Regional modelling of heavy precipitations in Portugal: application to the development of landslides warning system

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1. Introduction:

Landslides occurred in the Lisbon area during the last 50 years were induced by rainfall, and landslide activity has been confined to very wet periods (Zezere et al., 2005). In 2006, three new rainfall-triggered landslide events occurred in the study area, namely on the 20 March, the 25–27 October, and the 28 November (Zezere et al., 2008). High intensity rainfall episodes and long lasting rainfall episodes are recognized as major landslide triggering factors worldwide (Wieckzorek, 1996; Corominas, 2001; Guzzetti et al., 2007). The definition of rainfall amount/duration critical values for slope instability has been attempted for more than 25 years (e.g. Caine, 1980; Fukuoka, 1980; Crozier, 1986). All of these studies confirmed the non-universality of this relation.

The Lisbon area is part of the southern Portuguese Estremadura region being limited by the Tagus River, to the East, and by the Atlantic Ocean, to the West.

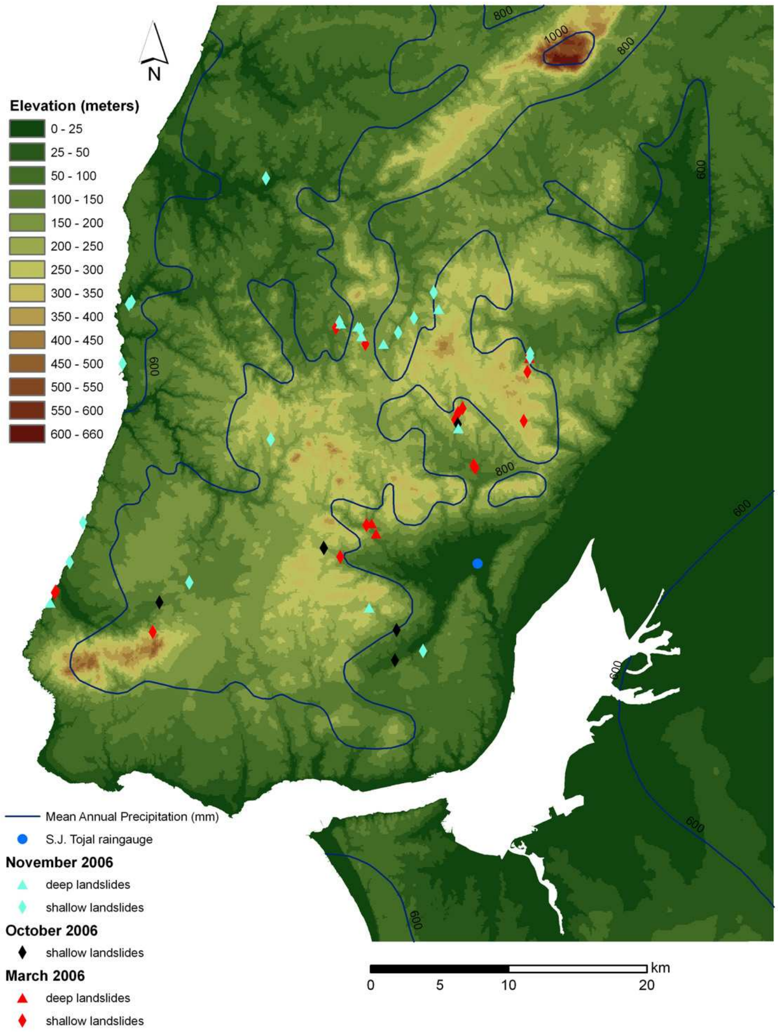

Figure 1 The Location and elevation of the study area, and distribution of landslides occurred in 2006 (Zêzere et al., 2008)

