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AGENCIA ESTATAL DE INVESTIGACIÓN

Towards a better understanding and simulation of heavy precipitation events

The catastrophic flash flood of the Francolí River basin in Catalonia, north-eastern Spain

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Contents

- Hydrometeorological data
- Atmospheric modelling
- Hydrological modelling

- Statistic analyses
- Hydrological simulations
- Sensitivity analyses

1. Motivation

We face significant exposure to flash-flood producing heavy precipitation events (HPEs)

Global warming is intensifying the hydrologic cycle → HPEs are expected to increase

Mediterranean region has been identified as a hotspot for climate change effects

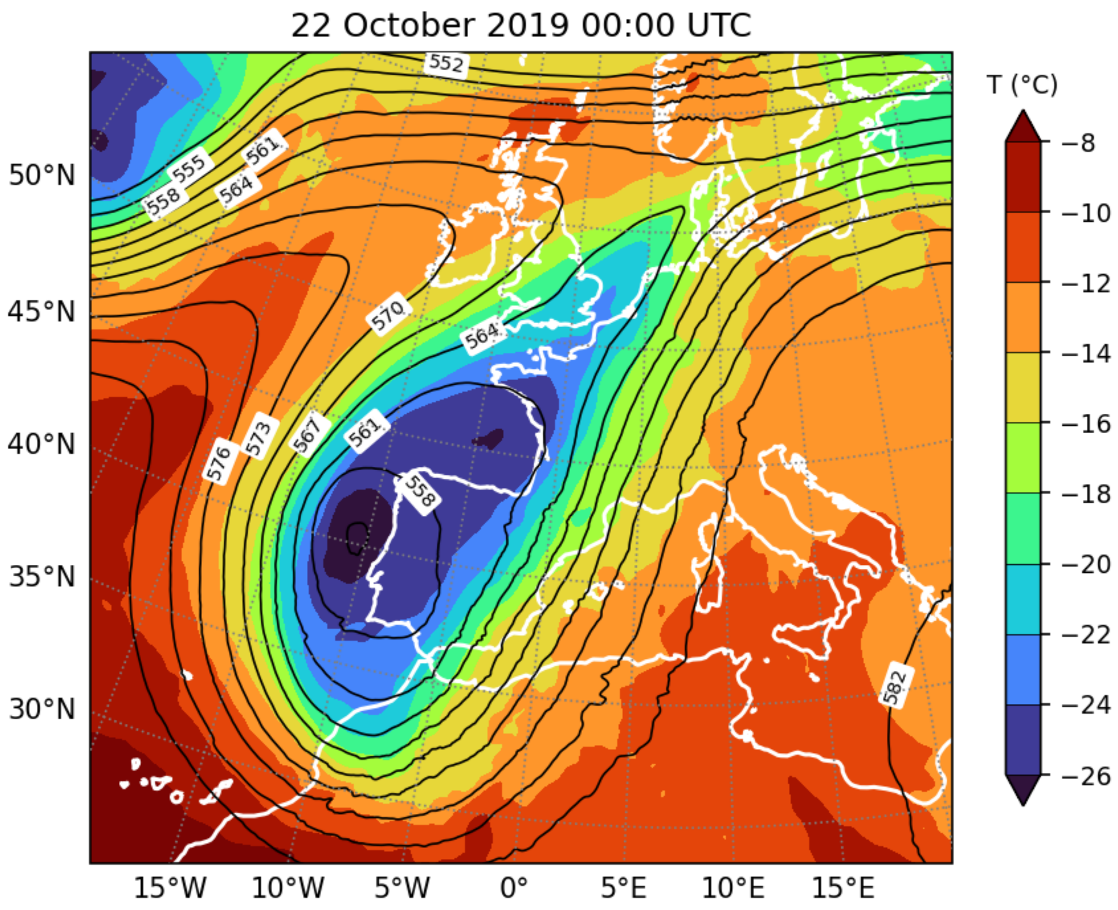
We aim to achieve **new insights in the onset and development of HPEs in Mediterranean Spain**

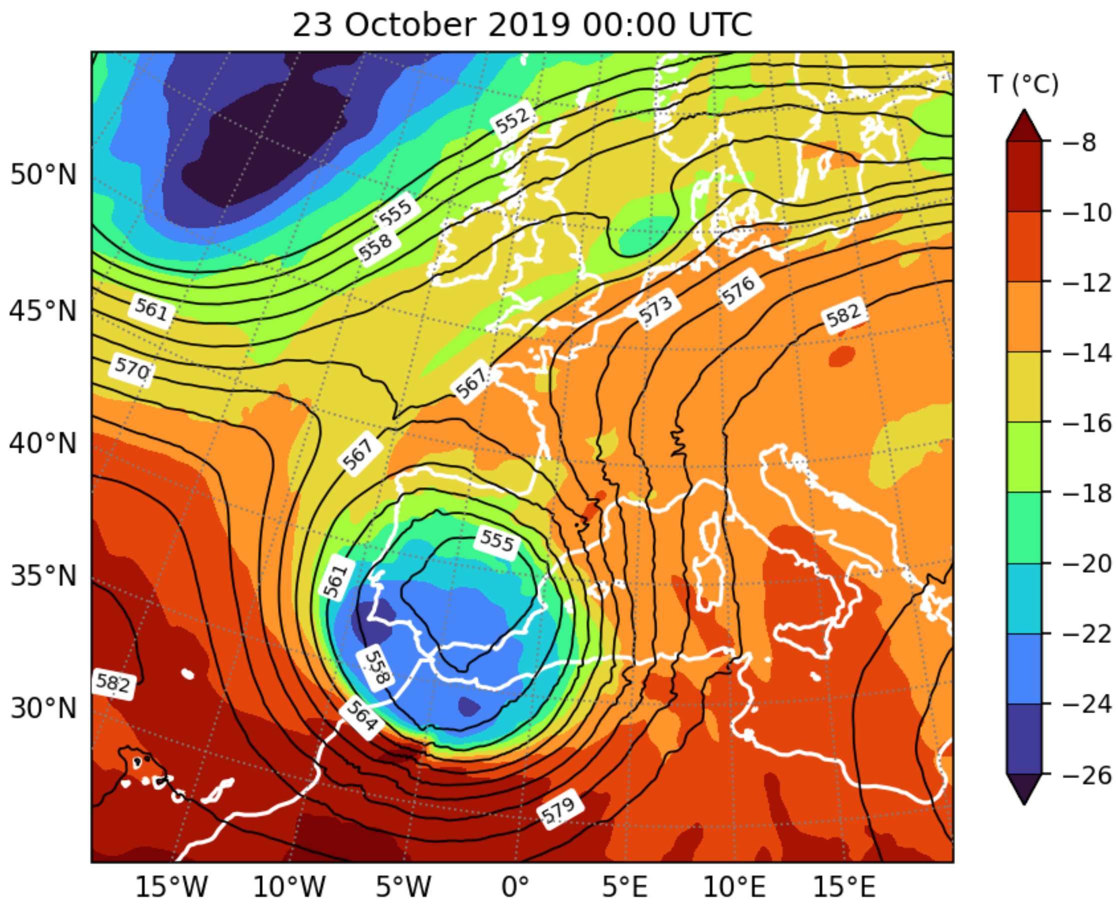
Testing the use of **hydrological simulation as advanced evaluation tool of HPE simulations**

2. Case study

HPE and flash flooding of the Francolí River basin (Catalonia)

22 and 23 October 2019





Synoptic scenery (CERRA reanalysis) → Cold-core, upper-level that then turned into cut-off low

2. Case study

HPE and flash flooding of the Francolí River basin (Catalonia)

