Universitat de les Illes Balears

A hydro-meteorological modeling study of a flash-flood event over Catalonia, Spain

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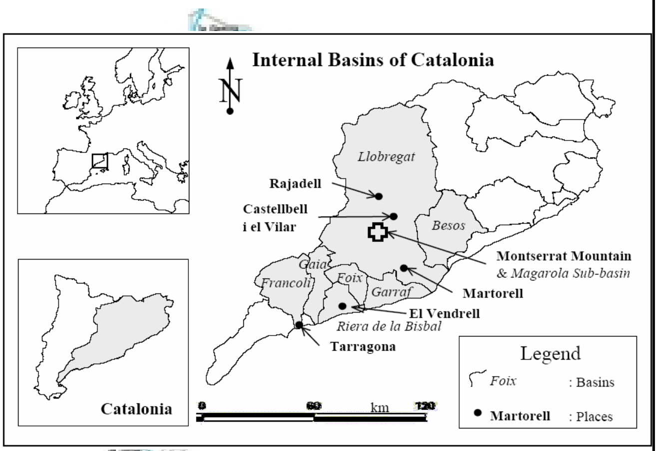
Part 1: Rain-gauge driven runoff simulation
Introduction

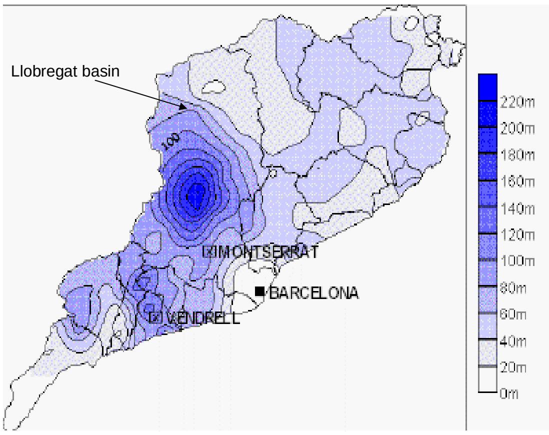
The affected region is located in the north-eastern part of Spain, in the internal basins of Catalonia.

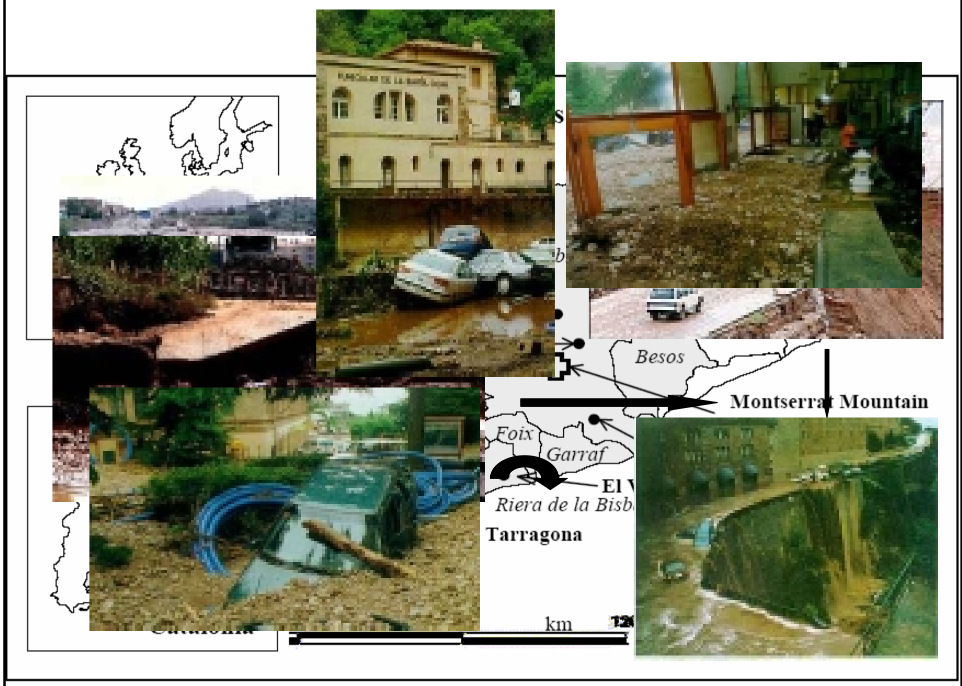
The Llobregat basin is the most important of these and it is composed by the Llobregat river and its main tributaries: L'Anoia and El Cardener.



