VALIDATION OF A NOWCASTING TECHNIQUE FROM A HYDROLOGICAL PERSPECTIVE

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Abstract

Nowcasting precipitation is a key point to anticipate risks in flood warning systems. In this environment, weather radars are very useful because of the high resolution of their measurements both in time and space.

The aim of this study is to assess the performance of a recently proposed nowcasting technique (SPROG) from a hydrological point of view. This technique is based on the advection of radar precipitation fields and its main point is that the forecasted fields get smoothed as the forecasting time increases, to filter out the smallest scales of the field when they become unpredictable.

The evaluation of the forecasted precipitation fields is done in two different ways: a) comparing them against the actually measured precipitation fields and b) according to the concept of "hydrological validation", comparing the hydrographs calculated by a distributed rainfall-runoff model simulating operational conditions (using the forecasted precipitation fields) against the hydrographs calculated by the model with the entire series of radar measurements. This part of the study has been carried out in the framework of the Besos basin flood forecasting system.

Key Words: **rainfall nowcasting, SPROG, hydrological validation, flood forecasting**

Introduction

Floods are the most important natural hazard in Mediterranean areas and anticipation is very important for flood forecasting and warning. In this environment, it has been shown that weather radar is a very useful tool, even if a dense network of raingages exists, thanks to the good temporal and spatial resolutions of radar data able to display the structure of precipitation field.

It is particularly interesting the use of radar data in combination with a distributed rainfall-runoff model to forecast floods in medium-sized basins (50-1000 km^2), where a the density of raingauges uses to be poor (below 1 gage/km^2). In this framework, the use of a short-time forecasting technique based on radar data may be very useful to extend the time with which flood warnings are given.

The main objective is to evaluate the usefulness of a nowcasting technique based on the extrapolation of radar fields for its hydrological implementation in an operative framework.

The performance of the chosen technique (based on SPROG -Seed, 2003-) is evaluated from a hydrological point of view. This is done from two different perspectives: in terms of rainfall, comparing forecasted against actually observed precipitation fields; and in flow terms, from the point of view of the hydrographs forecasted by a rainfall-runoff model.

A brief review on the nowcasting technique

The analysed nowcasting technique (although there are slight implementation differences with the original, it will be called SPROG, hereafter) is an extrapolation technique (see Wilson et al., 1998), based on advection of recent radar scans (Fig. 1 shows a general scheme).

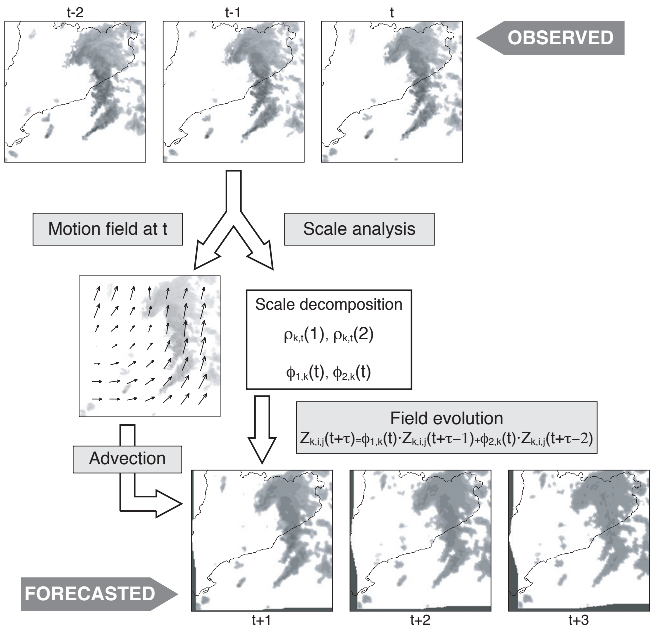

Fig. 1. Scheme of the nowcasting technique. From recently measured radar fields, the motion field is estimated and an AR(2) model is fitted to the temporal evolution of fields representing spatial variability in different scale ranges. Finally, the forecast is done by means of these AR(2) models, as they are advected according to the previously estimated motion field.

