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Hydrometeorological analysis of an extreme flash-flood: The 28 September 2012 event in Murcia, south-eastern Spain

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2. The San Wenceslao flash-flood event
3. Preliminary analysis
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5. Basin response and hydrological modelling
6. Kinematics of the San Wenceslao flash-flood
7. Conclusions and further remarks

1. Motivations and background

- Climate change poses major challenges for current societies: impact on mean and extreme hydrometeorological regimes

- The Mediterranean region emerges as especially responsive to climate change and extremes: more frequent and intense heavy precipitations are projected

- The Spanish Mediterranean is a flash-flood prone region during late summer and early autumn. Mesoscale Convective Systems (MCSs): high precipitation rates persist for several hours over individual basins

- Many small-to-medium size steep and densely urbanized coastal basins reduce further the hydrological response times and increase associated risks

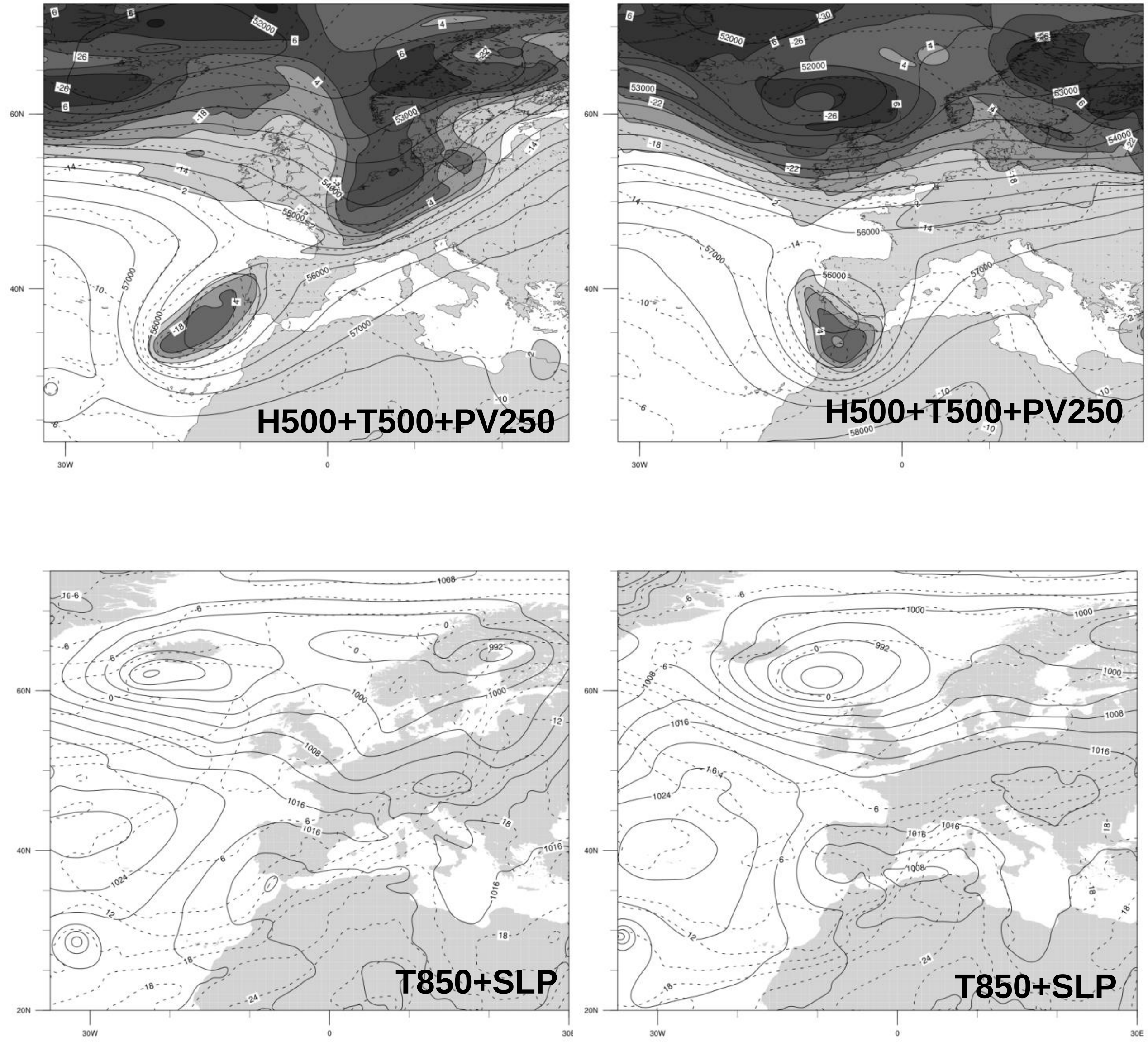
- To highlight the most relevant hydrometeorological mechanisms associated with a catastrophic flash-flood over south-eastern Spain

2. The San Wenceslao flash-flood event

Synoptic situation

- Entrance of a deep upper-level closed trough
- Generation of a surface mesoscale cyclone
- Advection of warm and moist air toward Almería and Murcia from the Mediterranean
- Convergence zone between easterly advection and westerly low-level flow from southern Spain and North Africa

