SENSIBILIDADE DO MODELO WRF A DIFERENTES CONDIÇÕES DE FRONTEIRA INFERIOR NUM EVENTO DE PRECIPITAÇÃO EXTREMA

WRF SENSITIVITY TO DIFFERENT LOWER BOUNDARY CONITIONS IN AN EXTREME PRECIPITATION EVENT

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SUMMARY

This work aims to study the sensitivity of the Weather Research and Forecast model to three different topography datasets as well as two different land use datasets. A test case study in which topography driven precipitation was dominant over Madeira Island was considered. Aggregated results show that there is no enhancement of model skill when using higher resolution topography or land use. However, locally the model skill may be enhanced with the new datasets showing a higher model skill for precipitation results on Madeira leeward and wind flow windward.

1. Introduction

Given the close relationship between the surface and the atmosphere, it is evident that the Earth's surface properties have an important role in atmospheric dynamics. Therefore, a deep knowledge of surface parameters is important to atmospheric studies and research, especially when dealing with numerical atmospheric models where small perturbations can propagate throughout the whole atmosphere. In fact, numerical atmospheric models are known to be very sensitive to surface characteristics. In particular, many authors have shown the direct influence of topography in atmospheric properties. Pointing examples related with the present work, Bond and Stabeno (1998), Colle and Mass (1998) and Koletsis et al. (2010) have studied the significance of orographic wind flow through a major gap between two high mountains and concluded that the varying elevations inside an elevated gap play an important role in the gap winds intensity and flow paths. It has also been shown that topography influences water vapour transport and thus it can modify precipitation patterns (Jiang, 2003). Due to the difficulty of simulating precipitation events in regions with complex topography and its eventual role as natural hazard, orographic driven precipitation has been the focus of several studies (Elementi et al., 2005; Ghafarian et al., 2012). Furthermore, it is also known that changes in land use can lead to changes in atmospheric properties such as local circulation, moisture and radiation balance (Bischoff-Gauß et al., 2006; Tomassetti et al., 2003).

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This work focuses on WRF results sensitivity to two different lower boundary conditions in an extreme orographic precipitation case in Madeira, Portugal. The Madeira Island is located in the

Atlantic Ocean South-west of mainland Portugal. It has a mountain ridge extending along the central part of the island, reaching a maximum altitude of 1862 m - Pico Ruivo.

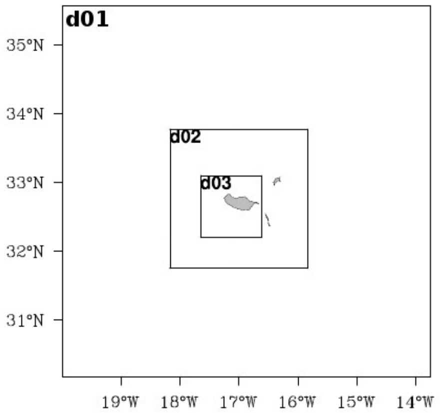


Figure 1: Three nested model domains used in WRF.

2. Methodology

The numerical model used in this work is the Weather Research and Forecasting Advance Research model (WRF-ARW) version 3.3 (Skamarock et al., 2008). Initial and lateral boundary conditions from GFS analyses (NCEP, 2003) were provided to the model at a three hour interval. Three two-way nested domains were applied to the study area - Figure 1. The parent domain (d01) with horizontal resolution of 25 km, and two nest domains (d02 and d03) with an horizontal resolution of 5 and 1 km, respectively. The model simulated 24 hours, starting on February 20th, 2010. Ferreira (2007) compared several sets of physical parametrizations used in the WRF model for mainland Portugal. The set of parametrizations which were found to provide the best results were used in the present study. Therefore, the following schemes were used: WRF Single-Moment 6-class scheme microphysics, Goddard shortwave radiation, Rapid Radiative Transfer Model longwave radiation model, the Eta similarity surface layer scheme, Mellor-Yamada-Janjic planetary boundary layer scheme and the Noah Land Surface Model. Cumulus were resolved explicitly as in Luna et al. (2011), showing that cumulus parametrization is not relevant to simulated precipitation in this particular event.