The elevation ranges from 0 to 666 m, and the highest area corresponds to the Montejunto Mountain that is located in the northern part of the study area, and the Sintra Mountain (580m) located further south and closer to the ocean. The fluvial erosion verified during the Quaternary promoted the degradation of the plateau, and was responsible by the creation of some steep slopes. The climate of the Lisbon region is Mediterranean but with a significant influence of low-pressure systems originated in the Atlantic. The Lisbon area is an important landslide-prone area in Portugal. Nineteen major landslide events occurred during the 50 year-long period that spans from 1956 to 2005, these events were concentrated in 11 different years and accounted for hundreds of individual landslide occurrences. About 15 new individual landslides occurred in March 2006 ., characterized the 2006 landslides events and discussed the rainfall regime prior to the landslide events as well as the associated atmospheric conditions that were responsible for their trigger (Zêzere et al., 2008).

The prediction of landslides triggered by precipitation requires a comprehensive knowledge of geomorphological characteristics and, additionally, an accurate forecast of the atmospheric conditions associated (e.g. precipitation and snow). However, the ability to predict precipitation at fine-scale remains a challenge in atmospheric modelling, because of the contribution of very fine-scale processes due to orography and convection, and their non-linear interactions with the larger scale processes.

In this work we use Regional Climate Model WRF (Weather Research and Forecasting model) to model precipitation over Portugal in order to force the landslides model developed in Zêzere et al., 2008. We aim to develop a landslide alert system based on a platform modelling of precipitation (with WRF) and of landslides (with the method of Zêzere et al., 2008). Hereafter, we describe the different experiments used to assess precipitation modelling with WRF on our domain, for the landslide event of the 20th of March 2006. We then evaluate the performance of WRF in precipitation modelling by comparing our modelled results to observations. Finally we present some conclusions and further perspectives.

2. Precipitation modelling with WRF:

2. a. Description of precipitation modelling with WRF

The description of atmospheric variables such as precipitation, temperature and wind at high resolution is performed here using a state-of-the-art Regional Climate Model (RCM); the

Weather Research and Forecasting model (WRF, V3). The atmospheric variable that has the major control on the occurrence of landslides is precipitation (Zêzere et al., 2008 and Schmidt et al., 2008). We evaluate then the sensitivity of modelled precipitation with WRF, in relation to the 1) type of external data forcing, 2) nudging time adopted, 3) spatial resolution implemented and 4) the number of embedded domains (Denis et al., 2002; Laprise et al., 2000; Salameh et al., in revision). Sensitivity studies do not define a "universal" configuration of RCMs that is optimal for the description of regional climate. In our case, large-scale phenomena (such as advection from the ocean towards the continent with intense moisture fluxes) and local phenomena (such as convection) affect precipitation in this region. The best precipitation modelling (i.e., that is the closest to observations) is an equilibrium modelling of the different variables that impact the evaluation of regional precipitation. It should be noted that in this work we do not separate convective from non convective precipitation.

All WRF's simulations employed here are conducted using the same schemes relative to micro-physics (Ferrier, new Eta) and long and short wave radiation (RRTM and Dudhia, respectively). We used Monin-Obukhov scheme for surface layer with the NOAH model for land-surface physics running over four soil layers. Mellor-Yamada-Janjic (Eta) TKE scheme was used for the boundary layer option and the Kain-Fritsh (new Eta) scheme for cumulus. We do not take into account the snow cover effects but we consider the cloud effect on the optical depth in radiation. The land use and soil category are generated with the standard initialisation of WRF. For all the runs, the urban canopy model was not activated.

The simulations cover 6 to 10 days around the landslide event and all experiments start on the 16th of March 2006. They are conducted over the same domain covering the region from -15°E to -3°E and from 36°N to 41°N for the biggest domain and from -10°E to -7.5°E and from 37.8°N to 39°N for the embedded domain when two embedded domains are used.

