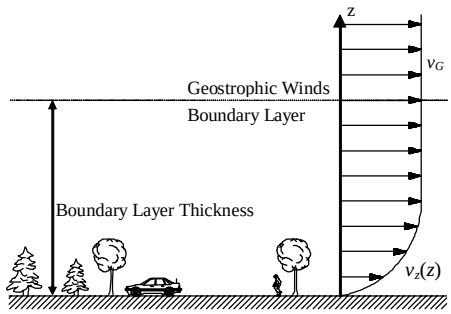
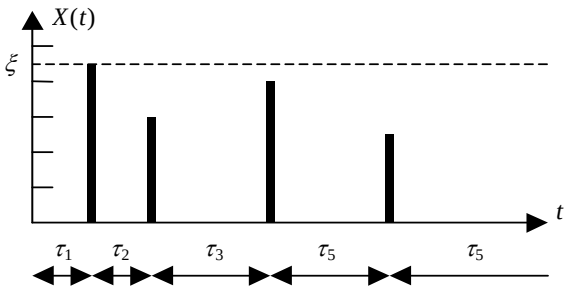
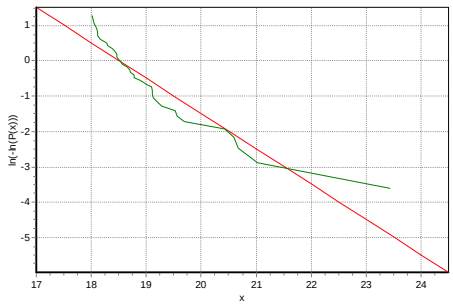
WindPRO / PARK

Introduction to the Estimation of Extreme Wind Speeds and Wind Loads







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Front cover

The front cover shows WindPRO logo, an idealized logarithmic wind profile, a Gumbel plot and an idealized Poisson process.

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1. Introduction

This document gives an introduction to the estimation of extreme wind speeds.

This document focuses on the extreme wind analysis by the means of a statistical extreme value analysis of time series.

An alternative approach (and recommended approach) is to use national structural codes; however this approach is not the primary subject of this document.

Figure 1: Semi-offshore turbines at Frederikshavn, Denmark.

2. Extreme Winds - Using Structural Codes

The extreme wind speeds for a given site are typically given in structural codes – used nationally in order to determine the safety of structures. The extreme wind speed – such as the 50 year extreme event – is then typically given in standardized conditions – e.g. by specifying the 10 minute mean wind speed and a corresponding roughness length (or roughness class). The structural engineer can then perform an on-site roughness classification – and then recalculate the standardized conditions to the on-site conditions.

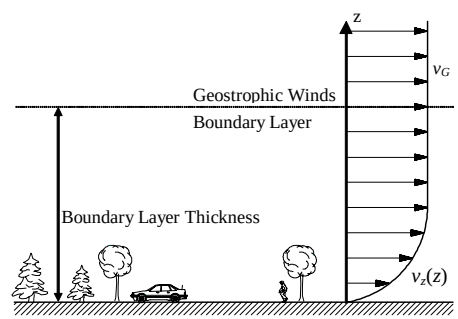
Procedures for determining the extreme wind speeds using the structural codes are described in many codes e.g. the *Eurocode 1 – Actions on Structures* [1] with the national application documents - or the *Danish Code of Practice for Loads for the Design of Structures DS 410* [2], see below.

Danish Code of Practice – DS 410:1982

The following text (extracted from [3]) outlines the specification of extreme wind loads as found in the DS 410:1982.

The mean wind velocity, $v(z)$, can be described using the logarithmic velocity profile [4]:

$$v(z) = \frac{1}{\kappa} v_F \ln\left(\frac{z}{z_0}\right) = \frac{1}{0.4}\left(\sqrt{\frac{\tau_0}{\rho}}\right)\ln\left(\frac{z}{z_0}\right)$$



Principle of the Velocity Profil([from[3])

where κ is the Kármáns universal constant, κ=0.4
v_F is the friction velocity
z_0 is the surface roughness
τ_0 is the friction between air and ground
ρ is the density of air

The Danish code of Practice, DS 410, uses the velocity profile above in a slightly different form. In this, the equation is written:

$$v(z) = v_b k_t \ln\left(\frac{z}{z_0}\right)$$

where v_b is the basis wind velocity, determined mean wind velocity in 10 meters height
k_t is a terrain parameter

The basis wind velocity is determined as the 50 year event 10 minutes mean wind velocity in 10 meters height with a surface roughness z_0=0.05. By comparison the equations above, it is easily seen the terrain parameter k_t has to comply with

$$k_t = \frac{v_F}{\kappa \cdot v_{z_0=0.05}(10)}$$

DS 410 states the terrain parameters for 3 different surface roughness: z_0=0.01, z_0=0.05 and z_0=0.3. The mean wind velocities are then obtained for these different terrain-types. (See table below)

Terrain Type, z_0	Terrain parameter, k_t	Mean Speed $v(10)$
0.01	0.17	31.7
0.05	0.19	27.0
0.30	0.22	20.8

The 50 Year Event of the Mean Wind Speed,according to DS 410:1982 [2].

References:

[1] *Eurocode 1 : Actions on structures – (1-4 General actions - Wind actions).*
[2] *Dansk Ingeniørforenings's Code of Practice for Loads for the Design of Structures*, DS410, 3rd edition, Dansk Standard DS 410 (or later edition)
[3] Misfeldt & Thøgersen, *Reliability Analysis of Wood Structures*, Aalborg University, 1997 (unpublished)
[4] Michael Brorsen: *Vind og vindbelastning*, Forelæsningsnoter til kursus i Strømningslære, Aalborg Universitet, 1996 *(Lecture Notes – in Danish - Wind and Windloads)*

3. Extremes - Using Probabilistic Methods

The extreme wind speeds may – alternatively - be determined through a long time series – available near the site of interest. The time series should last at least 10 years – otherwise the uncertainty in the estimation will be too large. Also, all significant extreme climatic events should occur in the time series – e.g. tropical cyclones. Beware, that no climatic event has so long return periods that they are not represented in the time series, e.g. tropical locations with very rare events of tropical cyclones. In those cases, other methods should be used – e.g. in lack of better data - climatic simulations using meso scale models could be used.

Introduction

The Gumbel distribution is widely used for determining extreme (extrapolated) values of measured distributions and time series data. The measured data is typically fitted to the Gumbel distribution – then the 50-year extreme value is determined (or another return period). Additionally, the uncertainty may be determined through a bootstrap resembling technique.

