Probabilistic streamflow prediction in ungauged natural catchments with Temporal Fusion Transformers

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Abstract

Streamflow prediction is critical for water resource management.

Key challenges
- Complex hydrological processes.
- Uncertain meteorological data.
- Limited or missing observations.

Our approach
Temporal Fusion Transformers (TFTs) learn hydrological temporal patterns from large datasets to predict streamflow in ungauged catchments.

What do we gain?
- Comparable TFT performance in ungauged conditions to calibrated HBV.
- Improved performance with TFT specialization (+28% median NSE, +45% median KGE, −7% CRPS).

The results can be applied to water management by providing enhanced, uncertainty-aware streamflow prediction.

1. Motivation and objectives

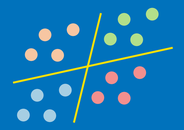
Most catchments worldwide lack streamflow observations.

Classical hydrological models struggle to generalize and face computational and scalability constraints.

Predict streamflow in ungauged conditions using controlled data withholding.

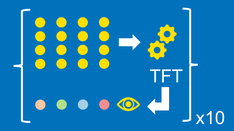
Assess model specialization for specific regions by retraining pre-calibrated TFT models for new catchments.

2. Methods



1. Division of the sample of catchments in 4 clusters.

2. Creation of groups with one catchment from each cluster.



3. Multiple TFT calibrations leaving one group out. Prediction for the held-out group.

4. Selection of the best calibrated TFT model and individually specialization for each held-out catchment.

5. Performance evaluation (NSE, KGE, CRPS), and benchmark with HBV hydrological model. CRPS is similar to MAE but for probabilistic predictions.

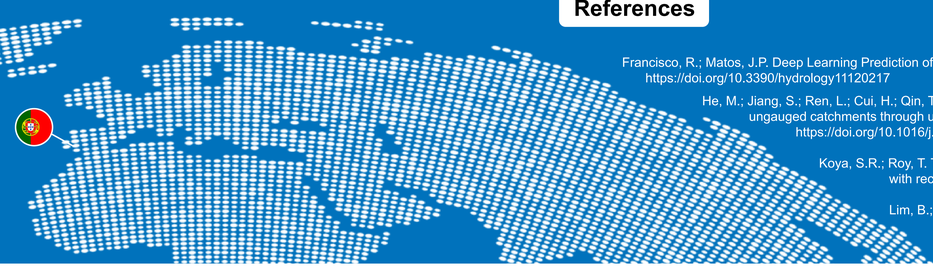
3. Case study

53 natural catchments in Mainland Portugal with at least 10 years of data.

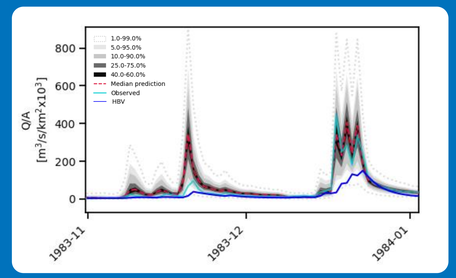
Target: Streamflow (SNIRH)

Inputs:

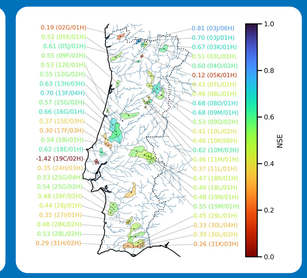
- Temperature (ERA5-Land)
- Precipitation (ERA5-Land)
- Land cover (Copernicus CORINE)
- Day of the year
- Mean elevation (Copernicus DEM GLO-30)
- Centroid coordinates
- Gravelius compactness index
- Drainage area



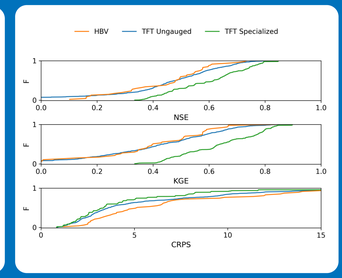
4. Results and discussion



Detail of a TFT probabilistic prediction (ungauged).

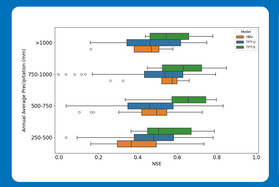


Spatial distribution of NSE of the best TFT models (ungauged).

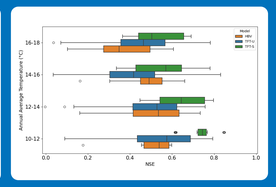


Cumulative CDF of model performance (F) across catchments, for HBV, TFT ungauged and TFT specialized.

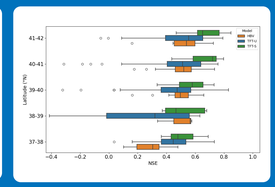
Performance distribution across catchments (NSE)



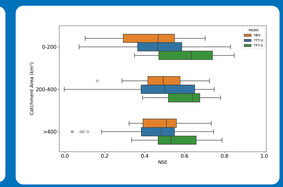
Annual average precipitation



Annual average temperature



Centroid latitude



Drainage area

TFT models in ungauged conditions achieve comparable performance to HBV (median NSE = 0.48), with improved KGE and CRPS.

Model specialization significantly improves performance, reaching median NSE = 0.62 (+28%). Median KGE increases 45% and CRPS median reduces 7%.

Performance gains are consistent across diverse catchments, and the model provides probabilistic predictions that quantify uncertainty in streamflow.

5. Conclusions

1. Improved prediction performance
2. Transferable to other locations
3. Quantifies predictive uncertainty
4. Supports data-driven decision making

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