Real-time Bayesian estimation of stage-discharge rating curves during floods

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Research Objective

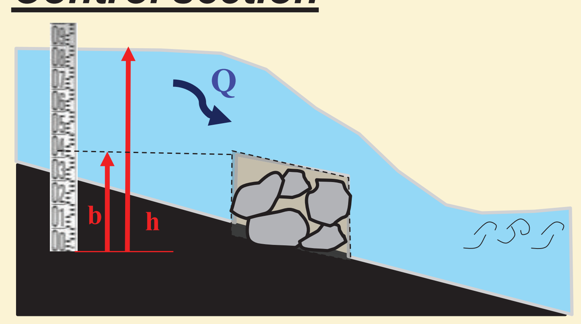
- **Real-time** streamflow estimation with uncertainties that can be assimilated in models and decision making.
- In particular, automatic **detection of rating changes** or "shifts" in the stage-discharge relation.

Background

River discharge time series are established using "rating curves" that approximate the stage-discharge relation. A major problem is that the river bed at many hydrometric stations can evolve during floods, leading to rating changes, or "shifts" (Mansanarez, 2016).

Hydraulic controls :

Control section

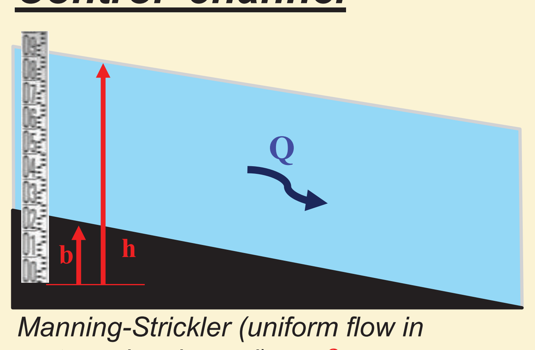


Rectangular weir / riffle:

$$Q(h) = \underbrace{C_Q B \sqrt{2g}}_{a} (h - b)^{\overbrace{3/2}^{c}}$$

Shift Δb ?

Control channel



Manning-Strickler (uniform flow in rectangular channel):

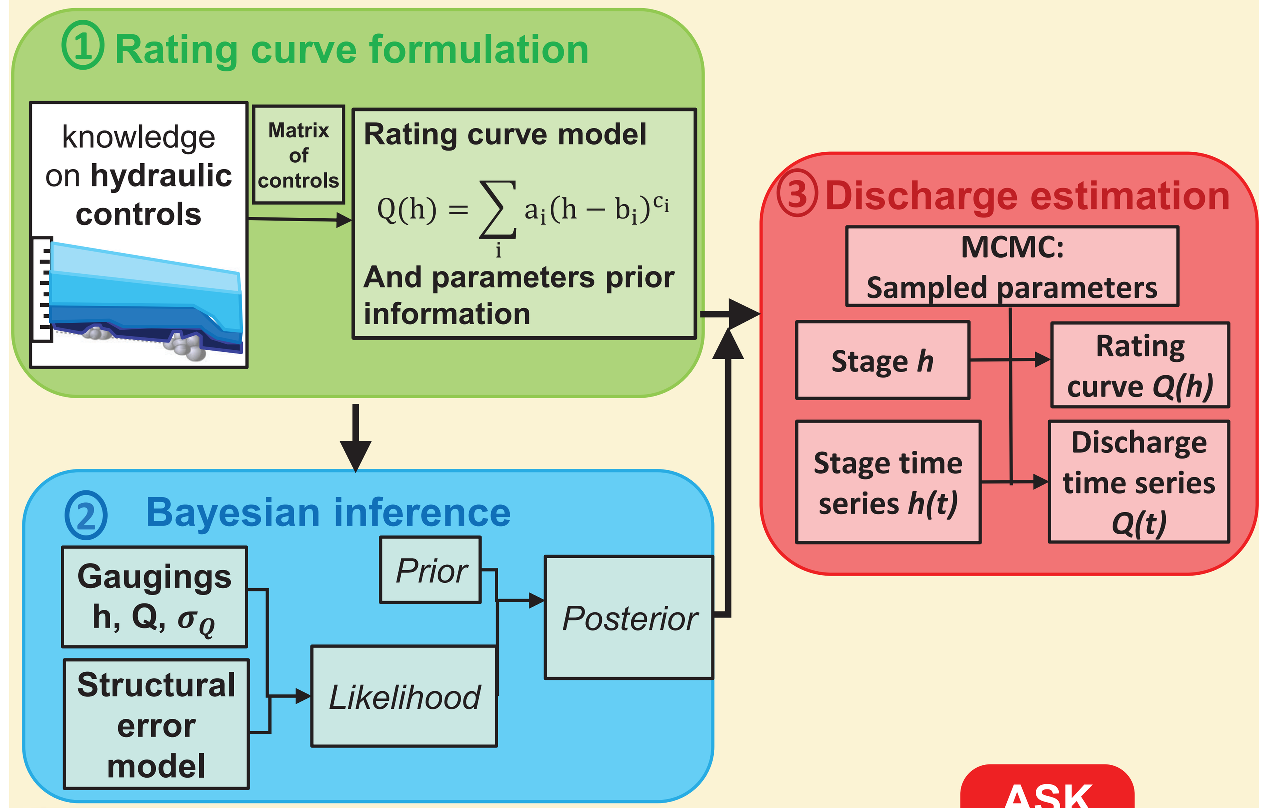
$$Q(h) = \underbrace{K_s B \sqrt{J}}_{a} (h - b)^{\overbrace{5/3}^{c}}$$

