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The October 1940 extraordinary flood in the Pyrenees revisited: validation of some hypotheses based on hydraulic simulations

Université Gustave Eiffel

1. The « Aiguat » of 17-18 October 1940: a record event

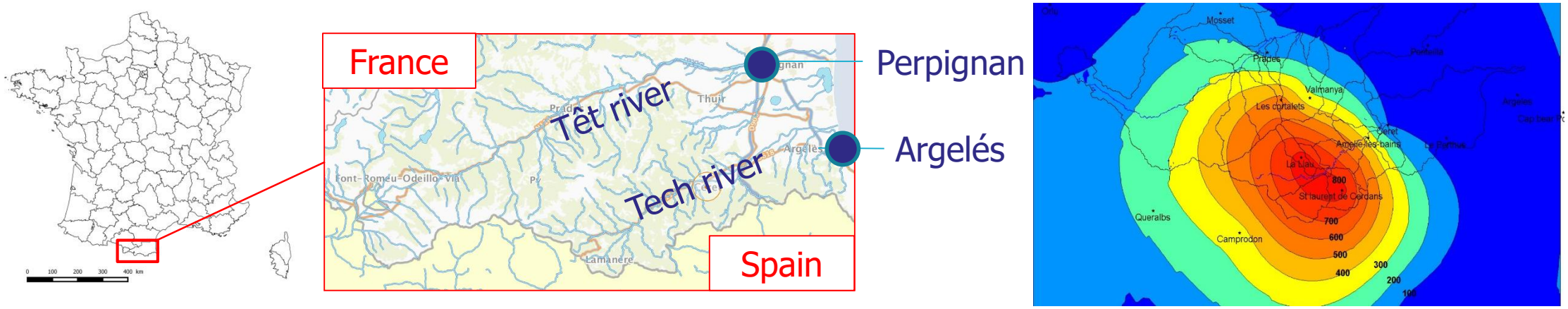

Figure 1: Location of the event and estimated rainfall (obtained by kriging)
E. Gaume, O. Payrastre, G. Degoutte, 2015

- One of the most impressive flash floods of the 20th century
- Eastern part of the Pyrenees: France and Spain
- Large floods on the Tech and Têt rivers
- Maximum observed 24-hour rainfall close to 1m (fig.1)
- Major erosion/sediment transport effects
- Casualties: 47 deaths in France, more than 100 deaths in Catalunia
- Large damages to buildings and infrastructures, destruction of town centers as Vernet-Les-Bains (fig.2)

Figure 2: Damages in Vernet-Les-Bains

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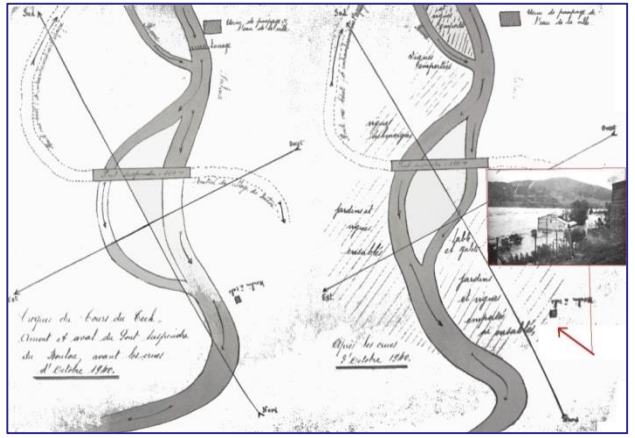
2. …A large body of available documentation

- Original rainfall and water levels observations
- Original accounts of witnesses (mainly teachers, gathered in 1940-1941):
  - Rainfall observations
  - Description of the flood: peak discharges, breaches in dikes, railways…
- Scientific reports:
  - Report by Bernard Quesnel (1941): a first synthesis of the information collected and first discharge estimates
  - Maurice Pardé report (1941): detailed analysis of the flood process, echoes and complements (sometimes critically) the report of Quesnel
  - B. Quesnel report (1942): detailed analyses, includes all the documentation on the event: rainfall records, records of flow cross sections with details of the corresponding discharge calculations, and records of water levels at the different flood locations



