Bayesian estimation of streamflow using satellite data and ground discharge measurements

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Watching water: From sky *and* stream

- Future SWOT satellite (NASA/CNES) will provide river stage, slope and top width
- How to combine satellite remote sensing with ground discharge measurements to produce streamflow time series?

Bayesian rating curves

- Stage-width-slope-discharge models can be applied to satellite data to compute streamflows and provide parameter estimates to hydrodynamical models
- 3 models were developed based on the Manning equation for a single channel control and implemented in *BaM!* (Bayesian Modeling, Renard, 2017)

Model "h": $$Q\left(h(t)\right) = k\, K_s\, \bar{B}\, \sqrt{\bar{S}}\, \left(h(t) - h_0\right)^M$$

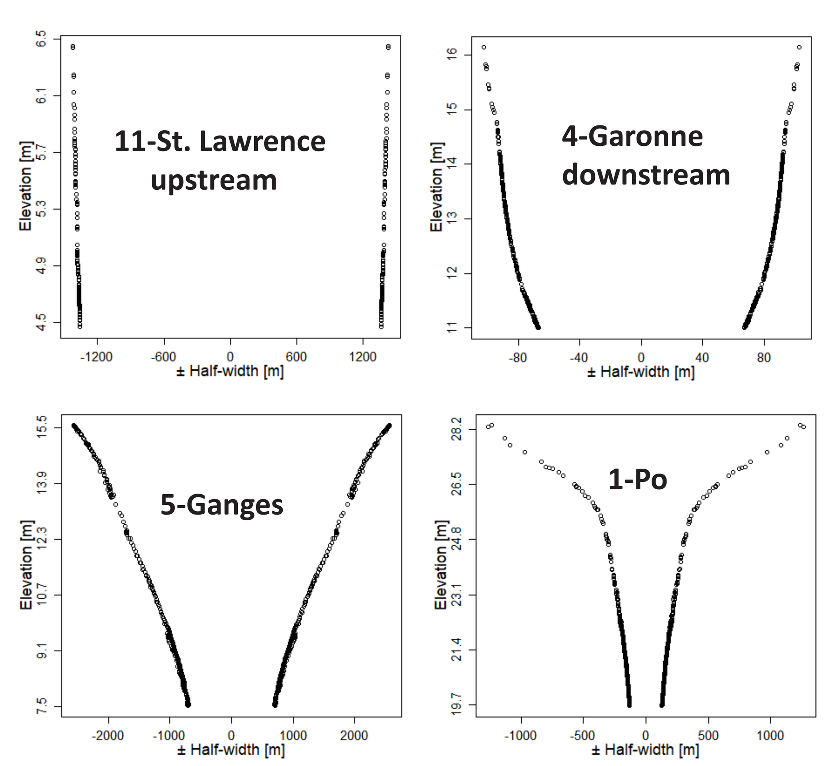
Model "hS": $$Q\left(h(t), \bar{S}(t)\right) = k\, K_s\, \bar{B}\, \sqrt{\bar{S}(t)}\, \left(h(t) - h_0\right)^M$$

Model "hSB": $$Q\left(h(t), \bar{S}(t), \bar{B}(t)\right) = k\, K_s\, \bar{B}(t)\, \sqrt{\bar{S}(t)}\, \left(h(t) - h_0\right)^M$$

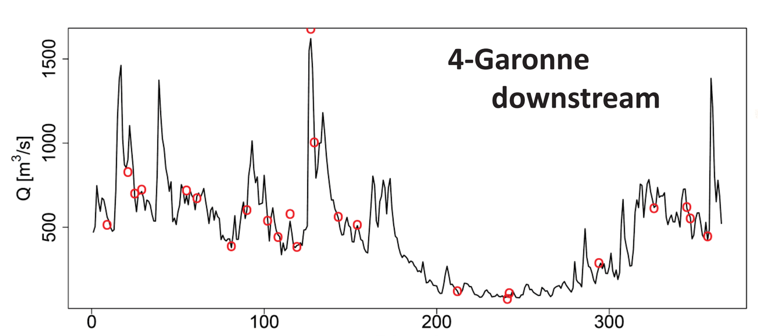
With Q discharge [m³/s], h stage [m], $\bar{S}$ and $\bar{B}$ reach-averaged slope [-] and width [m], t time, K_S Strickler flow resistance coefficient [m$^{1/3}$/s], h_0 mean bed elevation [m], k and M cross-section shape factor [-] and exponent [-].