Shift Δb ?

General formula : $Q(h) = a\,(h-b)^c$

BaRatin method:

For the estimation of rating curves and discharge time series with quantitative uncertainties we use BaRatin (BAyesian RATINg curve, Le Coz et al., 2014). The main philosophy of this method is to combine the information given by **gaugings** (stage-discharge measurements) and hydraulic knowledge of the site through a Bayesian approach.



BaRatinAGE v2-1 free software

ASK FOR DEMO

Retrospective Analysis

A retrospective analysis is required in order to calibrate models and tools that could be used in real time. For the retrospective analysis we propose here a general segmentation method to define homogeneous periods. This method can be applied to gaugings and stage records, taking into account their uncertainties. It has been applied to the case study of Ardèche River at Meyras (France) for the period 2001-2014.

1. General segmentation method

Bayesian method for segmentation with uncertainties

Segmentation Model :

$$Y(t) = \begin{cases} \mu_1 & if\ t \le \tau_1 \\ \dots & \\ \mu_{n_s} & if\ t \le \tau_{n_s} \end{cases}$$

with:

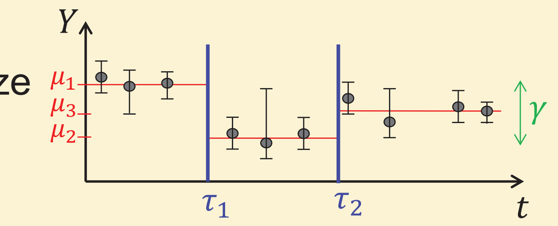
- $Y(t)$ *= target variable (e.g. rating curve residuals);*
- μ_i *= mean of segment i;*
- γ *= variability around the mean;*
- τ_i *= change point between segments i , i+1;*
- n_s *= number of segments*

Parameters :

$$\vec{\theta}_{SM} = (\mu_1, \dots, \mu_{n_s}, \tau_1, \dots, \tau_{n_s-1}, \gamma)$$

