

TRACKING HYDROLOGICAL DROUGHT PROPAGATION IN RIVER NETWORKS: AN EVENT-BASED FRAMEWORK

Alex Crespillo López^{1,2}, S.M. Vicente Serrano^{1,2}, L. Gimeno^{3,4,5}

¹ Pyrenean Institute of Ecology, IPE-CSIC, Av. De Montañana 1005,
50059 Zaragoza, Spain

² Laboratory of Climatology and Climate Services (LCSC), CSIC-
Zaragoza University, 50059 Zaragoza, Spain

³ Environmental Physics laboratory (EPhysLab), CIM-UVigo, Vigo
University, Ourense, Spain

⁴ CSIC-University of Vigo Associated Unit: Atmospheric and Oceanic
Physics Group, Pontevedra, Spain

⁵ Galicia Supercomputing Center (CESGA), Santiago de Compostela,
Spain

Corresponding author: alex@ipe.csic.es

1. MOTIVATION / PROBLEM

- ❑ Hydrological droughts are dynamic phenomena that propagates in space and time
- ❑ Not a simple linear process —————> Integrative systems (upstream conditions affecting downstream reaches)
- ❑ Approaches:
 - ❑ **Clustering algorithms** (Janzing et al., (2026)), **individual event perspective** (Laaha et al., (2017)), **total area under drought conditions** (Hanel et al., 2018; Wanders et al., 2015), **hydrological drivers** (Colombo et al., 2023; Van Tiel et al., 2023), **multiple basins** (Teutschbein et al., 2022; Brunner et al., 2021; Barker et al., 2019)
 - ❑ Gap: Explicit analysis of hydrological drought propagation from a **event-based perspective**
 - ❑ **Objective:** Track and quantify hydrological propagation dynamics using an even-based framework

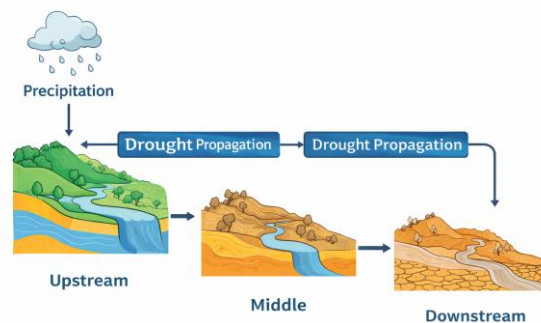


Figure 1. Hydrological drought propagation simple scheme

2. METHOD / ALGORITHM

- ❑ Drought event identification (SSI, Vicente Serrano et al., (2025))
- ❑ Network connectivity
- ❑ Link upstream – downstream events (**search window (W)** and **overlap filter (M)**)