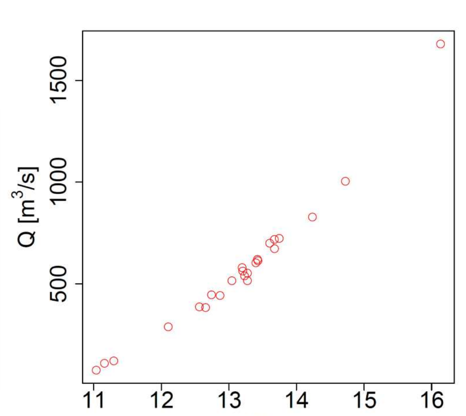
Synthetic satellite and ground data

- Benchmark dataset for 19 river sites from Durand et al. (2016)
- Simulated time series of stage, slope and top width with added uncertainties



Reconstruction of the reach-averaged geometry: at-station width-elevation cross-sectional shapes

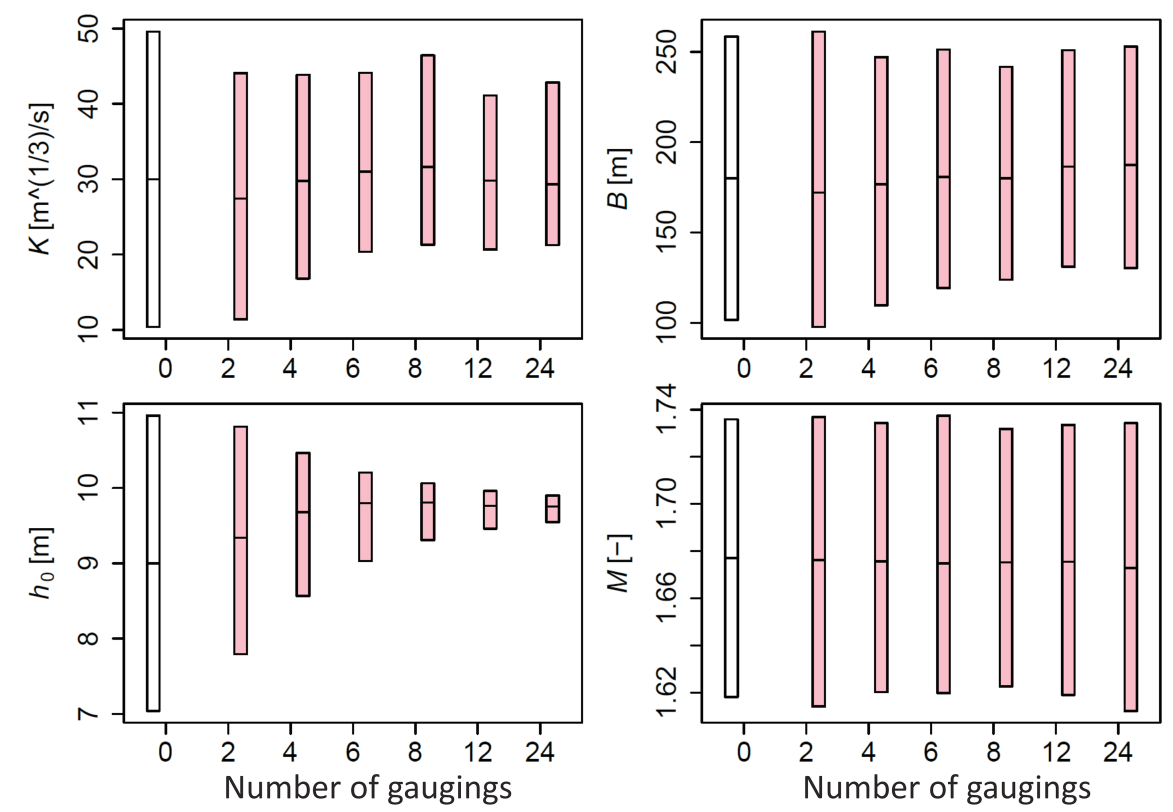




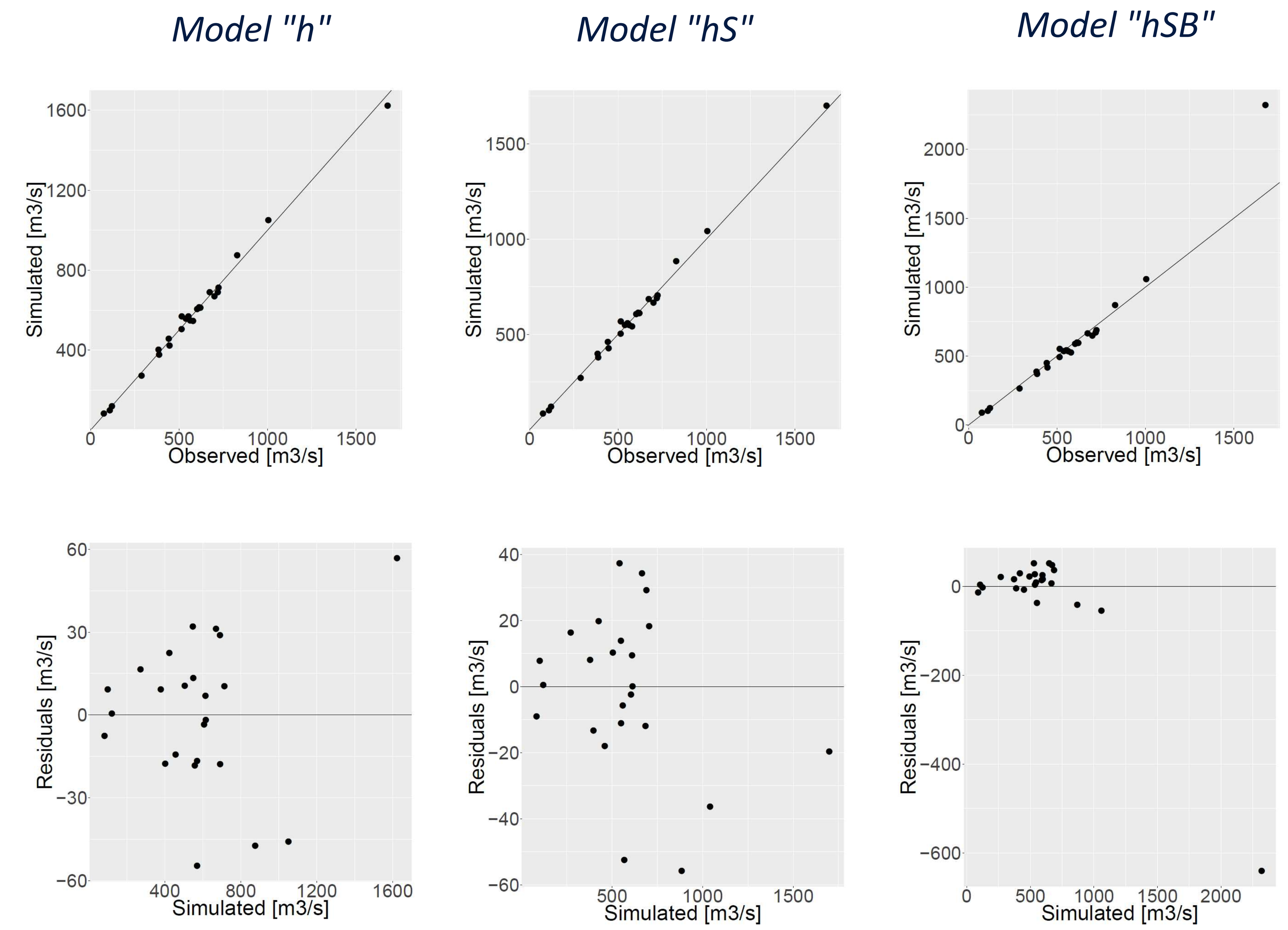
Simulation of 24 discharge measurements (a.k.a. gaugings): "realistic" sampling of discharges + measurement uncertainties

Rating curve estimation

- The mean bed elevation (h_0) is identified better than parameters that make the $K_s\, \bar{B}\, \sqrt{\bar{S}}$ product
- The "h" and "hS" models usually yield smaller residuals and better fits than the "hSB" model
- The top width of a river may not be representative of the mean control width



