HYDROLOGICAL FORECASTING IN COLOMBIA USING NUMERICAL WEATHER PREDICTION FROM WRF (ARW), SALDAÑA RIVER BASIN

Jorge GONZÁLEZ* **Supervisor: Tomoki USHIYAMA****
MEE14629 **Maksym GUSYEV*****

ABSTRACT

In this work is studied the performance of hydrological models using precipitation information from Numerical Weather Predictions (NWP) in a global scales, the process include a dynamical downscaling using Weather Research and Forecasting (WRF) model and evaluate the results to incorporate them as input in hydrological models. The methodology could be implemented in Colombia with the purpose to use this technique in the regional levels as one of the possible tools to be implemented in regional forecasting centers.
For the evaluation of the process was studied the Saldaña River Basin, in the period between April 5th to 10th in 2011, period of time in which there was a Niña phenomenon in Colombia that affected the climatological conditions in the country, caused the occurrence of high precipitation levels and as consequence of that a high increasing in the river levels in almost all the Andean region, because the availability of information and the physical conditions in the basin was considered to apply this methodology there, as a first trial for its possible use as operative tool for hydrological forecasting in other basins in Colombia.The results showed that the hydrological models coupling with meteorological forecast can improve in an efficient way the warning issuance in Saldaña river, given the forecast the event occurred in 10th April could be forecasted 9 days before, the process indicate that using forecasts based on simple average or the median of the ensemble the quantitative forecasts can be improved in an important way. This work shows an implementation of a technique that is used in some National Centers and that could be implemented in the Forecasts and Warning Office in Colombia as an additional operative tool.

Keywords: Hydrological forecasting, Numerical Weather Prediction.

1. INTRODUCTION

This research focuses in exploring the possible use of the Numerical Weather Prediction (NWP) as source of quantitative precipitation forecast (QPF) from General Circulation Model (GCM) and its use as boundary and initial conditions for a dynamical downscaling, using for it the Weather Research and Forecasting Model (WRF) and in this way obtain a precipitation forecast for the study area with a 5 kilometers resolution, this output will be used as input in a hydrological model to forecast the water levels in the Saldaña river. For this research the time

---

*Institute of Hydrology, Meteorology and Environmental Studies (IDEAM) of Colombia.
**Researcher, International Center for Water Hazard and Risk Management. (ICHARM), Japan.
*** Researcher, International Center for Water Hazard and Risk Management. (ICHARM), Japan.

scale used is daily, because mostly of the information that is generated in the IDEAM´s hydrometeorological stations has this kind of temporal resolution.
The use of numerical weather prediction from global models can contribute to extend the forecast horizon, in that way the hydrological forecasting in Colombia with a few days ahead could allow to the government and Prevention System to be prepared and to prevent the possible damage that can be caused for the floods in different kind of rivers in Colombia.
This information was used as boundary conditions for run the Weather Research and Forecasting Model to make the downscaling for the precipitation for a smaller domain, and use it as input in a hydrological model of the study area selected, in this case the Saldaña River Basin.

2. DATA

2.1. Study Area

The Saldaña River Basin is located in the south of Colombia, in the central mountain, its highest point is almost 4.000 m.a.s.l. and the lowest one is close to 285 m.a.s.l. in the point where the Saldaña River reaches the Magdalena River. The Saldaña River´s length is 225 kilometers and run from south to north. The total area of the basin is 9.963 km^2, because its location close to Magdalena valley in Colombia and in the mountainous zone the behavior of the precipitation is heterogeneous and its spatial and temporal variation is so high, actually the IDEAM has 25 different raingauge stations inside the basin.

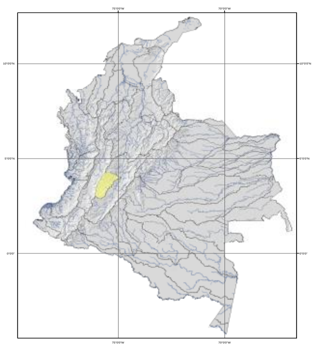

Figure 1. Saldaña River Basin Location.

The Saldaña River is one of the biggest river that reach the Magdalena River and its discharge in average is 318 m^3/sg, in dry year the discharge is 163 m3/sg. The quantity of water in normal conditions in the basin is 10.019 Mm^3, and in a dry year decrease to 5.129Mm^3. Because the conditions in the basin it presents a high retention capacity (0.75-0.85) in high percentage of its area and moderate (0.65-0.75) one in the zone close to the zone where the Saldaña river reach the Magdalena river in the low part of the basin. The index show the regulation capacity in the basin given the presence of big areas of forest, especially in zones with high altitude in the south of the basin.

