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Intensity and frequency of extreme novel epidemics

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Human-natural processes that generate extreme events with large financial, social, and health consequences, are inherently non-stationary due to ever-changing anthropogenic pressures and societal exposure. The issues posed by non-stationarity are recognized and addressed in Earth system science. However, extensive epidemiological information remains fragmented and virtually unexplored from this perspective due to the lack of approaches to leverage observations of a heterogeneous past. To address this gap, we assembled a long historical record (1600-present) of infectious disease epidemics from the literature. This new record enabled the development and applications of methods to quantify the time-varying probability of occurrence of extreme epidemic events. We define the intensity of epidemic events, the number of deaths/time/global population, and find that observations from several hundred years, covering almost four orders of magnitude of epidemic intensity, follow a probability distribution with a slowly-decaying power-law tail (Generalized Pareto Distribution, asymptotic exponent = -0.705). To the contrary, the yearly number of epidemics is non-stationary, implying that conventional extreme value analyses are inappropriate. We find that the rate of occurrence of extreme epidemics varies nine-fold over centennial time scales, from about 0.4 to 3.6 epidemics/year. As a result, yearly occurrence probabilities of extreme epidemics are far from constant: The intensity computed for the most extreme event on record – the “Spanish Influenza” of 1918-1920 – has a probability of occurrence varying from 0.27 to 1.75 %/year in the time frame from 1600 to present. When optimistically assuming that 1 year is required to develop, produce, and begin distributing a vaccine/treatment for a new disease (e.g. the recent COVID-19 case), we estimate that the average recurrence time of a pandemic killing most of the global population is now less than 12,000 years.