About the Gumbel Distribution (from [3])

The Gumbel distribution is also known as the Extreme Type I distribution of the largest extreme. This distribution can be applied if the upper tail of the parent distribution falls off in an exponential manner. The Gumbel distribution is a two-parameter distribution with the parameters α and u. The distribution function of some random variable X is:

$$F_X(\mathrm{x}) = \exp\left[-\exp\left[-\alpha(\mathrm{x}-u)\right]\right]$$

Where $\alpha > 0$ and $-\infty < x < \infty$. The mean value and standard deviation are given by:

$$\mu_X = u + \frac{\gamma}{\alpha} \qquad\qquad \sigma_X = \frac{\pi}{\sqrt{6}\cdot\alpha}$$

where γ is Euler's constant and equal to 0.5772. A useful property of the Gumbel distribution is, that the distribution of the largest extreme in n independent trials of a random variable, X, having a distribution function following (A.18) is:

$$F_{X_n^n}(\mathrm{x}) = \exp\left[-n\cdot\exp\left[-\alpha(\mathrm{x}-u)\right]\right]$$

the standard deviation of X_n^n does not change from the σ_X, given above, but the mean value can be calculated from:

$$\mu_{X_n^n} = \mu_X + \frac{\sqrt{6}}{\pi}\sigma_X \ln(n)$$

Defining the extreme event through a characteristic value

A characteristic event (load) is typically determined as the 98% percentile in the annual extreme event (load) distribution, $F_X(\mathrm{x})$. Thus, the characteristic event is determined as

$$x_k = F_X^{-1}(0.98)$$

The characteristic event – determined from the 98% percentile – is an event that is only exceeded with an annual probability of 2%. It is obvious to define this event as a 50 year event, as we per definition set the relation between return period - T – and the percentile - f_T – in the annual extreme value distribution as:

$$f_T = 1 - \frac{1}{T}$$

The above equation is not useable for $T \leq 1$, as the percentile here becomes less than or equal to 0.

Example (from [5])

The annual extreme value distribution of a load, P, follows a Gumbel distribution. The mean value of this extreme load is μ=20 kN and the standard deviation is σ=8 kN (these values corresponds to a coefficient of variation equal to COV=σ/μ=0.40=40%). The 50 year extreme event is now determined from the 98% percentile of the extreme value distribution. First, the distribution parameters α and β are determined:

$$\alpha = \frac{\pi}{\sqrt{6}\sigma} = \frac{\pi}{\sqrt{6}\cdot 8} = 0.160 \qquad \beta = \mu - \frac{\gamma}{\alpha} = \mu - \frac{0.5772}{\alpha} = 20 - \frac{0.5772}{0.160} = 16.4$$

The characteristic load is now determined as the 98% percentile by inverting the cumulative distribution equation:

$$p_k = \beta - \frac{1}{\alpha}\ln\left[-\ln\left[F_P(p)\right]\right] = 16.4 - \frac{1}{0.160}\ln\left[-\ln\left[0.98\right]\right] = 40.7 \text{ kN}$$

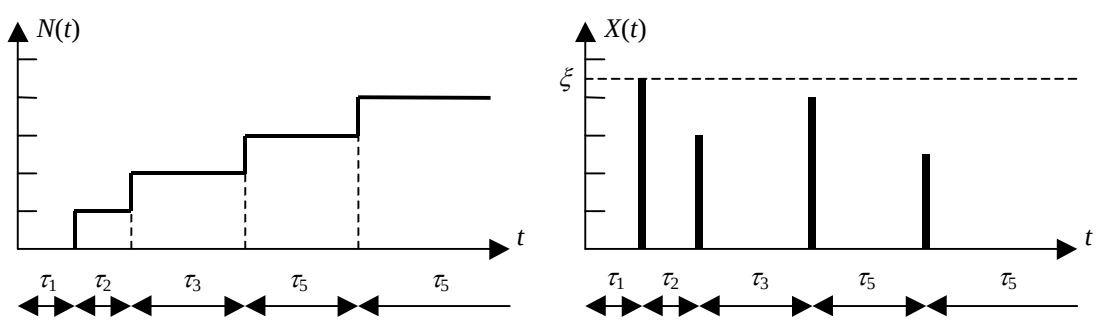
As shown, the characteristic value is – in this case – approximately the mean value plus 2.5 times the standard deviation.

Defining the return period through a stationary Poisson process

An alternative definition of the T-year extreme event is found by considering a stationary Poisson-process. The Poisson-process is a stochastic counting process, characterized by the intensity ν (the intensity is the number of events per unit time). It is known (see [6]), that the inter-arrival times (the time between two events) in a Poisson-process follow an exponential distribution. Then the return period, R, is determined as the expected value of the inter-arrival times of the Poisson process. The expected value and the variance of the inter-arrival times are

$$E[\mathrm{T}] = \frac{1}{\nu} \qquad Var[\mathrm{T}] = \frac{1}{\nu^2}$$

An example of a Poisson process is shown below



Left figure: Poisson process with inter-arrival times, τ. Right figure: Poisson spike-process.

A distribution function describing the 'height' of the spike in the Poisson process is now added to each event of the Poisson-process (as shown in the figure above – right side). It is then possible to derive the maximal level ξ, which is present in the period [0;T]. This level has the following distribution (presumed the Poisson-process):

$$F_{\max}(\xi) = \exp\left[-\nu \cdot T \cdot \left(1 - F_X(\xi)\right)\right]$$

If a fixed level ξ is set, the process consisting of crossings of this new level is also a new Poisson process with the intensity:

$$\nu_\xi = \nu \cdot \left(1 - F_X(\xi)\right)$$

The expected inter-arrival time for this new Poisson process is:

$$E[\mathrm{T}] = \frac{1}{\nu_\xi} = \frac{1}{\nu \cdot \left(1 - F_X(\xi)\right)}$$

The return period for the extreme event is now defined from the expected time between two crossings of the level ξ. The n-year return period is defined as n=E[T]. I.e. from the equations above there is a relationship between probability of crossing the level and the return period

$$F_{\max}(\xi) = \exp\left[-\frac{T}{E[\mathrm{T}]}\right] \Leftrightarrow E[\mathrm{T}] = -\frac{T}{\ln\left[F_{\max}(\xi)\right]}$$

The equation above – left side – approaches 1/n for large numbers of n. This corresponds to the definition made earlier from the raw percentiles. By the way, the T-year period is typically equal to 1 year.

Example (from [5])

We want to determine the annual probability of exceeding the 50-year event. Using the equation above:

$$F_{\max}(\xi) = \exp\left[-\frac{T}{E[\mathrm{T}]}\right] = \exp\left[-\frac{1}{50}\right] = 0.9802$$

I.e., the annual probability of exceeding the 50-year event is 1.98%. Assuming the same load as in the previous example, the extreme load is now determined to 40.8 kN.

