Identification of long-term trends in the wind climate based on simulations

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ABSTRACT: In recent years, the possible effects of a global climate change on the wind climate have been discussed. In regard to the safety of structures, unfavourable long-term trends in the wind climate could mean an increase in the intensity of storms and/or the number of storms over the years. A respective analysis of meteorological data however has to consider that due to the confined observation period observed trends may be obtained randomly. Therefore, any conclusion from a study on long-term trends can be expressed only in terms of probabilities. The randomness of trends in an ensemble from a parent distribution with basically stationary characteristics can be analysed by simulations. Usually, for the simulation some assumptions in regard to the probability distributions and in regard to the shape of the trend are required. Then, the results obviously depend on the appropriateness of the assumptions and therefore to some extent remain doubtful. A new approach is presented which tries to identify non-stationary characteristics in a set of random values by the Longest Increasing Sequence (LIS). In its first analysing step this approach does not require to specify the shape of the trend.

KEYWORDS: wind climate, long term trends, randomness, confidence, LIS

1 INTRODUCTION

In recent years, the possible effects of a global climate change on the wind climate have been discussed. In regard to the safety of structures, unfavourable long-term trends in the wind climate could mean an increase in the intensity of storms and/or an increase in the number of storms per year. A respective analysis of meteorological data however has to consider that due to the confined observation period observed trends may be obtained randomly.

For the analysis of the randomness of the observed 'trend' simulation techniques can be used, i.e. in the computer a large number of independent ensembles can be generated. However, in the next analysing step, the computer has to identify the 'trend' in each random ensemble based on an objective criterion, i.e. this step requires specifying the basic shape of the trend, e.g. a linear trend or an exponential trend. The basic shortcoming of this approach is the arbitrary choice of the shape of the trend. Furthermore for the generation of random ensembles for a physical process it is required to specify the parent distribution, e.g. an extreme value distribution type I or type III for extreme wind speeds or a Poisson distribution for the number of storms per year. Then, the simulation results obviously depend on the appropriateness of the introduced assumptions.

As final result of the simulation, the cumulative probability distribution of the describing parameters of the assumed trend for the assumed parent distribution is obtained. The respective results can be compared to the 'identified' trend in the observations, finally leading to the probability that a trend equal or larger than the observed one is obtained randomly.

Once the probability for a trend being random or not has been obtained, the next decision deals with the required confidence for accepting or rejecting the null hypothesis of a stationary
wind climate. As an appropriate value for the confidence, the Eurocode recommends in its chapter ‘Design by Testing’ a confidence interval of 75% [1] for the estimation of the characteristic values and design values of the resistance. Basically, this number has to be adopted for the specification of the design values of the action effects as well, i.e. the complete model for the wind action effect side has to lead to a 25% probability of obtaining a too low value. A reasonable value for the confidence in identifying a trend has to be larger, say 90% to 95%.

The question arises if it is possible to identify a trend in an ensemble of random numbers without specifying the shape of the trend. In the following, as indicator of a trend the longest increasing sequence in the ensemble of the random values will be used. An increasing sequence is distinguished from an increasing run, in that the selected elements need not be neighbors of each other. The selected elements however must be in sorted order. For example, consider the random sequence (9, 5, 2, 8, 3, 1, 6, 4, 7). The longest increasing run is of length 2, either (2, 8), (1, 6) or (4, 7). The longest increasing sub-sequence is of length 4, with either (2, 3, 4, 7) or (2, 3, 6, 7).

2 FINDING THE LENGTH OF THE LONGEST INCREASING SEQUENCE
The longest increasing sequence in a set of data can be obtained from the first step of the so-called 'greedy sorting algorithm' which is the basic sorting principle when playing the card game patience [2]. A deck of cards is shuffled; cards are turned up one at a time and dealt into piles on the table, according to the rule that a lower card may be placed on a higher card, while a higher card has to be placed into a new pile. The object of the game patience is to finish with as few piles as possible. The number of piles is identical with the length of the longest increasing sequence. For the initial sequence (9, 5, 2, 8, 3, 1, 6, 4, 7), the following sorting is obtained: the first value is sorted as top value of a first stack. The 5 can be put on top of the 9, the 2 can be put on top of the 5; for the 8, however, a new pile is required:

```
  2   2
 5  5  5
 9  9  9  8
```