2.a.1. Sensibility of modelled precipitation with WRF to boundary data:

The sensibility of WRF to the type of data on the boundaries and for initial conditions is assessed using ECMWF analysis at 0.5°x0.5° and reanalysis from NCEP-FNL at 1°x1°. We call herein WRF-NCEP-9km and WRF-ECMWF-9km WRF simulations at 9 km having NCEP reanalysis and ECMWF analysis as initial and boundary conditions, respectively. At each grid point of these simulations, we nudge every 12h WRF's wind and temperature to those obtained from NCEP or ECMWF. WRF simulations forced by ECMWF analysis or NCEP reanalysis agree on the description of the spatial and temporal evolution of precipitation patterns over our domain. Though, they show some differences in the daily cumulated precipitation patterns. Daily averaged wind (arrows) superimposed to daily accumulated precipitation patterns (colours) from the 16th to the 21st of March 2006, are represented for WRF simulations forced by NCEP (Fig. 2) and ECMWF (Fig. 3), respectively. Except for the 17th of March, the daily accumulated precipitations from WRF/ECMWF are more localized and intense than those obtained from WRF/NCEP. On the 17th accumulated precipitation from WRF/NCEP are more intense and localized on the central part of Portugal and southern coastlines. Wind patterns show for both simulations from WRF forced by NCEP and ECMWF that precipitation is being advected from the Atlantic. Note that precipitation shown here is convective precipitation, in our case it means that they were formed over the ocean and then precipitated over the continent.

In addition, we conducted over the same domain, simulations with WRF forced by NCEP and ECMWF at 3 km. WRF-NCEP-3km and WRF-ECMWF-3km show an overall agreement with simulations at 9 km, on the description of spatial structure and evolution of precipitation (not shown). Therefore we disregarded these higher resolution runs, as their results appear to be similar to the low resolution experiments, but they required considerable longer CPU time to run all sensitivity experiments.

