3. WindPRO Energy

3.0 ENERGY – Intro, modules, and step-by-step guide

3.0.1 Introduction to WindPRO energy calculation modules

Calculating the energy production for a wind energy project is one of the most important tasks. The annual energy production for a specific turbine can vary by several hundred percent depending on the site, even within a small country like Denmark. Since the installation and operation costs only vary a little between sites (expect for offshore, where the costs are much higher), the site-dependent energy production becomes crucial for the feasibility of a wind energy project. Also, within the selected site, the micro-siting is important for the expected Annual Energy Production (AEP), where
factors such as utilization of higher elevated locations, distance between turbines, and turbine orientation are important in lowering the wake losses.

WindPRO offers a range of options for calculating the AEP. WindPRO is the most flexible tool of its kind when it comes to modeling combinations of wind data in varying formats, multiple types of wind turbines, combining new and existing WTGs, and handling different hub types and heights. A great deal of effort has been put into developing the capabilities of intelligently checking input data as well as checking the calculation results in order to ensure that the user is producing the most reliable results and documentation.

From version 2.7, it's possible to calculate time-dependent variations of the expected AEP within the PARK module.

The RESOURCE calculation (part of MODEL) gives you the ability to establish a wind energy resource map. This gives you the information you need for selecting suitable sites, either on a micro-siting level for best positioning of the individual turbines, or for calculation of larger regions in order to determine the bestsuited sites for wind farms. The module has unique capabilities for calculating large areas in one process and has been used for calculating the entire Country of Denmark in a 200 m grid resolution. A wind resource map presented on-screen as a background map is a valuable tool for manually optimizing a wind farm layout.

For optimizing a wind farm layout automatically, see Chapter 8.

For calculation utilizing CFD models, see Chapter 9, but note this part is under reconstruction.

For long term correction of short term measurements, see chapter 11, MCP module.

For Loss and uncertainty calculations, see chapter 12.

The various modules for performing AEP calculations with WindPRO are structured in the following modules:

- METEO – includes the Meteo object for wind data import/screening/analyze and the Meteo analyzer for like cross predictions, substitutions etc. and AEP calculation direct from wind measurements.
- MODEL – includes the "simple" ATLAS model, interface to WAsP model, RESOURCE calculation and interface to CFD models (under reconstruction).
- MCP/Statgen – for long term correction of wind measurements and generation of wind statistics based on the long term corrected wind data. This is documented in separate manual chapter (11).
- PARK – Wake loss calculation as well as time varying AEP calculations and turbulence calculations. The PARK calculations can be performed on basis of METEO for "simple terrain sites" (where the wind is assumed the same for the entire site) or MODEL, where the models extrapolate the wind to each WTG position before the wake loss calculation.

The different modules and "sub modules" are explained further below:

METEO – With this module, you can calculate energy production based on measured wind data, where you've taken exact measurements at the future WTG location (in flat, open terrain the data can usually be used for larger areas). If the measurements are taken at a height other then the proposed WTG hub height, the data can be extrapolated by giving in a wind gradient exponent, but this must be done carefully. Only in flat and simple terrain (low roughness) can the height extrapolation be expected to follow simple rules. The module gives access to comprehensive tools for importing/screening/analyzing measured wind data, which is a mix of the METEO object and the Meteo analyzer. The Meteo analyzer has features for comparing more

measurement masts, performing data substitution, and conducting a cross prediction and generation of complete 1 year time series based on data interpolation/patching etc.

The METEO module will normally be used more for importing, analyzing, and preparing measured wind data for generation of a Wind Statistic with the WAsP Interface.

MODEL (ATLAS) - With this module, you can calculate energy production based on the simple ATLAS model (Wind Atlas method), which is based on a terrain description (roughness, simple hills, and obstacles) and a Wind Statistic. The roughness model is the same as in WAsP, but the hills and obstacles are calculated with less complex flow models than in WAsP. For this reason, ATLAS should only be used for noncomplex terrain, and should never be used in mountainous terrain. The future for the ATLAS model will only be smaller projects (smaller turbines), where the model cost is an issue. For large modern turbine projects, the further refined and updated WAsP model should always be used. Nevertheless, the ATLAS model has been used for calculating more than 6.000 WTGs in Denmark, which has worked quite well.

MODEL (WAsP Interface) – With this module you can calculate the energy production using WAsP (software from RISØ, DK) as the "calculation engine", This means that you can perform calculations for complex terrain using the Wind Atlas method with the advanced flow model incorporated into WAsP. The WAsP Interface is both a preprocessor to WAsP, for preparing and checking data, and a post-processor, for printing results in a report. It is also used for performing and printing a number of analyses, which provides the user with valuable feedback for evaluating the quality of the calculations.

3.0.1.1 Generating a Wind Statistic

STATGEN – With the METEO and WAsP Interface modules, measured wind data can be converted into Wind Statistics. The measured wind data is "cleaned" for local terrain conditions, so a regional wind climate is established for use in calculations at locations other than where the wind measurements were taken (e.g. at each turbine position).

3.0.1.2 Creating a Wind Resource Map

MODEL (RESOURCE) – This module can be used in a stand-alone fashion to generate a wind resource map based on an .rsf or a .wrg file from a WAsP calculation and an optional WTG (for an energy production map). Together with the WAsP Interface module, the RESOURCE module can calculate and generate the wind resource map for very large areas in one process. It can smoothly change the wind data used and automatically optimize digital maps for use in the WAsP calculation(WAsP can only handle limited-sized map files in a resource calculation). Lastly, local obstacles can be included, and calculations can be performed for more than one hub height at a time. These capabilities are not available when using WAsP as a stand-alone product. The RESOURCE module also provides the key input to the OPTIMIZE module based on .rsf files.

3.0.1.3 Wind farm calculations

PARK – This module is used for calculating wake losses and AEP for wind farms. The inputs for the PARK calculation are the WTG positions, types, and hub- heights, plus the wind data delivered from one of the three previously mentioned modules (ATLAS, METEO or WAsP Interface), from an .rsf file from the RESOURCE module, or from a CFD model. In order to utilize the PARK module, one of the four previously mentioned modules must be available. The PARK module can also calculate time varying AEP based on METEO data.

3.0.1.4 Optimization of wind farm layout

OPTIMIZE – This module provides access to the PARK Design Object, which is a useful tool for large-scale park design (e.g. off-shore).From version 2.4, it can run a parameter variation for auto-optimization. The other automatic energy-optimizing algorithm is based on utilization in more complex terrain (see OPTIMIZE Chapter 8). OPTIMIZE is based on the PARK module and the MODEL (RESOURCE) module, and can only be used when both modules are available.

3.0.2 Step-by-step guide for AEP calculations

3.0.2.0 PARK calculation based on local measurements, WAsP model

- ❑ Establish a map and a proposed WTG project (see BASIS Section 2.0.5)
- ❑ Establish height contour lines within approximately a 5-km radius around site in a Line Object
- ❑ Establish the roughness description within approximately a 20-km radius around site. There are three methods available:
  - 1) Roughness rose(s) (Site Data Object)
  - 2) Roughness lines (Line Object)
  - 3) Roughness lines exported from the Area Object.
- ❑ If there are local obstacles, establish them (Obstacle Object).
- ❑ Establish a Site Data Object for a WAsP calculation and select a Wind Statistic (if not available, see Calculation of a Wind Statistic, Section 3.0.2.4) NOTE: A correct Wind Statistic is extremely important to calculate correct results. Check Map data connected to the Site Data Object.
- ❑ Run PARK (if wind farm) or WAsP Interface (if single WTG or site analyses, e.g. wind profiles, additional hub heights or WTG types)

3.0.2.1 Based on measured on-site data WITHOUT a Model

- ❑ Establish a map and a proposed WTG project (see BASIS Section 2.0.5)
- ❑ Establish a Meteo Object
- ❑ Input measured data in the Meteo Object. The four acceptable types of input data are:
  - 1) Raw data logger files
  - 2) Time series from e.g. spreadsheet
  - 3) Table data (wind speed and wind direction frequency) or WAsP .TAB file
  - 4) Weibull parameters (or mean wind speed) versus direction sector (or just mean wind speed for preliminary calculations).
- ❑ Run PARK (if wind farm) or METEO (if single WTG or site analyses, e.g. additional hub heights or WTG types). NOTE: Data has to be representative of long-term wind conditions. Measurements must be at hub height or the wind shear must be known. When WTG positions are more than 50 m away from the mast, this method should only be used if the terrain is very simple (flat, without local obstacles or changing surface roughness), otherwise, see Section 3.0.2.4.

3.0.2.2 Based on Wind Statistic and terrain description, ATLAS model (simple)

- ❑ Establish a map and a proposed WTG project (see BASIS)
- ❑ Establish a Site Data Object for use in an ATLAS calculation and select Wind Statistics (if not available, see Calculation of a Wind Statistics, Section 3.0.2.4).
- ❑ Enter roughness rose information (20-km radius), local obstacles, and local simple hills. This is done graphically by using the options that appear on the pop-up menu when right-clicking on the Site Data Object.
- ❑ Run PARK (if wind farm) or ATLAS (if single WTG or site analyses, e.g. additional hub heights or WTG types)

3.0.2.3 Based on Wind Statistics and terrain description, WAsP model

- ❑ Establish a map and a proposed WTG project (see BASIS)
- ❑ Establish height contour lines within approximately a 5-km radius around site in a Line Object
- ❑ Establish the roughness description within approximately a 20-km radius around site. There are three methods available:
  - 1) Roughness rose (Site Data Object)
  - 2) Roughness lines (Line Object)
  - 3) Roughness lines exported from the Area Object.
- ❑ If there are local obstacles, establish them (Obstacle Object).
- ❑ Establish a Site Data Object for a WAsP calculation and select a Wind Statistic (if not available, see Calculation of a Wind Statistic, Section 3.0.2.4) NOTE: A correct Wind Statistic is extremely important to calculate correct results. Check Map data connected to the Site Data Object.
- ❑ Run PARK (if wind farm) or WAsP Interface (if single WTG or site analyses, e.g. wind profiles, additional hub heights or WTG types)

3.0.2.4 Calculation of a Wind Statistic (WAsP required)

- ❑ Establish a map for the measure mast site (see BASIS)
- ❑ Establish height contour lines within approximately a 5-km radius around the measure mast in the Line Object
- ❑ Establish the roughness description within approximately a 20-km radius around measure mast. There are three methods available:
     1) Roughness rose (Site Data Object)
     2) Roughness lines (Line Object)
     3) Roughness lines exported from the Area Object.
- ❑ If there are local obstacles, establish them (Obstacle Object).
- ❑ Establish a Site Data Object for STATGEN purpose and add data.
- ❑ Establish a Meteo Object (see Section 3.0.2.1)
- ❑ Run STATGEN from the calculation menu (takes data from the Meteo and Site Data Objects.)
- ❑ Use Wind Statistic (see Section 3.0.2.2 or 3.0.2.3).

3.0.2.5 Calculation of a Wind Resource Map (WAsP required)

- ❑ Establish a map and a proposed WTG project (see BASIS)
- ❑ Establish height contour lines within approximately a 5-km radius around the calculation map area in the Line Object
- ❑ Establish the roughness description within approximately a 20-km radius around the calculation map area. There are two methods available:
     1) Roughness lines (Line Object)
     2) Roughness lines exported from the Are Object. Using the Area Object, information can be imported from e.g. .dxf files
- ❑ Establish a Site Data Object for use in a RESGEN calculation and select Wind Statistics (if not available, see Calculation of a Wind Statistics, Section 3.0.2.4). Check MAP files and input region that you will calculate within.
- ❑ Run a RESOURCE calculation and set grid size, height(s) etc.
- ❑ Establish a Result Layer Object on the map for viewing the resource map layer and for manual or automatic optimization of the wind farm layout (OPTIMIZE module).

3.1. ENERGY – Fundamentals in Calculations

3.1.1 Basic data for energy calculations

Two basic sets of data are needed in order to estimate the AEP for a WTG:

1) The wind speed distribution at hub height
2) The power curve(s) for the turbine(s) – air density corrected and eventually turbulence/shear corrected

If more WTGs are placed together and form a cluster or a wind farm, the directional wind speed distribution, the precise micro-siting of the WTGs, and their C_t curve(s) must also be known.

3.1.2 Wind speed distribution

The wind speed distribution describes the probability for a specific wind speed versus the wind speed. The mathematical, two-parameter Weibull distribution is often used to describe the wind speed distribution. The figure below shows examples of measured distributions and corresponding Weibull curve fits.
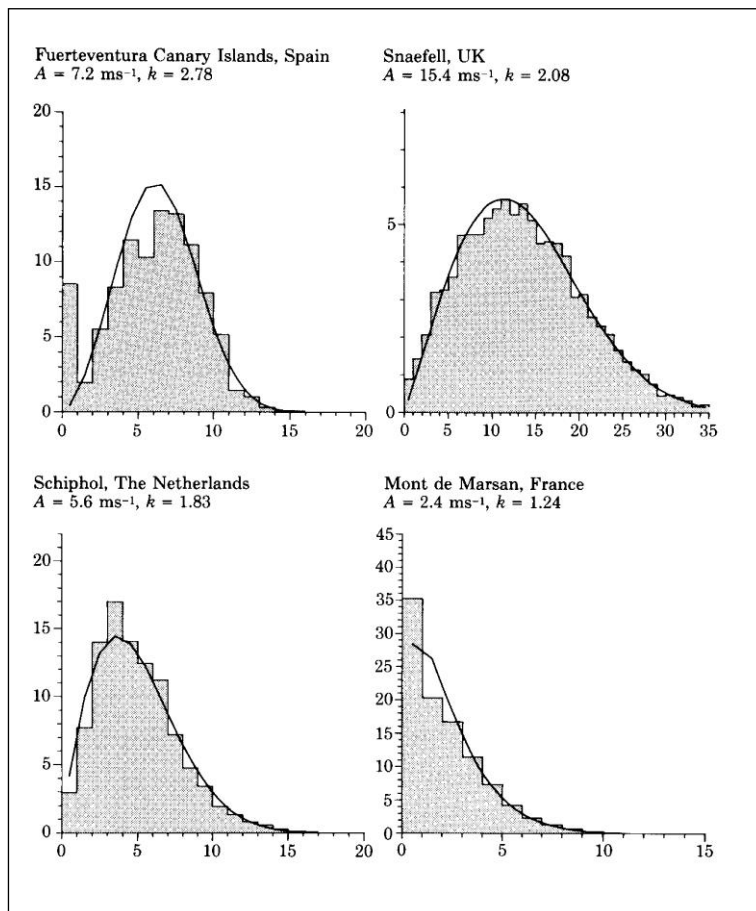
The two Weibull distribution parameters are defined by:

$$f(u) = \frac{k}{A}\left(\frac{u}{A}\right)^{k-1}\exp\left[-\left(\frac{u}{A}\right)^{k}\right]$$

Where:

> **u** = the wind speed
> **k** = the Weibull form factor
> **A** = the Weibull scale parameter (for typical distributions, A ≈ is approx. equal to 1.126 * u_{mean})

A special variant of the Weibull distribution is the Raleigh distribution where k = 2. This distribution is often assumed when only the mean wind speed is known.

3.1.2.1 Methods for establishing a wind speed distribution

The wind speed distribution can be established by one of the following methods:

A: Measurements at the WTG site

B: One or more Wind Statistics for the region and a terrain description for the WTG site (for simple terrain use the Wind Atlas method, ATLAS or WAsP)

C: One or more Wind Statistics for the region and a terrain description for the WTG site (for complex terrain use the Wind Atlas method, WAsP)

D: Measurements for the region (or on-site, where more WTGs with different terrain conditions will be sited), transformed to Wind Statistics for the region by WAsP (WindPRO module STATGEN). After establishment of a Wind Statistics, go to C:

It's crucial that the wind speed distribution is long term representative. Having measurements for shorter periods mean that a long term corrections should be performed, see chapter MCP module.

A precise wind speed distribution is crucial. One reason for this is the fact that the energy content of the wind increases cubically with the wind speed. The wind power output from a WTG is calculated with the following equation:

$P = ½ * \rho * u^3 * A * C_e(u)$ (W)

Where:
ρ = the Air Density
u = the Wind Speed
A = the Area Swept by the Rotor
$C_e(u)$ = the total efficiency, from wind energy to electric output of the WTG as a function of the wind speed.

An example:
At a wind speed of 10 m/s, with a 150 kW WTG with a 23-m rotor diameter that has an efficiency of 40%(@10 m/s) at an air density of 1.125 kg/m3.

Then the power is calculated as follows:

> $P = ½ \cdot 1.125 \text{ kg/m}^3 \cdot 10^3 \text{ (m/s)}^3 \cdot 23^2 \cdot \pi/4 \text{ m}^2 \cdot 0.4 = 93,434$ W

This means that the power is 93.4 kW and the energy production is 93.4 kWh in one hour. If the wind speed always is 10 m/s during an entire year, the AEP will be 8760h x 93.4 kWh = 818 MWh – but conditions are never this ideal, therefore the number of hours with all the varying wind speeds must be known (the wind speed distribution).

At half the wind speed (5 m/s), assuming the same WTG efficiency (which, in practice, will be lower), the power is 11.7 kW or only 12.5%.

NOTE: The formula above cannot be used to calculate annual energy production based on the annual mean wind speed. The wind distribution and the power curve must both be known.

Method A) Measurements at the WTG site
The measurements must correspond to the long-term wind conditions. Typically, this calls for continued measurements over a minimum period of three years. If at all possible, measurements of shorter periods must be controlled and correlated to the long-term measurements by utilizing a station within the same region.

The data should be available in one of the following formats:
- Time series from a data logger or spreadsheet, normally with records of both wind speed and direction
- Table or histogram with observations per wind speed interval (and normally by direction interval)
- Weibull parameters, possibly given per wind direction sector along with direction frequency
- Mean wind speed, possibly given per wind direction sector along with direction frequency

Data that is available in one of the above formats can be entered or imported into a Meteo Object in WindPRO (see also Sections 3.2.2 and 3.3.2).

Method B) One or more Wind Statistics for the region and a terrain description for the WTG site (simple terrain)
The wind speed distribution in a relatively simple terrain can be calculated with ATLAS, e.g. as for most of Denmark (except those areas with large hill formations or industrial areas with many dominating local obstacles). ATLAS requires a Terrain Data Object and one or more Wind Statistics. The Wind Statistics should be based on measurements made within a maximum radius of 200 km from the site (see also Sections 2.1.x and 3.1.x).

Method C) One or more regional Wind Statistics and a terrain description for the WTG site (complex terrain)
For sites in more complex terrain, i.e. with many hills, mountainous terrain, or terrain with dominating local obstacles, the calculation of the wind speed distribution can be carried out by using the energy calculation software WAsP. WindPRO calls WAsP (which must be purchased from RISØ separately as the calculation module once a Terrain Data Object has been created, WAsP has been selected as the calculation module, and one or more Wind Statistics have been selected. The Wind Statistics should be based on measurements made within a maximum radius of 100 km from the site. Please notice that Wind Statistics in mountainous terrain may only be valid within a very short distance (down to as little as a few hundred meters) from the measurement station (see also Sections 2.1.x and 3.1.x).

Method D) Measurements for the region transformed into Wind Statistics for a region by WAsP
The comments that were made under Method A are valid here too. The only difference is that the data cannot be used directly, but instead, must be transformed into a set of regional Wind Statistics which are based on the measured data combined with a terrain description as outlined under Method C.

In other words, first a Meteo Object must be created in WindPRO, and then a Terrain Object for the measuring station must be created and used to generate a set of Wind Statistics for the measuring station (the regional Wind Statistics). The regional Wind Statistics can then be used as described under Method B or C (see also Section 3.2.1).

3.1.3 Fitting Weibull Parameters for Wind Energy Applications

A number of different methods exist for estimating the distribution parameters in an arbitrary distribution. Among the most common methods are procedures using: 1) estimation of the statistical moments, 2) least squares methods, 3) maximum likelihood methods or 4) Bayesian methods. An introduction to these methods may be found in Ross [i]. Traditionally, it is recommended to use the maximum likelihood method for estimating the distribution parameters because of the ability of this method to estimate not only the parameters themselves but also a consistent estimate of any statistical uncertainty connected to the distribution parameters. When using the methods 1) or 2), it is possible to include uncertainty estimates on the distribution parameters using Bootstrap or Jackknife methods, see Efron and Tibshirani [ii].

3.1.3.1 The Weibull Distribution

For wind energy applications, the two-parameter Weibull distribution is used as the most common parametric distribution of the *T*-minutes averaged wind speed (often *T*=10 minutes):

$$F(u) = 1 - \exp\left[-\left[\frac{u}{A}\right]^k\right] \qquad (1)$$

$$f(u) = F'(u) = \frac{k}{A} \cdot \left[\frac{u}{A}\right]^{k-1} \exp\left[-\left[\frac{u}{A}\right]^k\right] \qquad (2)$$

where   *k* is the Weibull form parameter
         A is the Weibull scale parameter
         f(u) is the Weibull density function
         F(u) is the Weibull cumulative distribution function

The statistical moments, a_v, are related to the Weibull distribution parameters as follows:

Mean value: $\mu = a_1 = A \cdot \Gamma[1 + 1/k]$ (3)

v-th order statistical moment: $a_v = \int f(u)u^v du = A^v \cdot \Gamma[1 + v/k]$ (4)

3.1.3.2 Estimating Moments in the Sample (Measured/Observed) Distribution

In the sample distribution, the statistical *v*-th order moments, a_v, are given by [[iii], Chapter 27]:

$$a_v = \frac{1}{n} \sum_i x_i^v \qquad (5)$$

where a_v is the *v*-th order statistical moment
         n is the number of samples
         x_i is the sample with the index *i*

Note: The sample moments should be determined directly from the available time series/samples. However, it is also possible to estimate the sample moments from histograms – even if this procedure is slightly more inaccurate.

3.1.3.3 The Wind Power Density

The available wind power density is proportional to the mean cube of the wind speed. This may be expressed using the Weibull parameters:

$$E = \int 0.5(\rho u)u^2 f(u)du = 0.5\rho a_3$$
$$= 0.5\rho A^3 \cdot \Gamma(1 + 3/k) \qquad (6)$$

When dealing with the sample distribution, the wind power density is:

$$E_{sample} = 0.5\rho \frac{1}{n} \sum_i u_i^3 \qquad (7)$$

3.1.3.4 Estimating the Weibull Parameters for Wind Energy Applications

This section describes how to estimate the Weibull parameters using the method described in The European Wind Atlas [[iv]]. When using the 2-parameter Weibull distribution for wind energy applications, the requirements for the estimated 'optimum' distribution parameters may not be as specified in the four methods above. Indeed, The European Wind Atlas [iv] specifies two criteria quite different from the ones specified in the 'traditional' methods:

- The total wind energy in the fitted Weibull distribution and the observed distribution are equal.
- The frequency of occurrence of the wind speeds higher that the observed average speeds are the same for the two distributions.

These two requirements lead to an equation in *k* only. It is important to notice, that the average wind speed in the requirement in 2) is the sample wind speed. This leads to the required equation in *k* only. The equations (6) + (7) is used in order to determine the *A* parameter as a function of *k*:

$$E = E_{sample} \Leftrightarrow$$

$$A = \left[\left(\frac{1}{n} \sum_i u_i^3 \right) \Big/ \Gamma(1 + 3/k) \right]^{1/3} = \left[a_3 / \Gamma(1 + 3/k) \right]^{1/3} \tag{8}$$

Now, the requirement 2) is used with equation (8):

$$P\left[u > \mu_{sample}\right] = 1 - F(\mu_{sample}) = \exp\left[-\left(\frac{\mu_{sample}}{A} \right)^k \right]$$

$$= \exp\left[-\left(\frac{\mu_{sample}}{\left[a_3 / \Gamma(1 + 3/k) \right]^{1/3}} \right)^k \right] \tag{9}$$

A standard root finding algorithm is utilized in order to determine *k* from eq. (9), as the probability of exceeding the mean value, $P[u > \mu_{sample}]$ is calculated directly from the sample distribution (time series or histograms). Now, when *k* is known (calculated from (9)), *A* is easily determined from (8), assuming that *E* or a_3 are also determined from the sample distribution.

Example – samples with histograms and time series data
Using time series data in a section between degrees = [255;285[from a Danish wind farm at Torrild, then the first and third order moments may be calculated to a_0= 5.593 m/s and a_3= 321.88 (m/s)³ (using eq. 5). The probability of exceeding the mean wind speed is 0.45421 in the sample distribution. The *k* parameter may be determined to *k*=2.0444 and *A*=6.2801 m/s using equations (9) and (8).

Estimating the moments from a histogram using a 1 m/s bin width yields a_0= 5.654 m/s and a_3= 332.15 (m/s)³ and the probability of exceeding the mean is 0.4511. The Weibull parameters can be determined to *k*=2.0267 and *A*=6.3275, i.e. a slightly different result that the one obtained using time series. The current implementation in WindPRO differs slightly from the specifications stated in the European Wind Atlas (using the distribution density function instead of the distribution function), but it also uses histograms in estimating the Weibull parameters. Here, an *A*=6.316 and *k*=2.0340 is found. WAsP reports *A* = 6.3 and *k* = 2.04. The histogram values that were used are stated below:

```
Wind  [m/s]  <1  2    3    4    5    6   7   8   9  10 11 12 13 14 15 16 17 18 19 20
Count [o/oo] 11  62  121  155  122  120  97  84  77  73 41 22  8  4  2  1  1  0  0  0
```

Please note that when calculating the mean value from the Weibull *A* and *k* parameters (see eq. (3)), then the mean value is slightly different from the one found directly from the sample values. This is due to the fact, that the fitting criterion assures only that the energy in the sample and fitted distributions are equal, and furthermore that the probability of exceeding the sample mean are the same. The means calculated from the Weibull *A* and *k* parameters are 5.564 m/s for the time series data and 5.606 m/s for the histogram data.
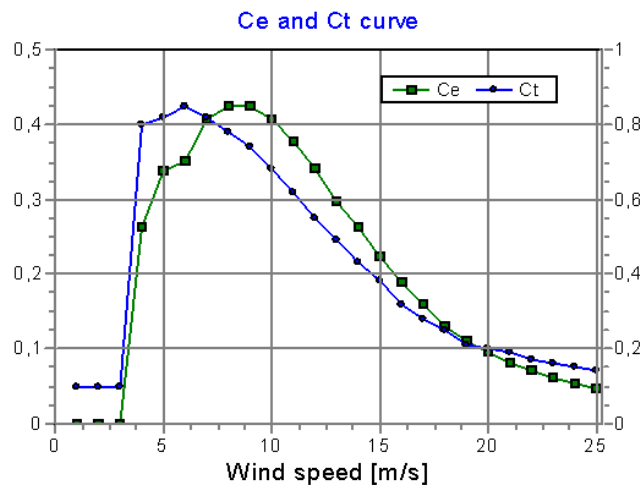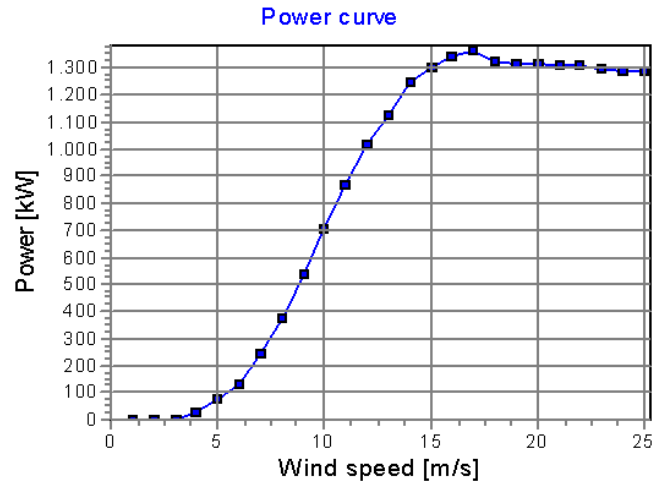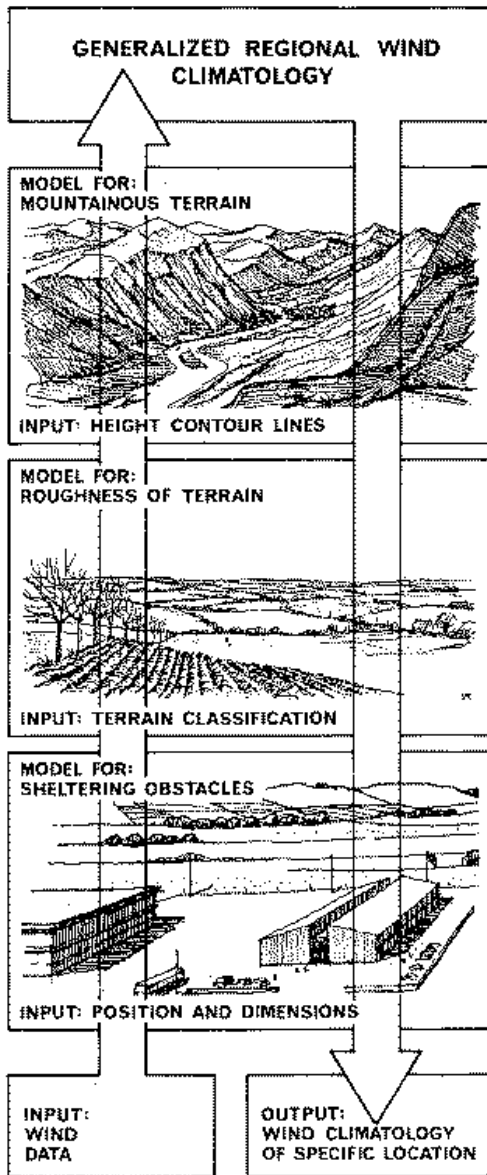
3.1.4 The power curve and the C_t curve

The power curve describes the electric power output from a specific WTG versus the wind speed at hub height. The power curve is typically measured by installing wind monitoring equipment close to a WTG, and measuring the coincident values of the wind speed and the electric power output. Alternatively, the power curve can be calculated using aerodynamic computer models.

Power curves for a large number of the WTGs are already available in the wind turbine catalogue in the WindPRO BASIS module (WTG catalogue). The power curves are generally based on measurements or calculations. The reliability of the power curves may vary. Therefore, it's important to check the power curves. Please refer to 3.5.2 Checking the Power Curve for further information on this subject.

The C_t curve, which is used in PARK calculations, can just be a standard curve for either stall-regulated or pitch-regulated WTGs, but better to have it more precise while it has a large influence on the calculated wake losses. For large modern turbines, it is normally available for the specific turbine.
Further information about the power curves can be found in the chapter 2.6 in WindPRO BASIS. A typical example of power curve, C_e and C_t curves for a stall-regulated 2-speed generator WTG are displayed in the above figures.

3.2. ENERGY – Calculation Methods and Models

3.2.0 Introduction to calculation methods and models

In this chapter you will find a short description of the various calculation methods that can be used from WindPRO. The following methods/models will be described:

- Wind atlas method (modules: ATLAS, WAsP Interface and RESOURCE)
- Direct use of measurements (module: METEO with Weibull or measure option)
- PARK model - this is used in conjunction with one of the methods mentioned above.
- WAsP model – focus on changes before after Wasp 10.0.

3.2.1 Wind Atlas method (ATLAS, WAsP and Resource)

All calculation methods are based on the Wind Atlas method.

The Wind Atlas method assumes that you use a set of Wind Statistics for a specific area (the local Wind Atlas). Combined with a terrain assessment of the area within round 20-km radius around the site, the program calculates the actual mean site-specific wind conditions at any specified height above the site terrain. These wind data can then be compared with the power curve of a specific WTG, after which the expected mean annual energy production for that WTG at the chosen site can be calculated.

Hence, three sets of information are required for an energy production calculation based on the Wind Atlas method:
- The governing Wind Statistics for the region
- A terrain assessment (roughness, orography and local obstacles)
- Power curves for the WTG (s) in question

3.2.1.1 Method description – ATLAS as opposed to WAsP

The WindPRO program module ATLAS complies with the algorithms that are described in the "European Wind Atlas" with the following limitations:

- Only one obstacle per wind direction sector can be entered. Also, the obstacle model is simplified compared to the WAsP obstacle model.
- The hill model is simplified and is not based on a flow model, as is the WAsP model. The hill model is based on a simple mathematical model, which only calculates with the height and the length of one hill in each directional sector.
- The stability model, which is described in the "European Wind Atlas" and which adjusts the wind profile at sites within 10 km from a coastline, is not included in the ATLAS program. However, sensitivity analyses carried out by EMD indicate that only marginal errors may occur if the stability model is not included for smaller turbines up to 50m hub height.

One of the key elements in the Wind Atlas method is the terrain assessment. The terrain must be described as follows:

- Roughness classification of the terrain - detailed within approximately a 5-km radius from the site, or coarser within a 20-km radius from the site.
- Hills (orography) - within approximately a 5-km radius if you use digital maps.
- Local obstacles - within approximately a 1-km radius from the WTG position.
The mentioned distances are for round 50 m hub height, by larger hub heights, the distances should be increased, and can similar be decreased at smaller hub heights.

Usually, a terrain assessment requires both good quality maps and a field survey.

3.2.1.2 Method description – Regional Wind Statistics

The governing regional Wind Statistics (Wind Atlases) for the present EU countries (1989) are mapped in the "European Wind Atlas" from RISØ. A number of other countries, e.g. the later EU members Sweden and Finland, have made similar maps. It's not possible to explicitly point out exactly which Wind Atlas to use for a specific site (in Denmark, one should generally choose DANMARK '07). But one should generally use a Wind Atlas which is based on the measuring station closest to the site, and then control the result by comparing the result with Wind Statistics from one or two adjacent measuring stations.

Another approach would be to specify a number of Wind Atlases in the same calculation, weighted by the reciprocal distance to the site.

The regional Wind Atlas constitutes a complete description of the governing wind conditions for the region in question, and consists of a table that contains the following default WAsP setup (the parameters can be changed manually in the WAsP parameter file):

Weibull A and k parameters for:

- Each of the roughness classes: 0, 1, 2, 3 (4 in total)
- Each of the heights: 10, 25, 50, 100, 200 m above ground level (5 in total)
- Each of the directions: N, NNE, ENE, E, ..., NNW (12 in total)

This gives a total of 4 * 5 * 12 = 240 wind speed distributions.

The most critical aspect of the Wind Atlases is their quality, which may vary significantly. An error margin of 50% in the estimated energy production is easily generated simply ifa Wind Atlas of poor quality is used. It's, therefore, important to crosscheck the applied Wind Atlas with other neighboring Wind Atlases, and preferably make test calculations for other WTGs in the region, which have been operating for some years.

Recommendations for Site Calculations in Denmark

When calculating the wind energy potential for sites in Denmark, the "Danmark '07" Wind Atlas is recommended. It includes a set of correction curves that scales the wind speed according to the geographical position (the correction for differences in the geostrophic wind conditions (~1000m agl.) over Denmark is based on comprehensive studies and production validation for a large number of Danish WTGs). The map below (EMD/InterCon I/S) shows the energy correction factors when one uses the "Danmark '07" Wind Atlas (which is based on the "Beldringe" Wind Atlas included in the European Wind Atlas). Ask for detailed documentation of the Danish '07 wind statistic (or find it at http://help.emd.dk/WindPRO/).
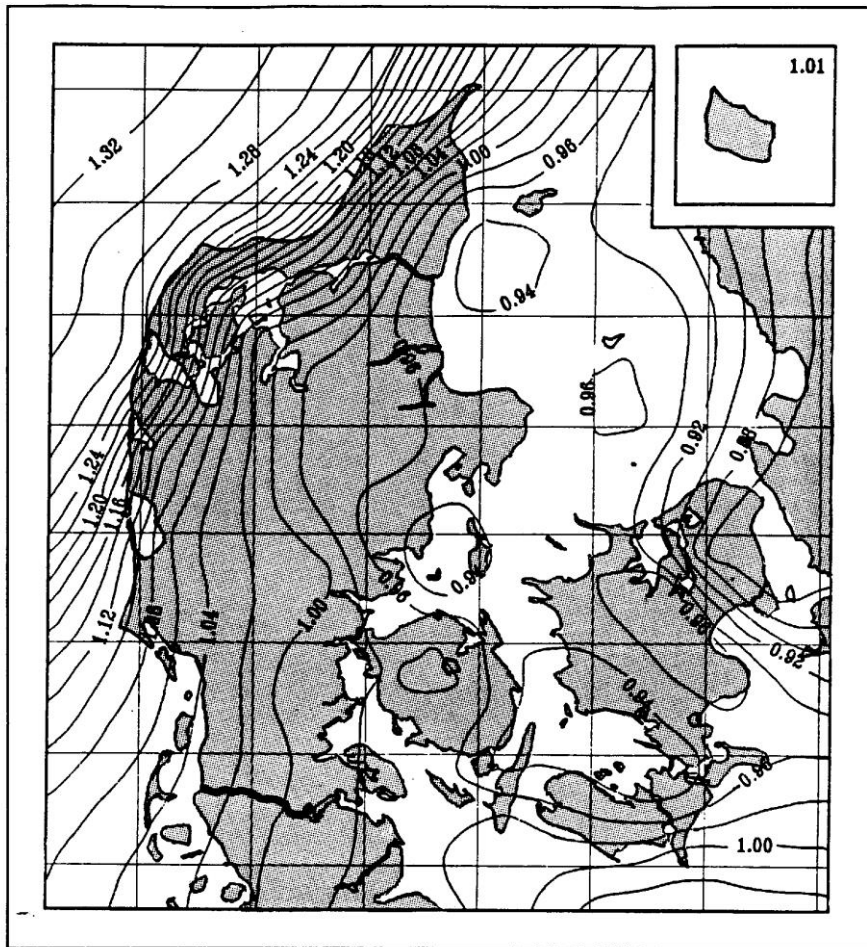
Recommendations for site calculations outside Denmark

In general, the data from the European Wind Atlas seems to be reliable. When other Wind Statistics are used, it's recommended to always include at least two Wind Statistics from the region, and to make sure that the differences between these data are acceptable, or to include the production from existing WTGs as control elements in the calculation.

WindPRO can work simultaneously with several Wind Atlases. The program automatically calculates weighting factors for the individual Wind Atlases proportional to their reciprocal distances to the site. These factors can, if needed, be edited afterwards based on more detailed information. For example, if the site is placed in a coastal area, it would often be more accurate to give coastal Wind Statistics a higher weighting, even if closer inland statistics are available.

The use of several Wind Statistics in the same calculation can reduce the uncertainty factor (see also Chapter 3.5 regarding the quality control of data).

For larger projects (>5 MW), it is, in most cases, recommended to establish local wind measurement masts. This pertains to all countries except Denmark and Germany, where the many existing turbines can provide detailed knowledge of the wind regime.

3.2.1.3 Method description – Roughness classification

Roughness classification can be performed in three different ways:

A. Roughness rose: Description from site for each separate sector (one or more different roughness classifications per sector)

B. Digitizing a roughness line map (Line Object

C. Export of roughness lines from land-use polygons. Land-use polygons can be digitized with the Area Object or imported into the Area Object from other information sources.

WindPRO makes it easy for the user regardless of which of the three methods is chosen. For method B, a Line Object must be used. For method C, an Area Object must be used. For more information on how to use these objects see Chapter 2, BASIS.

Proper classification of roughness is very important. This is illustrated below using method A, the roughness rose.

The terrain is divided into 8, 12 or more sectors depending on the available Wind Statistics. Most of the Wind Statistics available today are specified in 12 30-degree sectors with the following center angles:

    0 degrees: (345 degrees to 15 degrees) (N)
   30 degrees: (15 degrees to 45 degrees) (NNE)
   60 degrees: (45 degrees to 75 degrees) (ENE)
   90 degrees: (75 degrees to 105 degrees) (E)
   Etc.

The roughness of the terrain should be described in each sector for a distance of at least 10 km from the site. Depending upon the hub height and terrain conditions, a longer distance may be relevant. Whatever distance is chosen, it's recommended to use this distance in every sector of the terrain description. You can include up to 10 roughness changes in each sector in case the terrain changes its character with the distance from the WTG.
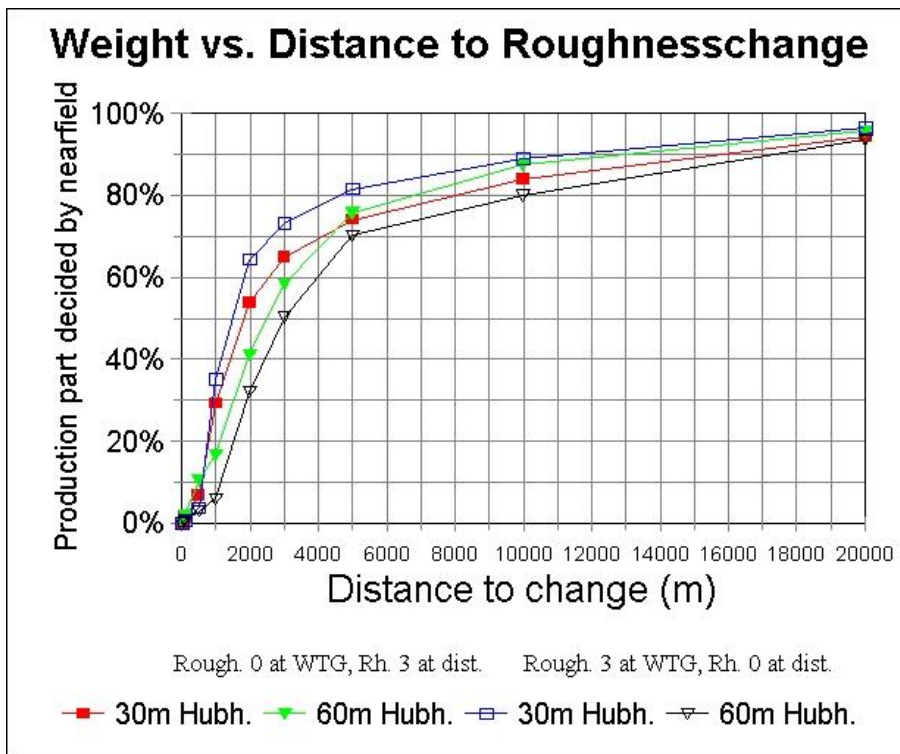

In the figure shown above, the impact of a roughness change at different distances from the WTG is illustrated. The figure illustrates, for example; that with an inner roughness class = 3, an outer roughness class = 0, and a change in 3000 meter distance; 72% of the production will be determined by the inner roughness class when the hub height is 30 m, while only 50% of the production will be determined by the inner roughness when the hub height is 60 m.

