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Modelization of the uncertainty associated to radar-based nowcasting techniques. Impact in flow simulation

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1 Introduction

Radar-based advection techniques are frequently used for short range rainfall forecasting. In particular, in the framework of real-time flow forecasting some authors (e.g. Berenguer et al. 2005) have shown the interest of coupling radar advection techniques with distributed rainfall-runoff models.

However, these techniques are affected by two main sources of uncertainty: due to the variation of precipitation motion with respect to the motion field used for the advection and due to growth and decay of rainfall intensity, which is not taken into account by these techniques (Germann and Zawadzki 2006).

In order to deal with this uncertainty, we propose a probabilistic approach for rainfall nowcasting based on the advection of radar fields. In particular, the developed technique is based on characterizing precipitation fields from a statistical point of view to generate an ensemble of "possible future scenarios", compatible with most recent observations. Therefore, the output of the proposed scheme is now a probability distribution function at each point and for each forecasting time, instead of an only deterministic forecast (that is the usual output of extrapolation techniques).

The main purpose of the presented work is to illustrate the uncertainty modeled with the proposed technique and to assess the impact of this uncertainty into the flow simulations obtained with a distributed rainfall-runoff model.

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2 The rainfall forecasting technique

The forecasting technique used in this study is based on the advection of the last observed radar map according to a motion field estimated from most recent radar observations using a TREC technique (see Rinehart and Garvey 1978) to which continuity is imposed (as proposed by Li et al. 1995).

2.1 Modelization of precipitation

The statistical characterization of reflectivity fields has been carried out using the concepts of the "String of Beads" model (Pegram and Clothier 2001).

This model is based in two main hypotheses: (a) reflectivity fields are Gaussian distributed with μ-mean and σ-standard deviation (N(μ, σ)); (b) their Fourier spectrum may be well characterized by a power-law of slope β:

$$P(w) = c \cdot w^{-\beta} \qquad (1)$$

where w is the wave number.

On the other hand, the temporal evolution of the reflectivity fields in the Lagrangian domain has been assumed to be well-modeled by a lag-1 auto-regressive model (AR(1)):

$$X(t) = \phi_1 \cdot X(t - \Delta t) + Z(t) \qquad (2)$$

where X(t) is the reflectivity field at t, ϕ_1 is the model coefficient (which may be estimated with the Yule-Walker equations), Δt is the time step and $Z(t)$ is a white noise process.

Therefore, in this technique, reflectivity fields are characterized by their motion field, mean and variance ($\mu(t)$, $\sigma(t)$), and parameters $\beta(t)$ and $\phi_1(t)$.

2.2 Generation of an ensemble member

At a certain time t, a member of the forecast ensemble (i.e. a series of n forecasts for times from $(t+\Delta t)$ to $(t+n\cdot\Delta t)$ -see an example in Fig. 1-), is generated from the most recently measured reflectivity field at t, verifying the ACF imposed by the AR(1) model ($\rho(\tau)=\phi_1^{\tau}$, where τ is the time lag) and assuming constant $\mu(t)$, $\sigma(t)$ and $\beta(t)$ along the forecast.

It is worth noting that the differences between different members of the ensemble are due to the randomness introduced by fields $Z(t)$ (see equation 2).