This technique uses a TREC algorithm (Rinehart and Garvey, 1978) to estimate the motion field of precipitation (in this case, with a resolution of 32 km) to which continuity is imposed (in the way proposed by Li and Schmid, 1995). This field is densified to the pixel resolution by means of linear interpolation. Forecasting consists on extrapolation of last-measured radar scan according to this motion field.

However, SPROG also takes into account some scale filtering. It has been shown (Germann and Zawadzki, 2002) that small-scale patterns of the precipitation fields decorrelate much faster than those that are bigger. If small scales are filtered as the lead time increases, forecasts are better (this was already pointed out by Bellon and Zawadzki, 1994, who filtered small scales out by means of spatial averaging).

SPROG proposes a more sophisticated way of filtering small scales: the idea is that reflectivity fields can be decomposed into a set of n different fields, Y_k (see (1)), representing the variability of precipitation in different ranges of scales ($2^k \div 2^{k+1}$ km, $k \in 1,\dots,n$). This decomposition is done by means of a band-pass filter in the spectral domain using the Fast Fourier Transform.

$$dBZ_{i,j} = \sum_{k=1}^{n} Y_{i,j,k} \qquad (1)$$

Fields Y_k are normalized (2) by convenience and it has been found that an AR(2) model can well-reproduce temporal evolution of X_k (3), where the coefficients of the model $\phi_{1,k}$, $\phi_{2,k}$ are derived from Yule and Walker equations.

$$X_{i,j,k} = \frac{Y_{i,j,k} - \mu_k}{\sigma_k} \quad (2)$$

$$X_{i,j,k}(t) = \phi_{1,k}(t) \cdot X_{i,j,k}(t-1) + \phi_{2,k}(t) \cdot X_{i,j,k}(t-2) + Z(t) \quad (3)$$

SPROG does the forecast in the Lagrangian domain (extrapolating the last measured radar scan according to the estimated motion field) and the evolution of $X_{i,j,k}(t+k)$ is forecasted according to the fitted model (3). Finally, forecasted fields $dBZ_{i,j}(t+k)$ are obtained as:

$$dBZ_{i,j}(t+k) = \sum_{k=1}^{n} \sigma_k(t) \cdot X_{i,j,k}(t+k) + \mu_k(t) \quad (4)$$

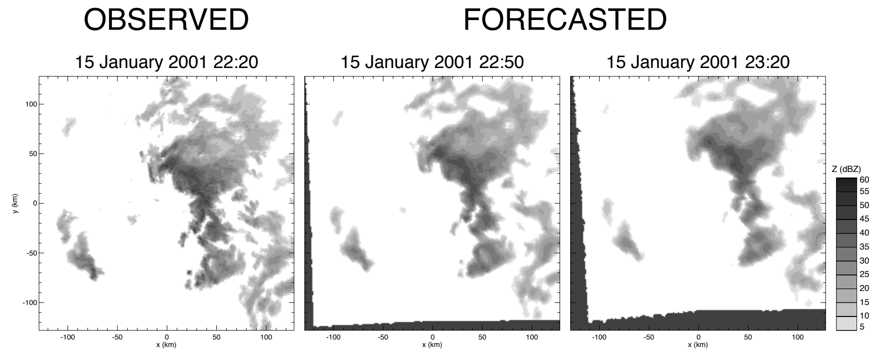

Fig. 2. Observed field at 22:20 UTC 15 January 2001 (left). This field is used to generate 30-minutes and 60-minutes forecasts for 22:50 and 23:20 UTC 15 January 2001.

As each scale *k* is modelled according to an AR(2) and $\phi_{1,k}$, $\phi_{2,k}$ are obtained from the auto-correlation coefficients, smallest scales (in general, poorly auto-correalted) tend to become filtered out as the forecasting time increases.

Validation

SPROG has been validated in the Barcelona area (NE Spain) using measurements from the INM (Spanish Meteorological Institute) Corbera C-band radar, with a resolution of 10 minutes and 1x1 km^2, covering an area of 256x256 km^2. Selected cases correspond both to convective and stratiform situations that produced significant rain/flow events in the Besos basin (1015 km^2). The effect of the domain size in the validation is also assessed analysing the results in different-sized areas (see Fig. 3).