The DS 410 Design Wind Velocity and the Extreme Distribution

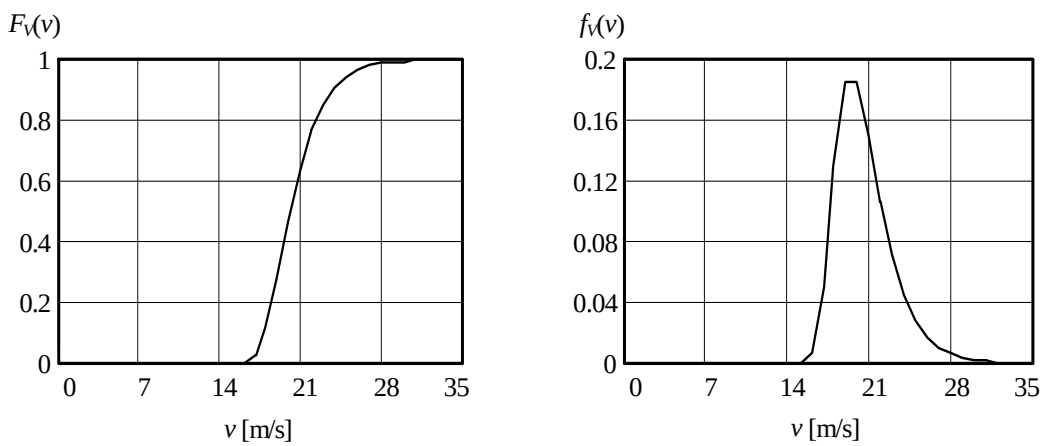
The Danish code of Practice of Loads, DS 410, uses the 50-year event as the deterministic design-value. This value is determined from the 1-year extreme event, using probability of non exceedence of 0.98, i.e. $F_V(v)$=0.98. No distribution function is stated in the code for the wind load, but some authors e.g. Dyrbye et al [7] and Hansen [8] state that the annual extreme-mean wind (velocity) distribution can be described by an extreme-type I (Gumbel) distribution, see above. With a surface roughness of z_0 = 0.05, v is found from statistical investigations to be 27 m/s. This value of the 50-year event is used in DS 410.

If this extreme distribution is used in the European area, then the coefficient of variation is approximately COV_W=0.12 (Dyrbye et al [7]). This value is in agreement with measurements performed in the Danish area, see e.g. Hansen [8].

The extreme distribution for the annual wind velocity based on the current code prescriptions is found to be:

$$F_{V_{DS}}(v_{DS}) = \exp\left[-\exp\left[-0.51899\left(v_{DS} - 19.481\right)\right]\right]$$

The distribution and density functions matching the equation above are drawn in the figure below:



The Annual Extreme Wind Distribution Based on Code Specifications in DS 410:1982 [2].

Gumbel Distribution Fitting

When using the WindPRO extreme wind speed estimation tool, then distribution parameters are estimated using least-squares estimates. Reference is made to S. Ross [10]

Statistical Uncertainties – Using Bootstrapping Estimates

The statistical uncertainties in extreme estimations may be (partly) determined through a bootstrap re-sampling technique (as in the WindPRO extreme wind speed estimation tool). This technique takes advantage of the computer-based numerical capacity in order to evaluate the uncertainty by a large number of replications. For further information, please consult Efron and Tibshirani [9].

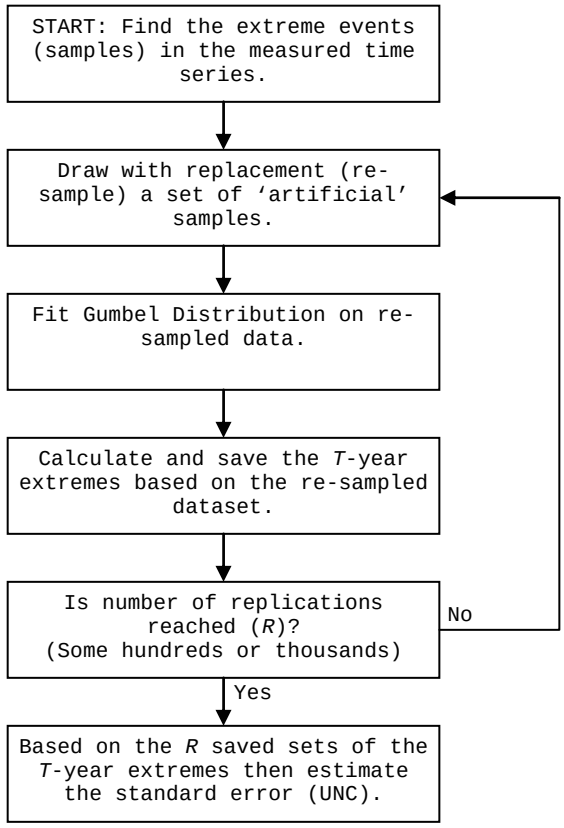
First, we need to make a few definitions:

n	is the sample size
x_i	is the observed values: $i = 1,2, \cdot\cdot,\cdot\, n$
$\hat{F}$	is the empirical distribution, where a probability equal to $1/n$ assigned to each sample

In the bootstrap method, several new bootstrap samples are now randomized or re-sampled from the sample distribution. The star superscript denotes that the 'observed' values are now 'artificial' data, which are drawn with replacement from the population of n-objects $\boldsymbol{x} = (x_1, x_2 \ldots x_n)$:

$$\hat{F} \rightarrow \left(x_1^*, x_2^*, x_3^*, \ldots, x_n^*\right)$$

In order to evaluate the uncertainties connected to the extreme wind speed estimation, the method used - a parametric bootstrapping method - involves a number of steps as shown in the pseudo code below:



In the step number 4, we calculate and save *R* number of *T*-year extremes based on the re-sampled dataset:

$$\hat{\theta}(r) = s(\mathbf{x}^{*r}), \qquad r = 1,2,...R$$

where $s(\mathbf{x}^{*r})$ is Weibull estimate of the T-year extreme

$\hat{\theta}(r)$ is the bootstrap estimate (on which we later on do the calculation of the standard deviation)

Further Processing: Application to Wind Turbines

Having done the extreme wind speed analysis for an anemometer mounted at a specific height at a specific mast position, then that extreme event may need further processing. This is due to the issue, that for wind turbines (WTGs), we typically need the result in hub-height and at the WTG positions rather that at the position and height for the meteorological mast.

This post processing procedure may involve a number of tools and calculations – dependent on the complexity of the site considered. Typically you may consider using the wind shear in order to extrapolate the extreme event into to hub-height position. Also you may consider using CFD (Computional Fluid Dynamics), WAsP or WAsP Engineering in order to spatially move the measured mast data into the WTG-positions.