You can choose to use either roughness classes or roughness lengths (see next table).

Roughness class	Roughness length	Relative energy %	
0	0,0002	100	Water areas.
0,5	0,0024	73	Mixed Water and land area or very smooth land.
1	0,03	52	Open farmland with no crossing hedges and with scattered buildings. Only smooth hills.
1,5	0,055	45	Farmland with some buildings and crossing hedges of 8 m height and about 1250 m apart.
2	0,10	39	Farmland with some buildings and crossing hedges of 8 m height and 800 m apart.
2,5	0,20	31	Farmland with closed appearance and dense vegetation - crossing hedges of 8 m height and 250 m apart.
3	0,40	24	Villages, small towns, very closed farmland with many or heigh hedges, Forrest, many abrupt oro-graphic changes, etc.
3.5	0,80	18	Large towns, cities with extended build-up areas.
4	1,6	13	Large cities with build-up areas and high buildings.

Production vs. Roughness class
(based on Bonus 150kW, 30m hub)
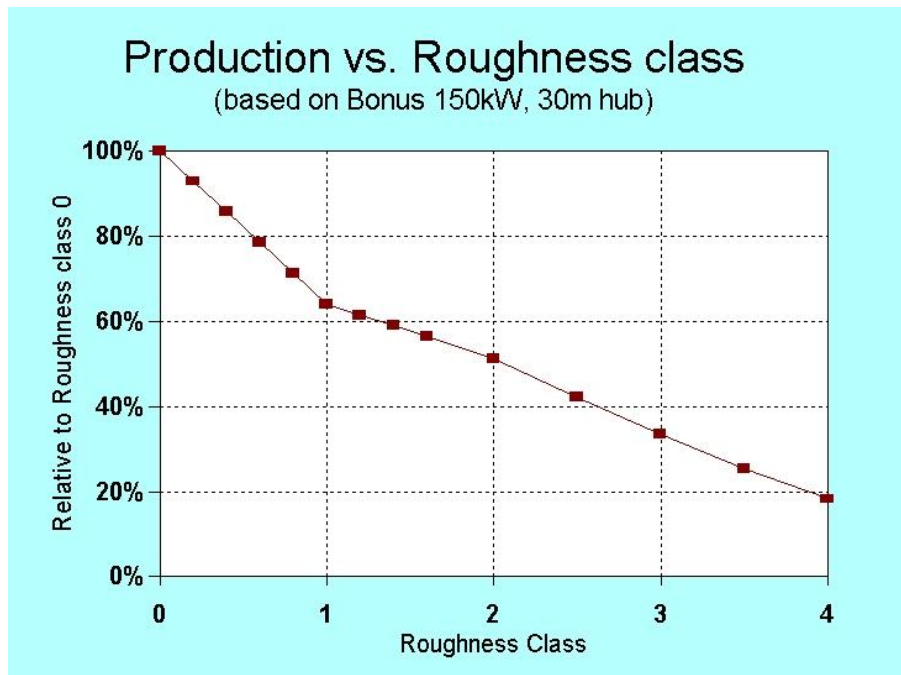
In areas with hedges, the graphs in the following figure can be used to estimate the roughness class or length. Notice the non-linear impact of the hedge height on the roughness class. Normal farmland is assumed to lie between the hedges. This is incorporated into the figure by adding 0.03 m to all specified roughness lengths. A porosity of 0.33 is assumed.

Farmland with windbreaks
Porosity: 0, 33 – Rough.class between: 1
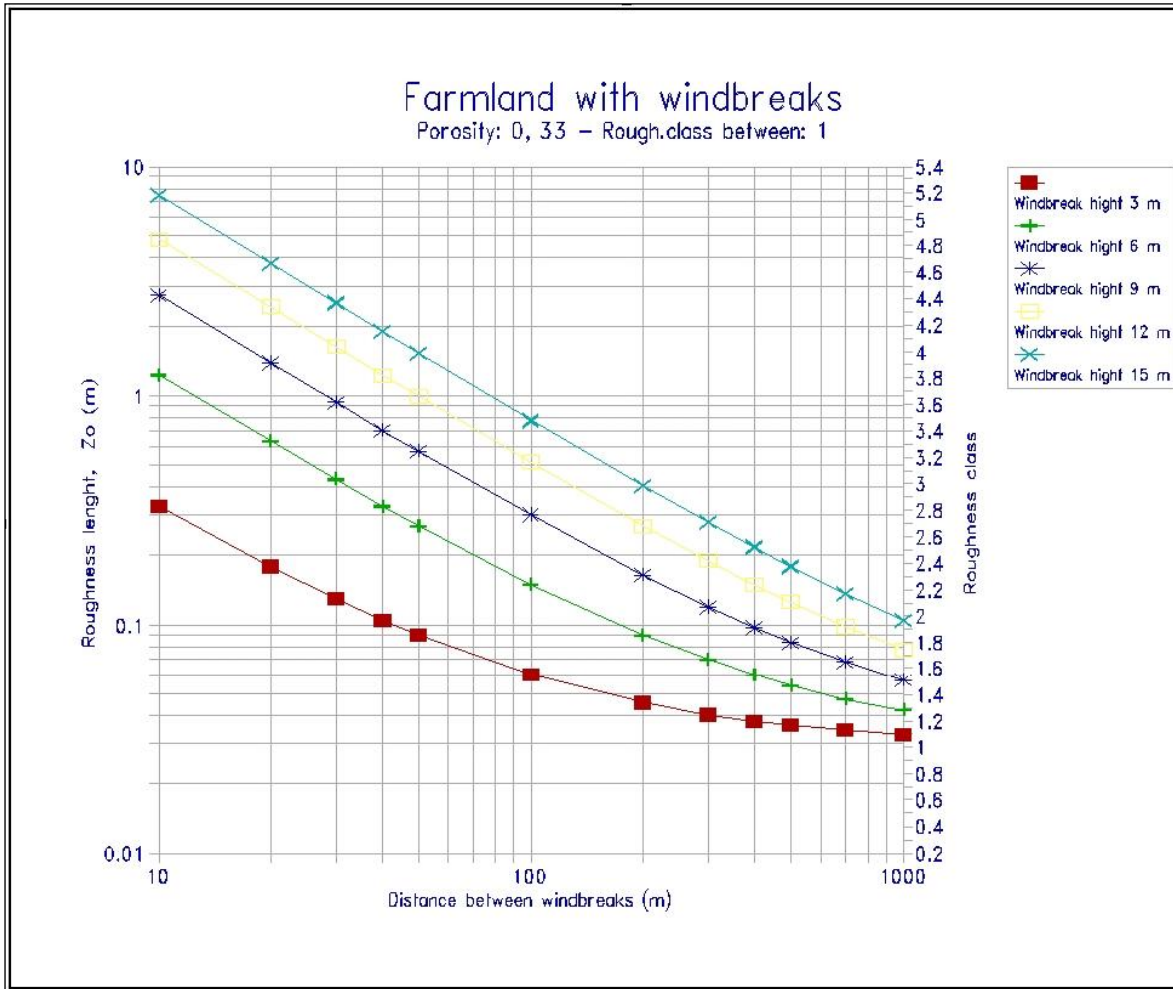
In an area with many buildings, the roughness length can be estimated by using the following equation:

$$z_0 = 0.5 * h^2 * b * n / A$$

Where:

        h = height of building
        b = width of building
        n = number of buildings
        A = total area within which the n buildings are situated

NOTE: The roughness length of the area between the buildings must be added to the roughness length which has been determined on the basis of the above equation, e.g. add 0.03 m to the calculated roughness length for normal farm land.

The correlation between roughness classes and roughness lengths is indicated in the next figure.
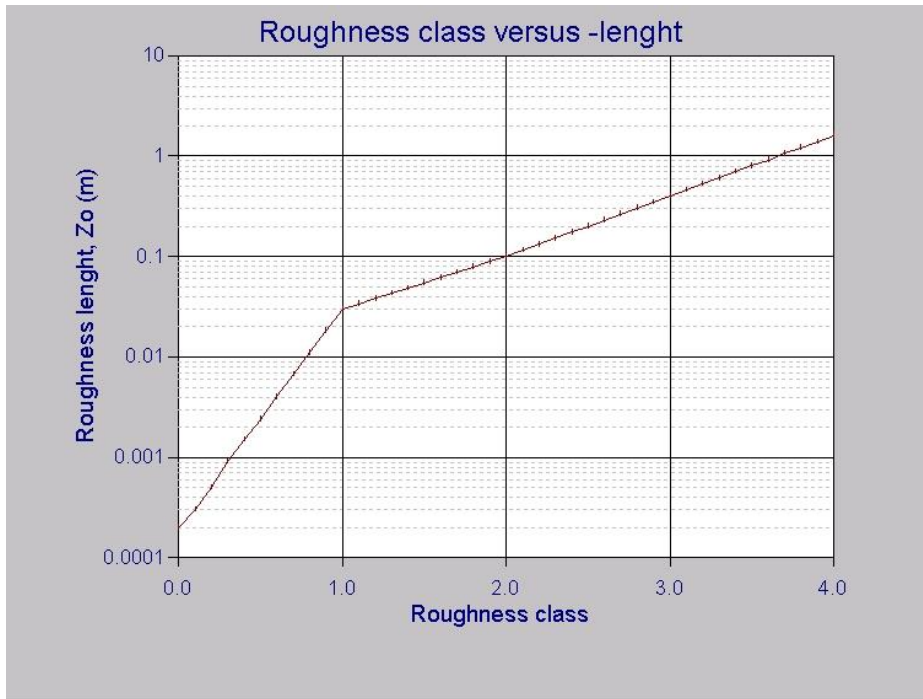
If a sector between two roughness changes consists of more than one roughness class, a simple weighting of the roughness classes in the area is recommended.

For example, if the area consists of 1/2 Roughness Class 2, 1/4 Roughness Class 1 and 1/4 Roughness Class 3, the resulting Roughness Class becomes: (2*2 + 1*1 + 1*3)/4 = 2.

It's important that a roughness classification covers an entire roughness area (belt), i.e. a roughness belt with a width 1000 m with one crossing hedge of 10 m heights should be assessed to the roughness class 2. It's often seen that such an area has been classified as roughness class 1 all the way to the hedge, with a shift to roughness class 3 for a few meters along the width of the hedge, and with a final roughness class of 1 just after the hedge. This is incorrect! The "European Wind Atlas" recommends doubling the width of every new roughness belt when moving outwards from the WTG.

Another important rule: Even if an area is located at a ground level which is lower than the turbine site, the roughness classification is not affected by this fact. *The differences in terrain heights are included in the hill model.*

In practice, it's important to visit the site and take preliminary notes regarding the roughness classes and the distances between the roughness changes. Furthermore, notes should be taken regarding local obstacles and their dimensions. Having completed the site visit, the exact distances between the roughness changes and the final design of the roughness classifications can be determined at your desk by using the map and the above-mentioned tools. However, much of the measuring work can be avoided by using digital background maps in WindPRO (see the description of this feature below).

It's important that you carry the map with you when you visit the site. It allows you to verify the map information and to evaluate the size and porosity of the local obstacles.

## 3.2.1.4 Method description – ATLAS Hills

By siting the WTG on the top of a hill you will usually be able to exploit the above-mentioned increase of the wind speed. During the visit to the site, it's necessary to judge whether or not the streamlines of the wind flow will be compressed at hub height and result in an increase of the wind speeds there. The same theory applies in a negative sense, if the WTG is placed on the leeward side of a hill. If the terrain is very complex, e.g. mountainous, an analysis using WAsP should be considered (see the description of this feature in the next chapter).

In the ATLAS model, a simple numerical calculation of the hill influence is carried out on the basis of information about the sector wise hill length (the length from the WTG to the hill base) and hill height. One set of data can be entered in each of the 12 sectors.
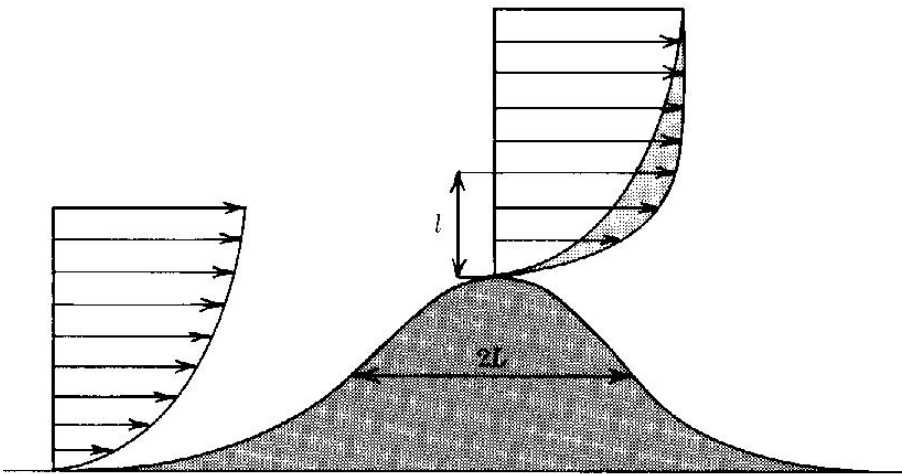
In the above figure you can see how hills usually increase the wind speed because of the compressed streamlines (the same amount of air per time unit passes through a reduced cross-section resulting in higher wind speeds).

Cliffs and other abrupt orography changes should not be included when using the hill model as there is no method available today which allows you to calculate the effects of such orography changes. Great precaution should be taken when siting WTGs close to cliffs or other abrupt orography changes.
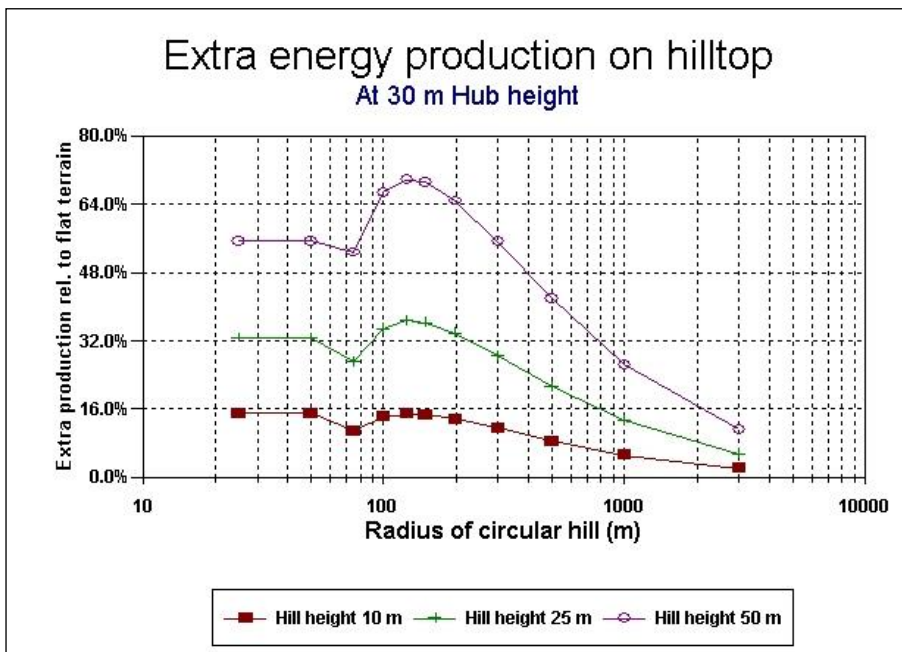
To illustrate the influence of siting a WTG on a hill, the above figure shows the production increase for a WTG situated on a hill with a circular base. Please notice that even for very small hill radius, the model changes so that it calculates the influence from the hill as if the hub height had been increased instead. If the mathematical model from "Vindatlas for Danmark" is used, the calculation would result in a negative change in the wind speed.
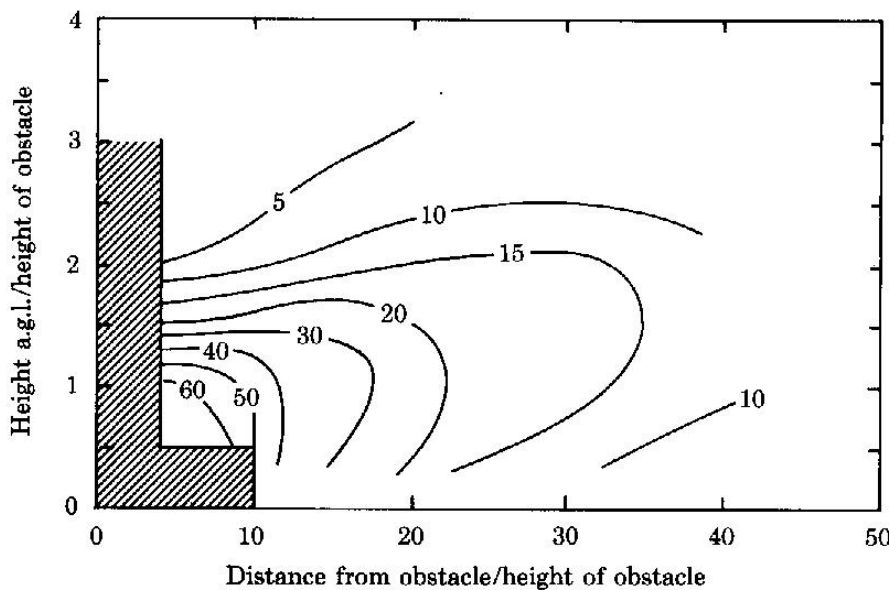
3.2.1.5 Method description – ATLAS Local Obstacles

Single obstacles, e.g. buildings, hedges etc. (of more than ¼ of the hub height) near the WTG (within approximately 1000 m of the turbines) should be treated as local obstacles and not as roughness elements.

An obstacle is measured by eye during the site visit and the accuracy of this measurement is purely based on the experience of the person. The exact distances are later on found by measuring the distances on the map.

If the obstacle is lower than ¼ of the hub height or farther than 1000 m away, it should not be included in the calculation as an obstacle as it will have little or no influence on the calculation result. However, it must be included as a roughness element in the roughness classification.

In addition to the dimensions of the obstacle, its porosity must also be estimated.

The following figure shows how the program handles obstacles.

3.2.1.6 Method description – WAsP Orography and Local Obstacles

The WAsP program from RISØ can be used as the calculation model from WindPRO's WAsP Interface module. With this method, the effects of hills and local obstacles are calculated by means of a flow model. This requires a much more detailed description than the less detailed ATLAS model. Hills are described through digital height contour maps. Local obstacles are described as rectangular boxes. Any number of local obstacles can be freely distributed in the same sector, and both the rotation and the depth of the local obstacle can be specified (see the WAsP user's manual for further details).

3.2.1.7 Method description – RESOURCE

The RESOURCE module is basically a series of WAsP calculations performed automatically for a grid. The advantage of using the RESOURCE module in WindPRO relative to using only the WAsP software alone is that WindPRO allows you to include local obstacles and to use additional Wind Statistics in the same calculation. This allows the wind climate to be changed smoothly from one part of the calculated grid to another.

3.2.2 Method description – Weibull and Measure

When calculating with the METEO module, two different options (Weibull and Measure) are available. The difference is that when choosing the Measure option, the raw measured table values in the Meteo Object are used instead of the Weibull data (normally this is the best Weibull-fit of the METEO table values).

If measured data for a representative period (see Section 1.1) is available for the actual site, the energy production can be calculated by simply integrating the bin-separated products of the wind speed distribution and the power curve.

Please notice that the program will automatically convert measurements, which have been made at a height other than the hub height, into hub-height data based on the user-entered wind gradient exponent by means of the following equation:

$$v_{new} = v_{old}(\frac{h_{new}}{h_{old}})^{\gamma}$$

Where:

γ = the wind gradient exponent (shear)
h = the height

Conversions over major height differences (more than 20-30%) are associated with large uncertainties.

The following general guidelines can be used if the wind gradient is not known. These guidelines are based on data from "Vindatlas for Danmark", and are not necessarily applicable worldwide (in complex terrain or even simple hills). You should not rely on these guidelines for any conversions other than marginal height differences.

Roughness Class	Roughness Length	Wind Gradient Exponent
0	0.0002	0.1
1	0.03	0.15
2	0.1	0.2
3	0.4	0.3

Shear (avg), for Beldringe			
	Class 0	Class 1	Class 2	Class 3
10-25 m	0,10	0,19	0,22	0,30
25-50m	0,10	0,20	0,22	0,26
50-100m	**0,11**	**0,23**	**0,24**	**0,26**
100-200m	0,12	0,28	0,27	0,27

The table to the left based on "old approach", working at lower hub heights, where the more detailed table to the right shows that the values when working in larger hub heights do change some. The table to the right is basically the WAsP approach, where the shear values are a combination of terrain given shear and stability correction model.

If only one set of Weibull parameters are available, an average wind gradient exponent should be specified. For example, you could use a weighting based on the distribution of wind directions.

When wind data are available in the form of frequencies that have been sorted into wind speed intervals (a histogram), you can use the data directly or you can use a Weibull curve fit of the data. The latter choice is usually recommended, since the curve-fitting procedure will filter the measured data and the effect of outliers is reduced or eliminated. The Weibull fit follows the procedure specified in the "European Wind Atlas", where low wind speed frequencies are weighted with lower values than wind speed frequencies within the normal operation range of the WTGs.

3.2.3 Model description – PARK (Wake loss calculations)

The PARK module calculates the wake losses due to the shadowing effects between WTGs sited close to each other (wind farms or clusters). PARK offers three different models for calculating wake losses. All are discussed in the appendix on wake and turbulence models. The standard method recommended by EMD follows the model that was created by N.O.Jensen from RISØ, but with small modifications that enables one to work with different WTG types and Hub Heights in the same layout.

The basic equation for calculating the wake loss behind a rotor is:

$$v = u[1-\frac{2}{3}(\frac{R}{R+\alpha x})^2]$$

Where:

      v = the wind speed at a distance **x** behind of the rotor
      u = the free wind speed just upstream from the rotor
      R = the rotor radius
      α = the wake decay constant.

2/3 is an approximation of the Ct value. In calculation model, the actual Ct value is used for each wind speed interval.

The figure below shows the basic idea behind the simplified wake model for wake losses behind a turbine. The wake decay constant is a measure of the down-stream widening of the "shadow cone" behind the wind turbines. The constant is specified as widening in meters per meter downstream of the rotor. A constant of 0.075 m, corresponding to an opening angle of approximately 4 degrees is usually recommended.
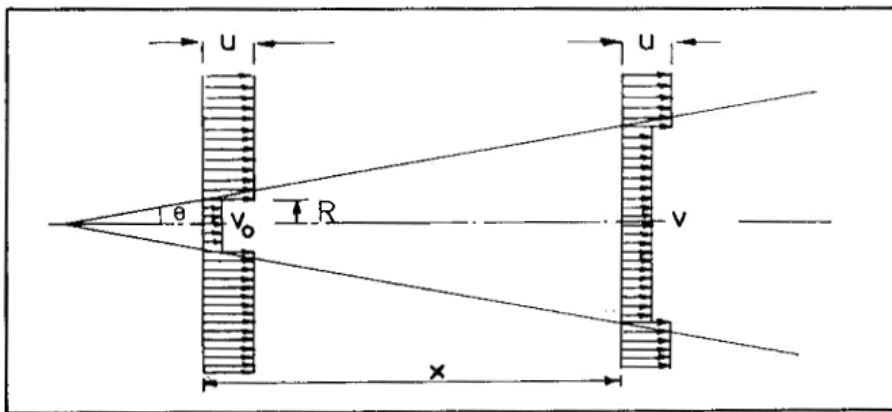
Measurements by RISØ on different wind farms indicate that the wake decay constant depends on the turbulence and therefore on the roughness class, varying from 0.04 for a roughness class of 0, to 0.1 for a roughness class of 3. The use of the default value of 0.075 for all calculations on land is judged to have only marginal impact on the results. For offshore applications, a value of 0.04 should always be used.

NOTE: For very large wind farms (more than 5 rows of WTGs, perpendicular to main wind direction), recent measurements indicate that the wake model used in PARK may not predict the array losses accurately. The wind farm itself changes the roughness, and the free wind speed inside a large wind farm might not follow the assumptions in the N. O. Jensen wake model. This knowledge might lead to an improved PARK module in the near future. A way to account for this in the current version is to increase the roughness inside the wind farm area, e.g. for an offshore wind farm, to a roughness class of 1.5 (a roughness length of 0.055 m).

As of version 2.5, the PARK module is able to perform calculations based on additional wake models as well as wake-induced turbulence. For more information on these features, please refer to the appendix on wake and turbulence models.

3.2.3.1 More than one wind data set in a wind farm calculation

When carrying out a PARK calculation, one must always judge whether one overall wind speed distribution represents the site conditions correctly, or if several terrain descriptions or measured sets of data are needed for an accurate calculation of the entire park layout. No guidelines can be specified, as the choice will depend on the complexity of the terrain, the size of the wind farm, and the accuracy required. If more than one set of data are specified, PARK will always use the data set closest to the individual WTG in the calculation.

Another way to get an individually calculated wind distribution for each WTG in a wind farm is by using a link to digitized roughness and height contour lines.

3.2.4 Generating a Wind Atlas (a set of Wind Statistics)

If measured wind data is available for the site or for the region in question you can choose to generate a regional Wind Atlas that can be used for both ATLAS and WAsP calculations as described in Section 3.2.1.2 The maximum distance where the wind statistics can be used is approximately 100 km from the measurement site depending on the complexity of the terrain – and possible meso scale wind variations (e.g. costal regions). If the wind climate or the meso scale wind varies in the region, the distance where a regional wind statistics can be used from the measurement point can be below 1 km. To generate a wind statistics requires the WAsP program, and that you are familiar with processing wind data. The METEO module and MODEL module provide automatic access to the STATGEN module for generating Wind Statistics. But the "natural place" for generating wind statistics is the MCP/Statgen module, where the basis is the long term corrected wind data, as it should be. The detailed information on the data used for generating a Wind statistics by WindPRO will be saved in the wind statistics file and can be printed as part of the energy calculation reports.

In addition to generating Wind Atlases, WindPRO can also import Wind Atlases that have been generated in WAsP (.lib files; see the WAsP manual for further information).

3.2.5 WAsP model – focus on changes from WAsP 10.0

The WAsP model itself will not be explained here (see Risø/DTU manual), only the changes of high importance for the user in the more recent model versions. From the very first versions until and including ver. 9, the model itself only has changed marginally, and the calculation results thereby so. The major improvements during the WAsP model versions are capability to handle more map file points. But from version 10.0, model modifications are seen. These mainly relates to stability correction handling, and especially offshore and near shore. But also roughness map interpretation. The corrections were partly included in ver. 10.0, but first fully implemented in ver. 10.1 - 10.2. We therefore do **not** recommend using ver. 10.0 in offshore or coastal regions. The corrections relate to as well the default heat flux parameters, the way roughness in coastal zone is interpreted, as formula modifications. The result of the corrections is a more smooth change between on shore and offshore stability correction. But it is also a some different wind statistic for the offshore part, if it is generated from WAsP 9 or 10.2.
This mean that an offshore or near shore wind statistic made from WAsP 9 SHOULD NOT be used from WAsP 10.2 or the other way round.

This can best be illustrated by an example: 4 wind statistics are generated from same time series data:

Mean wind speed [m/s]

Height	Roughness class/Length			
	0	1	2	3
[m]	0,00 m	0,03 m	0,10 m	0,40 m
10,0	7,4	5,2	4,5	3,6
25,0	8,1	6,2	5,6	4,7
50,0	8,7	7,1	6,5	5,6
100,0	9,4	8,4	7,7	6,7
200,0	10,3	10,3	9,4	8,2

Mean wind speed [m/s]

Height	Roughness class/Length			
	0	1	2	3
[m]	0,00 m	0,03 m	0,10 m	0,40 m
10,0	9,0	6,4	5,6	4,4
25,0	9,8	7,5	6,8	5,7
50,0	10,5	8,6	7,8	6,8
100,0	11,3	9,8	9,1	8,1
200,0	12,2	11,7	10,8	9,5

Mean wind speed [m/s]

Height	Roughness class/Length				
	0	1	2	3	4
[m]	0,00 m	0,03 m	0,10 m	0,40 m	1,50 m
10,0	7,4	5,4	4,7	3,7	2,5
25,0	8,1	6,4	5,8	4,8	3,7
50,0	8,7	7,4	6,7	5,8	4,7
100,0	9,4	8,6	7,9	7,0	5,9
200,0	10,2	10,3	9,5	8,5	7,3

Mean wind speed [m/s]

| Height	Roughness class/Length				
	0	1	2	3	4
[m]	0,00 m	0,03 m	0,10 m	0,40 m	1,50 m
10,0	8,7	6,4	5,6	4,4	2,9
25,0	9,5	7,5	6,8	5,7	4,4
50,0	10,2	8,6	7,8	6,8	5,6
100,0	10,9	9,8	9,1	8,1	6,8
200,0	11,8	11,5	10,7	9,6	8,3

Upper WAsP 9, lower WAsP 10.2
Left roughness class 0 based site, right, class 1 based site.

In the left part, the offshore site, the class 0 data are almost the same with the two WAsP versions. The highest level, 200m although slightly lower with WAsP 10.2 – a part of the formula modification. BUT, for the onshore classes, the wind speeds are essentially higher, round 0.2 m/s. **This mean that a WAsP 10.2 calculation could calculate up to round 10% higher AEP then WAsP 9 at an onshore site, if the data basis were offshore.**

In the right part, the onshore site, the onshore class data 1, 2 and 3 are almost identical from the two versions, again 200m slightly lower with WAsP 10.2 – a part of the formula modification. BUT the class 0 data is round 0.3 m/s lower when calculated with 10.2. **This mean that a WAsP 10.2 calculation would calculate up to round 10% lower AEP at an offshore site, if the data basis were onshore.**

The changes are of cause not serious, as long data just is used where they belong. But it shall be noticed that in the coastal region, where there partly are water and partly land, quite unpredictable changes can be seen and here it will especially be important to use same WAsP version for generation of wind statistic and later use.

From the tables are also seen that with large hub heights, >100m, WAsP 10.2 calculates slightly lower wind speeds than WAsP 9 – this is so both on and offshore and a result of a general modification of the stability correction model. Based on good test data offshore from tall mast this correction seems to give a better reproduction of the measurements.
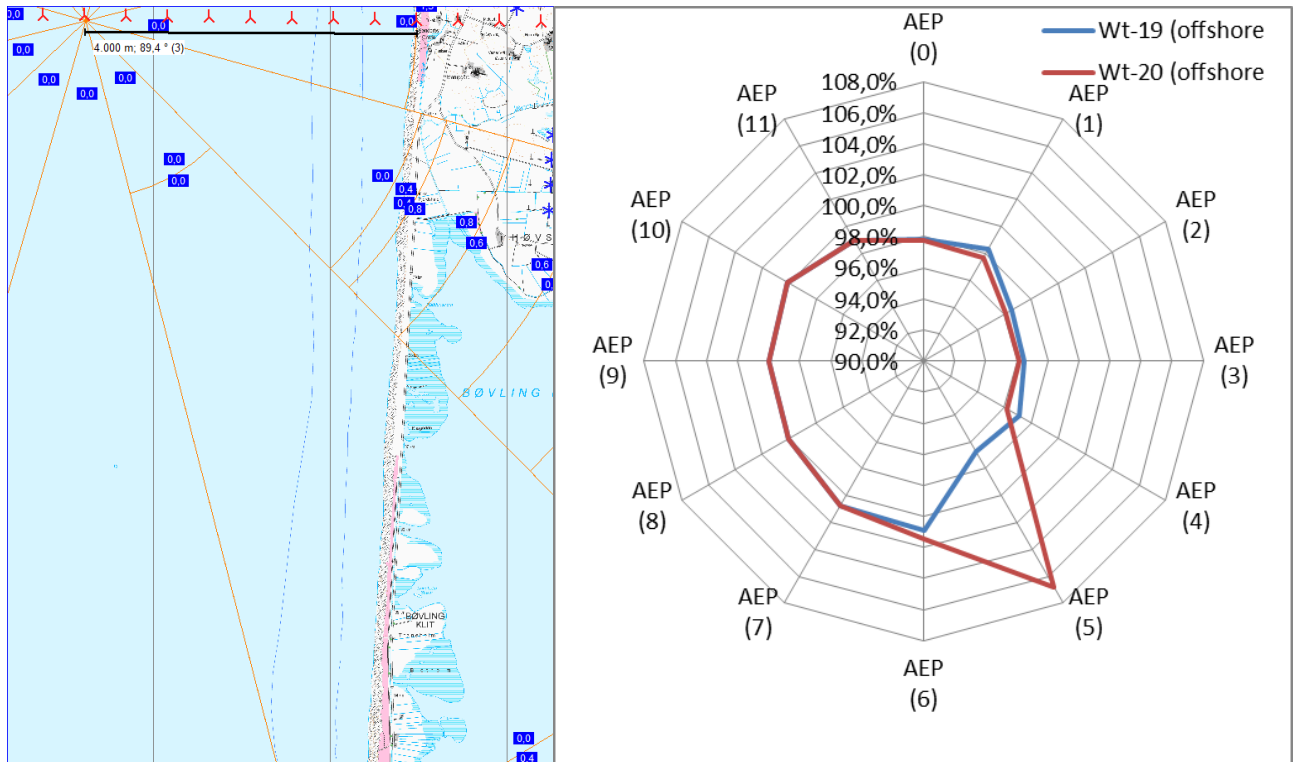
The example above illustrates the improvement regarding smoothing stability model shift. Two turbines just 200m apart, both round 4 km offshore are calculated. In sector 5, there is a roughness change from class 0 to class 0.4 in 10 km distance. The graphs show the ratio of the calculated AEP between WAsP9/WAsP10.2. Looking at the rose, it is seen that in sector 5 it is very different what happen for the two turbines. This is where the distance to roughness change in sector 5 is just around 10 km, a change from 0 to a higher class decides that W9 shall change between on and offshore stability in that direction. The parameter: "Width of coastal zone" decides this – can be changed but is default 10 km. It's an obvious inconsistence, which is in WAsP 9, but not in WAsP 10.2. But the graph also show how the calculation results are smaller in general with WAsP 9, when the wind come from land, while the 9 and 10.2 results are the same when wind comes from the open sea.

Høvsøre - W sector

Høvsøre - E sector

- ◆ W9
- ✕ Wasp 10.2
- ▲ Measured
- ▲ Measured-scaled from OMS mast
- ■ Measured - OMS mast
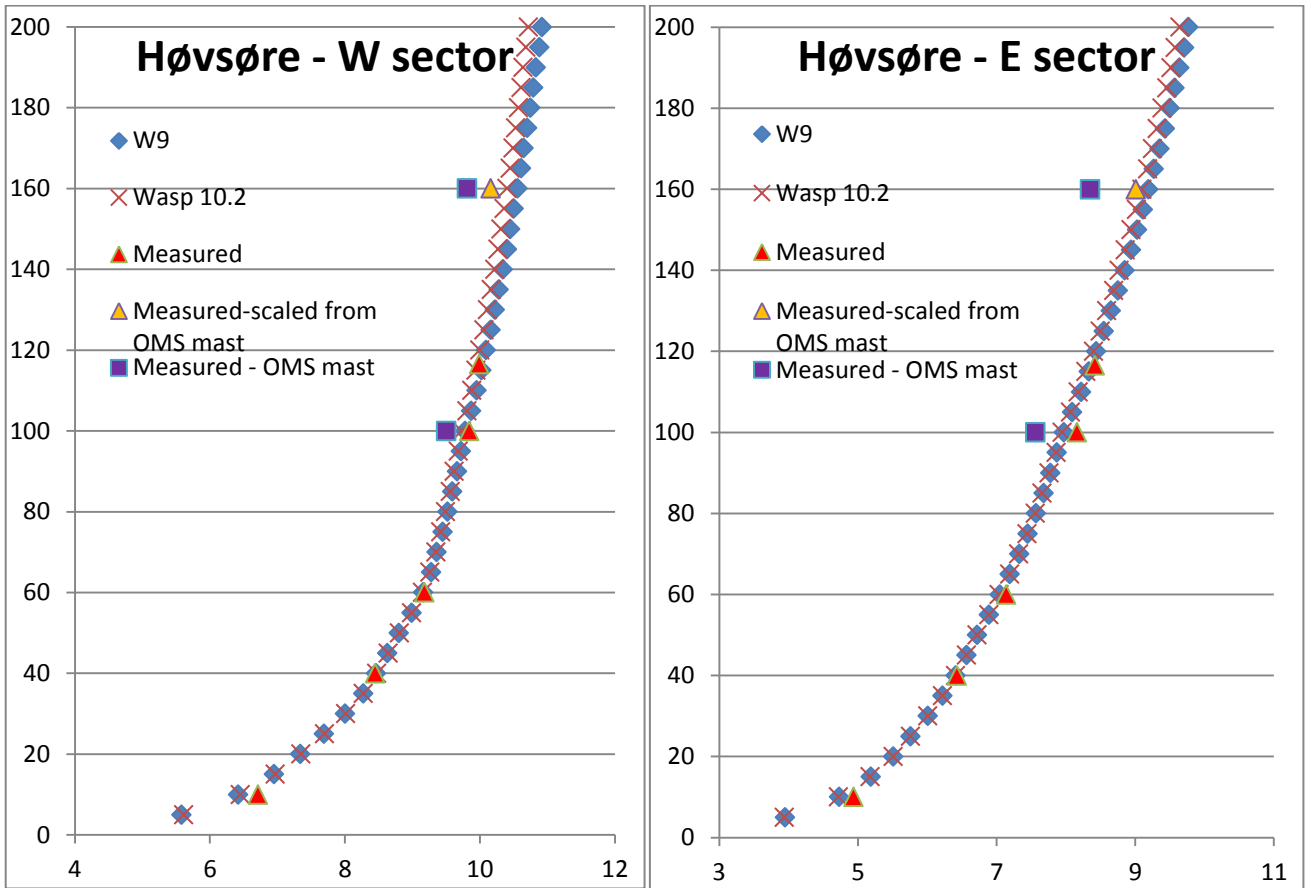
A test on reproducing measured profiles in large heights is shown above. It is seen that WAsP 10.2 does predict the vertical profile slightly better than W9. (Here WAsP 10.1i is the same as WASP 10.2).

Finally we will report tests of calculation in coastal region with different hub heights. The calculation setup:
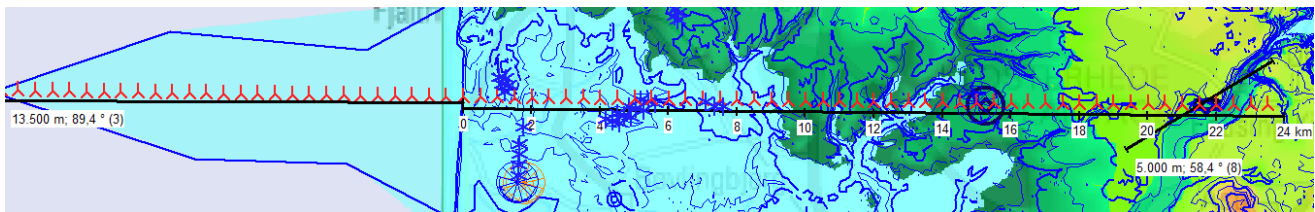
Map with the orography in focus – elevation is seen below.

