Hydrological model response to different estimations of rainfall inputs

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Abstract In this paper we discuss the effects on simulated storm hydrographs when different estimations of rainfall fields are performed from a real storm by following the application of different techniques of precipitation estimation. The main objective of this work is to evaluate the hydrological response to changes in rainfall inputs due to different techniques in their estimation. In order to model the hydrological response, the Feliciano River basin, with an area of 5500 km^2 in a subtropical and humid region in the eastern part of Argentina, was divided into 17 sub-basins. Area-averaged rainfall amounts over the sub-basins, coming from three different ways of estimating rainfall fields from remotely sensed infrared data, were available as inputs to the runoff–rainfall model. Accumulated rainfall fields over the basin were obtained in previous work for 6-h consecutive periods during three days by following two ways of estimating precipitation from GOES IR images: the first, by applying the “autoestimator” (AE) technique by Vicente *et al.* (1998) to observed IR images; the second, by applying the AE Technique to observed plus synthetic IR images. The latter were obtained by interpolation in time and space from two consecutive GOES IR images; by doing this, the displacement of cloud systems is captured better. Simulated hydrographs were obtained by applying the OCINE2 rainfall–runoff model. It is a conceptual, distributed parameters model, which computes both overland and stream flows by applying the kinematic wave theory. In this work, a topologic framework with 51 segments (34 for overland flow and 17 for stream flow) was utilized. The calibration was done by taking into account the Paso Medina station hydrograph for the storm which occurred between 9 and 11 April 2002. The best fits to the observed hydrograph were obtained when rainfall input values were estimated by means of the mentioned modification to the “autoestimator” technique. Comparison with the observed hydrograph showed the following: the calculated peak flow present relative errors smaller than 1% for the three methods, the rising limb adjusted better for the “autoestimator” technique but the peak flow is advanced 12 hours. Besides, the differences between observed and computed volume is large for the “autoestimator” technique (for this ultimate). On one hand these results show the progress on runoff prediction when remote sensing methods are applied in poorly instrumented basins; and on the other hand, the importance of making a correct estimation of the displacement of raining cloud cells to get better estimates of precipitation at the ground.

Key words hydrological model; remote sensing methods

PURPOSE

The purpose of this work is to assess the effects on simulated storm hydrographs when different estimations of rainfall fields are performed from a real storm by following the application of different techniques of precipitation estimation. That is, to evaluate the differences in the hydrological response when different techniques of estimation of rainfall inputs are applied. In order to model the hydrological response, the Feliciano River basin was divided into 17 sub-basins (Fig. 1).

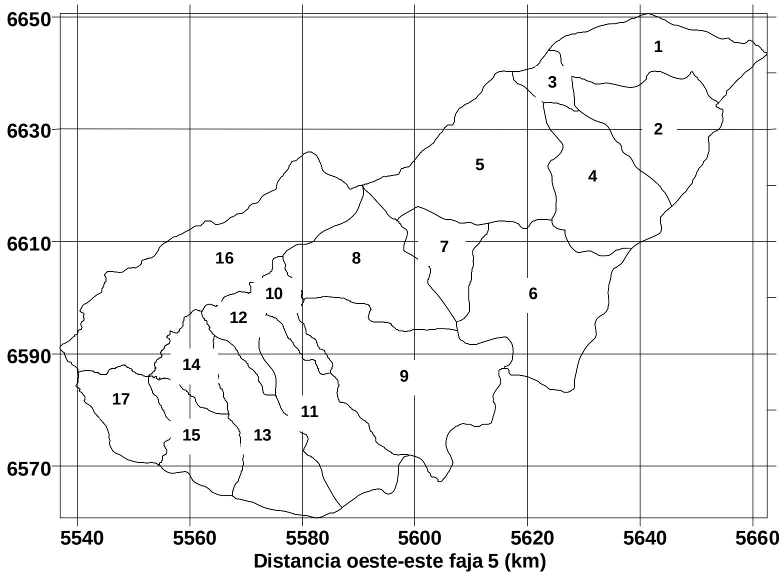

Fig. 1 Basin and sub-basins of the Feliciano River system.

METHODOLOGY

The methodology for the generation of rainfall input fields and area-average values of accumulated precipitation over the 17 sub-basins was presented in previous work (Barrera *et al.*, 2007). It applied the so called "auto-estimator" (AE) technique (Vicente *et al.*, 1998) following two different procedures: from observed GOES-8 IR images only (which is noted here as procedure 1), and from observed and synthetic images (noted as procedure 2). The latter were obtained by time interpolation between consecutive observed images. The generation of synthetic images allows the displacement of cloud systems over the terrain to be described better (Barrera, 2007).

