Probabilistic Methods for Estimation of Extreme Ice Loads on Ships

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Problem

Over the past years activities related to exploitation of natural resources in the Arctic areas have increased. Decreasing ice extent have revealed the Northeast Passage open for longer periods, which opens up for transportation of goods and commodities in the Arctic areas. Presence of ice is a challenge, both in a design perspective and an operational perspective, as the ice induces large local loads on the hull. However, the loading process and its extreme values are difficult to describe by probabilistic methods, and several models are proposed in the literature. As a response to these challenges, DNV GL has measured local ice loads during full-scale trials on KV Svalbard. This thesis provides a review and a comparative study of some of the existing methods, using the measurements from KV Svalbard to reveal their strengths and weaknesses.

Statistical Methods

- **Classical approach.** A known distribution is fitted to the measured loads. The applied distributions are the exponential, the log-normal, the Gumbel and the Weibull distribution.
- **Asymptotic approach.** The investigated time series is divided into sub-intervals of equal length, and their maximas are identified and fitted to the type I extreme value distribution, known as the Gumbel distribution.
- **Three-parameter exponential distribution.** This method, which was proposed by [1], is given as a weighted sum of two one-parameter exponential distributions. The total weight sum is equal to one. It was developed to capture the load pattern where two separate load populations seem to exist.
- **ACER method.** The average conditional exceedance rate (ACER) method provides an extreme value distribution by constructing a set of non-parametric ACER-functions. The method was developed by [2], and applied for the first time on ice loads by [3]. Its main advantages compared to the traditional methods are; it is applicable to both stationary and non-stationary time series, it accounts for dependencies in the time series, and it puts more weight on the empirical estimates when they are more accurate.

References

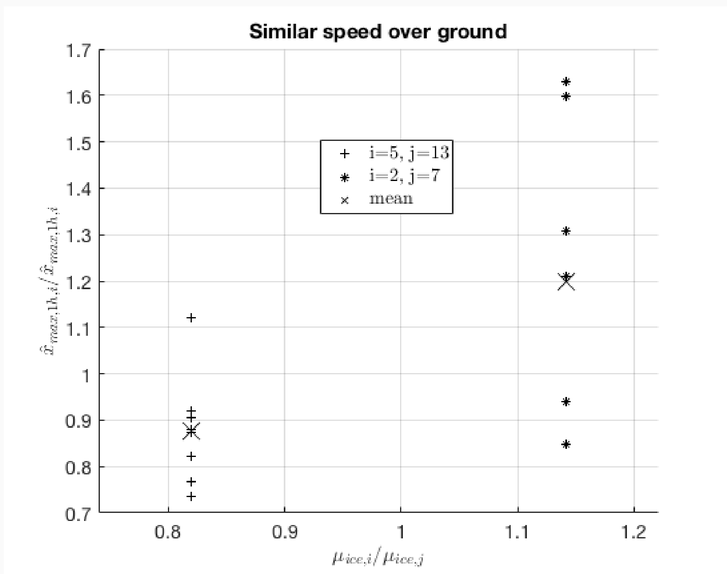
[1] Suyuthi, A., et al. (2014): A generalized probabilistic model of ice load peaks on ship hulls in broken-ice fields, *Cold Regions Science and Technology,97,* 7-20. doi: 10.1016/j.coldregions.2013.09.012

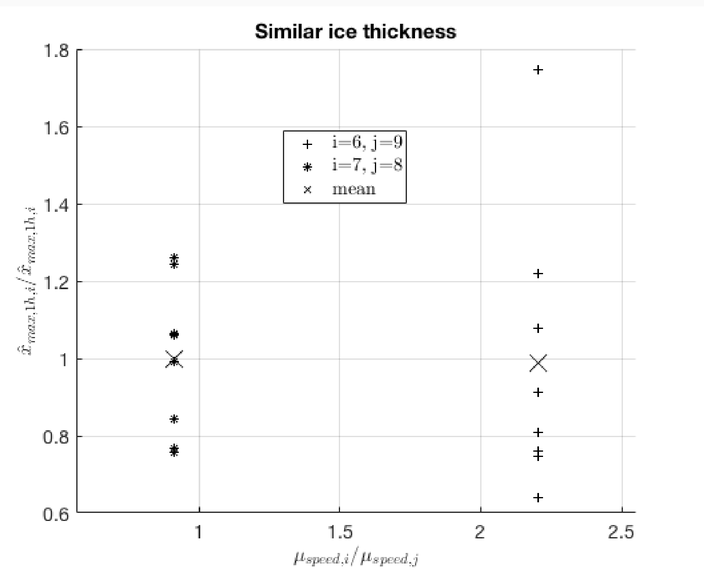
[2] Naess, A., Gaidai, O. (2009). Estimation of extreme values from sampled time series. *StructuralSafety,31,* 325-334. doi: 10.1016/j.strusafe.2008.06.021

[3] Chai, W., et al. (2018). Probabilistic methods for estimation of the extreme value statistics of shipice loads. *Cold Regions Science and Technology,146,* 87-97. doi: 10.1016/j.coldregions.2017.11.012

Effects of Ice Thickness and Vessel Speed on Extreme Loads

Many of the statistical methods applied for describing the ice loads require stationarity for the measured loads. Thus, it is important to know which conditions that are most important for the ice loading process when time series are selected for analyses. The effects of ice thickness and vessel speed where investigated by, among other analyses, comparing the most probable largest load during one hour for time series with similar vessel speed and different ice conditions, and vice versa.

