8-1-2014

The Contribution Of Fine Scale Atmospheric Numerical Models In Improving The Quality Of Hydraulic Modelling Outputs

Rabia Merrouchi

Dalila Loudyi

Mohamed Chagdali

11th International Conference on Hydroinformatics
HIC 2014, New York City, USA

THE CONTRIBUTION OF FINE SCALE ATMOSPHERIC NUMERICAL MODELS IN IMPROVING THE QUALITY OF HYDRAULIC MODELLING OUTPUTS

MERROUCHI RABIA (1,2), CHAGDALI MOHAMED (2) AND DALILA LOUDYI (3)
(1): National Meteorological Department, B.P. 8106, Casablanca, 20200, Morocco
(2): Faculty of Science Ben M'sick, Casablanca, B.P. 7955, Casablanca, Morocco
(3): Water and Environmental Engineering, University Hassan II Mohammedia-Casablanca, B.P. 146, Mohammedia, 20650, Morocco

The atmospheric numerical models have known great advances with the ongoing development of numerical weather prediction and computing resources. The spatial and temporal resolutions of the global atmospheric models have improved and therefore, the accuracy and reliability of their results have substantially increased. Emphasis was made on the improvement of models dynamics and physical aspects, but also on data assimilation and input data diversification using new numerical schemes and new physical parameterizations that better assess the small-scale weather phenomena. However, these models were not able to overcome their physical limitations and therefore, some small-scale processes are far from being thoroughly apprehended.
To overcome these limitations, new numerical models applied to limited areas and finer scale numerical weather models have been developed including additionally, the microphysics of clouds, atmospheric chemistry and soil characteristics (vegetation index, albedo, roughness property, etc.). The output of atmospheric models, particularly in the field of precipitation, is the main input of hydraulic numerical models and flood warning systems. Better control of the rainfall forecasts, especially during extreme weather events, will have a positive impact in improving the quality of numerical hydraulic models predictions.
The present work illustrates, through two recent cases studies, a real demonstration of the contribution of fine-scale atmospheric numerical models in improving the quality of hydraulic numerical models outputs taking into accounts that time series of predicted rainfall amounts issued from the fine scale atmospheric models provide more precise information at the scale of water basin and also that these models have demonstrated an ability to better predict stormy situations that are causing floods in many parts of the country.

MATERIAL AND METHODS

For the purpose of the study, both atmospheric general circulation models and limited area atmospheric numerical models are used. Numerical weather models results are compared to surface and remote sensing observations obtained from the national meteorological observing network and, precisely, from meteorological stations located in the study area.

General Circulation Atmospheric models
The ARPEGE model:
The French numerical model ARPEGE (Action Research for Small Scale and Large Scale) is a stretched global atmospheric circulation model using a variable horizontal grid mesh whose focal point is centered in the French territory. The vertical resolution of the model is 70 levels. The time step is 600 seconds and the ARPEGE model is using hybrid vertical coordinate "pressure -sigma", a finite element representation in the vertical direction and it uses a two levels semi- Lagrangian scheme for time integration.

The ECMWF model
The atmospheric general circulation model of the European Centre for Medium-Term Weather Forecast (ECMWF) is a deterministic model using a grid of 91 vertical levels and a regular horizontal spatial resolution of 0.25°. ECMWF model is providing numerical weather results all over the globe for 144 hours.

Limited area numerical model

The model AL-BACHIR:
The AL-BACHIR model, operational in the National Meteorological Department (DMN) since 1996, is a limited area atmospheric numerical model centered on Morocco. This atmospheric model produces weather numerical predictions at a finer spatial scale and at short time scale (3 days). AL-BACHIR model runs are using 43 vertical levels and a spatial resolution of 10km.
The initial conditions of the model are determined by a variational data assimilation incorporating all conventional and remote sensing observations available on the area of study as in Fischer *et al.* [1]. The boundary conditions are derived from the ARPEGE model.