Then, simulated hydrographs were obtained by applying the OCINE2 rainfall–runoff model (Ceirano *et al.*, 1979, 1982). It is a conceptual, distributed parameters model, which computes both overland flows (*Ov*) and stream flows (*St*) by applying kinematic wave theory:

$$\frac{\partial y}{\partial t} + \frac{\partial q}{\partial x} = p - f \qquad (1)$$

$$\frac{\partial Q}{\partial x}+\frac{\partial A}{\partial t}=q \tag{2}$$

$$q=\alpha_c * y^{m_c} \tag{3}$$

$$Q=\alpha_s * A^{m_s} \tag{4}$$

where y is the (m); q is the flow for unit width in the basin segment ($m^2\ s^{-1}$); x is the distance along the segment (m); p is the rain intensity (mm h^{-1}); f is the infiltration intensity (mm h^{-1}); A the area of the cross section (m^2); Q is the discharge ($m^3\ s^{-1}$).

The coefficients α_c, m_c, α_s, m_s are the parameters calculated with the physical characteristics of the overland and streams segments. The curve-number (CN) developed by the Soil Conservation Service (SCS) is the method for computing the amount of storm runoff, taking abstractions into account (Morín *et al*., 1993).

APPLICATION

General characteristics of the basin

The physical system studied is the Feliciano River basin, which has an area of 5500 km^2. It is located in a subtropical and humid region in the eastern part of Argentina. The streams run on an alluvial flood plain with irregular elevation contours. The main stream is 157 km long until the outlet at Paso Medina, and has a variable width (between 40 and 120 m). Its slope is 0.000256. The soils have low permeability. The vegetation is mainly natural pasture ground and brushwood.

Daily records of river levels and precipitation at Paso Medina station are available.

Basin segmentation

In this work, a topologic framework with 51 segments (34 for overland flow and 17 for stream flow) was utilized. The calibration of the simulated hydrograph at Paso Medina was done for the storm that occurred from 9 to 11 April 2002. Terrain elevations were obtained from official topographic charts at scale factor 1:100 000 and from aerial photographs. In order to obtain the stream segments, characteristics of areas, slopes, vegetation cover, soils and drainage density were taken in account. Some characteristics of the 17 sub-basins are show in Table 1.

Temporal distribution of area-average precipitation over the sub-basins

Accumulated precipitation every 6 hours were obtained from 12UTC (09:00 h local time) to 12UTC of the following day, during 9–12 April 2002, following procedures 1 and 2 (Barrera *et al*., 2007).

Tables 2 and 3 give the distribution of area-average rainfall in 6-h lapses for the considered period and the 17 sub-basins, obtained from procedures 1 and 2, respectively.

Table 1 Characteristic values of the sub-basins.

Sub-basin	Area (km^2)	Main stream longitude (km)	Sub-basins slope (E-02)	Main stream slope (E-03)
1	314.90	38.00	0.37	0.50
2	327.10	30.90	0.38	0.69
3	66.70	7.00	0.25	0.21
4	369.00	382.00	0.15	0.60
5	555.70	36.10	0.25	0.32
6	563.20	33.20	0.25	0.70
7	164.70	18.80	0.32	0.34
8	386.10	25.80	0.46	0.21
9	642.40	47.40	0.47	0.54
10	89.80	8.50	0.51	0.16
11	334.50	38.30	0.47	0.82
12	113.40	12.10	0.75	0.19
13	320.70	28.10	0.52	1.21
14	127.00	15.90	0.81	0.17
15	198.60	23.80	0.60	1.46
16	738.50	56.00	0.48	0.66
17	175.80	13.30	0.70	0.22

Table 2 Distribution of area-average rainfall over the sub-basins. Procedure 1.