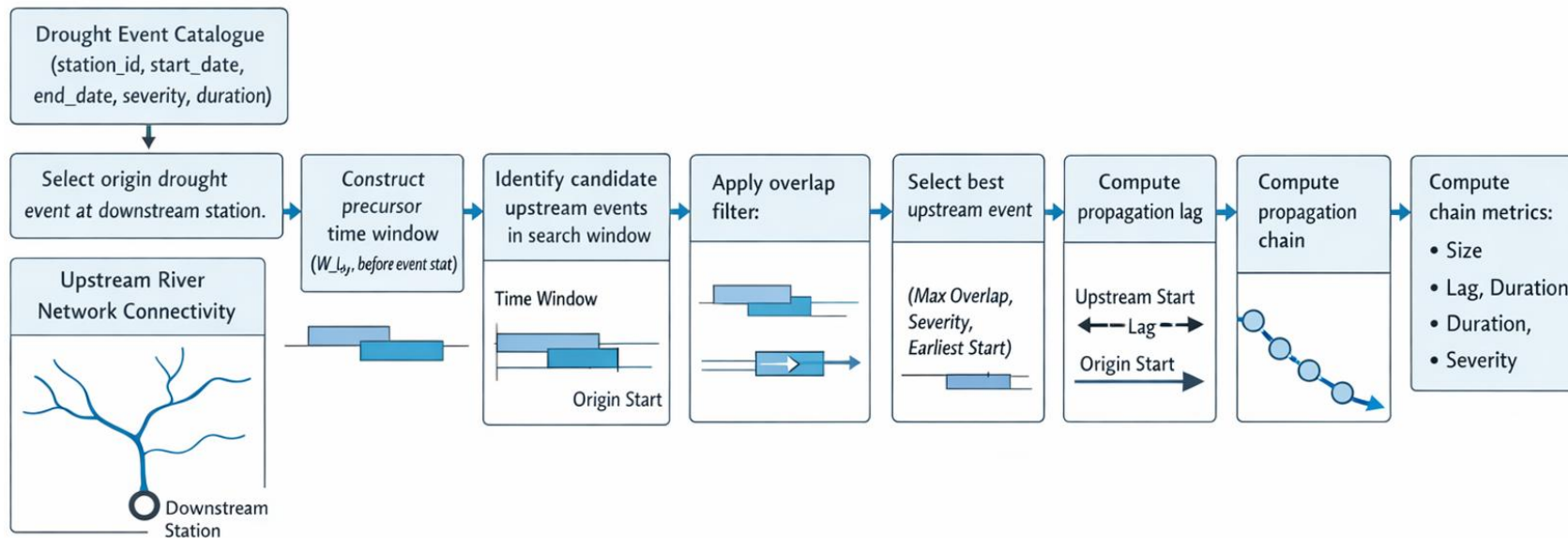


Figure 2. Conceptual workflow of the hydrological drought propagation algorithm used to identify upstream–downstream drought relationships within the river network. Starting from a drought event catalogue and the upstream connectivity structure of the river network, the method selects a downstream origin event and constructs a precursor search window extending W days before the event onset. Candidate drought events at upstream stations intersecting this window are identified and filtered according to a minimum temporal overlap criterion. When multiple candidates exist at a given station, the best upstream event is selected using deterministic tie-breaking rules.

3. CHAIN METRICS

Descriptor	Symbol	Description	Expression	Units
Chain start	$t_{(c,s)}$	Earliest onset among all chain events	$t_{(c,s)} = \min (t_{s,k}), k \in C$	—
Chain end	$t_{(c,e)}$	Latest termination among all chain events	$t_{(c,e)} = \max (t_{e,k}), k \in C$	—
Chain duration	D_c	Total span, from first onset to last termination	$D_c = t_{(c,e)} - t_{(c,s)} + 1$	days
Chain size	N_c	Total stations in chain (upstream matched + origin)	$N_c = N_{up} + 1$	—
Propagation fraction	f_p	Fraction of upstream network affected	$f_p = N_{up} / N_{avail}$	—
Mean lag	λ	Mean onset lag between upstream events and origin event	$\lambda = (N_{up})^{-1} \sum \lambda_{k'}, k \in C$	days
Chain severity	$S_{(c)}$	Cumulative SSI-based severity across all chain events	$S_c = \sum S_{k'}, k \in C$	—
Chain volumetric severity	$V_{(c)}$	Total discharge deficit volume across all chain events	$V_c = \sum V_{k'}, k \in C$	hm ³

C = set of events forming the propagation chain; k indexes individual events within the chain

N_{up} = total number of upstream stations connected to the origin station.

N_{avail} = upstream stations present in event catalogue

Table 1. Mathematical definition of the propagation chain descriptors. Chain properties include start and end dates, duration, propagation size, propagation fraction, mean lag, chain severity and chain severity in volume (hm³) units.

4. STUDY AREA / DATA

□ Centro de Estudios y Experimentación de Obras Públicas (CEDEX, <https://www.cedex.es>). Period 1961-2020