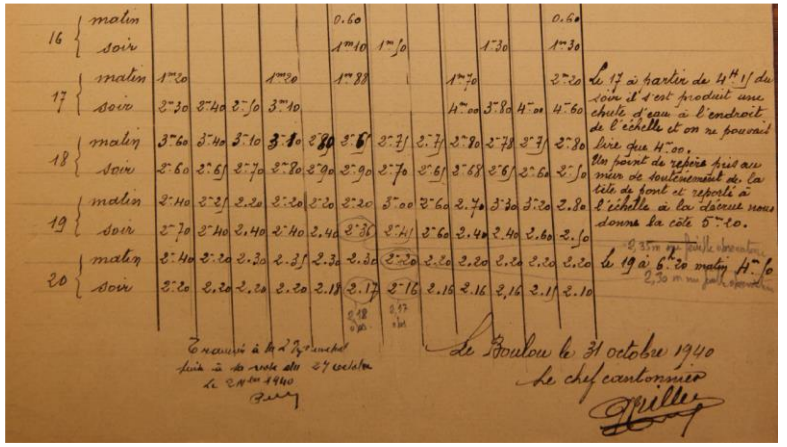


Figure 3: Extracts of teachers testimonies

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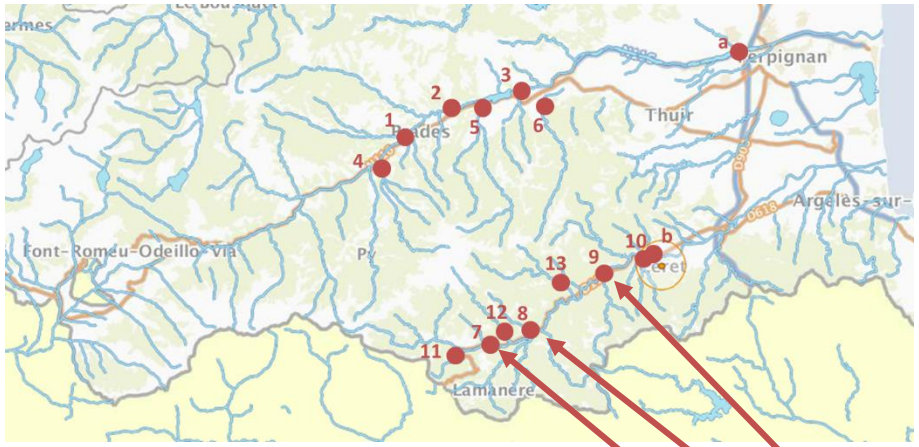
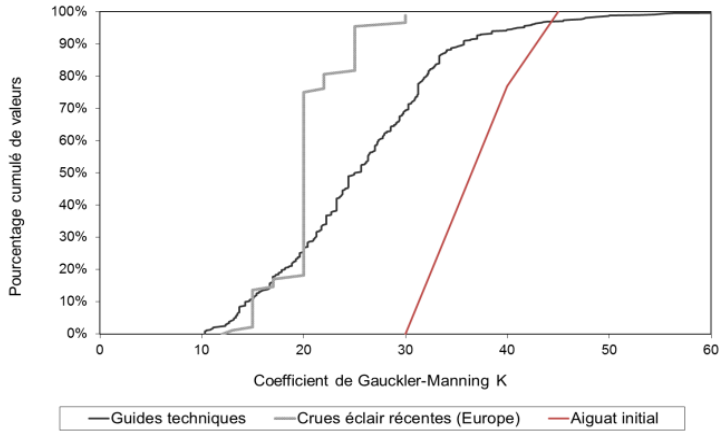
3. A new evaluation of the flood in terms of timing and peak discharges… (1/2)



River	K	V m/s	Q m³/s	S_{bv} km²	Q_{unit} m³/s/km²	Fr
Tech	30	**8.3**	5200	382	13.5	1.1
Tech	30	**7.5**	2200	186	11.9	0.9
Tech	40	**15.3**	2000	109	18	2.7

Figure 4: Examples of cross-sections and initial peak discharges estimations (from E. Gaume, O. Payrastre, G. Degoutte, 2015)