References

[1] *Eurocode 1: Actions on structures – (1-4 General actions - Wind actions).*
[2] *Dansk Ingeniørforenings's Code of Practice for Loads for the Design of Structures*, DS410, 3rd edition, Dansk Standard DS 410 (or later edition)
[3] Misfeldt & Thøgersen, *Reliability Analysis of Wood Structures*, Aalborg University, 1997 (unpublished)
[4] Michael Brorsen: *Vind og vindbelastning*, Forelæsningsnoter til kursus i Strømningslære, Aalborg Universitet, 1996 *(Lecture Notes – in Dahish - Wind and Wind Loading)*
[5] Morten Lybech Thøgersen, *Notat vedr. ændring af lastens returperiode*, Risø National Laboratory, 1999, (available online through www.risoe.dk/vea/offdes).
[6] H.O.Madsen, S. Krenk & N.C. Lind: *Methods of Structural Safety*, Pentice-Hall, Englewood Cliffs
[7[C. Dyrbye, S. Graversen, S. Krenk, N.C. Link and H.O. Madsen: *Konstruktioners sikkerhed*, Den private Ingeniørfond ved Danmarks tekniske Højskole, 1979.
[8] Svend Ole Hansen: *Reliability of Wind Loading on Low-Rise Buildings in a Group, A*fdelingen for Bærende Konstruktioner, DTH, 1992.
[9] Efron & Tibshirani: *An Introduction to the Bootstrap*, Monographs on Statistics and Applied Probability, Chapman & Hall, New York,
[10] S.M. Ross: *Introduction to probability and statistics for engineers and scientists*, San Diego, Harcourt/Academic, 2000

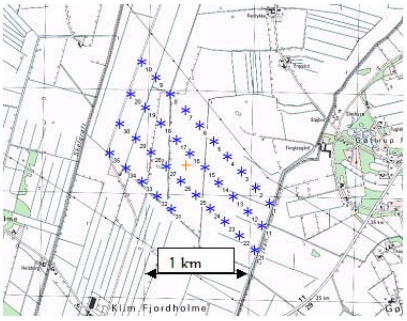
4. Case Study – Klim Fjordholme – Denmark

The terrain is flat and open. Even if the site is inland, then it is situated close open water at the Limfjorden. The project: Turbines at this site are situated in the northwestern part of Denmark. It is a good wind location with a mean wind speed equal to approximately 7 m/s given at 44 m a.g.l. (Hub height). The park contains 35 WTGs, all Vestas V44, 600 kW, with typical spacing: 4.5 RD in rows and 5.5 – 7 between rows. The first 13 turbines were erected in September 1996 - one year after the wind farm was completed to 35 WTGs.

For a detailed site analysis – the reference [1] should be consulted.

Wind Data for the Extreme Wind Analysis

In lack of real measured data, the 20 years time series data is taken from the NCAR/NCEP reanalysis project – holding global wind data for every 2.5 degrees. We use the 10 m data at the position N 57.5 E 10.0. The data were downloaded using the EMD online wind data service available in WindPRO 2.5.



The fitting method used is a least squares method. We calculate the extreme as omnidirectional distribution only, however the tool in WindPRO opens for doing directionally dependend estimates. The uncertainty (UNC) is the statistical uncertainty calculated using a bootstrap sampling technique. The UNC is taken as one standard deviation.

NCEP / NCAR Data at 10 meters height

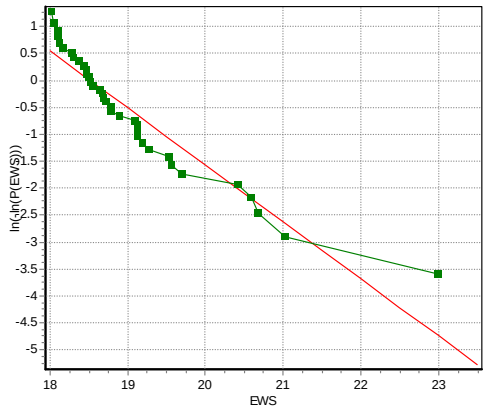
Data overview:

First record dated : 01-01-1976
Last record dated : 31-07-2005 18:00:00
Sample rate : 360 minutes
Number of samples (enabled data only): 43220
Max wind speed: 22.99
Mean wind speed: 6.45
Height : 10

The threshold value is adjusted until approximately 50 extreme values are left. The threshold value is determined to 18 m/s – leaving 36 independent extremes. The Gumbel data fitted to this data is shown in the table below.

Raw wind data
Points : 36
Alfa : 1.0587
Beta : 18.5192 [m/s]
Mean : 19.0644 [m/s]
StdDev : 1.2115 [m/s]
Lambda : 1.240 [events per year]
Summed error : 4.49585199243351
T = 1, EWS = 18.72 m/s, UNC = 0.18 m/s
T = 5, EWS = 20.24 m/s, UNC = 0.39 m/s
T = 10, EWS = 20.90 m/s, UNC = 0.51 m/s
T = 25, EWS = 21.76 m/s, UNC = 0.67 m/s
T = 50, EWS = 22.42 m/s, UNC = 0.80 m/s
T = 100, EWS = 23.07 m/s, UNC = 0.93 m/s

Squared wind data speed fitting (dynamic pressures):
Points : 36
Alfa : 0.0261
Beta : 342.4209 [m/s]^2
Mean : 364.5695 [m/s]^2
StdDev : 49.2132 [m/s]^2
Lambda : 1.240 [events per year]
Summed error : 5.55797637906249
T = 1, EWS = 18.73 m/s, UNC = 0.19 m/s
T = 5, EWS = 20.31 m/s, UNC = 0.38 m/s
T = 10, EWS = 20.95 m/s, UNC = 0.49 m/s
T = 25, EWS = 21.78 m/s, UNC = 0.62 m/s
T = 50, EWS = 22.38 m/s, UNC = 0.71 m/s
T = 100, EWS = 22.96 m/s, UNC = 0.80 m/s



Red: Gumbel Model;
Green: Extreme Samples.

Upper air NCEP / NCAR Data (850 hPa pressure level data)

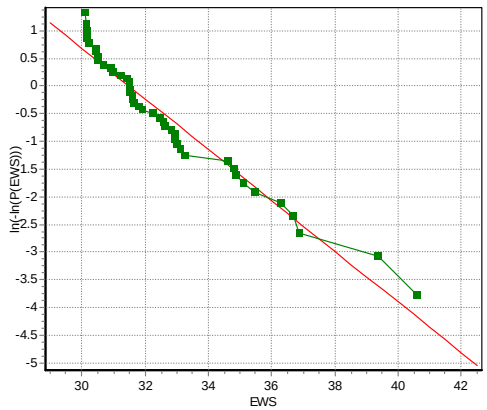
Data overview:

First record dated : 01-01-1976
Last record dated : 31-07-2005 18:00:00
Sample rate : 360 minutes
Number of samples (enabled data only): 43220
Max wind speed: 40.59
Mean wind speed: 9.82
Height : 850 hPa (upper air data)

The threshold value is adjusted until approximately 50 extreme values are left. The threshold value is determined to 30 m/s – leaving 43 independent extremes. The Gumbel data fitted to this data are:

Raw wind data fitting
Points : 43
Alfa : 0.4585
Beta : 31.4898 [m/s]
Mean : 32.7487 [m/s]
StdDev : 2.7972 [m/s]
Lambda : 1.644 [events per year]
Summed error : 2.57703511085677
T = 1, EWS = 32.57 m/s, UNC = 0.41 m/s
T = 5, EWS = 36.08 m/s, UNC = 0.89 m/s
T = 10, EWS = 37.60 m/s, UNC = 1.14 m/s
T = 25, EWS = 39.59 m/s, UNC = 1.48 m/s
T = 50, EWS = 41.11 m/s, UNC = 1.74 m/s
T = 100, EWS = 42.62 m/s, UNC = 2.01 m/s