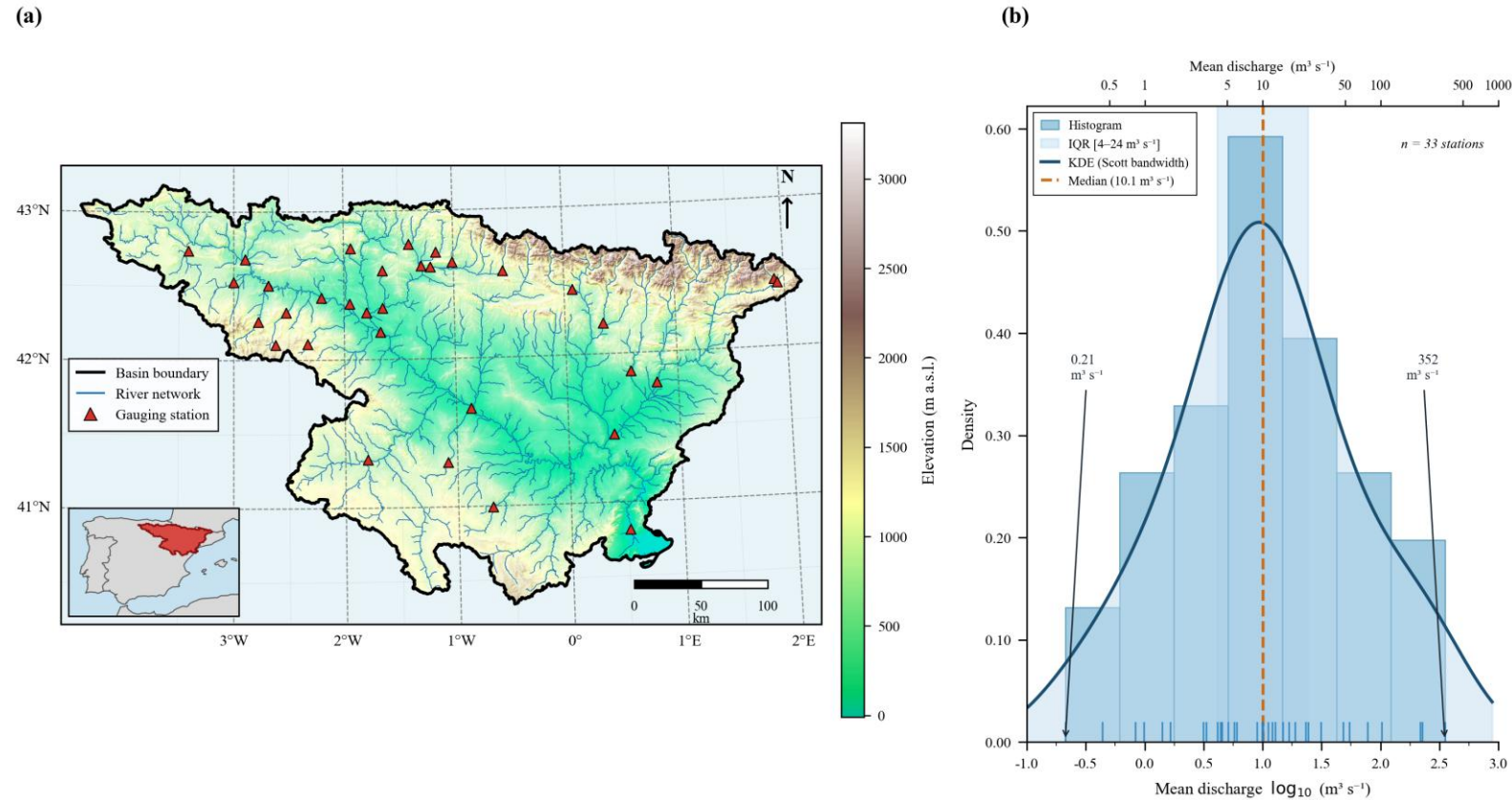


Figure 3. (a) Study area showing the Ebro River Basin (Spain), including the river network and the location of the 33 gauging stations used in this study. Elevation is represented as a shaded background. (b) Distribution of mean discharge across the gauging stations, expressed in log₁₀ scale. The histogram and kernel density estimate illustrate the wide range of flow conditions represented in the dataset, from low-discharge headwater stations to high-flow downstream sections.

5. RESULTS - PROPAGATION

- ❑ 525 propagation chains (20% of the 2265 original drought events)
- ❑ Duration: months to years
- ❑ Chain size / Propagation fraction: From few stations implicated to great part of the network
- ❑ Lag: days to months
- ❑ Severity: great variability, ranging from little impact on the hydrological system to events with a large impact