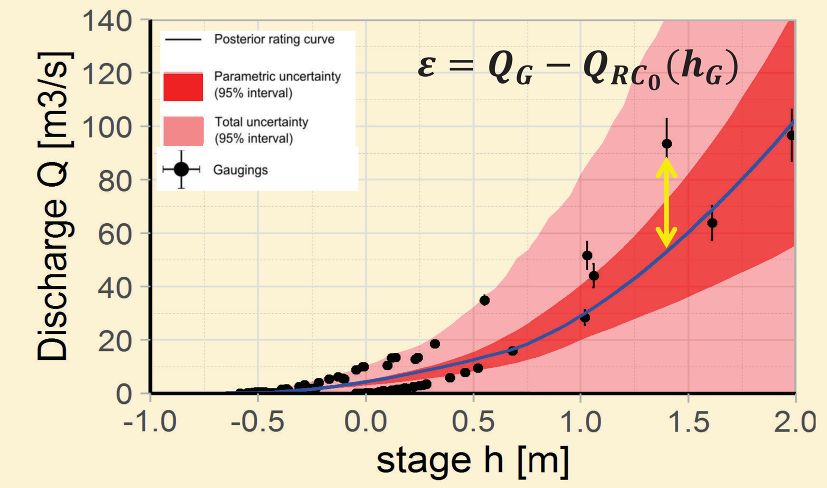
Bayesian Criterion :
Number of segments to minimize

$$BIC = log\, N_{par} - 2\, ln\, L_{max}$$

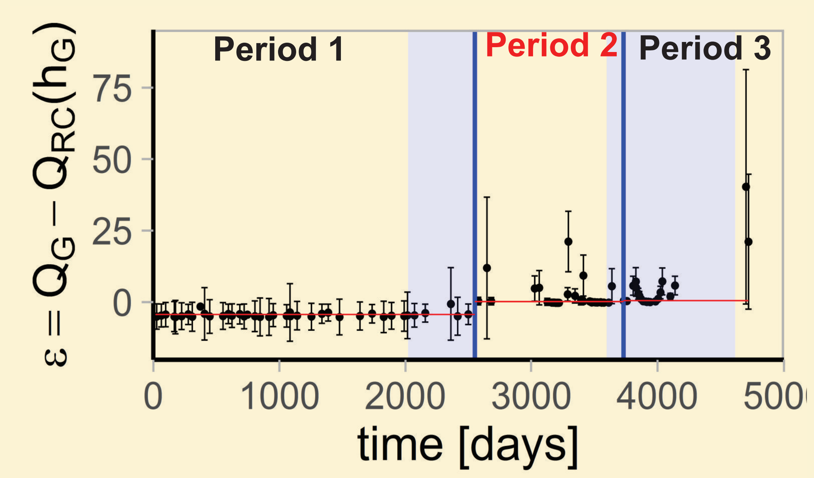


2. Segmentation of gaugings

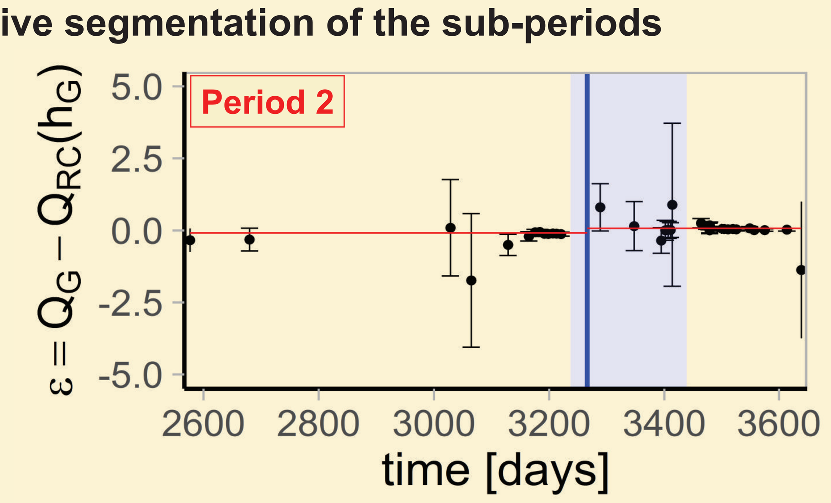
- **Estimation of the base rating curve with all gaugings** (Morlot et al.,2014)



