Universitat de les Illes Balears

MINISTERIO DE CIENCIA E INNOVACIÓN

AGENCIA ESTATAL DE INVESTIGACIÓN

PROJECTE TRAMPAS

Primera reunió: 2-3/12/2021

The role of storm motion in controlling hydrological response: the 28 September 2012 catastrophic flash flood in Murcia, southeastern Spain

1. Background

- Flash floods are typically associated with slow-moving convective precipitation systems: high sustained rainfall rates over specific catchments

- Rainstorm motion: continuous change of spatial and temporal variability in rainfall. Flood response can be closely linked to storm kinematics

- Impact of storm motion on flood response is not easily quantifiable from observational and numerical analyses of study cases: Complex interaction among the different properties in storms and catchments, strongly modulate flood response

- Little is known on the scale dependency of the effects of storm motion on flood peaks

2. Motivations and objectives

- The 28 September 2012 flash flood represents a prototype for organized convectively-driven precipitation systems that are likely responsible for the majority of extreme flash floods in Mediterranean Spain

- A noticeable characteristic of this event was the organized downstream motion of convective storm elements which combined to produce an otherwise unexpected, rapid rise of the river

- This extreme flash-flood event is a clear and compelling candidate to examine how rainstorm movement in the same direction as runoff may exacerbate the magnitude of flood peaks.

- Objectives:

(i) isolate the specific contribution of storm motion to flow peak

(ii) estimate the scale dependency between storm motion and flood response

3. The 28 September 2012 catastrophic flash flood event

- The upper and middle Guadalentín is a semi-arid basin with a drainage area of 2848.1km^2, located in Murcia, southeastern Spain

- Peak discharges:

Lorca:

