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Recent skew surges and historic record sea levels for the estimation of extreme skew surges

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CONTEXT AND MOTIVATION
Coastal facilities need to be designed considering the risk of marine submersion. The estimation of sea levels corresponding to high return periods is very important. Sea level at high tides is the sum between the tidal level (which is predicted) and the skew surge. It is usual to focus on the distribution of skew surges to estimate extreme sea levels. Historical observations consist in record sea levels occurred before the beginning of tide gauges recording (retrieved in archives) and their corresponding skew surges can be estimated. Extreme skew surges can easily remain unnoticed if they coincided with a low or moderate high tide and do not produced extreme sea levels. Then, the exhaustiveness of historical skew surges cannot be guaranteed but the exhaustiveness of historical information is an essential criterion for an unbiased statistical inference. A model is proposed to the use of historical observations and is compared to two previously published approaches 1,2.

PROPOSED MODEL
Global likelihood of the systematic skew surges $X_{sys}$ and the historical record sea levels $Z_{hist}$:

$$L(X_{sys}, Z_{hist} | \theta) = L(X_{sys} | \theta) L(Z_{hist} | \theta)$$

where $\theta$ are the parameters to estimate. $L(X_{sys} | \theta)$ is the likelihood of the systematic skew surges. Extreme skew surges above the threshold $u$ are chosen to be modelled by a General Pareto (GP) distribution.

Proposed likelihood of historical sea levels:

$$L(Z_{hist} | \theta) = \prod_{i=1}^{N-h} g_{\alpha}(Z_{hist}) = \prod_{i=1}^{N-h} [G_{\alpha}(u)]^{N-h} \cdot [1 - G_{\alpha}(u)]^{N-h}$$

where $G_{\alpha}, g_{\alpha}$ are respectively the probability density and cumulative distribution functions of sea levels which can be numerically computed given the distribution of skew surges and the distribution of astronomical high tides.

METHOD
Case study
Site of application: La Rochelle (French Atlantic coast)
Systematic data: tide gauges recordings of the SHOM corresponding skew surges with the same characteristics than the observed systematic and historical series are generated.

Monte Carlo simulations
1000 random samples of systematic skew surges, historical sea levels at high tide and their corresponding skew surges with the same characteristics than the observed systematic and historical series are generated.

Accuracy of the 100-year quantile estimated with the maximum likelihood (ML) $\hat{x}_{100}$ obtained with the 1000 random samples divided by the real value $x_{100}$.

Reliability of the posterior credibility intervals (Bayesian framework)
The non exceedance probability of the real quantile according to the posterior credibility interval $P(\hat{x}_{100} < x_{100})$ should be uniformly distributed for reliable credibility intervals.

MAIN CONCLUSIONS
• The proposed model combines, in a single Bayesian inference, systematic skew surges and historical sea levels at high tide.
• The proposed model has been successfully tested and applied to four different tide gauges located on the French Channel and Atlantic coast.
• The model proposed appears to be unbiased and more reliable than previously published methods.

APPLICATION TO THE OBSERVED SERIES
• With the proposed model, the posterior credibility intervals for the 100-year quantile seem accurate compared to other methods. Hamdi et al. (2015) is positively biased and Hamdi et al. (2015) is negatively biased.
• The proposed model provides unbiased quantiles with the ML compared to the previously published methods. Hamdi et al. (2015) systematically underestimate $x_{100}$ (historical skew surges under-sampled) and Frau et al. (2018) systematically over estimates $x_{100}$ (high skew surges are introduced in a short period).