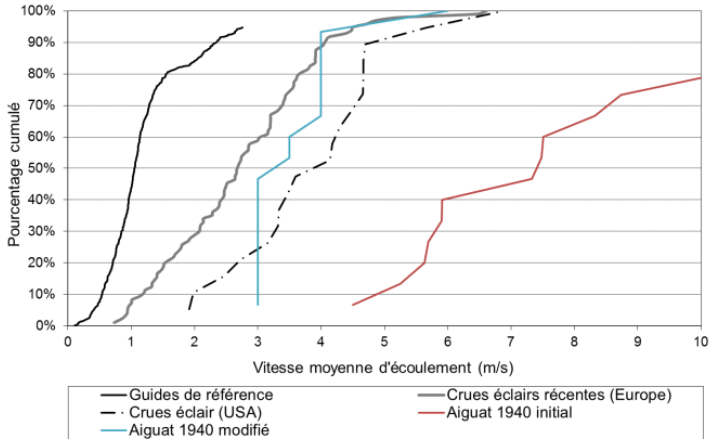


Figure 5: Distributions of roughness coefficients and mean flow velocities measured or estimated (various flash floods), compared to the values of velocities and roughness coefficients used by B. Quesnel for the 1940 Aiguat flow estimates (from E. Gaume, O. Payrastre, G. Degoutte, 2015)

- With the initial peak discharge estimations (fig.4):
  - Roughness values (i.e. 30 to 40 for Strickler's K coefficient) are in the highest range observed for natural streams and artificial channels
  - Velocities exceeding 10 $m.s^{-1}$ for some cross-sections

- Experience with comparable floods:
  - Supercritical flows (Froude number over 1) rarely observed in natural rivers and streams
  - Large differences between the distribution of roughness coefficients and mean flow velocities of recent flash floods and the values used in 1940 (fig.5)

- Initial roughness coefficients are not realistic must be reduced to obtain reasonable flow velocities
- Initial peak discharges of the 1940 flood seem to have been largely overestimated

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3. A new evaluation of the flood in terms of timing and peak discharges… (2/2)

- Revisited hydrographs with new estimations of peak discharges (fig.6)
  - Lower roughness coefficient than historical estimates (K~20 rather than K~35)
  - Smaller peak discharges

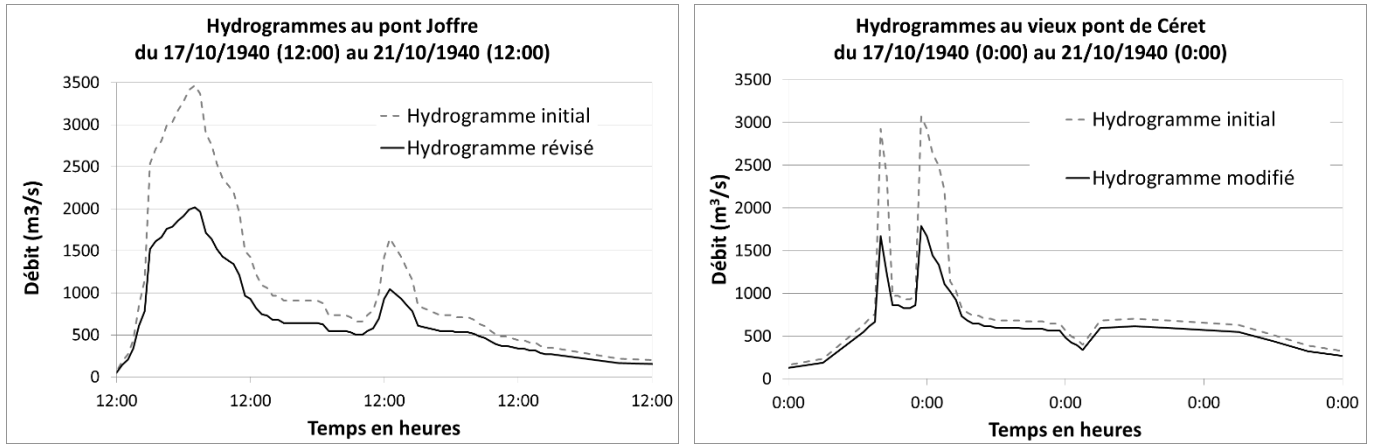
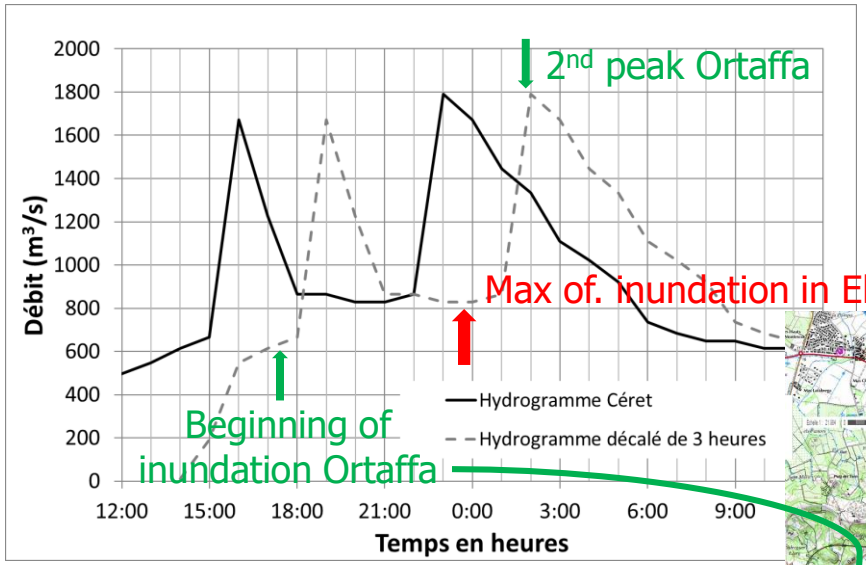


