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Discussions

Interactive comment on "How historical information can improve extreme coastal water levels probability prediction: application to the Xynthia event at La Rochelle (France)" *by* T. Bulteau et al.

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1 General comments

This is a well written paper which clearly demonstrates the benefits of incorporating historical data into an extreme sea level analysis. Partial historical data are treated as censored observations to greatly extend the duration of the dataset in a statistically robust manner. A Bayesian approach provides an ideal framework for quantifying the uncertainty which is shown to be significantly reduced in the tail of the distribution

when historical data are incorporated. The usefulness of this approach is emphasised by referring to the 2010 Xynthia storm at La Rochelle, France which appears to be an outlier before the historical information is applied.

2 Specific comments

1. P7067 L13–16: It is not clear why the annual maximum is referred to when discussing return levels here. There is perhaps a confusion between return levels of peak events and annual return levels (i.e. return levels of annual events)?

   The annual return level x_p for return period T is the level exceeded in one of every T years on average, i.e. the level exceeded by the annual maxima $\mathsf{maxy}(\mathsf{WL})$ once on average every T years. Since in T years there are T annual maximum events, the number exceeding x_p follows $\mathsf{Binomial}(T, \Pr(\mathsf{maxy}(\mathsf{WL}) > x_p))$ hence x_p satisfies the equation

   $$\Pr(\mathsf{maxy}(\mathsf{WL}) > x_p) = \frac{1}{T}.$$

   However, the model fits peak events $X > u$ so it is more natural to define the return level x_p for return period T as the level exceeded once on average by a peak event in T years. With n_{py} peak events per year, the number of exceedances of x_p in T years follows $\mathsf{Binomial}(Tn_{py}, \Pr(X > x_p))$ hence here x_p satisfies

   $$\Pr(X > x_p) = \frac{1}{Tn_{py}}.$$

   The paper therefore appears to be calculating return levels of peak events but presenting them as an approximation to annual return levels. If this is intended, it should be noted that the approximation holds only when the probability of exceedance is small, i.e. for high return periods. Though if annual return levels are intended, it is not clear why the approximation is required at all. Alternatively, if the use of annual return levels is not required, Eq. (3) should be simplified by removing all reference to the annual maximum.

2. It would appear that every observation above the threshold u is fitted to the GPD and then the extremal index is used to correct for the temporal dependence when estimating return levels. An alternative approach, which is perhaps more common, is to first identify independent peaks above the threshold and then fit only the cluster maxima to GPD. There is then no need for the correction, so long as λ represents the mean number of independent peaks above u per year.

   This approach would seem to be more consistent with the historical events used in the case study as they appear to represent the peaks of separate events rather than a complete list of all known time-steps when the perception threshold was exceeded.

3. P7069 L2–P7070 L8: It is much simpler to derive the historical likelihood of Eq. (12) by observing that the peaks exceeding the perception threshold X_0 in n_y years occur as a Poisson process. Since the number of exceedances of u in n_y years is assumed to be $\text{Poisson}(\lambda n_y)$, it follows that the number of events H exceeding X_0 in n_y years is also Poisson with mean given by

$$\lambda n_y \Pr(X > X_0 | X > u) = \lambda n_y (1 - G_\theta(X_0)).$$

   Eq. (12) then follows directly after writing the historical likelihood as

$$\begin{aligned} f(D_{hist}|\theta) &= \Pr(H|\theta) f(\text{historicaldata}|X > X_0, \theta) \\ &= \Pr(H|\theta) \prod_{j=1}^{h_1} g_{\theta,X|X>X_0}(y_j) \prod_{l=1}^{h_3} \left(G_{\theta,X|X>X_0}(y_l^{ub}) - G_{\theta,X|X>X_0}(y_l^{lb}) \right). \end{aligned}$$

3 Technical corrections

1. P7064 L22–24: Bayesian methods are not required to incorporate historical data as censored observations; any likelihood-based method would do (e.g. maximum likelihood). So the use of a Bayesian approach should instead be justified in terms of the better representation of uncertainty, for example.

2. P7065 L5–6 and elsewhere: The approach of integrating partial historical information into an extreme value analysis is referred to as *Bayesian Markov Chain Monte Carlo* (or BMC2) following Reis and Stedinger (2005). However, the essence of the method is to incorporate the historical data into the model likelihood as censored observations yet this is not reflected in the title. Moreover, in general the approach need not depend upon a Bayesian model nor on Markov Chain Monte Carlo (MCMC); other numerical integration methods could be used to fit the Bayesian model and obtain the same estimates, while the modified likelihood could equally be applied in a classical maximum likelihood analysis for example to obtain similar results. I therefore suggest that the title BMC2 is replaced by something more appropriate.

