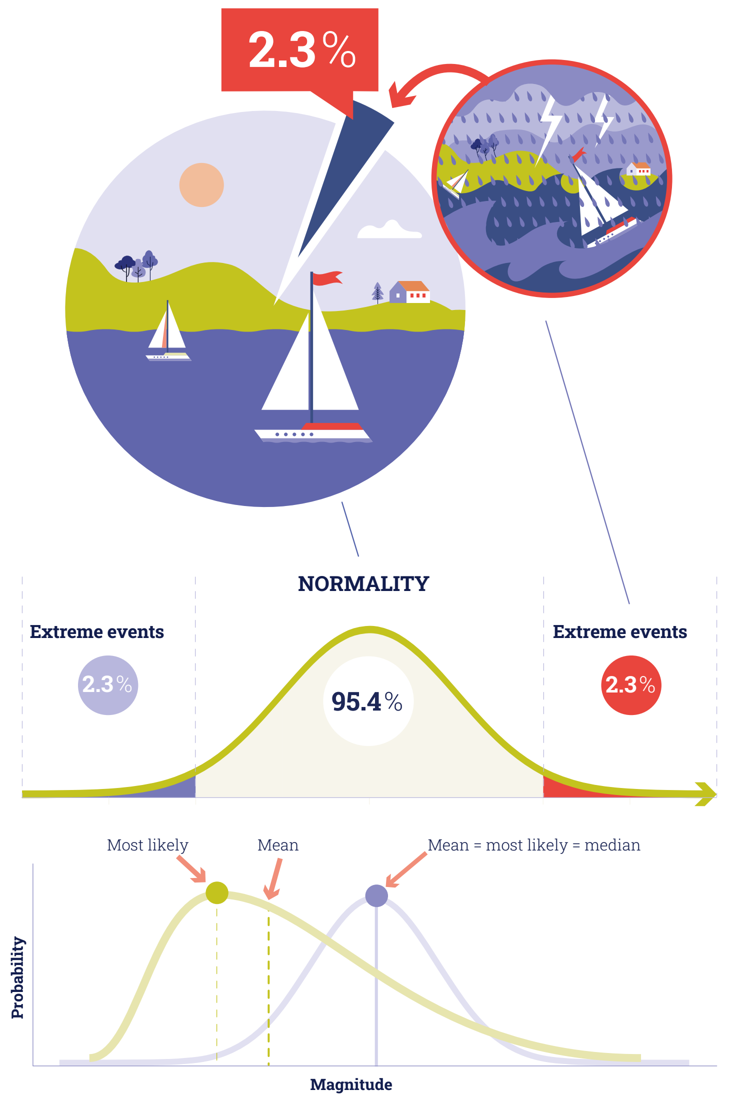
1.1. Extreme events

EXTREME events are often referred to as unusual or anomalous, semantically similar terms, chosen according to their negative implications. Basically, extreme events are those occurrences that deviate from the norm internalised by societies. However, from a scientific point of view, it is necessary to quantify and to refine the definition and, more specifically, to objectively separate an anomalous event from a non-anomalous event. This is not an easy or straightforward task and depends on the system under study. The most common criterion for defining an extreme event is the statistical approach, according to which it is an event "with a very low probability of occurrence". This definition includes two concepts: firstly, the characteristics of a normal state and, secondly, the degree of deviation from this normality.

To develop a quantitative statistical approach, we identify the statistical properties of the process and choose its characterising parameters. To illustrate this, let us suppose that we have established that the temperature in a given month follows a Gaussian statistical distribution with a mean value of 15.5 °C. In that case, the mean value and the most likely value of the temperature coincide and the standard deviation gives us an idea of how far the temperature value deviates from the mean temperature (let us assume it is 0.8 °C). This distribution indicates that 95 out of 100 times the temperature will be between 14.7 °C and 16.3 °C. This is what we would define as *normal*, while extreme events would be characterised by values above or below this range and are at the extremes or tails of the distribution. However, if the process were governed by another statistical distribution, we would have two effects. On the one hand, the mean value could differ from the most likely value, and on the other hand, the region of extreme values would be different, conditioning the probabilities of occurrence.