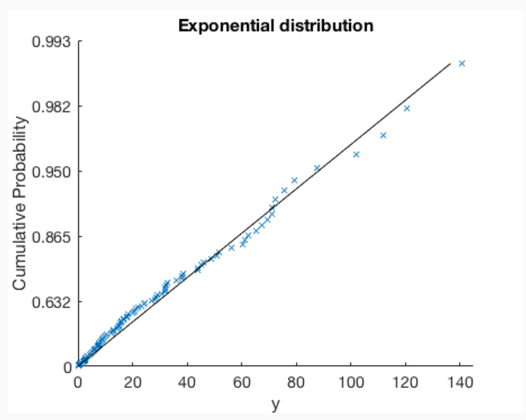


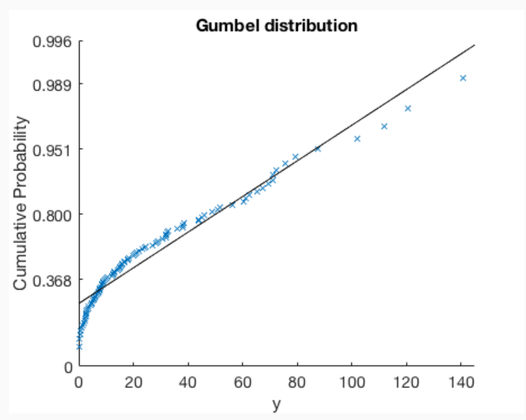


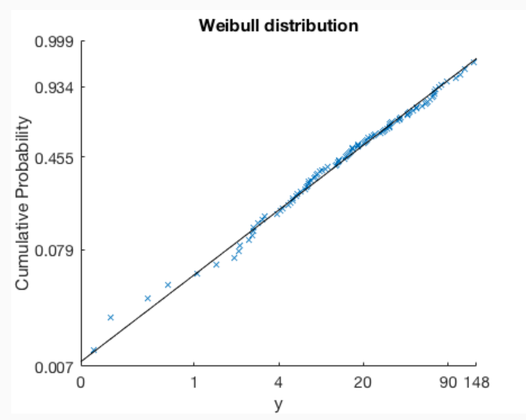
Fitting of Data

A selection of fittings to analyzed data by different methods are presented below:

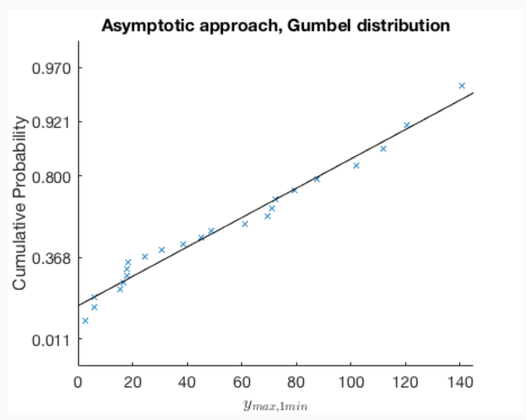
Classical approach:



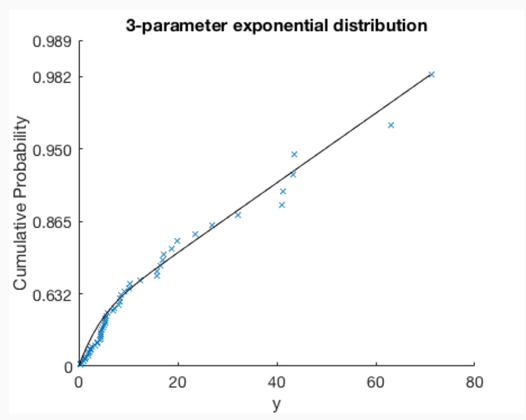




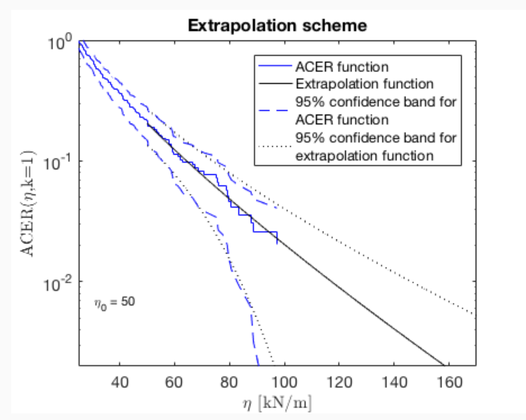
Asymptotic approach:



3-parameter exponential:



ACER method:



The same data set are applied for the first four figures, which was the most stationary of the analyzed time series in terms of ice conditions. Except of the Gumbel distribution, all the four approaches provide good fits to the data. A data set where two populations were found is used for illustrating the three-parameter exponential distribution, and a third data set is used for the ACER method.

Conclusion

Most of the applied methods provide good fits and estimates of extreme values if the data sets are selected with care. Thus, the selection of method should depend on what what kind of data that is being analyzed, and what the purpose is. For stationary ice conditions, the exponential and Weibull distributions provide good fits to the data. However, stationary ice conditions are rarely encountered in the Arctic waters, which makes these methods unsuitable for live estimation of extreme loads. On the other hand, they may be adequate for design purposes, such as loading due to level ice.

Contrary to the exponential and Weibull distributions, the asymptotic approach and the three-parameter exponential distribution provide good fits to data sets where two populations seem to exist, which were found for many of the analyzed data sets. They also performed well for the stationary data sets, making them more robust than the exponential and Weibull distributions.

The ACER method has several advantages compared to traditional methods, as described previously. However, the user must select a lower load level, η_0, from which the extrapolation function is fitted. For some of the data sets it was found that the fitted function is quite sensitive to η_0. The sensitivity decreased for increasing data set sizes. This made it difficult to compare the ACER method with the other approaches, as stationary conditions were not obtained for such long time intervals.