- **Segmentation of residuals with uncertainties**



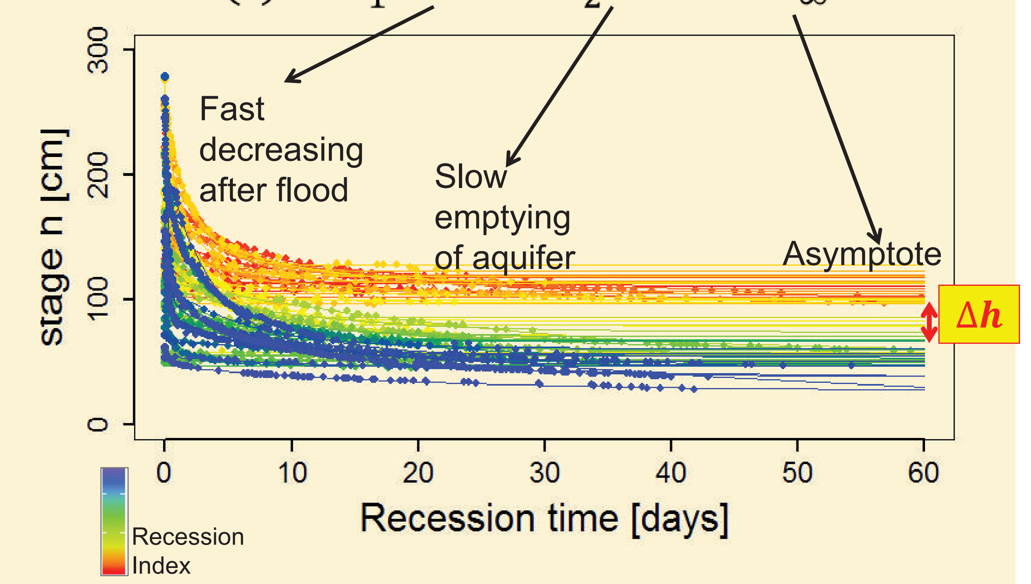
- **Iterative segmentation of the sub-periods**