22 and 23 October 2019

“DANA” over Iberian Peninsula

Warm-moist Mediterranean air

Low-level convergence

HPE in Catalonia especially in Tarragona

Catastrophic flash flooding of Francolí River basin

More than EUR 44 million in damages and six fatalities

3. Methodology

Observational data

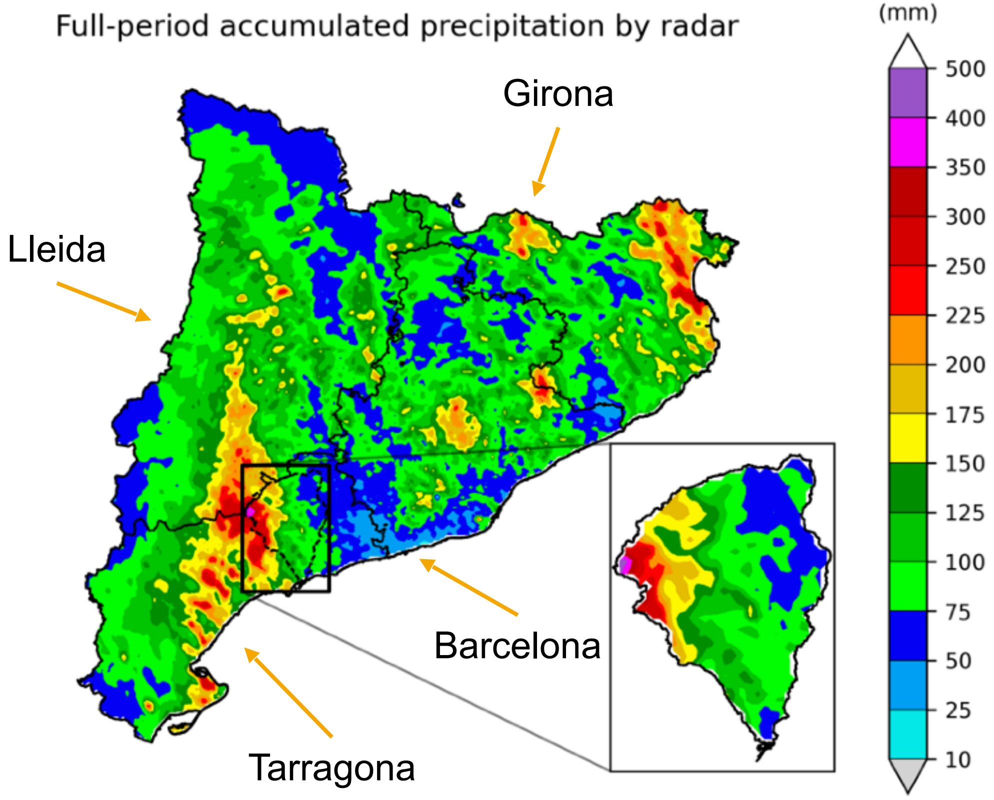
Radar-derived QPEs

QPEs from Barcelona's weather radar

- 10-minute data from *22 to 24 October 2019 at 00:00 UTC*
- Data processed to remove attenuation and orographic effects

- **Catalonia QPEs →** 1-hour amounts across Catalonia
- **Francolí QPEs →** 10-minute amounts in Francolí River basin

- High spatial correlation and average underestimation of 2.8%



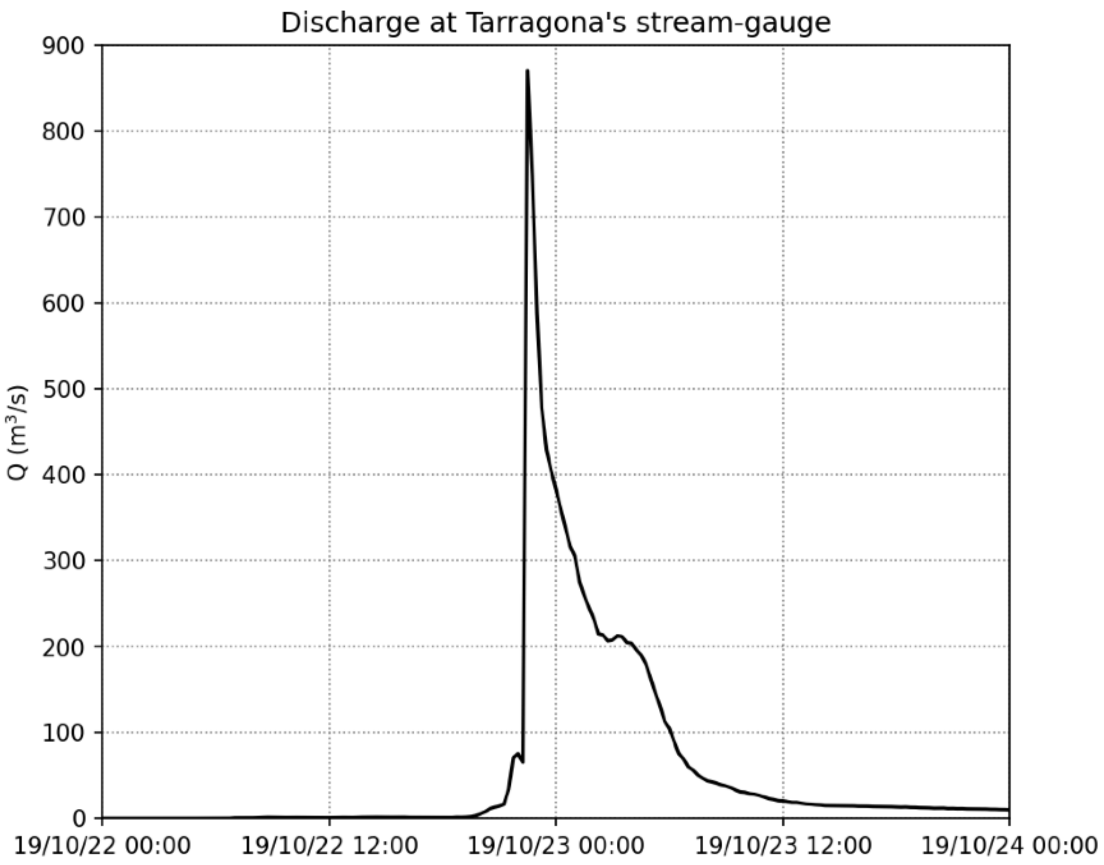
3. Methodology

Observational data

Streamflow measurements

Hydrograph from Tarragona's stream-gauge

- Montblanc and Tarragona stream-gauge stations
- Montblanc station destroyed by floodwaters
- Only Tarragona's stream-gauge to measure run-off
- Raw streamflow data every 5 minutes



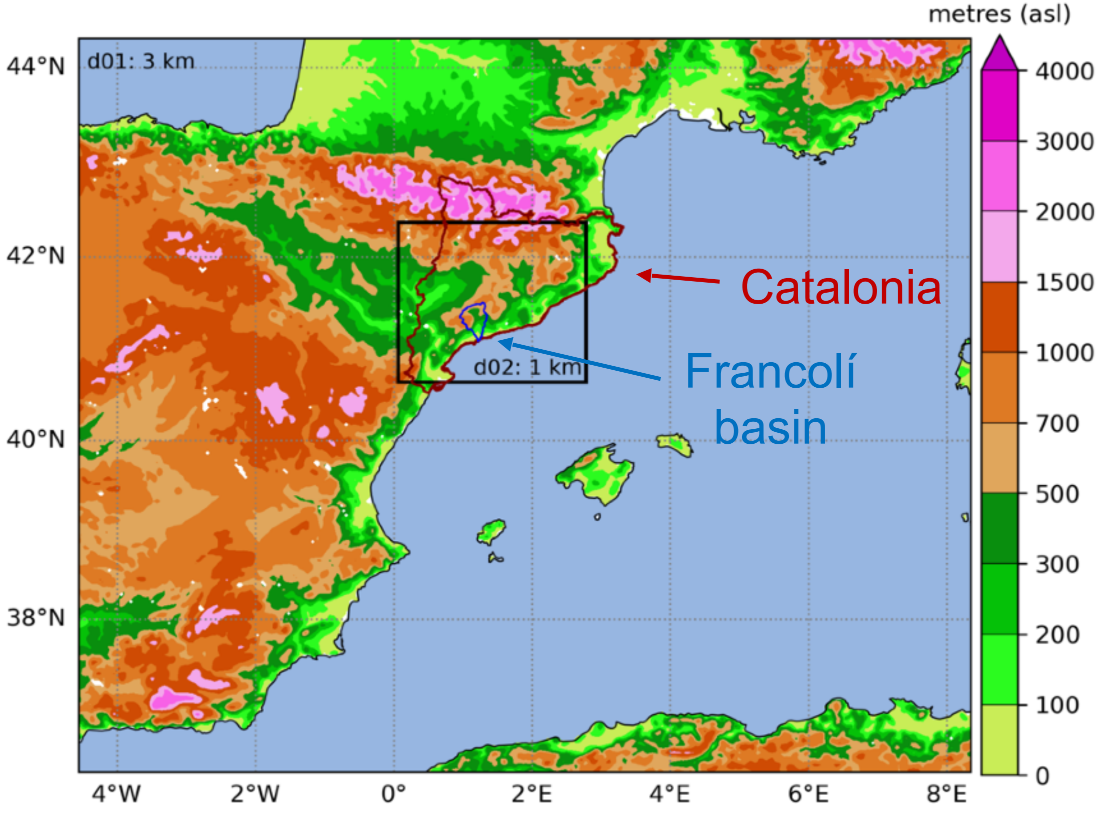
3. Methodology

Atmospheric modelling

- Mesoscale NWP Models → **WRF** and **TRAM**
- High-grid-resolution precipitation fields simulated

  22 to 24 October 2019 at 00:00 UTC
- Seven-member ensemble strategy for each model

- **Both →** ERA5 and IFS data as IC and BC every 6 hours
- **WRF ensemble →** Microphysics and PBL schemes
- **TRAM ensemble →** HRES and cumulus parametrisation



Numerical domain for WRF
TRAM used one similar (unique HRES though)

WRF ensemble members

1-hour outputs from:

22-24 October 2019 at 00:00 UTC

Member	Microphysics	Cumulus	PBL(2)	Data
W1	WSM6	X	YSU	IFS
W2	WSM6	X	YSU	ERA5
W3	WSM6	Kain-Fritsch(1)	YSU	IFS
W4	Thomson	X	YSU	IFS
W5	WSM6	X	MYJ	IFS
W6	Thomson	X	MYNN	IFS
W7	Thomson	X	MYJ	ERA5

(1) Only implemented at parent domain (3 km still corresponds to the cumulus grey-zone)

(2) Surface layer physics used the scheme matching PBL schemes' code numbers.