slow-moving V-shaped MCS



27 September 2012 12 UTC

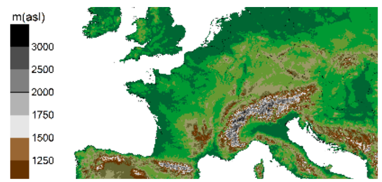
28 September 2012 12 UTC

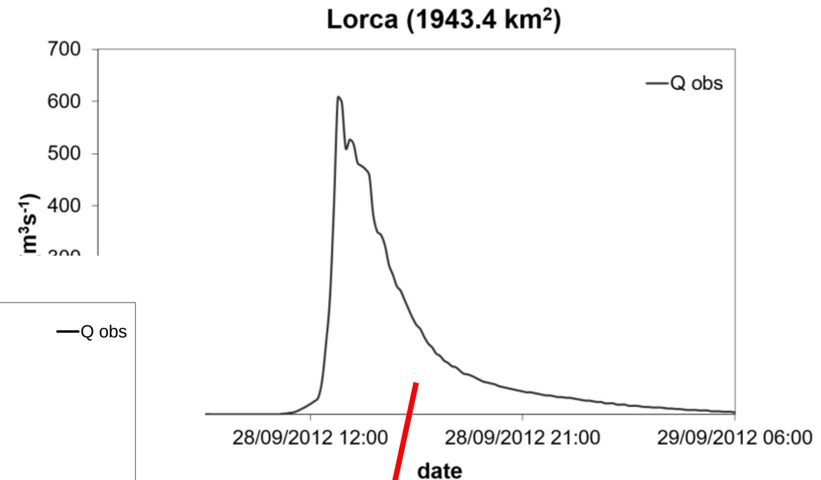
2. The San Wenceslao flash-flood event

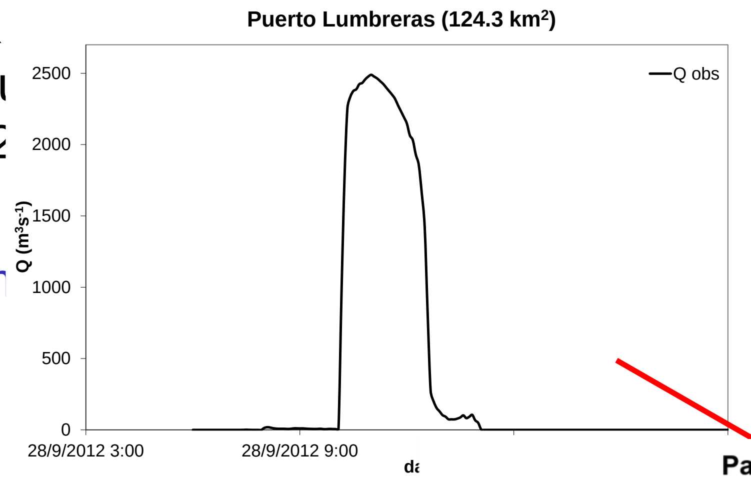
- Torrential precipitation took place on 28 September 2012 (San Wenceslao): 240 mm/day in Murcia

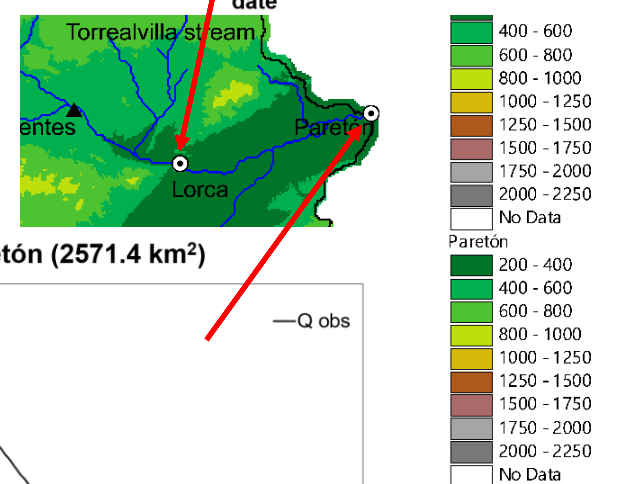
- The Guadalentín R… semi-arid and medi… basin with an area of 2…

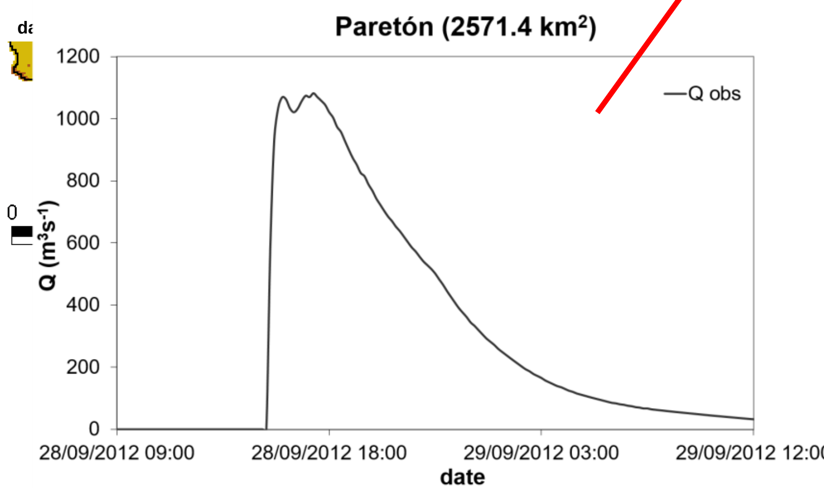
- 37 mm/5min, 119 m… 214 mm/8h inside the











- Peak discharges
- Lorca: 616.3 m3s-1 at 13:15 UTC
- Paretón: Two consecutive maximums of 1067.9 and 1081.2 m^3s^{-1} at 16:00 and 17:20 UTC