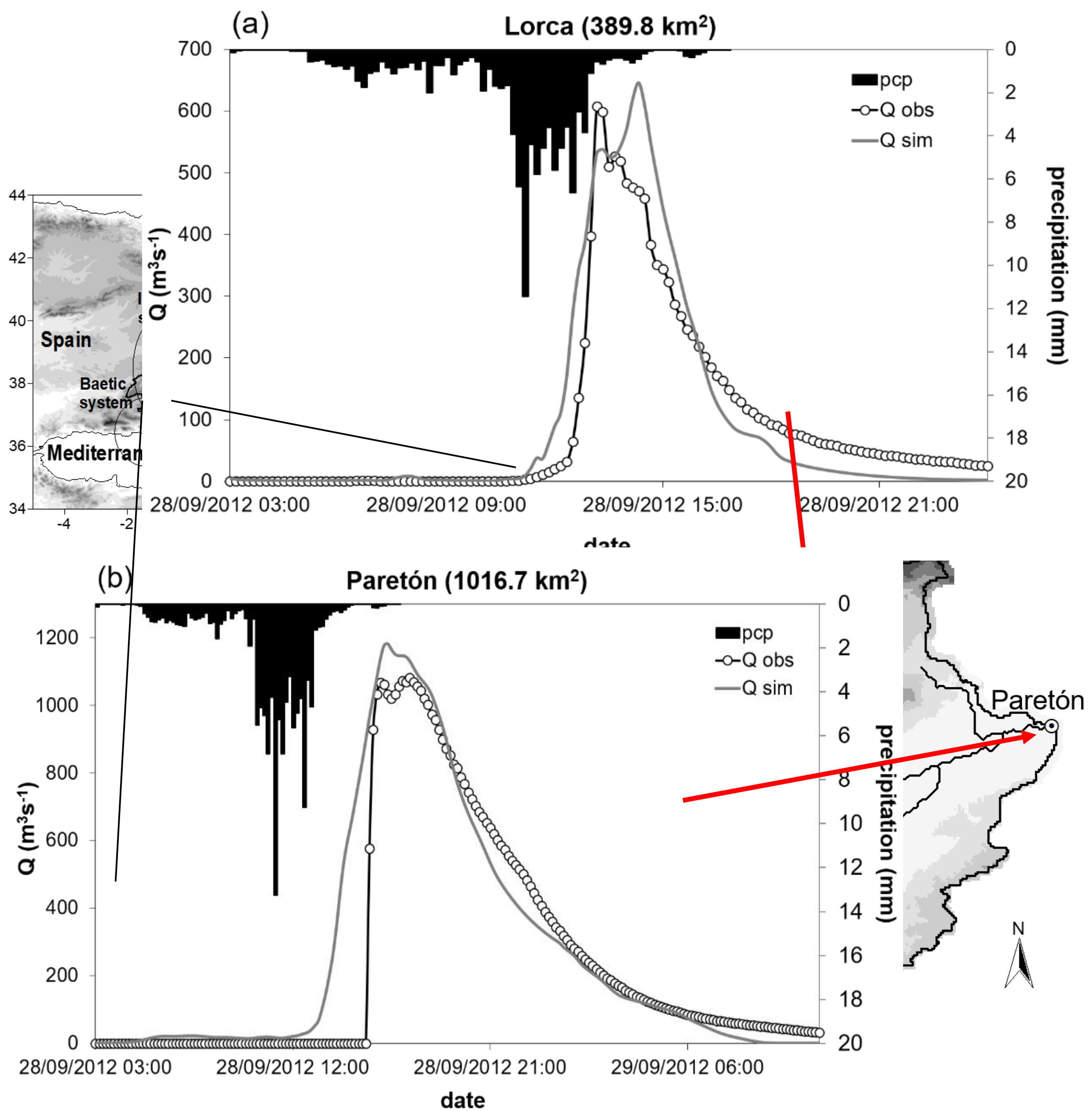
616.3 m^{3}s^{-1} at 13:15 UTC

Paretón:

1067.9 m^{3}s^{-1} at 16:00 UTC

1081.2 m^{3}s^{-1} at 17:20 UTC

- Valdeinfierno and Puentes dams were closed!!