Squared wind data speed fitting
Points : 43
Alfa : 0.0066
Beta : 991.2837 [m/s]^2
Mean : 1078.7413 [m/s]^2
StdDev : 194.3272 [m/s]^2
Lambda : 1.644 [events per year]
Summed error : 3.50455173051636
T = 1, EWS = 32.66 m/s, UNC = 0.44 m/s
T = 5, EWS = 36.20 m/s, UNC = 0.84 m/s
T = 10, EWS = 37.62 m/s, UNC = 1.03 m/s
T = 25, EWS = 39.43 m/s, UNC = 1.27 m/s
T = 50, EWS = 40.74 m/s, UNC = 1.44 m/s
T = 100, EWS = 42.00 m/s, UNC = 1.61 m/s



Red: Gumbel Model;
Green: Extreme Samples.

Comparing the results

The upper air data gives an estimate of the 50-year geotropic wind equal to 40.74 m/s or 41.11 m/s. The NCAR 10 m data gives an estimate of the 50 year 10 m wind equal to = 22.42 m/s or 22.38 m/s. The Danish code of practice (see chapter 2) – estimates the extreme wind to either 24 m/s or 27 m/s using standard conditions (10 m height, z_0=0.05 m). The higher value is used for sites near to the west coast.

H. Frank [2] estimates the 50 year wind speed from NCAR 1948-1999 data. The 10 m extreme wind speed is estimated to approximately 20 m/s. However, this reference uses a different fitting procedure (moment weighted procedure) – which is believed to yield slightly different results. However, the statistical uncertainty to the NCAR data estimates is in the magnitude of 1.0-2.0 m/s so the results may be regarded as identical.

Case Study – Validation

In order to validate the method, a calculation is made with an artificial generated time series. In this time series, the annual extreme values are sampled from a Gumbel distribution with the mean value equal to 40.0 m/s and a coefficient of variation equal to 20%. A 50 year long time series is generated with these extremes, filling the missing days with wind speeds sampled from a Gaussian distribution with mean 10.0 m/s and coefficient of variation equal to 20%. The 50 year event of this distribution – taken as the 0.98 percentile of the distribution - is 60.80 m/s, or approximately equal to the mean value plus 2.5 times the standard deviation.

The 50 extremes of the time series are shown below. The mean value of the 50 samples is 38.7 m/s and the coefficient of variation is 20.1%. A random seed equal to 132 was used to generated this series.

32.90	34.78	55.00	35.12	34.63	34.91	49.45	36.39	47.75	38.60	27.31	31.77
36.88	30.14	39.20	36.58	30.09	32.12	44.21	54.84	33.20	51.57	38.89	32.48
31.09	33.03	42.54	32.30	40.13	58.26	51.52	40.49	44.65	47.39	37.44	39.32
28.95	37.85	53.26	32.07	51.82	33.73	33.33	31.40	40.17	38.96	36.32	32.16
32.43	37.64										

Based on the distribution parameters from the Gumbel distribution, the expected maxima using different return periods can be calculated. This is shown in the table below, as well as the estimates calculating the WindPRO tool. Note, that the expected maximum of T-independent trials of the annual extreme Gumbel distribution gives a higher result than if the 'percentile' definition is used. The uncertainty from the sample extimates are given as ± one standard deviation.

T-Period [years]	Extreme wind speed from Gumbel Distribution or Samples				
	Expected max of *T* trials [m/s]	Characteristic WSP from percentile [m/s]	50 Samples (seed 132) [m/s]	50 Samples (seed 100) [m/s]	1000 Samples (seed 125) [m/s]
1	40.00	36.40	35.02 ± 1.05	33.90 ±0.87	36.30 ±0.22
5	50.04	46.44	45.94 ± 2,09	42.97 ± 1.74	46.69 ± 0.44
10	54.36	50.76	50.64 ± 2.80	46.88 ± 2.33	51.17 ± 0.57
25	60.08	56.48	56.85 ± 3.79	52.07 ± 3.15	57.09 ± 0.76
50	64.40	60.80	61.56 ± 4.56	55.95 ± 3.79	61.56 ± 0.91
100	68.73	65.12	66.26 ± 5.33	63.76 ± 5.08	66.04 ± 1.06
1000	83.09	79.49	-	-	-

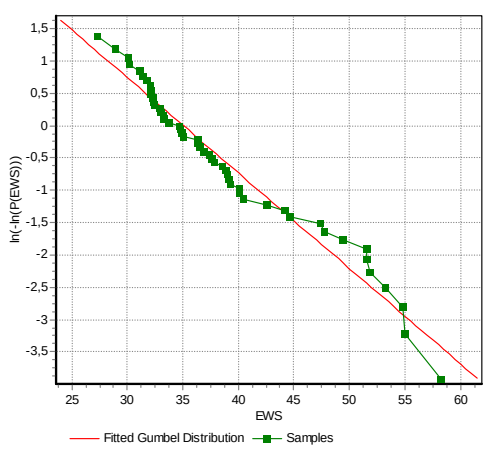
Data overview:

First record dated: 01-01-1900 01:00:00
Last record dated: 31-12-1949 01:00:00
Sample rate: 1440 minutes
Number of samples (enabled data only): 18262
Max wind speed: 58,26
Mean wind speed: 10,07
Height : 132 (is actually set as the random seed)

The threshold value is determined to 22 m/s – leaving 50 independent extremes. The Gumbel data fitted to this data as shown in the table below (random seed 132).

Raw wind data fitting
Points : 50
Alfa : 0,1474
Beta : 35,0205 [m/s]
Mean : 38,9357 [m/s]
StdDev : 8,6993 [m/s]
Lambda : 1,000 [events per year]
Summed error : 2,24036021517607
T = 1, EWS = 35,02 m/s, UNC = 1,05 m/s
T = 5, EWS = 45,94 m/s, UNC = 2,09 m/s
T = 10, EWS = 50,64 m/s, UNC = 2,80 m/s
T = 25, EWS = 56,85 m/s, UNC = 3,79 m/s
T = 50, EWS = 61,56 m/s, UNC = 4,56 m/s
T = 100, EWS = 66,26 m/s, UNC = 5,33 m/s
T = 200, EWS = 70,96 m/s, UNC = 6,11 m/s

Squared wind data speed fitting



Red: Gumbel Model;
Green: Extreme Samples.