In order to conduct sensitivity tests to the topography and land use, several experiments were performed. In these experiments two topography data sets - SRTM and ASTER GDEM - and a land use data set - CORINE - were used. A control experiment (CTL) was conducted with the WRF default topography data set - GTOPO30 - and the default land use data set - USGS global 30" vegetation data (USGS30). Some of the more relevant data set attributes are described in Table 1. Due to the different classification methods used in the CORINE and the USGS global vegetation data, a re-categorization was performed to the CORINE data set to be recognizable by the WRF model. The re-categorization process used to convert CORINE into USGS categories is described in Pineda et al. (2004).

	Resolution	Year	Soil Categories
GTOP030 (T)	30"	1996	*NA*
SRTM (T)	3"	2005	*NA*
ASTER (T)	1"	2009	*NA*
USGS30 (LU)	30"	1993	25
CORINE (LU)	100 m	2006	44

Table 1 : Topography (T) and land use (LU)data set attributes.

In order to analyse model results focusing on the evaluation of the WRF model sensitivity to topography, the difference fields related to precipitation and wind were computed between the experiments and the control simulation. Furthermore, the study domain was divided following the mountain ridge of the island, in order to be able to study the effects of the upslope and downslope flows. Also, in order to study the contribution of the highest parts of the island to the sensitivity experiments and precipitation distribution the analysis was separated according to the mountain heights - lower and higher than 800 m. Finally, model data was compared with observed hourly precipitation and wind data as well. The skill analysis for every experiment was performed.

A total of 12 weather stations were considered, five of which are owned and operated by the Portuguese Meteorological Institute and present only precipitation data - Areeiro, Funchal, Lugar de Baixo, Ponta do Pargo and S. Jorge. The other seven stations are owned and operated by the Madeira Regional Civil Engineer Laboratory and present precipitation and two meter wind speed and direction data - Bica da Cana, Calheta, Encumeada, S. Martinho, Machico, Parque Ecológico do Funchal, Porto Moniz. For both sets of weather stations, data is available on an hourly basis, for a period from 0000 UTC 20 February 2010 to 0000 21 February 2010. The location of these stations is shown in Figure 2. Furthermore, in order to produce vertical profiles of the atmospheric properties, a meridional cross section was considered at a longitude of 16.93° W, considering all latitudes as can also be seen in Figure 2.

Figure 2: Location of the weather stations in Madeira Island (blue doted - Portuguese Meteorological Institute; White doted - Madeira Regional Civil Engineer Laboratory) and the location of the cross section used in this work (red line).

In their study, Luna et al. (2011) have shown that, for this precipitation event, high model resolution enhances model skill. Therefore this study will only focus on the domain with higher resolution – d03. In order to evaluate model performance, some relevant measures were determined and applied by Luna et al. (2011) for WRF simulation of the same precipitation event.

3. Results and Discussion

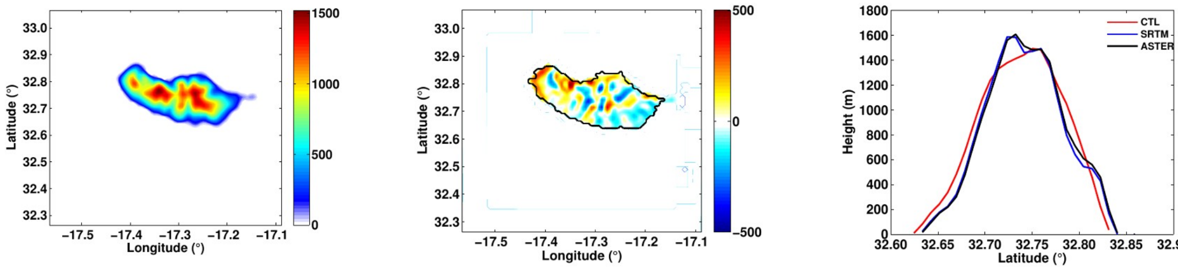
In Figure 3, the Madeira Island topography as was used for the CTL simulation can be seen - Figure 3 (a) - the difference between CTL and SRTM (SRTM - CTL) - Figures 3 (b) and the topography of the cross section used in this work for CTL, SRTM and ASTER – Figure 3 (c). As can be seen, the default topography tends to represent smoother topographic features. On the other hand, the high resolution datasets present a better representation of those features with higher peaks and deeper valleys as well as steeper terrain slopes. These characteristics better represents the Madeira Island topography when comparing to the default dataset used by the model.