Case description

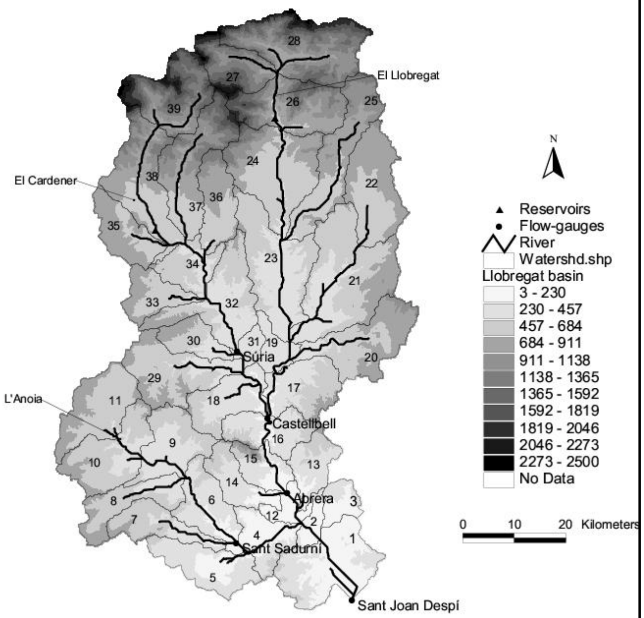
- Torrential precipitation took place on 10 June 2000, lasting 6h approximately
- Accumulated rainfall reached over 200 mm inside Llobregat basin
- Huge increase in the flow, producing great personal, economic and material losses: 5 fatalities, 500 evacuated people and material damage estimated at over 65.000.000 euros





Llobregat basin: an overview

- extension of 5000 km^2
- heights near 2500 m in the Pyrenees
- maximum length of 170 km.
- DTM has a resolution of 50 m
- It is shown the main river and its tributaries
- subbasin distribution and its numeration
- five flow-gauges available for this study
- Two reservoirs have been modelled in the upper part of Cardener and Llobregat rivers.

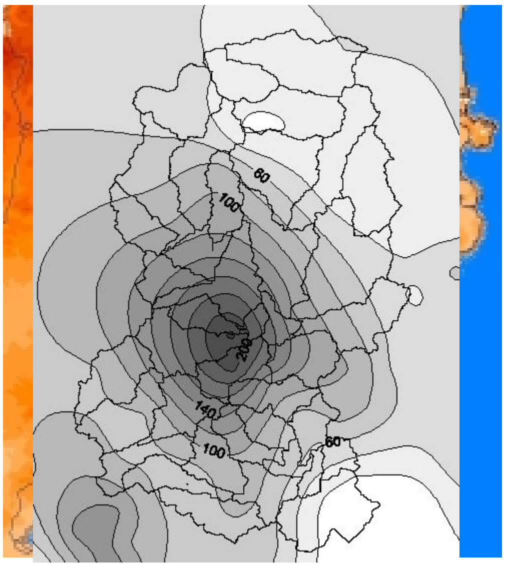


Rain-gauge network

- Precipitation has been obtained from the Automatic Hydrological Information System (SAIH) rain-gauges (126), inside the internal Catalonia catchments