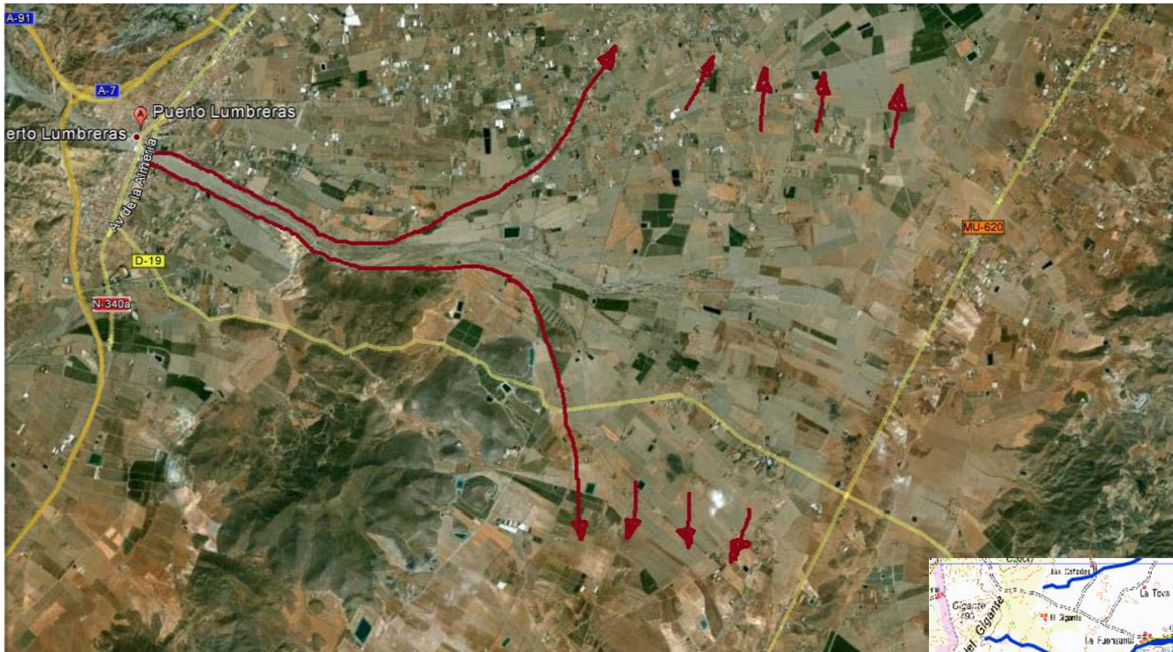
2. The San Wenceslao flash-flood event

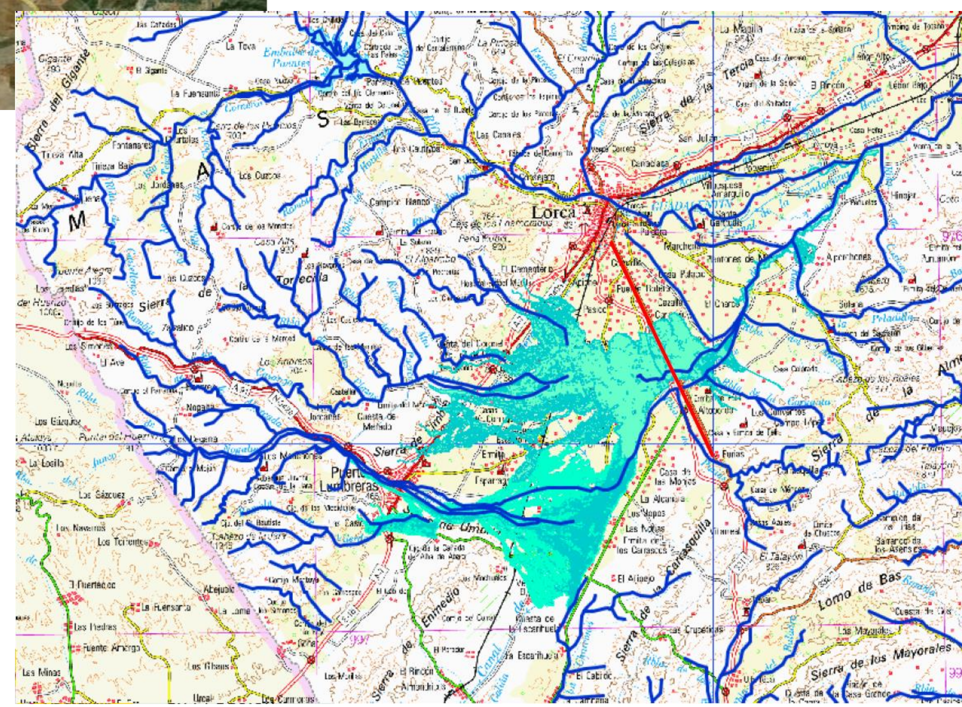
2. The San Wenceslao flash-flood event


Rambla de Béjar (Puerto Lumbreras-Lorca)

- 6 casualties. Material losses estimated at about 64 M€

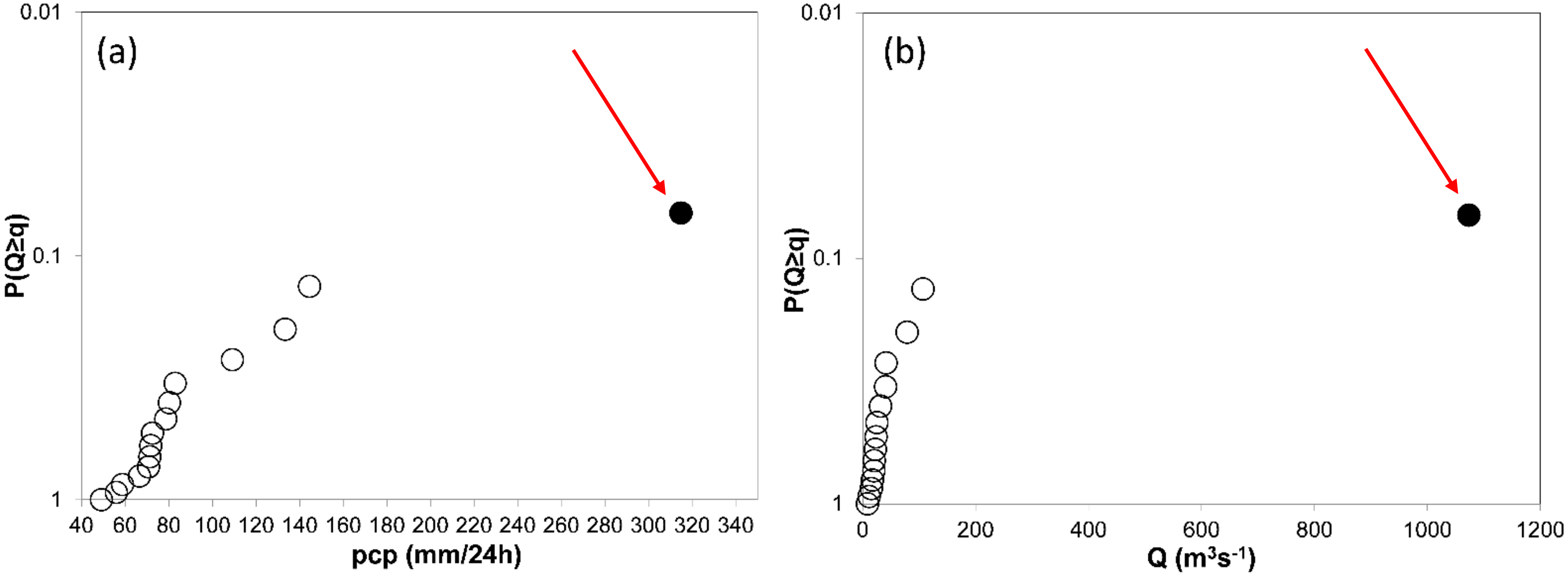
2. The San Wenceslao flash-flood event





2. The San Wenceslao flash-flood event

- Rare episode: dominates the upper tail of the precipitation and runoff frequency distributions