3. The 28 September 2012 catastrophic flash flood event

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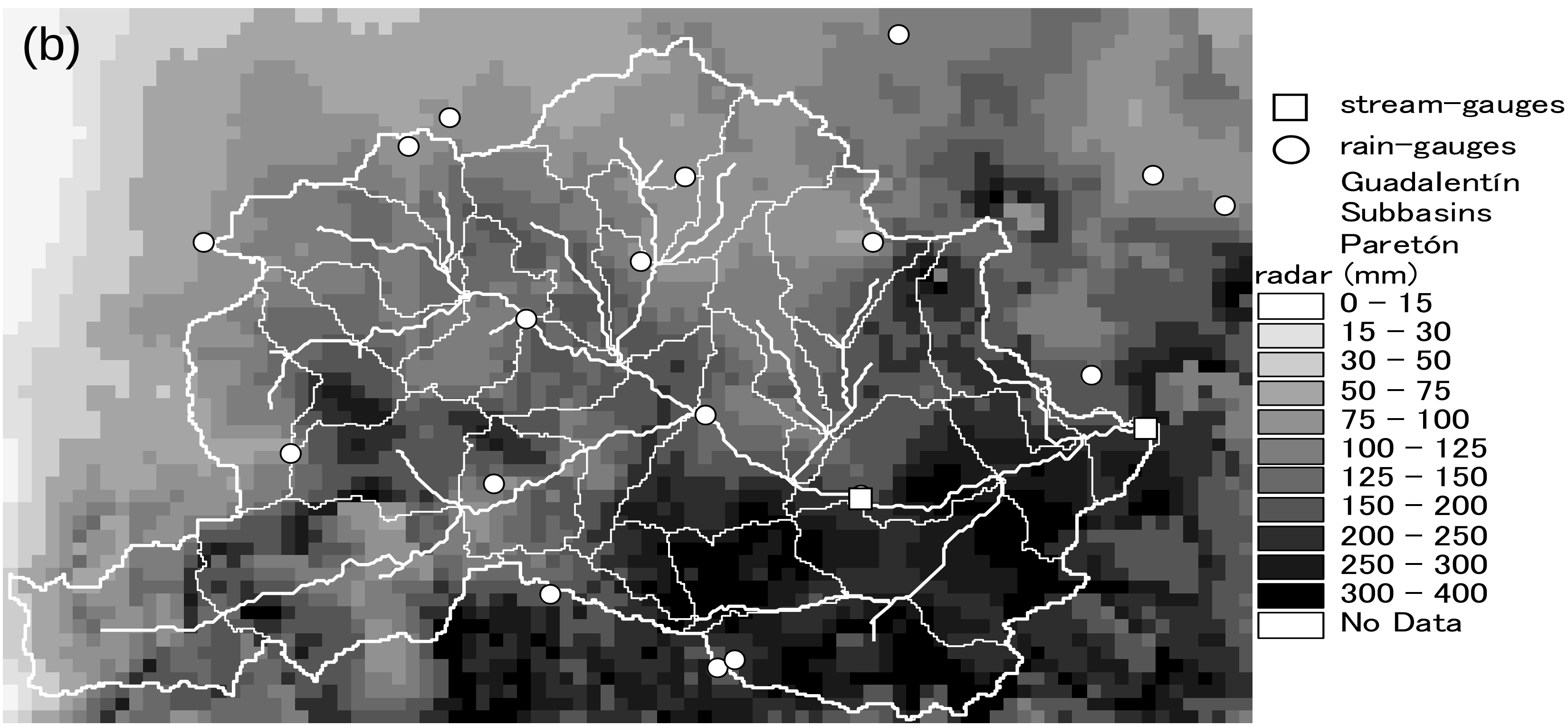
• 6 casualties within the basin. Material losses estimated at about 64 M€