This validation of the nowcasting technique has been done from 2 different perspectives:

- From the perspective of the **precipitation fields**, comparing forecasts against actually measured radar scans. This comparison is done in terms of the RMSE, expressed in $mm \cdot h^{-1}$. The conversion of reflectivity into rainfall-rate is done by means of a climatologic *Z-R* relationship (derived by Sempere-Torres et al., 1998).

- From the perspective of **forecasted hydrographs**. This is the concept of ***hydrological validation***: the goodness of a forecasting technique or a correction algorithm is evaluated in terms of the flows calculated by a rainfall-runoff model, compared against the hydrograph simulated by the model using a reference set of precipitation fields (see some examples in Sanchez-Diezma et al., 2001). In this study, forecasted hydrographs (generated using forecasted precipitation fields, reproducing operational conditions) are validated against hydrographs calculated with the entire series of radar fields (see Fig. 4).

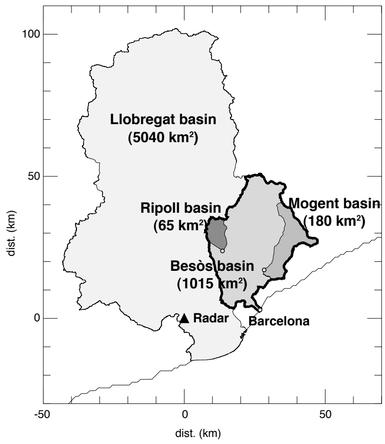

Fig. 3. Comparison of forecasted precipitation fields is done over 4 different-sized domains: Llobregat (5040 km^2), Besos (1015 km^2), Mogent (180 km^2) and Ripoll (65 km^2) basins. *Hydrological validation* is carried out over Besos, Mogent and Ripoll basins.

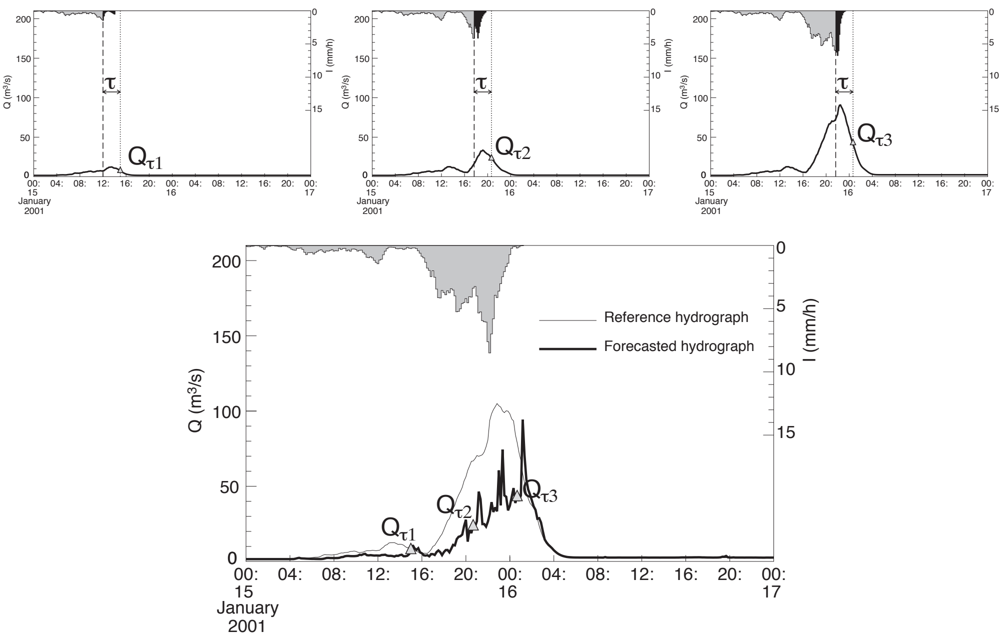

Fig. 4. The *forecasted hydrograph* for a forecasting time τ is generated with the flow estimates obtained all along the event by the model with an anticipation τ. Top: hydrographs simulating real-time conditions (dashed line indicates *present* time and triangles indicate flow forecasted with an anticipation τ, $Q_{\tau i}$). Bottom: hydrograph forecasted with an anticipation τ (thick line) compared against the hydrograph simulating the entire series of radar scans (thin line).