Elevation for the 75 test turbine pos.
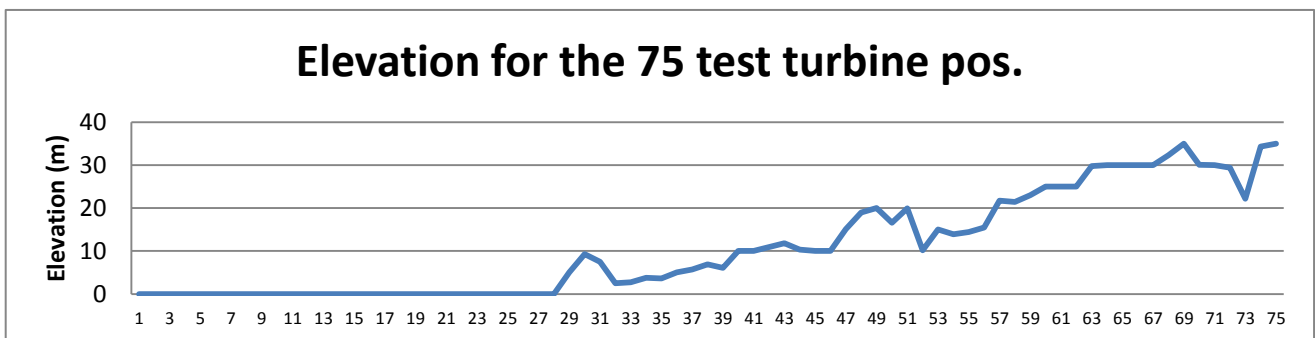
Based on met mast 1800m from west coast, a row of turbines are calculated based on the two different WAsP versions, where the wind statistics are generated with same version as in calculation. The turbine row starts 13,5 km offshore and ends 23.5 km onshore.
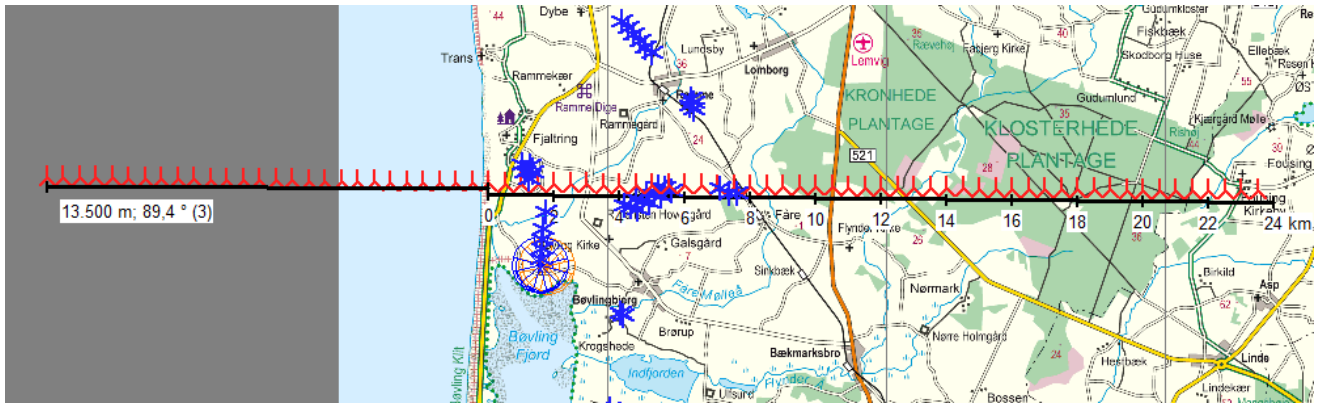
The map gives an idea of the surface roughness around the test row. The row crosses a large forest area along the onshore part.
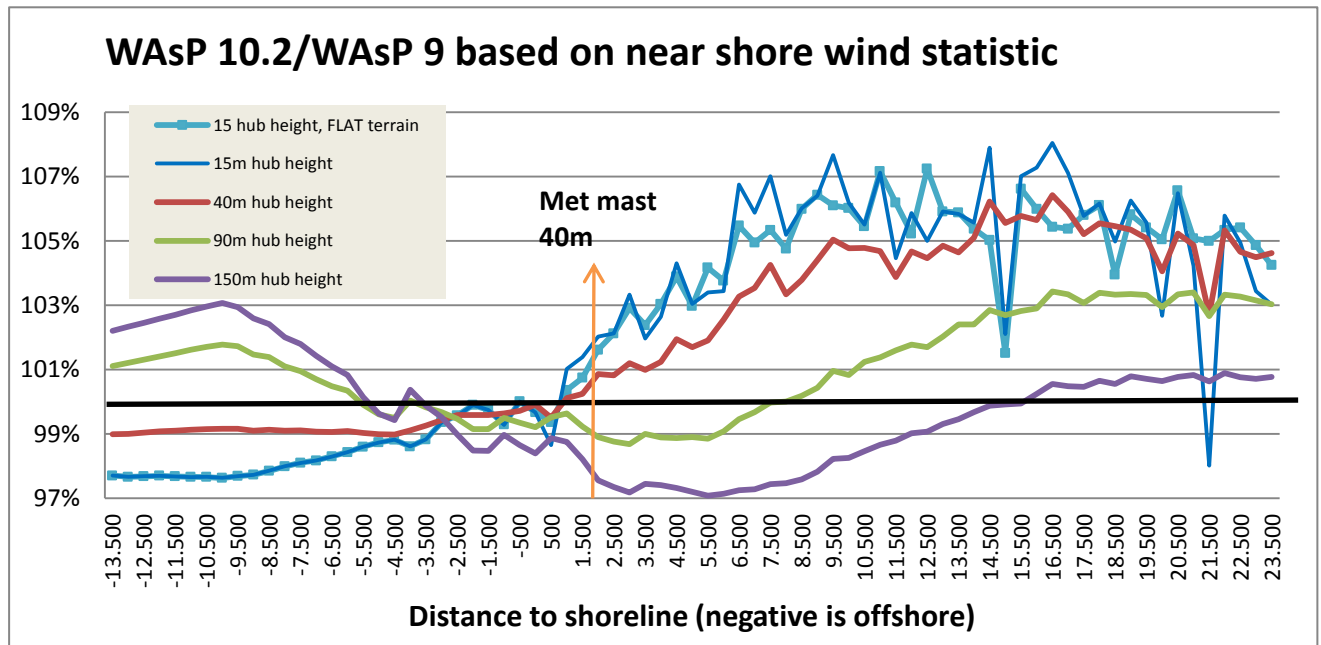
For 15 m hub height there is two variants, one calculated without orography, one with. For all other heights orography is included, and for all calculations digital roughness maps are included.

It is seen that there are quite some differences in the WAsP 10.2 and WAsP 9 results, but not that easy to describe in a clear conclusion. Starting with the 150m hub height, WAsP 10.2 results are round 1% lower first 3 km offshore, but then getting up to 3% higher at round 10 km offshore. Onshore the results are lower the first 15 km, up to 3%, but get then slightly higher. A "reversed" pattern is seen for very low hub heights, but with up to 8% higher results onshore. Two dramatic peaks are seen. These have been investigated further. The leftmost peak is due to differences in roughness interpretation in the two models, the rightmost is due to different orography modeling.

Concluding on WAsP 10.2 vs WAsP 9. There are obvious improvements, and especially offshore as in coastal regions we recommend using WAsP 10.2, due to better reproduction of the measured shear. For fully onshore sites (when measurements also are fully on shore) there seem only to be differences when hub heights are > 100m. But if measurements are in coastal regions, the changes in calculation results can be quite large. We cannot yet say based on actual turbines if the one or the other model performs better. But the most important conclusion is: **Do not use different WAsP versions in future in coastal regions to generate and use wind statistics! By this follow for DK especially: Do not use WAsP 10.2 (or higher) together with Wind statistic DENMARK'07 in costal regions!**

3.3 ENERGY – Input data for AEP calculations

3.3.0 Introduction to data input for AEP calculations

In this section, the procedures for entering the necessary information for performing AEP calculations in WindPRO are described (see also step-by-step guide, Section 3.0.2).

Please, refer first to the WindPRO BASIS description on how to create the basic project before entering the specific data for energy calculations.

The objects which can be entered specifically for AEP calculations are listed below:

Site Data Object – "the basket" that holds all information on the terrain data and wind statistics to be used in a MODEL or PARK calculation. Also used for STATGEN (generating of wind statistic), where only terrain data then is specified.

Meteo Object – measured wind data as Time series, Tables and/or Weibull distributions.

A Wind Statistics (Wind Atlas or .lib file) can be generated when you have both a Site Data Object (purpose STATGEN) and a Meteo Object along with WAsP.

A PARK calculation (array loss calculation) can be performed based on a Site Data Object, a Meteo Object, or a wind resource file (.rsf file).

WAsP Local Obstacles - NOTE: This object has no effect in an ATLAS Calculation.

The other relevant objects (described in Chapter 2, BASIS) are:

New WTG

Existing WTG

Line Object (for height contour lines and roughness lines)

Elevation grid Object (for elevation data, can be used as alternative to line object)

Area Object (for polygon roughness)

3.3.1 Input for MODEL calculations

Using a model to extrapolate the wind data from one position (measurement mast) to the planned turbine position(s) is the most common way to calculate the wind speed distribution at the turbine. The most common model for this is the WAsP model. After the WAsP model has calculated the wind speed distribution at each turbine, a wake loss model (PARK model) is used to find the reduction in wind speed distributions at each turbine (if more turbines). Finally, the wind speed distributions and the power curves multiplied including air density correction for calculation the AEP. Other models than WAsP can be handled for extrapolation of the wind speed distribution. The "simplified" version of WAsP is the ATLAS model that is a "built in" model in

WindPRO. Finally, any model, like CFD, can be used, which requires this model deliver the extrapolation output as a wind resource map (.rsf or .wrg file).

In case a wind resource map is being used for input, no further terrain or wind data input is required, go directly to chapter 3.6. (Although you should include elevation data for helping giving the right air density correction).

3.3.1.1 Siting and Setting Up Site Data Objects

A Site Data Object can be created by:
- Selecting the object from the toolbar
- Positioning it on the map at the location of the terrain assessment
- With a mouse-click, it is established and the input form appears

Normally, the Site Data Object will be located in the middle of the wind farm. But, please read the following carefully:

If a roughness rose is used as the roughness description method, all WTGs in a wind farm will be calculated with the exact same roughness description. To compensate for this, you can add additional Site Data Objects and thereby specify different roughness roses.

Each WTG in the wind farm will then use the nearest roughness description. The same applies to obstacles and hills when the simple ATLAS model is used.

If you use roughness lines or areas (only when using WAsP), all WTGs in a wind farm will be assigned a unique roughness description. (For more detail on roughness lines, see Section 3.6.1.1, Digitized Roughness Map. For more details on roughness areas, see Section 2.9.4, Area objects).

When using height contour lines (only when using WAsP), the energy production for each WTG in a wind farm is calculated individually with respect to orography.

Once the Site Data Object has been created, a window appears as shown below, where the use for the object is defined.

For more information about coordinates, description, labels, layers etc., see Section 2.5 in BASIS.

NOTE: The Z-coordinate of site data object has no influence on the calculations.

If WAsP is installed and linked to WindPRO, you can choose to use the Site Data Object in the ATLAS module or in the WAsP module exclusively, or in both modules. In the latter case, you have to select which to use when setting up the calculation. Another option is to use the site data object to generate a Wind Statistic (see Section 3.3.4) or to calculate a wind resource map (see Section 3.6).

The selection of the above purposes determines which data you can enter on the following tab sheets. ATLAS and WAsP have a simple and a detailed terrain description of the hill and local obstacles conditions respectively. STATGEN and RESGEN can only work with the more detailed WAsP data formats.

Depending of the use, the object will change color on the map. The different colors are:
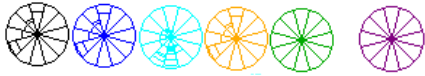
Black – for Atlas
Blue – for WAsP
Cyan – for both Atlas and WAsP
Orange – for STATGEN
Green – for RESGEN
Purple – For WAsP-CFD

3.3.1.2 Tab sheet Wind Statistics (Wind Atlas) in Site Data Object
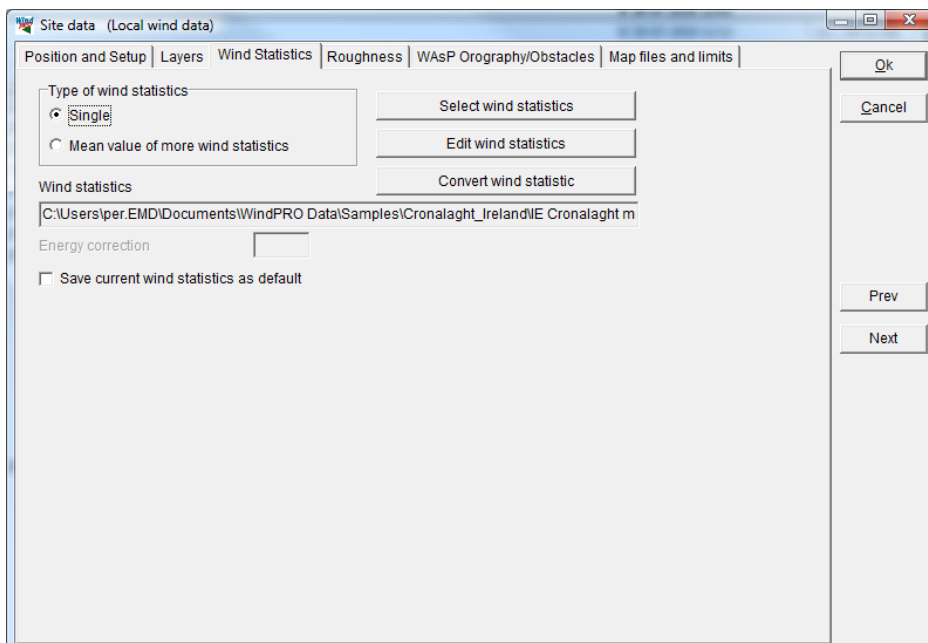
Regarding "Convert wind statistic", see chapter 3.4.5 - Wind index correction level conversion to wind speed

The "Edit wind statistics" button leads to a maintenance window, where, for example,.lib files can be imported and assigned coordinates, so that that they will appear on the map shown in the selection window.

Selecting wind statistics

One (select "Single") or more (select "Mean..") Wind Statistics can be selected for the same calculation.
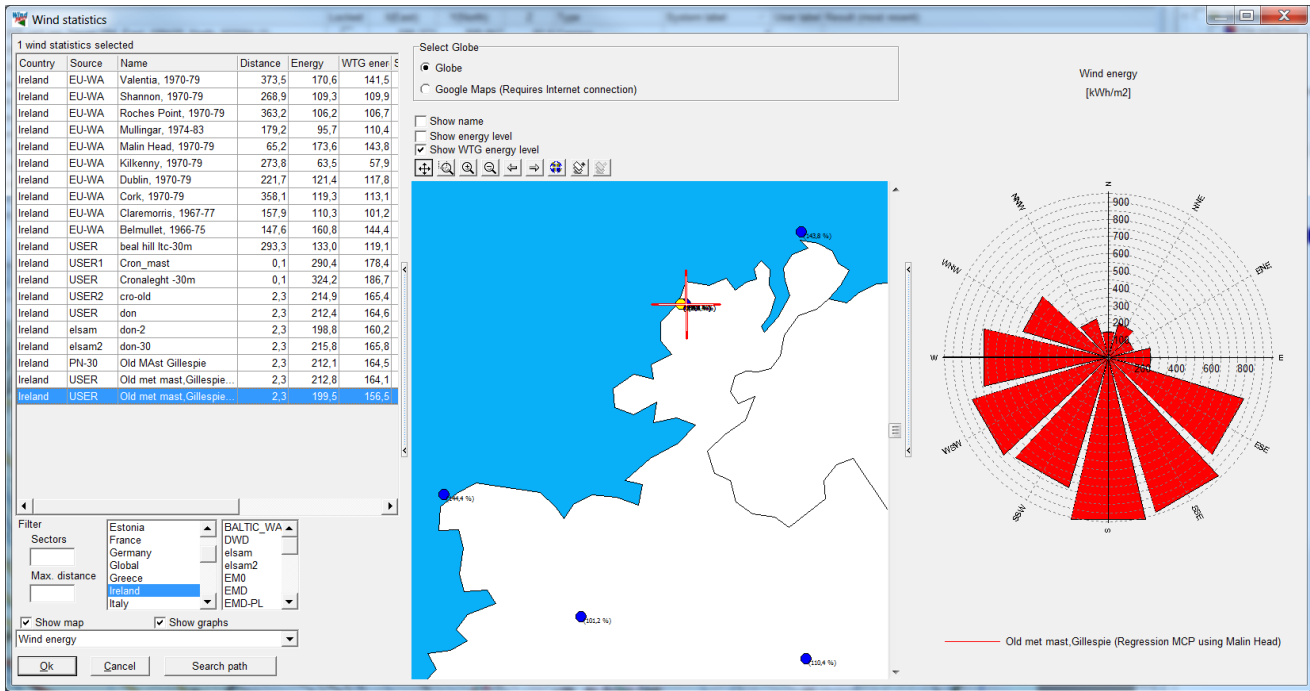
When "Select wind statistics" is chosen, there are several optional search filters available. If no country or source has been marked, then all Wind Statistics will be shown. You can also click on additional countries, sources etc.

NOTE: For calculations in Denmark the "Danmark '07" Wind Atlas should always be selected due to its special status. Regional correction curves have been linked to the Wind Atlas based on comprehensive investigations of a large number of Danish WTGs. Therefore, this Wind Atlas is judged to be significantly more accurate than other available Wind Atlases for Denmark.

NOTE: One of the most important things in an energy calculation is to evaluate the energy level of the Wind Statistic. There are so many possibilities for mistakes that a final evaluation of the energy level by comparison with the level for other Wind Statistics in the region may be a good way to discover fatal mistakes. From the Wind Statistics selection window, both the absolute as well as the power-curve-filtered power curve level is shown as a percentage compared to the Beldringe Wind Statistics (in the middle of Denmark).
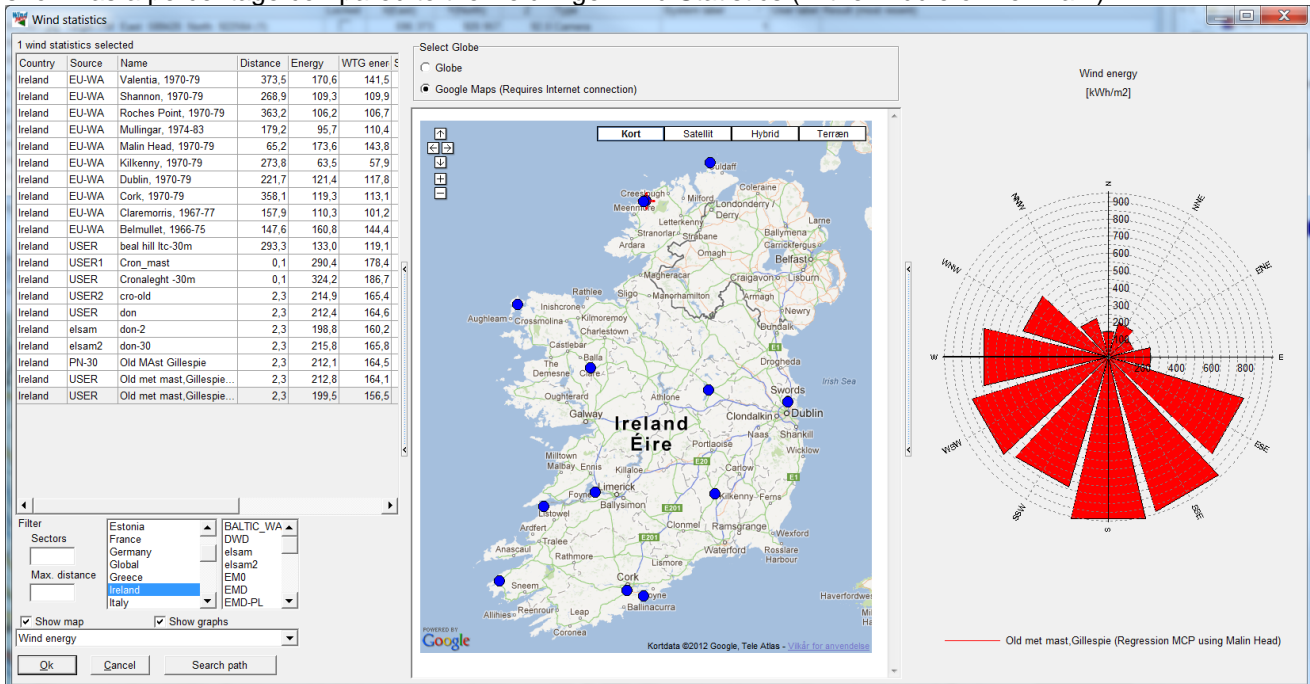
Also Google maps are available as background.

3.3.1.3 Tab sheet Roughness in Site Data Object
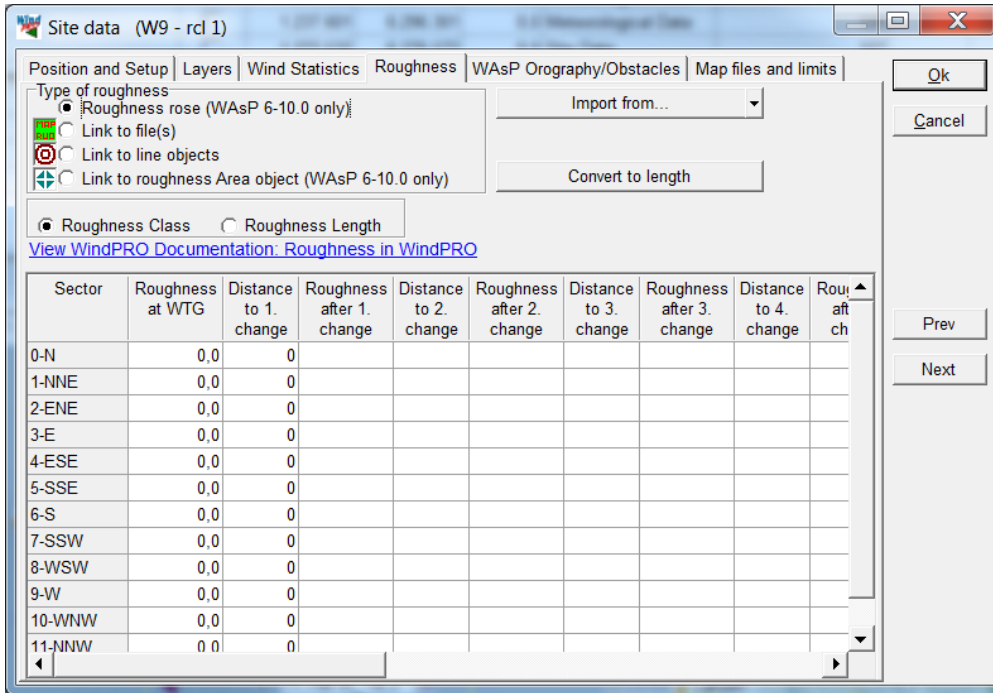
Note: From WAsP versions >10.0, roughness lines must be used. The reason is that the roughness file map is included in the way WAsP handles the stability correction calculation.

The roughness classification can be entered directly if you don't have a digital map or, if you've already received the roughness classification from another source.

The input tab sheet shows the input fields for the roughness classification i.e. enter the information for one sector at a time and shift to a new sector either by double-clicking or pressing the <Enter> key.

In addition, you can import and edit digital roughness maps (from a WAsP .map file) or read .rds files (WAsP roughness description) from previous WAsP calculations (see the explanation below).

One of the very powerful features in WindPRO is the ability to create and edit a roughness classification directly on the digital map.

Three other ways to define the roughness are:

Link to file(s) – define the roughness line file(s) in the tab sheet "Map files and limits".
Link to line objects – automatically use line objects in your project with roughness lines.
Link to area objects – automatically use area objects in your project with roughness areas.

Each of these three methods has the advantage that each WTG in a wind farm will get its own unique roughness classification. For more details on roughness lines, see Section 3.6.1.1, Digitized Roughness Map. For more details on roughness areas, see Section 2.9.4, Area objects.

NOTE: When changing between Roughness Class and Roughness Length, the values previously entered are not converted automatically. To convert Roughness Class values to Roughness Lengths, use the "Convert to length" button.

On screen roughness classification by roughness rose
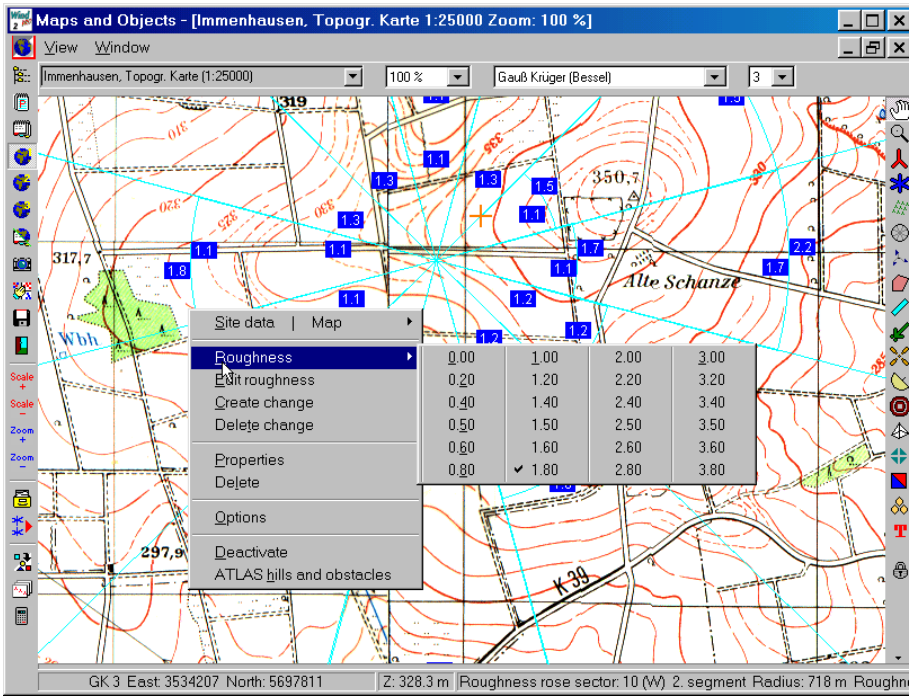
When the map has been rendered on the screen, you can drag the map around by moving the hand icon while holding down the left mouse button.

When the roughness rose is activated you gain access to the features listed below by clicking on the right mouse button:

- Roughness - the roughness class is selected from the table for the area where the cursor was placed at the time you right-clicked.
- Edit roughness - option for entering actual roughness classes.
- Create change - creates roughness changes in the area that was activated by the cursor at the time you right-clicked.
- Delete change - erases the roughness change closest to the cursor in the direction of the roughness rose center.
- Properties - activates the input window for the Terrain Data Object.
- Delete - erases the Site Data Object.
- Options - changes the setup for the size of the automatic roughness step size when they are moved.
- Deactivate/Activate - changes the status for the actual Terrain Data Object so that only its position is marked. This option is useful when entering other objects, including other Terrain Data Objects.
- ATLAS hills and obstacles - shifts the object status from input of roughness to input of hills and local obstacles (see the next section).

NOTE: The roughness-change lines can be dragged around by holding down the left mouse button when the cursor is positioned on a line.

3.3.1.4 Tab sheet ATLAS Hills/Obstacles in Site Data Object

Regarding the roughness classification, both hills and local obstacles can be entered either via the object list or directly on a digital background map. Please refer to the previous section for information on how to activate the graphic input menu.

For each sector you can create one hill and one local obstacle.
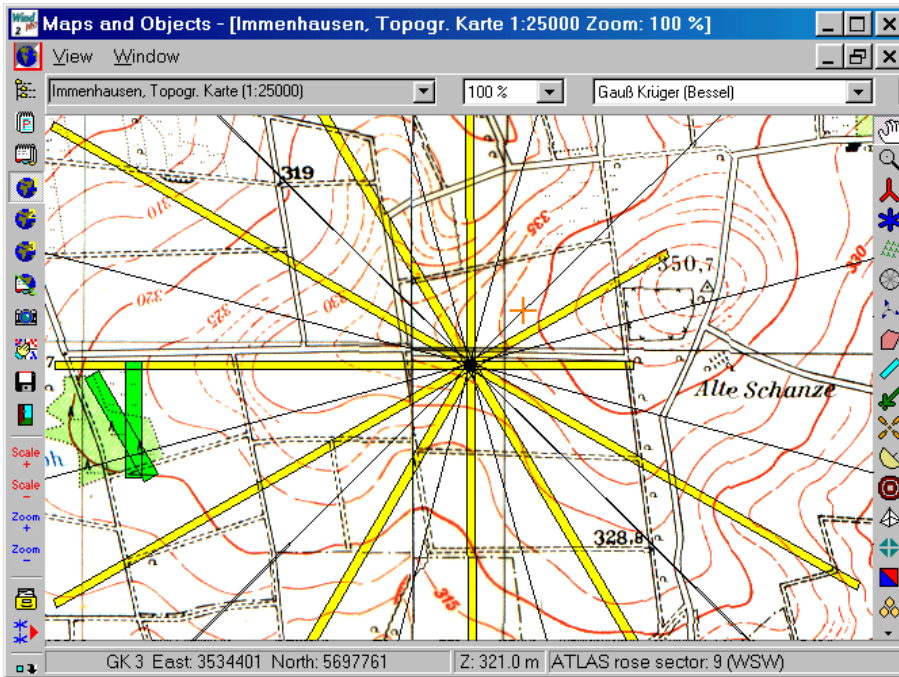
The program automatically calculates the distance from the center of the Site Data Object to the hill base or local obstacle and the obstacle width or width in the sector. The objects can be dragged to desired positions with the mouse when it's activated. The hill height (the distance from the base to the top) and the obstacle height and porosity must be entered in a table (select this option by right-clicking under "Properties").

NOTE: Entering the elevation of the hill base can also be used to enter the hill height. To use this method it's necessary to enter the Z-coordinate for the Terrain Data Object under the tab sheet "Position".

3.3.1.5 Tab sheet WAsP Orography/Obstacles
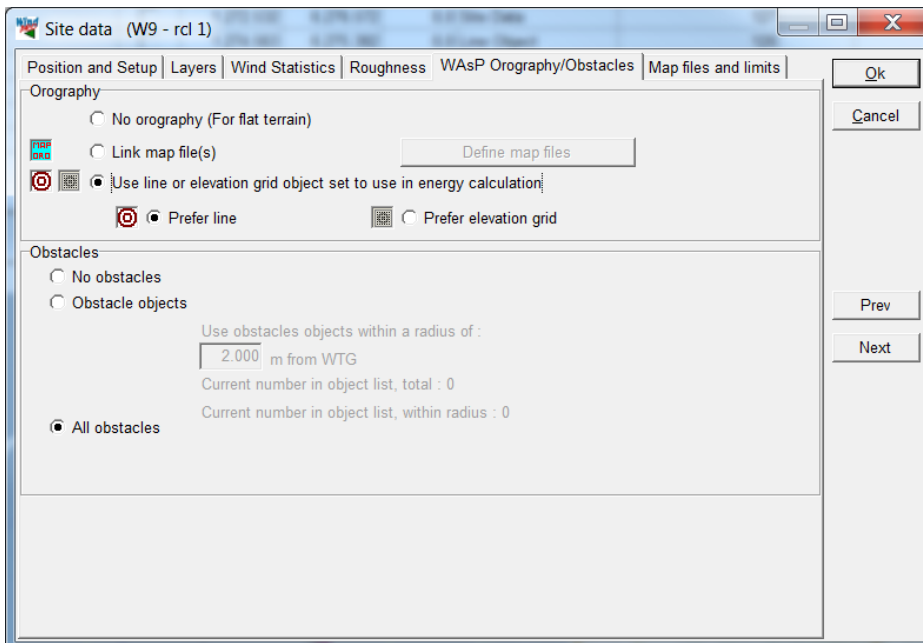
If WAsP is chosen as the calculation module, you can use digital maps with height contours (digital orography maps) and local obstacles in WAsP format.

Having both line and elevation grid data objects in the project (set for use in energy calculations), a choice must be made, which set to be preferred.

If you select "Use line or elevation grid objects", then one or more line or elevation grid objects marked "Use to link Site data in energy calculations" will be used automatically (see the check box in the bottom of line object properties shown below).
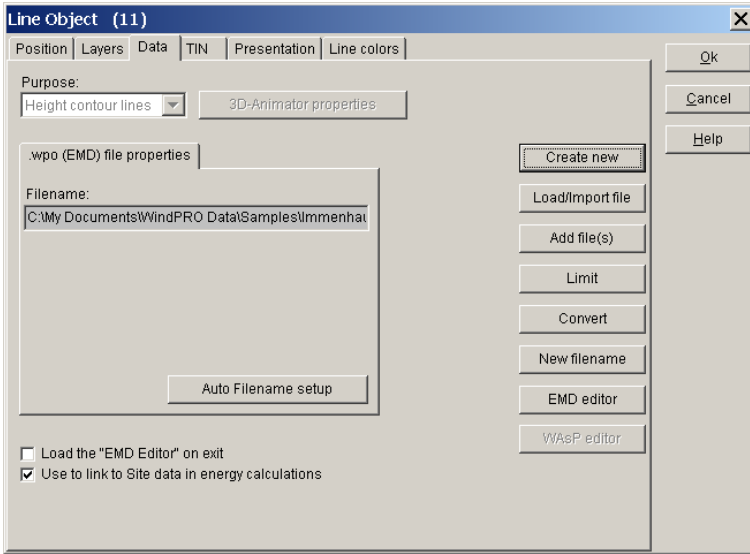
If digitized height contour line maps exist only in files (not loaded into line objects), they can be linked as files (see next section).

Once a series of local obstacles has been created (see Section 3.3.1.7), you can define which local obstacles are to be included in the calculations via the Site Data Object menu. Then, only those obstacles which are situated within a certain radius of the individual WTGs will be included in the calculation.

3.3.1.6 Tab sheet Map files and limits

If there are no height or roughness data assigned to Line Objects, but the data exists in files, these files must be added to the Site Data Object map list before they will be included in the energy calculation.
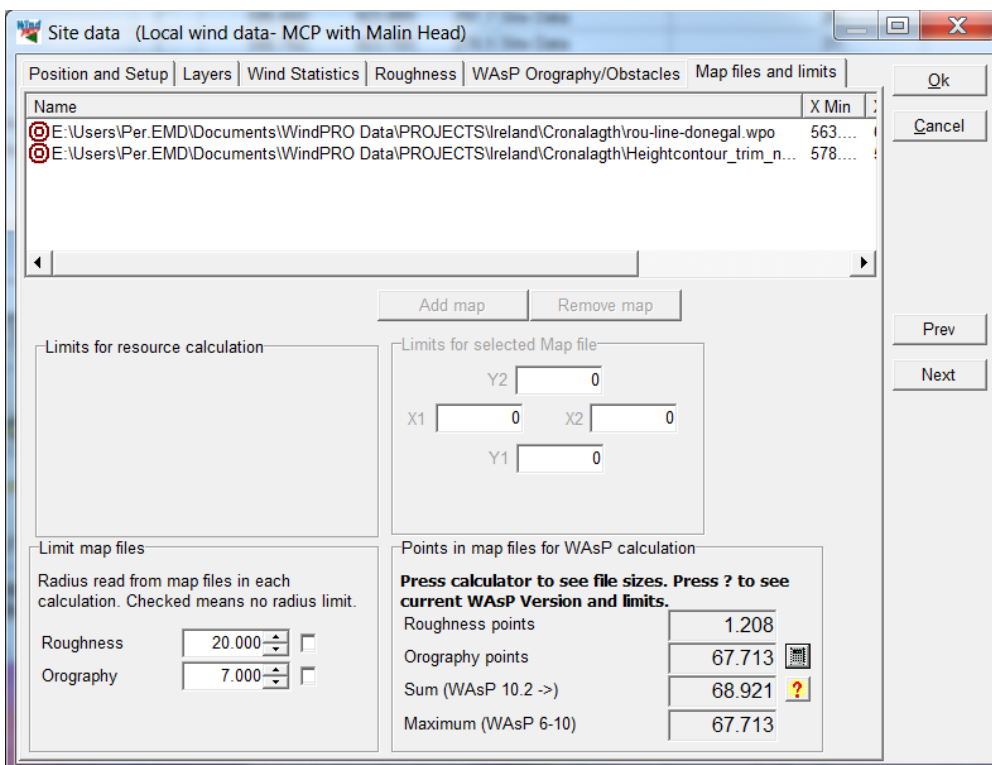
The list shows the .map and .wpo files to be used in calculation. If it shows some files (from line objects) that are not intended files, you must deselect "Use this object for energy calculation" on the line objects.

Once the .map files have been selected, you can define the area of the .map files to be included in the calculations, or you can define a radius around each of the WTGs to be included in the calculations. The indicator "Maximum points" shows the number of digital points which are included in the boundary file and calculated. Press the ? symbol for further information, and the following screen will show up:

Site data

Your current WAsP version is: WAsP 6-9

Map files are handled differently depending on WAsP version and calculation.

Resource calculation:
If no limits all the map files are used without reduction as calculated with the size calculator. When a limit is typed a map file will be created for each tile. This file will cover a square given by the tile size increased with the limitation radius. In this case the size calculation will not be correct.

All other calculations:
A common map file for the area will be used. The file will cover a rectangle surrounding the selected WTGs or Meteo objects increased with the limitation radius if selected, otherwise the entire file is used.

WAsP 6-9 + 10
Roughness files and orography files are used separately meaning that the limit is the maximum number of points.
Limit: App. 1,000,000 points

WAsP 10.2 and later
Roughness files and orography files are combined meaning that the limit is the total number of points.

Limit: App. 2,000,000 points (Sum of contour points and roughness line points)

OK

NOTE: The "Map limits" window in the lower right part of screen shown above indicates the position and size of the maps relatively to the project. This is an important check to make sure that the maps cover the appropriate area and that they are in the right coordinate system. If they are not, it will be easily seen in the "Map limits" window, see below.
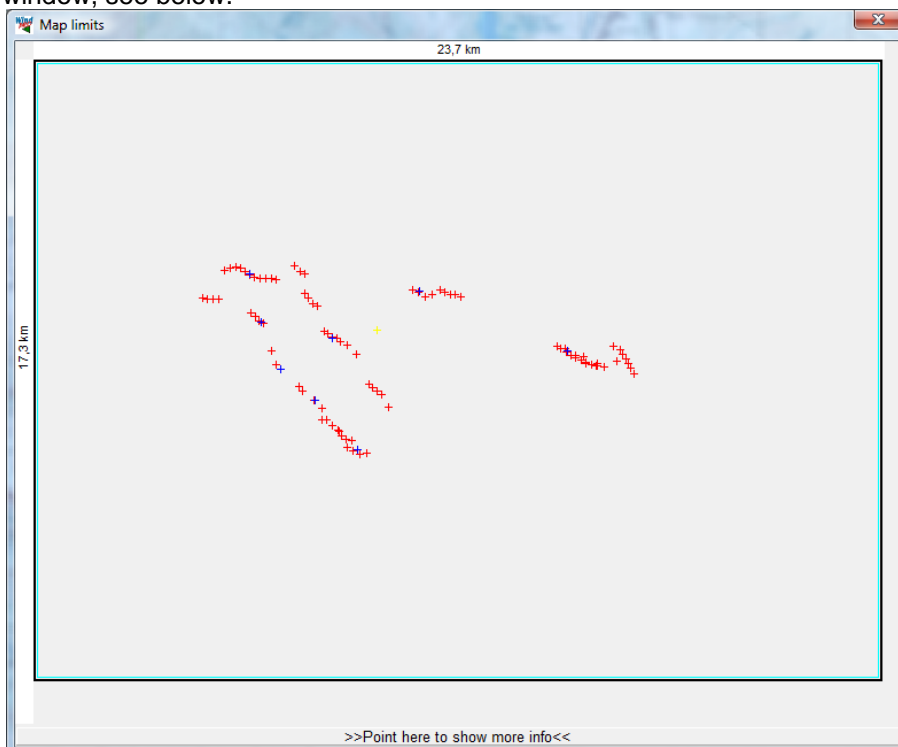
Pointing at the bottom part gives more precise information on the distances from relevant objects to map borders, see below.

Distances in used maps from "outmost point" to closest WTG or calculation point:

	Orography	Roughness	Distances used for validation:
North	6,0 km		Orography: 5,0 km (recommended value: 7 km)
East	6,7 km		Roughness: 20,0 km (recommended value: 20 km)
South	6,0 km		Red values indicates too low distances
West	4,8 km		

NOTE: Test is performed based on highest/lowest point in map files. The test does not verify if terrain is described properly within these points. For some sites, if there e.g. is a mountain 8 km from site, or a roughness change from land to sea at 21 km, recommended distances might be too low. For other sites, where the terrain only changes slightly at distance, less distance is needed. Note also that larger hub heights requires larger distances, recommendations are for round 100m

3.3.1.7 Input of WAsP Obstacles

Local Obstacles are created on a background map with the WAsP Obstacles icon.

Dimensions are defined by dragging the corners of the object to the desired size.

Once the object has been positioned, the following window appears where you can specify the height and porosity:
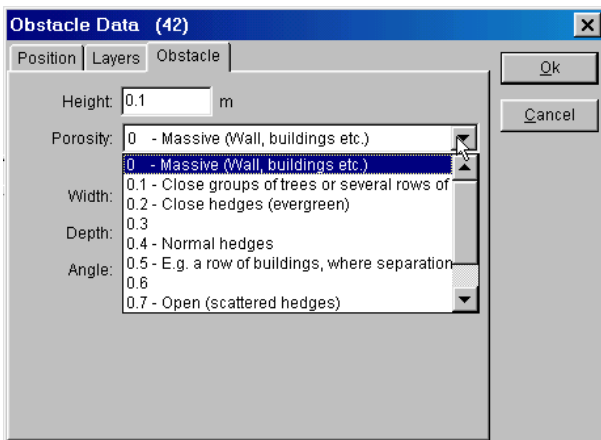
The porosity determines how much wind will pass through the obstacle and is seen as an average throughout the seasons.

3.3.2 METEO object; Input of wind data, screening, analyzing

The Meteo object is the input object for wind data. Input can be from the very simplest form;

- input manually one wind speed (annual mean) in one sector together with Weibull k=2, and you can calculate.

To the very advanced form:

- You import measurements from a Sodar or Lidar export file with 25 different heights for a long measurement period with high time resolution. The data files might even have changed format or units

during the measurement period, which also are handled efficient. The Meteo object importer can also read from compressed files, like .zip are read direct. Finally it can read the NRG logger files .RWD direct, although it is processed through the NRG data retriever software that must be installed. Is free download able from www.nrgsystems.com

BUT an important notice loading .RWD files: When loading direct, the "site" that is established in the NRG data retriever software, containing the calibration factors, is based on the data in the logger. Often users of NRG loggers have their "site" established locally on their PC, where they put in the calibration factors etc. These information's are NOT included unless you get these from the mast operator or you enter then by yourself. There can therefore be a risk of using wrong calibration factors importing these files direct.

The measurements can be used "direct" (without use of models) for AEP calculations in the calculation module METEO. But, the most common way is to generate a wind statistic based on the data in a Meteo object and terrain information from a site data object and then use the wind statistic in a site data object for calculation of AEP with ATLAS, WAsP interface or (most common) with PARK module. NOTE: Remember in-between the long term correction (MCP, see chapter 11).

You cannot direct load all raw logger file data, except NRG .RWD files. Other must first be converted to ASCII files (like .txt or .csv) with the logger software tools.

3.3.2.0 Compatibility to version 2.5 or older

The Meteo data object was completely redesigned after ver. 2.5. This also includes the data structure, so data stored from higher than 2.5 versions will no longer be backward compatible, meaning that v2.5 cannot read later WindPRO versions Meteo object data. But later versions can load v2.5 or older Meteo object data.

Some major changes to mention after ver. 2.5:
- Import filter now works on the entire data file, meaning that all measurement heights in a data file are set up in one process.
- No limits in number of signals in graphic view
- All measurement heights are handled together including new profile features
- Disabling can be performed in for all heights in one process
- Expanded/generalized statistics
- New efficient implementation of on-line data download
-

VERY IMPORTANT when recalculation of ver. 2.5 or older projects:

Time series, table and Weibull data are now fully linked meaning that changes in time series AUTOMATICALLY lead to a change in Table/Weibull data. If you have manually modified Table or Weibull data from version 2.5, these will, per default, NOT exist in later versions. You will get a warning if this is so when loading the data first time.