- Precipitation is cumulated and recorded every 5 minutes

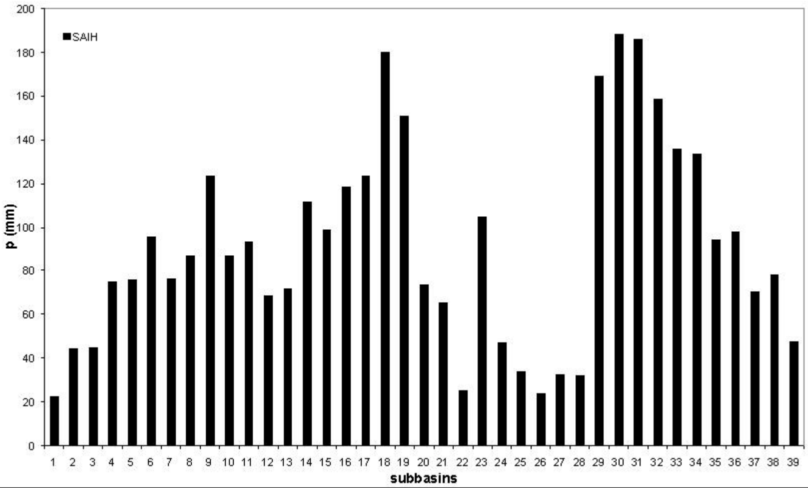
- Applying the krigging interpolation method has been obtained the observed spatial accumulated rainfall pattern for the basin.



Hydrologic model and precipitation input data

HEC-HMS is a hydrologic model developed by the US Army Corps of Engineers (www.hec.usace.army.mil) and it is widely used in Spain.

Precipitation has been included in the model using a single hyetograph for every subbasin. Values has been calculated as the areal average per subbasin of the gridded rainfall accumulated at the SAIH every 30-min. It is displayed the total amounts.



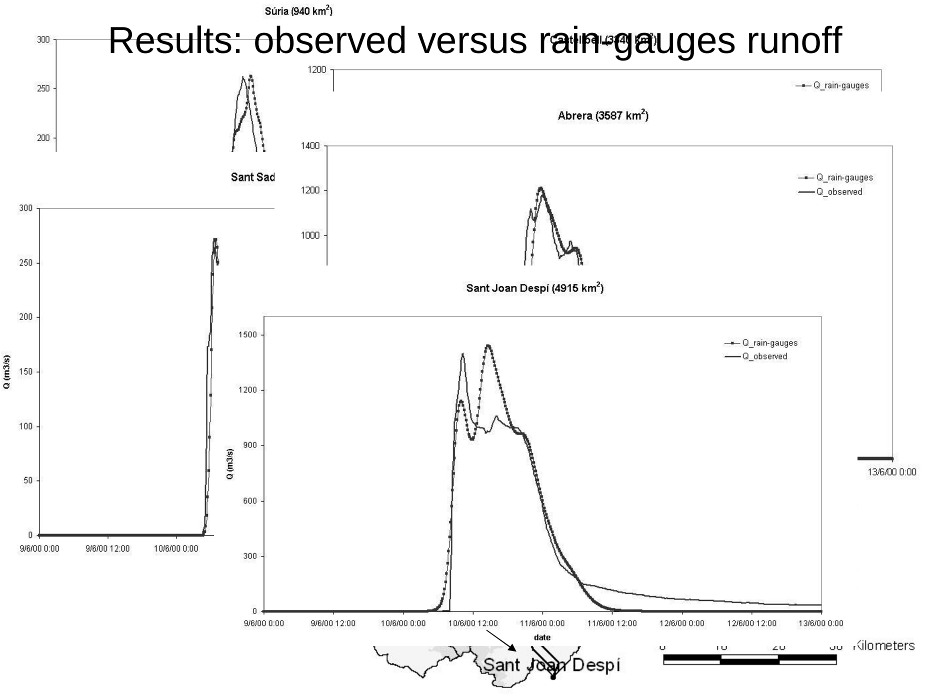
Hydrological processes and simulation performance

- Loss rate: SCS Curve Number (CN) model
- Transform: SCS Unit Hydrograph model
- No baseflow
- Reservoirs: characteristic elevation-storage-outflow relationship
- Flow routing: Muskingum method

- Control specifications:
  96–h simulation from 09/06/2000 at 00:00 LT until 13/06/2000 at 00:00 LT at 10-min time-step intervals.