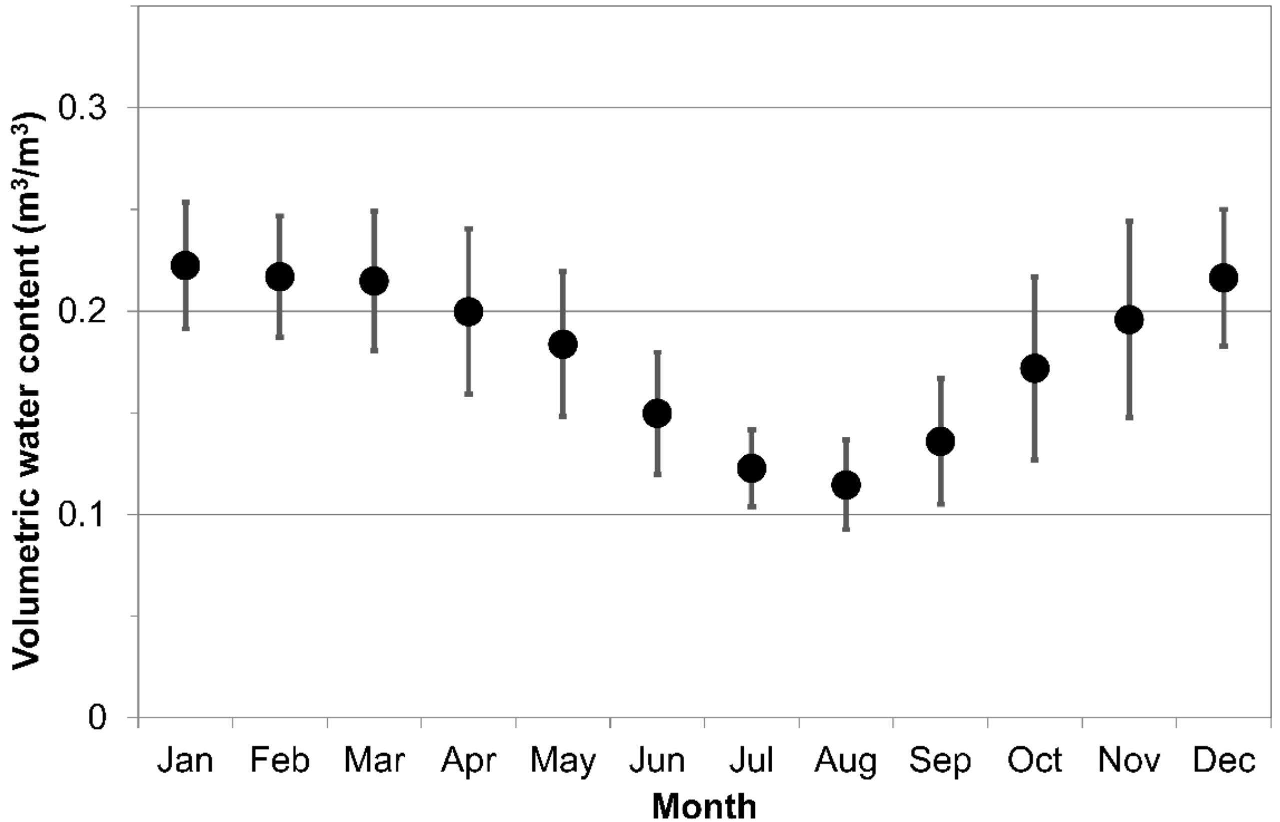


Annual frequency analysis of the daily observed rainfall amounts and hourly observed peak discharges for the 2000-2014 period

3. Preliminary analysis

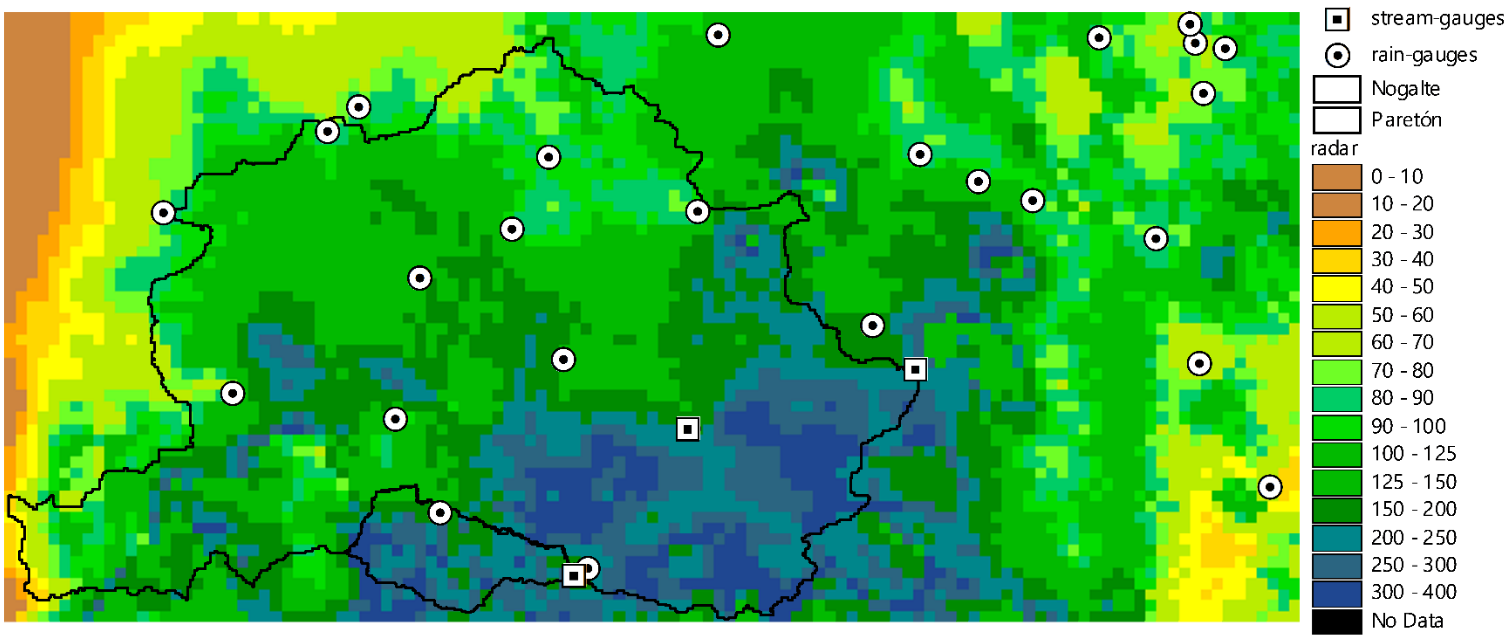
- Impact of torrential precipitations over a basin with persistent dry soils (<0.25 m^3m^{-3})
- Lithology features large spatial heterogeneities: karstic and dolomitic fractured bedrocks, but also relative impermeable substrates. High soil moisture capacities
- Sparse vegetation, thin soils and convective precipitations –which easily exceeds the high initial soil infiltration capacity– lead to fast Hortonian surface and flow velocities in the river streams