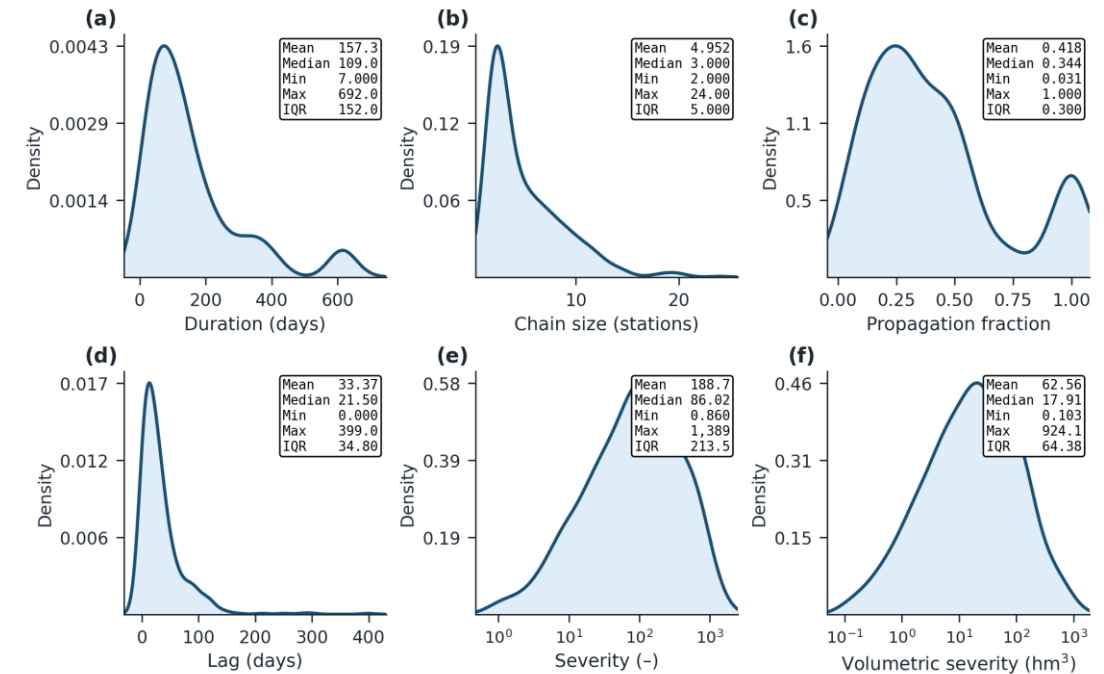


Figure 4. Distribution of hydrological drought propagation chain characteristics: (a) chain duration, (b) chain size, (c) propagation fraction, (d) propagation lag, (e) chain severity, and (f) volumetric severity. Shaded areas represent kernel density estimates.

6.a CASE STUDIES – BASIN WIDE PROPAGATION EVENT

Propagation chain 9027_38 | Origin: Station 9027 | 21 Sep 1988 – 24 Apr 1989

D = 216 days | N = 24 stations | $f_p = 0.719$ | Mean lag = -35.8 d | Severity = 1160.2 | Vol. severity = 896.6 hm³

