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RADAR MEASUREMENT OF RAINFALL IN REAL TIME AND OBJECTIVE CONTROL OF THE ADJUSTMENT BY RAIN GAGE DATA

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This paper presents a scheme for a real time utilisation of the radar measurement of rainfall in urban hydrology, with an objective control of the adjustment by rain gage data including assessment of uncertainties about gage measurements. This scheme is developed in an operational way by the Nancy District Metropolitan Authority.

Introduction

For many years, the Nancy District Metropolitan Authority has a dynamic policy for the management of his urban sewage system. Facing flooding problem, significant infrastructures have been built and an extensive measurement network has been installed. For the measurement of rainfall, a 23 gage network has been implanted and, at the present time, over 50% of data collected are transmitted in real time to a central station of supervision. These realisations have permitted to resolve the problems of flooding. The new European waste water treatment Directive of May 91 now requires that the local authorities find ways of controlling the pollution of their rainwaters. For that, it is necessary to modify the current management of the urban sewage system in order to reduce the impact of the rainwater pollution on the natural environment. These modifications require an improvement of the knowledge of rainfall.

The weather radar represents a crucial contribution with its spatial measurement of the rain and its short-range capacity to anticipate the evolution of the rainfall. The Nancy District Metropolitan Authority decided to add a real time radar receiving system to the information provide by its gage network. This system receives images every 5 minutes from the local radar of Météo-France located near Nancy (30 km) and for an area per pixel equal to 1x1km.

The radar data on the Nancy metropolitan area and the gage measurements of rainfall are validated by comparison in real time. This comparison between different sources of data from a same phenomenon and for different spatial representativeness is difficult, especially in real time and for small rainfall intensities.

There are two way of making these data more coherent :

- integration over time, the time interval must be short to maintain a capacity of action in real time, for the management of an urban sewage system for example
- integration over space, over the area of an hydrological basin for example.

1 - Scheme of the comparison

1.1 Principle

An objective method of comparison must allow taking into account part of the uncertainties about rain gage measurements and the shifts in time between the radar and the rain gage measurements.

The proposed scheme compares areal rainfall values estimated from radar and gage data. The areal rainfall value estimated from the gage measurement (GAR) are not an absolute reference but a value with a confidence interval. This confidence interval allows to determine if the discrepancy between the radar and the rain gage measurement is significant. The area is selected in order that the radar samples cover the rain gage network to the best.

1.2 Estimation of the areal rainfalls

The areal rainfalls are estimated from the radar measurements by the average values (in mm/h) of all radar samples over the selected area. For the time step t the radar areal rainfall is RAR(t).

The GAR(t) values and the confidence intervals are estimated according to a geostatistical approach [1]. This approach uses a model of climatological variogram $\gamma(h)$ fitted to historical measurements of the rain gage network, for time step of 5 minutes. This model of variogram is assume to be identical for all the rainfall fields. $\gamma(h)$ describes the variance between the values of any two points of a rainfall field R(x) separated by the distance h :

(1) $$\gamma(h)\sigma g^2 = \mathrm{Var}\left[R(x+h) - R(x)\right]/2$$

where σg^2 is the spatial variance of the rainfall field.

For the time step t, the value of GAR(t) is estimated as the weighted average of the measurements G(t) of the n rain gages inside the area :

(2) $$GAR(t) = \sum_{i=1}^{n} \lambda i . Gi(t)$$ λi = weight of the measurement Gi of the gage i

1.3 Estimation of the confidence intervals by kriging :

The use of the spatial kriging to find the set of weights λi has the advantage of estimating an unbiased value of the true areal rainfall AR(t) :

(3) $$E[GAR(t)]=E[AR(t)]$$

and providing an estimation of the quality of the interpolation. If the variance of the errors of estimation of the GAR(t) value is :

(4) $$\sigma e^2(t)=VAR[GAR(t)-AR(t)]$$

from the model of variogram, and subject to the respect of the hypothesis of stationarity usually used in geostatistic, an estimator of $\sigma e^2(t)$ is [1]:

(5) $$\sigma e^2(t) = \left[-\sum_{i=1}^{n}\sum_{j=1}^{n} \lambda i \lambda j \gamma(ij) + 2\sum_{i=1}^{n} \lambda i \gamma(is) - \gamma(ss) \right] \sigma g^2(t)$$ with $\sigma g^2(t)=VAR[G(t)]$

where

$\gamma(ij)=\gamma(hij)$	is the value of $\gamma(h)$ for the distance hij separating two rain gages i and j
$\gamma(is)=1/S \int_s \gamma\,(hix)dx$	is the mean value of $\gamma(h)$ between the gage i and a point x describing the area of surface S
$\gamma(ss)=1/S^2 \iint_s \gamma\,(hxx')dxdx'$	is the mean value of $\gamma(h)$ between two points x and x' independently describing the area S

$\sigma e^2(t)$ allows to define a confidence interval for the GAR(t) value representing the errors of rain gage measurements and the uncertainty of the spatial interpolation. For example, the 80% confidence interval is :

(6) $[GAR(t) \pm 1.28\ \sigma e(t)]$

1.4 Validity of the confidence intervals :

The validity of the model of variogram used can be verified by cross validation, interpolating the value R*(x) of the rainfall field at the point x of each gage position from the measurements of the other gages (the measurement of the interpolated gage excepted). For many realizations of rainfall field, the distribution of the errors of estimation $[R^*(x)-R(x)]/\sigma g^2(t)$, known in this case, can be compared with the theoretical model (mean equal to zero, standard deviation equal to 1).

The validity of the confidence interval of the GAR(t) values can be verified if the radar data are considered representative of an actual rainfall field : in this case the true value of the areal rainfall AR(t) can be calculated. The values of the radar samples over the rain gages position are identified with the Gi(t) values. The estimation of the GAR(t) values according to (2), and the comparison with the AR(t) values permit to verify the validity of the confidence intervals defined by the model.

2 - Operational application in the Nancy District Metropolitan

The radar data are received every five minutes at the central station of supervision of the Nancy District Metropolitan Authority. The data of n=12 rain gages are available every one minute.

2.1 Estimation of the areal rainfalls and confidence intervals

The area of integration selected is equal to the radar samples which give the best coverage of the rain gage network (figure 1).

The model of variogram used in this example is a spherical model with a nugget effect (nu) and with a range ra=8km and a sill si=1, chosen from previous studies on the rain gage network of Nancy [2] :

(7) $\gamma(h) = nu + (si - nu)(3h/ra - [h/ra]^3)/2$

The resolution of the kriging system allows to define the weights λi minimising the value of $\sigma e^2(t)$ for the variogram model used :

(8) $$\sigma e^2(t)=Var[GAR(t)-AR(t)]=minimum$$

In the case of this application, the area is selected according to the rain gage network. The best weights estimated by the kriging are not very different of the value 1/n. Each λi is therefore set to 1/n. In this way, the spatial interpolation is an average and the $\sigma e^2(t)$ value exceeds slightly the minimal variance defined in (8) .

With this weights $\lambda i=1/12$, for a variation of the nugget effect between 0% and 50% (nu value equal to 0. to 0.5), the values of $\sigma e^2(t)$ vary from $0.15\sigma g^2(t)$ to $0.24\sigma g^2(t)$. A mean value is selected, corresponding to a nugget effect of 30 % (nu=0.3) :

(9) $$\sigma e^2(t) = 0.2\ \sigma g^2(t)$$

This value of $\sigma e^2(t)$ allows to define the temporal variations of the confidence to give to the GAR(t) values. The confidence intervals estimated from (6) have been validated for 550 radar images according to § 1.4.

Nevertheless, to be applied in a method of control of the radar measurement, the relative time variations of $\sigma e^2(t)$ are more important than the precise values of $\sigma e^2(t)$.

2.2 Example of application : the rainfall event of the 18 May 1995

This rainfall event covered the entire North-East of France. The rainfall intensities were small. On the Nancy District Metropolitan area the best rainfall intensities occurred from 8h00 UT to 11h30 UT (Universal Time). After 11h00 UT, a very thin rainfall band with small intensities, oriented N50°, developed just above Nancy and at the vertical of the radar. Then this rainfall band moved about the South-East becoming visible on the radar images after 11h30 UT.