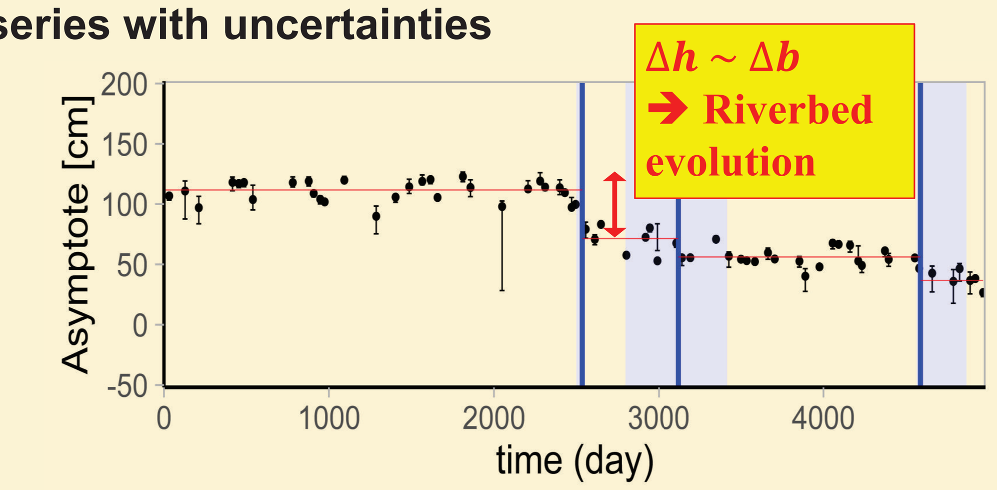
3. Recession analysis

- **Exponential regression of the recession curves from the stage record**

$$h(t) = h_1 e^{-\beta_1 t} + h_2 e^{-\beta_2 t} + h_\infty$$

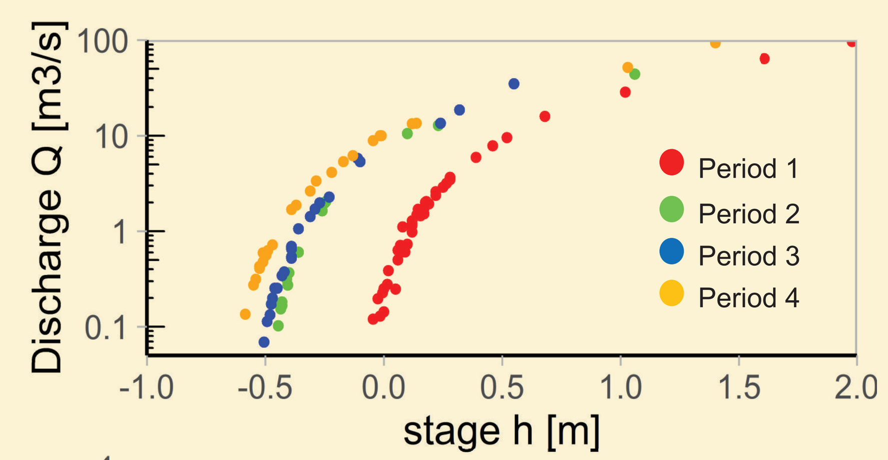


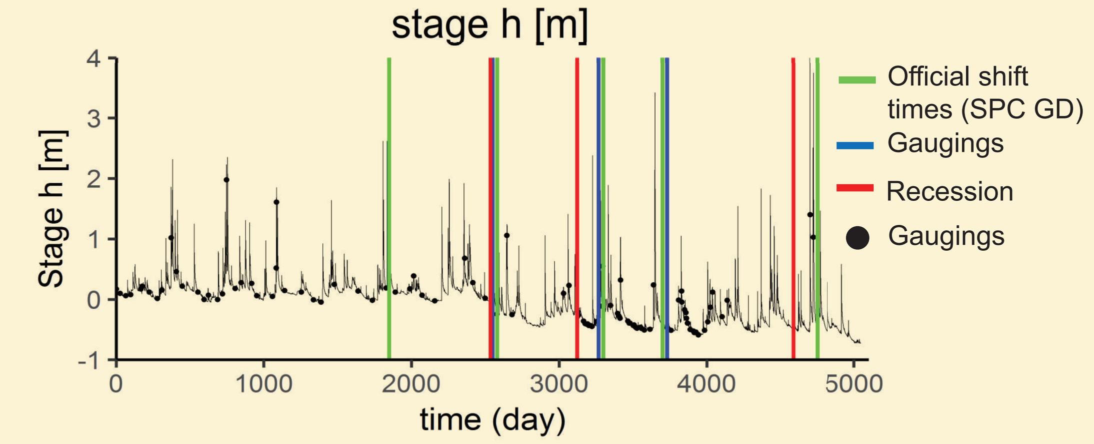
- **Bayesian segmentation of the asymptote time series with uncertainties**



4. Results

The combined results of gaugings and recessions segmentation are presented below. We observe a good agreement with the official "shift" times (green lines).