Sub	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Pixels	22	21	4	24	36	35	11	25	39	6	20	9	21	8	13	46	12
00–06	0	0	0	0	0.5	0	0.1	0.7	0	0.2	0.1	0	0.3	0.2	0.9	0.1	0.6
06–12	67.0	60.3	84.5	59.4	46.7	37.1	39.1	30.3	26.3	27.6	17.5	27.6	14.5	14.1	18.8	27.2	16.6
12–18	103.3	123.4	157.8	119.7	115.8	102.5	105.0	70.8	62.6	72.0	42.4	60.3	28.0	40.3	23.8	49.3	21.2
18–24	103.2	104.1	120.9	82.1	72.5	48.2	48.0	50.3	49.8	54.9	67.7	74.8	47.4	81.8	78.7	55.1	102.1
24–30	17.8	13.4	18.6	12.6	15.3	8.2	12.4	9.5	8.8	2.9	7.7	10.4	3.9	9.4	8.4	5.2	11.0
30–36	66.7	54.1	67.6	49.8	41.4	52.7	38.2	22.2	30.1	26.5	49.9	47.8	42.5	46.8	59.2	32.4	49.2
36–42	53.8	48.8	50.5	28.6	23.3	20.2	18.2	18.2	23.5	20.5	18.6	23.3	17.1	18.0	13.1	15.5	3.9
42–48	7.0	4.1	3.2	3.7	3.0	2.5	2.4	0.9	0.4	0.3	0.2	0.3	0.3	0.3	0.1	0.7	0.2
48–54	0.1	0.1	0.1	0.1	0.1	0	0.1	0	0	0	0	0	0	0	0	0	0

Table 3 Distribution of area-average rainfall over the sub-basins. Procedure 2.

Sub	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Pixels	22	21	4	24	36	35	11	25	39	6	20	9	21	8	13	46	12
00–06	0	0	0	0	0.4	0	0.1	0.5	0	0.2	0.1	0	0.3	0.2	0.7	1.1	0.4
06–12	56.3	52.6	70.2	48.1	45.0	28.6	33.6	27.5	17.9	21.8	12.9	16.3	11.9	10.6	15.1	24.0	13.2
12–18	94.4	111.1	118.1	104.4	97.2	80.5	89.2	51.1	44.8	45.7	29.3	41.9	19.3	33.1	14.4	35.6	13.2
18–24	121.2	129.7	173.4	94.4	79.1	57.2	55.2	54.0	46.9	50.4	66.2	76.4	51.5	73.7	67.6	57.7	99.9
24–30	31.1	25.5	40.3	23.6	32.9	16.3	24.0	19.1	13.8	10.5	9.9	10.4	8.3	11.3	7.8	8.5	8.4
30–36	9.0	2.9	1.3	0.4	0.1	0	0	0.1	0	0.1	0	0	0	0	0	0.2	0.1
36–42	103.6	97.9	112.9	79.0	67.4	65.3	57.1	43.2	61.9	57.5	69.9	76.1	67.6	66.2	82.6	52.6	50.4
42–48	27.1	16.1	7.4	11.0	4.8	1.0	2.4	1.3	0.9	0.3	0.4	0.3	0.3	0.4	0.1	0.8	0.1
48–54	0.1	0.1	0.1	0.1	0.1	0	0.1	0	0	0	0	0	0	0	0	0	0

The 6-hour lapse temporal evolution of area-average rainfall over the entire basin is shown in Figs 2 and 3, for Procedures 1 and 2, respectively.

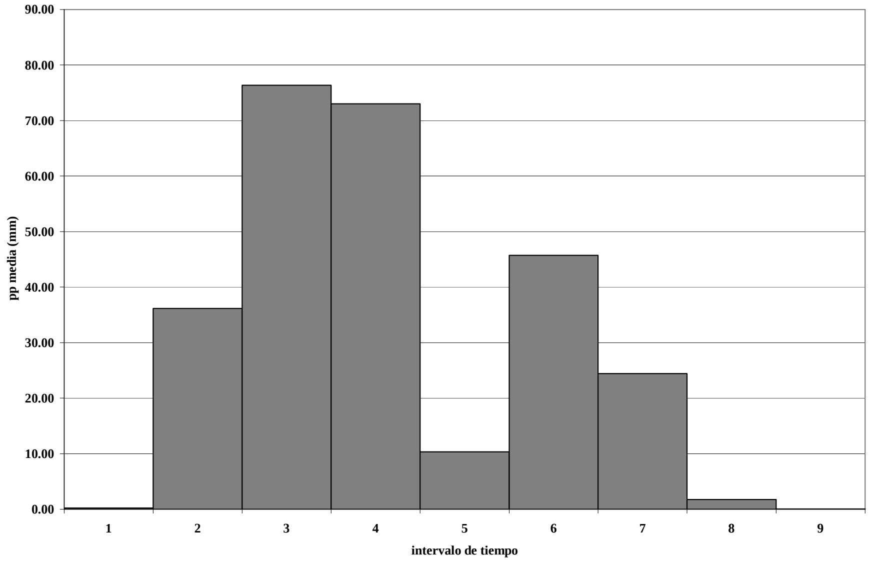

Fig. 2 6-hour period evolution of area-average rainfall. Procedure 1.