4. Observed databases and precipitation analysis

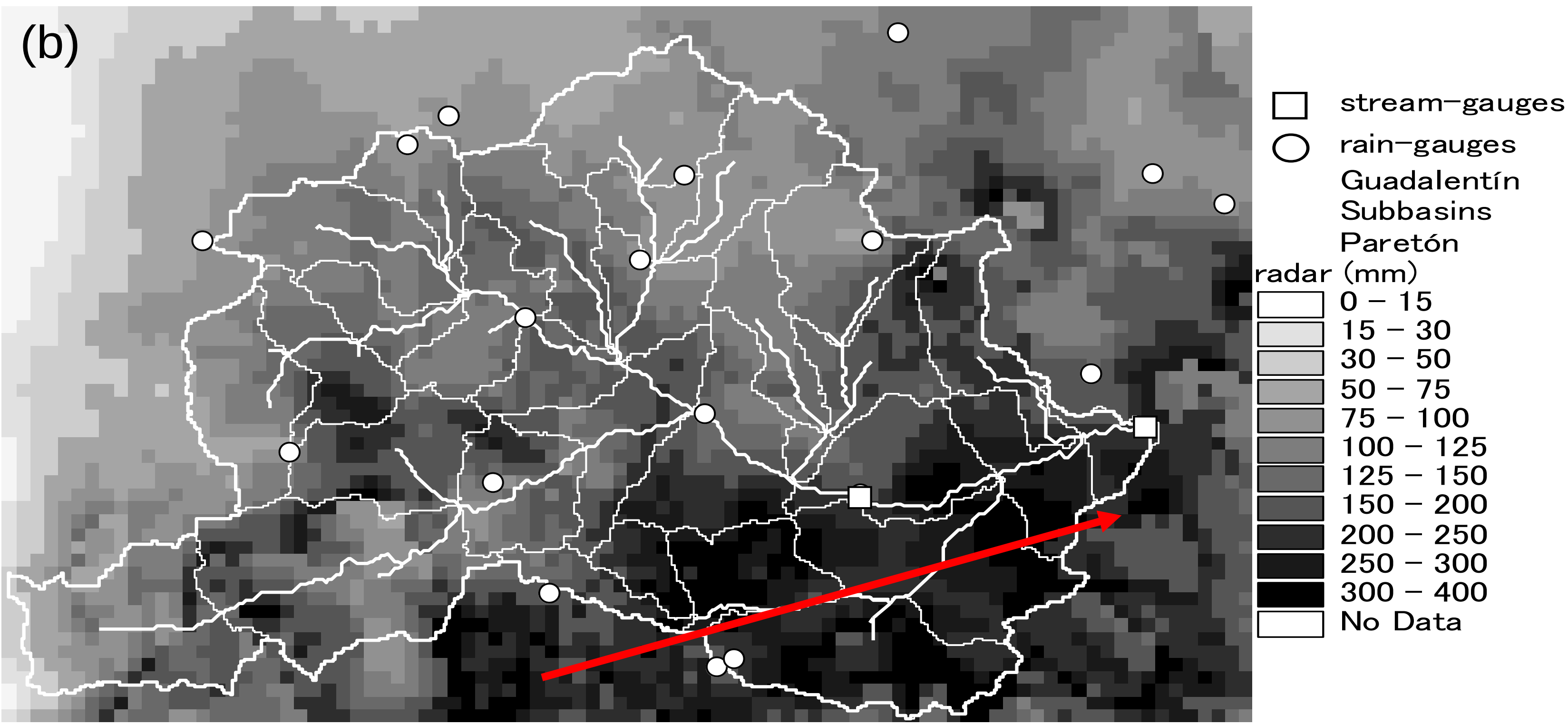
- Quantitative precipitation estimates (QPEs): reflectivity volume scans of Almería and València radars from 27 to 29 September 2012 00 UTC
- Spatial resolution: 1 km in range and 0.8º in azimuth. Every 10-min
- 5-min rainfall available from 19 automatic stations very close or inside the basin
- 5-min runoff available in Lorca and Paretón