Both SRTM and ASTER datasets show a similar representation of the island topography, with only slight differences between them at the top of the island and in the mid northern slope, which may change the topmost local geographical points in the model boundary condition.

As seen before, topography driven precipitation is highly dependent on flow intensity and direction. Furthermore, it is known that changes in topography may lead to changes in flow characteristics.

In the beginning of the period under analysis, the wind flow was perpendicular to Madeira's mountainous ridge - from South to North – originating a deceleration zone upstream Madeira Island, causing flow stagnation near the shore (not shown). The weak intensity (< 10 m/s^1) is associated to the ascent dominant flow until 12 UTC, time at which wind flow becomes more intense (> 20 m/s^1), flow splitting starts to dominate and the upwind stagnation zone deepens into the island enlarging the area of influence closer to the island peaks. After 18 UTC the wind flow weakens and changes direction to West, i.e. parallel to the Madeira Island mountainous ridge. At this time flow splitting becomes dominant due to the orientation of the wind in relation to the barrier. Therefore, a strong wind flow arises in the Southern and Northern Madeira's shore (not shown).

These flow characteristics cause high amounts of precipitation to occur in the centre of Madeira Island, near the highest peaks. It is also possible to observe that in the southern part of the island - upstream the main flow - there is a large amount of simulated accumulated precipitation as would be expected. As it encounters the barrier - Madeira Island - the air is forced to rise. The raising moist air cools and creates favourable conditions for precipitation to occur. On the other side of the island - the Northern part - there is a decrease in precipitation due to air subsidence and lower moisture content. Therefore, the simulated accumulated precipitation amounts are reduced in this area. This precipitation distribution and patterns are consistent with those described by Luna et al.



(a) Topography field from CTL simulation.

(b) SRTM dataset

(c) Cross section

(2011) and Couto et al. (2012), for the same particular precipitation event.

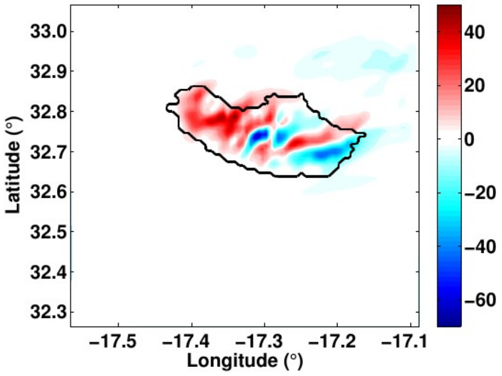


Figure 4: Difference fields for accumulated precipitation (mm/day1) between SRTM and the CTL simulation for February 20th.

When comparing the results of SRTM and ASTER simulations with the CTL it is evident that differences occur over the island. In Figure 4 the accumulated precipitation difference fields between SRTM and the CTL (SRTM - CTL) simulation for February 20th are shown. The difference field is similar in amplitude and distribution for both simulation SRTM and ASTER and thus only the SRTM is shown.

In Figure 4 it is evident that in the Western part of Madeira Island most of the differences are positive - increase in simulated precipitation. This region is characterised by a steep slope followed by a plateau at a height of 1400 m that is oriented perpendicular to the main flow.

As seen before, SRTM and ASTER simulation have a more detailed topography and therefore, there is an increase of the terrain slope adjacent to the plateau. Consequently it is plausible that steeper slopes enhance the terrain forcing leading to a stronger air rise that may then lead to an enhancement of topographic driven precipitation.