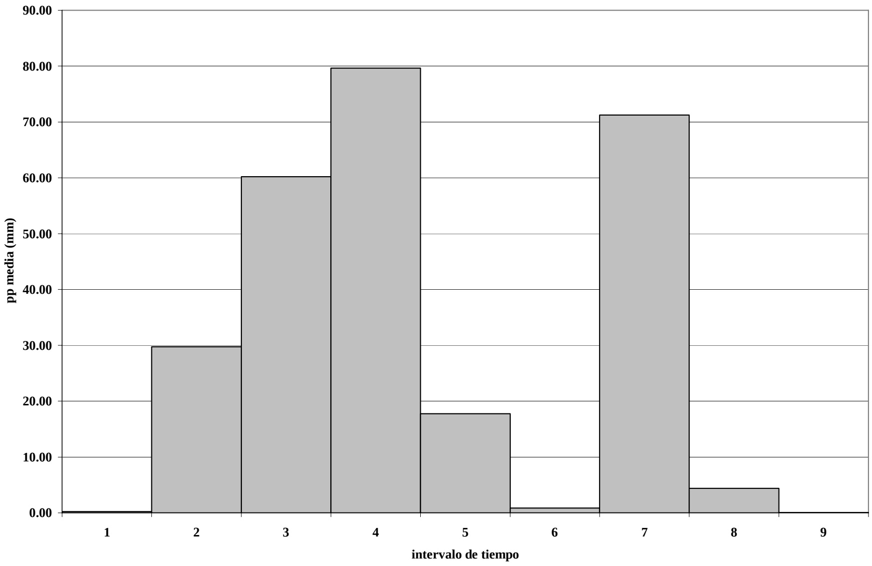

Fig. 3 6-hour period evolution of area-average rainfall. Procedure 2.

Figures 4 and 5 show the distribution of total rainfall over each one of the 17 sub-basins obtained by the two procedures.

RESULTS

Table 4 shows the observed values of peak flow, lag time and volume, while Table 5 shows the respective estimated values when model OCINE2 was applied with rainfall fields obtained by means of procedures 1 and 2.

Figure 6 shows the hydrographs corresponding to both procedures, while Table 7 presents the relative errors in both the peak flow and volume values of the hydrograph.

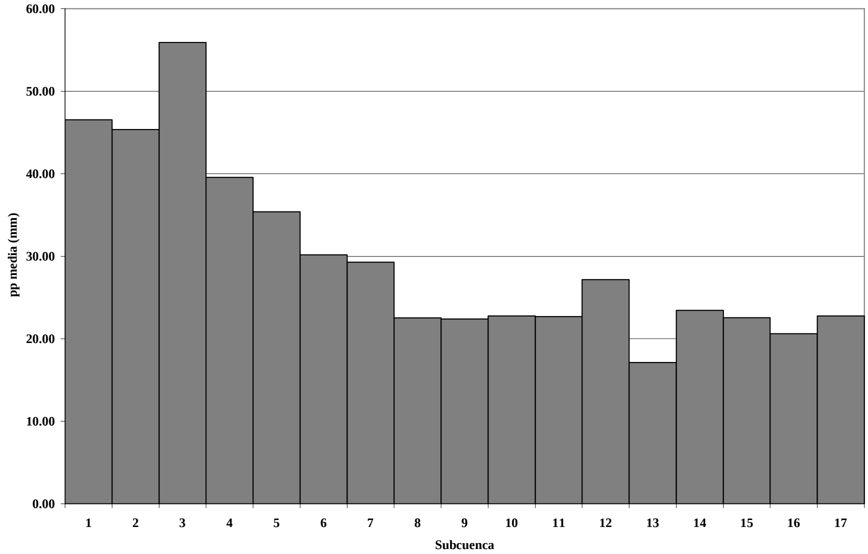

Fig. 4 Distribution of total over the sub-basins. Procedure 1.