The rainfall-runoff model

Dichitop (see a complete description in Corral et al., 2001) is a grid-based model, able to take into account distributed precipitation fields (and, in particular, radar fields). This model needs the basin to be split in square hydrological cells (1x1 to 2x2 km^2), which allows the incorporation of radar information.

In each hydrological cell a lumped rainfall-runoff model is applied to generate the cell flow. Depending on the degree of urbanisation the chosen lumped model is TOPMODEL (Beven et al., 1995) in rural areas or the *Soil Conservation Service* loss function (Mockus, 1957) in urban areas.

The flow generated at each cell is routed in a linear process according to a Unit Hydrograph derived from the drainage system of the basin. This transfer function differentiates between hillslope path (where lamination is important) and river path (where the flow is channelled). Final hydrograph is obtained as the sum of all routed cell hydrographs.

This model is nowadays working in real-time in the Besos Flood Warning System.

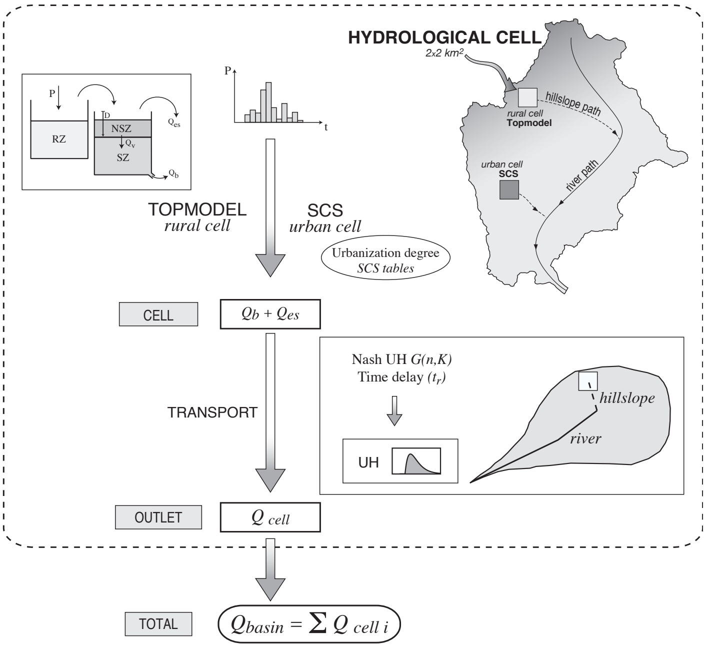

Fig. 5. Scheme of the rainfall-runoff model *Dichitop*. The basin is divided into square cells, where a lumped model (TOPMODEL or the SCS loss function) is applied to generate the cell hydrograph. These hydrographs are routed individually to the basin outlet to finally obtain the basin hydrograph.

Results

Fig. 6 shows the comparison between the forecasts obtained by SPROG against Eulerian persistence (that consists in keeping as forecast the last measured radar scan) and Lagrangian persistence (advection of last measured precipitation, without scale filtering) over the Llobregat basin (5040 km^2). In general, advecting last measured radar field produces better results than Eulerian persistence. Moreover, SPROG produces even better forecasts (specially for early forecasts) thanks to the ability of filtering small patterns of the precipitation field.