Workaround: If you wish to transfer table or Weibull data from 2.5 to later, you can copy the data to excel from 2.5 and then create a new measurement height in the new meteo object (or a new meteo object), only activated with Table and/or Weibull data and paste the data from Excel.

3.3.2.1 Guide – including on-line data description
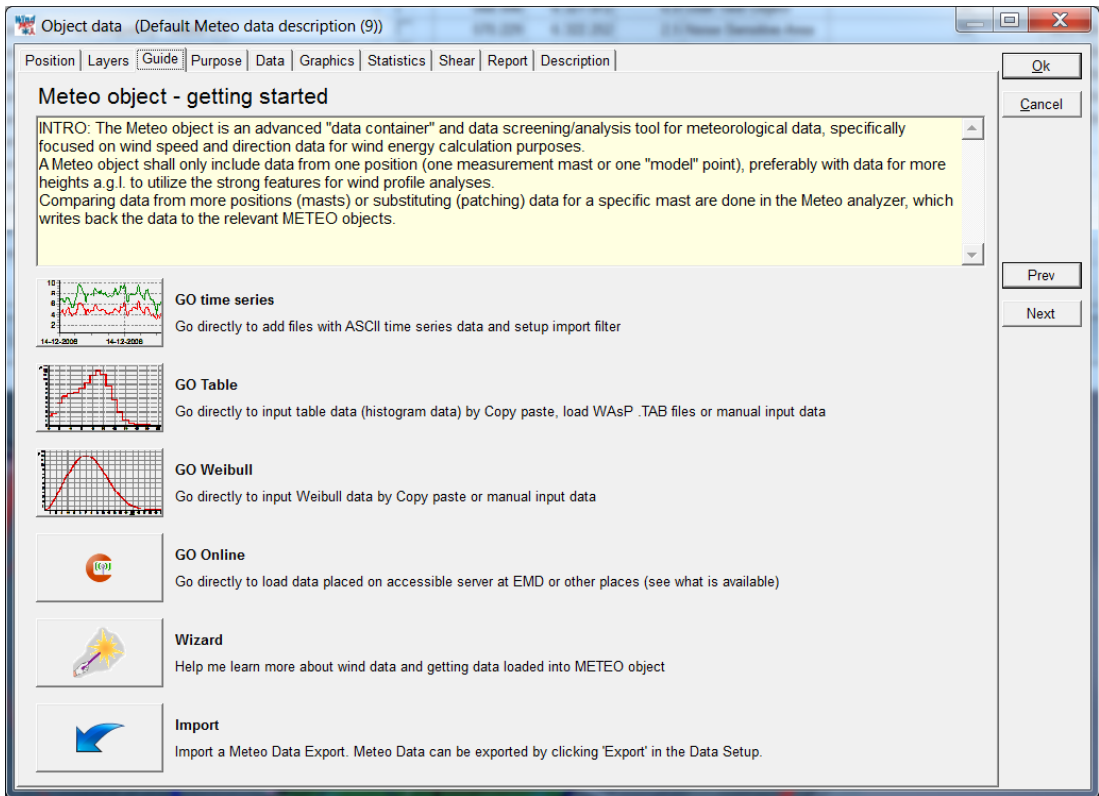
Figure 1 This is the first screen users will see when creating a new meteo object. This is "self explanatory".

Typically, time series will be the most common format in which data is made available – if users have any doubts about reading them, start with the Wizard.

Online data gives access to data on EMD On-line server, where EMD adds free data for fast and easy download. Also, data for purchase is available, where the EMD server relinks to commercial data servers. To download these requires a coupon code, which can be purchased through EMD. Press the On-line button to see your current options. These are expanded regularly. If a meteo object with On-line data is reopened, the Online button changes to "refresh online".

The online data download interface looks so:
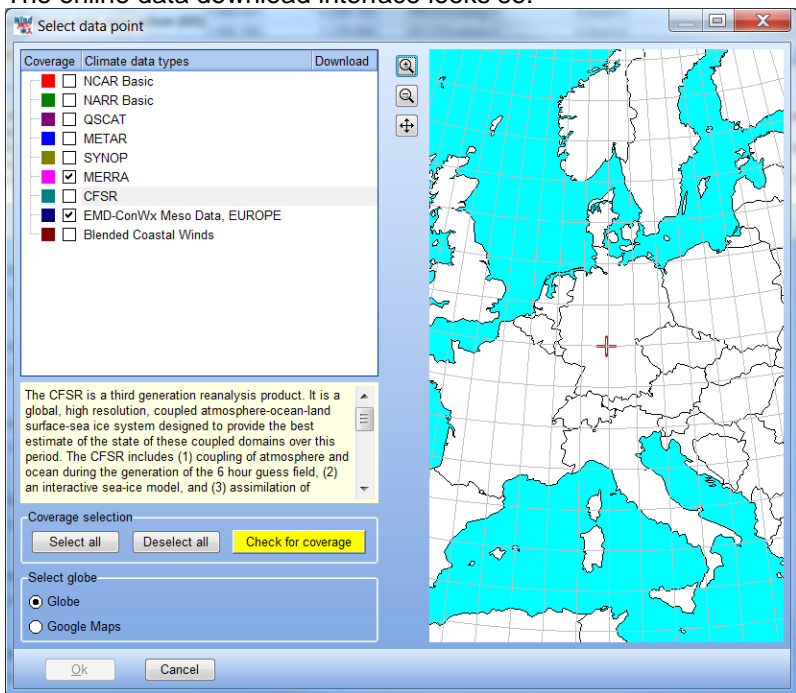
First screen show the list of possible datasets for download. It's now possible to check relevant datasets, for testing if there is coverage near the site.
The datasets are detailed described at: http://help.emd.dk/WindPRO/content/ReferenceManual/OnlineData.pdf

Short intro:
NCAR, NARR (US only) Merra and CFSR are model data, first mentioned in most coarse resolution, last two as high as 1 hour, 30 km.
QSCAT and blended Costal winds are offshore data based on scatterometer measurement technique.
METAR (Airports) and SYNOP (Meteorological institutes) are mast measurements, typical 10m height. Period and time resolutions vary much by region and station.
EMDConWx are high resolution meso scale model data, 1 hour, 3 km resolution (for Europe only so far – require subscription fee).
All data sets are monthly updated, except QSCAT, which stopped 2009. Most datasets go 30y back.
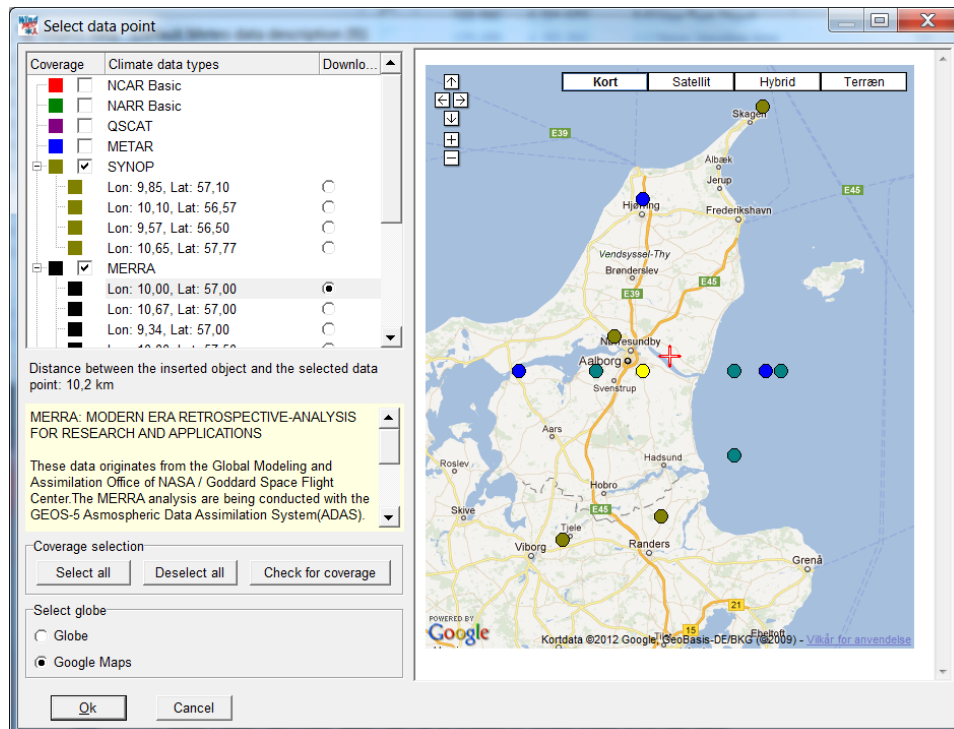
After coverage check, dots show locations for possible datasets. Click on one of the dots to see which dataset it refers to. Note the Google map can be used as background. With "OK" the selected dataset will be downloaded. The data will automatically be imported in the Meteo object, ready for analyses.
Note it is possible to download more data sets at a time from the Meteo Analyzer.

3.3.2.2 Purpose
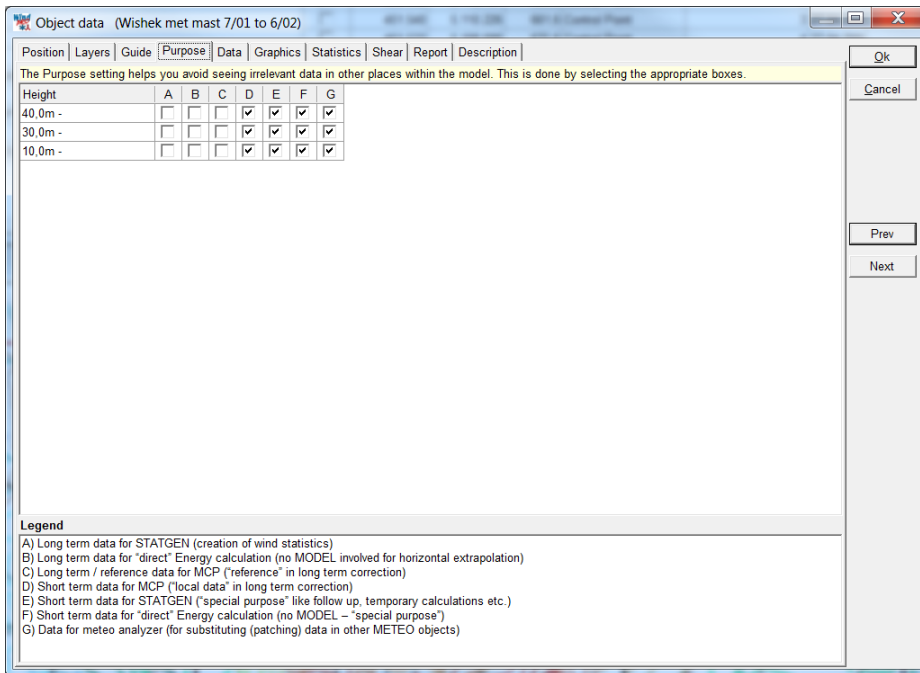
Figure 2 Purpose settings helps to structure the data.

If there are many wind measurement data in a WindPRO project, it can be difficult to keep an overview. Giving the data different purpose settings can improve the overview. Only the relevant data based on purpose settings will be selectable from different forms in the software.

3.3.2.3 Data
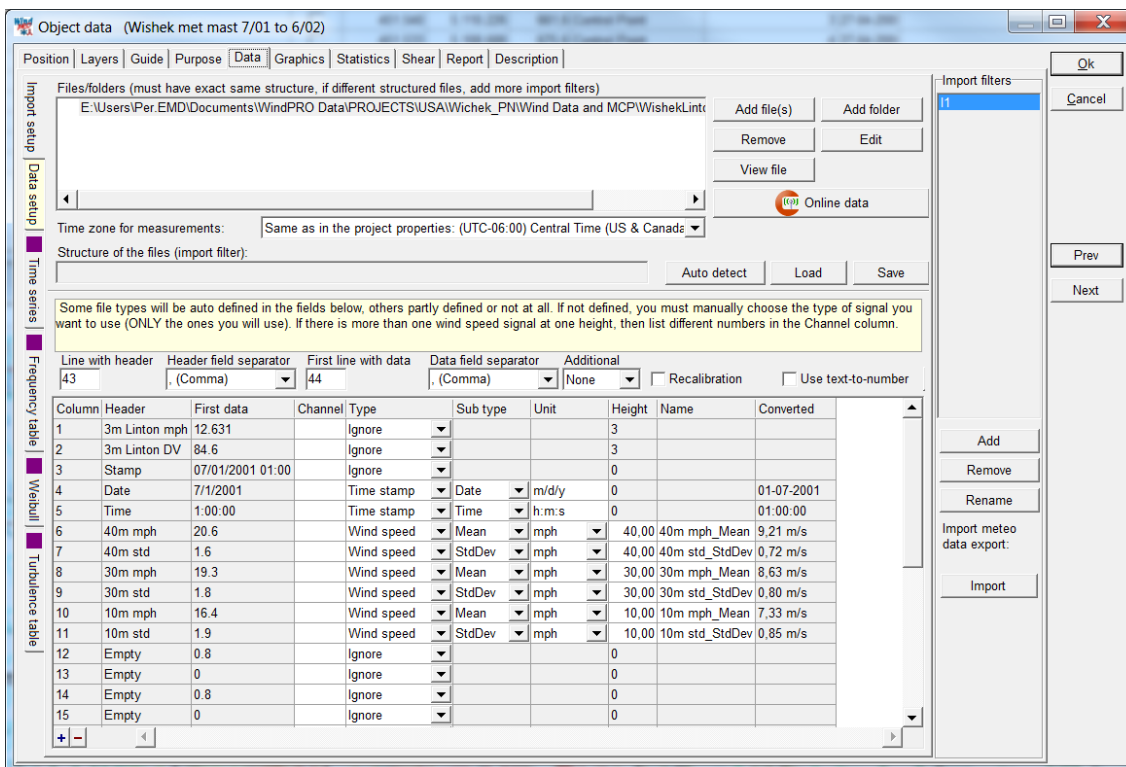
Figure 3 The data tab - import setup

The Data tab controls:
- Import setup (identifying file structure(s)),

• Data setup (setting up the signals wanted for each height)

and after importing data:

• Time series (view, analyze, flag time series data)
• Table data
• Weibull data
• Turbulence data

Below, each function in this form is explained.

Data; Import setup

File types supported: Only ASCII files can be imported at present. This means that raw logger files, Excel files or database files must be converted to text tiles before data can be imported. Compressed text files are supported, so it is ok to have the text files in .zip, .rar or other compressed files.

Add file(s); point out the files with the data to import. Note, these **MUST** have the same structure – if not, add more import filters and add the files "below" each import filter.

Add folder; point out the folder with the files that contains the data to import. Note, these **MUST** have the same structure – if not, add more import filters. When specifying a folder, and adding new data files after the initial set up, the Meteo data object can be updated. Simply choose "load new" in the data setup tab (see later). If there are data from more masts or more different files in the folder, it is possible to set a mask, e.g. "*.txt" so only relevant files is used.
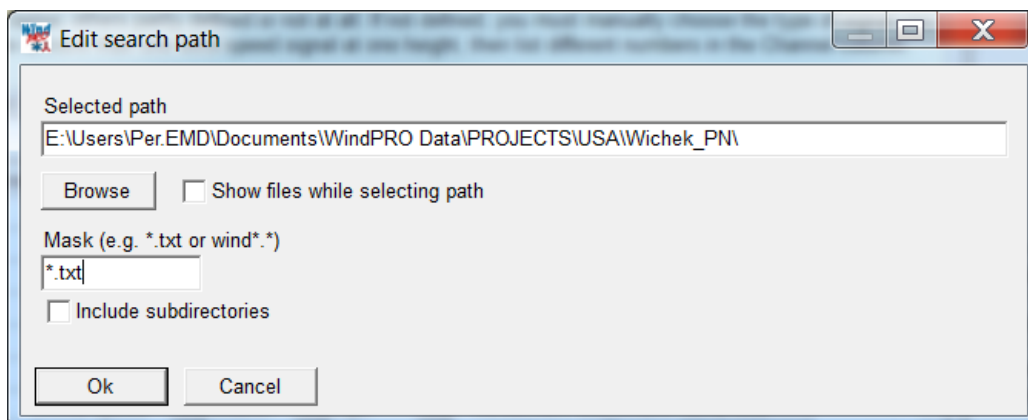
Figure 4 Adding folders gives high flexibility and fast import of new data subsequently placed in the folder.

Remove; Remove the selected files in the list from the import filter

Edit; Edit the import setting, like the file mask in "Add folder".

View file; View the selected file with current import settings applied. This is very useful to identify the structure of the file and to see if the import settings are working.

Online data; (requires an active license for the MCP/Statgen module) - start a communication with EMD server, see 3.3.2.1 Guide – including on-line data description.

Time zone; If data is in UTC (same as GMT) time, which often is seen for "general purpose data", or your data files are not in your local time zone, they will automatically be transformed to the local time zone set in the project properties. For the individual heights, you have the further option to time shift the data series individually. This is needed, for example, when importing NCAR data where 10m data is forecast data (6 hour ahead) while the other data is "normal".

Structure of the files (import filter); A file giving the structure can be loaded and saved. This helps save time if the same type of files is often used in different projects. If you do not have an import filter saved, use the "auto detect" feature.

Auto detect; is a very powerful feature, that can recognize the "base structure" of many types of wind data files. There will often be "manual work" to do – this can be avoided for subsequent files by saving the structure.

Recalibration; is a feature that allows to modify the calibration, if the used sensor calibration converting from logger data to ascii files later is found nor to be correct.

Use text to numbers; is a feature to make e.g. wind direction described as like N, NNE, ENE to be converted to numbers.

Figure 5 After "auto detect" the lower part of the form is filled. In the example above an NRG Symphonie^{TM} logger file is used, and everything is auto detected. Several other standard logger output files can be auto detected and new types are continuously added. Some file formats although must be manually setup, if it e.g. are user defined excel exports, the software has no chance to auto detect.

Import setup; Manual adjustment of "auto detections"

There has to be an entry for each data signal which is to be used in the object. The signals not to be used will just be "ignored", like "min" which is often not used. Signals can at a later stage be set up and used.

1. Chose "type" in drop down, like "Time stamp" or "wind speed" (note that the standard deviation (StDev) of a wind speed signal is also classed as a wind speed).
2. Chose "sub type", like "year" or "mean" etc.
3. Chose "unit" – note that wind speeds in non-metric units (e.g. mph, knots) will be auto converted to "m/s" in the object.
4. Chose "height" – must be in "meters" – eg. NRG Symphonie^{TM} files set to "feet" will be auto converted to meters. Always check that height is correct as it might be wrong in the data file!

When all signals are set up, go to the "data setup" tab.

Data; Data setup

1) **Create a time step by time step AEP calculation** for each turbine for a performance check/model calculation check. Comparing this calculation with real production from the Scada system, or turbine computer makes it possible to sort data by direction, hour, month, wind speed etc. This allows you to see where eventual problems might be if actual production does not match calculated.
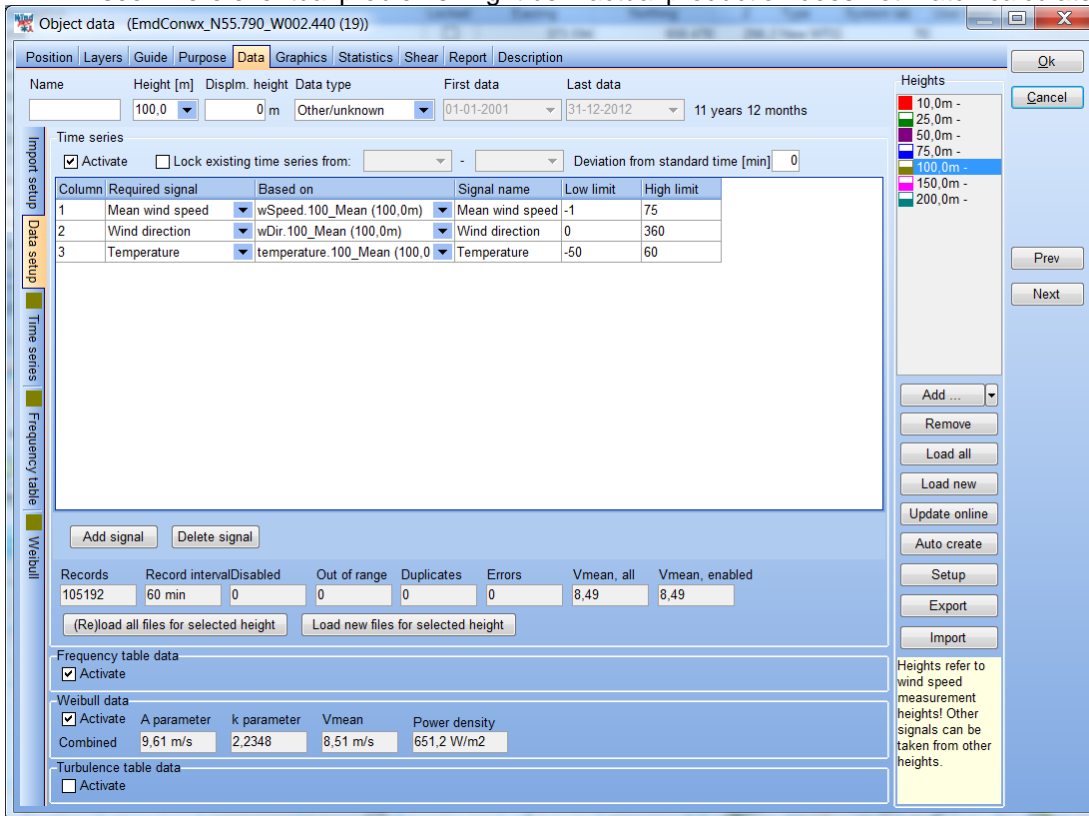
Figure 6 In "data setup" each wind speed height is defined.
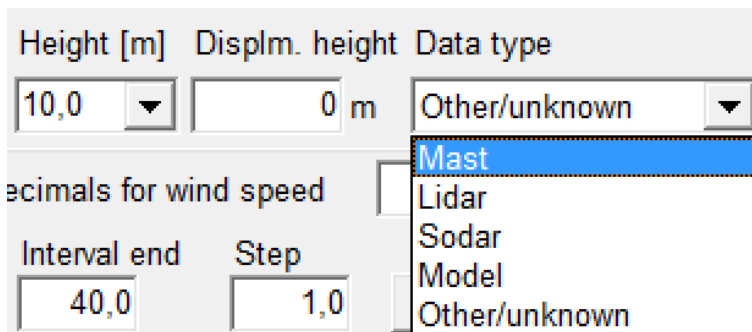
It is possible to set displacement height, if the mast e.g. is in a forest (positive disp. height) or on a very narrow rock (island) (negative disp. height), that NOT is included in elevation data. The data type, mast, Lidar… can be specified. This information can be used from like Site compliance module.

Auto Create are by default yellow while this will be the typical "start". This will automatically create all the wind speed measurement heights from the import setup. The signals created by default are:

Wind speed
Wind direction
Turbulence intensity

Wind direction is taken from nearest height to wind speed height.

Add/Remove signal; is used for adding other signals to measurement height, e.g. temperature or "max. wind speed". There is full flexibility. Even shear can be added as a signal, giving options for comprehensive analyses of shear with the graphics features.
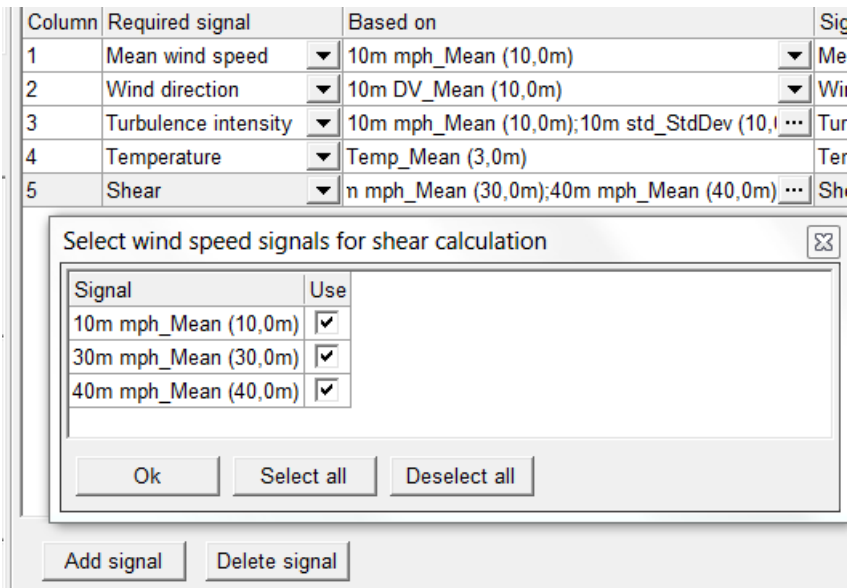
Adding shear gives full flexibility on which height shall be used to calculate the shear time series, although minimum 2 heights are needed.

(Re)load all/new files for selected signal; loads the data from the files via import filter into a time series. The right button (new) only loads new files added after last load operation.

Buttons to the right:

Add; Adds a new height. But the button also has more sub menu's: Add merged and add synthesized:
Add merged; Flexible way to merge two or more measurements, typically used to take out the tower shading when two sensors in same height. See example at the end of this part.
Add synthesized; Gives access to advanced shear calculator that is used to scale measured data to another height. See example at the end of this part.

Remove; add or remove (selected) measurement height

Load all/new; loads all heights in one process. The "new" only loads new files added after last load operation.

Update online; Refresh data previous loaded as EMD On-line data (update with recent months)

Setup; Rules for concurrency, disabling of turbulence and rules for use of data for turbulence table. Also a special feature for very high time resolution data.

Export; Export all or selected data in flat text file format. The flagging of the data is included in the export, see explanation in the text file, example below where 80m and 60m data are exported:

Geographical Coordi	Longitude:		-87,22	Latitude:	13,9									
Local Coordinates: (	Longitude:		475798	Latitude:	1536185									
Description:	4108													
User label:														
StatusValues:														
Ok	0													
Disabled	1													
Below limit	2													
Above limit	4													
Duplicate	8													
Null value	16													
Missing	32													
Other error	128													

Note that SampleStatus takes precedence over DataStatus which means that DataStatus is only relevant if SampleStatus is OK.

TimeStamp_80,0m	MeanWindSpeedUID_80,0m	Direction UID_80,0m	TurbIntUID_80,0m	Comment_80,0m	TimeStampStatus_80,0m	SampleStatus_80,0m	DataStatus_MeanWindSpeedUID_80,0m	DataStatus_DirectionUID_80,0m	DataStatus_TurbIntUID_80,0m	TimeStamp_60,0m	MeanWindSpeedUID_60,0m	Direction UID_60,0m	TurbIntUID_60,0m
	[m/s]	[Degrees]									[m/s]	[Degrees]	
11-06-2008 13:10	4,4	53	0,0682		0	0	0	0	0	11-06-2008 13:10	4,3	53	0,0698
11-06-2008 13:20	4	56	0,15		0	0	0	0	0	11-06-2008 13:20	3,7	56	0,1622
11-06-2008 13:30	4,3	57	0,2326		0	0	0	0	0	11-06-2008 13:30	4,1	57	0,2195
11-06-2008 13:40	4,7	55	0,1702		0	0	0	0	0	11-06-2008 13:40	4,6	55	0,1739
11-06-2008 13:50	4,2	48	0,2143		0	0	0	0	0	11-06-2008 13:50	4,1	48	0,2439

Status values are binary coded so the sum in the status columns can be decoded for precise identification of the flagging (means that more flags can be applied to the same data point. There is, as well, a status column for all signals as well as one for each signal. The headers are exported unicoded (UID) meaning that the same text will appear no matter from which language is exported. Thereby it is easy (only one WindPRO meteo importer needed) if a company wishes to maintain a large database with exports from many different users round the world.

Import; Import from previous explained export format. Note a full object export can be performed from the object list; import of this is done from the "Guide" tab.

Features in top of form:

Activate; The different types of data presentation can be activated/deactivated. If you have no intention of using the Weibull distribution, or you have table data but no time series data, this feature is useful.

[ ] Lock existing time series; is used when new data is added, but the older previous data loaded does not exist as data files on the PC or they have been added with different import settings in v2.5. Basically, adding new data requires intact import filters and files for all data except when older data series are locked.

Low/high limit; is used to flag the data record "out of range" data in the time series. Note wind speed low limit by default is "-1". Sometimes calibration of the raw measurements makes the "0" or very low wind speeds negative. To avoid these being "flagged" as "out of range" it is important not to set this to "0". If "0" wind speeds are not included in the data set, the Weibull distribution will be wrong and the calculations will be wrong.

Remove tower shading – add merged
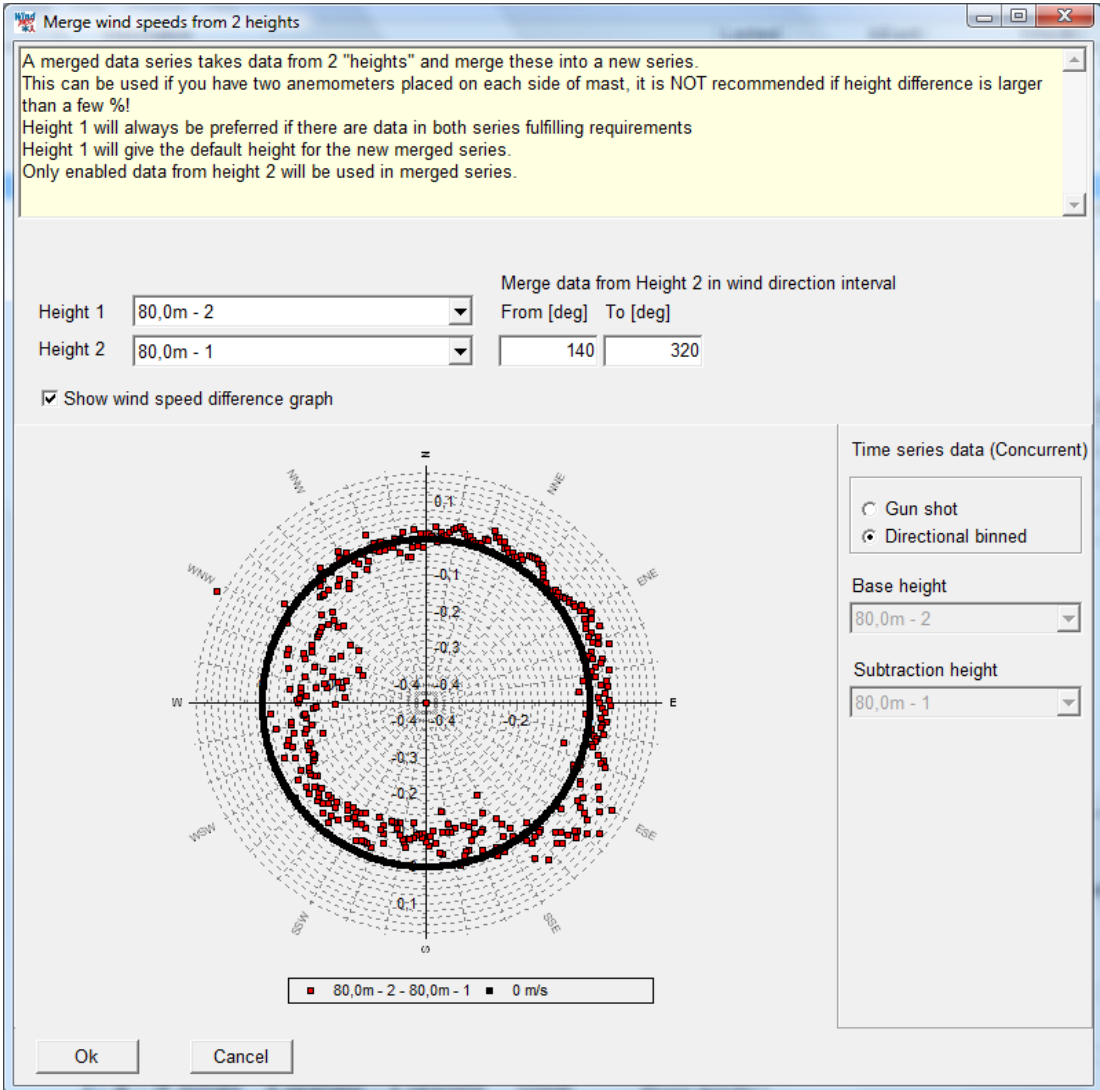
When two wind speed measurements are at the same height, the purpose often is to be able to remove the influence of tower shading and thereby get the "clean" signal by taking the wind speed from the "free" sensor at any wind direction. A typical setup is shown above. Here sensor 2 is used as "base" and there are merged data from sensor 1. Looking at the data it is obvious that sensor 1 measure higher values from 140 degrees to round 320 degrees (the difference sensor 2 – 1 is negative). This example is not as obviously clear as is often seen, probably while both sensors are close to top-mounting. Click on OK and the following screen appears:
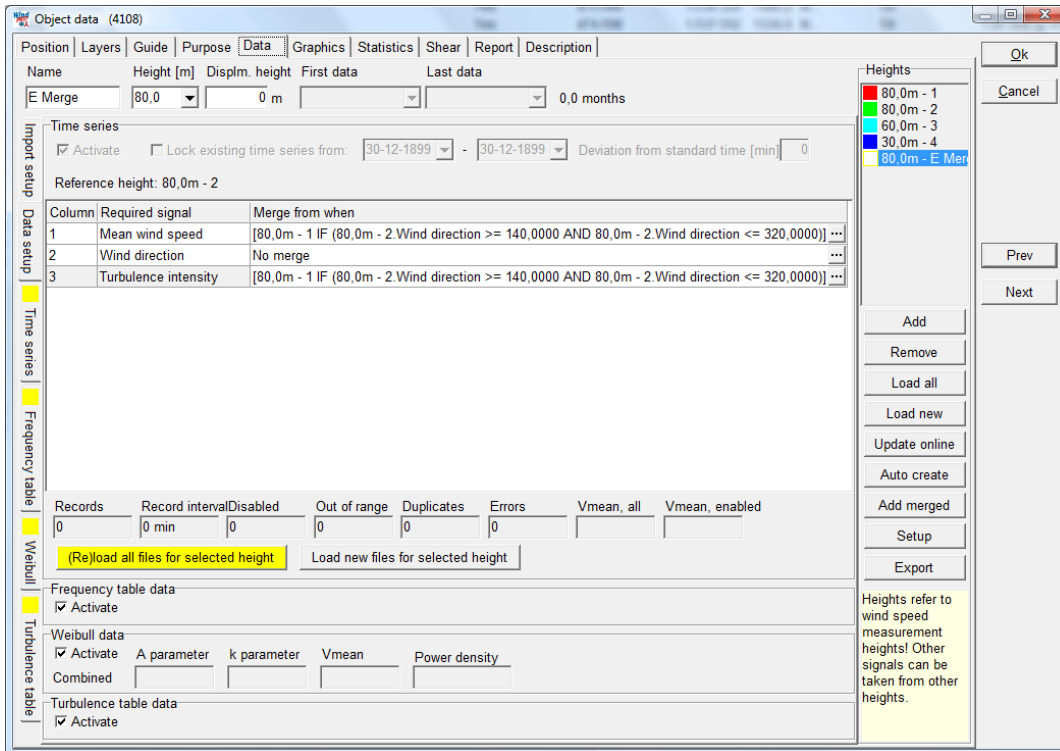
The rules established for the merged series are shown. Before loading the merged data the rules can be edited by clicking the small dots to the right of each rule, and any rule based on any signal can be created.

Add synthesized – creates shear matrix – scale to new height
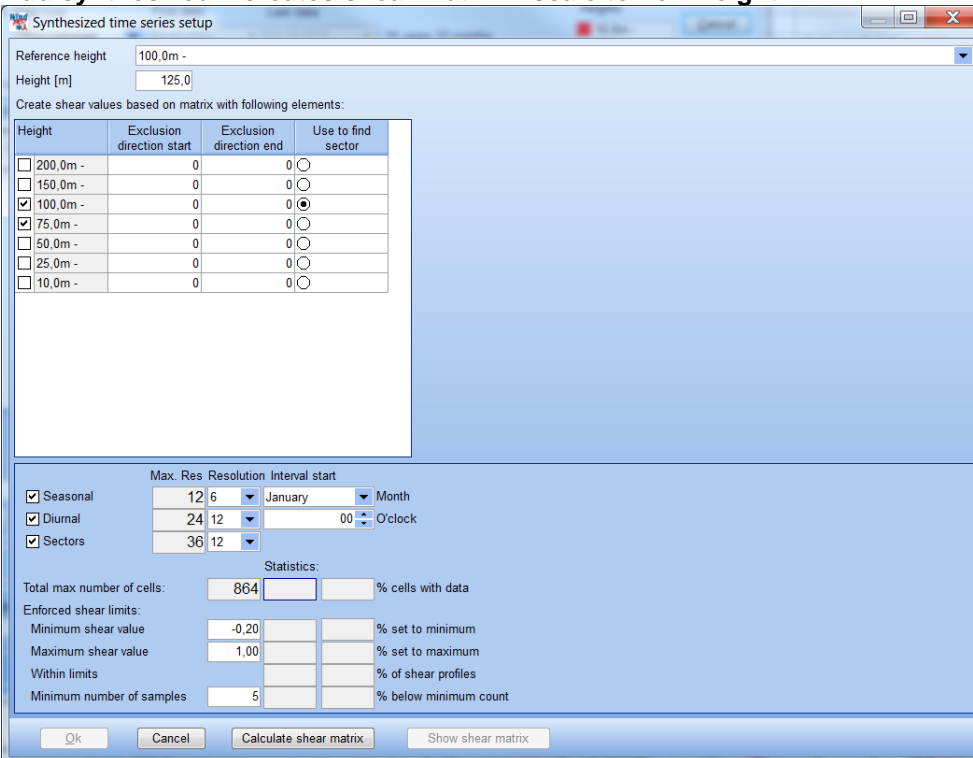
Based on two or more heights with measurements, data can be scaled to a new height based on a shear matrix. The shear matrix can be more or less detailed, depending on how good and long term period of data is available. Below an example is shown.
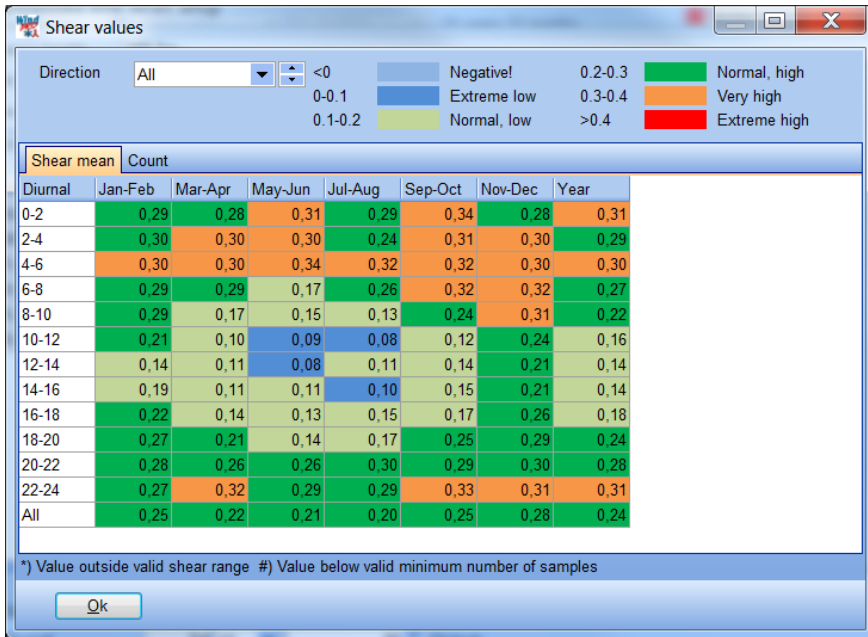
The shear matrix is calculated from mean wind speeds in each bin (season, time on day and direction) and will thereby partly represent stability conditions. Much sun heating the surface will give low shear due to mixing the air. The extrapolation to a new height will then be based on the individual bin values for shear. Note: in complex terrain or just on a smooth hill or in a forest, it can give very wrong extrapolations. Using a model, like WAsP, or better WAsP-CFD when really complex) for the extrapolation, will be the more correct choice.

If there are too few data for a bin (1 direction sector, one diurnal period and one seasonal period), the bin will be given data based on the following priority:

1. Year value for the direction and diurnal period.
2. Mean value for the nearest two directions
3. Overall mean

Meaning, if like a direction has almost none data, not even a year value might be present for a certain diurnal bin, and two nearest directions is used. If those (or just one of them) also have two few data, the algorithm moves to step 3. But note these substitutions are not very critically, while they basically will represent bins where wind very rare is seen.
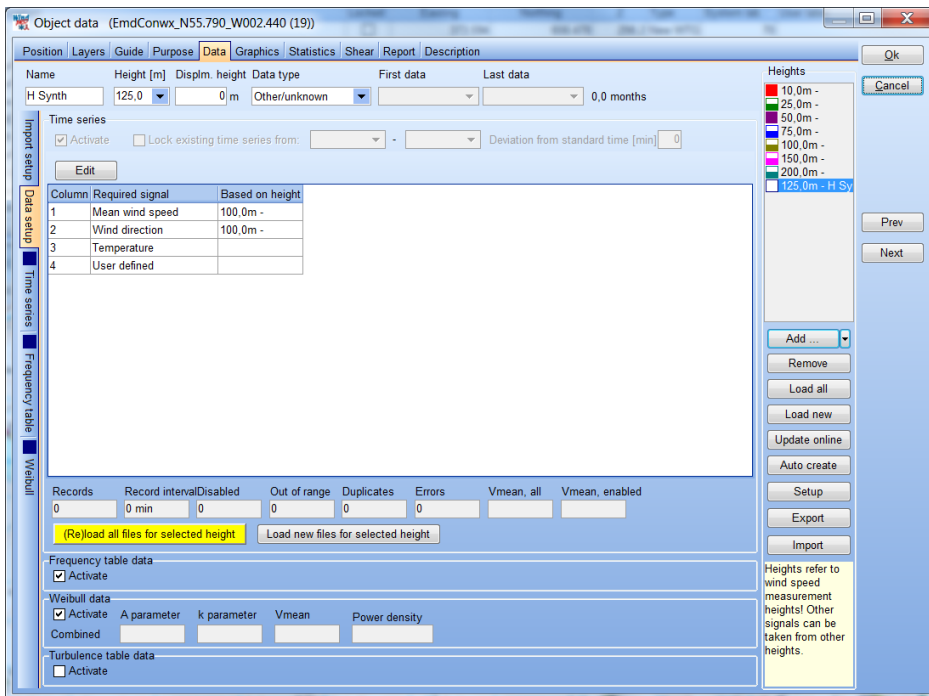
The new synthesized height is created and must be loaded. With the "edit" button it is possible to get back to the shear calculation setup and adjust.

