A hydrometeorological model ensemble strategy applied to four extreme rainfall events in a small-size basin of Majorca Island, Spain

A. Amengual, R. Romero and S. Alonso
Grup de Meteorologia, Departament de Física,
Universitat de les Illes Balears,
Palma de Mallorca, Spain

Introduction

- The region under study is located in Majorca, the biggest of the Balearic Islands, in the Mediterranean Spain
- The Albufera basin is the most important catchment in terms of size, water resources and socio economical activities (highlighted)
- It is formed by the Almedrà and Sant Miquel ephemeral rivers
- Whole extension of 610 km², heights close to 1500 m and maximum river length of 42 km
Introduction

- The region under study is located in Majorca, the biggest of the Balearic Islands, in the Mediterranean Spain.
- The Albufera basin is the most important catchment in terms of size, water resources and socio economical activities (highlighted).
- It is formed by the Almedrà and Sant Miquel ephemeral rivers.
- Whole extension of 610 km², heights close to 1500 m and maximum river length of 42 km.

The intense precipitation events

- 7-8 October 1990: with accumulated values above 100 mm in 2 hours and total amounts over 240 mm.
- 9-10 October 1990: with an hourly maximum close to 115 mm and cumulative values up to 235 mm.
- 10-11 November 2001: with cumulative values of 240 mm in 24 hours and total amounts up to 400 mm.
- 3-4 April 2002: with rainfall accumulations close to 230 mm in 24 hours and total values up to 300 mm.

The episodes caused floods of different spatial and temporal scales in the Albufera basin.
The intense precipitation events

- 7-8 October 1990: with accumulated values above 100 mm in 2 hours and total amounts over 240 mm
- 9-10 October 1990: with an hourly maximum close to 115 mm and cumulative values up to 235 mm
- 10-11 November 2001: with cumulative values of 240 mm in 24 hours and total amounts up to 400 mm
- 3-4 April 2002: with rainfall accumulations close to 230 mm in 24 hours and total values up to 300 mm

The episodes caused floods of different spatial and temporal scales in the Albufera basin.
The intense precipitation events

- 7-8 October 1990: with accumulated values above 100 mm in 2 hours and total amounts over 240 mm
- 9-10 October 1990: with an hourly maximum close to 115 mm and cumulative values up to 235 mm
- 10-11 November 2001: with cumulative values of 240 mm in 24 hours and total amounts up to 400 mm
- 3-4 April 2002: with rainfall accumulations close to 230 mm in 24 hours and total values up to 300 mm

The episodes caused floods of different spatial and temporal scales in the Albufera basin

The rain-gauge network and input data

- Precipitation has been obtained from 24-h accumulated values of the Spanish Institute of Meteorology rain-gauges system for Majorca Island (100; 40 lie inside or near the basin)
- Precipitation is cumulated and recorded every 10 minutes in 12 automatic rain-gauges (emas) of the network
- To permit hydrological applications, the emas inside or close to the basin have been used to accumulate the 10-min series into 1-h and to build hourly series for the rest of the stations by means of:

\[
P_{st_j}(t) = \sum_i \left( \frac{p_{emas_i}(t) \cdot p_{Tst_j}}{d_{emas_i, st_j} \cdot p_{Temas_i}} \right)
\]

where:
- \( p_{st_j}(t) \) is the 1-h value of the rainfall series at \( t \) for the daily \( j \) station;
- \( p_{emas_i}(t) \) is the 1-h value of the emas \( i \) at time-step \( t \);
- \( p_{Tst_j} \) is the daily accumulated value of the station \( j \);
- \( p_{Temas_i} \) is the daily accumulated value of the emas \( i \);
- \( d_{emas_i, st_j} \) is the distance between the daily station \( j \) and the emas \( i \)
The hydro-meteorological chain

REAL-TIME MM5 WEATHER FORECASTS

- Control simulations for the events have used the same model configuration as in the real-time operational version at UIB (http://mm5forecasts.uib.es)
- Initial and boundary conditions: ECMWF analyses
- Additional experiment for November 2001 episode with NCEP analyses: multi-analyses ensemble to test the hydro-meteorological chain errors owing to the initial and boundary conditions in the databases
- Three domains: 22.5, 7.5 and 2.5 km, interacting with each other and 24 vertical σ-levels
- Kain-Fritsch scheme is used to parameterise convection for the first domain, no convective scheme for the inner ones
- The experiments consider a 48-h period simulation

Multi-physics ensemble of MM5 simulations

- Defined as multiple combinations of the model’s physical parameterizations:
  - to assess the sensitivity of the small-scale features of the QPFs to errors in the approximations of these schemes
  - to better encompass the atmospheric processes leading to heavy precipitations