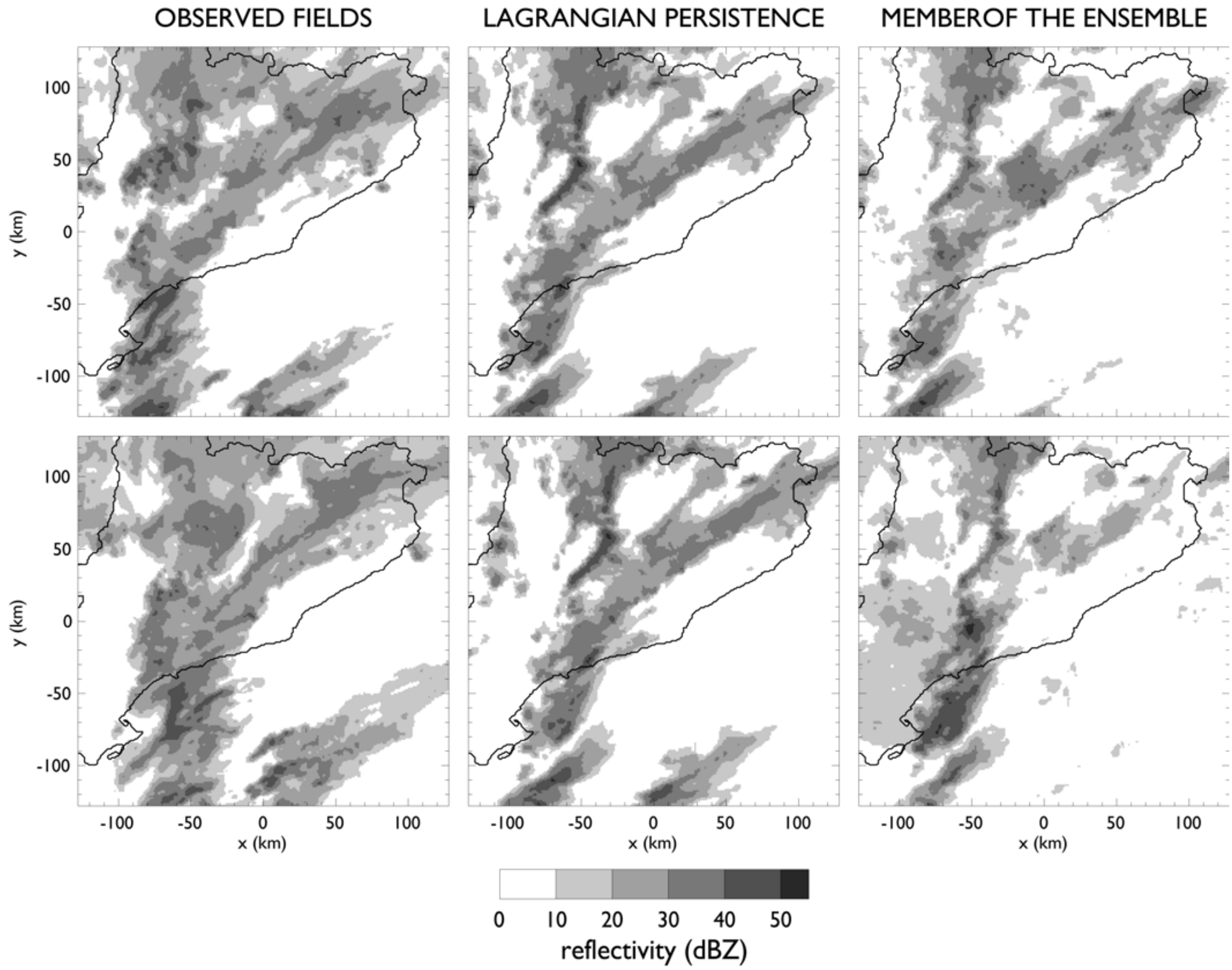

Fig. 1. Observed (left column) and forecasted reflectivity fields obtained by Lagrangian persistence (centre column) and using the described probabilistic technique (only one member of the ensemble is presented -right column-), corresponding to a 30-minute forecasting time (top row) and to a 60-minute forecasting time (bottom row).

3 Case study

The performance of the technique is illustrated for a case study occurred in 19 July 2001 in the vicinity of Barcelona (Spain). The study has been carried out reproducing operational conditions, both in terms of precipitation forecasts and from the perspective of the flows forecasted using a distributed rainfall-runoff model.

3.1 Radar data

Precipitation data were measured using the INM Corbera de Llobregat C-band radar, located close to Barcelona (see Fig. 2).

These data were processed to mitigate mountain screening effects (with the algorithm of Delrieu and Creutin 1995) and to remove clutter contamination (see Sánchez-Diezma et al. 2001; Berenguer et al. 2006).