Figure 6: Reconstructed hydrographs of the October 1940 flood at Pont Joffre (Têt) and Pont de Céret (Tech), from E. Gaume, O. Payrastre, G. Degoutte, 2015

- A complex inundation dynamic in the downstream floodplains of the Tech river according to the teacher's testimonies (fig.7)
  - Flood chronology decribed in Ortaffa consistent (fig.7) with the chronology of upstream hydrograph at Céret (with a 3 hours time shift)
  - Reported max. of inundation in Elne appearently not consistent with the same hydrograph.

- Is the new hydrograph consistent with the inundation observed in the downstream floodplain?
- How to explain the maximum of inundation in Elne ? Assumption to be validated: Railway dike breach upstream the city?



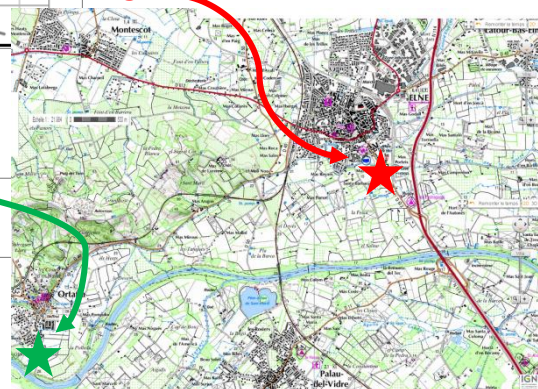


Figure 7: Report of Ortaffa and Elne's testimonies on the hydrograph of Céret shifted by 3 hours (from E. Gaume, O. Payrastre, G. Degoutte, 2015)

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4. Validation through hydraulic simulations (1/4)

- Hydraulic model chosen for the simulation, Basilisk – 2D:
  - Shallow-Water finite volume numerical scheme
  - Order 2 in space and time
  - Quadtree-adaptive grid refinement:
    - Cohabitation of several mesh sizes at the same time
    - Reflecting the characteristics of the flow: precise calculation in areas of interest and broader calculation in areas of less interest
- Simulation area: from Ortaffa to the Mediterranean Sea (fig.8 A)
- Creation of a breach of the railway embankment in the DEM (fig.8 B):
  - Location based on original testimonies and historical aerial views (Geoportail website)
  - opening of about 130m length
- Realization of two hydraulic simulations (historical and new hydrograph) and comparison of the results with the available validation data (flood marks and original testimonies):