Monthly mean climatological soil moisture for the 2000-2014 period



4. Observed databases and precipitation analysis

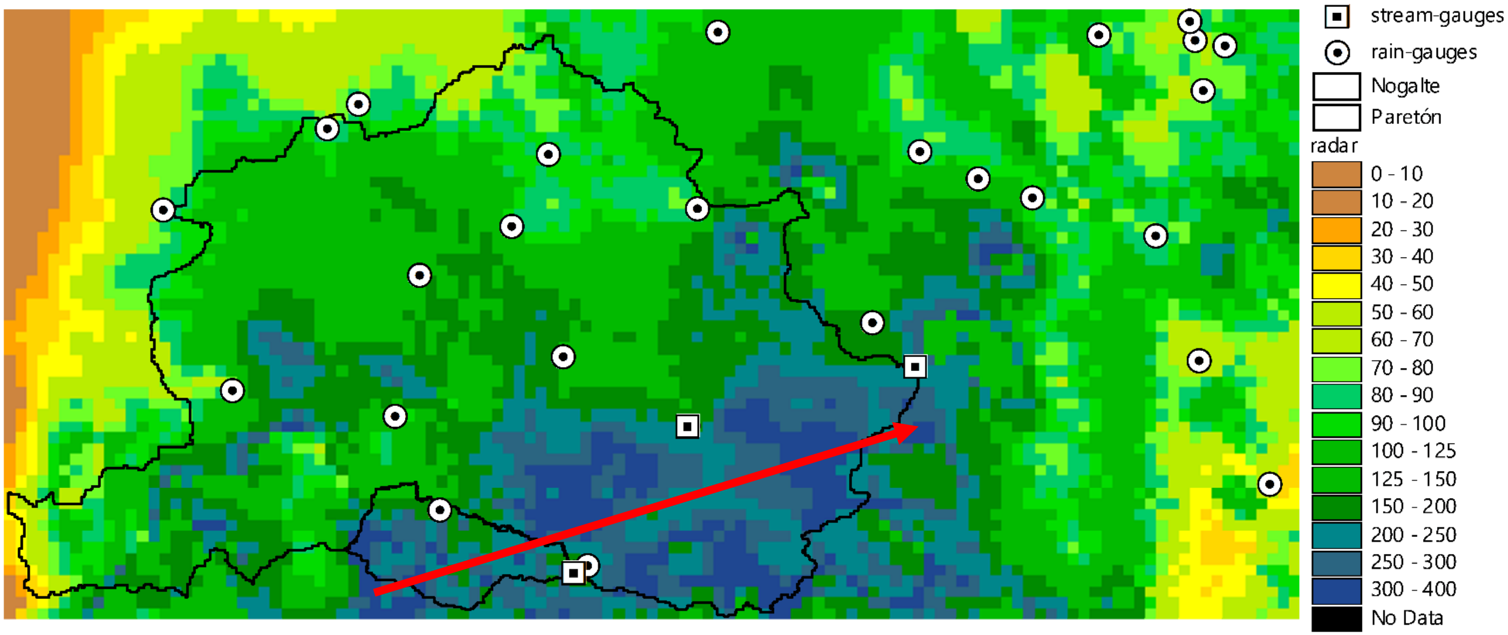
- Quantitative rainfall estimations derived from 10-min reflectivity scans of the Almería and Valencia radars at 1 km spatial resolution from 27 to 29 September 2012 00 UTC
- 5-min rainfall available from 108 automatic stations. 28 close or inside the basin
- 5-min runoff available in Puerto Lumbreras, Lorca and Paretón



Spatial distribution of the 48-h accumulated radar-derived precipitation

4. Observed databases and precipitation analysis

- Clear trail of the MCS passage along southernmost part of the basin
- Followed a south-west to north-east direction, affecting the basin from 09 to 13 UTC on September 28
- Estimated speed: 3.0 ms^{-1}



Spatial distribution of the 48-h accumulated radar-derived precipitation

5. Basin response and hydrological modelling

- Initially dry and spatially heterogeneous soils enhanced a nonlinear hydrological response to intense precipitations: general small runoff coefficients, but Nogalte exhibited impressive unit peak discharge and channel flow velocities

Basin	Contributing basin area (km^2)	Total rainfall (mm)	Total runoff (mm)	Peak discharge (m^3s^{-1})	Unit peak discharge ($m^3s^{-1}km^{-2}$)	Runoff ratio (–)
Valdeinfierno	430. 6	123.8	13.6	NA	NA	0.11
Puentes	1011.0	130.7	9.3	NA	NA	0.07
Torrealvilla	236.4	136.6	NA	300-450*	1.27-1.90	NA
Lorca	389.8	154.8	18.7	607.6	1.56	0.12
Paretón	1016.7	210.4	28.6	1081.2	1.06	0.14
Nogalte	124.3	211.7	NA	1050*-1500**	8.45-12.07	NA

5. Basin response and hydrological modelling

FEST model set-up

- Physically-based and fully-distributed. Soil moisture fluxes, θ_{ij}, are computed by solving the water balance equation at each grid-point as:

$$\frac{\partial \theta_{ij}}{\partial t} = \frac{1}{Z_{ij}} \cdot (P_{ij} - R_{ij} - D_{ij} - ET_{ij})$$

where P is the precipitation rate, R and D the runoff and drainage fluxes, ET the evapotranspiration, and Z the soil depth.