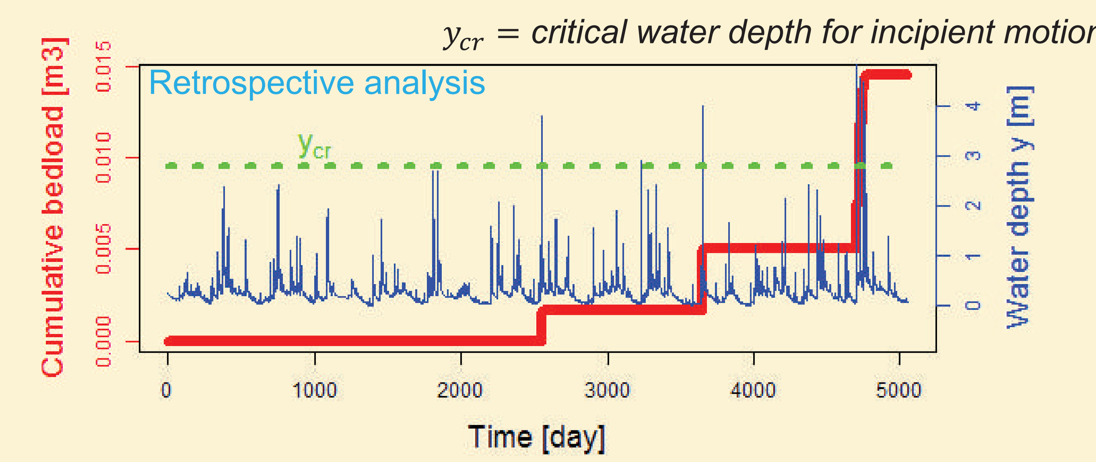




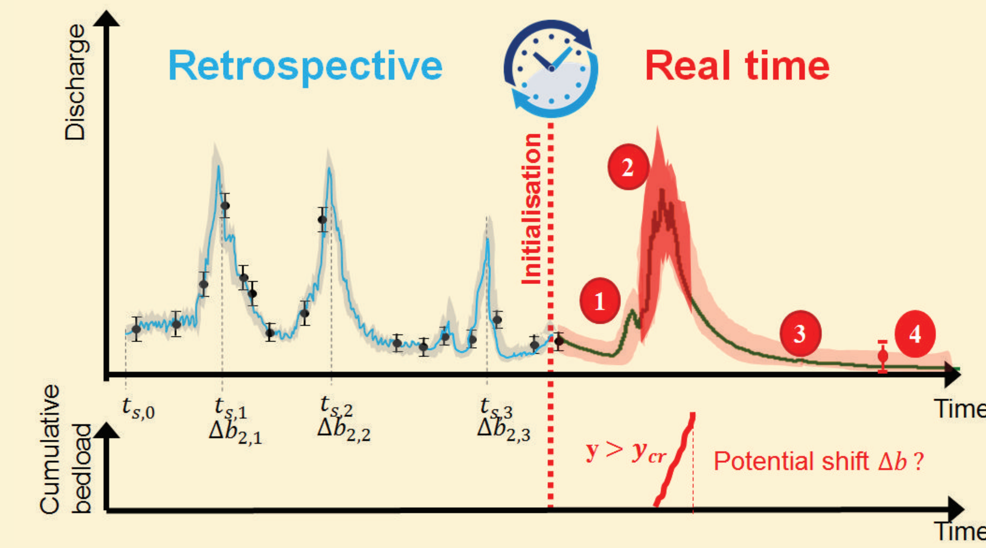
Ongoing research

Sediment transport analysis

Cumulative bedload (Meyer-Peter and Muller, 1948):



Real-time rating curve estimation



Five possible actions:

1. No flood ➔ no modification of the current rating curve
2. Flood event ➔ sediment transport analysis ➔ increasing uncertainty to account for potential rating change
3. Recession analysis ➔ First estimation of riverbed evolution Δb
4. New gauging ➔ Refined estimation of riverbed evolution Δb

Perspectives

- Analysis of sediment transport ;
- Correlation between neighbouring stations;
- Bathymetry;
- Velocity measurements;
- Validation of the method with more challenging case-studies.

References

- **Le Coz, J., Renard, B., Bonnifait, L., Branger, F., and Le Boursicaud, R., 2014**. Combining hydraulic knowledge and uncertain gaugings in the estimation of hydrometric rating curves: A Bayesian approach. J. Hydrol. 509, 573-587. doi:10.1016/j.jhydrol.2013.11.016.
- **Mansanarez, V., 2016.** Non-unique stage-discharge relations: Bayesian analysis of complex rating curves and their uncertainties. PhD dissertation, Irstea, Grenoble Alpes University, 282 p.
- **Meyer-Peter, E., and Muller, R**. Formulas for bed-load transport. In Report on second meeting of IARH, Stockholm, Sweden, 39-64, 1948.
- **Morlot, T., Perret, C., Favre, A.-C., and Jalbert, J., 2014.** Dynamic rating curve assessment for hydrometric stations and computation of the associated uncertainties: Quality and station management indicators. J. Hydrol. 517, 173-186. doi:10.1016/j.jhydrol.2014.05.007.