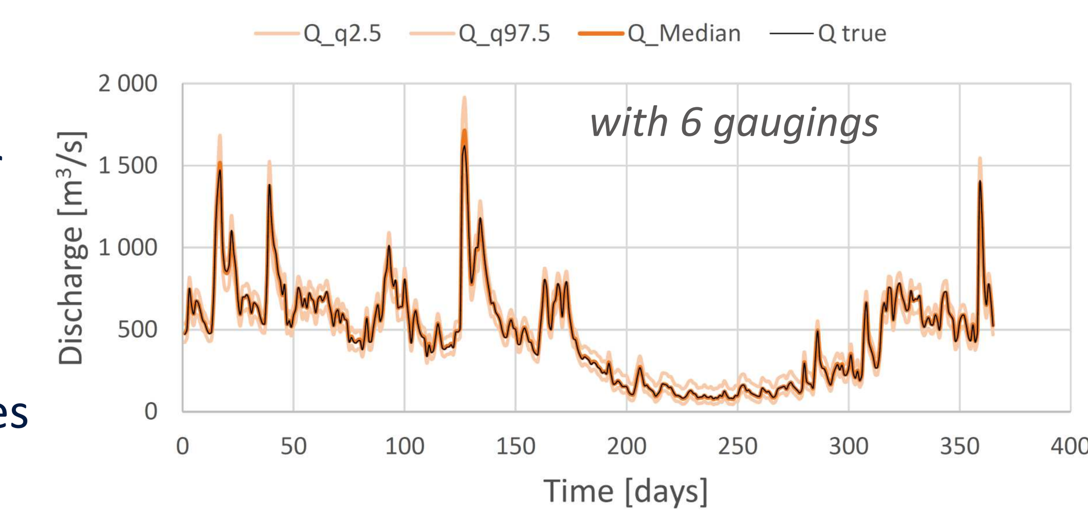
Parameters uncertainties vs. number of gaugings: prior (white) and posterior (pink) quantiles (2.5%, 50%, 97.5%) of the parameters (K_S, B, h_0, M) of the "hS" model applied to the Garonne downstream site

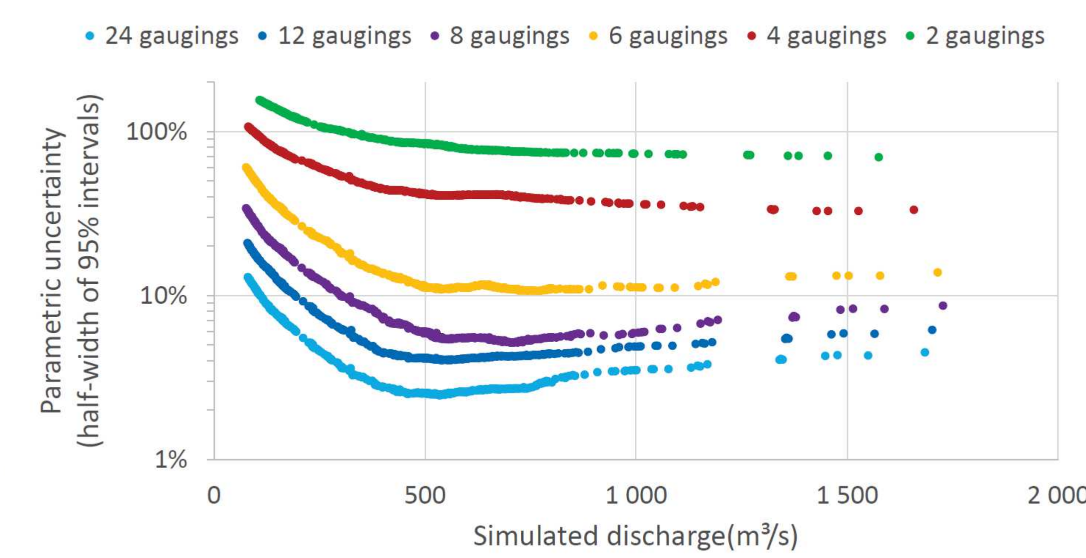


Discharge residuals and goodness-of-fit of the 3 models estimated using all the 24 gaugings of the Garonne downstream site

Streamflow uncertainties

- Acceptable uncertainties require using 6 gaugings or more, typically
- Streamflow relative uncertainty is higher for low flows: due to transition to a section-control, as shown by near-zero, constant slopes
- Similar results are obtained for other sites depending of breakpoints in the cross-sectional geometry and control transitions





Streamflow parametric uncertainties of the "hS" model applied to the Garonne downstream site

What's next?

- More sensitivity tests, at all sites in the benchmark
- More prior knowledge on channel geometry from ground measurements
- Include the uncertainties of the input data (SWOT measurements)
- Combine several controls (cf. BaRatin method, Le Coz et al., 2014) and use slope measurements to identify them

References:

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- **Gejadze and Malaterre (2016)** Discharge estimation under uncertainty using variational methods with application to the full Saint-Venant hydraulic network model. International Journal for Numerical Methods in Fluids, 83(5), 405-430
- **Le Coz, J. et al. (2014)** Combining hydraulic knowledge and uncertain gaugings in the estimation of hydrometric rating curves: A Bayesian approach. Journal of Hydrology, 509, 573-587
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- **Renard (2017)** *BaM!* (Bayesian Modeling) : Un code de calcul pour l'estimation d'un modèle quelconque et son utilisation en prédiction, technical report, Irstea.