Spatial distribution of the total accumulated QPE

4. Observed databases and precipitation analysis

- Clear track of the MCS passage along southernmost part of the basin (> 300 mm)
- Followed a south-west to north-east direction, affecting the basin from 09 to 14 UTC on September 28th
- Advective speed: 3.0-3.5 ms^{-1}



Spatial distribution of the total accumulated QPE

5. Spatial moments and catchment-scale storm velocity

- Need to quantify how the kinematic properties of storms are filtered by catchment morphological properties

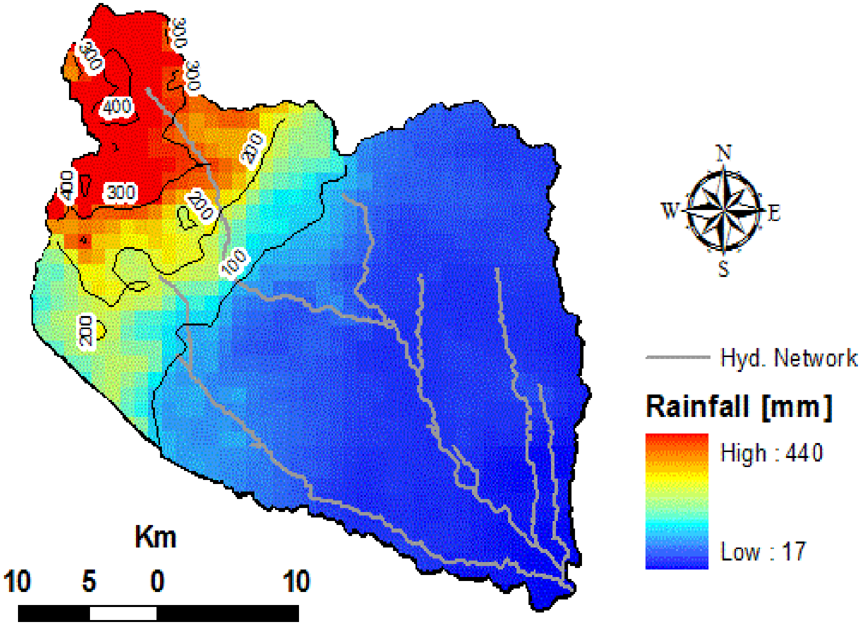
- Spatial moments of catchment rainfall: Relate the spatial and temporal organization in rainfall, r(x,y,t), to flow distance, d(x,y), a basic descriptor of the drainage network structure