3. P7065 L22–23: There are strong arguments in favour of extrapolating to extreme values via fitting Peaks-Over-Threshold to GPD so these should be referred to (see e.g. Coles, 2001).

4. P7066 L4–5: The support of the GPD is stated here as $x \leq u - (\sigma/\xi)$ if $\xi < 0$ and $x \in \Re$ otherwise but this does not account for the additional constraint $x > u$.

5. P7066 L5–6: The text states "σ represents the width of the distribution" but I suggest 'scale' is used rather than 'width' here to avoid confusion with the width of the support of the distribution, which is referred to in the preceding sentence.

6. P7067 L1: I assume the non-informative prior distribution applied was the improper flat prior ($f(\theta) \propto 1$) since the uniform distribution cannot be used for variables with infinite support.

7. P7067 L5: MCMC algorithms are very flexible but some would argue that they are not a very efficient sampling method since they can take many iterations to converge etc.

8. P7067 L10: It is not obvious how the mode can be retrieved from a set of samples of continuous variables since every sample value is likely to be unique. Nor is it clear why it is particularly useful to extract maximum likelihood estimates when a Bayesian approach is being used.

9. P7068 L14: The non-historical data are first referred to as 'systematic' here in passing but this has not been defined. Nor is it clear why 'systematic' is an appropriate name for the non-historical data.

10. P7068 L14: It is not clear what is gained by partitioning the data into 'systematic' and 'historical'. Mathematically, it would seem that the systematic data is treated the same as the historical data for the special case that the perception threshold is equal to u and there are no censored observations (i.e. $h_2 = h_3 = 0$). Since ultimately a collection of perception thresholds are applied, each with separate sets of known and censored observations, the first of these could be taken as the systematic data to simplify the presentation.

11. P7070 L1–2: The number of exceedances of u is assumed to be Poisson when deriving the historical likelihood. However, earlier in the paper when defining the return level it is stated that there are n events per year which would imply that the number of exceedances should be Binomial. A reason should be given for this discrepancy.

12. P7070 L2: The threshold exceedance rate λ is first introduced when defining the return level and applied again to derive the historical likelihood. However, the paper does not state how it is estimated. While the rate could be treated as uncertain under the Bayesian framework, the case study implies that it is instead fixed at the proportion observed in the synthetic data. This should be clarified.

13. P7074 L16–18: What is meant by "The standard estimation of return period is" here? Is this calculated from the predictive exceedance probability, perhaps after averaging out the parameter uncertainty? Alternatively, is the return period derived as a function of the parameters and then summarised by the mean or median estimate?

14. P7079 L4–5: It should be made clear here that the plotting positions are not used for the model fitting (as they are in some classical estimation methods) but are used only for plotting return level estimates in Fig. 3.

    Appendix A would appear to only show how exceedance probabilities are assigned to observed values X_i but there is no mention of how the censored observations are plotted.

15. P7080 L12: This should cite Cunnane (1978):
    Cunnane, C. (1978) Unbiased plotting positions - A review. *J. Hydrol.*, **37**, 205–222.

16. Table 2: What is meant by "Standard estimative return values" here? The text implies that return levels are estimated by solving for $\tilde{x}_p$ after averaging over the parameter uncertainty (P7068 L7). However, the same paragraph states that credibility intervals are no longer defined, in which case how are those in Table 2 constructed?

    As with return period above, it is possible to algebraically solve for return level conditional upon the parameters which then provides a probability distribution for each return level estimate. If this was used, was the best estimate taken as the mean, median or mode? Similarly, the table caption states that it provides 95% credibility intervals but are these central probability intervals (corresponding to the 2.5% and 97.5% quantiles) or perhaps a highest posterior density interval?

The table caption should either indicate what the four cases are in the first column or refer to where they are defined (i.e. in Fig. 3).

17. Figure 3: Of the four cases defined in this plot, the historical data is used in cases 3 and 4 while the 2010 data is used in cases 1 and 4. The order would perhaps be more intuitive if the 2010 data was instead used in cases 2 and 4 (i.e. if cases 1 and 2 were swapped).

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