- Parameters calibrated in the simulation:
  subbasins: infiltration by means of CN and soil imperviousness
  reaches: flood wave celerity in main channels by means of K parameter

Results: observed versus rain-gauges runoff



Results: goodness-of-fit indexes

To compare observed and rain-gauges discharge simulations has been used:

- Nash-Sutcliffe efficiency criterion (NSE = 1: perfect simulation):

$$NSE = 1 - \frac{\sum_{i=1}^{n}(x_i - y_i)^2}{\sum_{i=1}^{n}(x_i - \bar{x})^2};$$

$x_i = observed\ runoff$, $y_i = simulated\ runoff$,

$\bar{x} = mean\ observed\ runoff$

- % error in volume (% e.v.>0: volume simulated is overestimated):

$$\%\ e.v. = \left(\frac{V_S - V_O}{V_O}\right)\cdot 100 \qquad V_S = simulated\ \ hydrograph\ \ volume \quad V_O = observed\ \ hydrograph\ \ volume$$

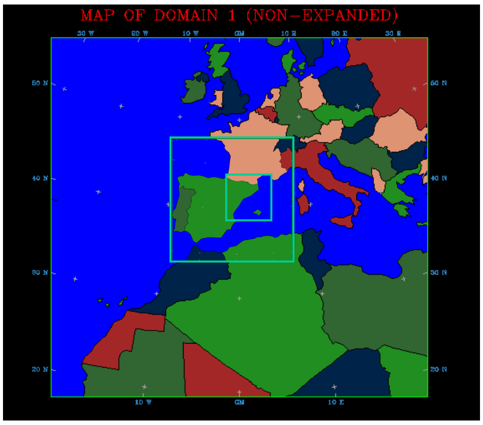
Results: goodness-of-fit indexes

Súria		Castellbell		St. Sadurní		Abrera		St. Joan Despí	
NSE	% e.v.	NSE	% e.v.	NSE	% e.v.	NSE	% e.v.	NSE	% e.v.
0.9	-4.8	0.85	-2.2	0.84	-11.3	0.94	6.5	0.93	-4.8

- NSE indicates a goodness-of-fit in time peak and volume in all stream-gauges, even at Abrera and St. Joan Despí gauges, overcoming 0.9
- % .e.v. depicts a slight underestimation on discharge volume in all cases, excepting Abrera

Part 2: MM5 driven runoff simulations

Characteristics of the forecast simulations



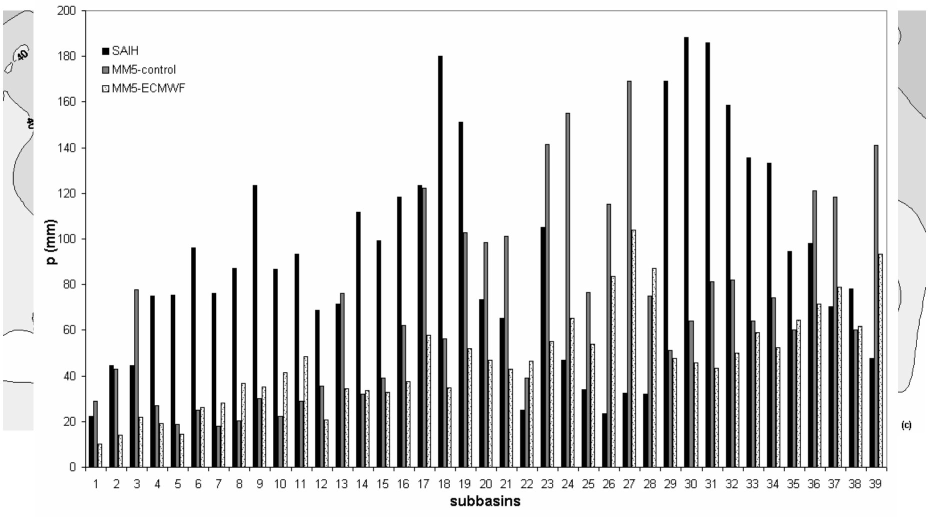
- Initial and boundary conditions obtained from:

  1. **NCEP analysis** (updated every 12-h, 2.5º spatial resolution)
  2. **ECMWF analysis** (updated every 6-h, 0.3º spatial resolution)