- N-order spatial moments of rainfall field:

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

- N-order moments of flow distance:

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



5. Spatial moments and catchment-scale storm velocity

- First two spatial moments of catchment rainfall ($\delta_1(t)$ and $\delta_2(t)$) describe the instantaneous spatial rainfall organization at t:

$$\left.\begin{aligned} \delta_1(t) &= \frac{1}{g_1}\frac{p_1(t)}{p_0(t)} \\ \delta_2(t) &= \frac{1}{g_2 - {g_1}^2}\left[\frac{p_2(t)}{p_0(t)} - \left(\frac{p_1(t)}{p_0(t)}\right)^2\right] \end{aligned}\right\}$$

- δ_1 : distance between catchment rainfall and basin centroids
- δ_2 : relates the ratio between catchment rainfall and flow distance dispersions

- Effective storm velocity:

$$v_{eff} = g_1 \frac{d}{dt}\delta_1(t)$$

- V_{eff} copes with the role of relative basin orientation and morphology with respect to storm kinematics. It limits to convective systems having constant rainfall intensity

5. Spatial moments and catchment-scale storm velocity

- Time-integrated spatial moments of catchment rainfall Δ_1 and Δ_2: describe the rainfall organization over the total storm duration (T_s)

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

- Catchment-scale storm velocity:

$$v_s = g_1\left[\frac{cov_t[T,\delta_1(t)\cdot w(t)]}{var[T]} - \frac{cov_t[T,w(t)]}{var[T]}\Delta_1\right];\ w(t) = \frac{p_0(t)}{P_0}$$

- V_s quantifies the combined effect of rainstorm motion and dynamics of the mean rainfall rate over the drainage area

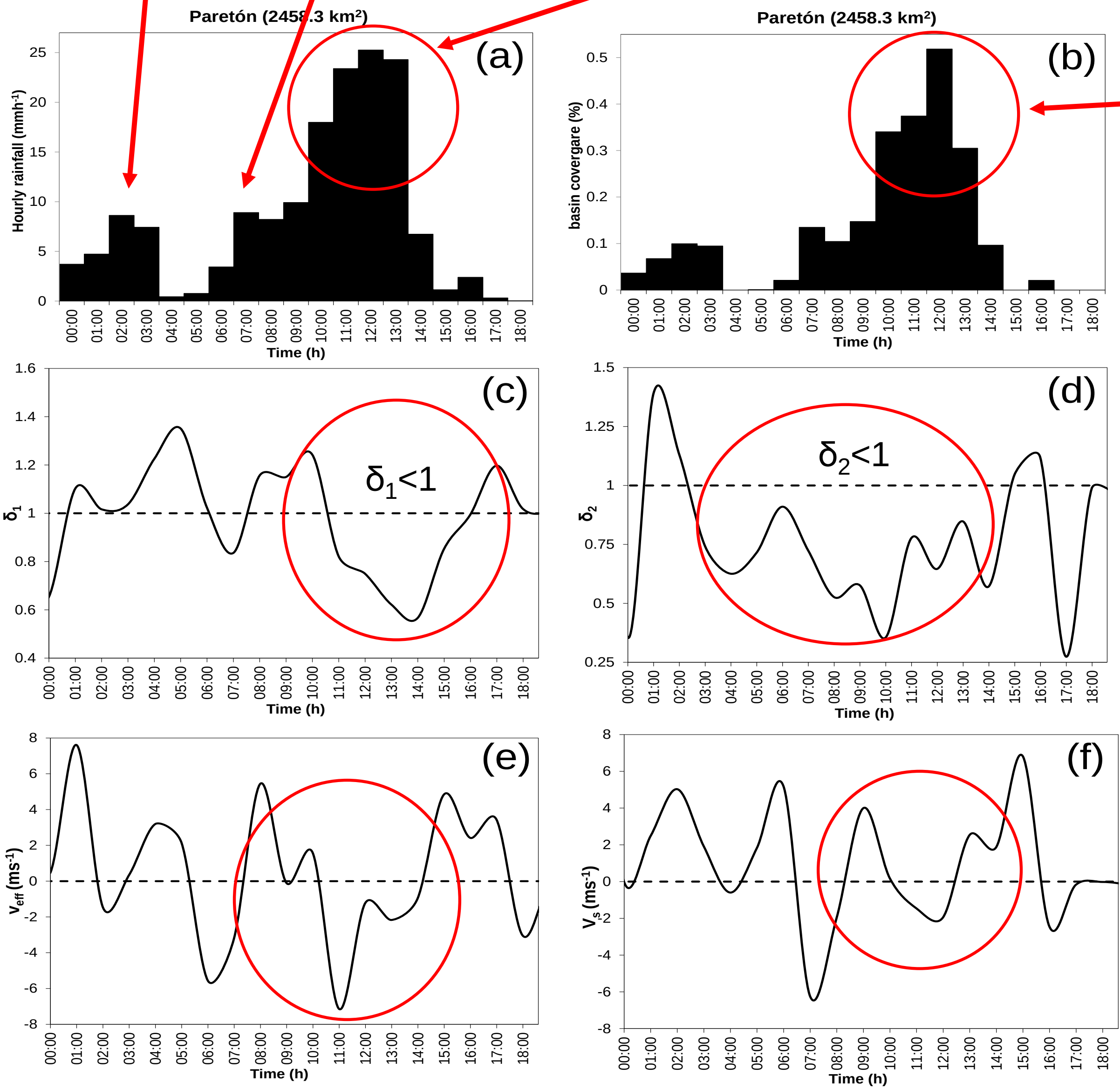
- V_{eff}, V_s > (<) 0: up- (downstream) storm movement