TRAM ensemble members

10-minute outputs from:

22-24 October 2019 at 00:00 UTC

Member	HRES (km)	Cumulus(1)	Data
T1	1.50	Kain-Fritsch 2(2)	IFS
T2	1.50	X	IFS
T3	0.75	X	IFS
T4	1.50	Kain-Fritsch 2	ERA5
T5	1.50	X	ERA5
T6(3)	1.50	Kain-Fritsch 2	ERA5
T7	0.75	X	ERA5

(1) Aimed to evaluate TRAM's capabilities for explicit cumulus resolution

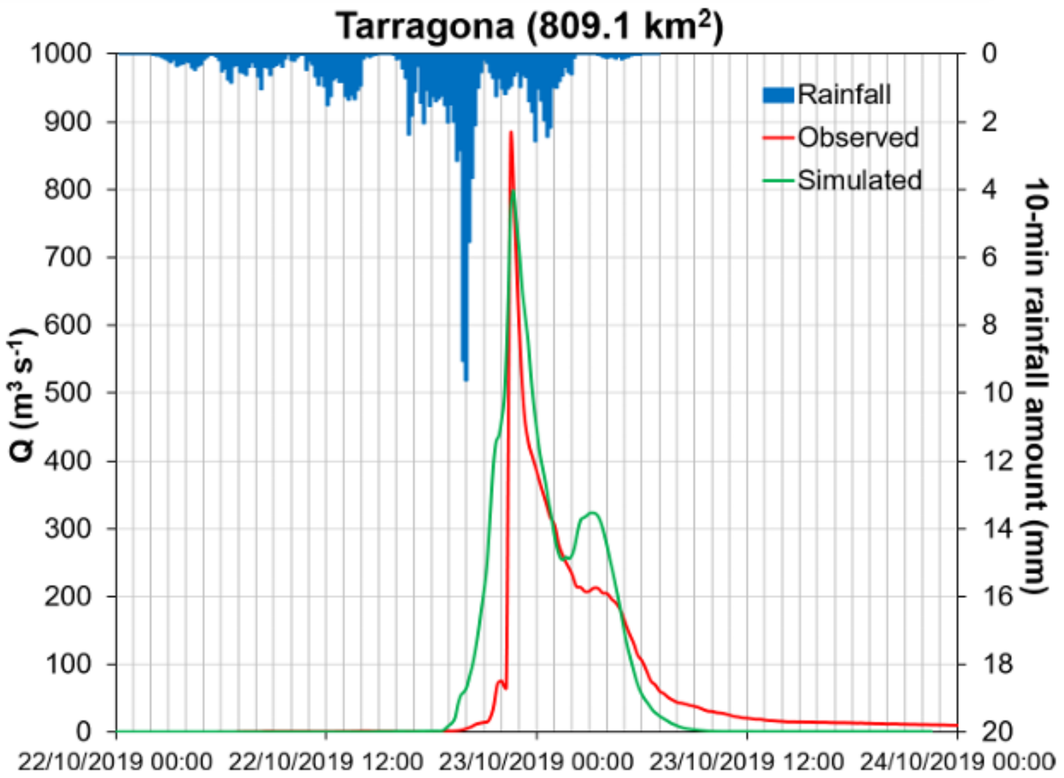
(2) Same cumulus convection parametrisation scheme used by MM5 model

(3) Assessed the effect of stochastic perturbations in short-range HPE simulation

3. Methodology

Hydrological modelling

- KLEM model to simulate run-off at Tarragona's station
- Calibrated with Tarragona's steam-gauge data
- **Francolí's QPEs** used for **control run-off simulation**



- KLEM forced with high-grid-precipitation ensembles
- **Hydrological indices** *(Q ≡ Discharge, V ≡ volume)*

Nash-Sutcliffe efficiency coefficient

$$NSE = 1 - \frac{\sum_{i=1}^{n} \left(Q_{obs} - Q_{sim}\right)^2}{\sum_{i=1}^{n} \left(Q_{obs} - \bar{Q}_{obs}\right)^2};$$

Relative error of total volume and peak discharge

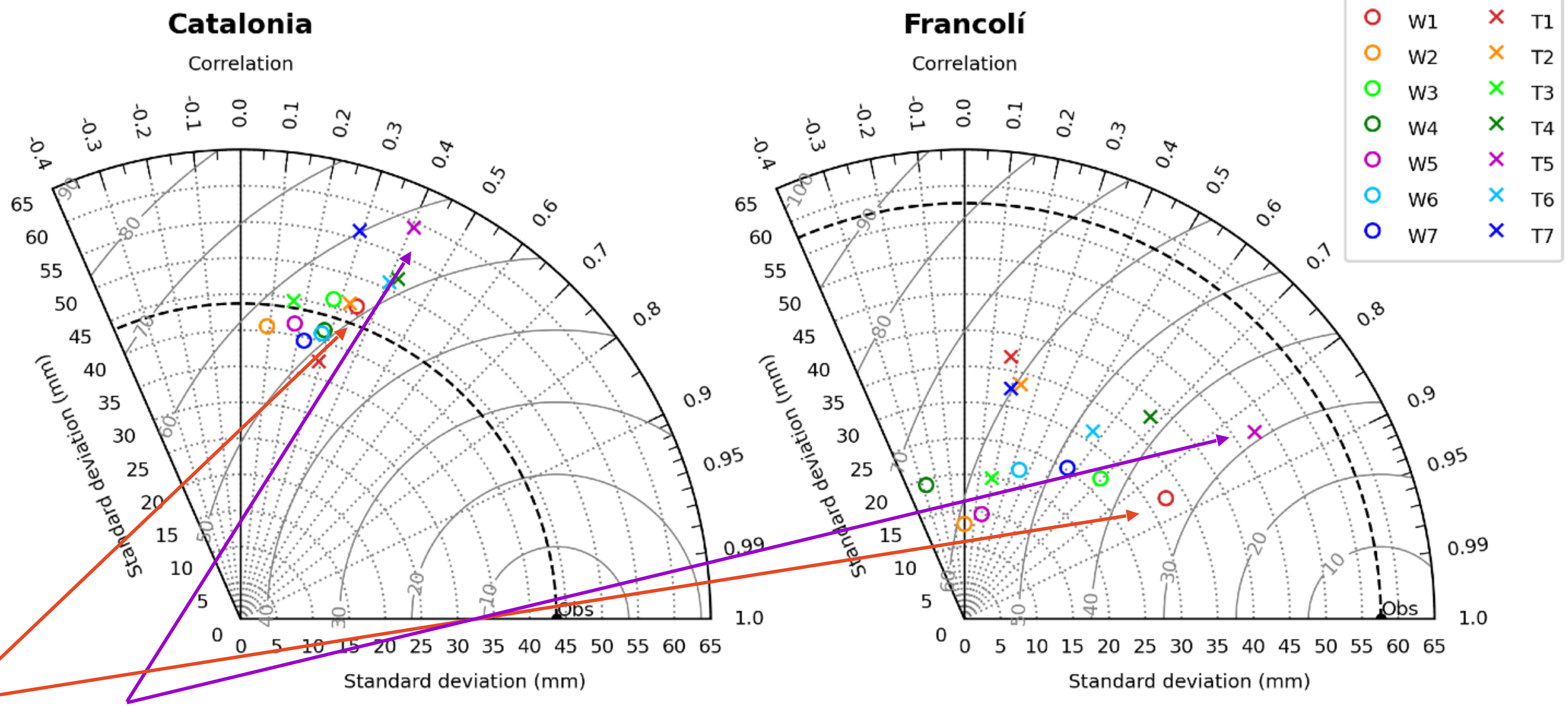
$$\%EV = \left(\frac{V_{sim} - V_{obs}}{V_{obs}}\right) \cdot 100; \qquad \%EQ_{max} = \left(\frac{Q_{max,\,sim} - Q_{max,obs}}{Q_{max,obs}}\right) \cdot 100$$