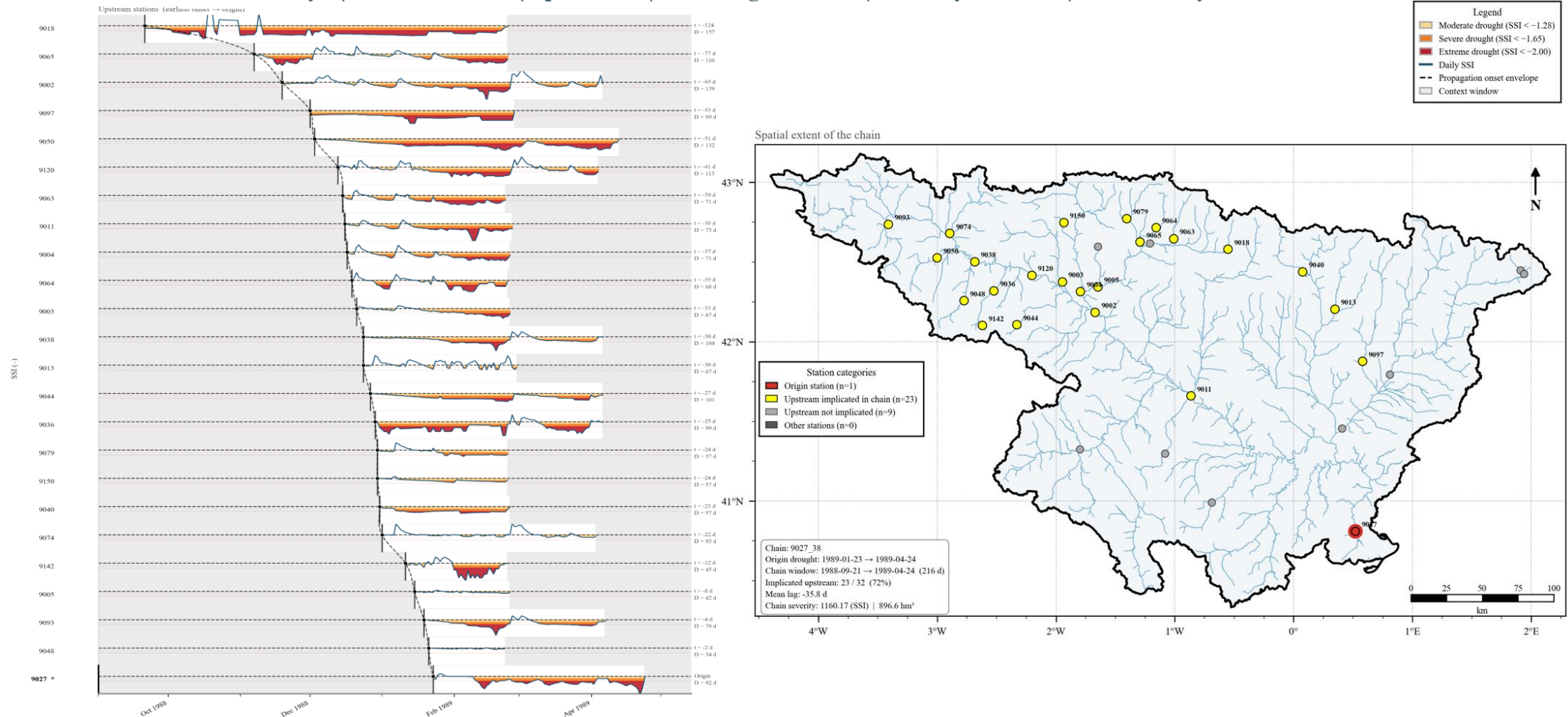


Figure 5. Spatiotemporal representation of the hydrological drought propagation chain associated with the event originating at station 9027 (Ebro River at Tortosa).

6.b CASE STUDIES – LOCALIZED PROPAGATION EVENT

Propagation chain 9011_89 | Origin: Station 9011 | 30 Dec 2016 – 01 Mar 2018
 D = 427 days | N = 11 stations | fp = 0.455 | Mean lag = -119.4 d | Severity = 1298.8 | Vol. severity = 597.7 hm³

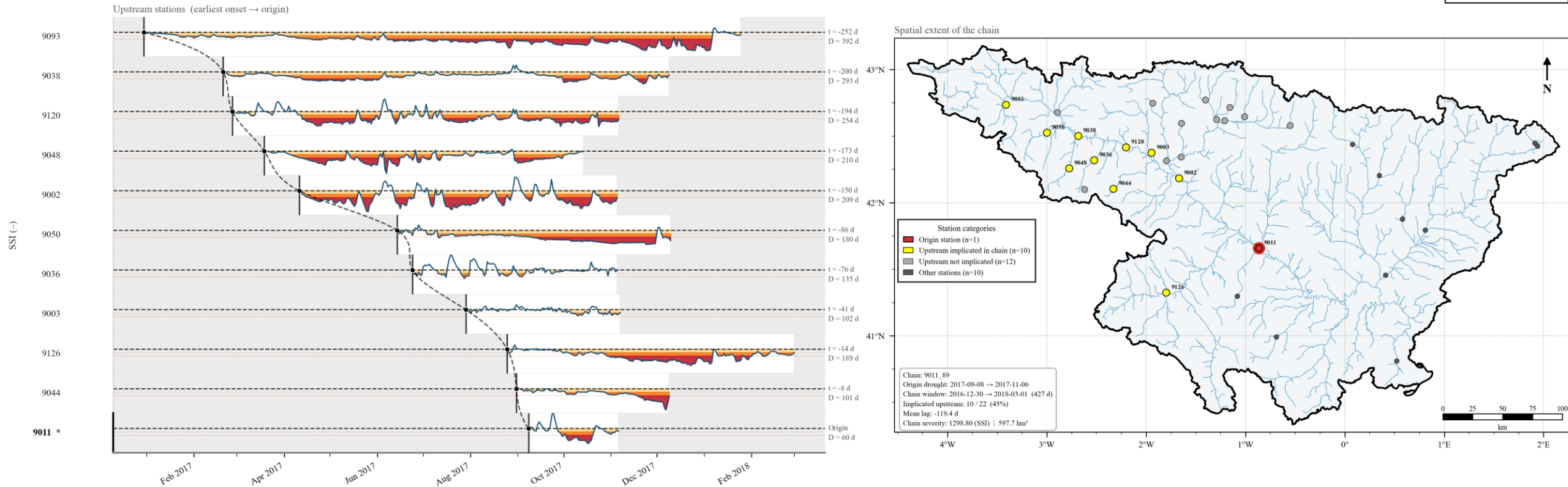


Figure 6. Spatiotemporal representation of the hydrological drought propagation chain associated with the event originating at station 9011 (Ebro River at Zaragoza).

7. CONCLUSIONS

❑ Method

- ❑ New scalable **event-based framework** to track hydrological drought propagation in river networks
- ❑ Reconstructs **upstream-downstream propagation chains**

❑ Findings

- ❑ Hydrological drought propagation is **highly variable across space and time**
- ❑ Ranges from local sub-basin events to basin-wide processes

❑ Impact

- ❑ Provides a **process-based understanding** of hydrological droughts
- ❑ Useful for water management and early warning systems

“Hydrological droughts are not isolated events – they propagate through different reaches of the river network”