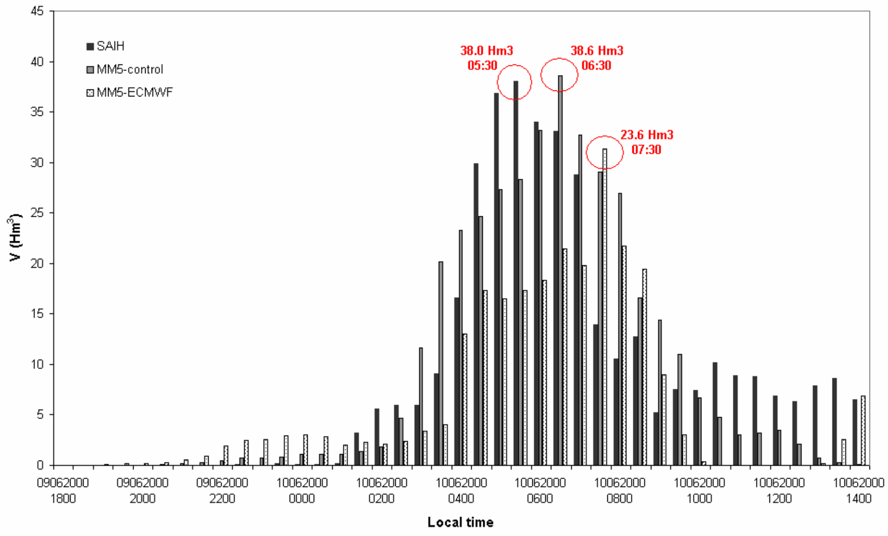
- **Three domains**: 54, 18 and 6 Km, interacting with each other.
- 24 vertical levels.
- The experiments consider a **36 hours** simulation (from 09/06/00 at 0000 UTC to 10/06/00 at 1200 UTC).

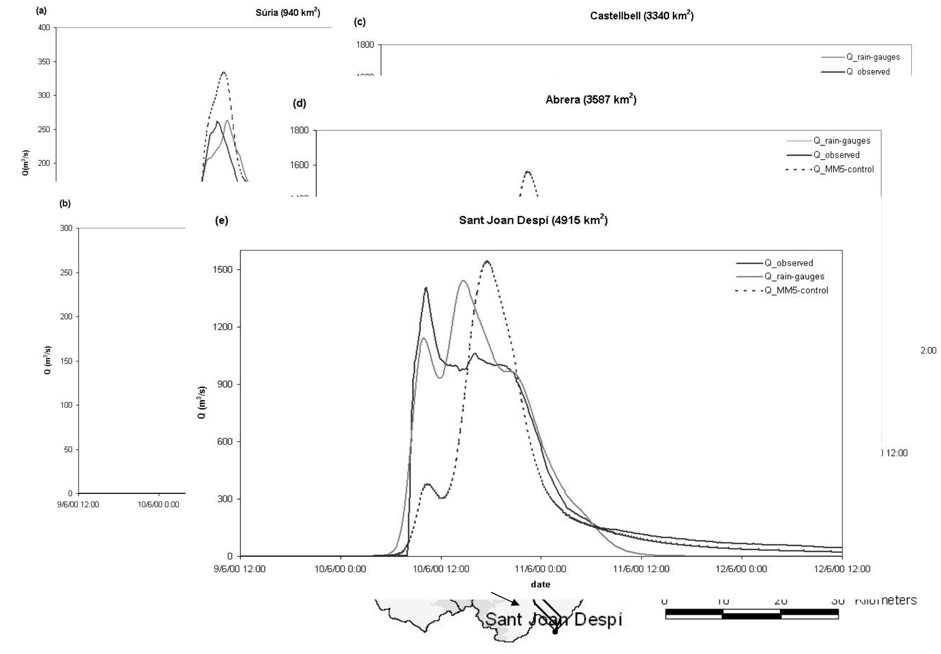
- **Full physics** is used (control experiment).
- **Kain-Fritsch scheme** is used to parameterise convection for the first and the second domains, and no convective scheme in the inner.

It is shown the rain-gauges, MM5-NCEP and MM5-ECMWF spatial accumulated precipitation for the watershed and the subbasins. First is adopted as control simulation.