The model AROME:
The fine scale atmospheric numerical model (AROME) was designed to improve short-term forecasting of hazards such as strong Mediterranean rainfall, thunderstorms, fogs or urban heat islands during heat waves [2]. The model AROME is operational at the NMD with a spatial resolution of 2.5km and is nested to the AL BACHIR model to obtain the boundary conditions.

Surface and Remote sensing Observations:
For this study, images from the weather radar located at Agadir Al-Massira airport (images are available every 10 minutes), Meteosat Second Generation satellite images (available every 15 minutes in multiple channels) and hourly cumulative rainfall and weather observations made by the meteorological stations of Agadir airport and Taroudant are used.

RESULTS

Case of heavy rainfall in the Souss valley (31 October 2012)
The region of Souss-Massa experienced a heavy rainfall episode during the night of 30 and the morning of October 31st, 2012 which reached about 100mm in the station of Taroudant as shown in Figure 1 and 84mm in Agadir airport meteorological station. The recorded quantities of rainfall during this short time episode (less than 15 hours) accounts for the equivalent of 30%

of the annual rainfall normalized average (300 mm) observed in the Souss Valley known generally for its semi-arid climate.

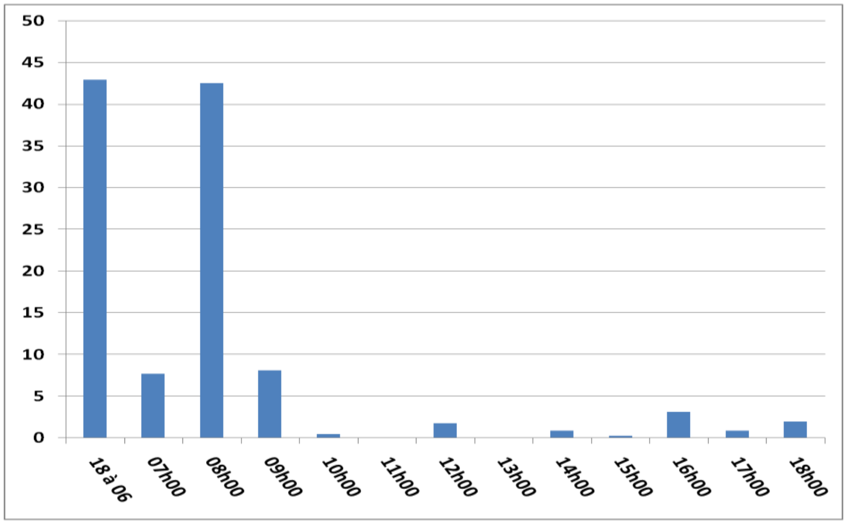

Figure 1. Histogram of hourly rainfall observed at the meteorological station of Taroudant since October 30th, 2012 at 18h00 to October, 31st, 2012 at 18h00.

The meteorological situation prevailing in the day of October 31st, 2012 was characterized on the surface level by the presence, over Morocco, of a relative minimum of the thermal field and also of the field of atmospheric pressure promoting the formation of a cloud cluster on the south west of the country moving to east. This cloud clusters (Figure 2) consists of low cumulus clouds having an averaged vertical extension of 4km altitude above the ground as observed by the weather radar of Agadir airport meteorological station (Figure 3).

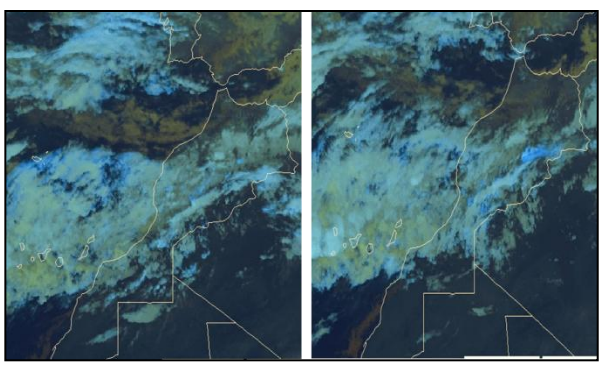

Figure 2. Infrared Satellite images of the 31 October 2012 at 03h00 (left) and 06h00 (right)