Figure (2) shows some graphics results of the treatment program computing in real time. The radar image shows the rainfall field at 11h40 UT. The front of the rainfall band delimiting the rainfall area in the South-East is visible.

The upper left graph shows the evolution of the RAR(t) values (one value for 5 minutes) and of the mean value of the 12 rain gage measurements (one value per minute) for the last 250 minutes (from 7h30 to 11h40 UT). The values of the areal rainfall are small (1 to 5 mm/h). An under-estimation of the RAR(t) values clearly appear during the last hour (11h40 to 11h25 UT).

At the upper right, is plotted the value of the ratio GR(t)=GAR(t)/RAR(t) with two confidence intervals for 80% and 90 % (one value per 5 minutes). If the variations of the GR(t) values are important, the confidence intervals are close to the value 1 during the first three hours, even if a little radar under-estimation of the rainfall can exist during the first hour. On the contrary, a significant bias appear during the last 50 minutes, the more likely value of GR(t) being nearly 3.

The lower right graph indicates the evolution of the sum of the RAR(t) and GAR(t) values from the beginning of the rainfall event. The sum of the GAR(t) values is plotted with several confidence intervals for 1.28 $\sigma e(t)$, 3 $\sigma e(t)$ and 5 $\sigma e(t)$. The total depth is nearly 10 mm during a little more than 4 hours, corresponding to a winter rainfall usual for Nancy. During the first three hours the sum of the RAR(t) values is close to the evolution of the sum of the GAR(t) values.

But during the last 50 minutes the sum of the RAR(t) values increases more slowly than the sum of the GAR(t) values, and diverges from the confidence intervals.

All this observations indicate an important under-estimation of the areal rainfalls from the radar measurements during the last hour, when the thin rainfall band developed at the vertical of the radar

3 - Interest for a real time use

Taking into account confidence intervals makes the comparison between two very different measures of a same rainfall field more objective. The more important interest is to highlight the non significant small differences and the important bias of short duration really significant of a problem of the radar rainfall measurement.

In real time, it is difficult not to be too close to the measurements by integrating the observations over time : the longer the duration of integration, the bigger the delay of detection. And when the source of error accountable for a bias is of a short duration (one hour in the example given in this paper), the least delay of detection can be very prejudicial and can induce a reaction at the wrong moment (i.e., detection of a significant bias when the effect of the source of error has disappeared). But if the integration over time is limited, the risk is important to take into account many non significant discrepancies between radar and rain gages measurements.

Consequently, to perfect a method of bias detection of the radar measurement, it is necessary to have a selective criterion of detection adapted to the rainfall situation and **available in real time**. $\sigma e^2(t)$ provide such a statistical criterion, varying in time as a function of the variance of the rainfall field estimated by the rain gage measurements.

Strictly, the detected bias is significant only of the mean trend for the area used for the interpolation of the areal rainfall. To take into account correctly the problem for the entire radar image, it is necessary to use a specific treatment adapted to each source of error concerned (e.g., attenuation by precipitation, heterogeneity of the atmosphere and variations of reflectivity, anomalous propagation of the radar beam ...).

References :

[1] J.P. DELHOMME, Kriging in the Hydrosciences, Advances in Water Resources, Vol 1 No. 5 1978

[2] A. HAMMOUDA, Connaissance et modélisation des précipitations pour l'hydrologie urbaine à travers l'exemple de l'agglomération Nancéienne, thèse de l'Université des sciences et technologies de Lilles,1995