Temporal evolution of the cumulative precipitated water volume over the basin, at 30-min time-steps, for rain-gauges, NCEP and ECMWF





Results: goodness-of-fit indexes

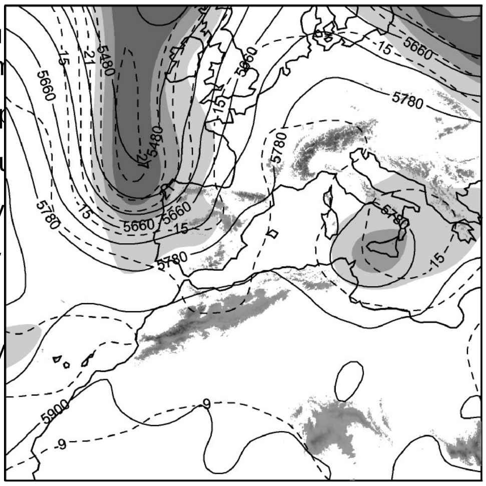
Súria		Castellbell		St. Sadurní		Abrera		St. Joan Despí	
NSE	% e.v.	NSE	% e.v.	NSE	% e.v.	NSE	% e.v.	NSE	% e.v.
0.79	11.8	0.44	11.8	-0.12	-100	0.67	-1.1	0.64	-22.4

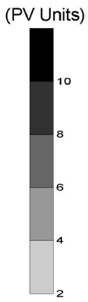
- NSE indicates the best goodness-of-fit at Súria
- North-eastward displacement of maximum rainfall quantities plus the lamination effect due to Llobregat’s reservoir determines a lag in time peaks for Castellbell, Abrera and St. Joan Despí (~ 3 h)
- St. Sadurní depicts the worst behaviour since MM5-control driven simulations underestimates precipitation in l’Anoia’s branch
- % e.v. depicts an overestimation at Súria and Castellbell and an underestimation in the remaining ones due to the spatial assessment of control simulation producing negligible water contribution from l’Anoia affluent

Part 3: Addressing meteorological uncertainty: the MM5-perturbed driven runoff ensemble

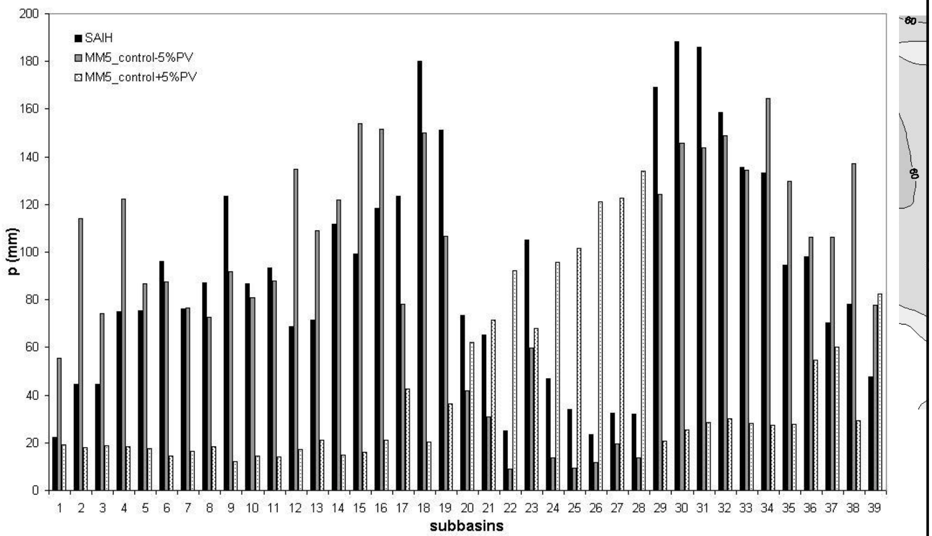
- MM5-NCEP initial conditions of the upper-level precursor trough at 00 UTC 9 June 2000
- Slight perturbations of the initial state: first approximation to study the spatial and temporal uncertainties of the rainfall forecast into a medium size catchment like Llobregat basin