Points : 50 Alfa : 0,0017 Beta : 1242,4716 [m/s]^2 Mean : 1577,4365 [m/s]^2 StdDev : 744,2784 [m/s]^2 Lambda : 1,000 [events per year] Summed error : 3,43466655530497 T = 1, EWS = 35,25 m/s, UNC = 1,29 m/s T = 5, EWS = 46,65 m/s, UNC = 1,87 m/s T = 10, EWS = 50,78 m/s, UNC = 2,29 m/s T = 25, EWS = 55,77 m/s, UNC = 2,80 m/s T = 50, EWS = 59,27 m/s, UNC = 3,16 m/s T = 100, EWS = 62,57 m/s, UNC = 3,49 m/s T = 200, EWS = 65,71 m/s, UNC = 3,79 m/s	

References

[1] P. Nielsen et al, *20 Detailed Case Studies*, EMD.dk A/S, December 2002, available online as pdf-files http://www.emd.dk -> go to 'reports'
[2] H. Frank*: Extreme Winds over Denmark from the NCEP/NCAR Reanalysis*, Risø-R-1238(EN), Risø Natinal Laboratory, 2001,
[3] P. Thoft-Christensen & M. J. Baker: *Structural Reliability Theory and Its Applications*, Springer Verlag, 1982

5. User Guide

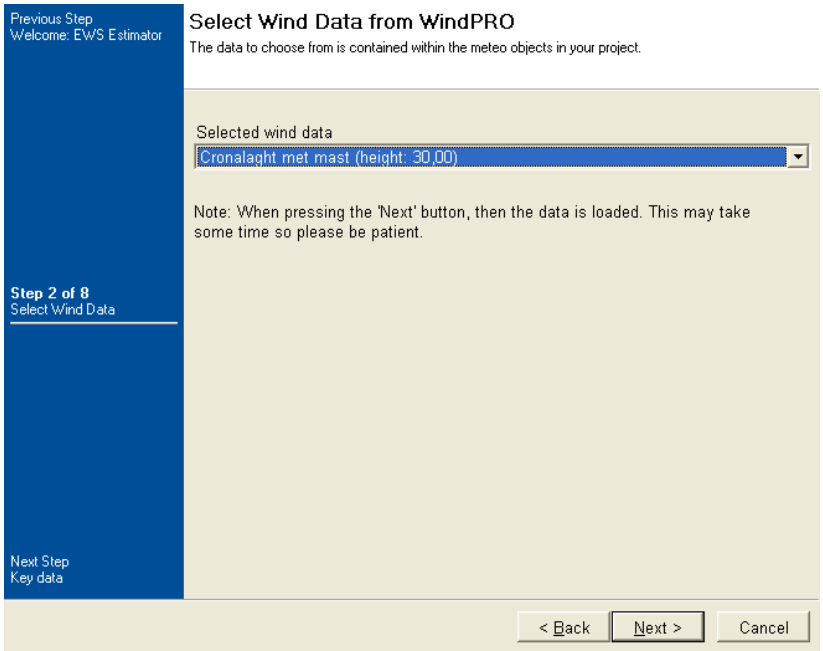
This chapter gives instructions on how to operate the Extreme wind speed estimator in WindPRO. The theoretical background is covered in the previous two chapters.

Background

The Extreme wind speed estimator can be started from the Tools menu in Maps and objects. It works as a wizard that guides the user through each step of the process. The estimator requires a meteo object in the project with a data time series. While it can work on time series of any length, longer time series will result in more reliable results. Preferably a time series should hold at least 10 years of measurements. Also the calculation will give extreme wind speeds with the averaging time which has been used as input data, i.e. a time series of hourly mean values will give an extreme hourly mean value. A time series of gust values will give the extreme gust wind speed.

Selection of data

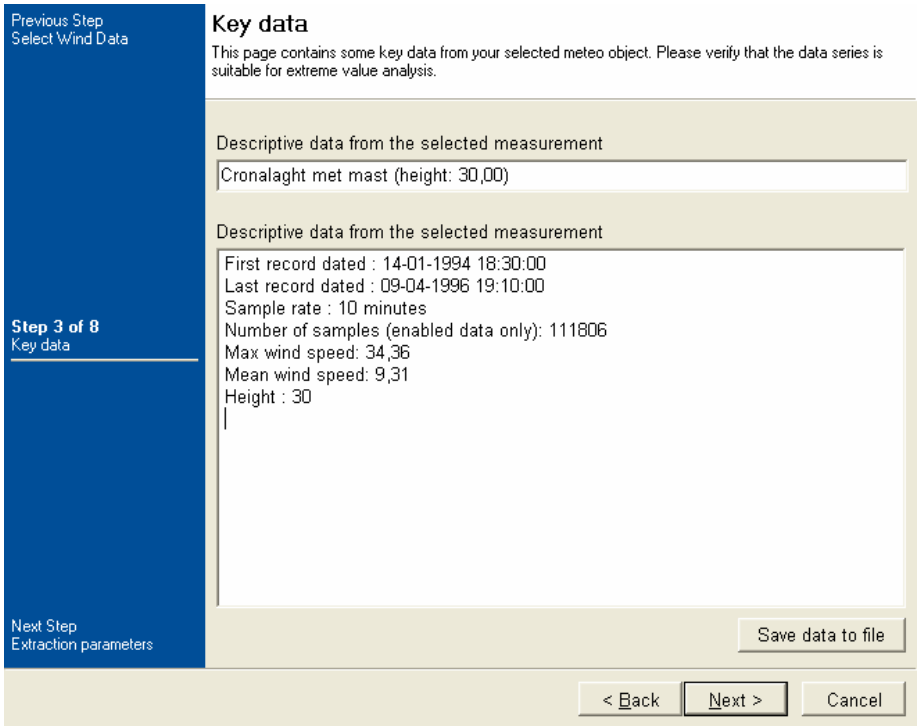
Starting the estimator will bring you to the opening window of the estimator wizard. Continue to the next window by clicking “Next”.



Here it is possible to select among the available time series. Each height on each Meteo object in the project can provide a time series.

Key data

At step 3 the key figures of the selected time series are presented. These include the measurement period, sample rate and how many samples have been included. Mean and max values are found.
These data can be saved to a text file by pressing the “Save data to file” button.



Press Next.