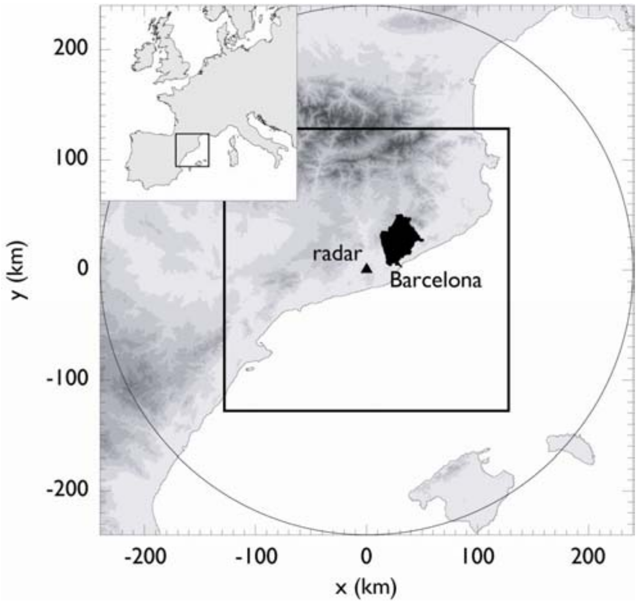

Fig. 2. Studied area. The circumference shows the radar domain and the black thick 256x256 km^2 square is the domain for which precipitation forecasts are generated. The black triangle indicates the radar location and the black shaded area corresponds to the Besòs basin (1015 km^2).

3.2 The rainfall-runoff model

DiCHiTop (see a more complete description in Corral et al. 2001) is a grid-based rainfall-runoff model able to use distributed rainfall fields (measured with a radar, for example).

In order to implement the model, the basin has to be split into square hydrological cells matching the radar information (in this case, with a resolution of 2x2 km^2). At this cell scale, a lumped model is applied to transform precipitation inputs into flow. Depending on the degree of urbanization of each cell, the chosen lumped model is TOPMODEL or the SCS loss function (for rural and urban areas, respectively).

The runoff generated at each cell is routed to the outlet of the basin according to a transfer function derived from the main drainage system. Finally, the hydrograph at the basin outlet is calculated as the linear combination of all transferred cell hydrographs.

Nowadays, this model is running in real-time in the control centre of the Catalan Water Agency for real-time flood warning in the framework of the Besòs basin (1015 km^2), which is the basin where the hydrological validation presented in this study has been carried out.

3.3 Analysis of rainfall forecasts

In this section the performance of the presented probabilistic technique is analyzed from the point of view of its ability to forecast precipitation.

At each time step, an ensemble of 100 forecasts has been generated. Fig. 3 shows the evolution of the mean areal rainfall over the Besòs basin forecasted with a lead time of 30 minutes. It can be observed that the mean hyetograph (black thick line in the figure) is approximately unbiased. However, although the confidence intervals are relatively narrow, the bias at some individual time steps is significant.

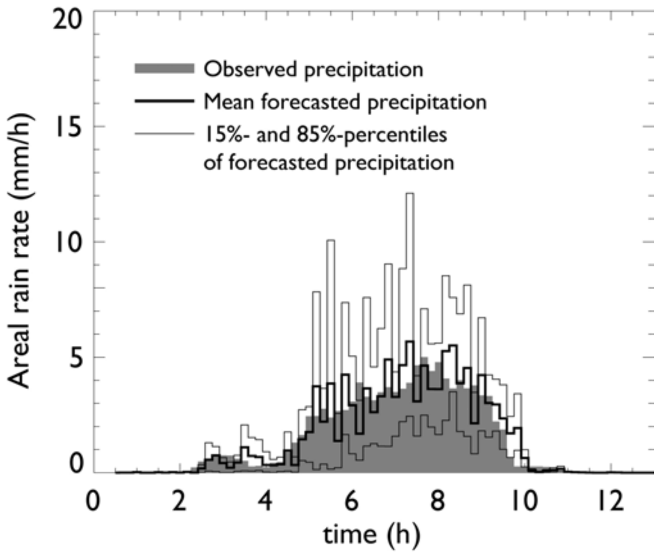

Fig. 3. 30-minute forecasts of the mean areal rainfall over the Besòs basin with the presented probabilistic technique (mean forecasts are plotted with thick black line and thin lines show the 15%- and 85% percentiles). Grey shaded area corresponds to the mean areal rainfall over the basin estimated from radar measurements.

3.4 Uncertainty in flow forecasts

The ensemble of rainfall forecasts has also implemented in the framework of flow forecasting.

This has been done simulating real-time conditions. At each time step, rainfall inputs for the model have been constructed with the radar observations available at the simulation time and the ensemble of 2-hour rainfall forecasts.

Fig. 4 shows the mean hydrograph simulated with the model at the Besòs basin at a certain time, compared against the reference hydrograph (simulated with the model using the whole series of radar observations). Although the uncertainty in forecasted flows is relatively high at this simulation time, the quality of forecasted mean flows can be considered as satisfactory.