The next value 3 can be put on the top of 8, the value 1 can be put either on the top of 2 or on the top of 3; the optimum strategy is obtained by choosing the leftmost possible pile:

```
  1
 2   2
 5  3  5  3
 9  8  9  8
```

For the next value 6, a new pile is required, 4 can be placed on top of 6 and the final value 7 requires a new pile, finally leading to:

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  1   1   1
 2   2   2
 5  3  5  3  4  5  3  4
 9  8  6  9  8  6  9  8  6  7
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It has been shown [1] that with sorting algorithm the number of piles equals the length of the longest increasing sequence (LIS). The above sorting algorithm can easily be implemented in a computer program. Then, the Monte-Carlo-simulation for an ensemble size N leads to the prob-
abilities of obtaining longest increasing sequences with length from 1 to N. Since for the general approach values can be repeated, the algorithm has to consider that lower or equal values may be put on top of an existing pile.

The analysis of the randomness of LIS in an ensemble of random values based on simulations seems to require knowing the parent distribution. However, a closer look to the basic simulation strategy reveals that this is not always the case. The first step of any simulation is to generate pseudo-random numbers which are uniformly distributed between 0 and 1. If these random numbers are understood as non-exceedence probabilities p, random values of a physical process x can be obtained by translating the random p-values to random x-values based on the cumulative probability distribution F\(_x\)(x) of the process. If the cumulative probability distribution F\(_x\)(x) is a strictly monotonic increasing function, the translation of p to x is an operation with a monotone characteristic, i.e. a couple of values with p\(_1\) > p\(_2\) will always produce a couple of values with x\(_1\) > x\(_2\). The basic monotone characteristic of a random trend in the ensemble of the pseudo-random numbers p will therefore not be altered by the translation to the 'true' process x; however, the translation will affect the shape of the trend.

3 EXAMPLE OF APPLICATION

The method of counting the LIS in a random set of n values and analyzing the probability of LIS = k is applied in the following to the wind climate of Düsseldorf, Germany. Basically, the intensity of two storm phenomena and the corresponding number of events per year are analyzed in regard to trends. The intensity of a storm event can be assumed to have a strictly monotonic increasing parent distribution. For the storm type frontal depressions, in 46 years 78 independent events with an hourly mean above 14 m/s have been found for Düsseldorf. The corresponding LIS has a length of 13. As second storm phenomenon, overshooting gusts [3] are analyzed. In 46 years, 25 independent events have been observed. The LIS of this ensemble has a length of 7. Figure 1 shows the corresponding random LIS for the respective ensemble sizes. Both observed LIS are in the range of the 'natural' scatter, i.e. the observed trends are with a large probability of random nature.

![Figure 1: Random LIS for a parent distribution with strictly monotonic increasing characteristic](image_url)

The numbers of storms per year are given in integer numbers. The corresponding parent distribution is obviously only monotonic increasing. Then, a more sophisticated simulation for analyzing the randomness of trends is required. A more reasonable variable for counting and analyzing the LIS is obtained with the average number of storms per year obtained for an averaging period of M years. In the following, for the averaging period 11 years are introduced. As crite-
rion of a trend in the number of storms per year, the LIS in the moving average of the number of storms per year will be used assuming as null hypothesis that the number of storms per year remains constant.

Figure 2 shows the observed moving averages for the number of storms per year for the two storm phenomena strong frontal depressions and overshooting gusts. In both cases the observed LIS are of length 10. The random LIS are shown in figure 3. While for the number of frontal depressions the observed length of the LIS is in the frequently occurring range, the observed length of the LIS for the number of overshooting gusts is identified as a rare event with a probability of only 2.1%. A random length of the LIS smaller than 10 is obtained with a probability of 97%, i.e. the observed trend is random with a probability of only 3%. The probability of a long-term in the wind climate is large enough to demand that the respective influence has to be considered in the design.

Figure 2: Moving average for the average number of storms per year (Düsseldorf 1952 - 1999)

Figure 3: Random LIS for an 11-year moving average for the average number of storms per year

4 REFERENCES

1 C.E.N. European Convention for Standardisation (2002) - EN 1990: Basis of structural design