<table>
<thead>
<tr>
<th>Explicit moisture scheme</th>
<th>Labels</th>
</tr>
</thead>
<tbody>
<tr>
<td>IMPHYS=4</td>
<td>Simple ice</td>
</tr>
<tr>
<td>IMPHYS=5</td>
<td>Mixed-phase</td>
</tr>
<tr>
<td>IMPHYS=6</td>
<td>Graupel</td>
</tr>
<tr>
<td>IMPHYS=7</td>
<td>Reisner-Graupel</td>
</tr>
<tr>
<td>IMPHYS=8</td>
<td>Schultz</td>
</tr>
<tr>
<td>Convection scheme in 2nd domain</td>
<td></td>
</tr>
<tr>
<td>ICUPA=8</td>
<td>Kain-Fritsch</td>
</tr>
<tr>
<td>PBL parameterization</td>
<td>Hong-Pan</td>
</tr>
</tbody>
</table>

The best estimation of the initial conditions for the hydrological parameters can be obtained from the high resolution observational campaign developed by the CORINE Land Cover project
- The experiments consider a 72-h period simulation
Spatial distributions of accumulated rainfall patterns for the control simulations (in mm)
Results: MM5 control simulations

Spatial distributions of accumulated rainfall patterns for the control simulations (in mm)
Results: rain-gauge and MM5 control driven runoff simulations

It has been used to compare rain-gauge and QPFs driven discharge simulations:

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

\[
NSE = 1 - \frac{\sum_{i=1}^{n} (x_i - y_i)^2}{\sum_{i=1}^{n} (x_i - \bar{x})^2},
\]

\[x_i = \text{observed runoff}, \quad y_i = \text{simulated runoff}, \quad \bar{x} = \text{mean observed runoff}\]

• % error in volume (% EV>0: volume simulated is overestimated)

\[
\% EV = \left( \frac{V_S - V_O}{V_O} \right) \times 100, \quad V_S = \text{simulated hydrograph volume}, \quad V_O = \text{observed hydrograph volume}
\]
Results: rain-gauge and MM5 control driven runoff simulations

<table>
<thead>
<tr>
<th>MM5-control</th>
<th>NSE</th>
<th>% EV</th>
</tr>
</thead>
<tbody>
<tr>
<td>7-8 Oct 1990</td>
<td>0.28</td>
<td>55.4</td>
</tr>
<tr>
<td>8-9 Oct 1990</td>
<td>-0.2</td>
<td>-98.7</td>
</tr>
<tr>
<td>9-10 Oct 1990</td>
<td>-0.15</td>
<td>-91.6</td>
</tr>
<tr>
<td>10-11 Nov 2001</td>
<td>-1.53</td>
<td>73.1</td>
</tr>
<tr>
<td>10-11 Nov 2001 (NCEP)</td>
<td>0.94</td>
<td>1.7</td>
</tr>
<tr>
<td>3-4 Apr 2002</td>
<td>0.60</td>
<td>27.8</td>
</tr>
</tbody>
</table>

- 7-8 Oct 1990, 10-11 Nov 2001 (NCEP) and 3-4 Apr 2002 experiments are found to be suitable in order to introduce discharge predictions.
- 8-9, 9-10 Oct 1990 and 10-11 Nov 2001 runs show a very deficient performance. A noticeable impact due to the uncertainties of the initial and boundary conditions are found.
- Can the multi-physical ensemble address the low forecast skill?
- Explore the external-scale uncertainty of the QPFs owing to the physical parameterizations.
• 7-8 Oct 1990, 10-11 Nov 2001 (NCEP) and 3-4 Apr 2002 experiments are found to be suitable in order to introduce discharge predictions
• 8-9, 9-10 Oct 1990 and 10-11 Nov 2001 runs show a very deficient performance. A noticeable impact due to the uncertainties of the initial and boundary conditions are found
• Can the multi-physical ensemble address the low forecast skill?
• Explore the external-scale uncertainty of the QPFs owing to the physical parameterizations
Results: multi-physics ensemble of MM5 simulations

Ensemble mean (mm; shaded contours) and ensemble standard deviation (mm; continuous line) of the accumulated precipitation for each case study.

(a) 7-8 Oct 1999

(b) 8-9 Oct 1999
Results: multi-physics ensemble of MM5 simulations

Ensemble mean (mm; shaded contours) and ensemble standard deviation (mm; continuous line) of the accumulated precipitation for each case study.

(c) 9-10 Oct 1990

Results: multi-physics ensemble of MM5 simulations

Ensemble mean (mm; shaded contours) and ensemble standard deviation (mm; continuous line) of the accumulated precipitation for each case study.