4. Results

Statistical analyses

Spatial

Spatial Taylor Diagram of the 48-hour accumulated precipitation

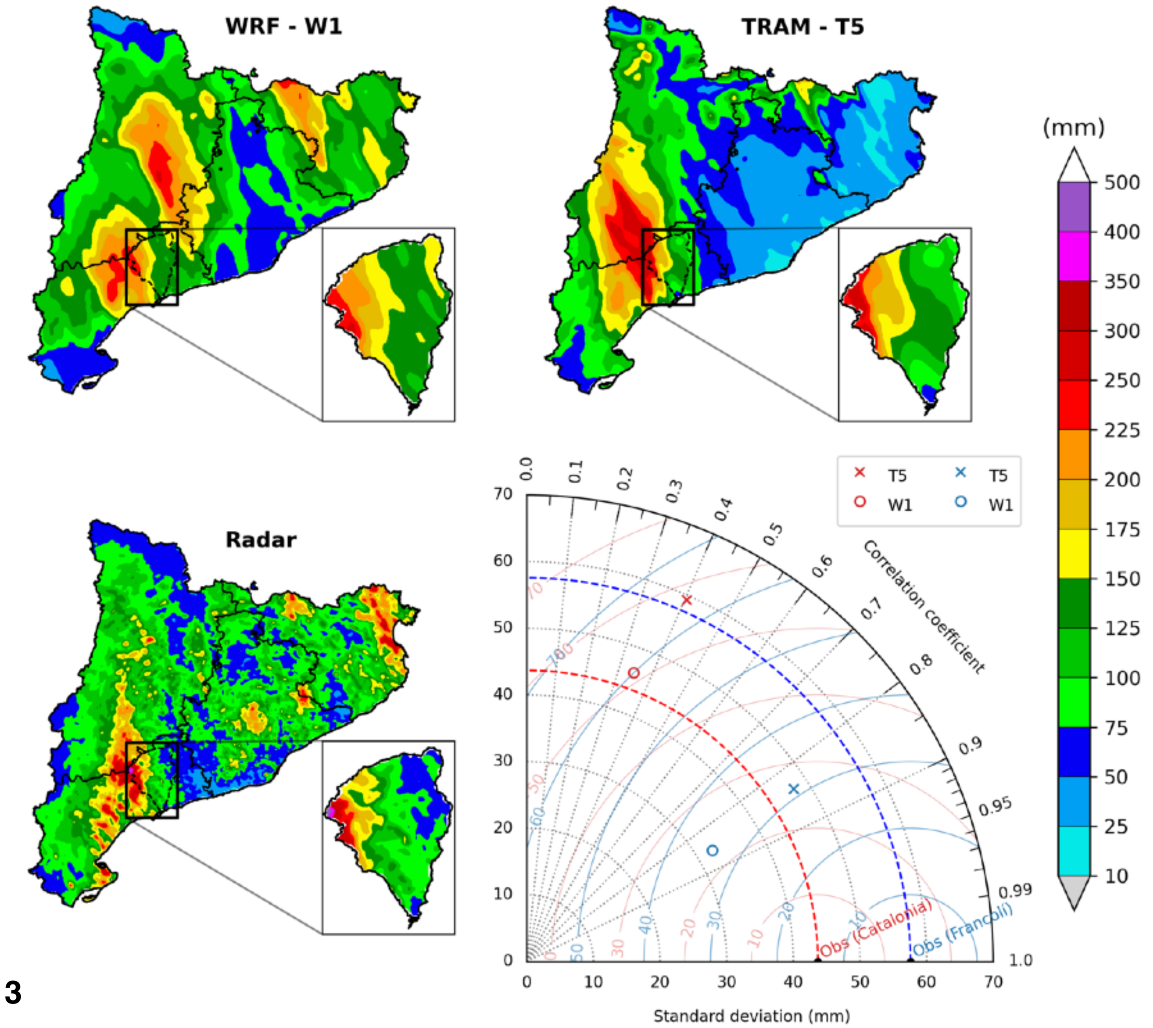


W1 and **T5** performed the best in terms of **RMSD**, **sp. Correlation** and **sp. standard deviation**.

4. Results

Statistical analyses

Spatial



48-hour accumulated precipitation fields

W1

- Consistent precipitation across Catalonia
- Large overestimation over Lleida
- Underestimated at eastern Girona

T5

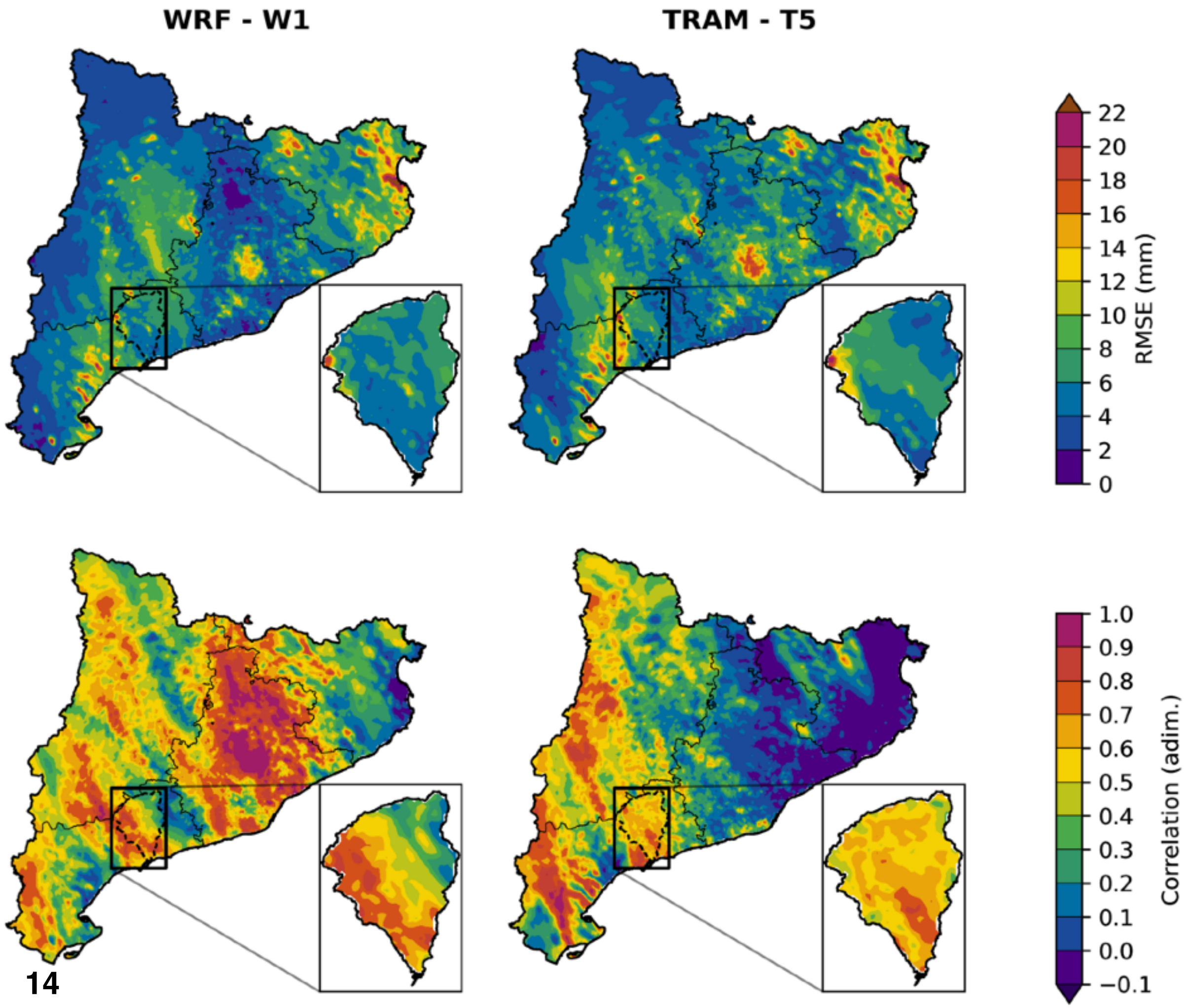
- Better representation of the main HPE strip
- Large underestimation at north-eastern regions

Distribution **within basin** is well-represented
However, heavily underestimated at westernmost side