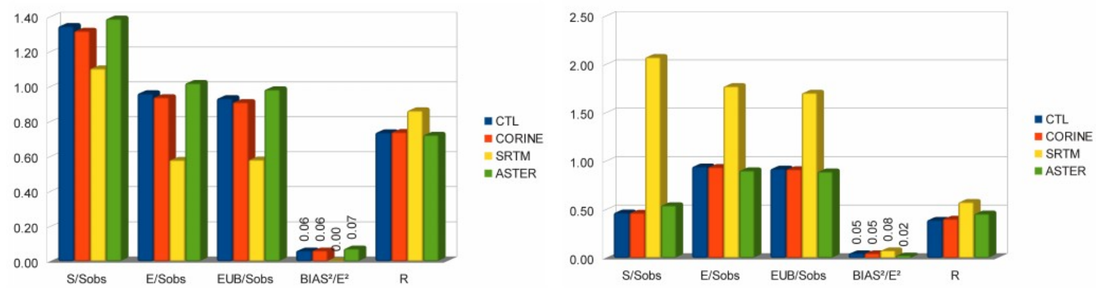
In addition, centred in Madeira Island, it is possible to observe a high negative value of accumulated precipitation difference for both simulations. This negative isolated difference is associated to a deep valley - Ribeira Brava - located near Lugar de Baixo weather station and that extends to the top of Madeira Island. As the new high resolution topography data sets tend to deepen the valleys, the area of terrain forcing the air to rise is reduced which results in a decrease in precipitation. The highest peaks of Madeira Island are located in its Eastern region. However, near the eastern shore the slopes are not as steep as in the Western region of the island. When applying the high resolution topography it results in a decrease in precipitation near Madeira shore - negative values of accumulated precipitation difference - and an enhancement of precipitation in the Eastern mountainous regions - positive values of accumulated precipitation difference. Furthermore, the correlation between the accumulated precipitation difference and the topography difference for both SRTM and ASTER was calculated with values of 0.36 and 0.46 respectively. These values, albeit small (< 0.5), show a relation between the change in topography and the precipitation difference distribution.

With regard to the land use simulations it was possible to see that CORINE dataset gives a more approximated coastline representation of the Madeira Island geographic features to the numerical model (not shown). Furthermore, significant differences in land use categories can be distinguished. For example, contrary to CTL simulation, urban and build-up land category is recognized by the model when CORINE dataset is cupied by evergreen broadleaf and dryland cropland is reduced when the CORINE dataset is used. Also an increase of the area occupied by mixed forest and grassland can be observed. These changes between CTL and CORINE simulation may lead to changes in wind flow proprieties, due to differences in soil roughness length and thus, it can change precipitation patterns.

In Figure 4.11b, where the difference field for accumulated precipitation is shown, it can be observed that their amplitude is smaller than those previously seen caused by the topography. Also it is possible to see that most differences are located only upwind Madeira Island with positive differences near Madeira's shore in an area of high density of urban and build-up land in CORINE simulation, and negative differences in the mountainous region.

The difference field between CORINE and CTL shows small differences when compared to those produced by the use of a high resolution topography dataset (not shown). Nonetheless, most differences are located only upwind Madeira Island with positive differences near Madeira's shore in an area of high density of urban and build-up land in CORINE simulation, and negative differences in the mountainous region.

When comparing the results with observation, one can see that the results for the combined errors for the considered regions show that there is low



(a) Windward region

(b) Leeward region

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mountainous region (not shown) with an overestimation of precipitation variability and with high amplitude and phase errors. Furthermore, the use of high resolution topography - SRTM and ASTER simulations - results in a slight decrease of model skill, not bringing any advantage to model performance when simulating precipitation in this region. On the other hand, for the Shore region, model skill is high for all simulations. Moreover, the SRTM and ASTER simulations show skill enhancement (not shown).