(d) 10-11 Nov 2001
Results: multi-physics ensemble of MM5 simulations

Ensemble mean (mm; shaded contours) and ensemble standard deviation (mm; continuous line) of the accumulated precipitation for each case study.
Results: multi-physics ensemble of MM5 driven runoff simulations

- Some members of the ensembles have outperformed the control simulations and have reduced biases at the basin outlet
- For the 10-11 Nov 2001 event, the MM5 ensemble driven by NCEP analyses have shown a better accuracy. But the differences owing to the initial and boundary conditions are considerable smoothed by the multi-physics ensemble
- Convection in 2nd domain seems to benefit some episodes
Results: multi-physics ensemble of MM5 driven runoff simulations

- Some members of the ensembles have outperformed the control simulations and have reduced biases at the basin outlet
- For the 10-11 Nov 2001 event, the MM5 ensemble driven by NCEP analyses have shown a better accuracy. But the differences owing to the initial and boundary conditions are considerable smoothed by the multi-physics ensemble
- Convection in 2nd domain seems to benefit some episodes

Results: multi-physics ensemble of MM5 driven runoff simulations

- Some members of the ensembles have outperformed the control simulations and have reduced biases at the basin outlet
- For the 10-11 Nov 2001 event, the MM5 ensemble driven by NCEP analyses have shown a better accuracy. But the differences owing to the initial and boundary conditions are considerable smoothed by the multi-physics ensemble
- Convection in 2nd domain seems to benefit some episodes
• Some members of the ensembles have outperformed the control simulations and have reduced biases at the basin outlet.

• For the 10-11 Nov 2001 event, the MM5 ensemble driven by NCEP analyses have shown a better accuracy. But the differences owing to the initial and boundary conditions are considerable smoothed by the multi-physics ensemble.

• Convection in 2nd domain seems to benefit some episodes.
Results: multi-physics ensemble of MM5 driven runoff simulations

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>MMS-4-5</td>
<td>0.75</td>
<td>-0.8</td>
<td>0.22</td>
<td>0.055</td>
<td>0.49</td>
<td>0.71</td>
</tr>
<tr>
<td>MMS-5-5</td>
<td>-0.13</td>
<td>1.18</td>
<td>0.06</td>
<td>-0.05</td>
<td>0.52</td>
<td>0.51</td>
</tr>
<tr>
<td>MMS-6-5</td>
<td>0.31</td>
<td>-0.6</td>
<td>-0.01</td>
<td>-0.14</td>
<td>0.33</td>
<td>0.57</td>
</tr>
<tr>
<td>MMS-7-5 (control)</td>
<td>0.28</td>
<td>0.5</td>
<td>0.07</td>
<td>0.015</td>
<td>0.51</td>
<td>0.84</td>
</tr>
<tr>
<td>MMS-8-5</td>
<td>0.31</td>
<td>-0.5</td>
<td>-0.17</td>
<td>-0.13</td>
<td>-0.14</td>
<td>0.74</td>
</tr>
<tr>
<td>MMS-9-5</td>
<td>-0.63</td>
<td>-0.2</td>
<td>-0.11</td>
<td>0.17</td>
<td>0.57</td>
<td>1.7</td>
</tr>
<tr>
<td>MMS-10-5</td>
<td>0.39</td>
<td>-0.5</td>
<td>0.03</td>
<td>-0.09</td>
<td>0.57</td>
<td>18.5</td>
</tr>
<tr>
<td>MMS-11-5</td>
<td>-0.30</td>
<td>-0.2</td>
<td>0.05</td>
<td>-0.02</td>
<td>0.57</td>
<td>13.6</td>
</tr>
<tr>
<td>MMS-12-5</td>
<td>0.58</td>
<td>-0.6</td>
<td>0.20</td>
<td>0.04</td>
<td>0.52</td>
<td>1.5</td>
</tr>
<tr>
<td>MMS-13-5</td>
<td>0.21</td>
<td>-0.7</td>
<td>0.09</td>
<td>0.04</td>
<td>0.52</td>
<td>1.5</td>
</tr>
<tr>
<td>mean</td>
<td>0.68</td>
<td>-0.7</td>
<td>0.26</td>
<td>-0.13</td>
<td>0.73</td>
<td>0.14</td>
</tr>
</tbody>
</table>

Conclusions and further remarks

- The high-resolution numerical weather control forecasts have reproduced some of the extreme precipitation events under study: feasibility to introduce discharge predictions despite the small-sized basin

- Some elements of the multi-physics ensemble outperform the control simulations and reduce biases at the Albufera outlet. The inclusion of an enhanced description for convection seems to benefit some episodes (e.g. 9-10 Oct 1990 convectively driven flash-flood)

- Initial and boundary conditions uncertainties are found to play an important role in the quality of the control QPFs for the 10-11 Nov 2001 event. These errors are smoothed by the use of the multi-physics ensemble

- The one-way coupling between the meteorological and hydrological models has been regarded as a complementary tool to evaluate the QPFs

- No precipitation assimilation technique has been used in the one-way coupling: future implementation of applications such as statistical downscaling or disaggregation techniques