When data are loaded, the tabs with the different data presentations will be added.

Time series;
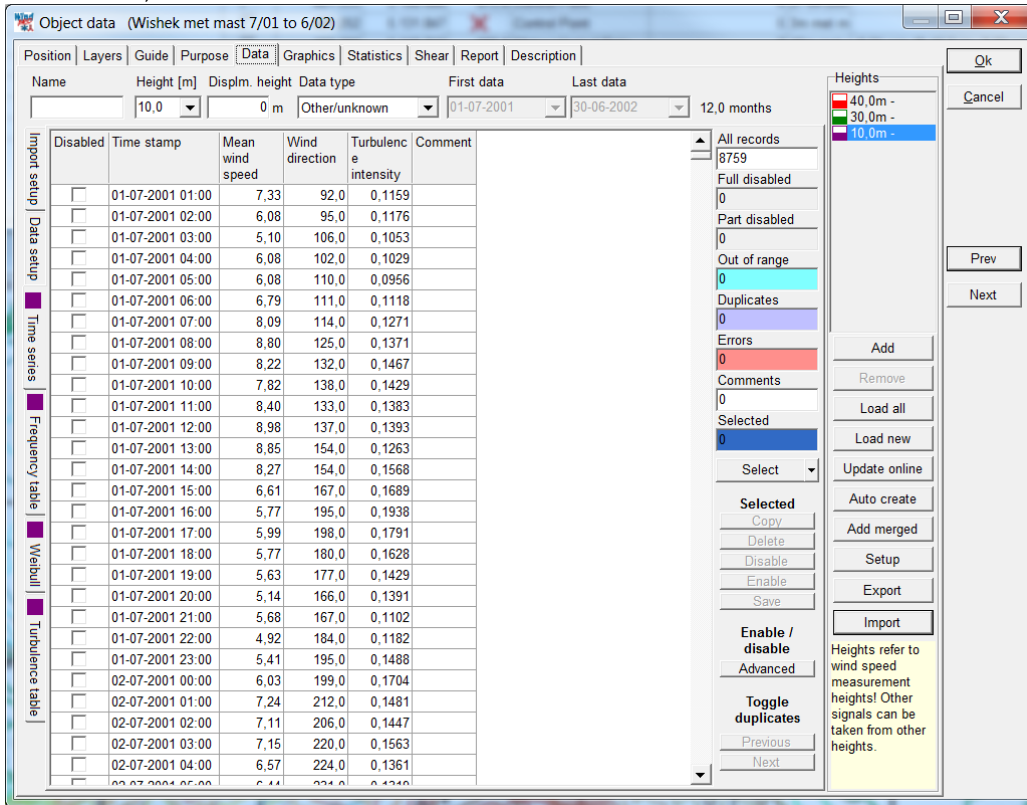
Figure 7 With color background, data characteristics like "Out of range" data are clearly shown. Click in the color field and the cursor jumps to the first event. Data can be sorted by clicking on the header; this is very efficient for like finding the highest measured wind speeds.

Select; can select "enabled" data – selection can also be performed "manually" by dragging with mouse in the list.

Selected; data can e.g. be copied to clipboard and pasted to other programs, e.g. Excel.

Enable/disable; can be performed manually in the list checking the checkbox, or the "Advanced" feature can be used.
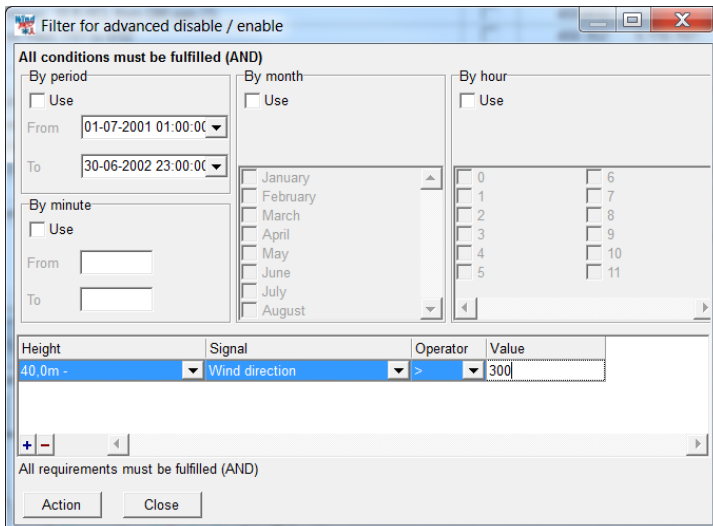
Figure 8 With "advanced" enabling/disabling, flexible data selection can be performed, e.g. based on the value of any signal in the data files.
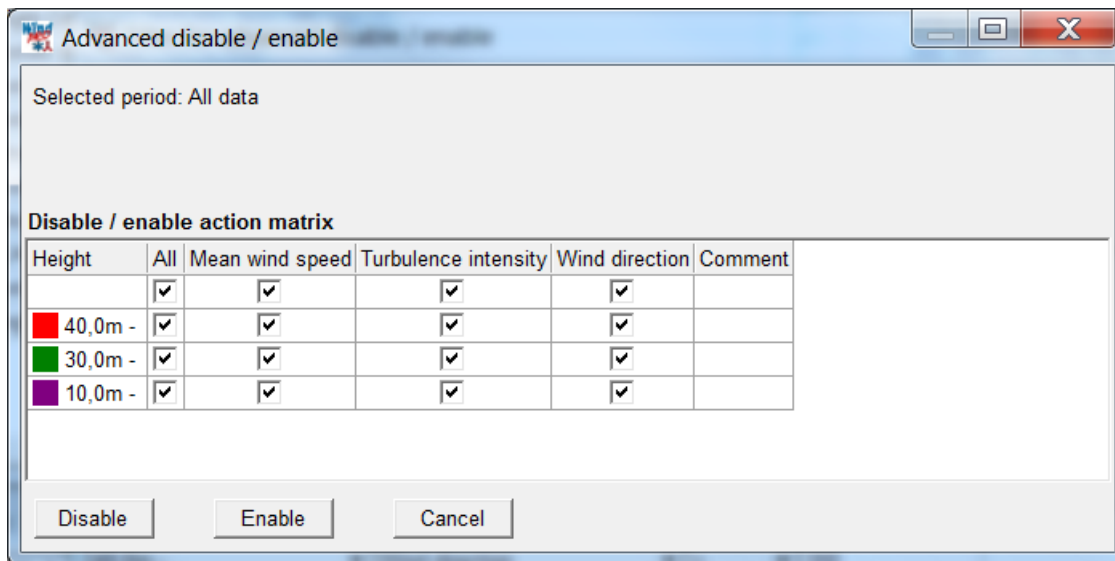
Figure 9 Pressing the "Action" button (shown in previous Figure) gives access to the Advanced disable/enable feature for ALL heights (with same time stamps within +/- 5 min.) that fulfill the conditions in the filter settings.

Only the Enabled data that is NOT out of range or duplicated is used in the aggregated data described in following. The aggregated data is automatically updated if changes in the original time series data are performed.

Data; Frequency table
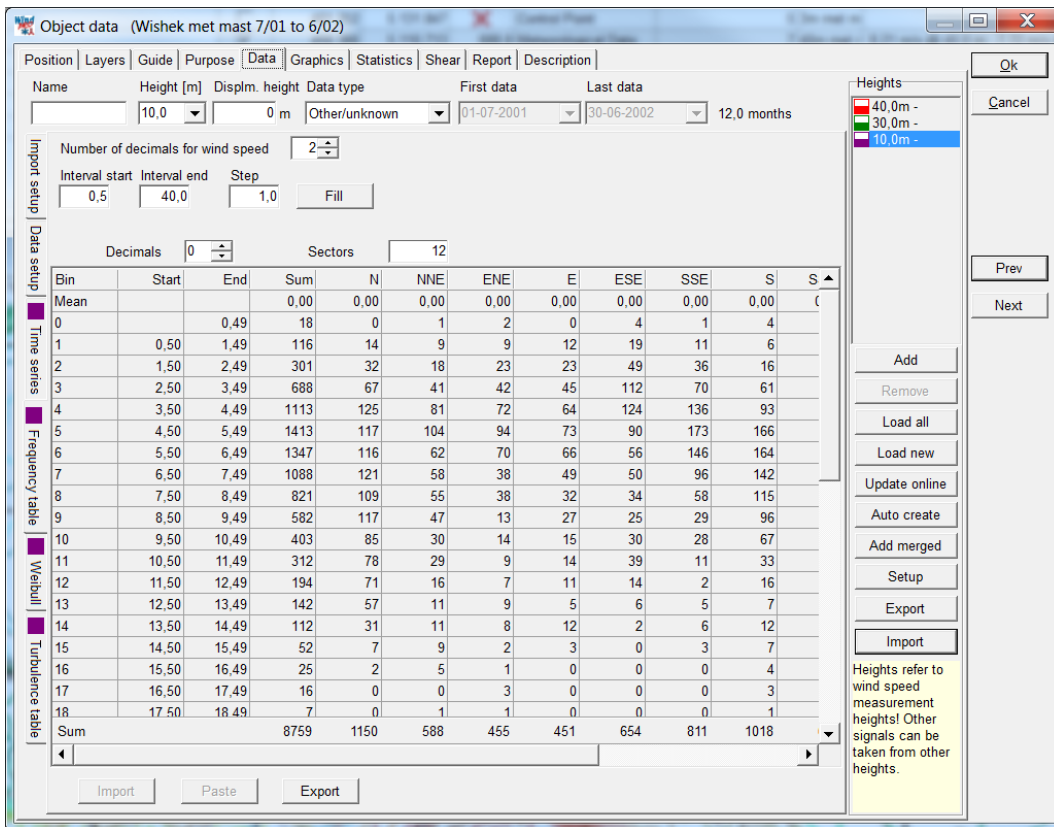
Figure 10 Frequency table shows the binned data by direction and wind speed.

Data; Weibull
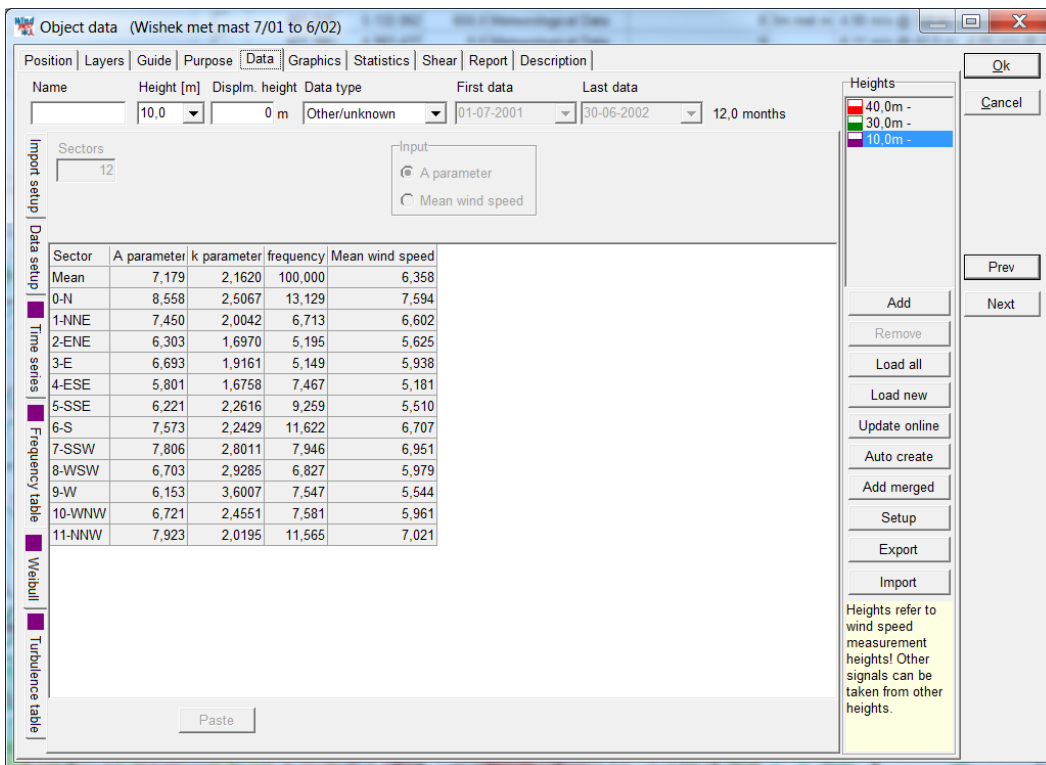
Figure 11 The Weibull fitted data.

The method for Weibull fit is energy weighted, by the same method as Risø's WAsP uses, as described in "European Wind Atlas". The Weibull distribution is used as input if the Meteo object data is used for further calculation, e.g. within the WAsP model.

Data; Turbulence
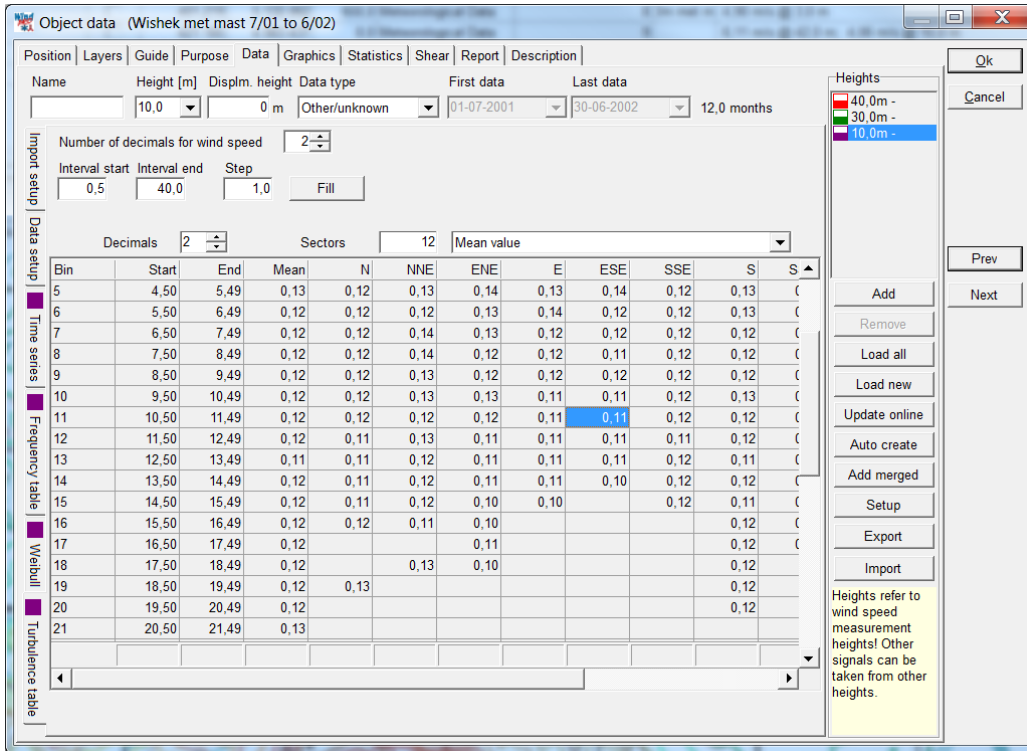
Figure 12 Turbulence data can be shown as mean values and as standard deviations. By copying these two tables to Excel, any combination of mean and standard deviation can be made for turbulence evaluations (e.g. Characteristic values as defined in IEC 61400-1 ed.2 = mean + 1 x StDev and ed. 3 as mean + 1.28 x StDev).

3.3.2.4 Graphics

The Graphic tab holds advanced features for evaluation of the measurements. Also included are features for disabling erroneous data found by the graphic evaluation of the data.

At each graph there will be a "Copy to Excel" button. The graph data "as seen" can be copied to clipboard, and from there pasted to Excel or similar.

There will be the following main graph windows, each with different view options:
- Time series
- Weibull/table
- Rose view
- Turbulence
- Wind speed difference
- General X-Y graph
- Profile

Only a selection of the graphs within each option will be shown below while the others should not need any further explanation.

Graphics; Time series

Figure 13 The time series view is efficient for finding erroneous data – simply right click in graph at start and end of erroneous data for disabling those. You can also ad comments (right click) and these can be reported in a separate report. Zoom by mouse drag is possible.

With the check boxes for each height and signal, viewing can be controlled.

Graphics; Weibull/table
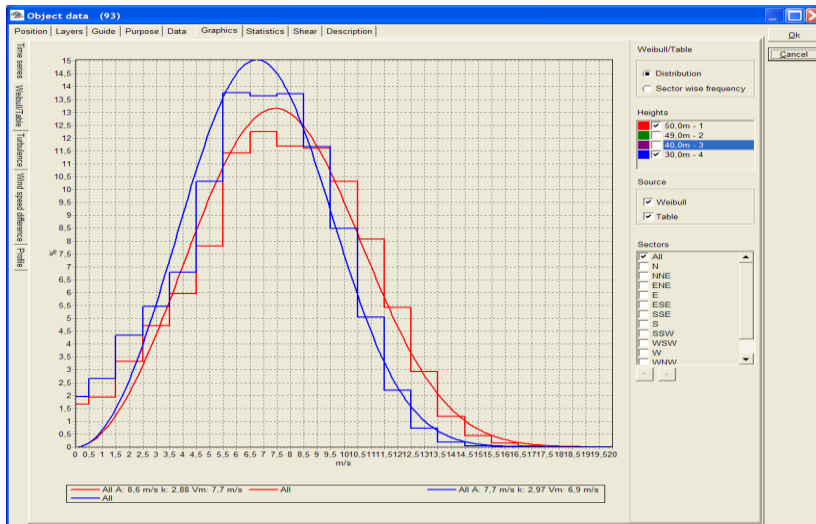
Figure 14 The Weibull/table graphs are here shown for two heights. Note that the axis can be scaled manually by the "Edit graph" feature, activated by double clicking on the graph.
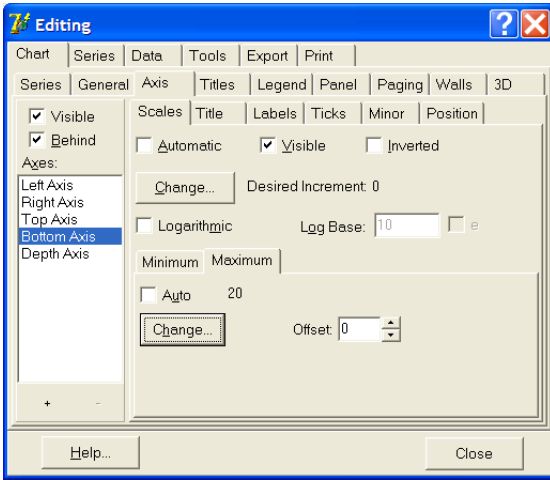
Figure 15 Double clicking on a graph gives access to advanced editing of the graph setup. Here we show the method of manually adjusting the x-axis.

Graphics; Turbulence
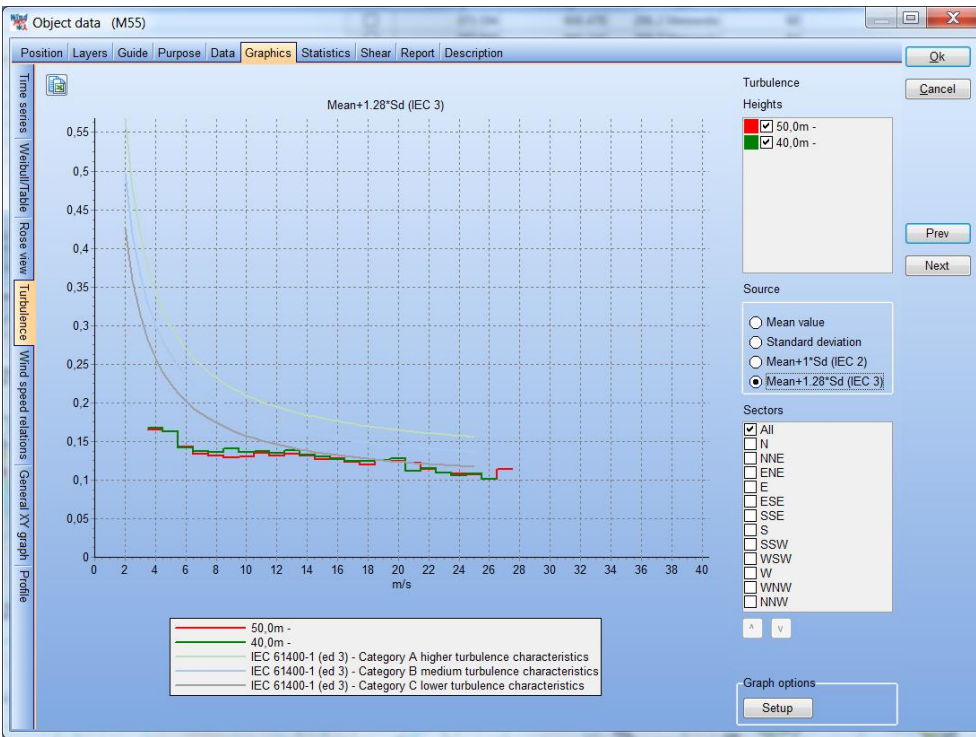
Figure 16 The Turbulence graphs are here shown for two heights. Different options for inclusion of IEC check graphs are available. Note that the axis can be scaled manually by the "Edit graph" feature, activated by double clicking on the graph.

Graphics; Rose view
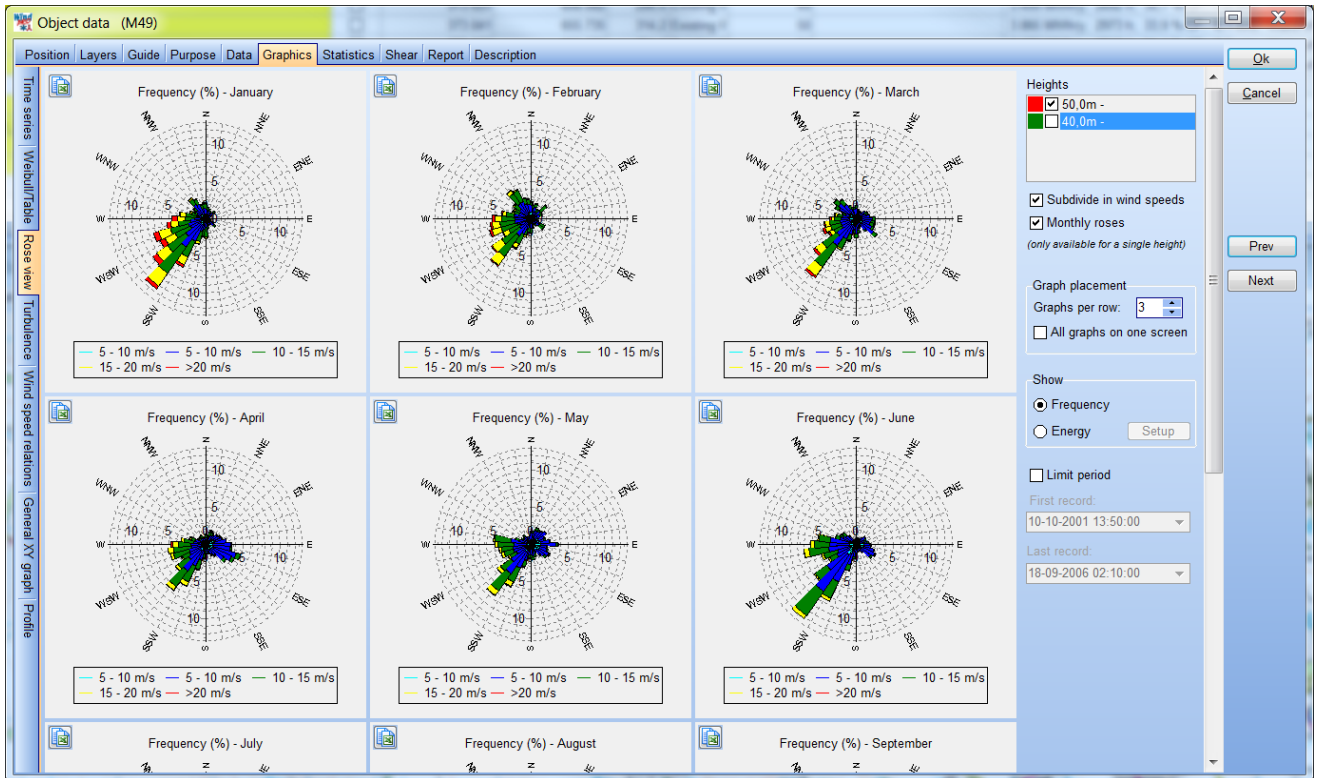
Figure 17 The Rose graphs are here shown for one height, giving the option to show month by month.

Graphics; Wind speed difference
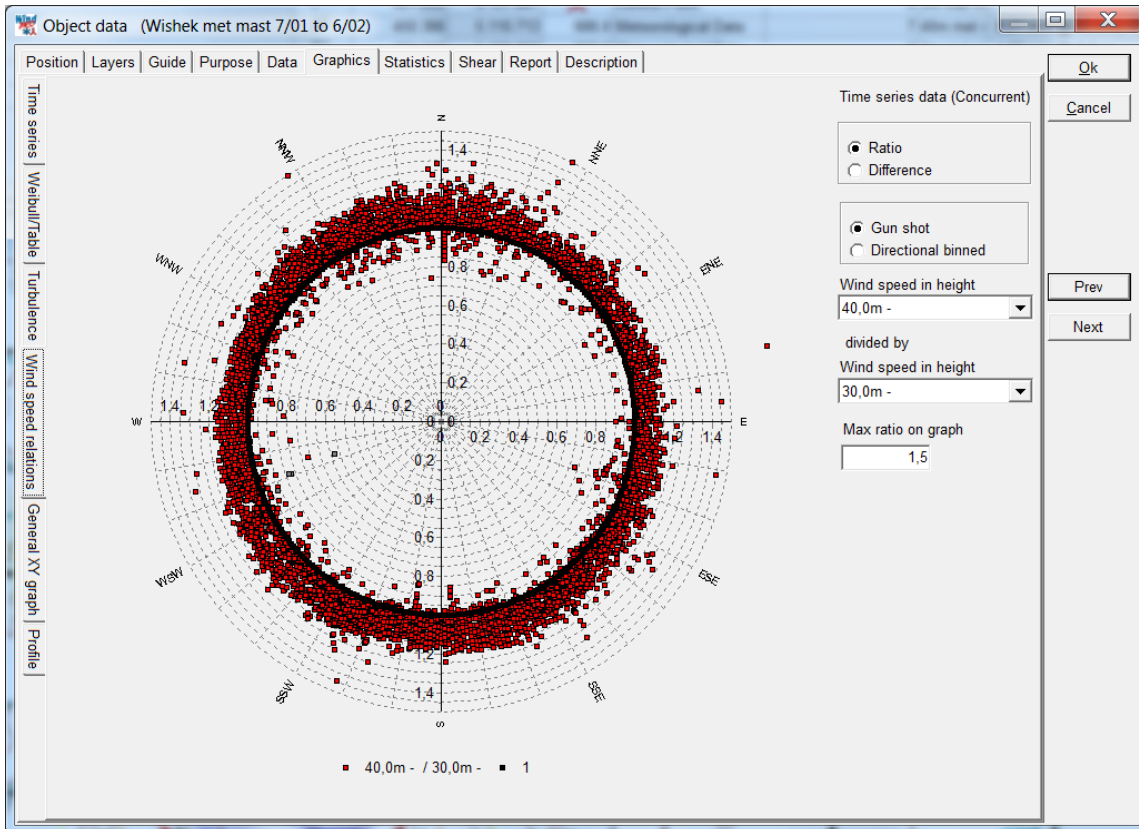
Figure 18 Based on two different wind speed sensors, a difference plot can be created. This is a useful way to evaluate boom directions and influence. As well difference as ratio can be selected, and the data can be binned.
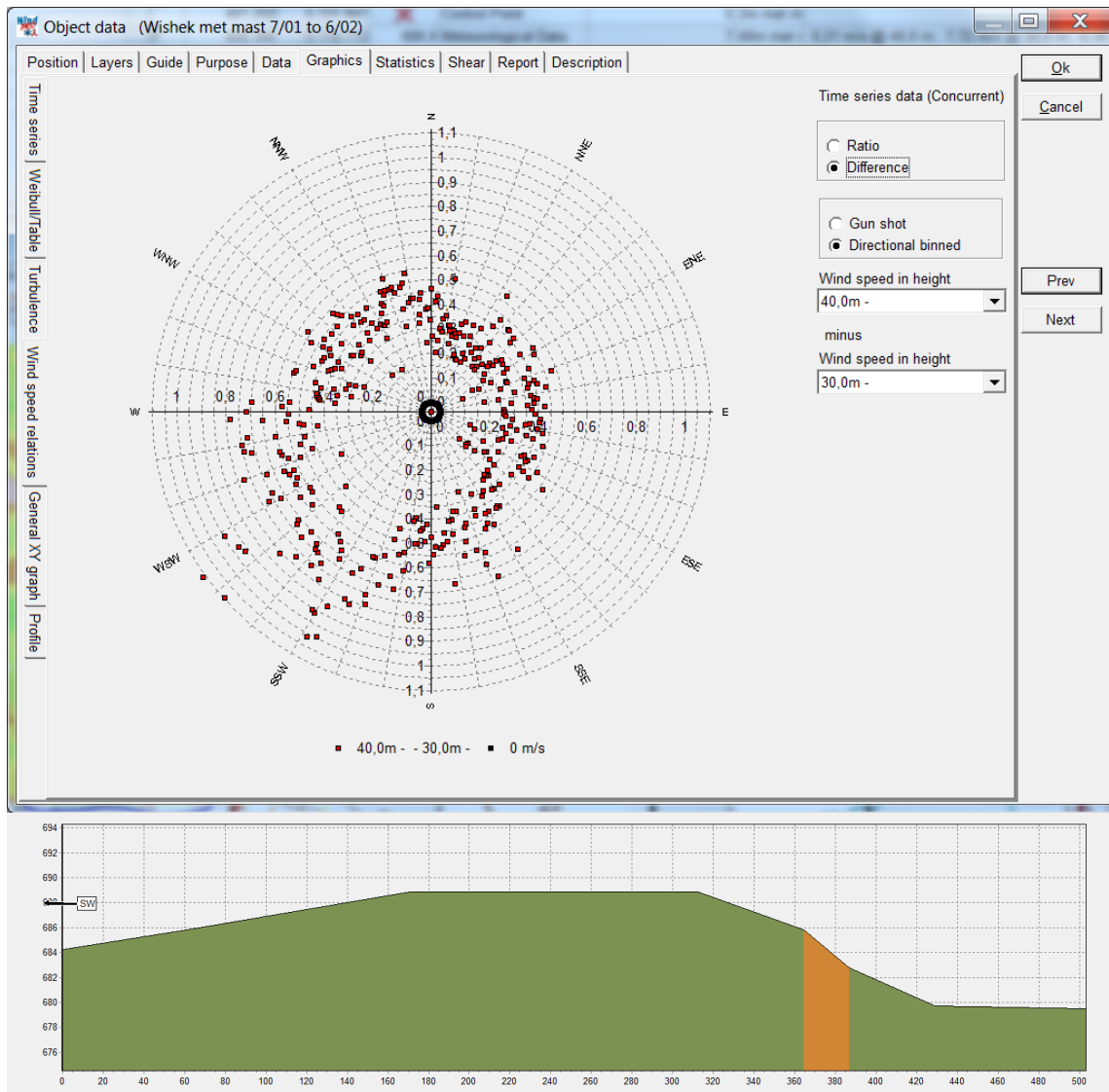
Figure 19 Showing difference, binned, the Shear is seen to be some higher at SW than NE winds. This is explained by the terrain profile, where the steeper hill towards NE gives more speedup in lower heights.

Graphics; Generel X-Y graph
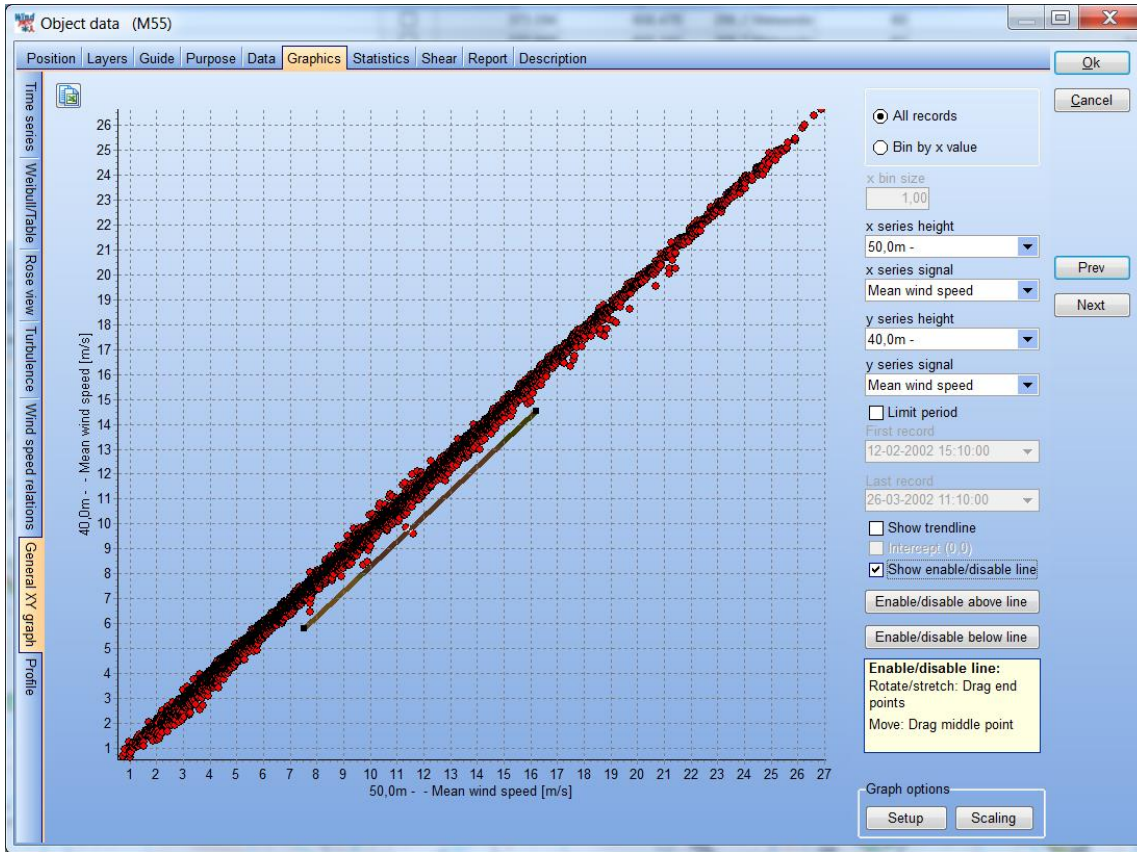
Figure 20 With the general X-Y graph you can plot any signal versus any other. When the cursor is placed on top of a point, the hint box shows the values and the date-time. This is an efficient tool to evaluate "outliers" – double click at the point, and the time series will be shown with focus on this point. Right click at point to disable or use the "disable/enable line" to disable a "block" of outliers in one operation.

Graphics; Profile
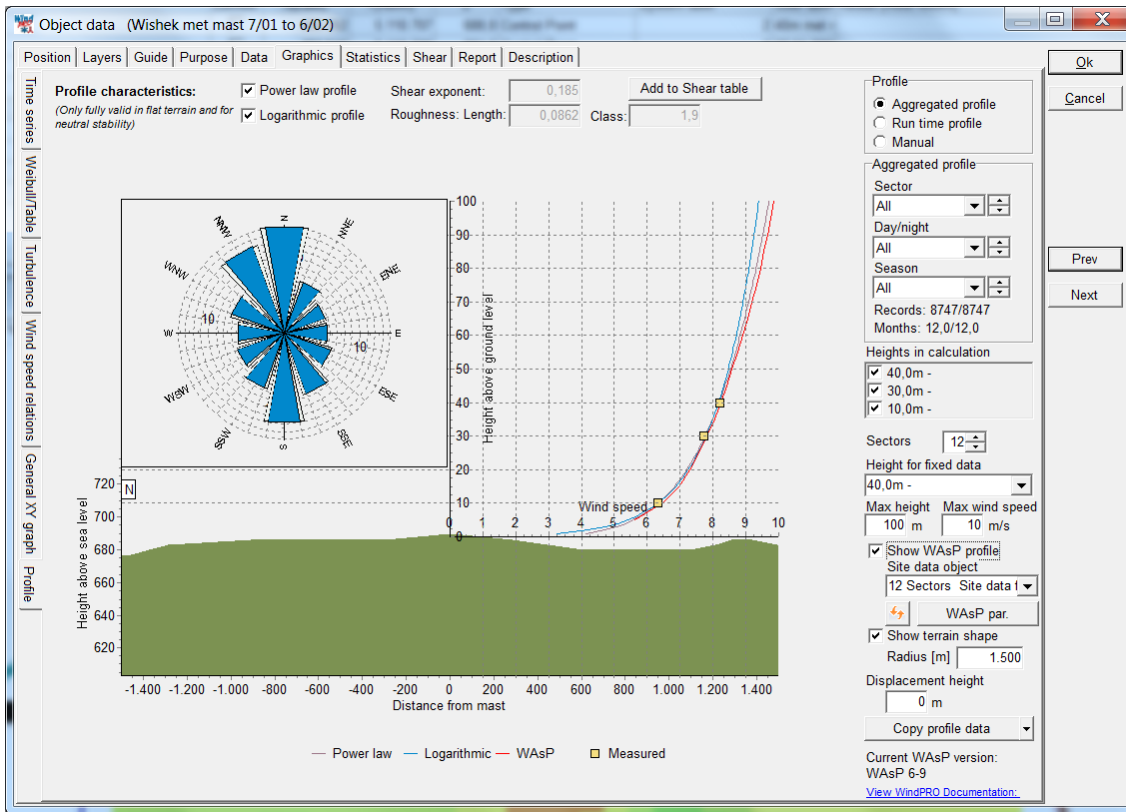
Figure 21 The profile viewer show as well the terrain profile as the wind speed profile. This is an efficient tool to analyze the data and compare to model calculations.

The profile viewer illustrates how the measured wind profile looks by showing the best fit of both power law profile and logarithmic profile. Also, a WAsP-calculated profile can be shown.

There are 3 view options;
- Aggregated (average values of concurrent data for all heights used)
- Runtime (record by record)
- Manual (aggregated, but manually controlled values for power and logarithmic profiles)

The "height for fixed data" will be used as input in WAsP calculation, if the WAsP profile is chosen. (WAsP can only calculate from one measurement height and creates the profile shape based on the flow and terrain model).

Note that only in flat terrain can the power or logarithmic profiles be extrapolated to higher levels with reasonable accuracy. If there are flow compressions due to hills, simple power or logarithmic profile extrapolations should NOT be trusted. Here the WAsP profile will be a better estimate since it will include corrections by a flow model to account for the compression effects.

Figure 22 To illustrate the capability of the tool, here one of the WAsP parameters are changed (Heat flux offset). This modifies the calculated WAsP profile (compare to previous graph). In especially warm desserts, the WAsP heat flux parameters should be changed. This tool makes it possible to find best parameters based on the measurements. But these changes must be handled with care – detailed knowledge on wind behavior is a must.

3.3.2.5 Statistics

Three different tabs for statistics;
- Main statistics
- Monthly means
- Availability (data recovery)

Figure 23 Raw views of main statistics.