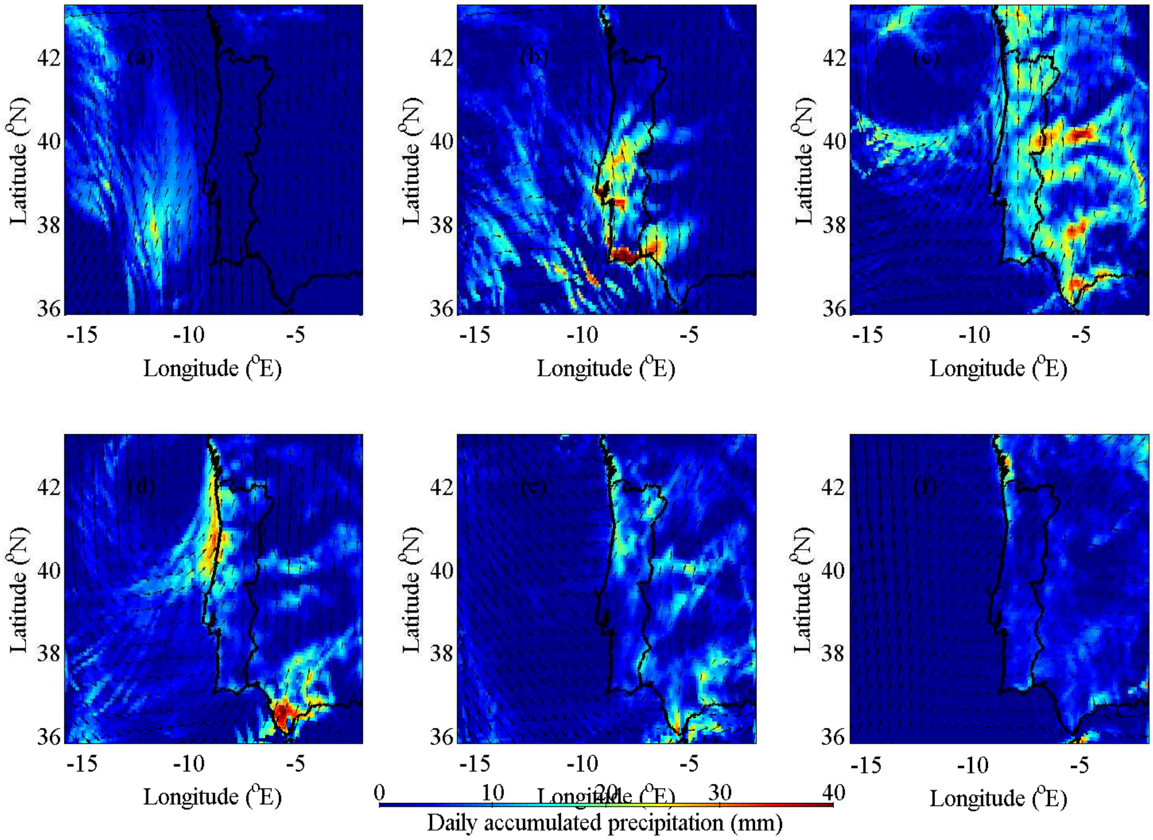

Figure 2 (a) to (f) represent daily accumulated precipitation (colours) modelled with WRF-NCEP-9km from the 16th to the 21st of March 2006, respectively. Arrows correspond to daily averaged wind.

2.a.2. Sensibility of modelled precipitation with WRF to the nudging:

One way to overcome the possibility of large deviation of WRF from reality is the use of nudging (Davies and Turner, 1977; Schraff, 1997; Li et al., 1998; Vidar et al., 2003). This technique consists on guiding at each nudging time, regional variables to the forcing variables, usually supposed to be more accurate. In order to evaluate the effects of nudging on the assessment of precipitation with WRF, we conduct two additional simulations, one with no nudging and the other with a nudging time of 2 hours. Recently, it has been shown that nudging can improve the scores of precipitation because of a better representation of the physics near the surface (Lo et al. 2008). The results that we obtain with different nudging times are very similar to those attained with WRF-NCEP-9km (with nudging time equals to 12 hours). Therefore, we concluded that the nudging plays a minor role in these simulations. This result confirms that the impact of nudging is more relevant when conducting long term or climatic simulations. In our case and for synoptic simulations, the impact of nudging is very weak. In addition, this result confirms the non-universality of WRF configuration for precipitation modelling.