The comparison between the outputs of general circulation atmospheric models (ARPEGE-ECMWF) and those of the small-scale numerical models (AL BACHIR- AROME) reveals that the difference between the two types of models becomes clearer when comparing the rainfall results provided by the different numerical models used. Indeed, the ECMWF model fails to isolate the cloud cluster that affected the region of Souss-Massa (Figure 4) showing weak to moderate rainfall quantities not exceeding 10mm, while the ARPEGE model manages to highlight this cloud cluster laying from Agadir to Taroudant with predicted values rainfall quantities reaching the ground exceeding 15mm near Agadir city.

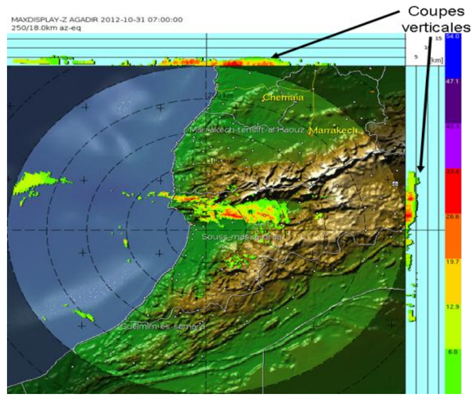

Figure 3. Weather radar image of 07h00 giving indications on clouds reflectivity

Al BACHIR numerical model provides more precisions concerning the geographical position of the precipitating clouds and of the amount of predicted rainfall (Figure 5). AL-BACHIR model succeed to mark the spatial extent of the maximum of rainfall which is approaching the shape and the position of cloud reflectivity reported by the weather radar of Agadir (Figure 3). The predicted amount of rainfall exceeds 20mm over the axis Agadir-Taroudant which is still less than real quantities reaching the ground.

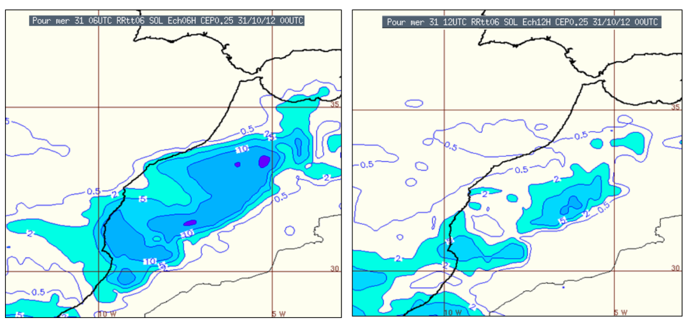

Figure 4. Chart of predicted rainfall amounts issued from the CEPMMT model for 06h00 am (L) and 12h00 am (R)