- Loss rate: Modified Soil Conservation Service-Curve Number (SCS-CN) method extended for continuous simulation as:

$$S = S_1 \cdot (1 - \varepsilon) + S_3 \cdot \varepsilon$$

where ε is the degree of saturation and S_1 and S_3 are the maximum potential retention for AMC I and III, respectively.

- Surface flow routing: Muskingum method.
- Reservoir: Third-order Runge-Kutta method for the level pool scheme
- Continuous observation-driven simulations at hourly time-step

5. Basin response and hydrological modelling

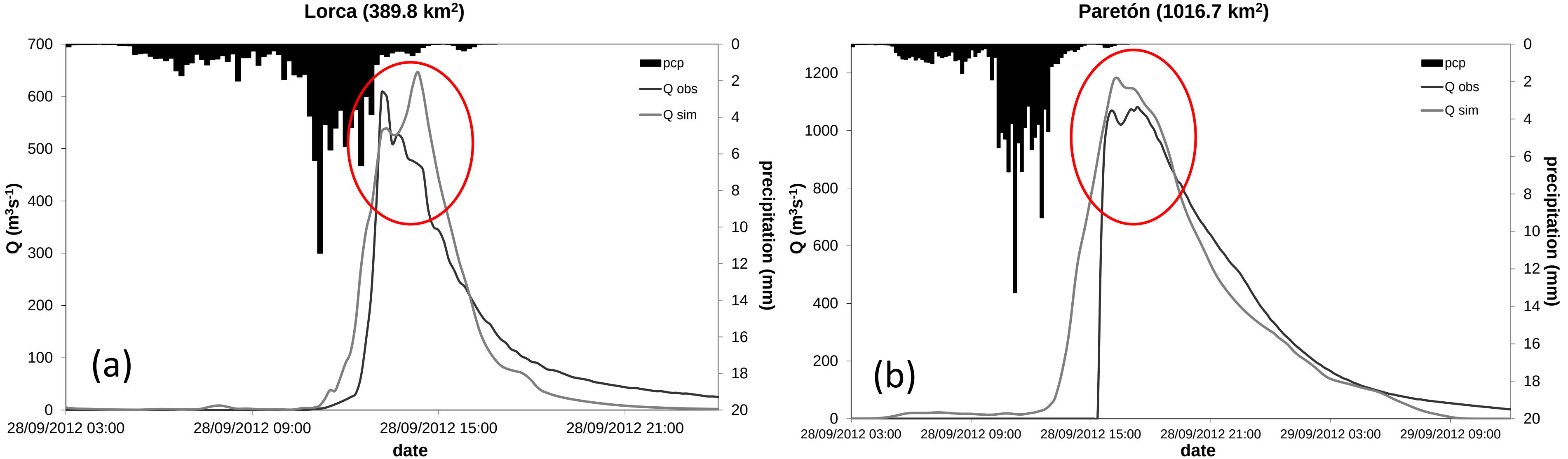
• Multisite calibration due to diversity of physiographic features and heterogeneities in the basin response.

• Calibration parameters

- Dynamical routing (Muskingum method): Overland (V_{hs}) and channel (V_c) velocities
- Losses (SCS-CN method): Infiltration storativity (S_0) and initial abstraction ratio (λ)

Basin	Contributing basin area (km²)	Total rainfall (mm)	CN (II)	So (mm)	λ	V_h (ms^{-1})	V_c (ms^{-1})
Valdeinfierno	430. 6	123.8	70.1 (11.3)	304.8	0.30	0.28	2.9
Puentes	1011.0	130.7	68.1 (12.1)	508.0	0.40	0.32	3.3
Torrealvilla	236.4	136.6	67.7 (11.3)	558.8	0.35	0.34	4.0
Lorca	389.8	154.8	70.2 (11.0)	508.0	0.30	0.31	2.2
Biznaga	404.8	255.8	72.6 (11.1)	355.6	0.30	0.06	1.1
Paretón	1016.7	210.4	70.8 (11.1)	304.8	0.30	0.24	2.1
Nogalte	124.3	211.7	81.0 (9.8)	254.0	0.20	0.38	5.0

5. Basin response and hydrological modelling



basin	Flow volumes			Flow peaks			
	OBS (mm)	FEST (mm)	Rel. Error	OBS (m^3s^{-1})	FEST (m^3s^{-1})	Rel. error	NSE
Valdeinfierno	13.6	13.0	-0.04	NA	595.8	–	–
Puentes	9.3	9.4	0.01	NA	1172.0	–	–
Torrealvilla	NA	11.9	–	300-450*	369.8	–	–
Lorca	18.7	18.8	0.01	607.6	646.2	0.06	0.89
Biznaga	NA	33.3	–	NA	495.6	–	–
Paretón	28.6	31.2	0.09	1081.2	1182.6	0.09	0.84
Nogalte	NA	124.8	–	1050*-1500**	1544.3	–	–

6. Kinematics of the San Wenceslao flash-flood

- Spatial moments of catchment rainfall: relate spatial organization of precipitation to a basic descriptor of drainage network structure, the flow distance