	Simulation with the new hydrograph	Simulation with the historical hydrograph
Roughness coefficients	Riverbed K=20 (n=0.05) Floodplain K =10 (n=0.1)	Riverbed K =35 (n=0.029) Floodplain K =10 (n=0.1)
Hydrograph	New estimates E. Gaume, O. Payrastre, G. Degoutte, 2015	Historical estimates Quesnel and Pardé, 1941-42
DEM	RGE ALTI 1m with a breach in the railway embankment from 11PM on October, 17	

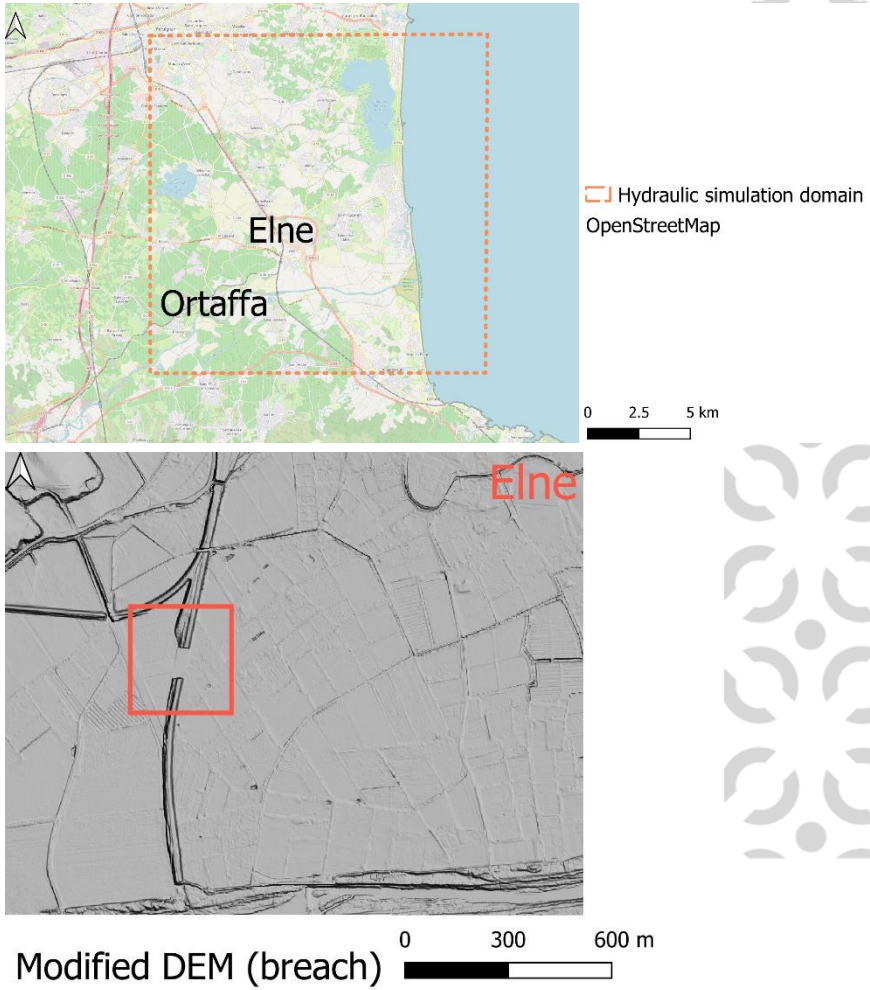

Figure 8: Simulation area (A) and railway breach in the DEM (B)

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4. Validation through hydraulic simulations (2/4)

- Across the entire simulation area, numerous flood marks were recorded after the flood:
  - way to check the simulation results with a comparison between the reported and simulated water surfaces
- The flooded area (fig.9 B.1) is significantly larger with historical flow values than with new values (fig.9 A.1):
  - logical since the flow rate is 50% higher in the case of historical values
- The differences between the measured in 1940 and simulated free water surfaces are mostly negative (fig.9 A.2 & fig.9 B.2):
  - regardless of the hydrographs used, overestimation of the free water surface