Figure 24 By dragging "Signal" up into the header bar area, a more convenient view can be established.
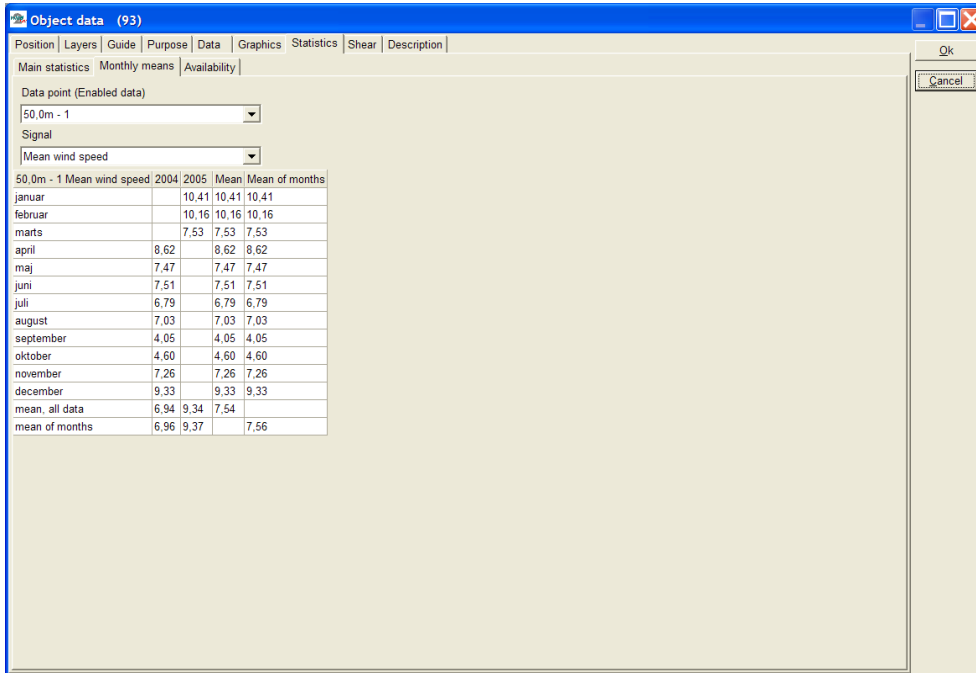
Figure 25 Monthly means can be shown signal by signal – by right click, the tables can be copied to the clipboard and easily integrated in documentation.
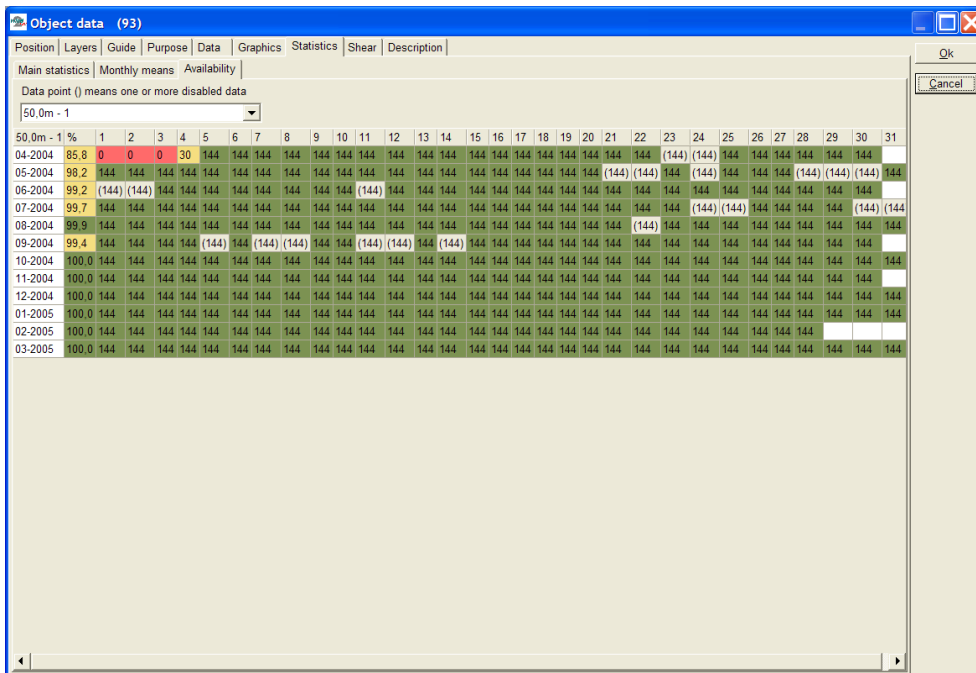

Figure 26 Availability can be shown height by height. Color coding gives a fast overview of the availability.
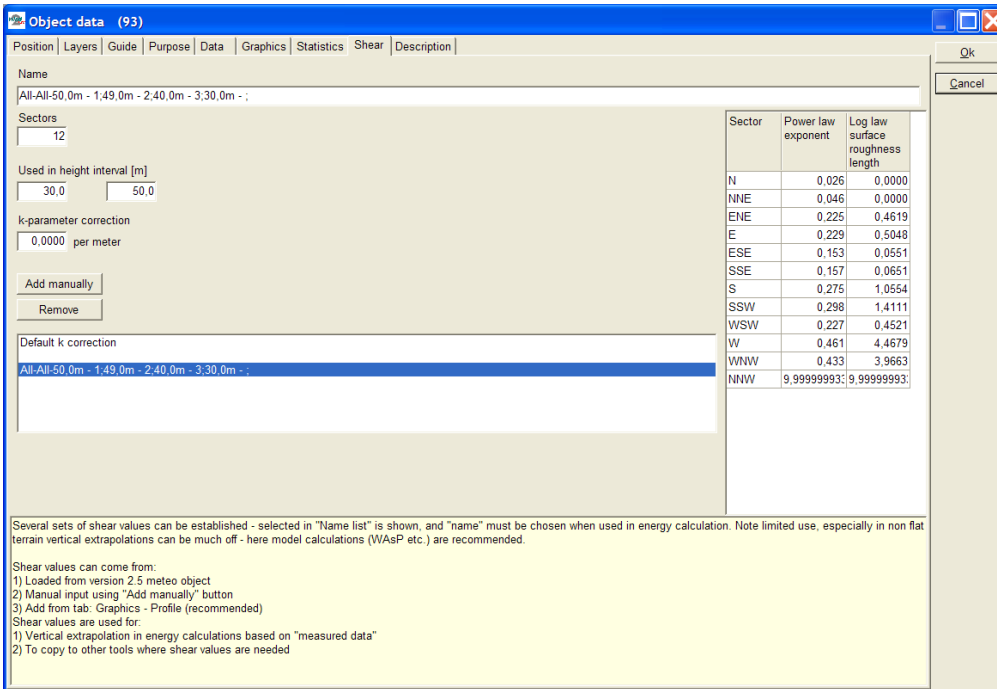
3.3.2.6 Shear

Figure 27 Shear can either come from v2.5 calculations, manual input or calculated from the graphic profile viewer.

The Shear tab can hold an unlimited number of shear calculations. The text in the box explains the use of the shear tab.

The shear calculations do use Weibull mean wind speed. Only direction from one height is used, so the mean Weibull wind speeds used is based on concurrent time records. This is a change implemented in ver. 2.7, where the calculation previous were based on each heights own direction sensor, if present. We found this change more correct and robust, while we often saw direction sensor problems leading to unrealistic shears in some directions, leading to unrealistic results using the shears.
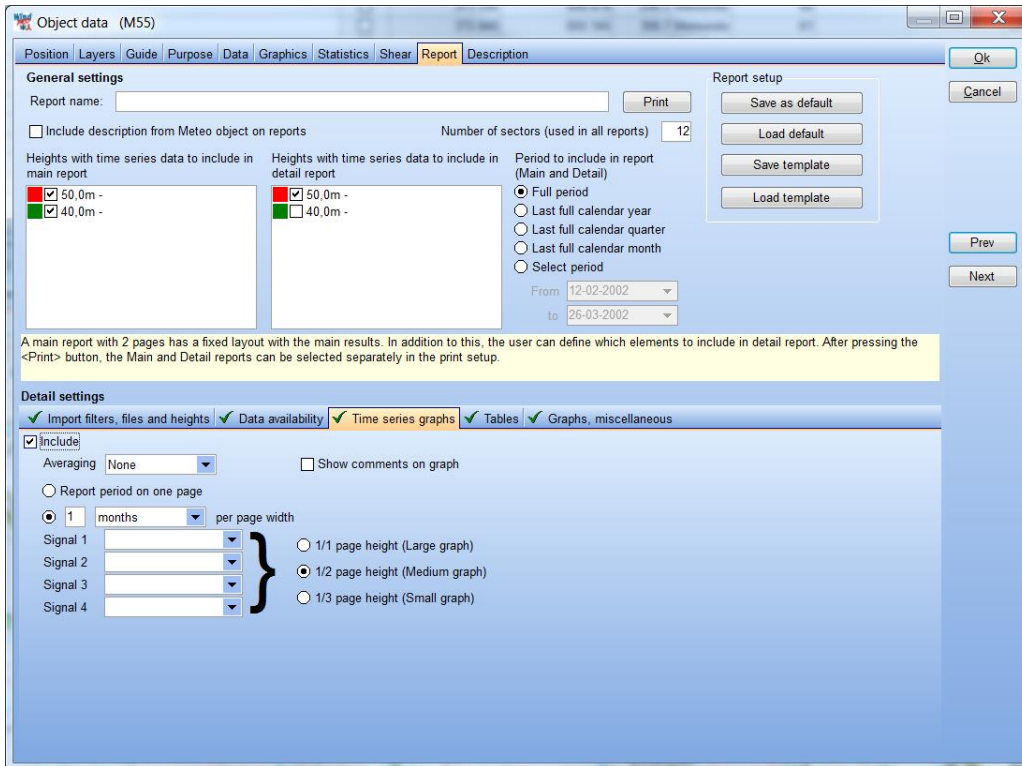
3.3.2.7 Report

Figure 24 The Report tab allows for setting up a report, where a number of optional tables and graphics can be selected. A template with preferred setup can be saved for later use.

To define the report should be self-explanatory.

When all data are entered, and reports eventually printed for documentation, click "OK" and the data can then be used from the calculation menu. If you intend to generate a Wind Statistics using WAsP, you must enter a Site Data Object, we suggest STATGEN, with a description of roughness, hills, and obstacles around the measurement tower.

Performing a STATGEN calculation will automatically transfer the necessary data to a WAsP-calculation and create a WAsP .lib file (by default the native WindPRO format .wws, which holds additional information.

3.3.3 METEOANALYSER

The MeteoAnalyser is a tool started from the left tool bar [icon] or the tool menu.

The MeteoAnalyser works directly on the data in the Meteo data objects. MeteoAnalyser works on data from more Meteo data objects in parallel and can therefore also perform operations that are not possible within the individual Meteo data objects, such as:

Graphic comparison of data from more Meteo data objects (measurement masts)
Disable/enable concurrent data from multiple masts
Substitute / Fill data from one signal to another – scaling optional!
Cross predictor – set up and perform a cross prediction analysis based on the WAsP model from height to height, and mast to mast (test accuracy of vertical and horizontal model extrapolation). In addition RIX correction parameters can be found with the cross predictor.
Time variation data files (.WTI) can be generated from one or more measurements by merging/interpolation/patching. The WTI files generated holds a complete 1 year data file with user defined time resolution for use in time varying PARK calculations or for detailed Loss calculations.

An example of its use:

Situation:

A user has data from two wind measurement sensors at the same height placed on the north and south sides of a mast. They may want to use the north sensor when wind is from 270⁰-90⁰, otherwise use the south sensor.

Method:
- Use "Advanced disable/enable" (available both in Meteo data object and in MeteoAnalyser) to disable all data in north sensor from 90⁰ – 270⁰.
- Create a substitution data series based on this meteo height (data series).
- Substitute all disabled data from the south meteo height (data series).

Now the substituted data series holds the required data.

The example above are although "overruled" but the previous explained "Merge" function in the Meteo object, but it still illustrate functionality. Another example often used. On one mast or height, the wind vane is out of order for some period. The direction signal is substituted in that period from either meso scale data or from another mast nearby.

A strong feature in the Meteo analyzer is that it can update data import in several meteo objects at a time. If new data files are copied to the relevant folders, the "Load new files" will work for all selected masts/heights. And, using the "create meteo object from on-line data", makes it possible to download several sets of online data in one process.

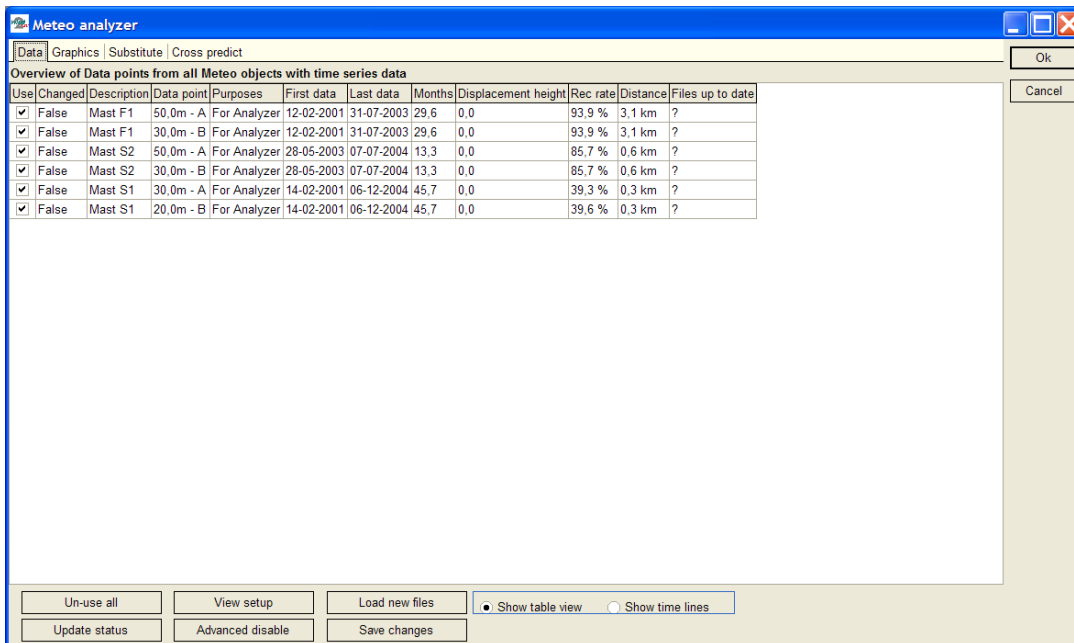## 3.3.3.1 Compare time series graphics for more measurement masts

Figure 25 Selection of data - here the data you do not want to use for "analyzing" can be deselected (Unused).
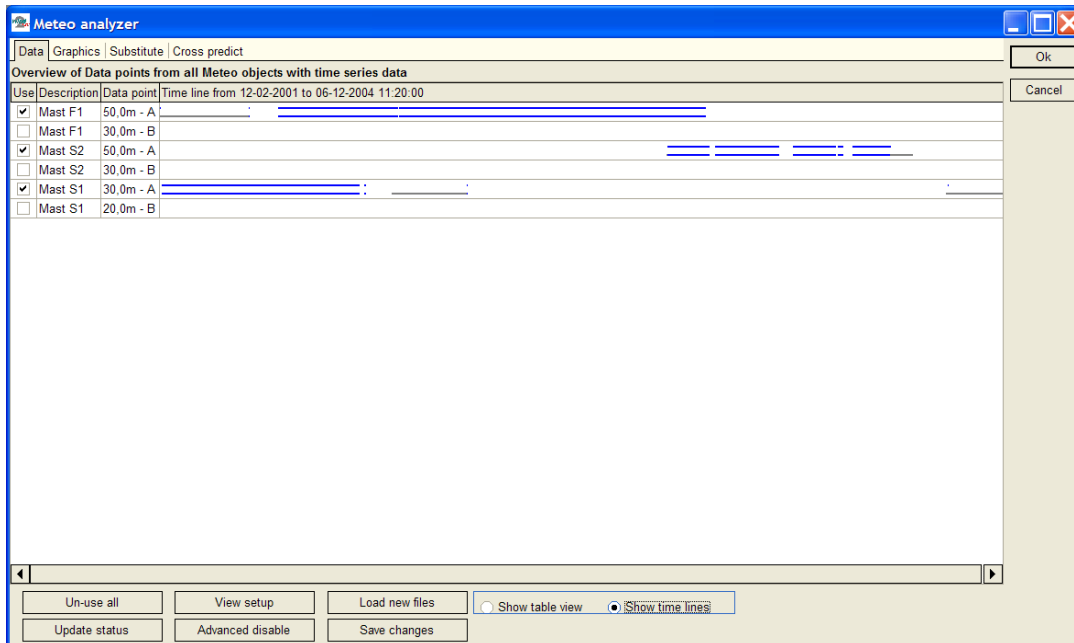
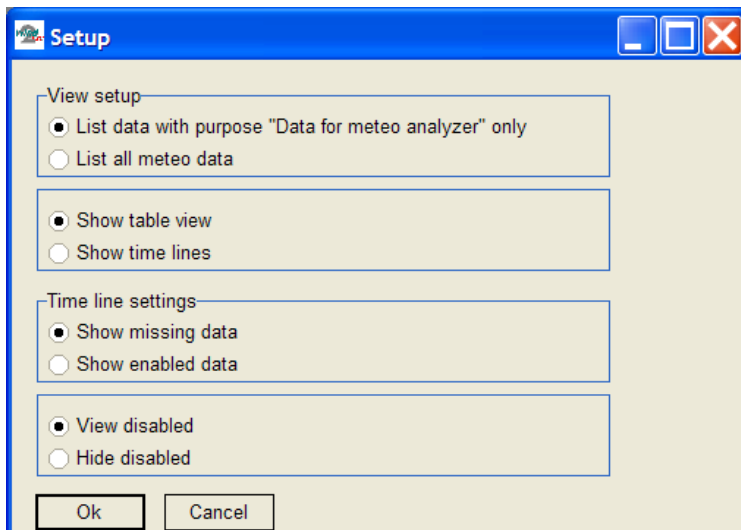*Figure 26 The "Show time lines" gives a nice overview of selected data.*

Figure 27 The view setup gives access to showing time lines with different settings.

Figure 28 In the "graphics" tab, you will see basically the same graphs as in Meteo object, only now with comparison of data from more Meteo data objects.

3.3.3.2 Perform data substitutions from other measurement signals

First a data series for substitution is created – or selected if one or more previous series have been created. The name of a substitution series will get the extension "Subst." as the last part of the name.
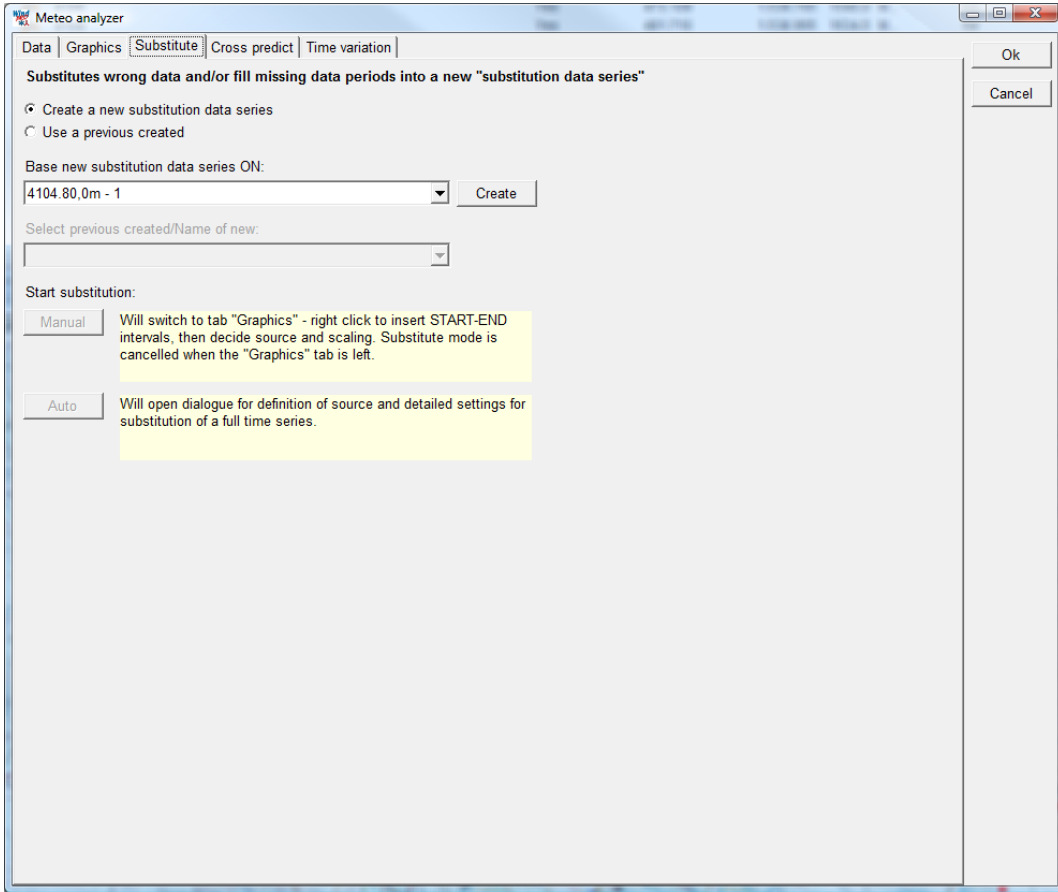
Figure 29 On the Substitute tab you can create a data series copy from one of the existing data series (heights) that will work as the new series into which substitutions/fillings from other data series can be performed.

There are two ways to perform a substitution;

- **Manual**; based on graphic view, where intervals for substitution are marked manually.
- **Auto**; where the entire time series is substituted based on the rules defined by the user.
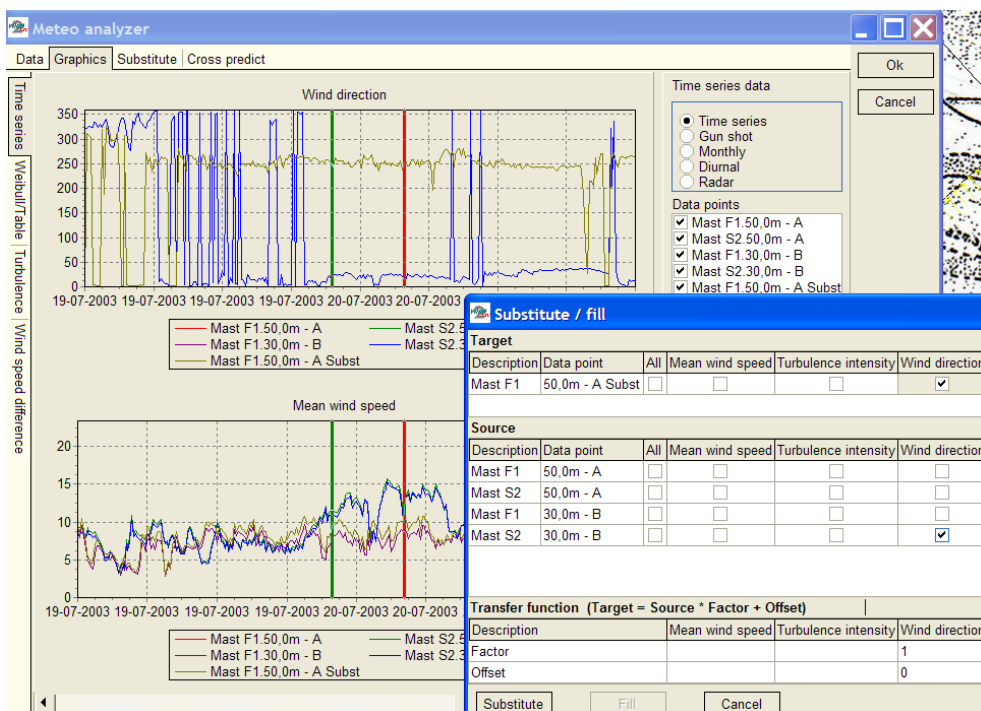
Figure 30 Manual substitution; select "start" and "end" of interval by right click, and the substitution settings appear. Here you can decide which signal(s) are to be substituted and the source and transfer function (scale and offset).

Figure 3281 Auto substitution: Set up the rules for substitution, typically only disabled and missing data records will be substituted (while disabling of "bad data" is performed first), and only enabled data used for the substitution.

3.3.3.3 Cross predict; WAsP vertical and horizontal extrapolation

Cross prediction from one mast or height to another by a model based on concurrent data is the best way to find how well the model performs for the site. This is a very time consuming process in previous tools, but can now be performed with a single mouse click - and some waiting time for the calculations.
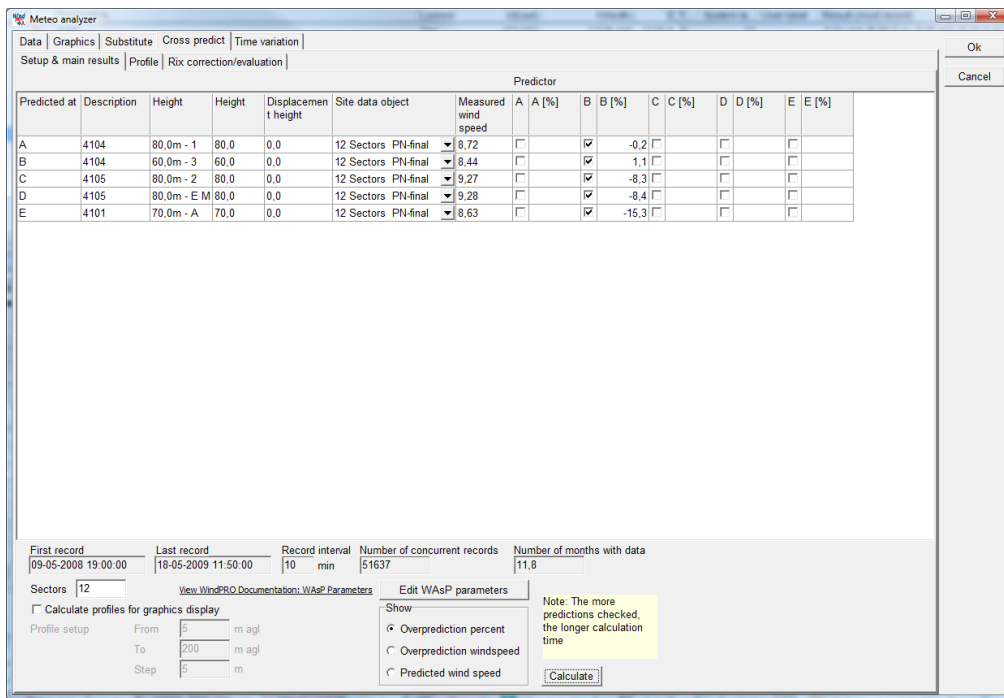
Figure 32 The WAsP model capability of horizontal as well as vertical extrapolation of data is tested in one process on concurrent data. Above, a calculation where, listed as Prediction B, Mast 4104 60m predicts other heights and other masts. At Mast 4104 itself at 80m it under predicts by 0.2%, at mast 4105 it under predicts by 8.3-8.4%. So here vertical extrapolation is reasonable, while the horizontal prediction is poor. At mast 4101 it under predicts with 15.3%.

The cross predictor tool is also a very convenient tool just for extracting concurrent mean wind speeds from more data series. Data can be copied to clipboard by selecting the cells to copy and right clicking.

If cross predictions are poor, there can be several reasons like:
1. Measurement equipment is poorly calibrated
2. Masts are wrongly positioned in the terrain
3. Terrain is not described well enough (roughness, height contours, local obstacles)
4. The wind climate is not the same at the different masts (and thereby the model cannot cross predict, while this assumes the wind climate at the site is the same). This could be if one mast is close to a mountain ridge that gives meso scale wind flow modifications.
5. The steepness in the terrain is high and "known model problems" (flow separation) results in poor model handling of the wind flow transformation.

For the last one a "fix" is developed by Risø, the RIX correction. If this seems to be the problem, the tab RIX correction/evaluation can be used to find the best RIX correction parameters (end to evaluate if the RIX method seems to fix the cross prediction issue):
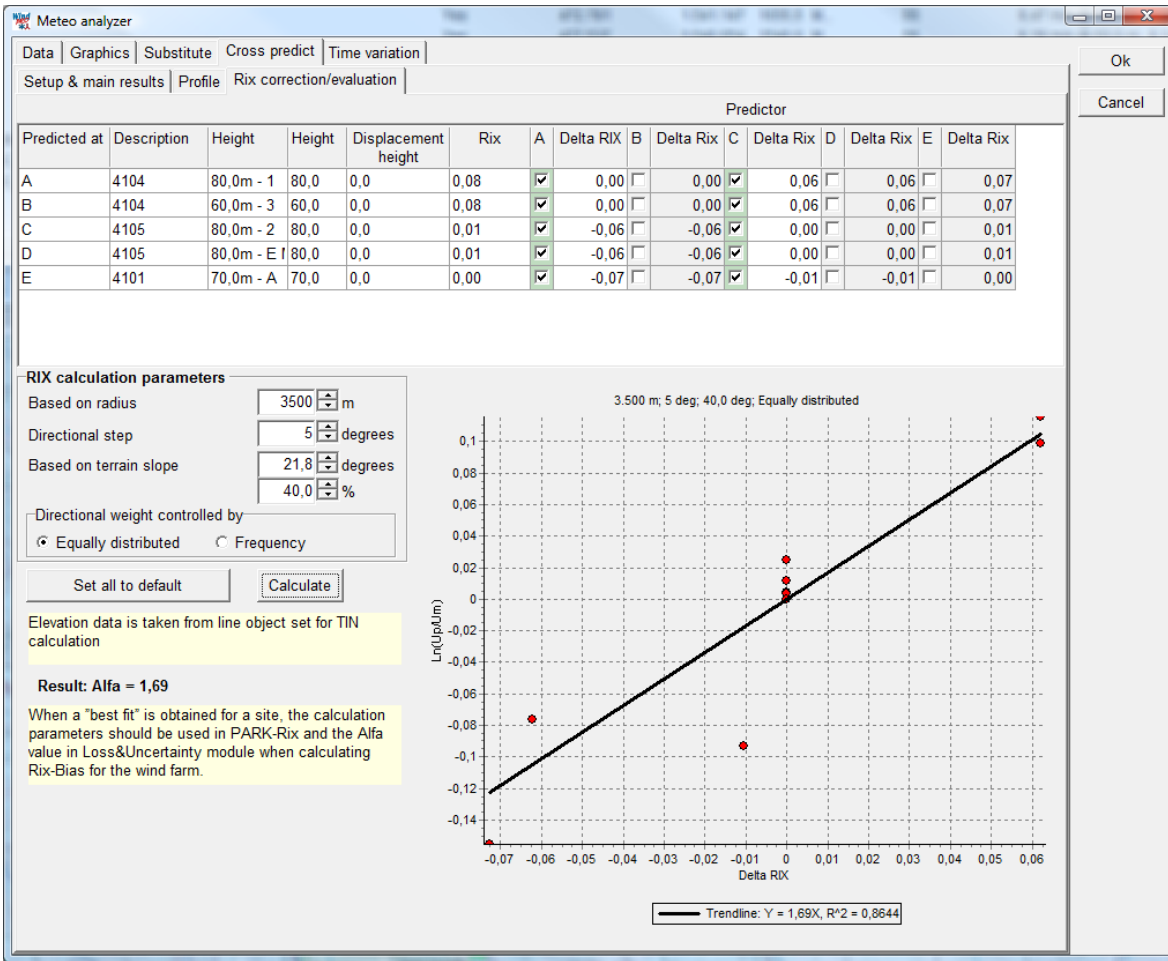
Figur 33 The RIX correction/evaluation tool shows the logarithmic wind speed deviation versus the Delta Rix. From the trend line based on the cross prediction errors, the Alfa value that can be used in the Rix Bias calculation in the WindPRO Loss & uncertainty module can be found. In the graph above it seems reasonable that RIX can explain the cross prediction errors (all points on a reasonable straight line). The found Alpha = 1,69 would be the choice in the RIX correction, that can be performed in the Bias part of the Loss & uncertainty module.

Only the cross predictions calculated at previous tab can be used in the Rix evaluation. See further documentation on RIX calculation in 3.4.3.1 RIX calculation or in Loss & uncertainty manual Bias part.
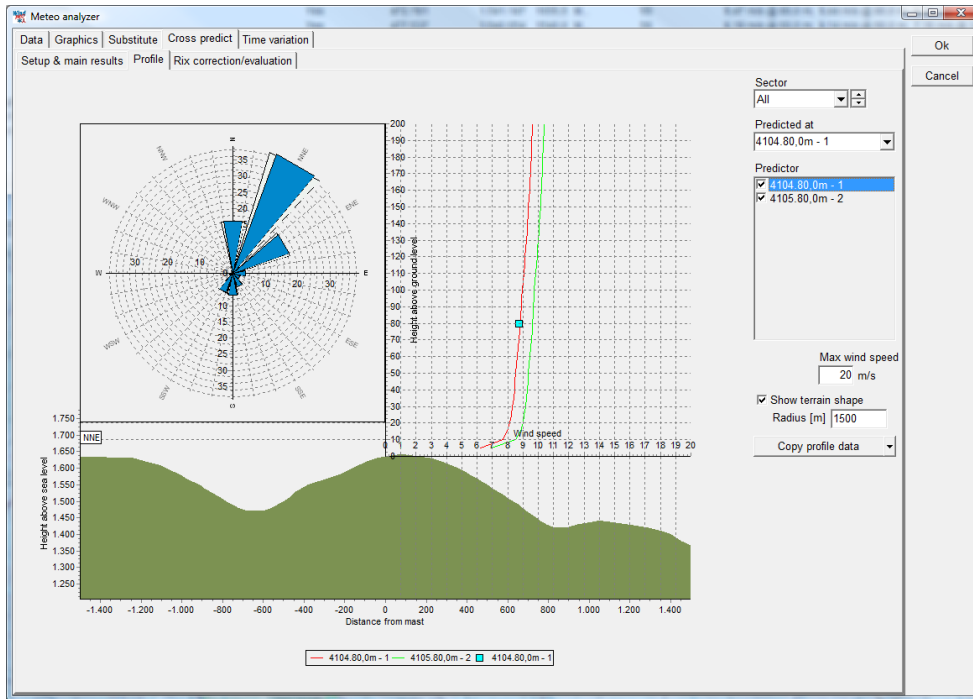
Figure 34 Finally, the prediction versus measurement can be inspected with the profile viewer. But note only one measurement point is shown, the one from the selection "predicted at". But more profiles can be shown based on the different predictors (if more exist). For analyses of how well the vertical profile is predicted, use the Meteo object.

NOTE: The profiles are ONLY shown if you have checked the "Calculate profiles for graphic display" BEFORE calculation. See form below.

3.3.3.4 Time variation; Complete 1 year data from .WTI file generator

WTI (WindTImevariation) is the file extension selected for the generated file with time varying wind data (and other meteorological data). Therefore, the tool described below often is named the WTI generator.
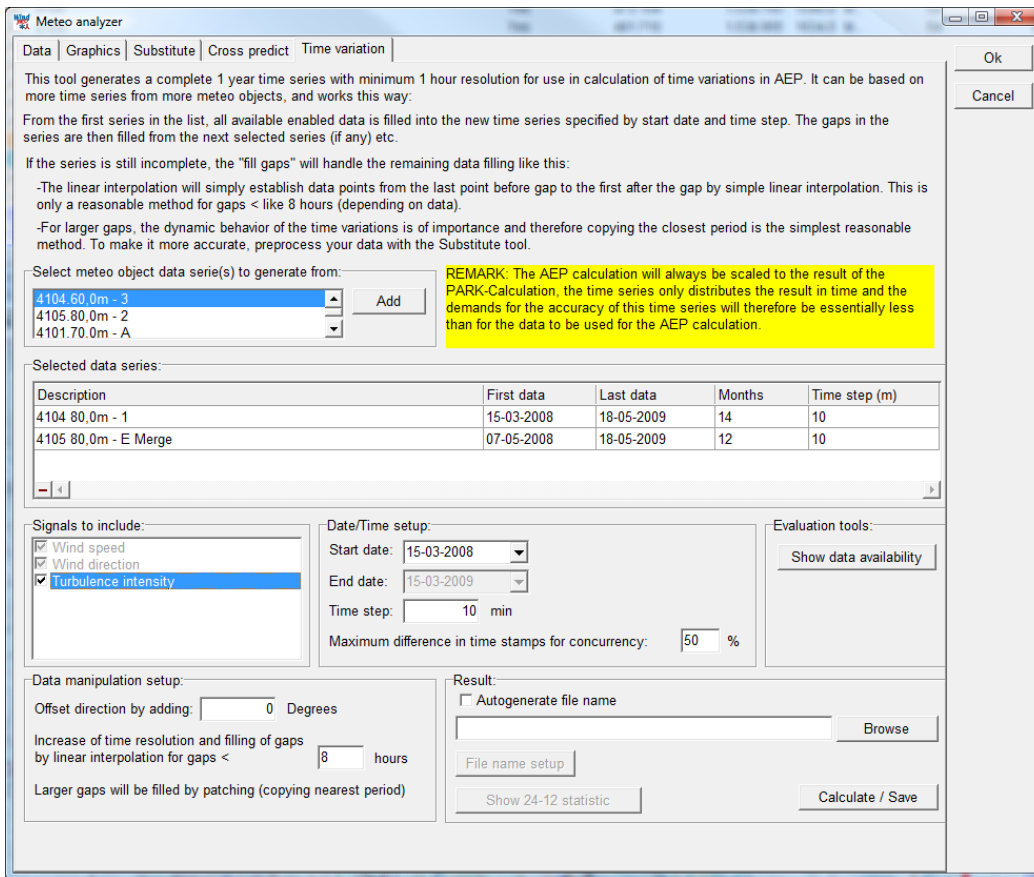
Figure 35 The setup for generation of a complete 1 year wind data file for the purpose calculation time varying AEP and/or detailed loss calculations.

The basic idea with the tool for generating a complete 1 year wind data file is that for some purposes like calculation of the expected AEP variation in time (as e.g. 12-24 tables for negotiation PPA), an often seen problem is that half a month of data is missing. There will, therefore, be no production calculated that half month. Leaving out half a month is of course, not realistic, but it might not need to be a very accurate calculation for that half month. Then the WTI generator is convenient, while this can fill in the gaps in reasonably intelligent ways and make sure that every 10-minute or 1-hour has a reasonable value for wind speed and direction (and other parameters like temperature, if selected).

Another use is in loss calculation. If e.g. the loss due to shut down below -20 ^{o}C shall be calculated, a time series with both wind and temperature can be used, where the loss module finds how much energy is calculated to be produced in the time steps where temperature is below 20 ^{o}C. If the temperature sensor was not working all the time (1 year) or simply not present, data can be substituted from nearby met station or NCAR data into the basic measurement, so all relevant time stamps are included after the data has been processed by the WTI generator.

Basically 3 methods are available for filling gaps:
- Take from other measurement (other height, other mast or like NCAR data)
- Fill the gap by linear interpolation (if the gap is smaller than X hours)
- Fill by patching (copying nearest period of same length into the gap)

The 3 methods can be used in combination. Data will be "resampled" to any user defined time resolution, but typically a 10 minute or 60 minute resolution should be used. NOTE: taking data from another mast does not include any scaling options. Eventually, scaling is needed to bring the two masts to the same level. This must be done up front by the substitute part in the MeteoAnalyser.

The .WTI file is, by default, saved in the project folder and can be selected from PARK time varying calculation or from Loss & uncertainty module. The wind speed data is automatically scaled to the calculated mean wind speed for the actual site for as correct a distribution of the calculated AEP on time stamps as possible, even though the data might not be from the hub height or maybe not even from the site.

3.3.4 Input for a PARK calculation

It's not necessary to create WTGs as objects in order to perform an ATLAS or WAsP calculation. Instead, you can choose which WTGs and hub heights to calculate when you launch the calculation.

However, when performing a PARK-calculation you must input the WTGs on the map, since it's their inter-placement and WTG-type that is essential for the PARK calculation.

If the wind farm is extended over a wider area, you may need to use several Site Data or Meteo Objects. Each turbine will then use the nearest object (only from the ones selected in calculation setup, by default, all are selected). Using digital roughness and height contour lines is the best method. Using a WAsP calculation for each WTG in the park will calculate the effect of the orography and local obstacles individually. To calculate the roughness classification individually, you must attach a digital roughness map produced by WAsP.

If you've created combined ATLAS and WAsP Site Data Objects, the PARK calculation will always use the WAsP calculation. However, if you want to use the ATLAS calculation as input for the PARK calculation, you must change the setting of the Site Data Object to only use an ATLAS calculation.

Details on how to input the more specific parameters for a PARK calculation are described in Section 3.4.1.

3.4 ENERGY – Calculations and Printouts

When all the objects have been created, you can return to the WindPRO main menu, e.g. by clicking on the Calculation Tree icon.
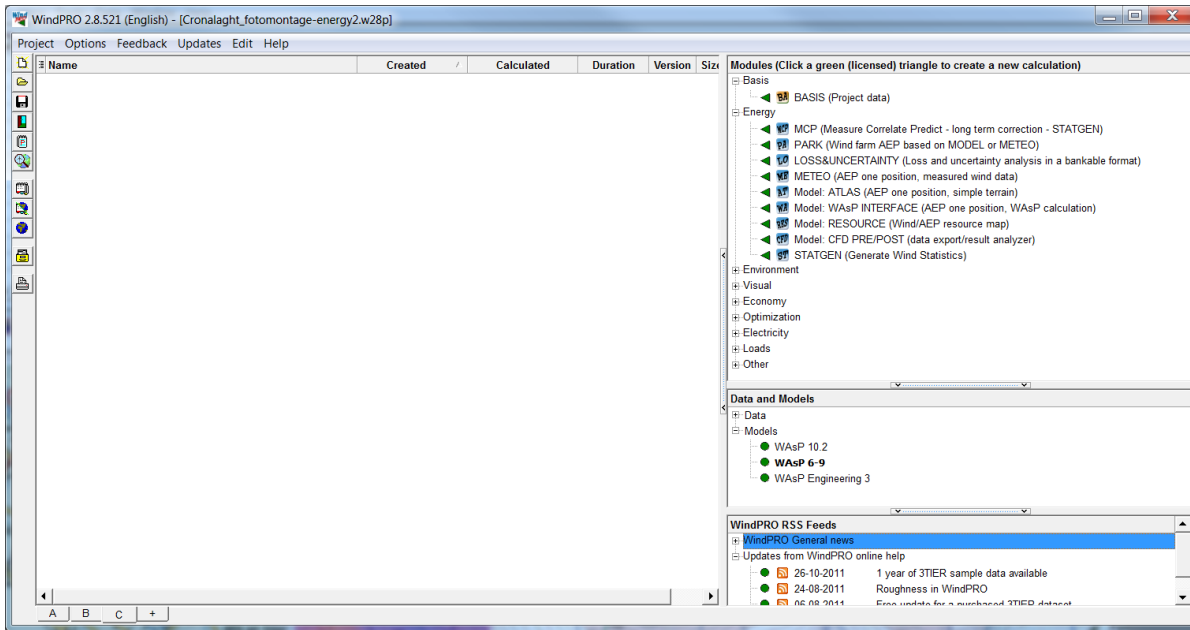
A calculation is started by clicking on the green button (arrow) beside the required calculation.