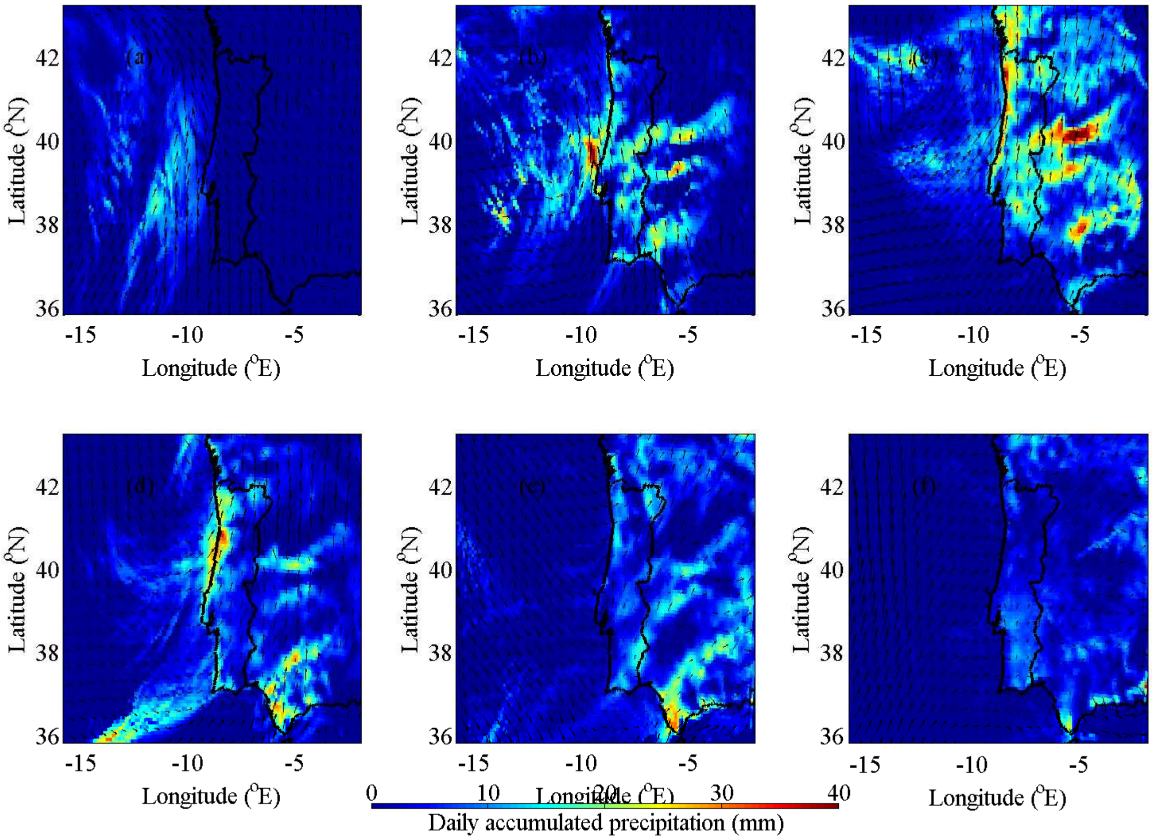

Figure 3 Same as Fig.1 for modelled precipitation and wind with WRF-ECMWF-9km

2.a.3. Sensibility of modelled precipitation with WRF to the resolution:

It is accepted that, in most occasions, higher spatial resolution seems to improve the scores of precipitation since interaction with orography is represented at higher resolution (Mass et al., 2002). Therefore, we conducted two additional experiments in order to test the sensitivity of WRF precipitation to spatial resolution. These simulations are identical to WRF-NCEP-9km and WRF-ECMWF-9km but at 3 km resolution, respectively. Only the WRF-NCEP-3km is shown here (Fig. 4) since the results are similar to WRF-ECMWF-3km. An additional simulation of two embedded domains is in procss: the coarse domain is the WRF-NCEP-9km domain and the second domain is 3 km resolution zoomed over central Portugal. This experiment will show the impact of two embedded domains in the modelling of extreme precipitation at high spatial resolution. Note that for this simulation we conduct a one way nesting, i.e. with no feedback from the small domain to the coarse one.