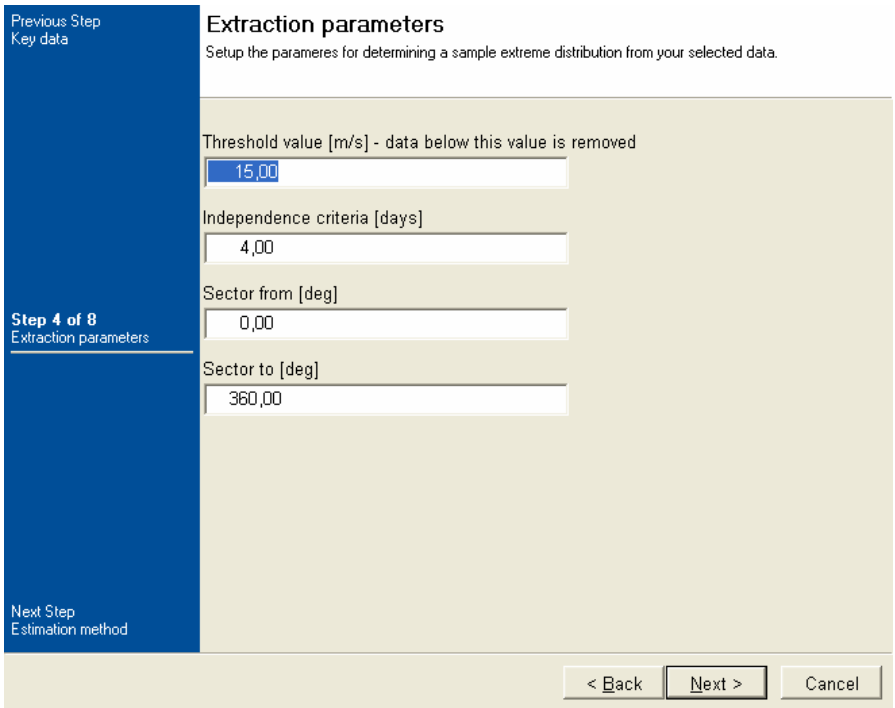
Extraction parameters.

At step four the extraction parameters must be defined. The analysis requires only one measurement from each independent episode. There must be so many selected measurements as to provide a sufficiently reliable fit, but not so many as to include too many low wind speed events that will affect the information on the high speed events. Between 20 and 50 m/s is recommended.

This is done by selecting a threshold value, so only values higher than this will be included and a independence criteria making sure only one measurement from each storm episode is included. For each episode the highest value is chosen.

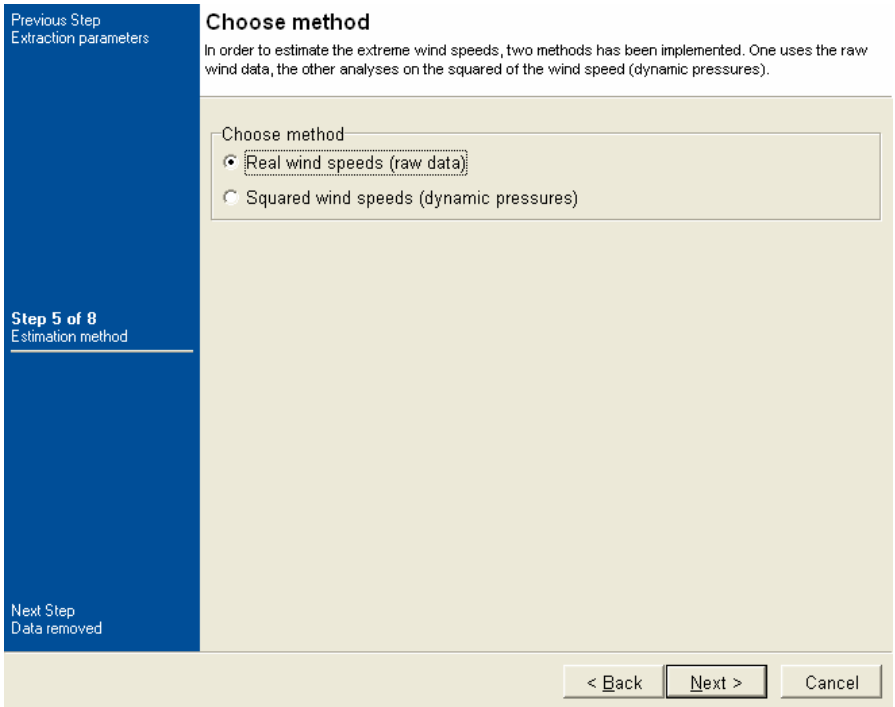
While 3 to 4 days seem to be a reasonable independence criterion it is not so easy to recommend a threshold value. Usually testing different wind speeds will be needed in order to establish which wind speed will provide the necessary number of samples.

The Sector to and Sector from options makes it possible to test extreme wind speeds for particular sectors.



Choose method

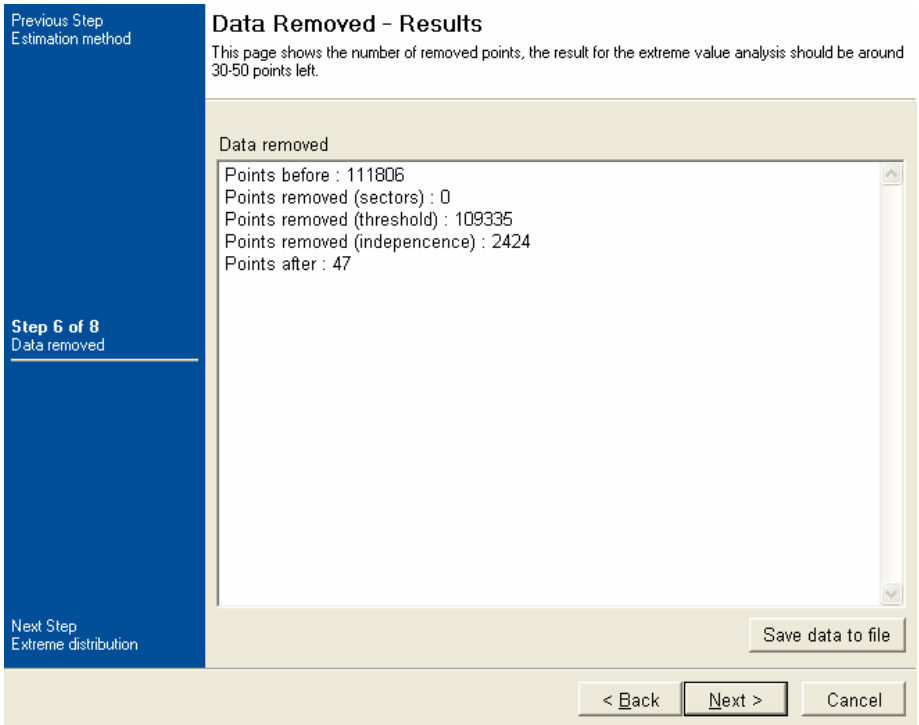
At step 5 two methods can be chosen: Either to calculate using the real wind speed or by using the dynamic pressure (squared wind speed). The theoretical background covers the real wind speed choice. Dynamic pressure is an alternative to this.



Data removed – Results

The data which does not fulfil the independence and threshold criterion are now isolated and the resulting number of samples given. If the number of samples is below 20 or above 50 a warning is given and the threshold should be adjusted to reach the proper number of samples

This table can be saved to a text file.