NOTE: Modules for which you have no license activated will be marked with a yellow button indicating that these will only run in DEMO mode (calculations will use standard values and not the actual values entered). If an arrow is marked with a T it means the license activation is time limited.
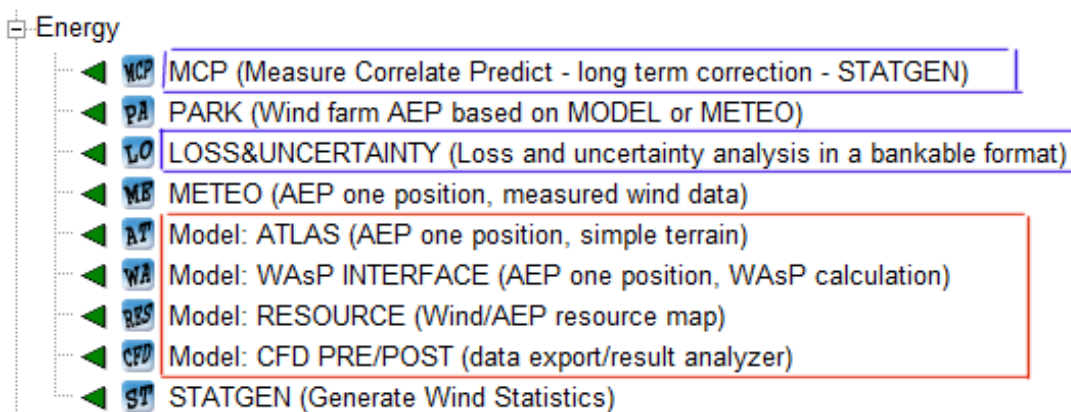
Figure 36 Zooming in on all energy related modules. The blue framed, MCP and Loss&Uncertainty have separate manual chapters. The ones in the red frame are sold as one module called MODEL. The last mentioned STATGEN is not "sold" but automatically activated if you have activated METEO and MODEL. The appearance is decided due to the "natural way" of performing the work: 1) Make the long term wind statistic (MCP), do the layout/PARK calculation and 3) Do the loss & uncertainty calculation. On this direct road, there might be need for "auxiliary calculations", like wind resource maps for layout optimization (see OPTIMIZE module) or WAsP interface calculations comparing different turbines at the site wind conditions.

NOTE: The Model (RESOURCE) Module is described separately in Section 3.6. OPTIMIZE module is not included in the Energy block, while this also can be used for Noise optimization, and possible optimization involving other parameters in future (like cost of energy).

The different Energy calculation modules are explained in the following; starting with PARK, while this is the normal choice for an AEP calculation, the other is more for "special purpose" calculations.

3.4.1 Calculation Energy: PARK (AEP for Wind Farm + RIX etc.)

3.4.1.1 Standard PARK calculation

Tab sheet Main

Under the first tab sheet "Main" you can enter general data for the calculation. Note the "Enable advanced options", which gives access to more input options, which will be explained later.

Calculate:
*   **AEP**; requires turbine object established on the map and wind data (can be in METEO object or a Site data object, which holds all needed information for a model calculation).
*   **Time varying AEP**; requires you have a .WTI file or a meteo object with time series data
*   **RIX**; requires elevation data in a line or elevation grid object set to be used for TIN calculation

For the two last mentioned, additional tabs for input specification will appear if checked.

Model parameters:
Wake decay constant – defines how much the wake expand behind the rotor. The default figure 0.075 means that per meter behind the rotor, the wake expands 7.5 cm. In "non advanced mode" the choices are:

A lower expansion (offshore) gives a higher reduction of the wind speed behind the rotor and thereby larger wake losses. In high roughness or high complex orography (mountain area), the "Very closed farmland" can be used. In advanced mode there are more options.

Report features:
Hub height for key results gives calculated mean wind speed, energy and the equivalent roughness class for this height at the location where the Site Data Object is placed.

WTG area(s) on map give the option to include selected WTG Area's on the map as part of the report.

Handling of losses and uncertainties:
Here it is decided how the user wants to integrate these issues into the reporting. It is recommended to use the Loss & Uncertainty module to give this important part of the AEP calculation the right focus. For more "simple" or preliminary calculations, the other options can be used. The "Add simple reduction" to compensate for bias, loss and uncertainty reductions, add an extra column in the report with the reduced AEP result. You can define the text written at the print. The default is "Result – xx%"

WTGs
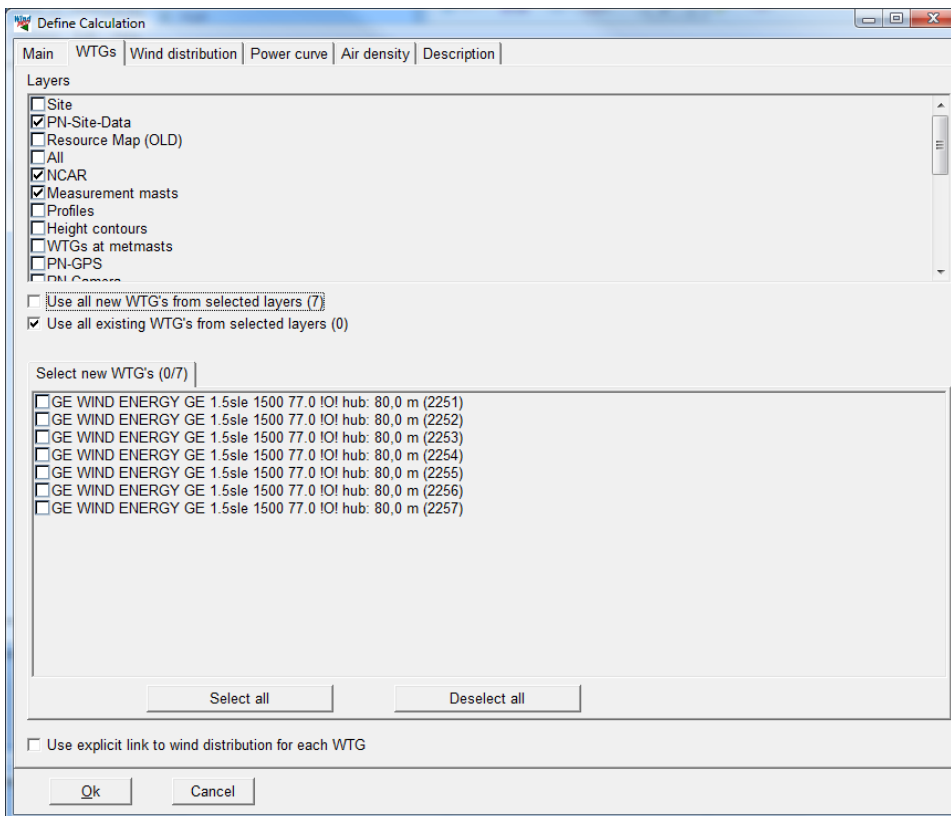
At the WTGs tab, the turbines to be calculated are selected. By default the turbines from visible layers appear, but other layers can be activated and, by unchecking "use all new from selected layers", turbines can be individually selected.

Checking the "Use explicit link to Wind distribution for each WTG" add another tab "Link site data to WTG":

Turbines with displacement height

If the input field "displacement height" is given a value on the turbine object, the calculation hub height is automatically reduced with the displacement height. In the report as well the turbine hub height as the displacement height are shown. The displacement height is typically used if turbines are sited in forests where the wind profile is assumed lifted by the forest.
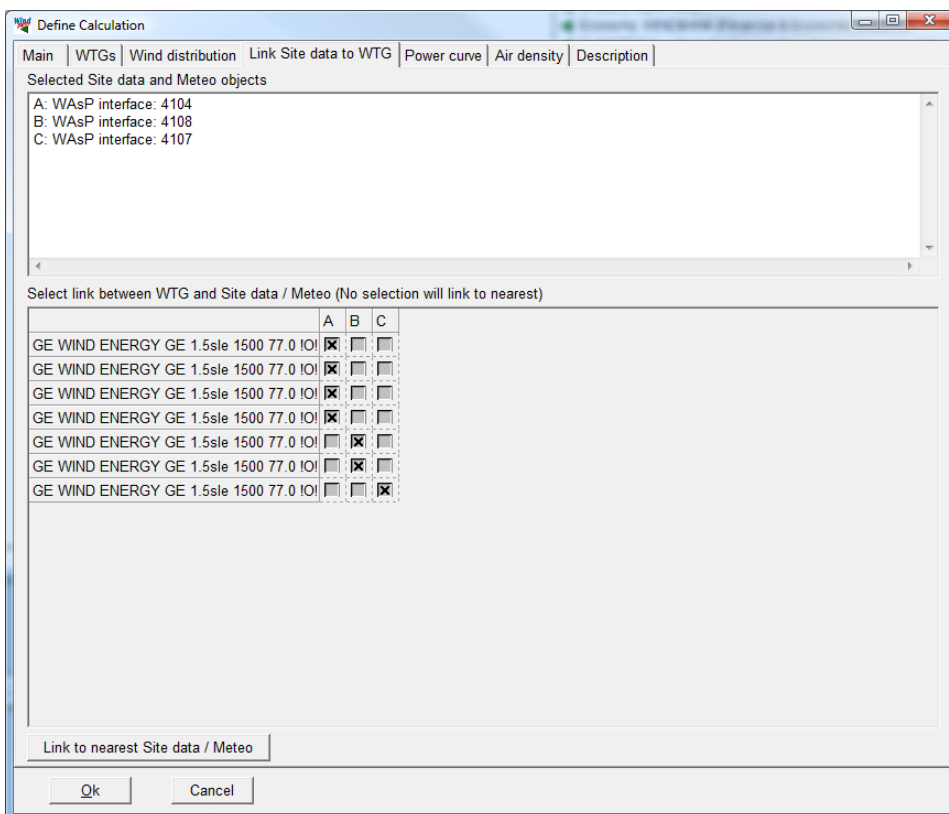
Before activating this, wind distributions must be chosen.

By default, each WTG "chooses" the nearest wind distribution object. In the matrix above, checkmarks can be moved so the user has full control as to which wind distribution object shall be used for which WTG.

Wind distributions
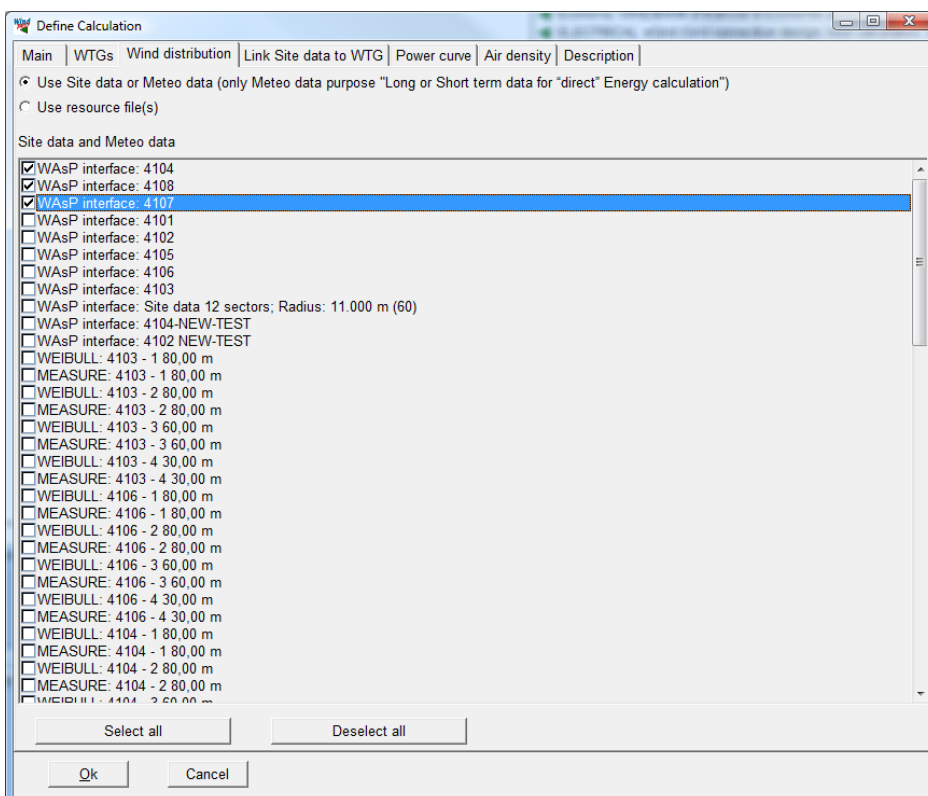
Wind distributions can also be allocated from site data objects as meteo objects – or based on wind resource maps.

Power curve
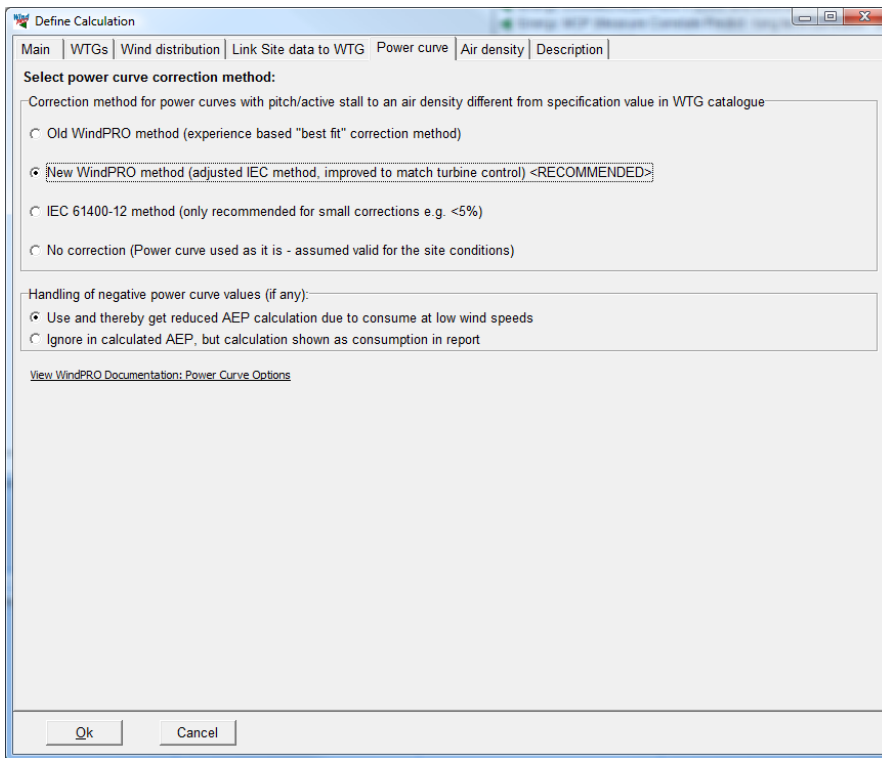
Power curves in WindPRO are normally only entered at standard air density (1.225 kg/m^3), and are then by WindPRO recalculated to the site air density. But the user can also enter the power curve in the turbine catalogue at local site air density and then choose "No correction" – or, basically, if the default correction is used and the site air density is used as input in the turbine catalogue as well as in the air density setup, no correction will be made.

There are more methods for air density correction, see the documentation by clicking the hyperlink text.

Some power curves have negative values, which can appear from 0 to around -4 m/s. But, most often the power values in this interval are set to 0. If the negative values are included, these can be handled two different ways:
1. Default: the power consumed at low wind speeds are included in the AEP calculation, and the AEP result thereby reduced.
2. Ignore the negative values in AEP calculation, but then report the calculated power consumed separately. This makes sense if a very accurate financial calculation is required, and the power purchase cost is higher than the price paid for delivered power.

Air density
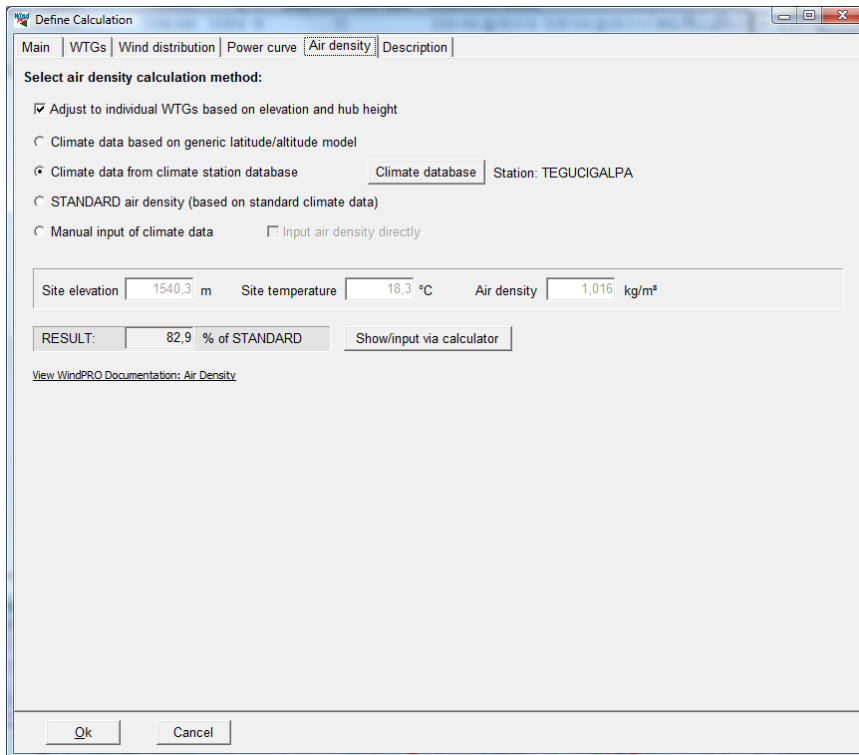
Air density is, by default, calculated automatically based on site location, where the altitude is taken from each WTG object and the temperature is taken from the nearest climate database point. This is the recommended method, but please check if the climate database parameters seem reasonable by clicking the ""Climate database" button:
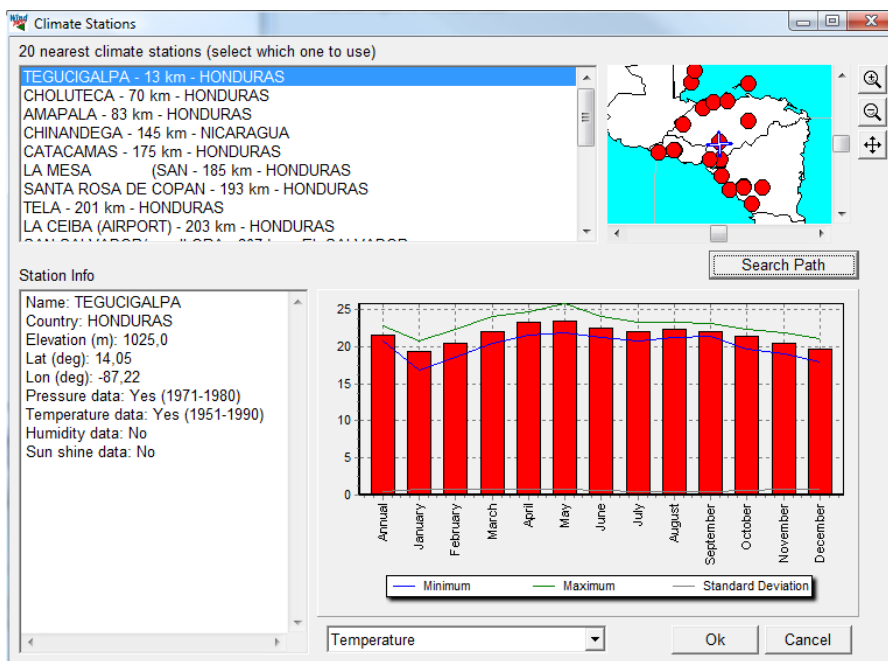
Important is that the Elevation for the climate station and the temperature is correct. If not, choose another station.
Eventually, also check how the air density is "scaled" from the climate station to the site by clicking the "show/input" via calculator:

Here it is seen how the climate station is located in 1025 m elevation and the site in 1540 m. The temperature is thereby converted from 21.6 to 18.3 ^{o}C and the pressure from 902 to 850 hPa. This reduces the air density for the site to 1.016 kg/m3 where it is 1.066 at the climate station. This is a 5% reduction which almost gives 5% reduction in calculated AEP relative to the use of the nearest climate data "as-is". It is also seen that the air density at this site only is 82.9% relative to standard, giving round 17% reduction compared to a site at standard air density conditions (15 ^{o}C at sea level).

3.4.1.2 Time varying PARK AEP calculation
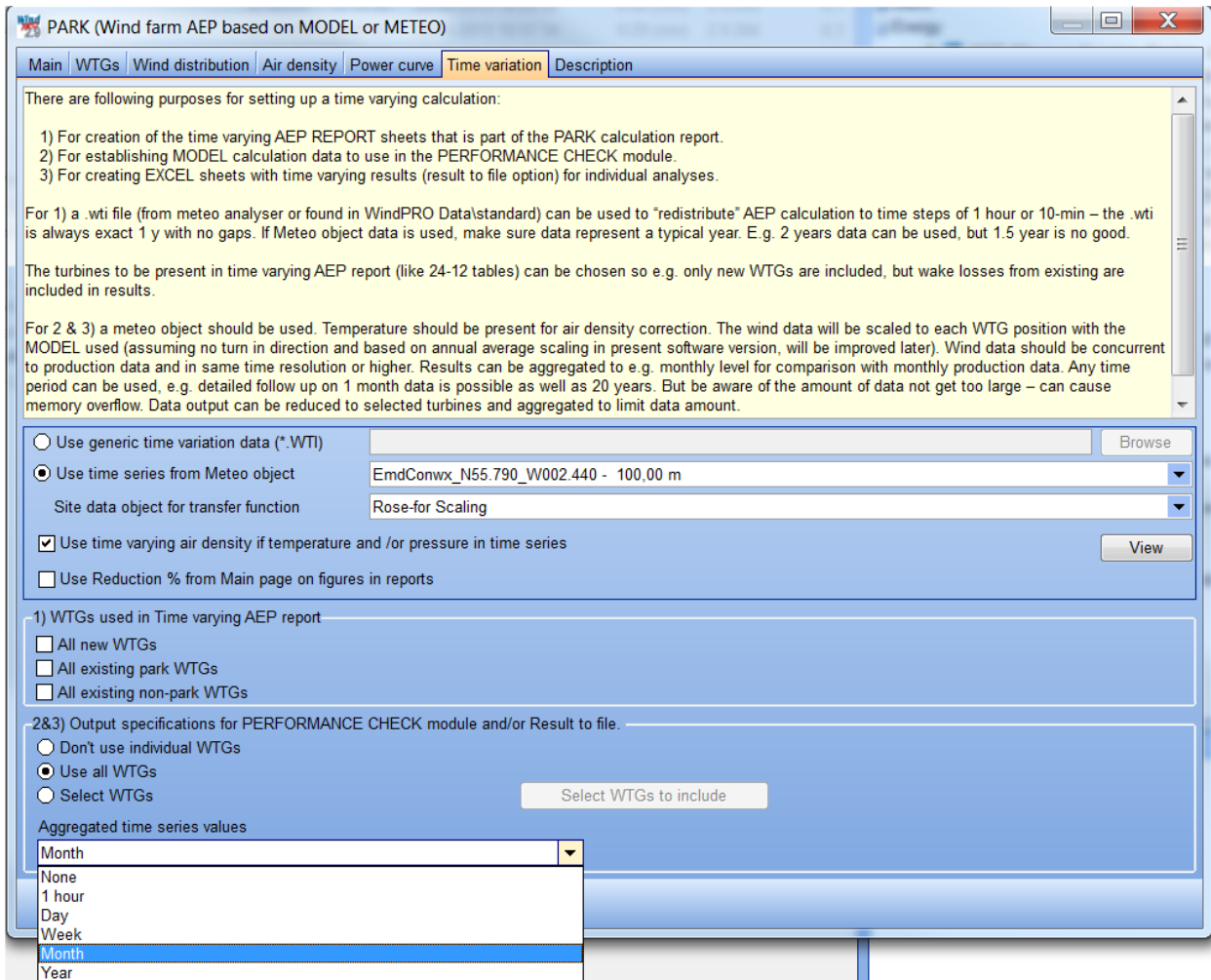
Time varying calculation is a powerful option for different purposes, where the two most important are:

2) **Create a statistic**, like the 12-24 (12 months-24 hours) matrix, that can be used for negotiating PPAs or for evaluation of how like time tariffs invoke the expected income from the sold energy. Also, the duration curve produced as a part of the time varying calculation is a powerful tool for evaluation of e.g. how many hours a year a specific power demand can be operated from the wind parks production.

3) **Create a time step by time step AEP calculation** for each turbine for input to the performance check Module. See details in the performance check chapter.

4) **Create a time step by time step AEP calculation** for each turbine for output to file or clipboard via the "Result to file" option. Data can be taken into like Excel for further analyses.

Output from the first issue is part of the standard reporting. For the second, the Performance check module can load the data by pointing at the PARK calculation. For the third, the "Result to file" option must be used. A text file is saved and can be loaded from Excel or similar. Or data can be transferred directly via clipboard. While the data amount can be extreme, by default only the PARK AEP is available. Checking "save for each WTG" create 5 data columns for each WTG (see later figure) – together with one row per time step. Therefore the output can be aggregated on hourly, daily etc. level. Especially if the actual productions you shall compare calculation values to only are monthly, there is no need for more detailed calculated data.

NOTE: For ALL Time varying calculations, the AEP results are scaled to the non-time varying calculation, so the reader of the reports does not get "confused" by varying results. The calculated "Power" in the result to file, represents the "raw" calculation result and is therefore best suited for checking how the model performs, and is the output used by the Performance check module.

If a calculation is based on a WTI file, the result is a simple scaling of the calculated AEP (the normal PARK AEP calculation) based on a wind energy index time step by time step created from the WTI file, where the mean wind speed is scaled to calculated mean wind speed for each turbine. Same procedure, if the PARK calculation is based on Weibull or Measure wind distributions, also if a METEO object is used instead of WTI file.

If a calculation is based on a METEO object in **combination** with a WAsP calculation (wind distribution chosen as site data object(s) with terrain specifications) OR a resource map, the measured wind is transformed by the WAsP model from mast position to each WTG position on directional resolution (sector wise).
So this shall be used if a WAsP model performance check is wanted. There will be calculated mean wind speeds for each sector at mast and each turbine position based on the data in site data object(s) or wind resource map chosen at the "wind distribution" tab. The ratio calculated; **turbine mean wind speed/mast mean wind speed (sector)**; is simply multiplied on the measured wind at the mast (sector) for the given time stamp, and this is used to calculate the power for the time stamp (after the wake loss model has reduced wind speed). Possible turning of the wind (in very complex terrain) is not yet implemented, which can make this method making wrong conclusions. Note the site data object(s) chosen from tab wind distribution work as usual, meaning if it is roughness roses, each object select the nearest by default, if it is roughness lines (recommended), an individual roughness is established at each object position (turbines and mast). By wind resource maps (which can be from other models than WAsP), results must be available in both turbine hub heights as Meteo data height.
Pay special attention to that a site data object can be selected for "transfer function". This can be used if e.g. meso scale data is used, and these need a special scaling to match the micro scale level. The site data object for scaling can e.g. be a roughness rose (only WAsP 9) with flat terrain. By scaling the roughness sector by sector, a match between the meso scale data and a local mast or turbine production can be obtained sector by sector. This is an iterative process that typically will require the Performance Check module, but very powerful way of "downscaling" the Meso model data to match the real site wind.

For issue 1) mentioned above, it is important to have a full representative year of wind data. No gaps in the data. This is best secured by generating a WTI file (see MeteoAnalyser). The "View" button can be used for checking the content of the file (or a meteo object data series):
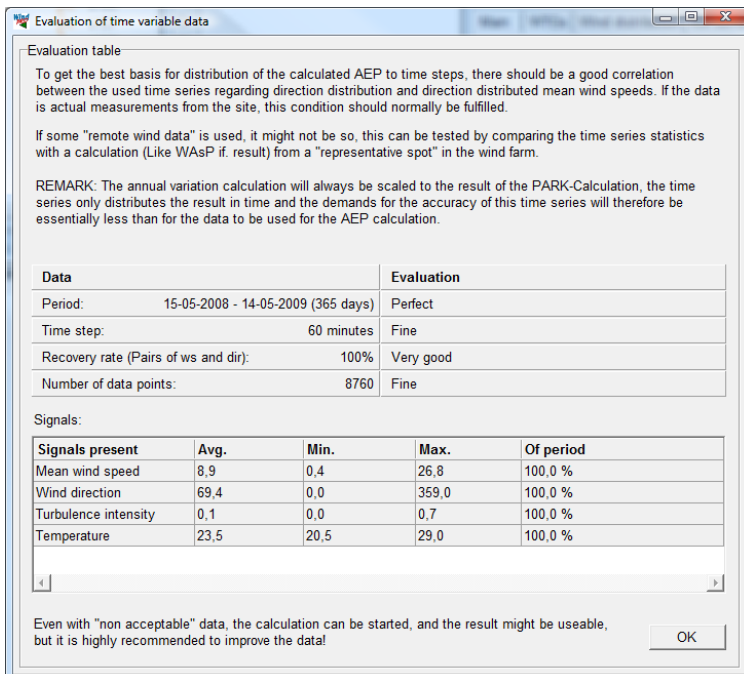
For issue 2), the length of the period is less important. What is important is to have local wind measurements concurrent to actual production data. A performance check can be performed on few months or more years of data. A problem can be the amount of data, if hundreds of turbines with several years of 10 min resolution data are calculated; there might be RAM overflow on the PC. Therefore, by default, only the sum for all turbines in the wind farm is reported in the result to file report. It must be checked on the input form if you want results turbine for turbine. If the data amount is too large, you can split your Meteo data in more part time series, e.g.

by cloning the Meteo object and then delete different parts of the data. After more part calculations these can be merged in Excel.
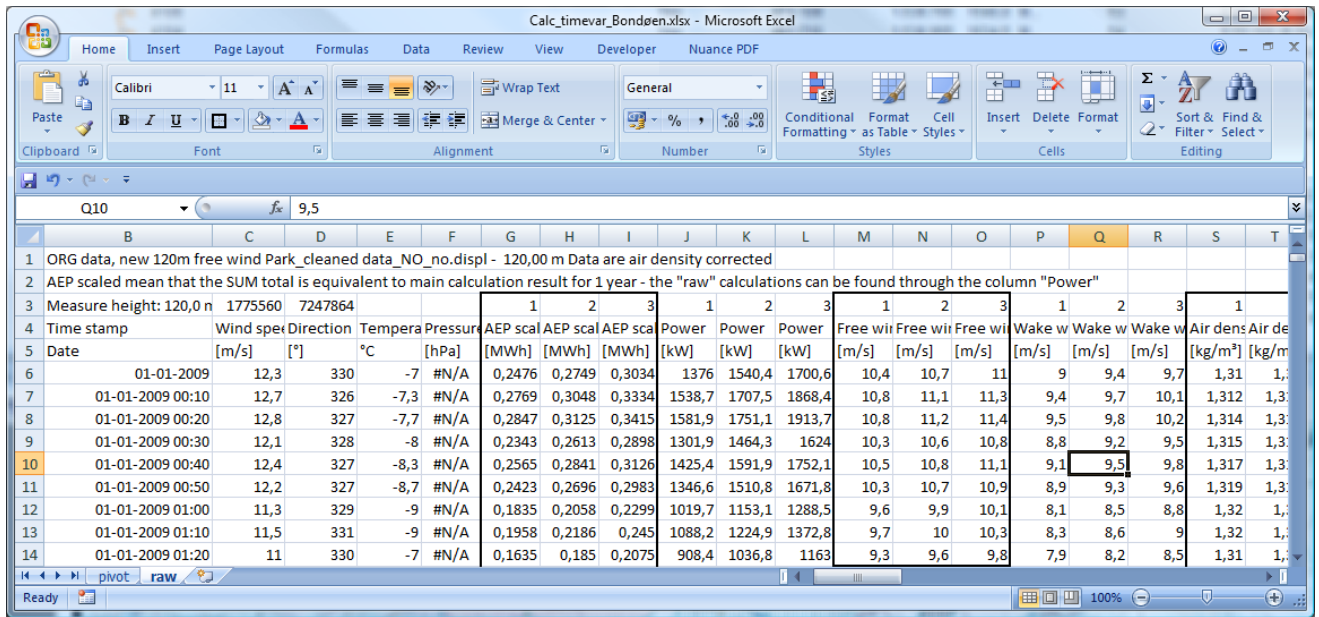
Figure 37 The result to file into Excel. Here an example with 3 turbines. The columns are explained below.

Time stamp, Wind speed, Direction, Temperature and Pressure all come from the used meteo data series (or WTI file). If temperature and/or pressure are present an air density correction is performed for each time step. Pressure data is less important than temperature data while temperature variations typically influence air density much more than pressure.

AEP scaled – the calculated AEP scaled so the sum is the same as in the PARK main result. (so there are not different, confusing results). This can be used, e.g., if a utility want to know expected AEP hour by hour for analyzing the expected value of the wind production.

Power – the raw calculated power time step by time step. This is NOT scaled and should be used for comparing with actual power taken from turbine controller or Scada if model calculations shall be tested.

Free wind speed – wind speed transformed by WAsP to WTG location, before wake reduction.

Wake wind speed – wind speed transformed by WAsP to WTG location, after wake reduction.

Air density: The calculated air density for the specific time step and turbine.
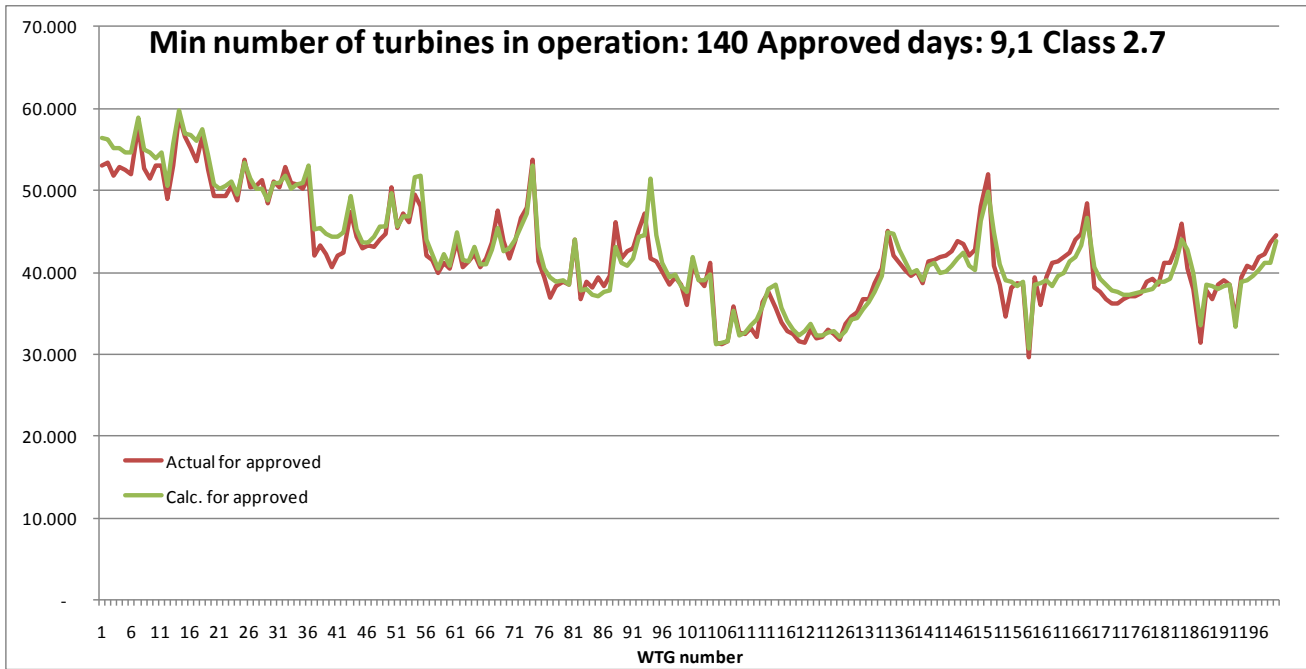
Figure 38 Example of a model performance check with 200 turbines calculated by 10 min. values. The data is sorted so only the time steps where most turbines are in operation (which are few days in this example) are included. The sample show there is a very fine correspondence between calculated and actual production, but in this case the model has been manipulated by increasing the roughness inside the wind farm from class 0.8 to class 2.7. This is so far the best repair option for very large wind farm arrays, which typically are over predicted by the wake model.

Plenty of "manual" Excel work can be saved by using the Performance check module for these analyses.

3.4.1.3 PARK RIX calculation
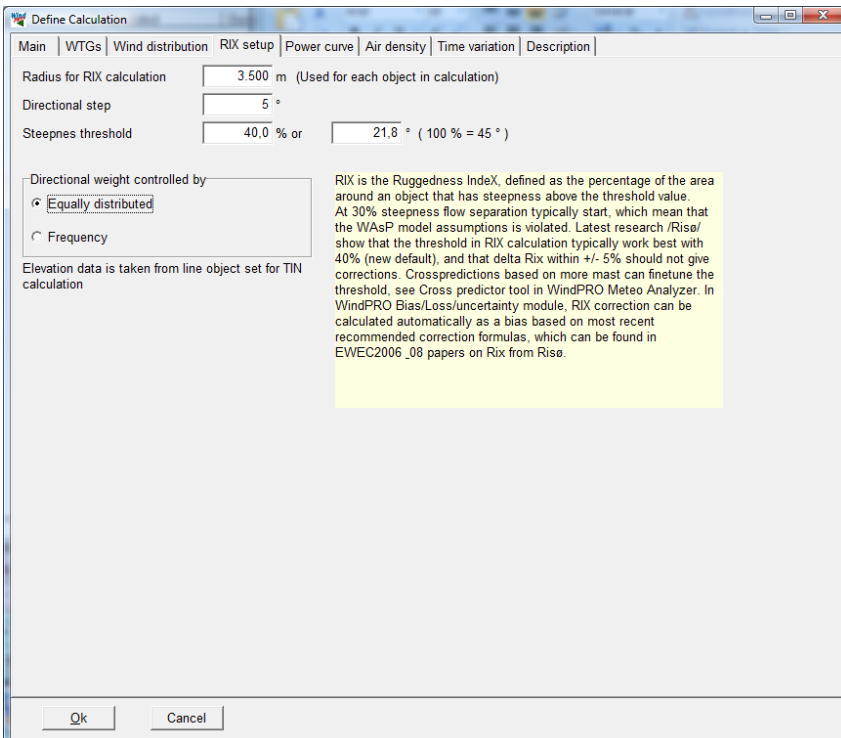
RIX is the Ruggedness Index, defined as the percentage of the area around an object that has a steepness above a given threshold value. At 30% steepness, flow separation typically starts, which means that the WAsP

model assumptions are no longer valid. Experiments show that the RIX values can be used to fix WAsP model calculation problems in steep terrain – or at least reduce the error introduced by flow separation. It is even seen in papers that RIX correction also improves CFD calculation results.

The Latest research by /Risø/ shows that the threshold in RIX calculation typically works best with 40% (new default), and that delta Rix within +/- 5% should not give corrections. Cross predictions based on more mast can fine tune the threshold, see Cross predictor tool in WindPRO MeteoAnalyser. In WindPRO Bias/Loss/uncertainty module, RIX correction can be calculated automatically as a bias based on most recent recommended correction formulas, which can be found in EWEC2006 & 08 papers on Rix from Risø/DTU, see extract below:
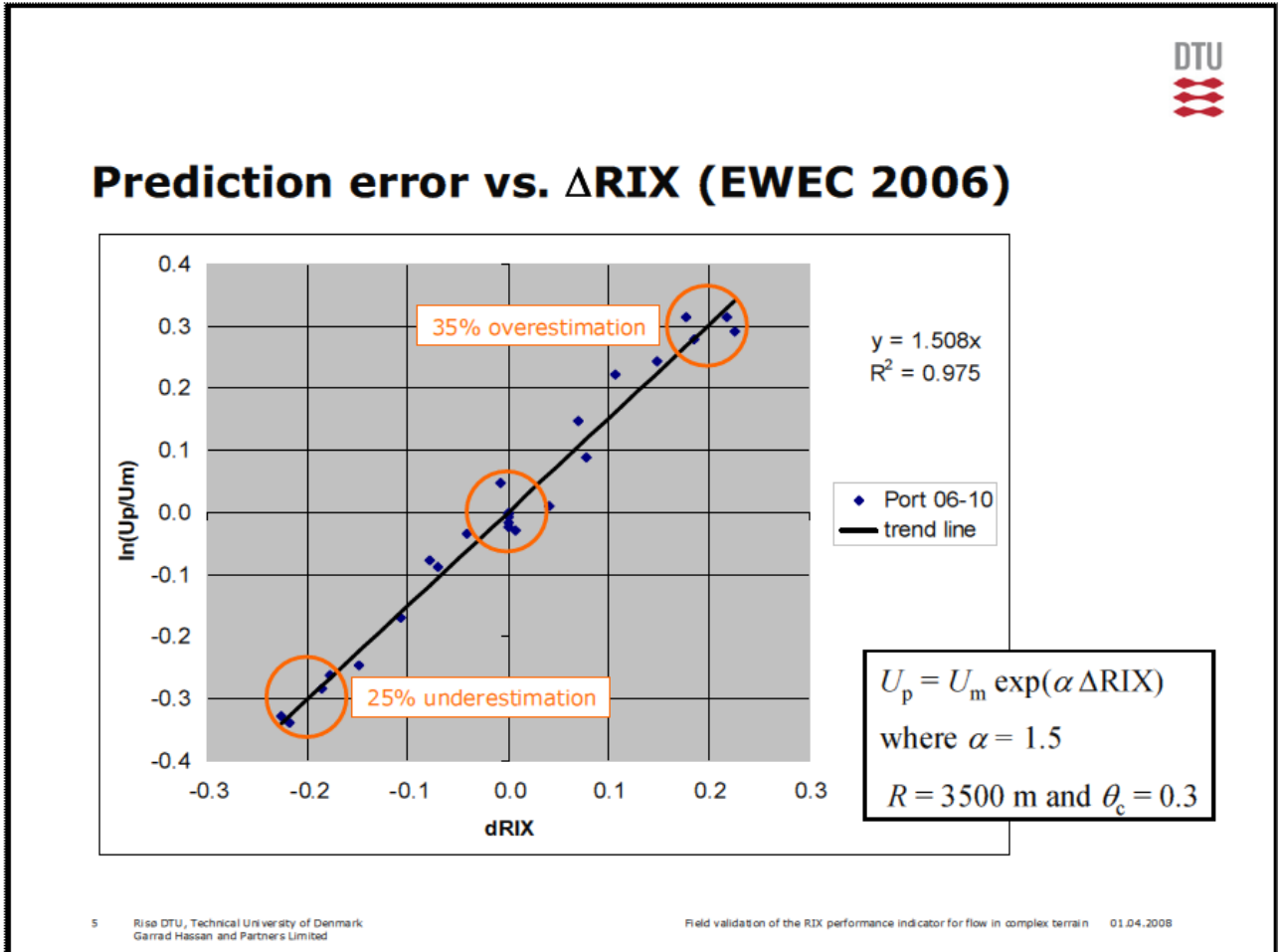
The main conclusion based on use of the RIX method is that if both reference site (measurement mast) and predicted site (WTG) are equally rugged (Delta RIX < 5%), very small calculation errors are expected.