1. n-order spatial moments of the rainfall field:

$$\mathrm{p_n}(\mathrm{t}) = |A|^{-1} \int_A r(x,y,t)\, d(x,y)^n \, dA$$

2. n-order moments of the flow distance:

$$\mathrm{g_n} = |A|^{-1} \int_A d(x,y)^n \, dA$$

- First two spatial moments of catchment rainfall describe the instantaneous spatial rainfall organization at t:

$$\left.\begin{aligned} \delta_1 1(\mathrm{t}) &= \frac{1}{\mathrm{g_1}} \frac{\mathrm{p_1(t)}}{\mathrm{p_0(t)}} \\ \delta_2(\mathrm{t}) &= \frac{1}{\mathrm{g_2} - \mathrm{g_1}^2} \left[\frac{\mathrm{p_2(t)}}{\mathrm{p_0(t)}} - \left(\frac{\mathrm{p_1(t)}}{\mathrm{p_0(t)}} \right)^2 \right] \end{aligned}\right\} \xrightarrow{\mathrm{P_n} = \frac{1}{T_s} \int_{T_s} p_n(t)\, dt} \left\{\begin{aligned} \Delta_1 &= \frac{1}{\mathrm{g_1}} \left[\frac{\mathrm{P_1}}{P_0} \right] \\ \Delta_2 &= \frac{1}{\mathrm{g_2} - g_1^2} \left[\frac{P_2}{\mathrm{P_0}} - \left(\frac{\mathrm{P_1}}{\mathrm{P_0}} \right)^2 \right] \end{aligned}\right.$$

- Δ_1 and Δ_2 describe the rainfall organization over the total storm duration (T_s)

6. Kinematics of the San Wenceslao flash-flood

- δ_1: distance between catchment rainfall and basin centroids
- $\delta_1 \cong 1$: rainfall distribution concentrated on catchment centroid or spatially uniform
- $\delta_1 < (>) 1$: rainfall distributed close to the basin outlet (headwaters)

- δ_2: dispersion rainfall-weighted flow distances about their mean value with respect to dispersion of flow distances
- $\delta_2 \cong 1$: uniform-like rainfall distribution
- $\delta_2 < (>) 1$: unimodal (multimodal) distribution along the flow distance

Based on these metrics:

- Effective storm velocity: $\mathrm{v_{eff}} = g_1 \frac{d}{dt} \delta_1(t)$
- Catchment-scale storm velocity: $\mathrm{v_s} = \mathrm{g_1} \left[\frac{cov_{\mathrm{t}}[T, \delta_1(\mathrm{t}) \cdot w(t)]}{\mathrm{var}[T]} - \frac{cov_{\mathrm{t}}[T, w(t)]}{\mathrm{var}[T]} \Delta_1 \right]$

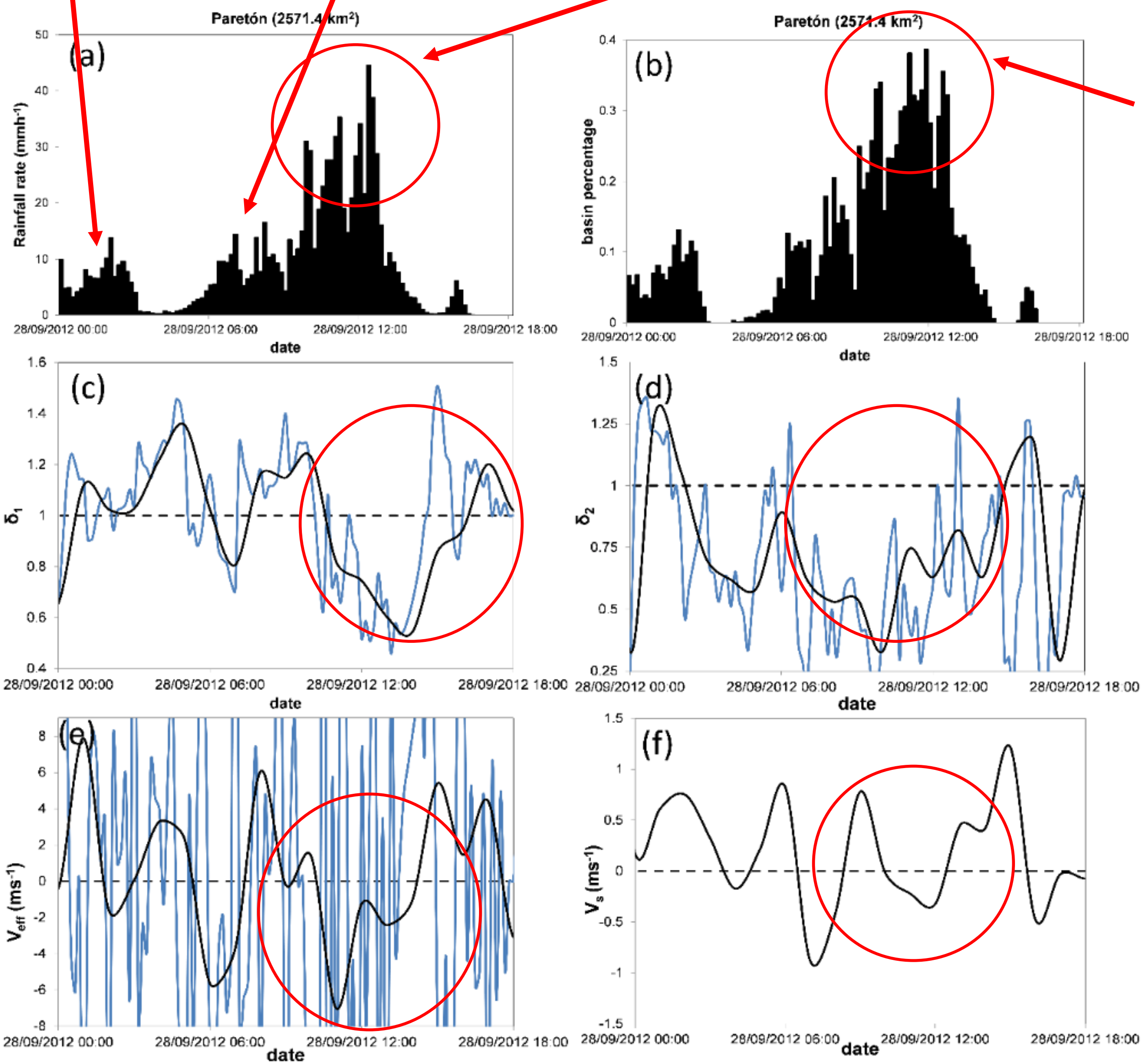
- $\mathrm{V_{eff}}$ and $\mathrm{v_s}$ quantify the rate of storm motion up and down the basin accounting for the interaction between spatial and temporal variability in rainfall and the structure of the drainage network. Assessment of the impact of storm motion on flood shape.
- $\mathrm{V_{eff}}, \mathrm{V_s} > (<) 0$: upstream (downstream) storm movement

