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A metastatistical approach to modelling extreme hurricane intensities

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Estimating the probability of occurrence of extreme hurricane intensities is significant in a vast number of fields and plays a crucial role in hurricane risk assessment. The method typically employed for these analyses applies traditional Extreme Value Theory (EVT) to fit the Generalize Extreme Value Distribution (GEVD) to hurricane maximum wind speed. In this framework, an asymptotic regime or a Poisson occurrence process are assumed to derive the GEVD, which is fitted using values over a high threshold or yearly maxima. However, the relative rarity of hurricanes implies that the number of events per year is not nearly sufficient for this asymptotic hypothesis to be valid, and the selection of a subset of the events drastically reduces the amount of information used. To overcome this limitation, we apply an alternative approach based on the Metastatistical Extreme Value Distribution (MEVD) to extreme hurricane intensity analyses. The derivation of the MEVD relaxes the limiting assumption of the traditional EVT, by taking into account the distribution of the entire range of recorded event magnitudes, rather than just the distributional tail. Taking advantage of this method, we can use the entire observational set, including hurricanes with relatively lower intensities, with clear statistical advantages.
We comparatively assess the MEVD and the classical EVT quantile estimation uncertainties using the 130-year long Maximum Sustained Wind (MSW) speed time series for all hurricanes in the north Atlantic basin obtained from the National Hurricane Center (Atlantic HURDAT2). The parameters of the GEVD are estimated using a range of methods to ensure an optimal estimator is found. The MEVD is fitted assuming a Generalize Pareto Distribution (GPD) for the "ordinary" values of MSW over 5- to 10-year blocks using Probability Weighted Moments (PWM). The statistical tests are performed by dividing the dataset (of length L) into two distinct parts: S years for calibration and L-S years for performance testing. The splitting of the data set is done by random sub-sampling, such that many realizations of the estimation error are obtained, and its whole statistics can be quantified for arbitrary values of the average recurrence interval Tr and of the calibration sample size S. Our results show that the MEVD on average outperforms the widely used GEVD, particularly for small samples and high quantiles. More specifically, the MEVD is characterized by a smaller root mean square error than the EVT approaches when the average recurrence interval considered exceeds the size of the sample used for fitting, arguably the case of greatest practical interest. For Tr/S greater than 1, the average MEV error tends to an approximately constant value and is about half of the corresponding error for the GEVD. The values of the GPD parameters obtained in the proposed MEVD-GPD approach suggests the presence of an upper bound to the MSW speed, which we evaluate in about 170 knots (or about 315 km/h). Overall, we conclude that, for extreme hurricane intensities in the North Atlantic, the MEVD presents remarkable improvements in the estimation of high quantiles over the traditional EVT.