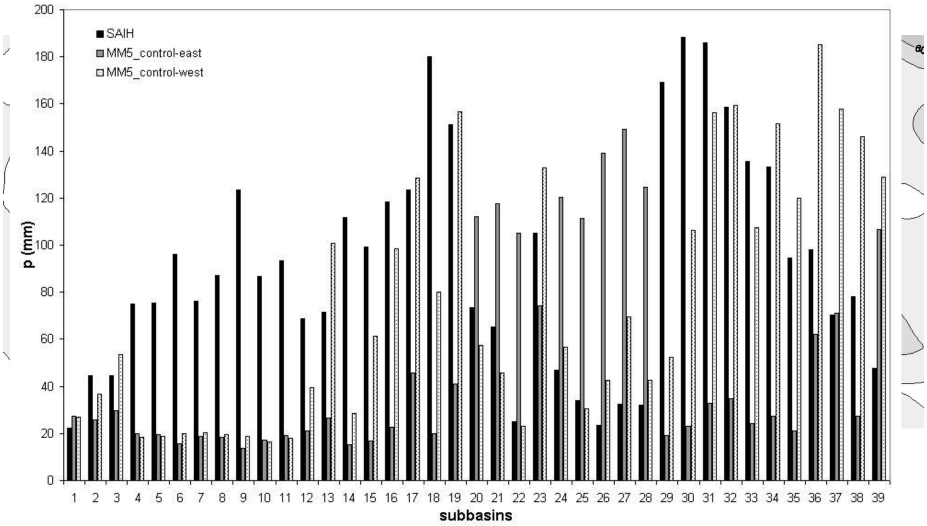
1. Four perturbed simu… using PV inversion m…
   - Increasing 5% the up…
   - Diminishing 5% the u…
   - Shifting the anomaly
   - Moving the anomaly
2. In addition MM5-ECM…



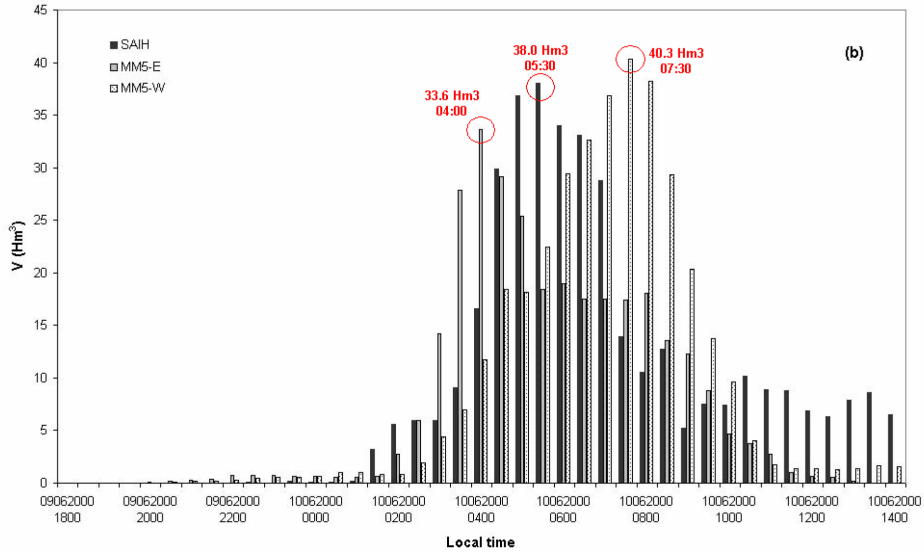


It is depicted the spatial and subwatershed accumulated rainfall distributions for the set of perturbed simulations:





Temporal evolution of the 30-min accumulated water volume upon the catchment:



Results: spatial and temporal rainfall distributions

	NCEP	ECMWF	PV -5%	PV +5%	PV -WEST	PV-EAST
NSE						
spatial	-1.18	-1.04	0.44	-2.28	-2.51	-0.38
temporal	0.60	0.45	0.53	0.47	0.45	0.33
RMSE						
spatial	75.5	73.2	38.3	92.8	95.9	60.2
temporal	66.0	77.4	71.4	76.4	77.7	85.6

- NSE and RMSE indicate the best spatially performance for the -5% PV simulation and temporarily for NCEP simulation
- The ensemble of simulated rainfall fields exhibit larger heterogeneities in space that in time
- The external-scale uncertainty addressed by means of the ensemble is basically reflected on the spatial distribution of the rainfall patterns

Results: total precipitated volume and its 30-min maximum distribution

	SAIH	NCEP	ECMWF	-5% PV	+5% PV	WEST	EAST
Precipitated water (Hm^3)	407.3	376.5	252.3	386.2	253.8	355.7	301.2
Discharged volume (Hm^3)	69.7	56.8	12.4	78.7	28.0	56.5	45.3