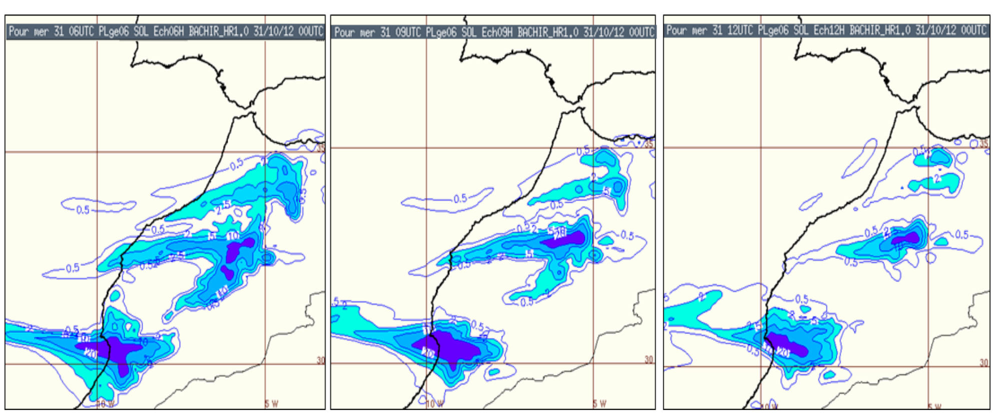

Figure 5. Chart of predicted rainfall amounts issued from the AL-BACHIR model for 06h00am (L), 09h00am (M) and 12h00am (R)

The finer scale numerical model AROME (2.5km) provides more accurate information on the period of persistence of these heavy rains showing its beginning after 03h00 am and its declination beyond 09h00 am. Comparing these outputs with weather radar images indicate a good match, in terms of geographical localization, between the high reflectivity area and the area of heavy rains predicted by the model AROME.

Case of heavy rains in the region of Tetouan (29 August 2013)

The stormy summer meteorological situation of the 29 August 2013 was particularly interesting. Unstable weather conditions prevailed in southern Spain and northern Morocco leading to the development of thunderstorm cloud cells. Those thunderstorms produced intense precipitation in many locations in the northern part of Morocco leading to some floods and physical damages in urban regions as was the case in the cities of Tetouan and M'diaq.

The cloud cluster, consisting in a cluster of thunderstorm cells, grew since 09h00 am to cover the entire region from Ksar Sghir to Oued Lao. The observed amounts of rainfall reaching the ground were highly variable but quite interesting in terms of rainfall intensity. In fact, in M'diq city, six hours cumulative rainfall recorded 58mm between 00h00 and 06h00 and in Tetouan Airport 31mm between 09h00 and 12h00. The analysis of the weather radar images, recorded every 10 minutes by two weather radars located in Fes airport and in Larache city, shows the existence of stormy cells extending vertically over 8 km above the ground and having very high reflectivity exceeding 40 dbz indicating intense rainfall (Figure 6.).

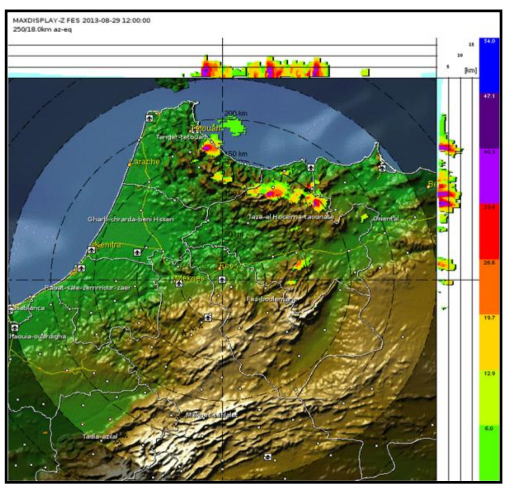

Figure 6. Weather radar image of 12h00 –*situation of the 29 August 2013*

The general circulation atmospheric models ARPEGE or ECMWF and even the first version of AL-BACHIR numerical model with spatial resolution of 16km failed to predict the rainfall observed in the northern part of Morocco or to oversee the storm formation in this part of the country. The six hours cumulative rainfall predicted by the model ECMWF illustrates the fact that large-scale numerical models were not suitable for such kind of stormy situations consisting of isolated thunderstorm cloud cells that are smaller than the spatial resolution of the model itself, despite the efforts deployed in terms of research and development for better control of these so-called "sub-grid" phenomena.