3. METHODOLOGY

There are available data from General Circulation Models (GCM) as ECMWF, NCEP, etc, the use of Numerical Weather Prediction(NWP) for GCM can allow to the professionals related with the hydrological forecasts to know the behavior of the river levels using the precipitation forecasts as input in the hydrological models to create a series of different results that can be evaluated for them, with this purpose in the research are used the products from the ECMWF in a first domain with a resolution close to 16 kilometers in its deterministic forecast, and a downscaling with the use of the WRF model to a second domain to improve the resolution of the forecast in a regional level.
The information generated with the process is used as input in a precipitation raster with a resolution of 5 kilometers. This allows to the hydrological model improve the spatial resolution of the precipitation in the basin, which can improve the performance of the hydrological models. The forecast will be done with the use of time lagged ensemble forecasts, composed of forecasts with different initial times.

We used two different hydrological models to evaluate the performance of the methodology, using the same inputs, hydrometeorological, land use, soils and topographical information for both models in the study area. The calibration of the hydrological models was done using the information from discharge stations located in the basin.
In a first step the results from the QPF was compared with the observed rainfall that was measured with the use of raingauges operated by IDEAM in the Saldaña Basin. The validation of the process is madding according with the discharge observed values in the hydrological stations inside the basin.

3.1. Precipitation forecast.

The precipitation forecasts was taken from Global Forecasts from European Centre for Medium Range Weather Forecast (ECMWF), with information 4 times each day. Using this information was realized a Dynamical Downscaling by the Weather Research and Forecasting Model (WRF), using different initial days and 15 days (360 hours) of forecast, it means 15 days ahead that can be used as forecasts in each case.
To run the WRF model was used data from ECMWF THORPEX Integrated Grand Global Ensemble (TIGGE-ECMWF). TIGGE is a main component of THORPEX and it is part of WMO Weather Research Program. The data obtained for ECMWF are available twice daily at 00 UTC and 12UTC, the output time could be from 0 to 360 hours (0 to 15 days) using 6 hours intervals. ECMWF Global 15 day forecast is 16 km resolution.
For this analysis the boundary and initial conditions were extracted using information from ECMWF combined with data from ERA-Interim for the pressure levels, it is important to note that this procedure was done given that Colombia as tropical country has a higher troposphere level and it is necessary the use of additional information to complement the pressure levels, ECMWF forecast data in TIGGE includes vertical levels from surface to 200 hPa we borrowed 100 and 50 hPa layer data from ERA Interim (reanalysis data) to complement upper tropospheric layers; the global model has 721 cells in x sense (longitude) from 0 to 360 degrees, and 361 cells in y sense (latitude) from -90 to 90 degrees, the cell size for the model is 0.5°, and the initial data cover all the world.
The forecast for the first domain was extracted in a domain with cell size of 20km (0.17°) and the domain in longitude goes from 272.557 degrees to 299.433 degrees with 150 cells and in latitude from -8.90277degrees to 17.6615 degrees with the same number of cells, the second domain goes in longitude from 283.316 degrees to 288.823 degrees in 112 cells and in latitude from 1.82014 degrees to 6.8118 degrees with 112 cells, the size of each cell is 5km (0.044°).
The WRF process was developed starting from day March 23rd as initial day and until April 6th, running the model for each initial day to have the results of the precipitation forecasts for April 7th to April 12th.
The configuration of the WRF model in microphysics was WRF Single-Moments 3-class scheme: A simple, efficient scheme with ice and snow process suitable for mesoscale grid sizes; and the cumulus parametrization used was Kain-Fritsch scheme. The Kain-Fritsch scheme is widely used in weather forecasting centers in the world. Japan Meteorological Agency (JMA) tuned this scheme for Japanese climate (Narita, 2008). We found this tuned scheme works better in Colombia given the climate conditions, then we used the tuned Kain-Fritsch scheme in this study.
Thermal diffusion scheme is used for land surface process, YSU scheme is used for planetary boundary layer physics, the integration time step is from 30 to 180 second in outer domain, and 7.5 to 45 seconds in inner domain.

3.2. Hydrological Model

Rainfall Runoff Inundation (RRI) is a model with the capabilities to simulate rainfall-runoff and inundation process simultaneously. The model was develop in fortran code and to solve the different equations uses two kinds of approximation using 1d kinematic wave in the river channel and solving 2d diffusion wave in the slopes of the basin. The equations that are solved in the model are the mass balance equation and momentum equation for gradually varied unsteady flow (Sayama, et al., 2012).