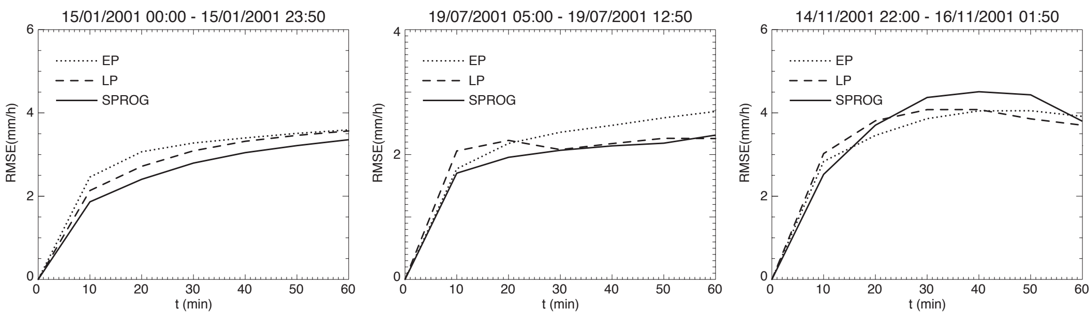

Fig. 6. RMSE over the Llobregat basin (in mm h^{-1}) vs the forecasting time for the three studied events for the three forecasting techniques: Eulerian persistence (EP, dotted line), Lagrangian persistence (LP, dashed line) and SPROG (continuous line).

In Fig. 7, a comparison of results obtained in smaller domains is shown. No important differences with the results of the Llobregat basin are observed: SPROG generates the best forecasts, again (at least, for early forecasts of less than 30 minutes).

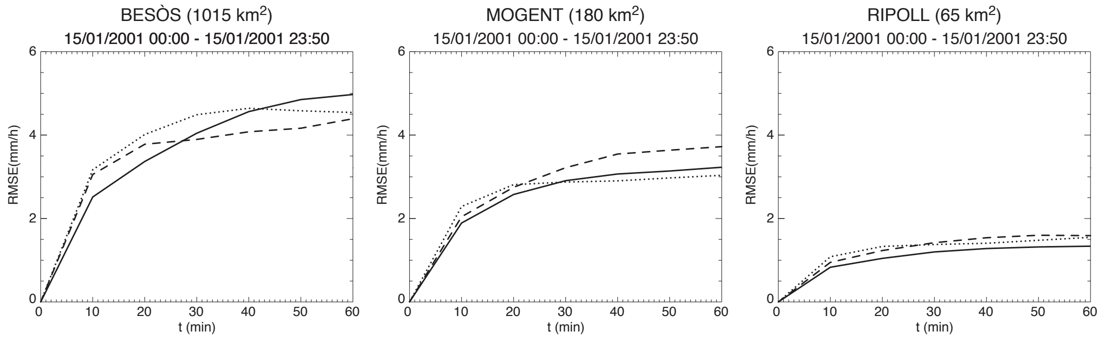

Fig. 7. RMSE (in mm h^{-1}) vs the forecasting time calculated in the Besos, Mogent and Ripoll basins (see Fig. 3) for the event of 15 January. Different lines correspond to Eulerian persistence (dotted line), Lagrangian persistence (dashed line) and SPROG (continuous line). Similar results have been obtained for the 2 other events.

Tables 1-3 show the results of hydrological validation of SPROG in terms of the simulated hydrographs (see an example in Fig. 8). These results are presented in terms of the anticipation time with which forecasted hydrographs (using different nowcasting techniques) have different values of the Nash' efficiency (Nash and Sutcliffe, 1970) when compared against the reference hydrograph.

Table 1. Forecasting time (τ_{ef}) for which hydrographs forecasted at the Besos basin (1015 km^2) have a Nash efficiency *ef*. Three columns for each τ_{ef} correspond to different methods of precipitation forecasting: SPROG (left), simple advection (centre) and without rainfall forecasting (right).

	$\tau_{0.95}$ (min)			$\tau_{0.90}$ (min)			$\tau_{0.75}$ (min)		
15/01/2001	110	100	70	140	130	80	170	170	105
19/07/2001	120	110	70	140	140	80	185	210	100
15/11/2001	60	60	60	75	75	70	100	100	90

From these tables it may be concluded that in general (15/01/2001 and 19/07/2001), both SPROG and simple advection forecasts are very similar in the sense that simulated hydrographs have almost the same quality. When these hydrographs are compared against the simulation made without any kind of precipitation forecast, the conclusion is that the introduction of this radar-based nowcasting techniques, sensibly improves the quality of simulated hydrographs and extends the anticipation time with which hydrographs are forecasted with enough quality.

Table 2. Same as Table 1, but for the Mogent basin (180 km2).