4. Results

Statistical analyses

Temporal



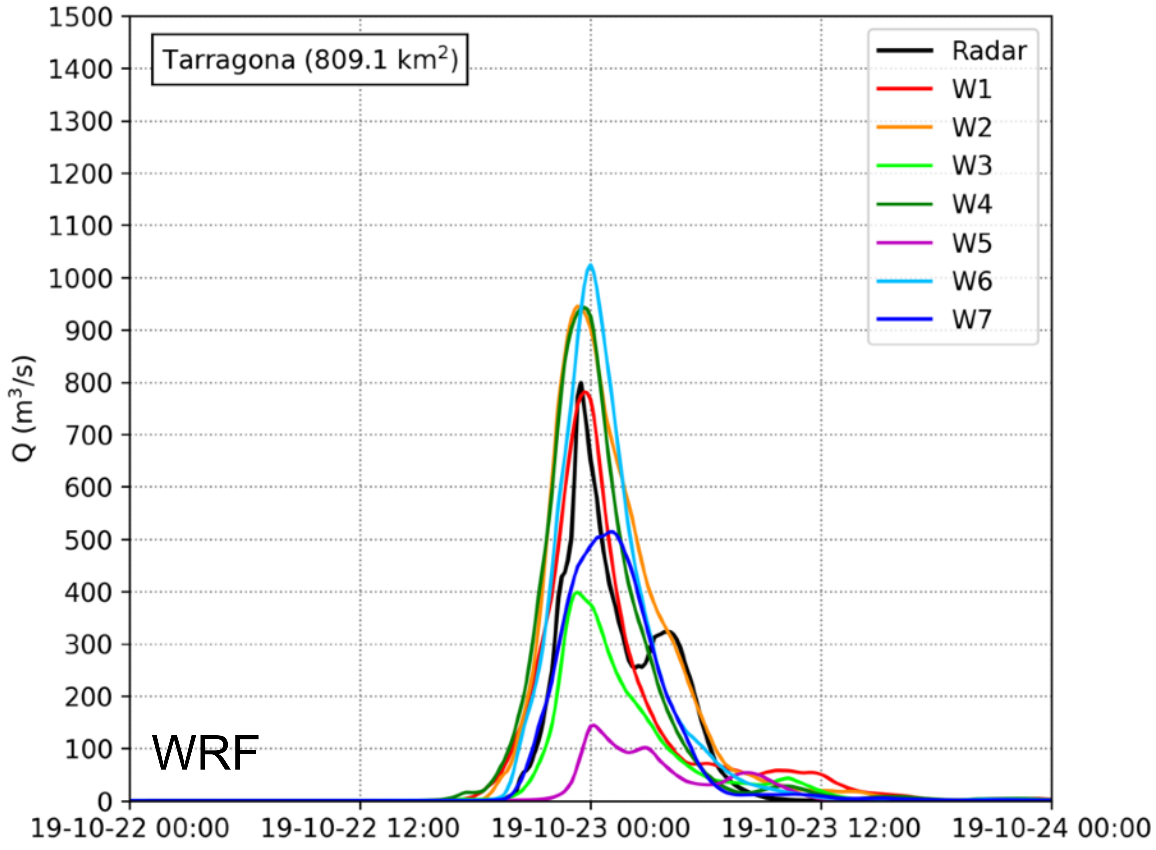
48-hour temporal RMSE and correlation fields

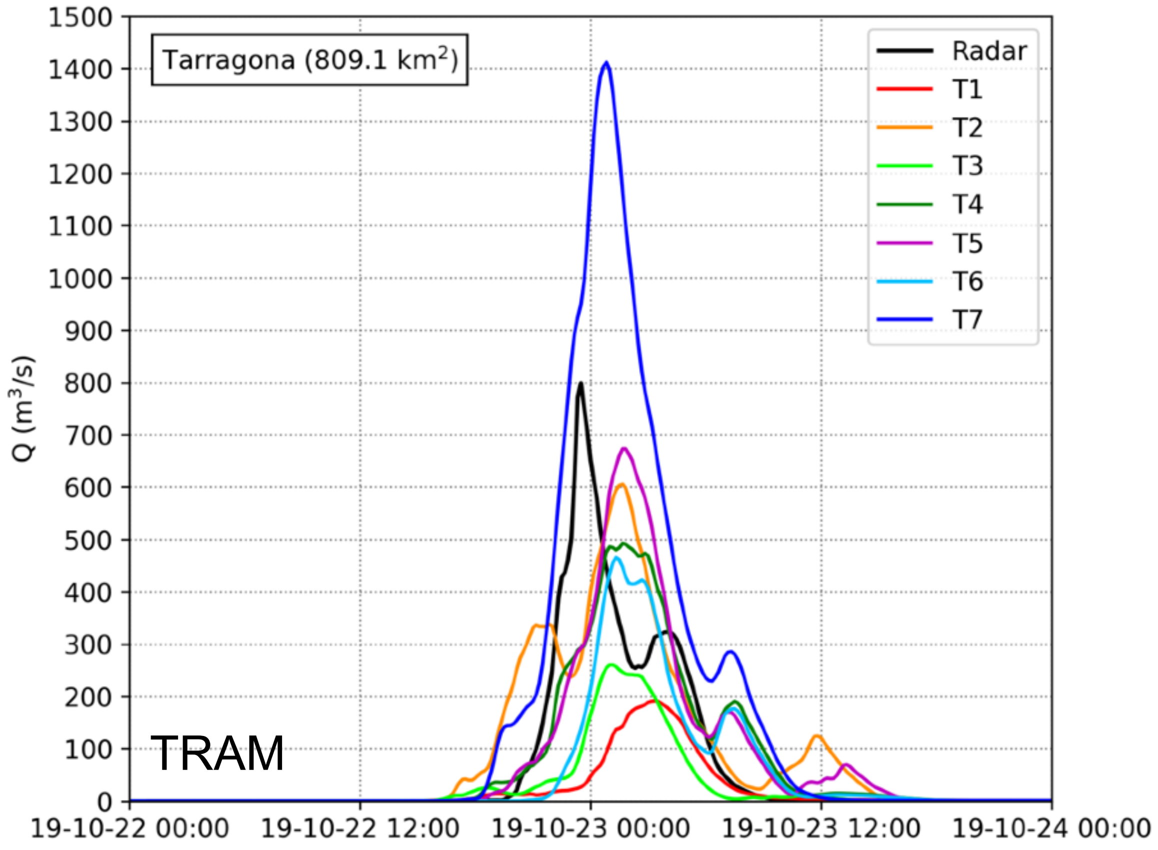
- Overall low values of RMSE across Catalonia
- High RMSE → Barcelona's centre and eastern Girona
- Highest RMSE → Westernmost part of the basin

- W1 achieves very high correlations
- T5 large area with negative correlation
- High positive correlation within basin, especially W1

4. Results

Run-off simulations



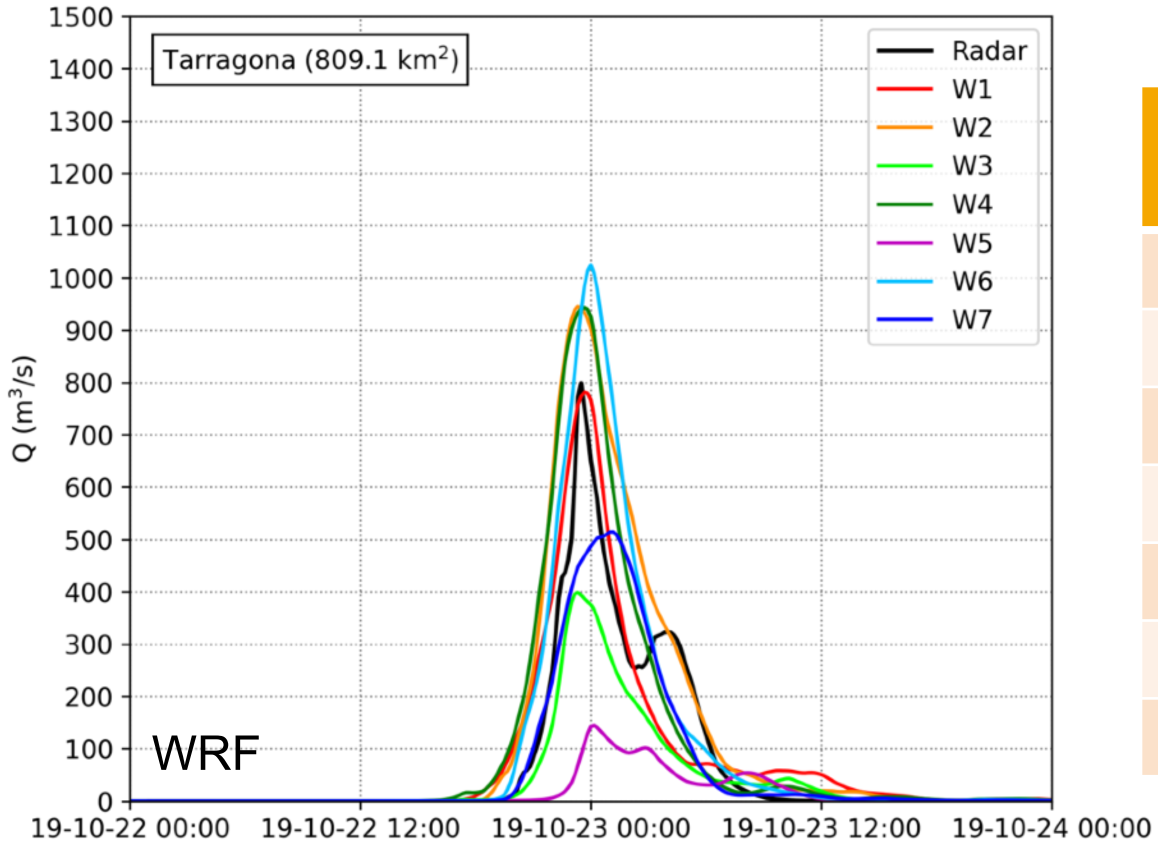


Flash flood-producing HPE simulations were achieved → Though not all performed as well