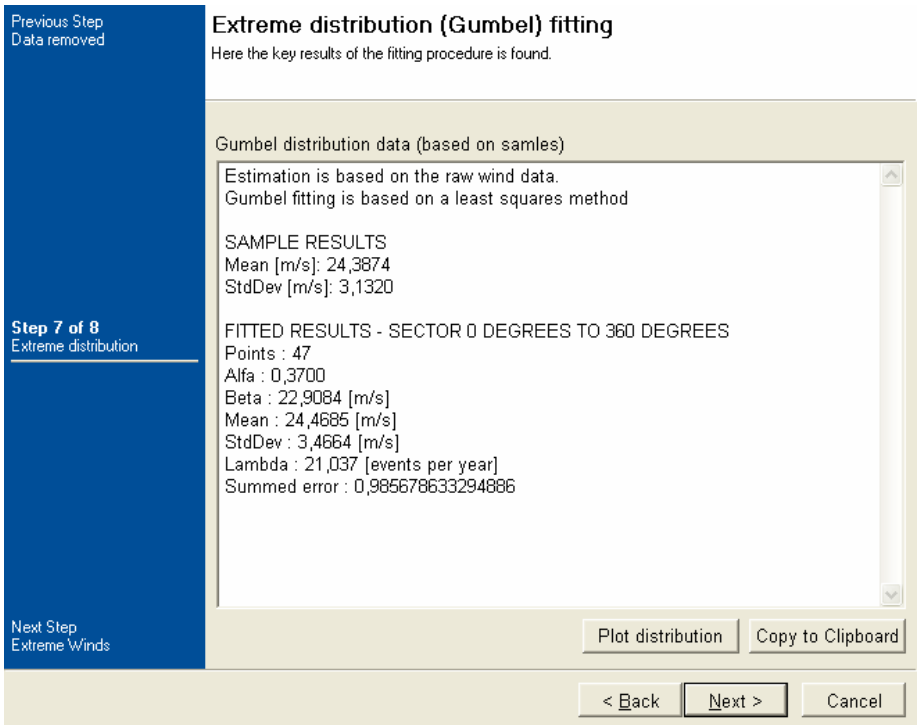
Extreme distribution fitting

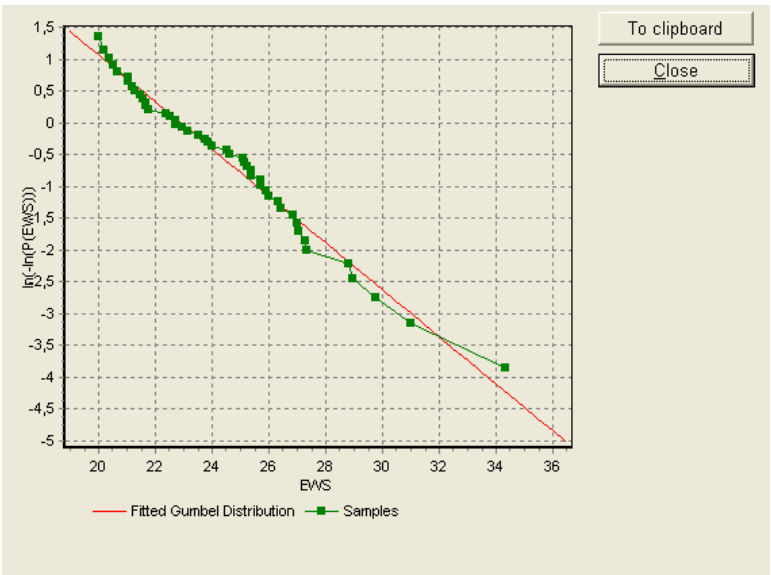
The samples are now fitted to a Gumbel function as described in the theory. The parameters of the fit is presented in the window and a graphic presentation of the fit can be obtained by clicking on the “Plot distribution” button..

An example of such a plot can be seen below.

The closer the data fit around the ideal Gumbel function the smaller the statistical uncertainty.

The plot can be copied to the clipboard.

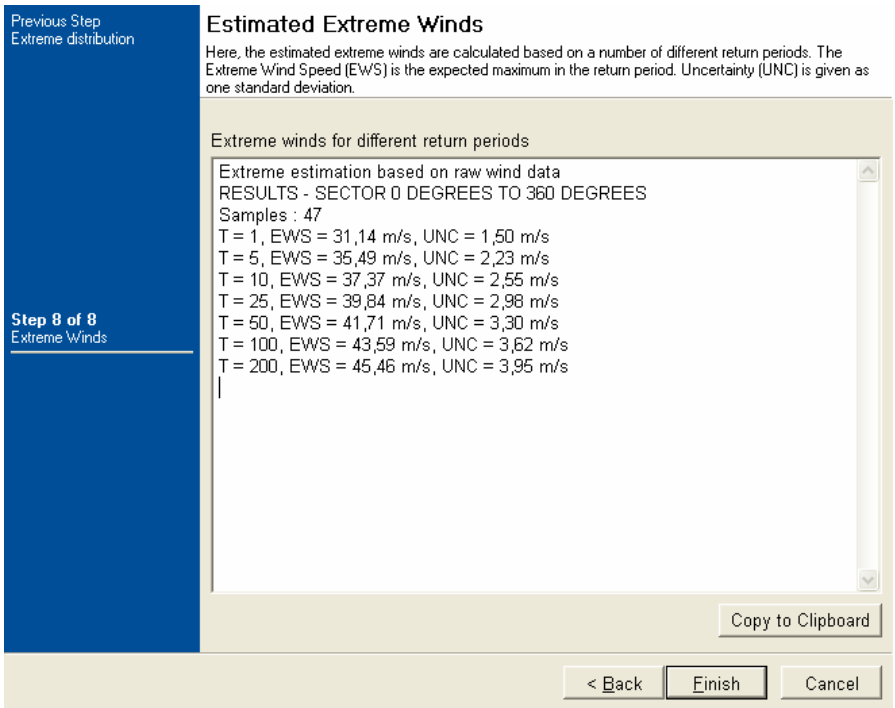




Estimated extreme wind speeds

Finally the extreme wind speed is calculated for different return periods based on the Gumbel fit. The statistical uncertainty relates to the Gumbel fit but does not include external uncertainties such as data quality and only to a limited degree the length of the time series.

The results can be copied to the clipboard.


Previous Step
Extreme distribution
Step 8 of 8
Extreme Winds
Estimated Extreme Winds
Here, the estimated extreme winds are calculated based on a number of different return periods. The Extreme Wind Speed (EWS) is the expected maximum in the return period. Uncertainty (UNC) is given as one standard deviation.
Extreme winds for different return periods
Extreme estimation based on raw wind data
RESULTS - SECTOR 0 DEGREES TO 360 DEGREES
Samples : 47
T = 1, EWS = 31,14 m/s, UNC = 1,50 m/s
T = 5, EWS = 35,49 m/s, UNC = 2,23 m/s
T = 10, EWS = 37,37 m/s, UNC = 2,55 m/s
T = 25, EWS = 39,84 m/s, UNC = 2,98 m/s
T = 50, EWS = 41,71 m/s, UNC = 3,30 m/s
T = 100, EWS = 43,59 m/s, UNC = 3,62 m/s
T = 200, EWS = 45,46 m/s, UNC = 3,95 m/s
Copy to Clipboard
< Back
Finish
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