Figure 1



Top: definition of the normal state, extreme events and their probabilities of occurrence according to the probability distribution function of the data. Below: the parameters (mean, median...) according to the type of probability distribution that characterises the underlying dynamic processes.

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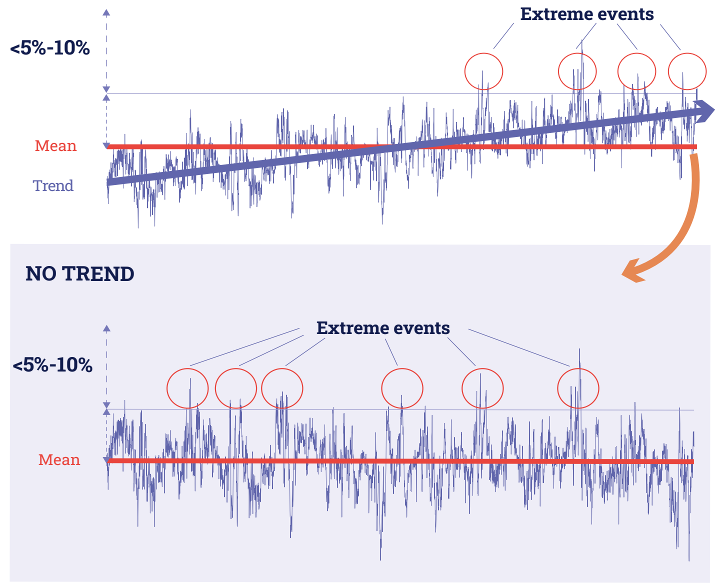
Another aspect to be taken into account in the statistical approach to extreme events has to do with the data source. In many cases, these sources are not, strictly speaking, the result of independent observations of a random process, but usually come from a series of time-sequenced observations that are usually correlated temporally and spatially at different scales. For example, when we roll a die several times in a row, the result of each roll does not depend on the order in which it was rolled. We say then that the events are independent and uncorrelated, i.e., the order in which they occur does not matter. In general, the time series of observations of the characteristic magnitudes of the atmosphere and the ocean are usually spatially and temporally correlated.

Finally, it is particularly relevant how to characterise the *normal* state used as basis to identify an event as extreme, especially when a time series of values is available. Thus, the World Meteorological Organisation defines climate as the reference state over a 30-year period. If the phenomenon we want to study oscillates during that period around a constant value (statistically stationary), then the reference state defined as *climatology* can be established by simply averaging over time. However, if the value of the magnitude we want to study oscillates while monotonically increasing (or decreasing) during the reference time period (such as global warming or sea level rise), simple time averaging does not allow us to characterise an unambiguous reference state. This can alter the way we detect and characterise events.

Figure 2



Identification of extreme events from time-series data (irregular curve). The thick blue line is the trend over time and the red line indicates the mean value over the period. The thin horizontal line indicates the level of variability, and extreme events are those data that appear above the level of variability. The long-term trend affects how marine events are detected.

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In summary, extreme events are those that are statistically characterised by a low or very low probability of occurrence and are located at the tails of the distributions that depend on the dynamic properties of the processes. The low probability of these events implies long recurrence intervals. A key element to understand the causes and consequences of these extreme events and to be able to predict them with increasing accuracy is the implementation of a multidisciplinary information system that allows us to know with sufficient spatial-temporal resolution the state of the system before, preferably during and after the impact produced by an event of these characteristics. In other words, we need a sustained monitoring system over time that allows us to construct historical series to be able to study and understand in detail the processes that produce these extreme events, and whether or not they are in fact extreme in comparison with the reference state, how often and with what intensity they occur, etc.