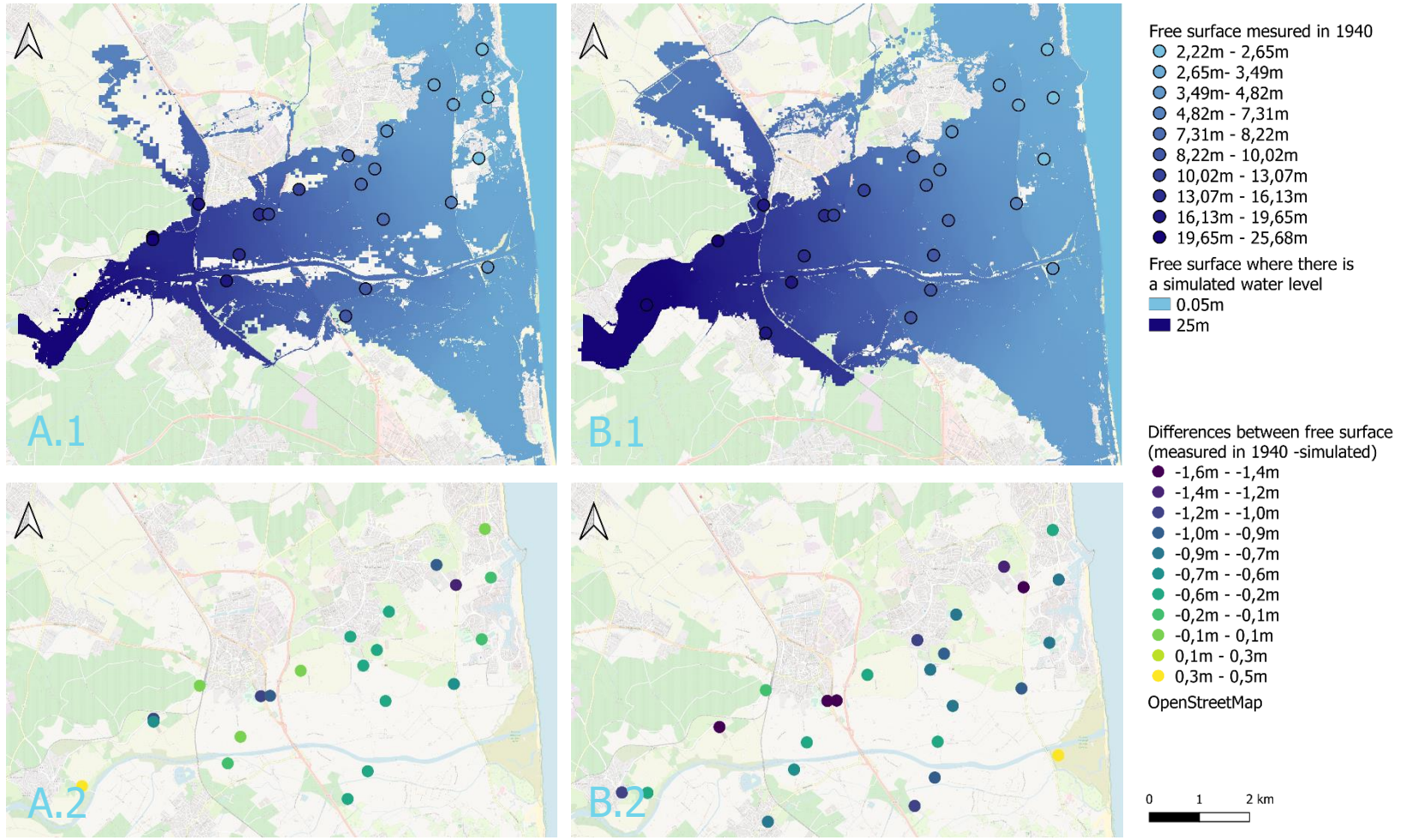

Figure 9: Difference between the water surfaces measured in 1940 and calculated by Basilisk
A - New hydrograph and Manning coefficients
B- Historical hydrograph and Manning coefficients

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4. Validation through hydraulic simulations (3/4)