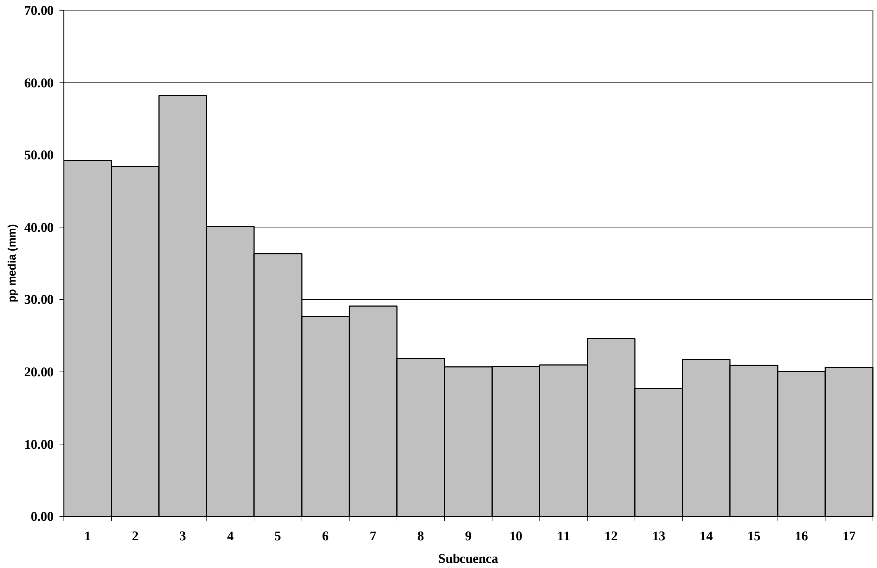

Fig. 5 Distribution of total over the sub-basins. Procedure 2.

Table 4 Observed values.

Peak Flow ($m^3 s^{-1}$)	Lag Time (days)	Volume (Hm^3)
221.96	6.00	71.22

Table 5 Computed values.

Temporary distribution	Peak Flow ($m^3 s^{-1}$)	Lag Time (days)	Volume (Hm^3)
Procedure 1	224.47	5.5	74.65
Procedure 2	221.40	5.5	71.76

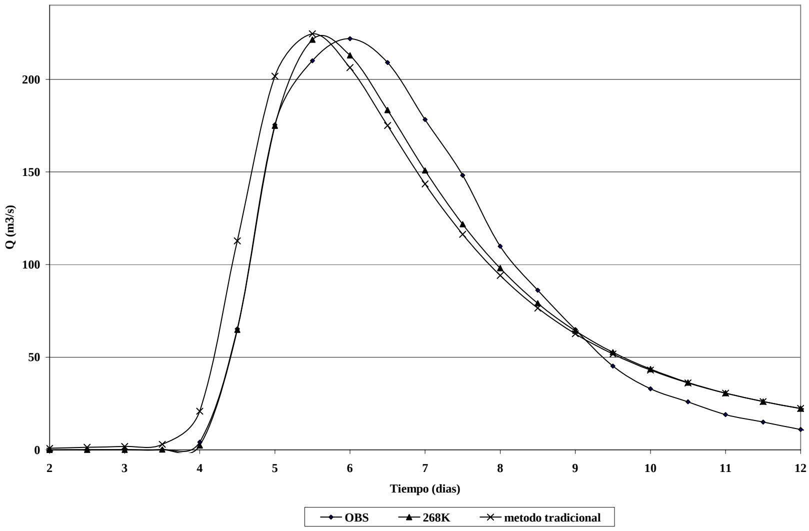

Fig. 6 Observed and simulated hydrographs for rainfall inputs obtained by procedures 1 and 2.

T**able 7** Relative errors.

Temporary distribution	Err Peak Flow (%)	Err Volume (%)
Procedure 1	1.13	4.80
Procedure 2	–0.25	0.75

The best fits to the observed hydrograph were performed when rainfall input values were obtained by applying procedure 2.

Comparisons to the observed hydrograph yielded the following results:

– Simulated peak flows present relative errors smaller than 1% for procedures 1 and 2.
– The rising limb obtained by procedure 2 fitted very well, while the one obtained by procedure 1 is advanced by about 12 hours.
– Simulated peak flows by procedures 1 and 2 are advanced by about 12 hours.
– Simulated volume for procedure 2 shows a very good fit, while the one obtained by procedure 1 is overestimated.

CONCLUSIONS

– The OCINE2 model was shown to be versatile when applied to the Feliciano River basin. The division of the basin in to 51 segments seems to appropriately represent the system.
– The obtained results are considered satisfactory for this stage of the research. They evidence the applicability of rainfall inputs generated by remote sensing techniques in hydrological modelling.
– When larger lapses are taken for the area-average rainfall over the sub-basins (i.e. 12 or more hours), the resulting model inputs allow significant differences

between the observed and simulated hydrographs to be obtained.
- The modelled hydrograph is highly sensitive to the distribution of rainfall in both space and time. The knowledge of the time of the beginning and end of the storm, obtained in this case by means of remote sensing techniques, had a great impact on the goodness of fit between observed and simulated hydrographs.
- These results show, on one hand, the progress on runoff prediction when remote sensing methods are applied in poorly instrumented basins.
- For the completion of the investigations it will be necessary to identify new storms, of diverse duration and intensity in order to systematize the calculations.

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