6. Application to the study case

First organized convective bands

Successive organized convective bands

MCS impacted the south-westernmost part of the basin from 09 UTC. Time of passage: 5 hours



Maxima fractional coverages close to 0.5 during passage of the MCS (~1400 km^2)

δ_1 reflects the passage of different convective rainfall bands and MCS throughout the basin. Rainfall distributed close to the basin outlet

δ_2 mainly indicates a unimodal distribution along the flow distance

Veff and Vs describe successive up- and down-stream motions. Clear signal of the MCS downstream motion

The metrics clearly quantify MCS impact

7. Impact of storm motion on flash flood response

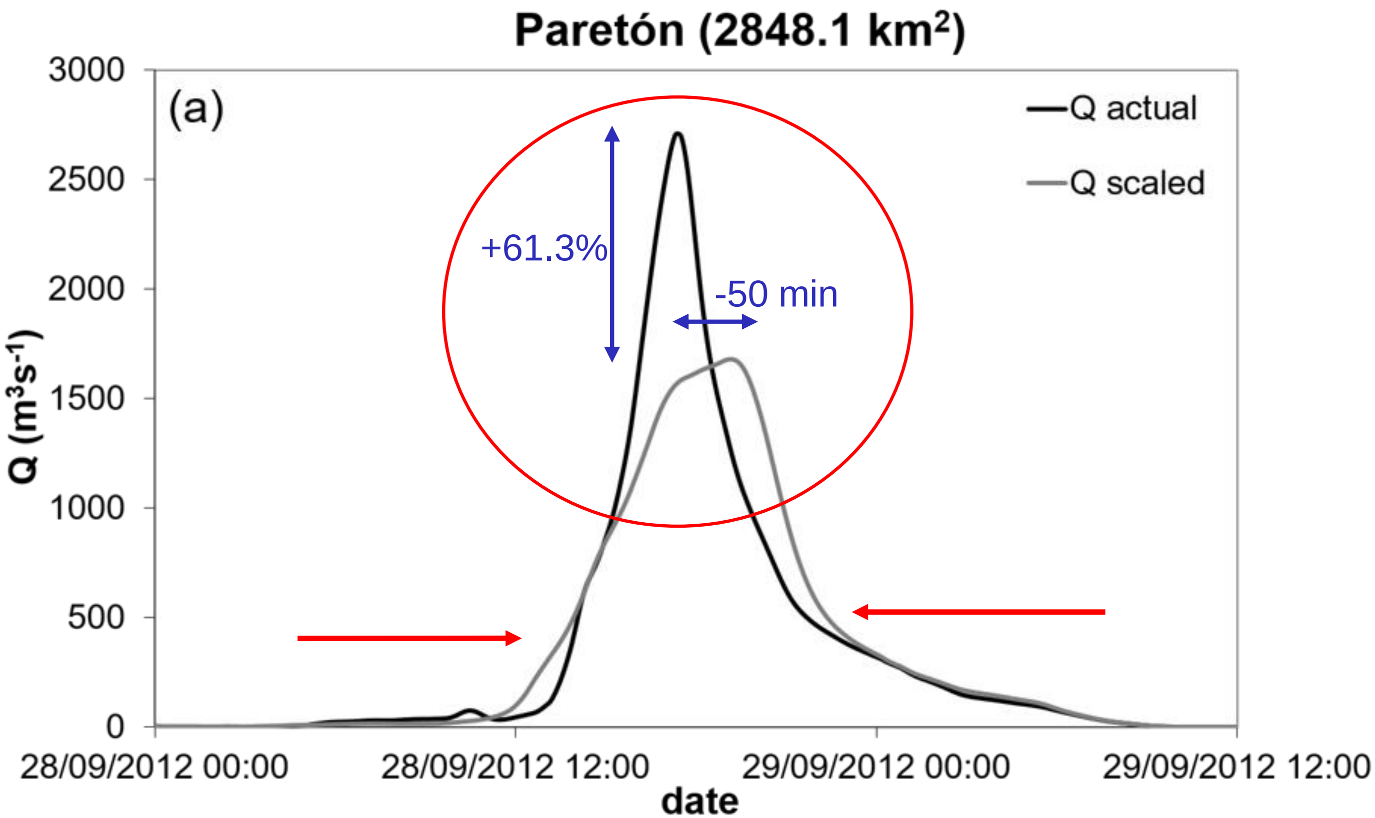
- Two distinct hydrological simulations are performed by using 10 min actual (control, e_0) and time-constant rainfall spatial (e_1) QPEs. Time-constant rainfall spatial patterns keep a constant instantaneous spatial variability equal to that of the total rainfall amount

- Effective isolation of the influence of storm motion on basin response by calculating the difference between these two driven runoff simulations