In RRI the process files from the downscaling, are used as input and simulated as virtual station with rainfall information in each one of the cells in the domain of the basin, this process assures that all the information generated by the forecast model is used in the hydrological model, in this case the cell size for the precipitation input is the same from the output of the meteorological model: 5 km. Using all the information means that in the moment that the user runs the rainThiessen.exe tool to generate the precipitation files from the model, it assumes the presence of one raingauge station in each one of the cells, making the Thiessen polygons wide dense and increasing in this way the resolution of the precipitation. In the Saldaña basin the difference is from 26 different raingauge stations that are used in normal run we used 319 different cells in the basin.

4. RESULTS AND DISCUSSION

The RRI model was running using the best performance find in the calibration process, the model runs with precipitation information from raingauge stations 30 days before the first forecasted day, to obtain initial conditions for the RRI model. After that was used the precipitation forecasted on each one of the different initial days and processed to generate the rain.dat file on each case, to use it as input in the RRI model with the previous initial conditions and the new rain file. The process was realized for each forecast, it means 18 different times, once for each initial day starting on 23rd March to 9th April (see Table 1).

Table 1. Parameters used in the RRI model.

Soil type	Manning river	Manning slope	Soil depth	Gamma	Ksv	Faif
1	0.03	0.3	0.4	0.653	0.606 e -7	0.1101
2	0.03	0.4	0.3	0.463	0.367 e -7	0.0889
3	0.03	0.3	0.4	0.398	8.33 e -7	0.2185
4	0.03	0.4	0.3	0.653	1.67 e -7	0.3163

In the RRI case the model was ran using real information 30 days before the initial day forecasted, with the purpose to generate initial conditions, after that the results for each one of the forecasts were used as input in the hydrological model, as was explained before the process included the generation of each one of the raster files and the extraction for the Saldaña river basin.

The figure 3 shows the boxplots for each one of the forecast days starting with one simulation in 24th March to 10th April in this case, with 13 simulations.

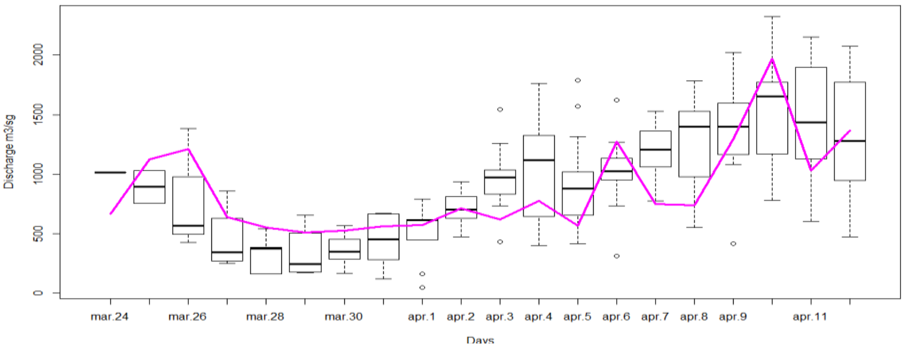

Figure 2. Results RRI model.

The use of simple average can improve the forecast results widely, using the lagged forecasts correlation coefficient values are over 0.7 and even in some of the lagged forecasts can reach values over 0.8, that show a strong relation between the observed and modeled discharges, in the same way the calculated values for the RMSE are under 300 m^3/sg, smaller than the calculated for each one of the forecast in an individual way. The RMSE results showed values over 300 m^3/sg and in some cases close to 700 m^3/sg, and increase its value when the forecasts were closer to 9th April, these analysis was made for the individual forecast.

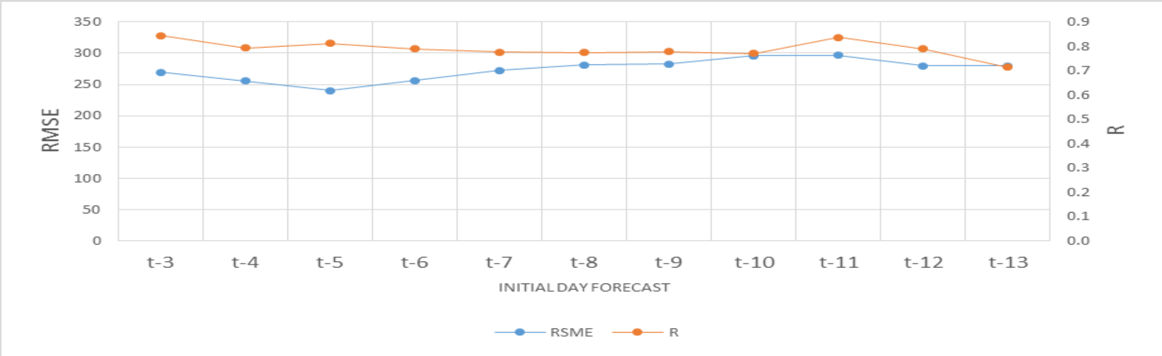

Figure 3. Root Mean Square Error and Correlation Coefficient as function of the average of different number of previous forecasts.