4. Results

Run-off simulations

WRF ensemble as inputs



Input	NSE (n.u)	RMSE (m^3/s)	EV (%)	EQ_{max} (%)
W1	**0.81**	**68.01**	**14.29**	**-2.14**
W2	0.51	109.94	62.0	18.35
W3	0.74	80.4	-39.79	-50.09
W4	0.54	106.75	40.97	18.05
W5	0.19	141.47	-75.68	-81.89
W6	0.61	98.14	40.76	28.21
W7	**0.86**	**58.07**	**-11.00**	**-35.59**

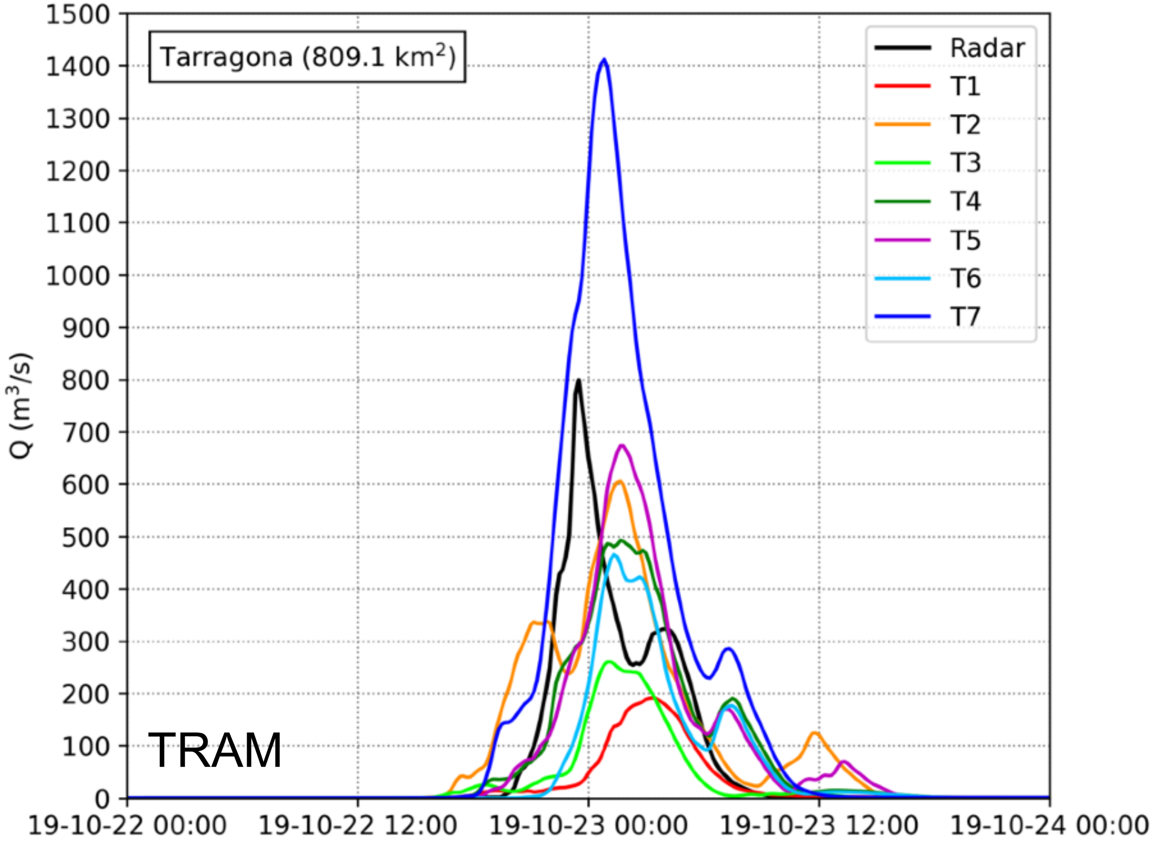
W1 and W7 achieve high goodness-of-fit → W1 is the best hydrological simulation

4. Results

Run-off simulations

TRAM ensemble as inputs

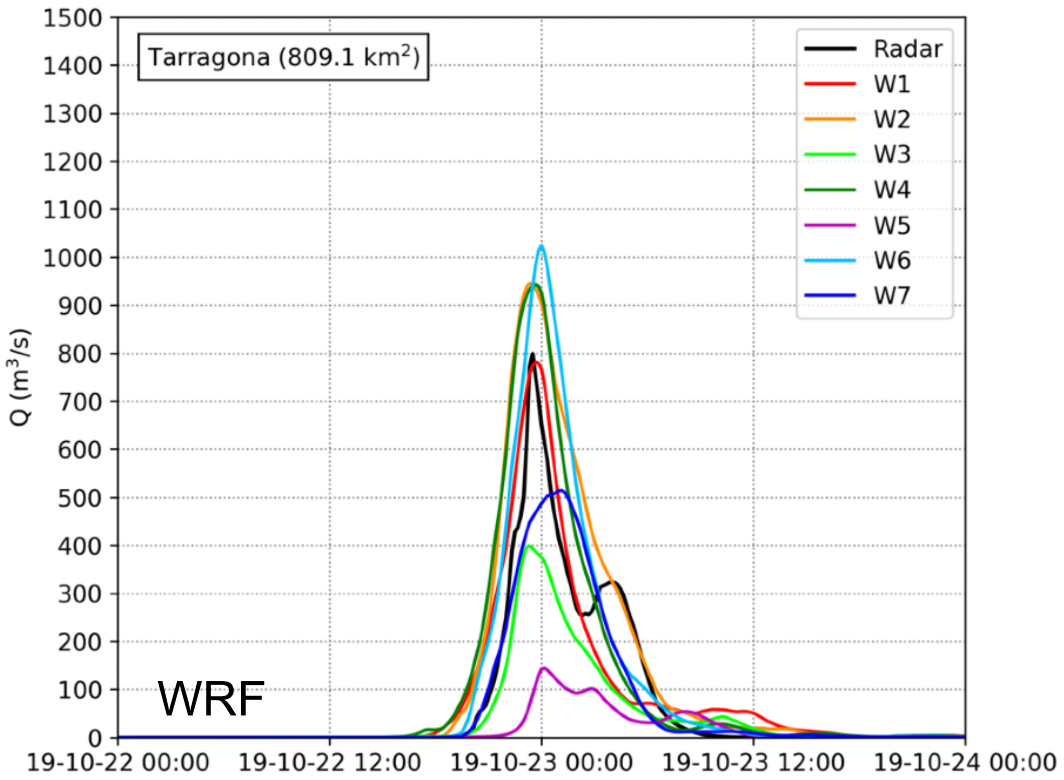
Input	NSE (n.u)	RMSE (m^3/s)	EV (%)	EQ_{max} (%)
T1	0.20	140.35	-68.71	-76.43
T2	0.62	96.75	27.63	-30.00
T3	0.41	120.96	-59.14	-67.96
T4	**0.69**	**86.64**	**-59.14**	**-38.08**
T5	**0.56**	**105.37**	**15.29**	**-15.98**
T6	0.48	112.78	-24.24	-44.39
T7	-0.96	219.78	133.14	75.79