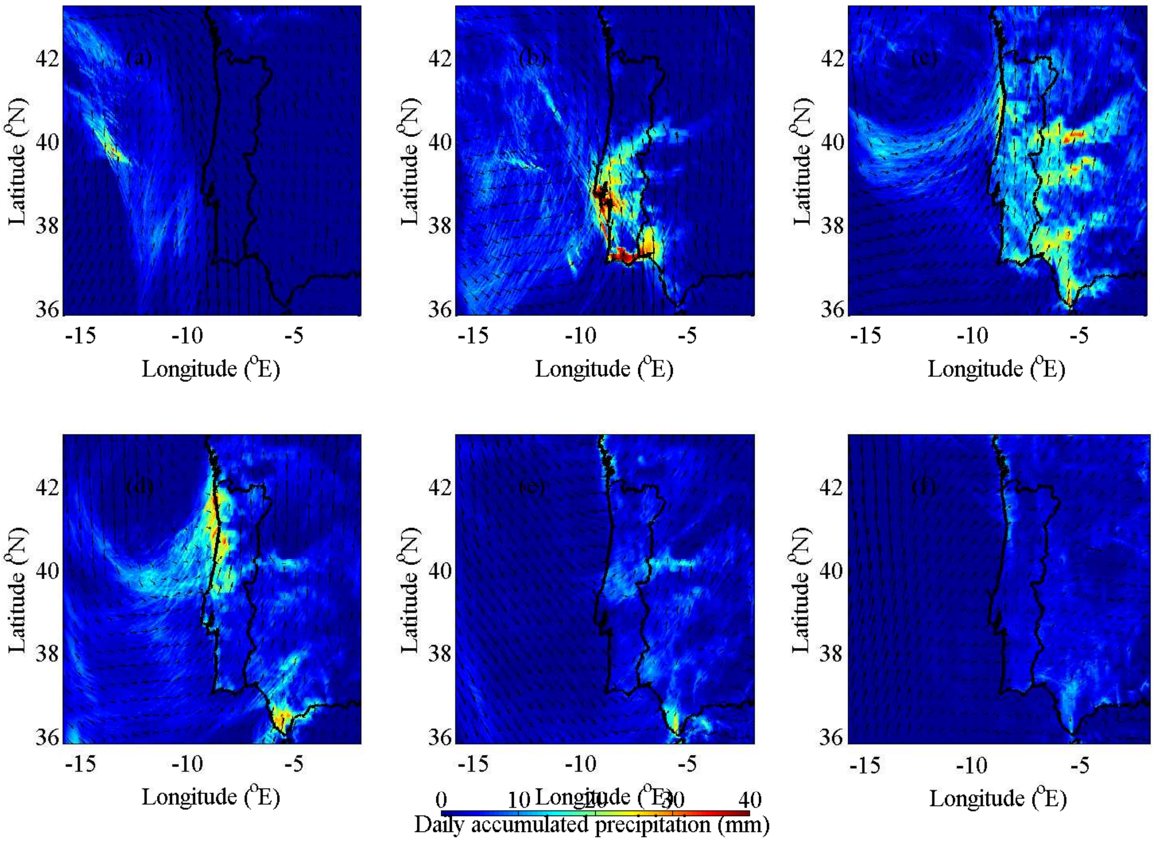

Figure 4 Same as Fig.1 at 3 km resolution

Even though simulations at 3 km reveal an overall agreement with those at 9 km, they show, as expected details at higher spatial resolution. For example, on the 17th of March (Fig. 3 b), daily precipitations seem to be more localised over central Portugal and less spread over the ocean (Fig. 3 b) and over the continent (Fig. 3 e).

2.b. evaluation of uncertainties:

In order to assess the accuracy of modelled precipitation using WRF, we compare the output with observations available for about 20 meteorological located within the landslide region (represented in Fig 1). It must be stressed that observed data correspond to daily accumulated precipitation recorded at 9:00 am. The comparison of observed precipitation with those obtained with both RCMs shows higher accuracy of the intensity of modelled precipitation with WRF-NCEP-9km and of the timing of modelled precipitation with WRF-ECMWF-9km (Fig. 5). Spatial resolution seems not to affect the accuracy of precipitation (Fig. 5). The determination of a spatial resolution over which, no improvement are recorded on precipitation modelling, is still an open question. Studies like Mass et al., 2002 and Denis et al., 2002 showed that higher resolution improves the scores of some modelled variables, but they do not determine an optimal spatial resolution that compromises scores and computational cost.