	$\tau_{0.95}$ (min)			$\tau_{0.90}$ (min)			$\tau_{0.75}$ (min)		
15/01/2001	75	80	40	100	110	50	140	170	80
19/07/2001	110	80	45	130	120	60	175	170	80
15/11/2001	25	25	25	40	40	35	75	90	60

Table 3. Same as Table 1, but for the Ripoll basin (65 km²).

	$\tau_{0.95}$ (min)			$\tau_{0.90}$ (min)			$\tau_{0.75}$ (min)		
15/01/2001	60	55	45	70	70	55	90	90	65
19/07/2001	70	70	40	80	90	50	100	185	65
15/11/2001	55	55	50	60	60	55	70	70	65

In the Besos basin, the introduction of one of the two tested nowcasting techniques allows the anticipation (which may be estimated by $\tau_{0.95}$ or $\tau_{0.90}$) to be extended in around 40-50 minutes (except for the event of 15/11/2001). In general, smaller basins are supposed to have smaller response times and, therefore, anticipation times use to be smaller. This is what happens with Mogent and Ripoll basins compared to Besos. In these other two basins, the introduction of a nowcasting technique extends anticipation in around 40-50 minutes (Mogent) and in 15-25 minutes (Ripoll).

Poor results obtained in all cases for the event of 15 November 2001 are due to the difficulties in this situation for the forecast of precipitation. The sudden generation and development of some important convective cells over or very close to the basin (enhanced by orographic effects) made the techniques fail in the forecasts, obtaining almost the same results as without precipitation forecasting.

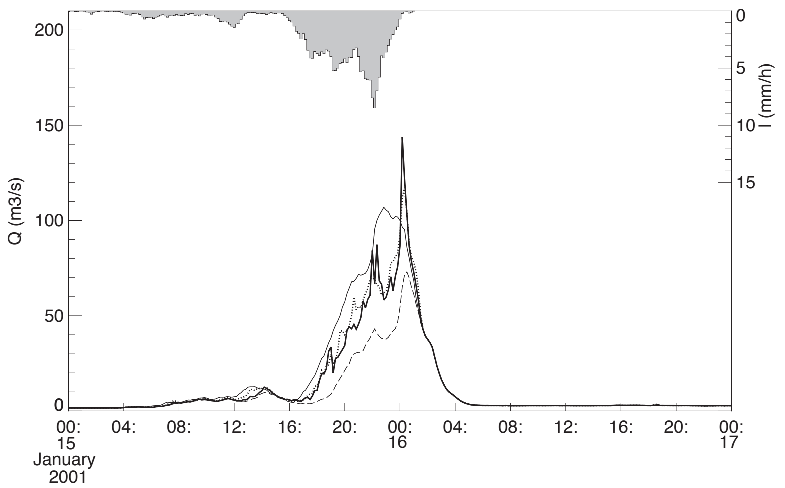

Fig. 8. 2h-forecasted hydrographs (using SPROG fields –continuous thick line-, using advected radar fields -dotted line- and without rainfall forecasts –dashed line-) simulated by Dichitop in the Besos basin for the event of 15 January 2001. Reference hydrograph is plotted in continuous thin line. On top (grey-shaded): mean areal rainfall over the basin.

Conclusion

The inclusion of a nowcasting technique based on advection of radar fields to forecast floods with a distributed rainfall-runoff model in medium-sized basins allows to sensibly extend the anticipation with which hydrographs are forecasted.

In the case of the Besos basin (1015 km²), the use of these advection techniques produced an increase of the anticipation of up to 40-50 minutes, while in smaller basins, this anticipation is extended in up to 40-50 minutes in the Mogent basin (180 km²) and in around 20 minutes in the Ripoll (65 km²) basin.

However, although precipitation fields forecasted by SPROG seem to be better in terms of the RMSE than without scale filtering, when they are used as input of a distributed rainfall-runoff, forecasted hydrographs are very similar to those simulated without scale filtering in forecasted precipitation fields.

This study will be extended for more events affecting the same area and future work will focus on the analysis of the sensitivity of forecasted hydrographs with forecasted mean areal rainfall over the basin or estimated motion field of precipitation.

Acknowledgements

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