The AL-BACHIR numerical model with spatial resolution of 10km predicted very well this stormy situation, either in terms of spatial and temporal distribution (geographical location, beginning and end of the rain episode) or in terms of expected rainfall. Indeed, a maximum rainfall accumulation, between 00h00 and 06h00, of about 60 mm was forecasted by the model AL-CACHIR near the city of M'diq where 58mm was actually observed during same period. The fine scale numerical weather model AROME with a spatial resolution of 2.5km added some finesse in the spatial representation of boundaries and shape of thunderstorm cells (Figure 7) succeeding to represent the isolated thunderstorm cells as observed in the weather radar images of 12h00 (Figure 6). However, the total predicted rainfall for six hours was larger than the observed ones (58mm in M’diq) with a maximum value exceeding 100mm in six hours in the M’diq city.

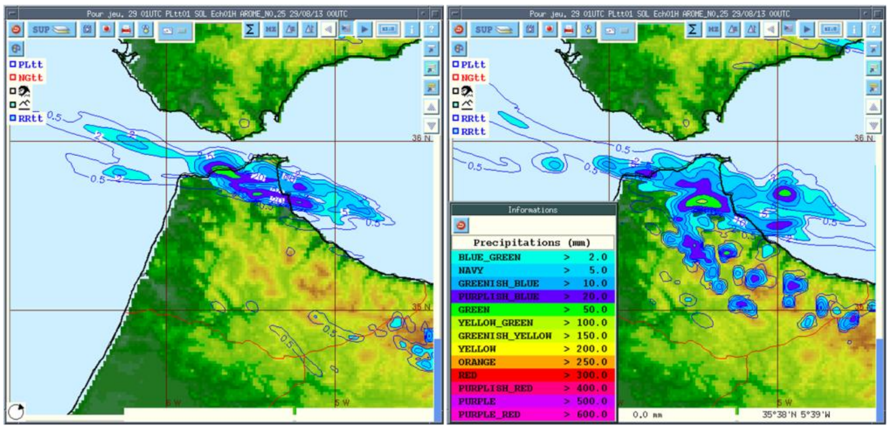

Figure 7. Chart of six hours predicted rainfall amounts issued from the AROME model for 00h00-06h00 (L) and 06h00-12h00 (R)

DISC USSION AND CONCLUSION

For these two case studies, the contribution of fine scale models is clearly remarkable as they allow meteorologists to refine their forecasts and thus to improve the early warning system in terms of both spatial location and temporal duration. This contribution of small and fine scale atmospheric numerical models is not only due to their low spatial resolution, allowing them to incorporate more realistic representations of surface characteristics, but also to their physical parameterizations, including all microphysical processes of clouds, cloud-surface interaction, atmospheric chemistry and other processes, and the implementation of data assimilation cycles that integrate all types of available observations. In particular, important work was made aiming to improve the parameterization of deep convection processes in the fine scale atmospheric models as reported by Ducroq *et al.* [3] and Gérard *et al.* [4]. The strength of these numerical models also draws the progress experienced by general circulation atmospheric models or limited area numerical models since they provide the boundary conditions.

ACKNOWLEDGMENTS

Our thanks go to the staff of the National Meteorological Department for their contribution providing numerical model outputs and observational data related to the studied cases.

REFERENCES

[1] Fischer C., Montmerle T., Berre L., Auger L. and Ştefănescu S.E., “An overview of the variational assimilation in the ALADIN/FRANCE numerical weather prediction system”, *Quarterly Journal of the Royal Meteorological Society*, Vol. 131, No. 613, (2005), pp 3477-3492.

[2] Boutier F., “ Arome, avenir de la prévision régionale ”, *La météorologie*, No. 58, (2007).

[3] Ducrocq V., Lapore J.-P, Redelsperger J.-L. and Orain F., “Initialisation of a fine scale model for convective system prediction: A case study”, *Quarterly Journal of the Royal Meteorological Society*, Vol. 126, No. 570, (2000), pp 3041-3065.

[4] Gérard L. and Geleyn J.-F., “Evolution of a subgrid deep convection parameterization in a limited area model with increasing resolution”, *Quarterly Journal of the Royal Meteorological Society*, Vol. 131, No. 610, (2005), pp 2293-2312.