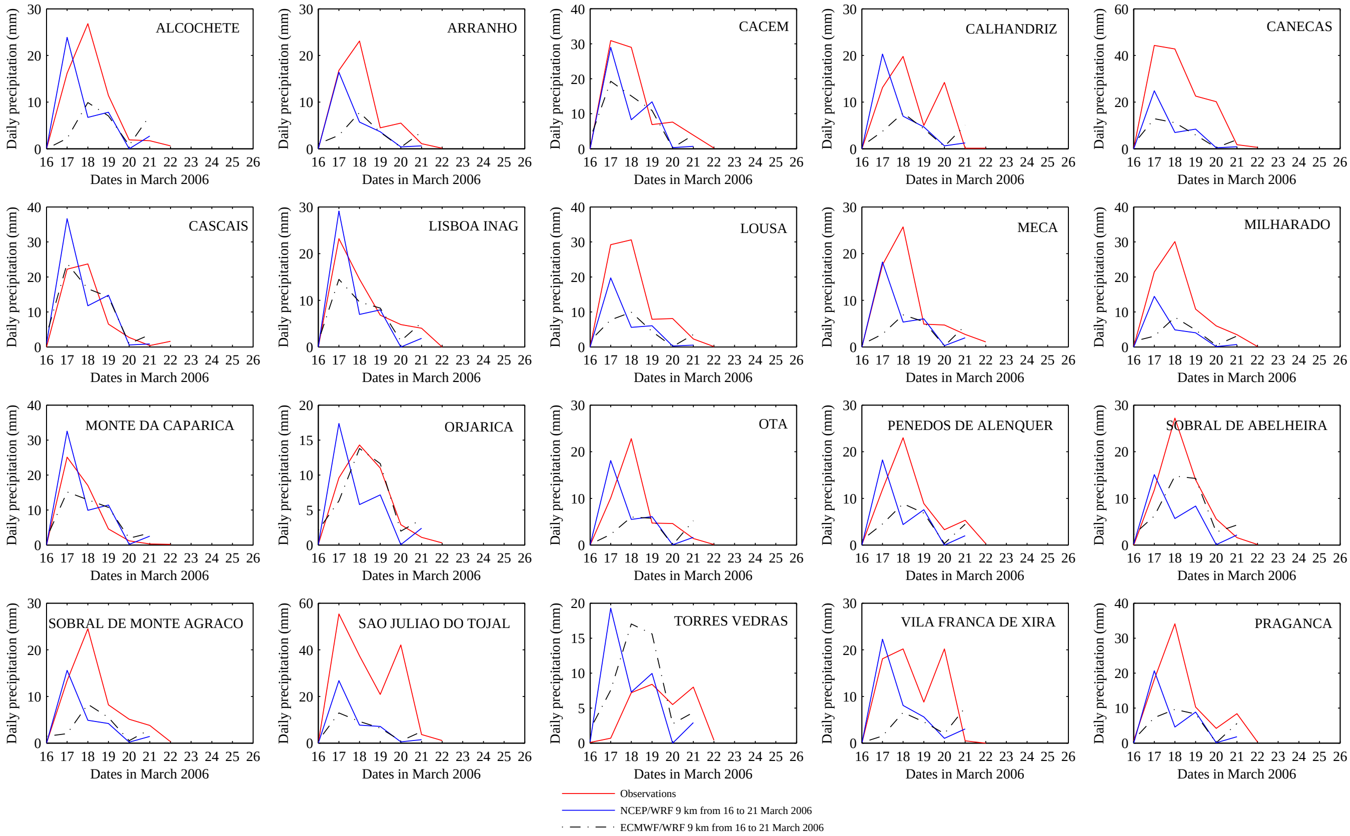

Figure 5 Red, blue and black lines correspond to daily accumulated precipitation from observations, WRF-NCEP-9km and WRF-ECMWF-9km, respectively.