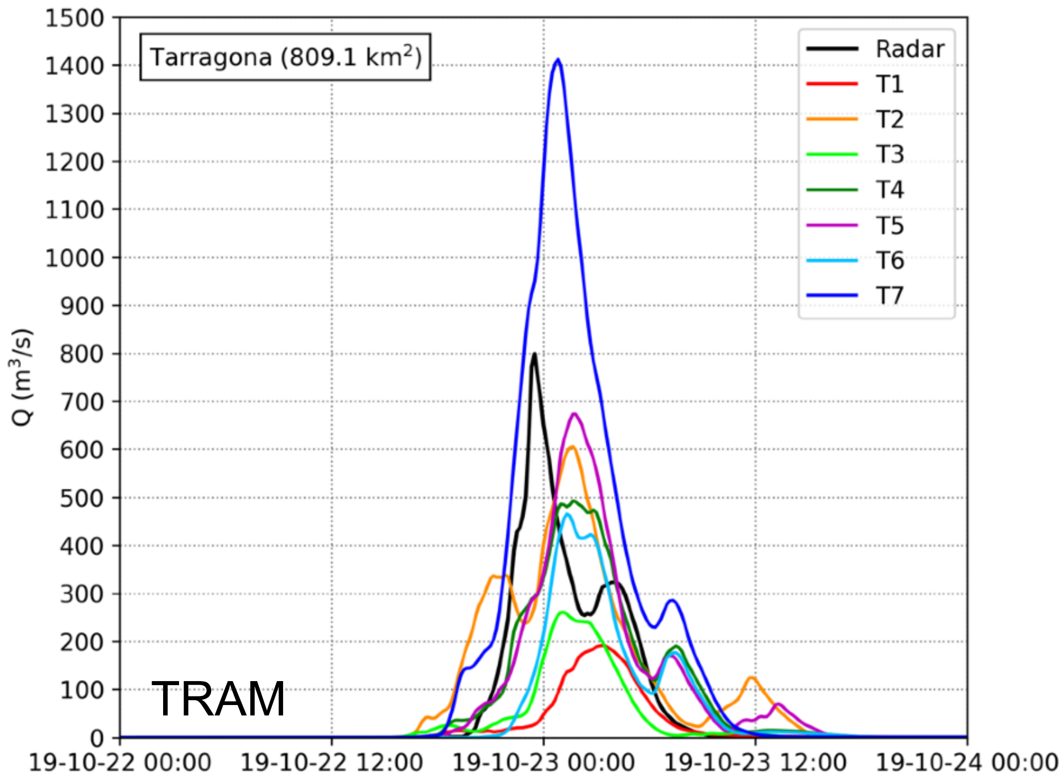


T4 and T5 achieve high goodness-of-fit → T5 is the best hydrological simulation

4. Results

Run-off simulations





W1 best simulation of the HPE

Member	NSE (n.u.)	RMSE (m^3/s)	EV (%)	EQ_{max}(%)
W1	**0.81**	**68.01**	**14.29**	**-2.14**
T5	0.56	105.37	15.29	-15.98

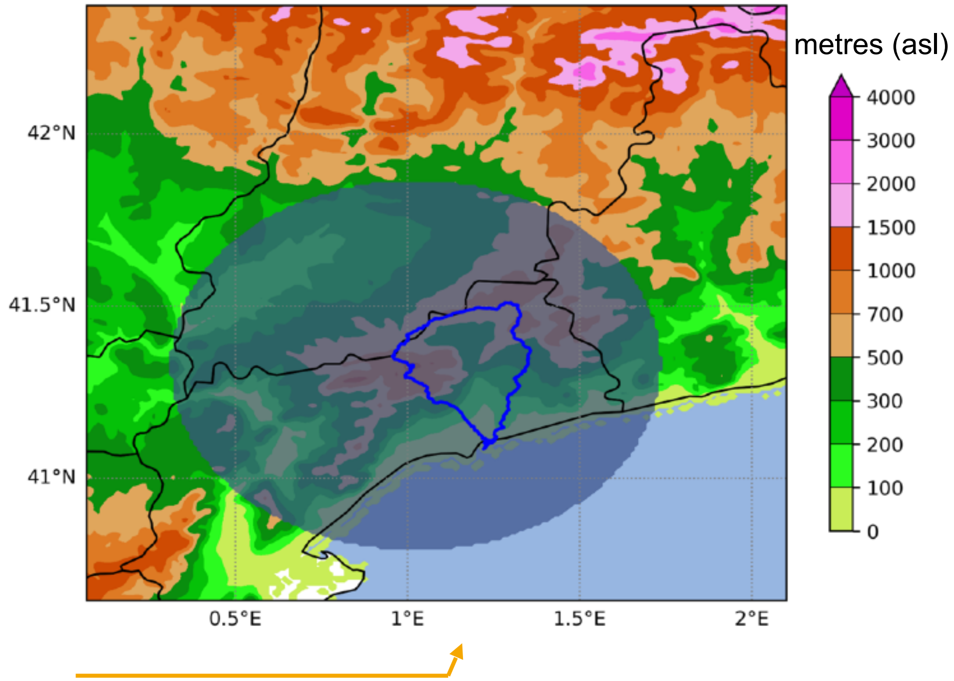
Consistency with statistical analysis

4. Results

Sensitivity analyses

Simulation	SST anomaly	Topography
CNTRL (W1)	-	-
SST-M3	-3 °C	-
SST-M2	-2 °C	-
SST-M1	-1 °C	-
SST-P1	+1 °C	-
SST-P2	+2 °C	-
SST-P3	+3 °C	-
No-TOPO	-	Removed
SST-M2 + No-TOPO	-2 °C	Removed
Local-TOPO	-	Limited to 500 m on a 60 km radius

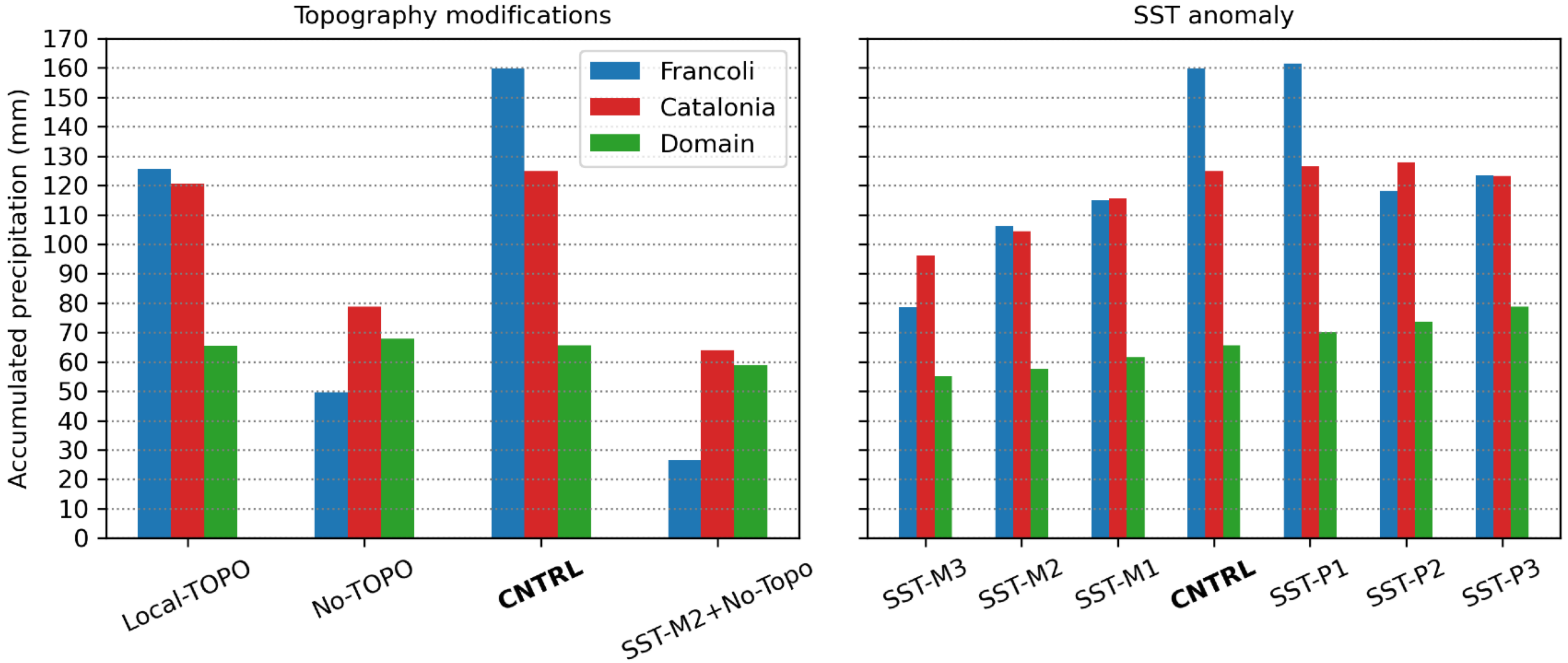
9 simulations were carried out to analyse the effects of **SST** and **topography**