$$\Delta T = T_{e_0} - T_{e_1}$$

$$\Delta Q_p = \frac{Q_{p_{e_0}} - Q_{p_{e_1}}}{Q_{p_{e_1}}} \cdot 100$$

7. Impact of storm motion on flash flood response



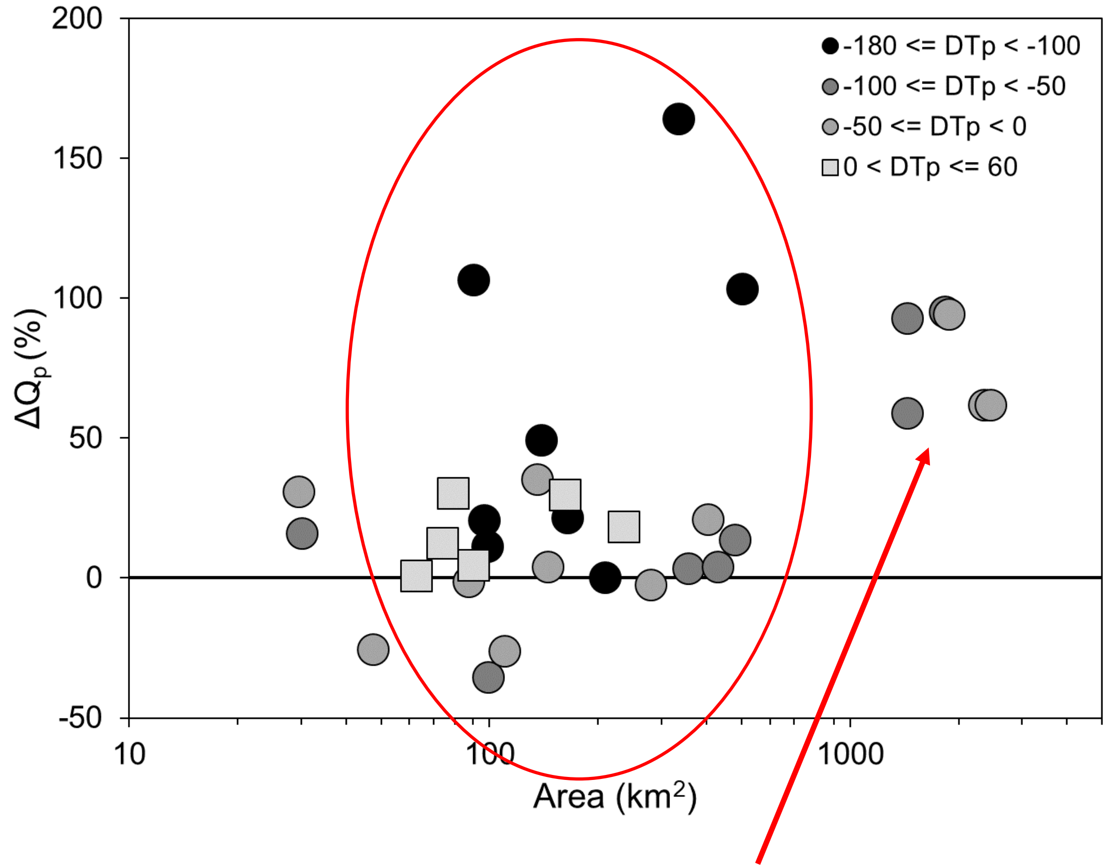
- MCS movement emerges as a key factor in the severity of the 28 September 2012 flash flood

- Storm motion reshaped flood hydrograph by reducing its base time, resulting in steeper concentration limbs and magnifying flood peak discharge

8. Basin scale dependence of storm motion on flash flood response

- Most impacts of storm kinematics result in an advancement of peak timing and an enhancement of flood magnitude

- The strongest effects of storm motion on runoff response emerge for basin scales ranging from 100 to 500 km^2



- This high inter-scale heterogeneity is smoothed out as the drainage area increases above 1000 km^2

9. Conclusions and further remarks

• The 28 September 2012 flash flood provides a compelling template helping to gather insides on the impact of storm motion on hydrological response

• Combination of different amplifying phenomena:

1. Flood magnitude was enhanced by the specific sequence of the spatial and temporal rainfall distributions: overlapping of hydrological responses

2. Quasi-stationary MCS movement downstream for a period comparable to the basin lag time (~5 h)

3. Similarity between the frequency distributions of MCS and channel flow velocities (~3.0 ms^{-1})

9. Conclusions and further remarks

- Storm motion was the main factor controlling the hydrograph shape: substantial advancement of the time to peak (50 min) and a notable increase of the peak discharge (61.3 %)

- The largest sensitivity to the impact of storm motion on hydrological response has emerged for basin scales ranging from 100 to 500 km^2.

- Drainage network has a major role in filtering variability in hydrological response to storm motion. Runoff routing imposes an effective averaging of the rainfall distribution across the catchment locations with equal routing times

Further technical details and results:

Amengual, A., Borga, M., Ravazzani, G., and Crema, S., 2021: The role of storm movement in controlling flash flood response: an analysis of the 28 September 2012 extreme event in Murcia, southeastern Spain. Journal of Hydrometeorology, 22 (9), 2379-2392