The Threshold Exceedance Diagram or persistence diagram, consists in a series of forecasts presented in rows and the lead times are in the columns, these make a matrix where a sequence of forecasts is showed in the rows. This diagram can give to the forecasters an idea of the forecast persistence and can help to support the decision for flood management. (Mainardi et al., 2014).

The Figure 7.10 shows the boxplot including all the forecasts for each one of the forecasted days and the different warning levels established for the IDEAM in that station, the levels were created according with the magnitude of the discharge and the affectations that can cause downstream for this point. However the visualization of the results has a better representation and an easy lecture using the exceedance table that is shown in the Table 15, but using the days with the maximum number of forecast 13. The hydrographs as results from the forecasts are not a decision element by itself, however the inclusion of decision-making elements can turn it in a flood forecast: is the discharge going to exceed a critical threshold or not? (J. Thielen, 2009).

Table 2. Threshold Exceedance Table Piedras Hydrological Station, from 5th April to 10th April.

	FORECASTED DAY					
INITIAL DAY	**5-Apr**	**6-Apr**	**7-Apr**	**8-Apr**	**9-Apr**	**10-Apr**
23-Mar						
24-Mar						
25-Mar						
26-Mar						
27-Mar						
28-Mar						
29-Mar						
30-Mar						
31-Mar						
1-Apr						
2-Apr						
3-Apr						
4-Apr						
5-Apr						
6-Apr						
7-Apr						
8-Apr						
9-Apr						

5. CONCLUSIONS AND RECOMMENDATIONS.

This work evidences how the use of NWP can improve the lead time for the issuance of the hydrological forecasts in Saldaña river basin, and the quantitative forecast could be improved with the use of the methodology of "poor-man's" ensemble that uses the results for each forecast and calculate a simple average without weighting. The RMSE decrease with the use of average in comparison with the individual forecast, the RMSE average for all the individual forecasts was 450 m^3/sg, and is reducing to 250 m^3/sg with the use of the simple ensemble. The correlation coefficient for both set of data, forecasts for each initial day and the average of different number of previous forecasts show that in the first case its value just is greater than 0.7 in 9th April, however in the second case all the sets are close or over 0.8. The results obtained in this study demonstrate that the use of simple ensemble could increase the forecasted discharge accuracy in the Saldaña River. The work demonstrate the skills for extend the lead time of precipitation and subsequent floods, with the use of Numerical Weather Prediction with hydrological models.

Using the procedure was noting the possible occurrence of an extreme event 8 days before, and the event was showed in a persistence way, this could indicate the imminence of it. The advance time could allow to the forecasters give a timely warning to the regional and local authorities in charge of the disasters attention, with the warning issuance they could make a better following of the river conditions and prevent to the population located downstream of the monitoring point, this could avoid the occurrence of losses and damages in their goods or even in themselves.

The use of this methodology can be applied and evaluated in other basins in the country that have special interest for the forecasters and the institutions in Colombia, given the relatively low computational cost for the process, it could be used as operational tool that complement the existents in the Forecast and Warnings Office in IDEAM.

The use of threshold exceedance diagram is an easy way to see the forecast evolution in the time and to evaluate the persistence of the different warnings that can happened during the forecasted time, this tool could be implemented as a complementary tool in the daily work in the Forecasts and Warnings Office in the IDEAM. Include elements in the forecasted hydrographs as the warning levels bring a better view of the situation context and the evolution in time for the forecasts and for the real data.

ACKNOWLEDGEMENTS

I would like to express my sincere gratitude to the supervisors Tomoki USHIYAMA and Maksym GUSYEV for their continuous guidance, valuable suggestion and instruction during the development of this work.

REFERENCES

Cuo, L., Pagano, T.C., Wang, Q.J., 2011. Journal of Hydrometeorology, Volume 12.

H.L. Cloke, F. Pappenberger. (2009). Journal of Hydrology, Volume 375.

Jens Bartholmes and Ezio Todini. (2009).Hydrology & Earth System Sciences, Volume 13. J. Thielen, L. Calvetti and A. José Pereira. (2014).Advances in Meteorology, Volume 2014.

M. Gusyev, J. Magome and K. Takeuchi. (2015).The Block-wise TOP (BTOP) Model with Supplementary Tools, User Manual. Technical Note PWRI.

Narita, M. (2008) Improvement of Kain-Fritsch scheme and adjustment of parameters, Numerical Weather Prediction division report, Japan Meteorological Agency (Japanese)

T. Sayama. (2015). International Center for Hazard and Risk Management (ICHARM).

T. Ushiyama, T. Sayama, Y. Tatebe, S. Fujioka and K. Fukami. (2014). Journal of Hydrometeorology.