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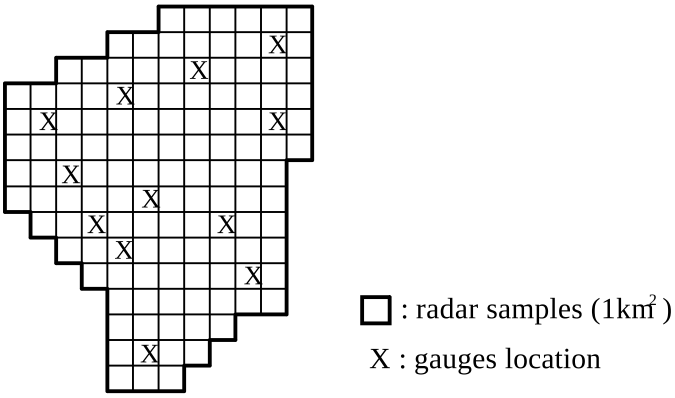

Figure 1: Area of integration of the areal rainfalls.

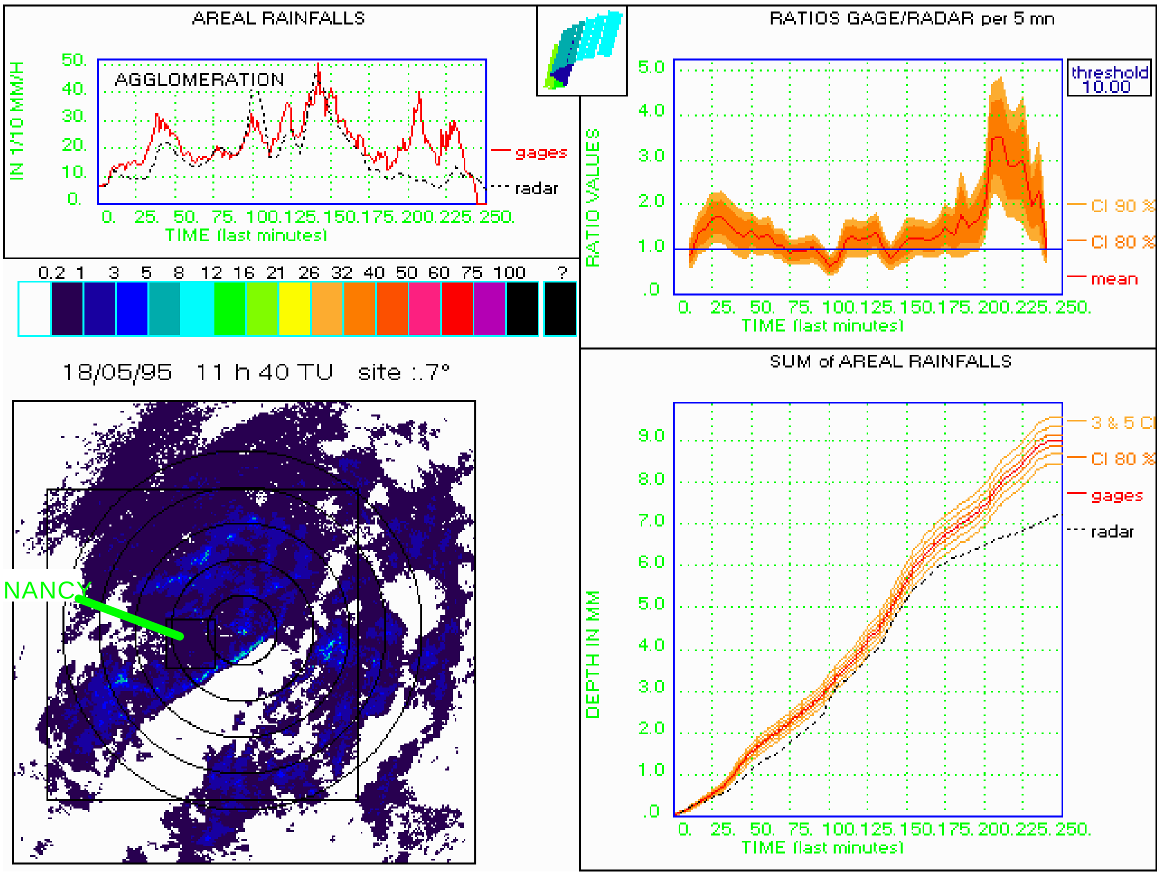

Figure 2: **graphics displays of results of the treatment program in real time.**