On the other hand, Fig. 5 shows the flows forecasted with an anticipation of 3 hours all along the event. In this case we can see the evolution of the quality of 3-hours flow forecasts. It can be appreciated that mean forecasts are quite close to the reference hydrograph (it has to be noted that the *lag time* of the Besòs basin is around 90-120 minutes).

In the figure we can also analyze the evolution of the uncertainty in flow forecasts along the event. Again in this case, at some time steps it is relatively high, especially at the end of the event.

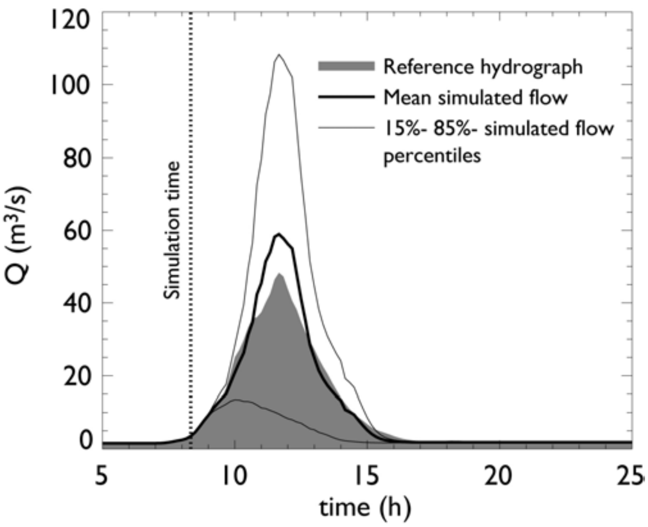

Fig. 4. Simulation of real-time implementation of the presented probabilistic forecasting scheme for flow forecasting. Thick black line is the mean hydrograph simulated at a certain time (indicated with dotted line) and thin black lines are the 15%- and 85%-precentiles of simulated flows. Grey shaded area corresponds to the reference hydrograph (obtained using the entire series of radar fields).

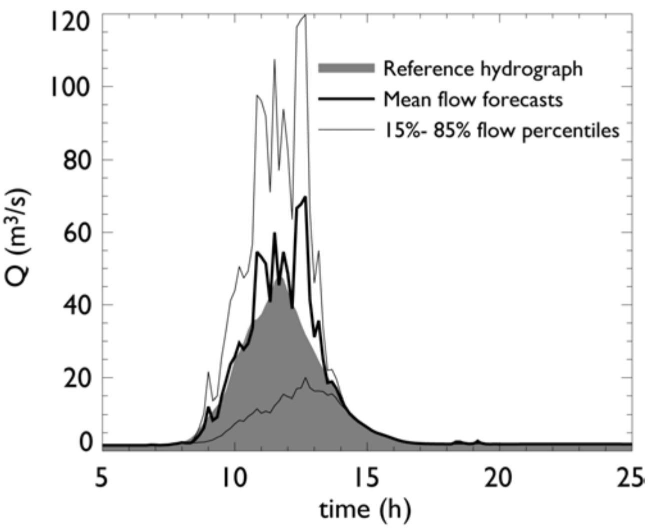

Fig. 5. Flow forecasts obtained with an anticipation of 3 hours (the thick black line shows the mean forecast and the thin black lines the 15%- and 85%-percentiles). Grey shaded area corresponds to the reference hydrograph (obtained using the entire series of radar fields).

4 Conclusions

We have presented the first results obtained with a probabilistic rainfall nowcasting technique both in terms of rainfall and flow forecasts.

This probabilistic approach would allow us to quantify the uncertainty due to the forecasting technique and how this uncertainty is propagated through a rainfall-runoff model, which may be helpful to quantify the reliability of flow forecasts in the framework of real-time flood warning.

Results show that the mean areal rainfall forecasts over the Besòs basin are sometimes biased. However, mean flow forecasts are, in general, satisfactory, though sometimes affected by significant uncertainty.

Some additional analyses have to be carried out in future work. It is of particular interest the analysis of the effect of keeping the parameters used for rainfall modeling (see Section 2) constant along the forecast. On the other hand, it is also necessary to compare the uncertainty in the rainfall forecasts obtained with the proposed technique against the real uncertainty inherent in the forecasts obtained by Lagrangian persistence.

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