6. Kinematics of the San Wenceslao flash-flood

First organized convective bands

Successive organized convective bands

MCS impacted the south-westernmost part of the basin from 09 UTC. Time of passage: 4 hours



Maxima fractional coverages close to 0.4 during passage of the MCS (~1000 km^2)

The metrics clearly quantify MCS impact

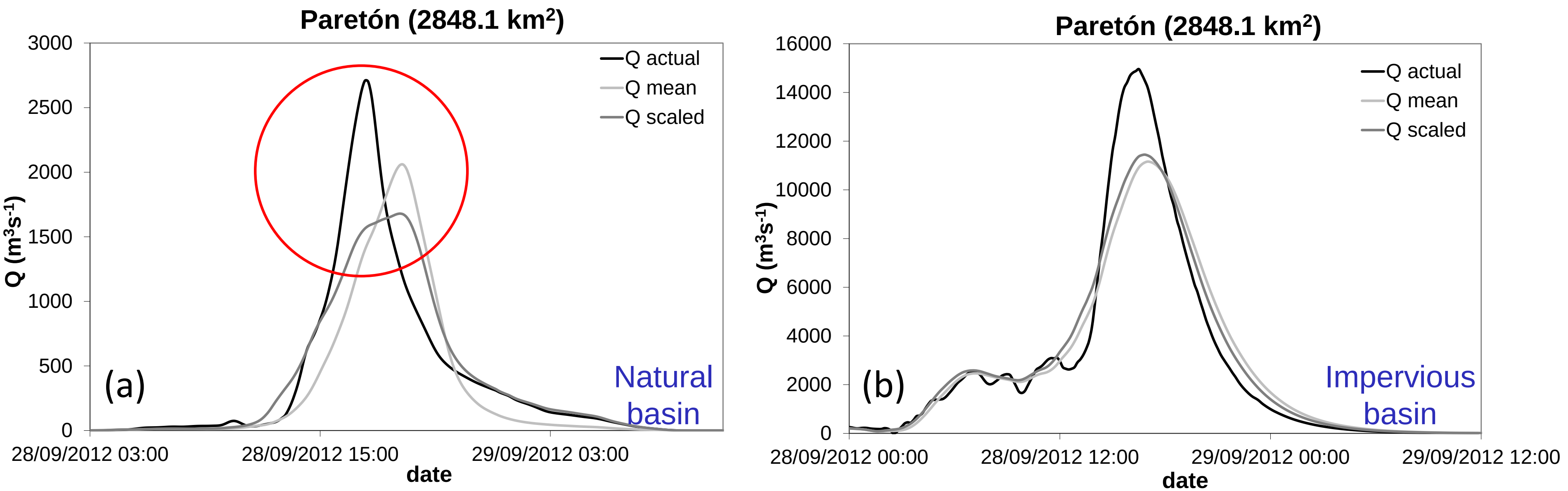
δ1 reflects the passage of different convective rainfall bands and MCS through the basin

δ2 mainly indicates a spatial concentration over the catchment centroid.

V_{eff} and V_s describe successive up- and down-stream motions. Clear trail of the MCS downstream motion

7. Storm movement and soil variability

- Three distinct hydrological simulations were performed by using 10-min actual, spatially uniform and scaled radar-derived precipitations
- Encompass different levels of spatial and temporal variability. Spatially uniform rainfall fields neglect spatial variability. Scaled precipitation neglects storm movement



- Impact storm motion on the flood hydrograph: reduce base time, focusing and exacerbating peak discharge
- Basin drainage structure, temporal pattern of the rainfall rates and overall precipitation organization modulate time to peak, resulting in an advancement (~2 h)
- These features appear to be little sensitive to soil heterogeneities

7. Conclusions and further remarks

- Climate change: redistribution of hydrometeorological mean and extreme regimes over the Mediterranean. Region characterized by high level of exposure to flash-floods

- The San Wenceslao episode provides a paradigm of an extreme flood over the Mediterranean Spain. Main conclusions are:

1. Heavy precipitation and flash-flooding had a multifaceted origin: deep convection triggered by local orography but also by the passage of convective bands and a slow-moving MCS

2. Distinct soil substrates led to myriad soil responses and runoff generation. Multisite calibration of the hydrological model to reproduce satisfactorily the basin response

3. Downstream motion of MCS exacerbated the peak discharge. Time to peak modulated by river network geometry, temporal rainfall patterns and overall precipitation organization

- Flood control structural measures were effective but not enough to avoid catastrophic impacts

7. Conclusions and further remarks

- Any structural measure can fully guarantee complete safety before such hazardous events. Complemented by diverse non-structural measures:

1. Precise forecasting of small-scale convection and MCSs is challenging, but early warning systems based on advanced hydrometeorological EPS can help expand the lead times many hours ahead

2. Awareness, information and training campaigns for local populations arise a fundamental to minimize casualties and material damages

3. Policymakers and water management agencies should also devote their efforts in reducing the high level of exposure to flash-flooding in the Mediterranean. Building and agricultural activities should be carried out well beyond floodplains of ephemeral streams

Amengual A. and Borga M., 2019: Hydrometeorological analysis of an extreme flash-flood: The 28 September 2012 event in Murcia, south-eastern Spain. In Leal Filho, Nagy, Borga, Chavez, Magnuszwesk (Eds). Climate Change, Hazards and Adaptation Options: handling the impacts of a changing climate. Springer (in press).

8. Epilogue

28/09/2012

After 2012… Social illiteracy in natural risks still remains or are we just playing with risk?