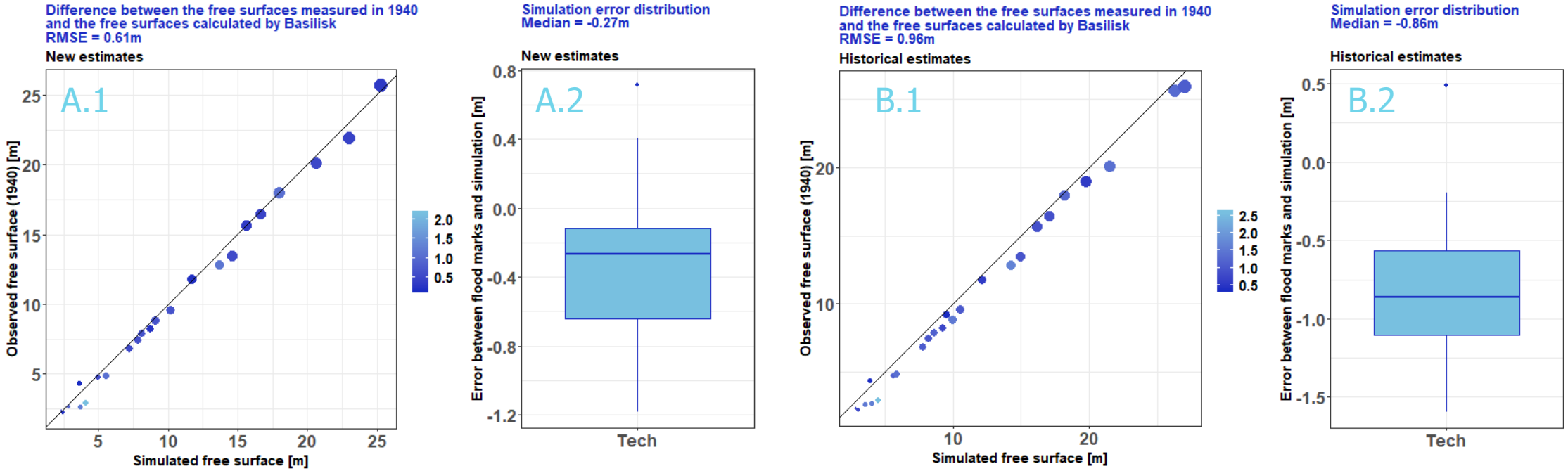

Figure 10: Difference between the water surfaces measured in 1940 and calculated by Basilisk and distribution of simulation errors
New estimate of flows and Manning coefficients - A
Historical estimate of flows and Manning coefficients - B

- The scatter plots (fig.10 B.1 and fig.10 A.1) confirm the clear overestimation of the free water surface, which is more important with the historical hydrograph than with the new one.
- Best approximation with the new hydrograph: smaller RMSE, Error distribution closer to 0

- Better results with the new hydrograph and roughness estimates,
- However it is not really possible to invalidate historical hydrograph (results not significantly different)

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4. Validation through hydraulic simulations (4/4)

- Comparison of the chronology of the testimonies and of the two simulations :
  - Can the breach in the SNCF embankment explain the flooding of the lower districts of the town of Elne during the night of 17 to 18 October?
  - Do the reduced discharges influence the chronology of the event ?
- Chronology based on testimonies:
  - accumulation of water in the Pla de la Barca basin (upstream the railway line) from 5 p.m. onwards.
  - the breach in the railway embankment occurred between 10 p.m. and 00 a.m. according to testimonies (made at 11 p.m. in the simulations).
  - maximum water level reached at 11 p.m. on 17 October.
  - after the breach, the Pla de la Barca empties rapidly, the flow to the north of the railway line stops quickly.
- With the historical hydrograph:
  - the Pla de la Barca is already almost full by 5 p.m.
  - at 7 p.m., the water already passes over the railway line and reaches the lower districts of Elne (fig.11 B.2, contradiction with the testimonies).
- With the re-estimated hydrographs, results seem in better agreement with the testimonies:
  - the Pla de la Barca is only filled from 7 p.m.
  - beginning of the flooding in the lower districts of Elne around 11.30 p.m. (fig.11 A.3).