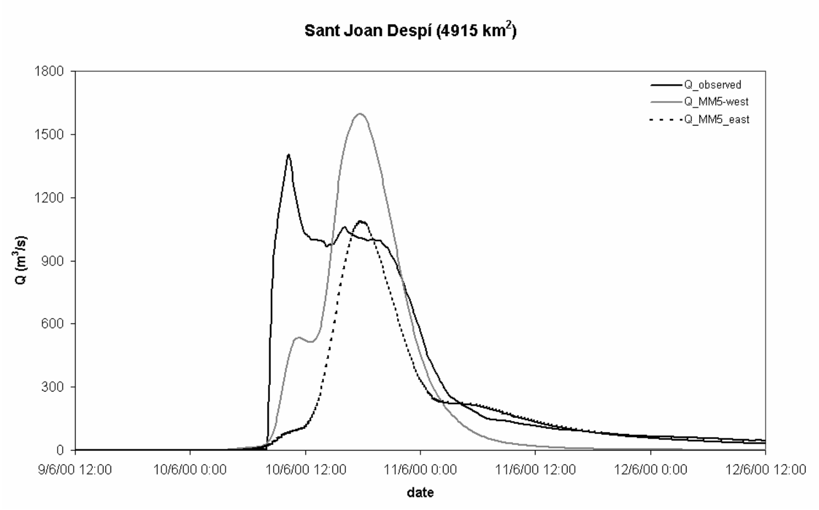
	SAIH	NCEP	ECMWF	-5% PV	+5% PV	WEST	EAST
Maximum volume (Hm^3)	38.0	38.6	31.4	33.6	30.7	40.3	33.6
Local time	05:30	06:30	07:30	06:00	03:00	07:30	04:00

- The whole set underestimates the total precipitated water volume in the basin, with better estimations for +%5 PV and NCEP simulations

- NCEP performances the more realistic maximum 30-min accumulated volume for the entire basin with only an excess of 0.6 Hm^3 with 1 hour of difference

Results: goodness-of-fit indexes

Runoff at the outlet basin gage



Results: goodness-of-fit indexes

ECMWF		PV - %5		PV + %5		PV - W		PV - E	
NSE	% e.v.	NSE	% e.v.	NSE	% e.v.	NSE	% e.v.	NSE	% e.v.
-0.03	-83.1	0.52	7.5	0.25	-61.7	0.66	-22.9	0.49	-38.2

- -5% PV, WEST and EAST driven runoff simulations show rather similar results to the MM5-NCEP simulation (NSE= 0.64, e.v.=-22.4%)

- The set of perturbed driven runoff simulations does not exhibit any remarkable degradation of the forecast skill, exempting the MM5-ECMWF element

- Llobregat basin shows relatively insensitive to forecasted precipitation patterns with spatial shifts of few tenths of km or temporal changes around 1-2 h

Conclusions and further remarks

- It seems feasible to introduce driven runoff simulations by numerical weather prediction mesoscale models over the Llobregat basin to help gaining additional lead-times for warning and emergency procedure

- The used methodology can be automated to obtain short-range runoff forecasts driven by high resolution mesoscale predictions available in real-time (e.g. http://mm5forecasts.uib.es)

- Results derived from a single flash-flood event. For a reliable and general hydrological performance model before hazardous flash-flood events it must be realised a wider calibration and verification task, from similar events affecting the Llobregat watershed, to optimize the hydrological parameters

- An expected future increase of the number of flow-gauges in the basin will permit an improvement in the previous issue and in the forecast and alert schemes.

Conclusions and further remarks

- A multi-analysis ensemble prediction system (EPS) to account for the forecast variance associated to the initial conditions uncertainty can avoid poor detection of a flash-flood event from a deterministic hydro-meteorological system

- None of the experiments was able to reproduce adequately the flow increase in l'Anoia subcatchment (736 km^2): forecasting limitations for smaller hydrological scales

- To attempt to mitigate this lack of coherence between the spatio-temporal meteorological and hydrological scales can be applied numerous techniques as:

✓ Model Outputs Statistics
✓ Statistical Downscaling
✓ Disaggregation techniques