Analysing the precipitation combined error chart for the windward and leeward regions, presented in Figure 5, great differences between SRTM and all the other simulations can be seen. For the windward region - Figure 5 (a) - most simulations tend to overestimate precipitation variability. Additionally, every simulation has fair model skill when simulating precipitation amplitude and phase. However, precipitation simulated using the SRTM topography dataset has a variability identical to the one found for the observed data. Also, a reduction in model error between the observations and the modelled precipitation can be observed. On the contrary, for the leeward region - Figure 5 (b) - SRTM simulation has the worst model skill, not accurately reproducing the observed precipitation amplitude and variability. All the other performed simulations present high skill simulating precipitation amplitude, underestimating the observed variability and presenting small differences between themselves. As can be seen through the analysis of these results, the use of a high resolution lower boundary condition dataset may not change model skill in most situations studied.

Considering the results presented, one can see that, as mentioned before, SRTM is the simulation that produces smallest amplitude errors, variability closer to the observed one and presents the best correlation with the observed data. Still, it can be observed for precipitation data, with high model

for every performed simulation and a slight decrease of model skill when simulating precipitation in the Mountainous region, due to the more complex topography.

4. Concluding Remarks

The main objective of this work was to assess the atmospheric numerical model sensitivity to lower boundary conditions in an extreme orographic precipitation event that occurred in Madeira Island, Portugal. Three high resolution lower boundary condition datasets were use, the SRTM and ASTER for topography and CORINE for land use. The simulations started on February 20th 2010 and were extended to the following 24 hours, thus simulating all the event duration.

This sensitivity experiment showed that the use of any of the high resolution topography datasets may lead to changes in wind flow, especially over Madeira Island and in the leeward region. It was shown that these changes are correlated with the differences between the topography datasets. Additionally, changes for precipitation pattern and distribution between CTL, SRTM and ASTER simulations over Madeira Island could also be observed. These changes, as seen before, are related to topographic features, as the change in terrain slope may change terrain forcing, resulting in an intensification of up lifting which may result in an increase of precipitation and vice versa. Therefore, an increase of precipitation over the mountainous ridges and a decrease of precipitation accumulated amounts over the valleys may be associated with this topographic forcing. Comparing the simulated wind and precipitation results against observations it was possible to see that there is low model skill for u and v wind components over Madeira Island for all the performed simulations. Precipitation model results show higher skill. Using high resolution datasets impacts the model skills of the wind and precipitation variables in opposite ways. A small improvement is observed in wind components whereas precipitation presents a decrease in model skill when compared to the control simulation. However this decrease is small and an overestimation of the variability can be found in all simulations.

These changes were evaluated with more detail considering four distinct Madeira Island regions, namely mountainous, shore, windward and leeward regions. These results show that, for precipitation data there is high model skill in simulating precipitation for altitudes lower than 800 m for all performed simulations. The use of the SRTM topography leads to an improvement of model skill on the windward region. However, the use of this dataset produces more amplitude and phase errors when compared to observations for the leeward region. Nonetheless, one should consider that the differences found for skill in these regions are not only caused by the use of a different topography dataset. When applying the criteria for these two regions - windward and leeward - stations located along Madeira ridge are considered to be in the different regions for SRTM, ASTER and CTL. This change may occur due to differences in the location of Madeira's ridge in the SRTM when compared to all other datasets.

The sensitivity tests performed with the high resolution land use dataset – CORINE - showed negligible changes to model results when compared to the control simulation and observed data.

Given this, it may be concluded that the use of a high resolution dataset within WRF model leads to changes to model results for this particular orographic precipitation event. Furthermore, when comparing with observed data it can be concluded that overall, there is no gain in model skill when using any of the high resolution lower boundary conditions datasets. However, when analysing specific regions of Madeira Island, one can see that SRTM gives an improvement of model skill on the windward region for precipitation. The above results show contradictory results depending on the variables analysed, wind components or precipitation, when using higher resolved topographic fields. This result is in favour of using different model runs configurations over the same domain as members of ensemble forecasts.

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