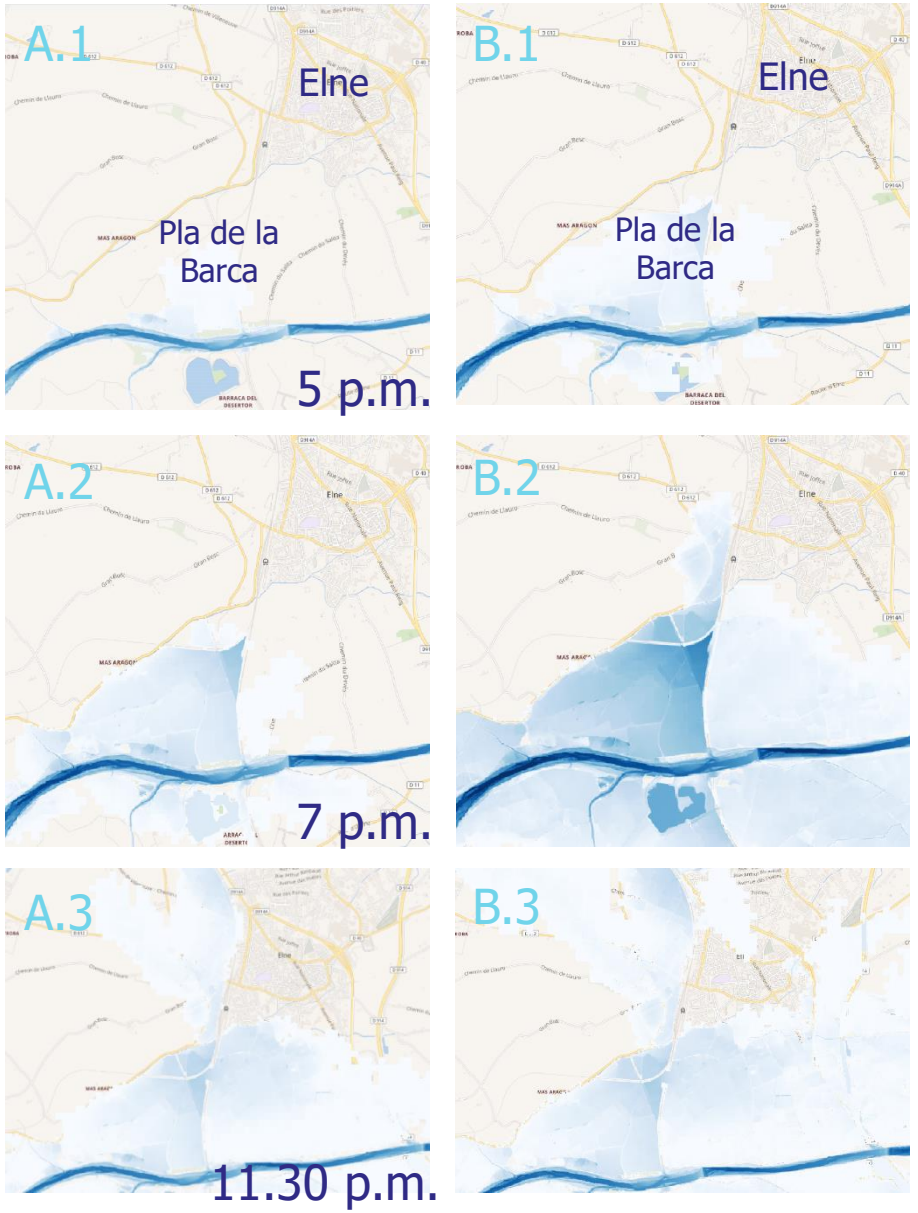

Figure 11: Comparison of the water level for the two simulations
New estimates of flows and Manning coefficients - A
Historical estimates of flows and Manning coefficients - B

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5. Conclusion

- A large amount of archive documents providing detailed information on the flood, but historical peak discharge estimates appearing as largely overestimated
- Determining role of the reservoir created upstream of the railway line in the flooding of the downstream plain:
  - The water retained at the Pla de la Barca and the breach in the railway embankment are certainly at the origin of the flooding of the lower districts of Elne
- The revised hydrographs and reduced peak discharges appear to be more realistic according to the data retracing the inundation in the downstream plains:
  - Better estimate of free water surface from comparison with flood marks recorded
  - Chronology closer to the testimonies
- Illustration of the possibility to re-interpret major past-flood events at the light of our increased scientific knowledge

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