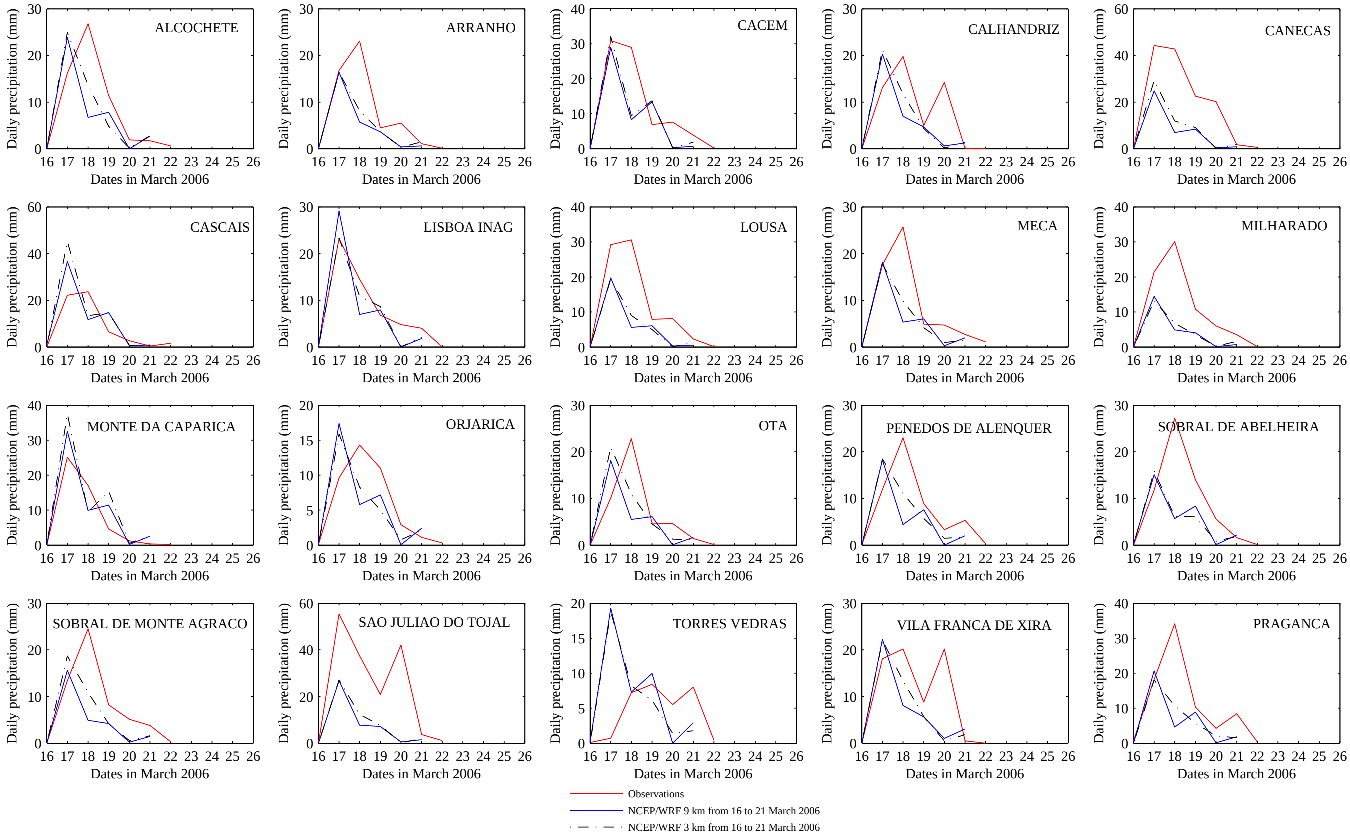

Figure 6 Red, blue and black lines correspond to daily accumulated precipitation from observations, WRF-NCEP-9km and WRF-NCEP-3km, respectively.

3. Conclusion and future works:

Regional dynamical modelling over a given domain is more complicated than an adjustment of one or two variables since it is an equilibrium and an interaction between different variables. The adaptation of regional dynamical modelling for an optimal assessment of a given variable can be inadequate to others. Improved results cannot be obtained with an optimal forcing, nudging or resolution. It needs improved physical parameterization to take into account the interaction between different atmospheric variables.

We assess herein the performance of precipitation modelling with WRF over Portugal by testing the sensibility of WRF to different configurations. For our case study, precipitation with WRF seemed to be affected by the data type of initial and boundary conditions. WRF forced by NCEP gives better results considering the intensity of precipitations, while WRF forced by ECMWF gives better results considering the timing of the events. Both simulations were far from perfect and miss, to a certain level, the intensity, the timing or the duration of precipitating events. Furthermore, in relation to the specific case study evaluated here, nudging and nudging time and spatial resolution appear to affect very little the precipitation scores.

In the near future, we will assess the impact of nesting on precipitation modelling and consider either nesting or one domain at 9 km for WRF forced by NCEP in order to furnish precipitation to the landslides model. This work is the first step in the development of the landslide platform that allows predicting multiple landslides, their time occurrence and their location at fine-scales.

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