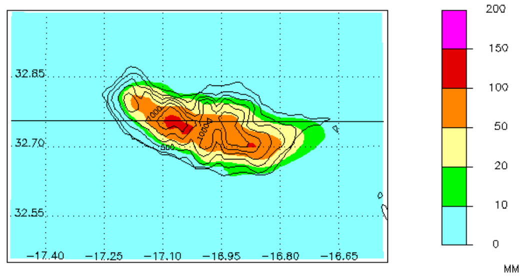

FIG. 4: The shaded areas represent accumulated precipitation (mm) on 22 December 2009 simulated with the MESO-NH Model and solid lines the Madeira orography (m).

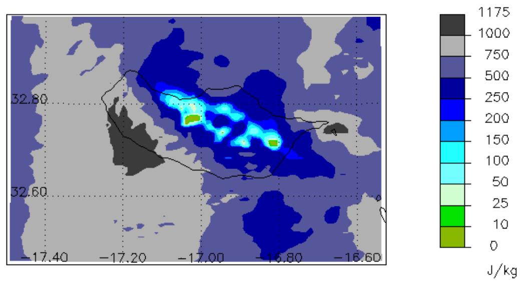

FIG. 5: Convective Available Potential Energy (CAPE) (J/kg) simulated with MESO-NH Model at 20 UTC.

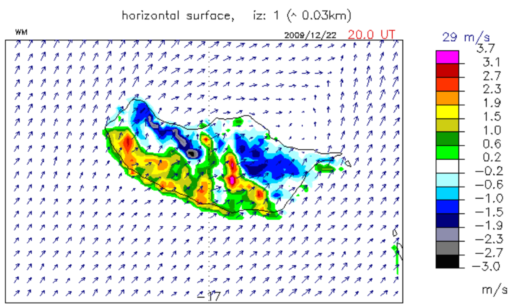

FIG. 6: The shaded areas represent the vertical velocity (m/s) and vectors the horizontal wind in the first level of the model at 20 UTC.

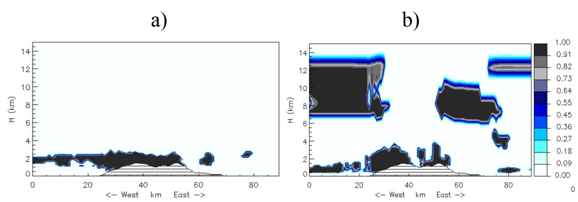

FIG. 7: West-East vertical cross section whose base is indicated in figure 4 of simulated cloud fraction (a) at 12 UTC and (b) at 20 UTC.