4. Results

Sensitivity analyses

Spatial averages of the 48-hour accumulated precipitation for each experiment



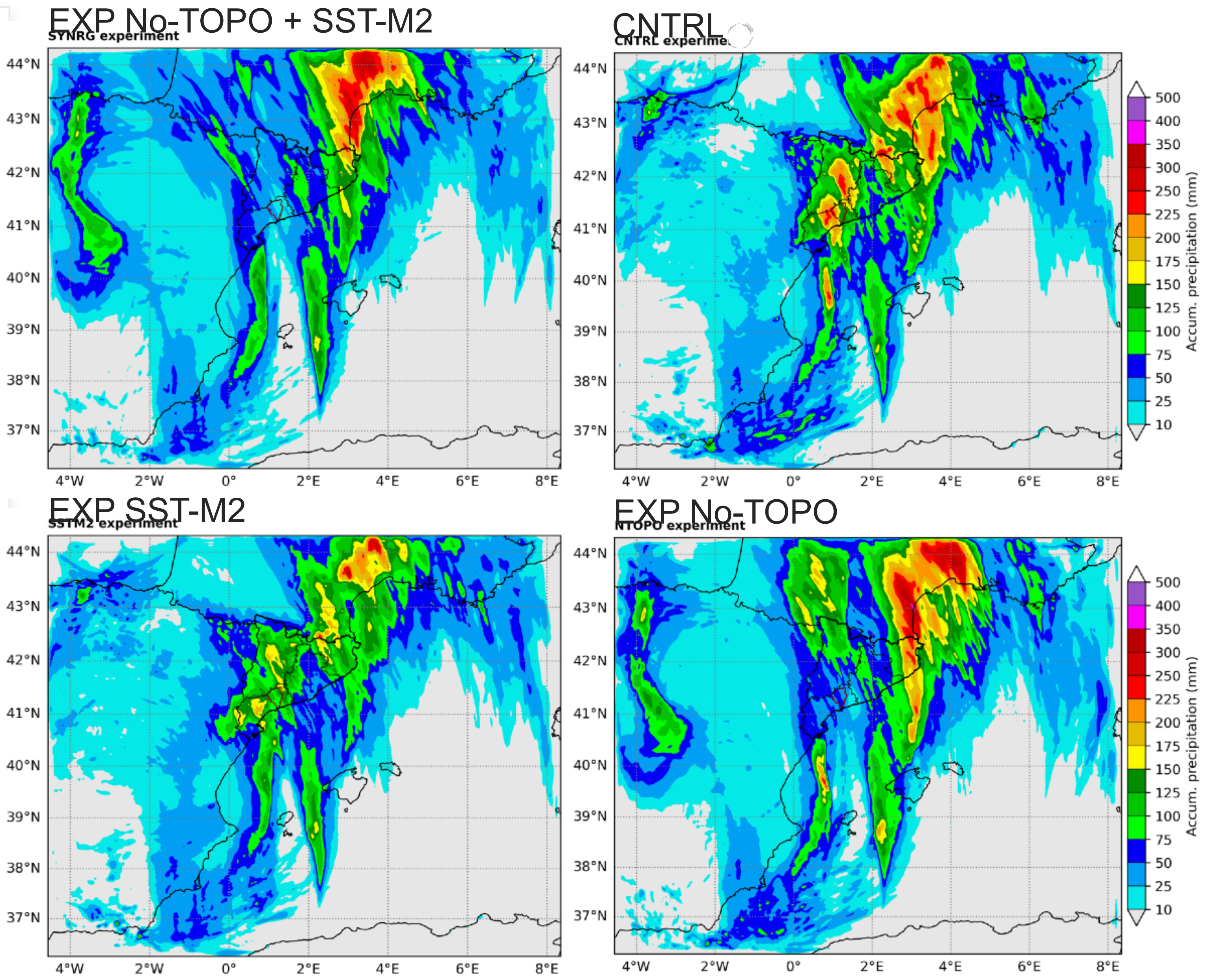
4. Results

Sensitivity analyses

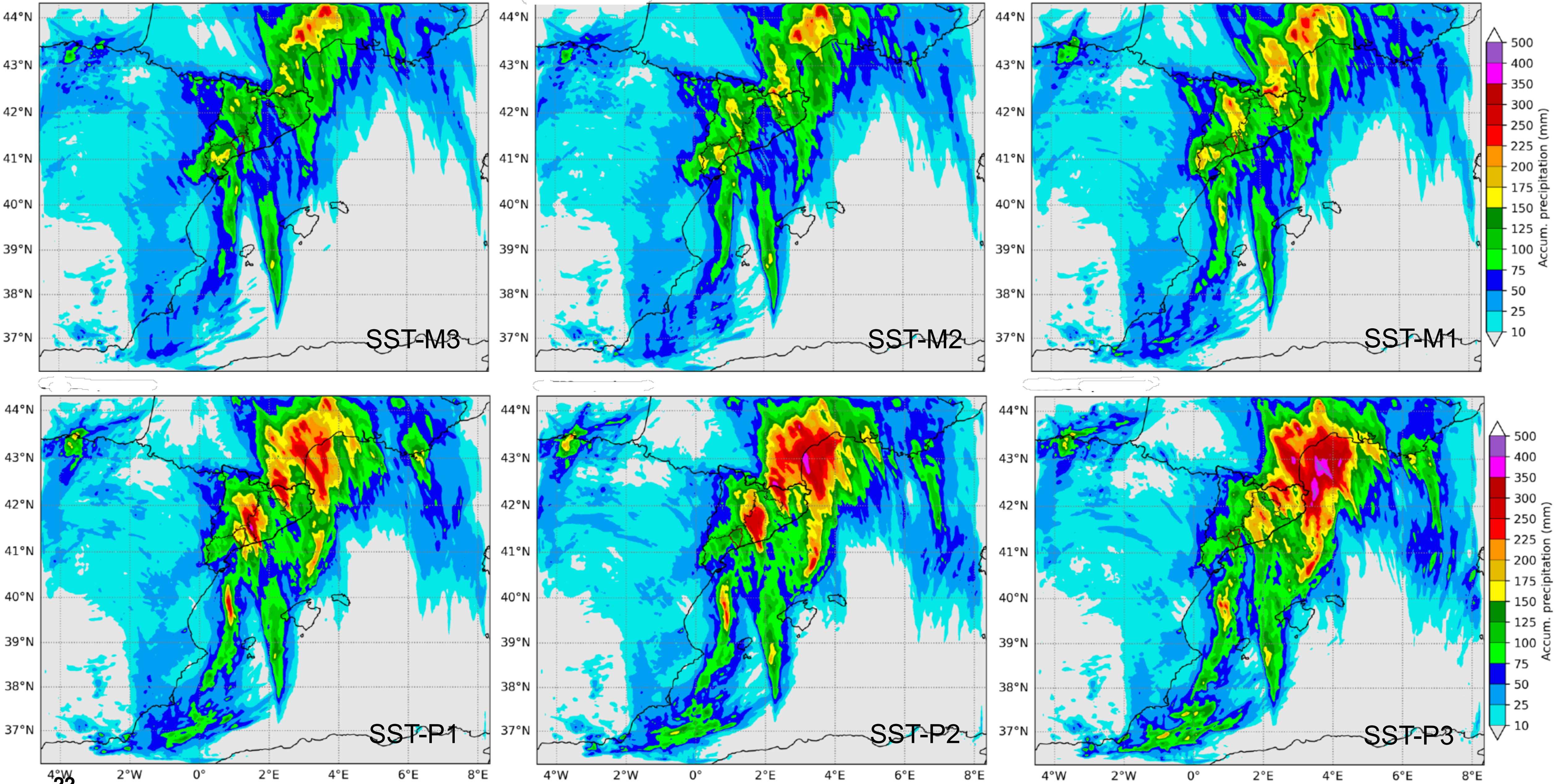
- **SST-M2 →** Lesser rain overall
- **No-TOPO →** Much less rainfall, no HPE over the Francolí River basin.
- **No-TOPO + SST-M2 →** Very little rain over Francolí River basin, and lesser across Catalonia.

If topography removed, convective system for Catalonia travels northwards

48-hour accumulated precipitation



48-hour accumulated precipitation for SST anomalies



5. Future work

- Larger ensembles to try to find better configurations for HPE modelling
- Additional studies for similar HPE events (e.g. Valencia October 2024)
- More complex hydrological models (e.g. FEST-WB) for enhanced validations
- Further meteorological factors should be studied (e.g. surface fluxes, PV anomalies, etc.)

6. Take-home messages

- Hydrologic simulation has potential as advanced validation tool of HPE simulations
- Higher SST entails more precipitation overall but not within the studied region necessarily
- Topography seems to be the leading factor. It enhances and modulates the precipitation, causing persistent rain within small regions, and consequently flash flooding
- Lowering SST and removing topography doesn't result in a particularly different outcome when compared to solely removing the topography

Thank you for your attention

Any questions?

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