If reference site (measurement mast) is very rugged, e.g. RIX = 0.2 and predicted site (WTG) are less rugged (e.g. RIX = 0), Delta RIX will be -0.2 and according to the graph, 30% too low wind speed prediction at WTG site could be expected. This could lead to around 60%[1]) to low calculated energy production.

If the reference site is less rugged, e.g. RIX = 0, and the predicted site (WTG) is very rugged (e.g. RIX = 0.2), Delta RIX will be +0.2, and according to the graph, 30% too high wind speed prediction at WTG site could be expected. This could lead to around 60%[1]) to high calculated energy production.
*1
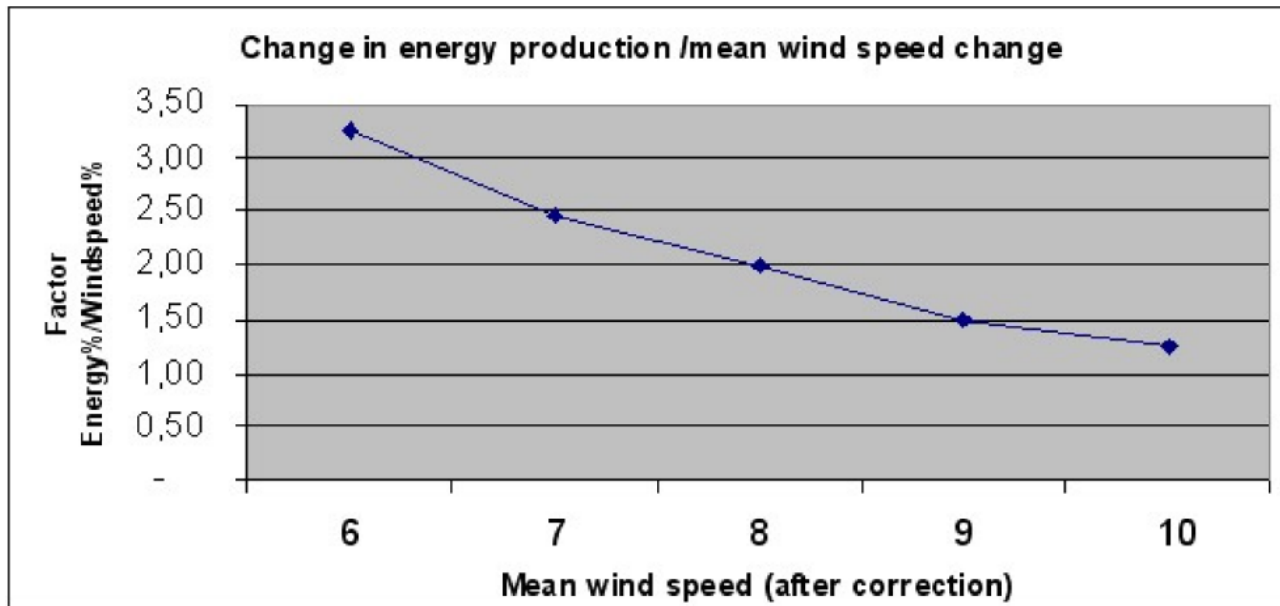
Source: EWEC06 paper:
IMPROVING WAsP PREDICTIONS IN (TOO) COMPLEX TERRAIN

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Christchurch, New Zealand

[1] Doubling of energy prediction error based on mean wind speed error is a rough conversion, which holds for wind speeds around 8 m/s. At 6-7 m/s tripling is more right, while only 1.5 factors should be used for 9 m/s, see graph below based on a typical WTG.

3.4.1.4 PARK calculation with "advanced options"

Checking the "Enable advanced options" gives access to several more features described in the following. Before this, we would like to introduce the WindPRO Online help page, where, typically, the more advanced features are frequently updated based on the latest research. The page can be opened from WindPRO menu "Help – FAQ (Internet)":

Access to advanced calculations:

Advanced calculations:
☐ Reduced wind speeds inside wind farm
☐ Park power curve based on PPV model
☑ Turbulence

These require you to choose another wake model than the default N.O.Jensen model.

The reduced wind speeds inside a wind farm creates a matrix that can be used to lookup the calculated reduction at a specific point, for any direction and any free wind speed. A way to use this is to place a very small turbine (0.1 m rotor diameter) at the position where a measurement mast are inside the wind farm, and thereby get the reduction in wind speed measurements due to surrounding turbines. Then the expected free wind speed can be established, which can be useful for performance check calculations.

Park Power curve based on PPV model gives the calculated Park power output related to a specific measurement mast position outside the park. This can be useful for like prognosis systems, where the wind prognoses are given at a specific point (measurement mast position). With the table the transfer function from wind speed and direction to Park output is given.

Turbulence calculations give the ambient + wake added turbulences for each turbine. NOTE this part is transferred to the Site Compliance module in future versions (after ver. 2.8).

☐ Calculate weibull for +/- ½ rotor diameter, used in result to file

By "report features" there are an additional checkbox. Here you can add calculation results for +/- ½ rotor diameter in the result to file. This makes it easy to evaluate the variation of the calculation results over large rotors. With the present AEP calculation tools, it is always assumed the hub height represents the average for entire rotor diameter. With a large increase in rotor diameters this might require changes in future calculation methods. With this report the user can start performing experiments for evaluation of the importance.

Wake decay constant/turbulence settings:

Open farmland WDC: 0,075 RC: 1,5 TI: 0,15 ▼

User defined
Offshore & Water areas WDC: 0,040 RC: 0,0 TI: 0,08
Mixed water and land WDC: 0,052 RC: 0,5 TI: 0,10
Very open farmland WDC: 0,063 RC: 1,0 TI: 0,13
Open farmland WDC: 0,075 RC: 1,5 TI: 0,15
Mixed farmland WDC: 0,083 RC: 2,0 TI: 0,16
Closed farmland WDC: 0,092 RC: 2,5 TI: 0,18
Very closed farmland WDC: 0,100 RC: 3,0 TI: 0,21

More choices are available in the list. For other Wake models than the N .O. Jensen, it is not the Wake decay constant, but the ambient turbulence that is used as input for the wake model. By the "Edit / Load from Meteo" you get access to refine the settings further:

Sector wise Wake decay constant/turbulence parameters

Sector wise WDC or turbulence can be entered or loaded from meteo data.

When loading ambient turbulence data as input into PARK, where this is required (depending on the array loss and turbulence model combination chosen), it is now possible to specify this data in more detail.

The ambient turbulence is loaded from a time series data in a Meteo data object. It is possible to specify the setup, e.g. add one standard deviation to mean turbulence as required in the IEC edition 2 for turbulence calculation, or 1.28 standard deviations for IEC ed. 3 compatible calculations.

Wake model selection:

Regarding wake models, EMD recommends using the N.O. Jensen (RISØ/EMD) model. If you need turbulence calculations, the N.O. Jensen (EMD) 2005 is recommended. The three other models are intended for experimental use. Tests so far indicate that these models do not reduce calculation results enough when using the standard parameters. The parameters will be tuned based upon ongoing research in order to better correlate the predicted values to actual performance.

Turbulence model selection:

For turbulence calculations, the S. Frandsen 1999 or the TNO model are recommended as the most-accepted ones at this time.

The wake and turbulence models and other advanced functions of the PARK calculation are described in detail in the appendix on Wake and Turbulence Models.

3.4.1.5 Edit WAsP parameters

The WAsP parameters can be modified from this input form:

Edit project WAsP parameters

WAsP parameters

On this form it is possible to change the parameters used in WAsP calculations. When you click "Ok" the settings will be saved to an internal file, which will be used in all WAsP calculations in this project. Any non-default parameters will be highlighted in yellow.

Parameter	Minimum	Maximum	Default	Value
Site roughness assessment (Non-default parameters: 0)				
Max. number of roughness changes/sector	1	10	7	7
Sub-sectors in roughness map analysis	1	9	6	6
WAsP wind modelling (Non-default parameters: 1)				
Avg. offset over land from neutral at z=P2	0,01	0,25	0,11	0,11
Azimuth resolution in BZ model [°]	1	15	5	5
Decay-length for roughness area size	1000	1000000	10000	10000
Depth of daily variation over land	50	100	100	100
Depth of daily variation over water	25	300	50	50
Factor in height of min. stab. induced var.	0	0,005	0,002	0,002
Height of inversion in BZ model	100	5000	1000	1000
Max. interpolation radius in BZ model	5000	50000	20000	20000
Offset heat flux over land	-200	200	-40	0
Offset heat flux over water	-200	200	15	15
Rel. amplitude of daily variation near ground	0,01	0,25	0,12	0,12
Rms heat flux over land	0	200	100	100
Rms heat flux over water	0	200	30	30
Softness of inversion in BZ model	0	1	1	1
True upwind direction in BZ model	-1	0	0	0
Width of coastal zone	5000	50000	10000	10000
Wind atlas structure (Non-default parameters: 2)				
Number of standard heights	2	5	5	5
Number of standard roughness classes	2	5	4	4
Standard height #1 [m]	5	200	10	10
Standard height #2 [m]	5	200	25	25
Standard height #3 [m]	5	200	50	50
Standard height #4 [m]	5	200	100	100
Standard height #5 [m]	5	200	200	120
Standard roughness length #1 [m]	0	2	0	0
Standard roughness length #2 [m]	0	2	0,03	0,03
Standard roughness length #3 [m]	0	2	0,1	0,1
Standard roughness length #4 [m]	0	2	0,4	0,4
Standard roughness length #5 [m]	0	2	1	2

Ok | Cancel | Set all values to default | Import | Export

Currently used WAsP parameters: **User modified WAsP parameter settings**
WAsP version: WAsP 6-9

For example, a few modifications are made to illustrate where it can be relevant:
Std. Height 5 is changed from 200 to 120m. If your hub height is 110 m, you might be better off using 100m and 120 m than 100m and 200m. The interpolation distance simply becomes smaller.
Std. Roughness #5 is changed from 1 m to 2 m. This could be relevant in a very high roughness region, where you expect above 1 m length (class 3.7), and thereby will avoid extrapolation, which is more uncertain than interpolation.
Finally, the heat flux parameters could be relevant to change in very hot areas (deserts), or if you want to force water stability conditions, you can simply set the water parameters for land.

Remark: if WAsP parameters are changed from defaults, the button becomes yellow. When you are in other parts of the software, like in meteo object, profile viewer, where you also have access to WAsP parameters, the button here will also be yellow. This reminds you that you are working with the modified WAsP parameters. It is, of course, important that the modified WAsP parameters BOTH are used when generating the wind statistics AND in the AEP calculation. (Going up/down with WAsP with same parameters). It will typically be in the meteo object or the MeteoAnalyser experiments for "fixing" the WAsP parameters that will be performed.
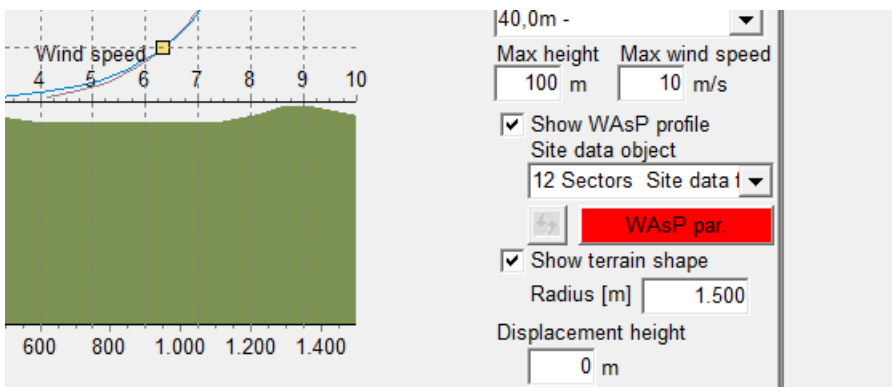
If the WAsP parameters are changed, and the wasp version afterwards are changed between <10 to 10+, the WAsP par button becomes red. The reason is that the default wasp parameters are different for the different versions. This means that the user should reconsider parameters. If STANDARD parameters are used, it is always the defaults belonging to the given WAsP version, which are used.

3.4.2 Calculation Energy: METEO (Energy, one site)

In order to perform an energy calculation, you need a Meteo Object with purpose checked in under B or F, see description from METEO object below.
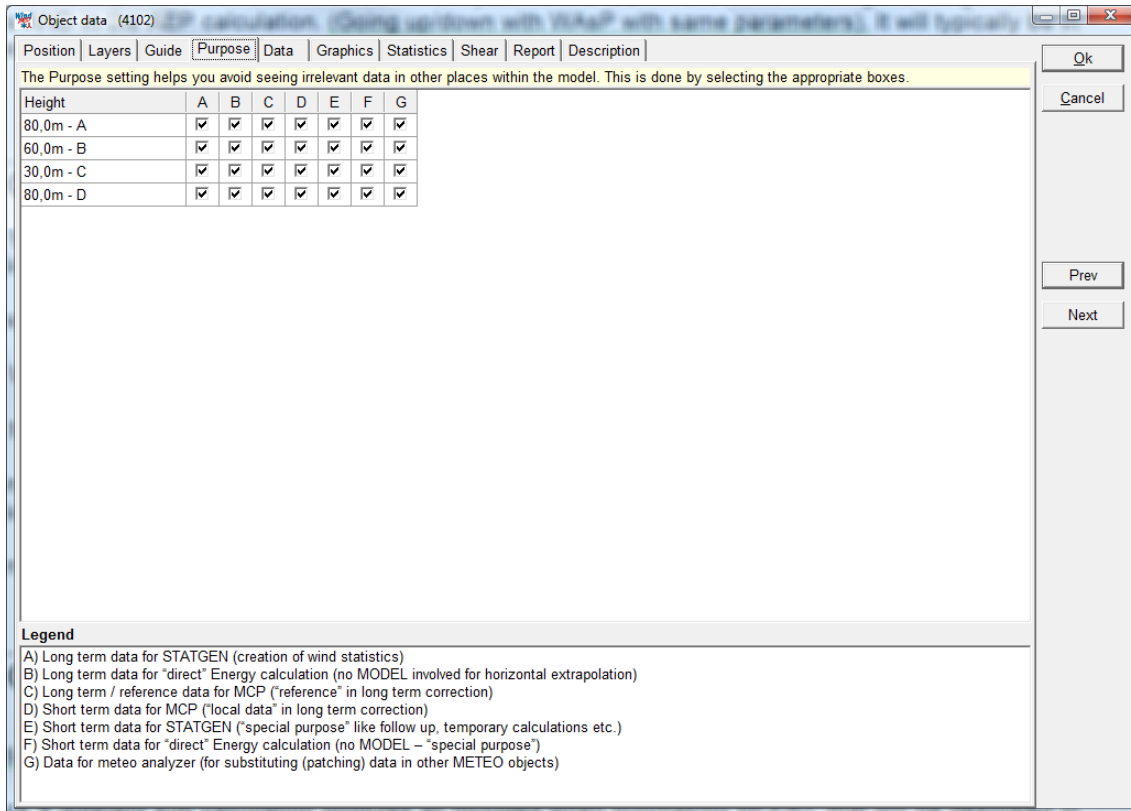
The METEO calculation is for calculation of AEP for one turbine, based on the data in a Meteo object. Data can be represented as a Time series, a TABLE (histogram) or a WEIBULL distribution. All can be manual entered in Meteo object (or imported). When Time series are imported, Table and Weibull data are automatically created.

Thereby, the calculation can among other purposes be used for investigation of the difference using the time series, the "raw" table data or the "smoothed" Weibull data.

It can also be used for very simple calculations, e.g. just enter a mean wind speed into a meteo object (Weibull sheet) and a k=2, and you have the input for a simple calculation.

The METEO calculation can be used for comparing the expected AEP for a number of different turbines based on the same wind conditions.

Finally, a wind profile based on simple shear assumptions can be calculated.
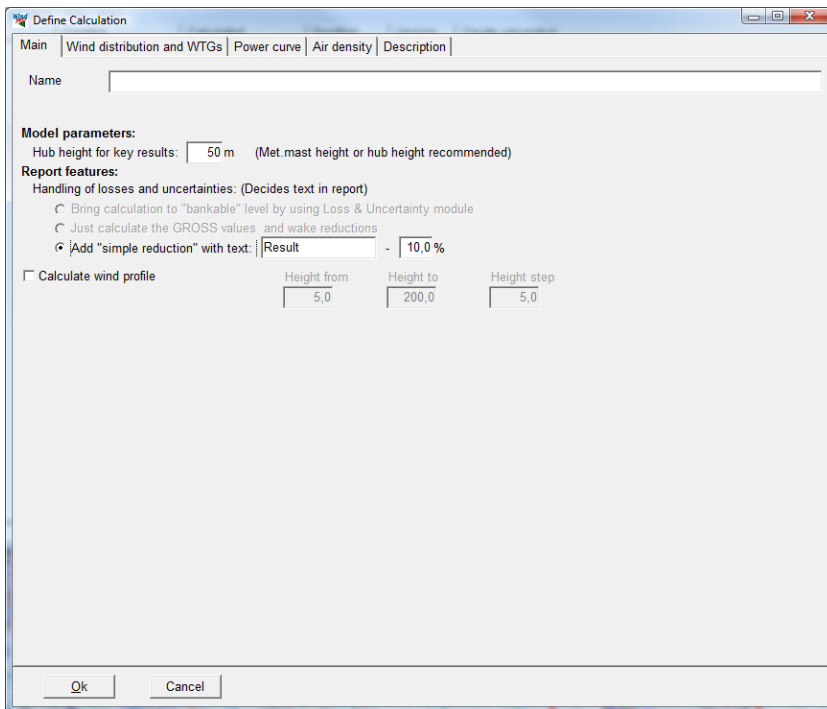
At the Main tab, the wind profile specification can be set up. Other inputs are explained in the previous chapter 3.4.1.
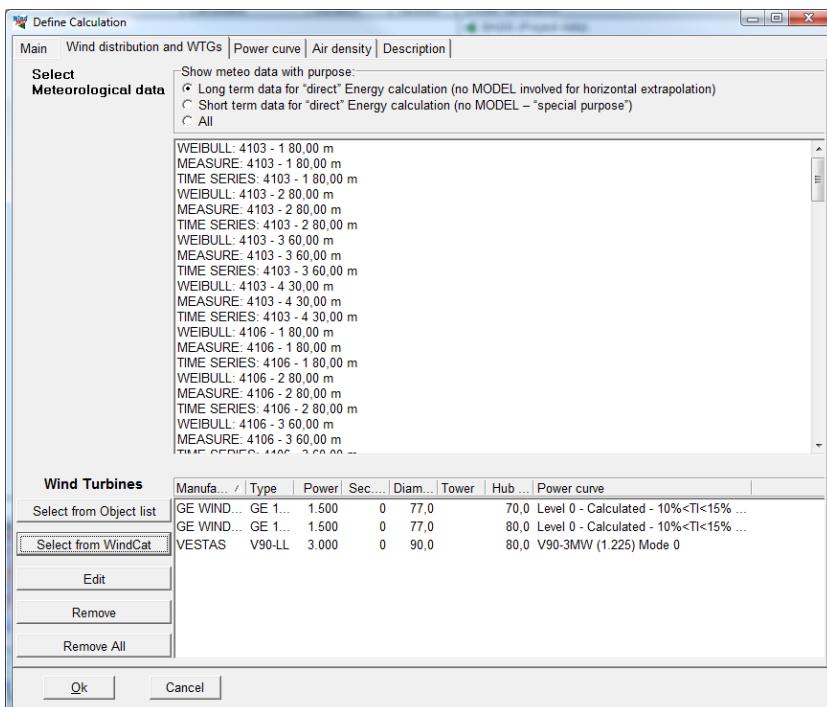
On the Wind distribution and WTGs tab, the wind data to be used is selected. By choosing the WEIBULL version, the data are smoothend by the best Weibull fit, while the MEASURE version takes the histogram (binned data) established from the raw data (or entered direct in the Meteo object). Choosing time series will use the very raw data.

The turbines can be selected from the turbine catalogue, and you can, in one operation, load all that are represented in the project by loading from the object list.

The tabs power curve and Air density are explained in previous chapter 3.4.1.
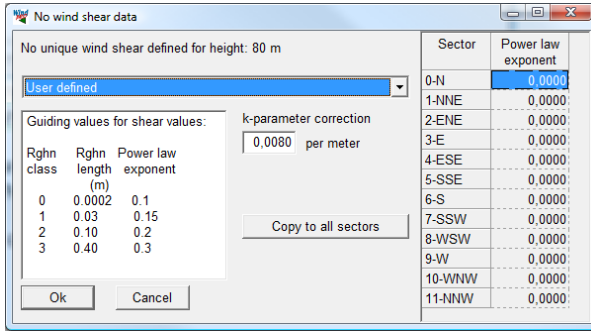
Shear (avg), for Beldringe				
	Class 0	Class 1	Class 2	Class 3
10-25 m	0,10	0,19	0,22	0,30
25-50m	0,10	0,20	0,22	0,26
50-100m	**0,11**	**0,23**	**0,24**	**0,26**
100-200m	0,12	0,28	0,27	0,27

If no wind gradient exponent is specified in the Meteo Object, you are asked to specify when launching a calculation, if the calculation height differs from the wind speed height. Similarly, if there are more sets of wind shear defined in the Meteo object, you can choose between those from the drop down menu.

The table to the left based on "old approach", working at lower hub heights, where the more detailed table to the right shows that the values when working in larger hub heights do change some. The table to the right is basically the WAsP approach, where the shear values are a combination of terrain given shear and stability correction model.

The k-parameter correction is a little complicated, while it highly depend on the height scaled from and to.
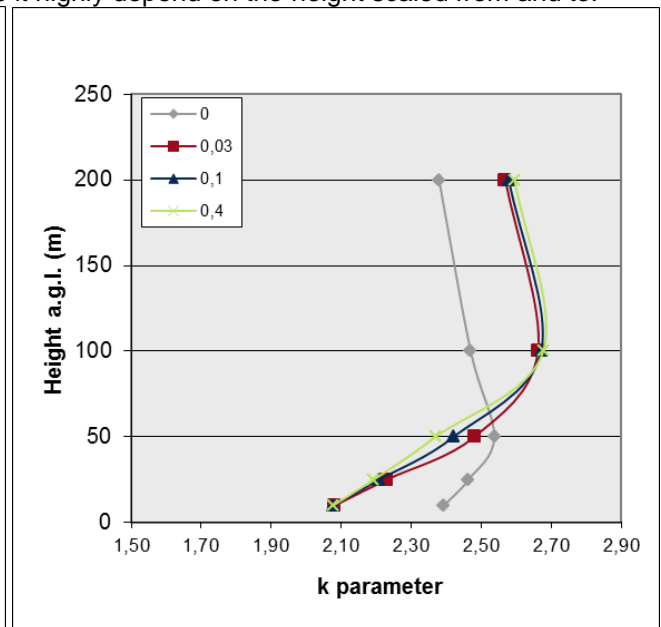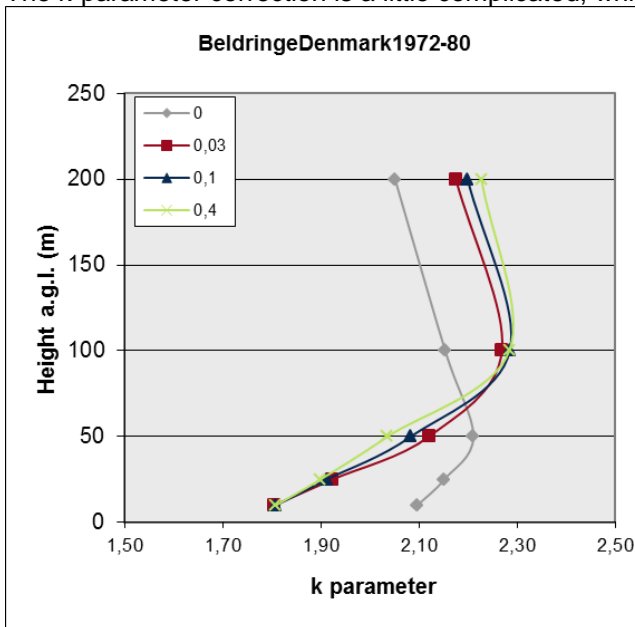
The figures shows how WAsP assumes the k-parameter to change for the 4 roughness classes 0 – 3 for a given wind statistic. Left the Danish "basis" wind statistic, right a Danish offshore based wind statistic. The general picture is the same, only the offshore based values are higher, which partly is due to higher mean wind speeds. It can be seen that onshore from 50m to 100m the increase is round 0.2 for 50m, meaning 0.004 pr. m. Going higher than 100m or offshore, the increase becomes negative. -0.001 seem to be a reasonable value if your measurements are from 100m and you want to scale to larger heights, or if you go up from 50m offshore.
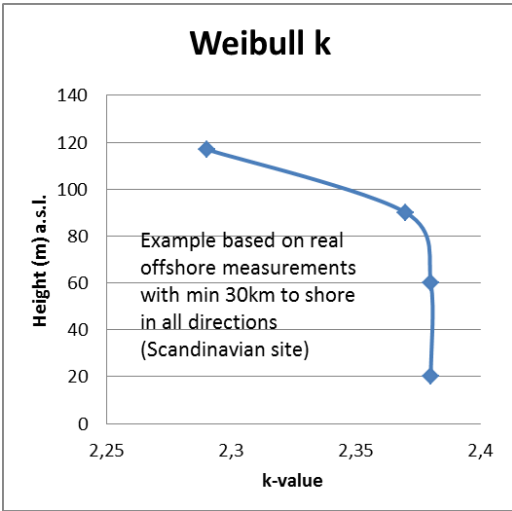
Example of real measured k-values on tall offshore mast

After calculation:

Valid	Manufact.	Type-gene	Power, ra	Rotor dian	Hub heigh	Total	Regional (	Equivalen	Mean win	HP-value	Air densit	Displacem
			[kW]	[m]	[m] (Watc	[MWh]			[m/s]	[%]	[kg/m³]	[m]
Yes	GE WIND	GE 1.5sle-	1.500	77	70	3.772,80	1		6,58	97	1,028	0
Yes	GE WIND	GE 1.5sle-	1.500	77	80	3.770,60	1		6,58	97	1,027	0
Yes	VESTAS	V90-LL-3.0	3.000	90	80	6.162,60	1		6,58	96	1,027	0

With the "result to file" option, results can be pasted to Excel for further processing.

3.4.3 Calculation Energy: MODEL

Calculations with WindPRO module MODEL involve a calculation model.

There are 4 different sub calculation modules, all included when purchasing MODEL that will be described roughly in this chapter - most of the features are similar to the ones explained under PARK, 3.4.1. For the first two described, WAsP interface and ATLAS, the purpose setting in site data object decides which will be available.

3.4.3.1 WAsP interface

The WAsP interface calculation can be used for comparing the expected AEP for a number of different turbines based on the same wind conditions, i.e. it is assumed the turbine is located where the site data object selected in the calculation is positioned.

The WAsP interface "operates" the WAsP model – it is thereby the WAsP model that calculates the wind distribution based on terrain and wind statistic. The wind distribution calculated by WAsP model is then taken over by WindPRO that do the power curve and air density post processing work.

Finally a wind profile based on simple shear assumptions can be calculated.
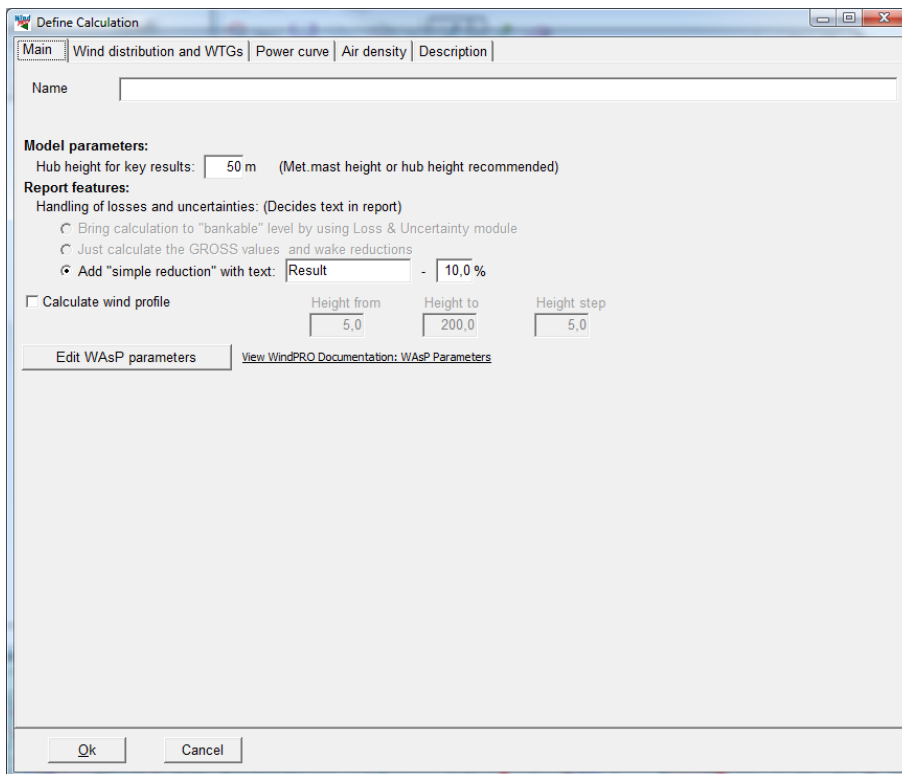
At the Main tab, the wind profile specification can be set up. Other inputs and the Power curve and Air density tab are explained in chapter 3.4.1. The tab "Wind distributions and WTGs" are explained in previous chapter 3.4.2, just with the difference that, here, site data objects must be selected giving the wind distribution, not Meteo objects.

3.4.3.2 ATLAS

The ATLAS calculation is basically operated as the WAsP interface calculation (see previous chapter). It just does not require a WAsP license, but the model is far simpler and therefore not recommended for large scale projects.

3.4.3.3 RESOURCE

The RESOURCE calculation is documented in separate chapter 3.6.

3.4.3.4 WAsP-CFD

The WAsP CFD module is described in separate chapter.

3.4.4 Calculation Energy: STATGEN (Wind Statistics / Wind Atlas)

Note your measured data must be long term representative, if the wind statistic is for long term energy prediction. See MCP module for long term correction.

Generation of a Wind Statistics requires the following:

- Measured wind data (inserted in a Meteo Object, where "For use in STATGEN" is selected)
- A terrain description (inserted in a Terrain Data Object where "For use in STATGEN" is selected)
- The program WAsP from RISØ/DTU.

The terrain description must be accurately performed, centered at the location of the measurement tower. It will be centered at the measurement tower automatically if the Line Object containing the roughness lines is set to "linked to Site data in energy calculations". In this case, the position of the Meteo Object determines the position of the roughness rose.

When the data for the two objects have been entered, you click on the calculation menu and select STATGEN.
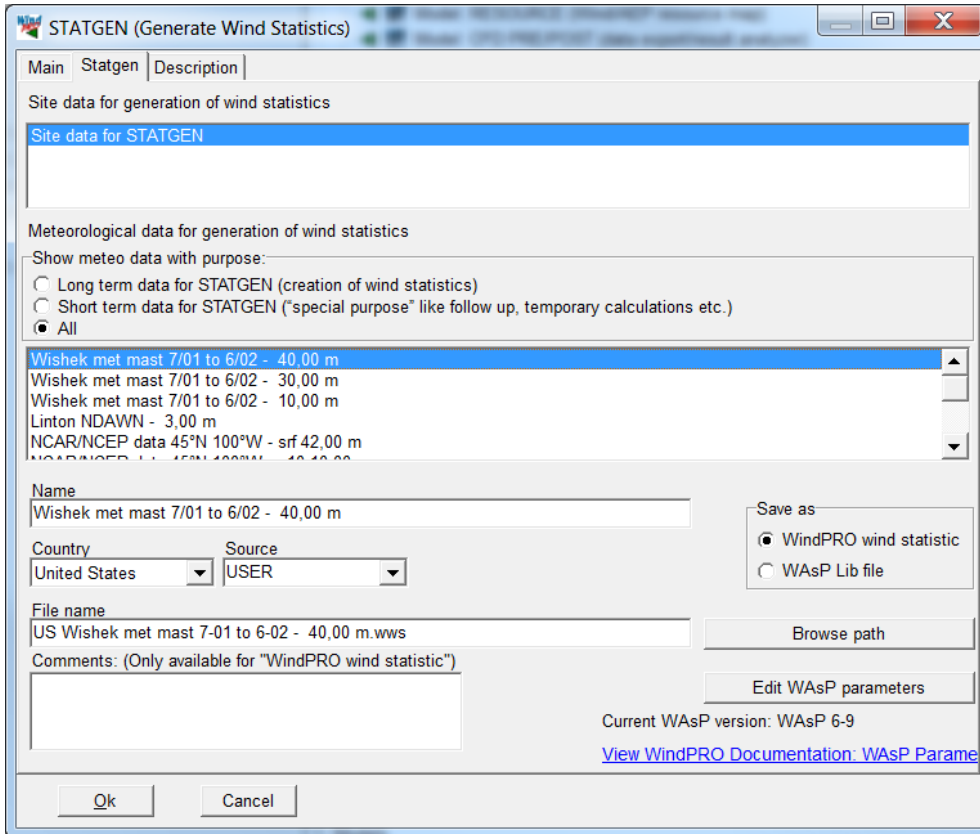
When the appropriate combination of available objects has been selected, clicking on the "OK" button will start a WAsP-calculation. The Wind Statistics will be saved according to the specifications given in the window shown above.

NOTE: You can save the results as either a WindPRO Wind Statistic, which is an internal binary format, or in an ASCII WAsP format. In both cases, coordinates will be saved in the .lib file as a part of the header, which WindPRO can read for correct geographic presentation of the Wind Statistics. The internal WindPRO format has additional features. A comment text field can be saved together with the Wind Statistic. A regional correction factor can also be included. Finally all information's about the measured data, WAsP version, WAsP parameters etc. will be saved. These information's will be included in energy calculations printouts, se example below.

STATGEN - Wind statistics info

Main data for wind statistic

File   US Wishek met mast 7-01 to 6-02 - 40,00 m.wws
Name   Wishek met mast 7/01 to 6/02 - 40,00 m
Country   United States
Source   USER
Mast coordinates UTM WGS84 Zone: 14 East: 450.366 North: 5.110.713
Created   10-05-2012
Edited   10-05-2012
Sectors   12
WAsP version   WAsP 6-9 RVEA0011.dll 1, 0, 0, 13

Additional info for wind statistic

Source data   Wishek met mast 7/01 to 6/02
Data from   01-07-2001
Data to   30-06-2002
Measurement length   12,0 Months
Recovery rate   100,0 %
Efficient measurement length   12,0 Months

Note
Note that to get most correct result, the wind statistic should be generated with same WAsP version as used in calculations. For WAsP versions before WAsP 10 although there will be no differences.

Once the calculation has finished, you can generate a report, and the Wind Statistics can be evaluated (see below).
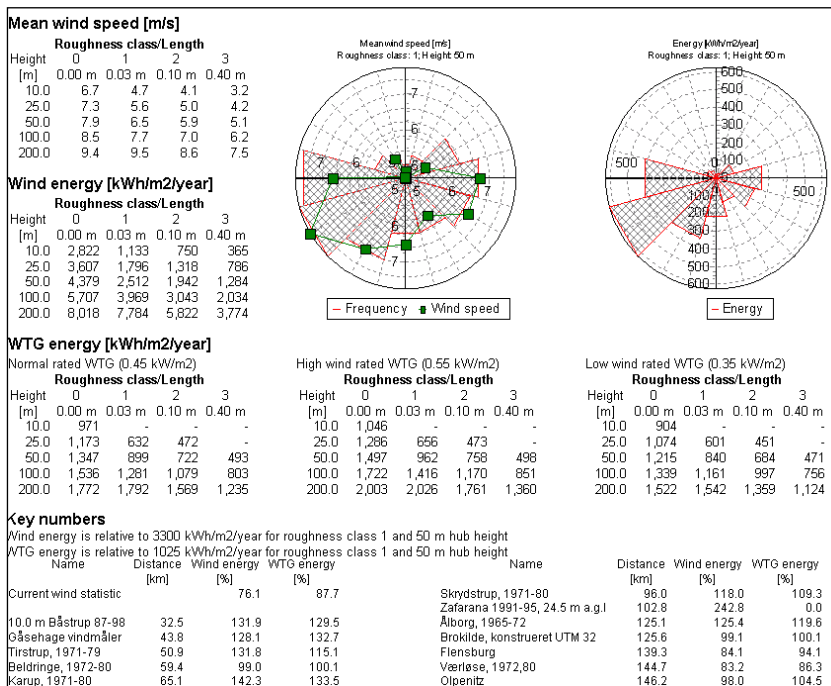
NOTE: Both the total wind energy content and the turbine energy level are calculated. The latter is "filtered" with a power curve. A list shows comparison with the nearest Wind Statistics in the current search profile for Wind Statistics.

The Wind Statistics are saved as specified in the calculation settings and can then be used for calculations in projects within the region. (See the WAsP manual for further details on generation of Wind Statistics).

Before using the Wind Statistic(s), it's necessary to set the Site Data Object to "for use in WAsP" (or ATLAS) and then select the generated Wind Statistic(s) when launching the calculation.

3.4.5 Wind index correction level conversion to wind speed

In WindPRO wind statistics, it is possible to include a correction factor that is applied to the calculated energy calculation (energy correction).

This works well as long as any adjustment of the wind statistic is only around the wind speed that was the basis for the creation of the correction factor. If it is, for example, created using data based on smaller reference turbines and then subsequently applied to much taller turbines (with a significantly higher average wind speed), the method can create an unintended bias, while the conversion "factor" from wind speed to AEP changes with adjusted mean wind speed.

We have, therefore, developed a modified conversion method, which changes the energy correction factor to a wind speed correction in the wind statistic. This has an additional advantage in that the calculated mean wind speed which is based on the wind statistic will be more accurately adjusted and the Weibull A-parameter in, for example, the "Result to file" export from the PARK module will now be correct.

In previous versions of WindPRO, the use of a wind statistic with an energy correction factor applied has resulted in a simplified conversion of the mean wind speed in the reports, but the Weibull A parameter was not corrected.

The existing method using an energy correction factor will still be available in v2.6 but the plan is to remove this from v2.7.
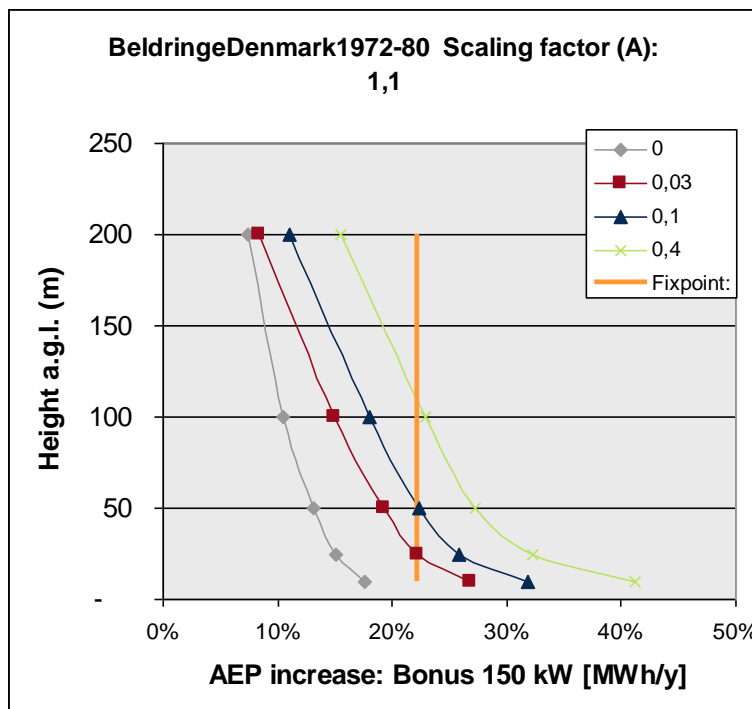
Figure 39 An illustration of the energy scaling compared to wind speed scaling. With energy scaling, the correction on AEP in any calculation will be as shown with the "fixpoint" line, here approximately 22%. With wind speed scaling, the AEP correction will be the same for the fixpoint, that was basis for the creation, here 25m hub, roughness length 0.03m (Rcl. 1) and a Bonus 150 kW turbine – but used for a 100 m hub height, for example, roughness length 0.03m (Rcl. 1) and the same power curve, the AEP correction will now be approximately 15%.

From v2.6, there will be three possible conversion situations as described in the following:

3.4.5.1 From MCP calculations

This is the simplest conversion since the software will have information on power curve as well as mean wind speed used for creation of the correction factor.

The Index correction method in the MCP module produces a correction factor, which is supposed to be valid for the specific type of turbine and mean wind speed selected in the calculation setup. That information is used when the index correction factor is converted to a wind speed correction factor. In this way we ensure the correct wind speed correction factor in the wind statistic.

Compared to v2.5 this means that a correction factor is no longer applied to the final production. Instead a correction factor is applied to a wind statistic based on the original local time series.

Tests have ensured that the results are very close to the original v2.5 method. If, however, one wants to calculate exactly as the v2.5 method, one performs the Index correction as normal and in the calculation report or when saving the wind statistic notes down the correction factor. Then a regular Statgen is performed on the original local data and in the Site data object for WAsP calculation the wind statistic is edited with the correction factor (see below). Note that this possibility is supposed to disappear in v2.7.

3.4.5.2 Older or manual adjusted

In this situation we do not know the basis for the creation, and offer the user a tool for manually entering the adjustment.
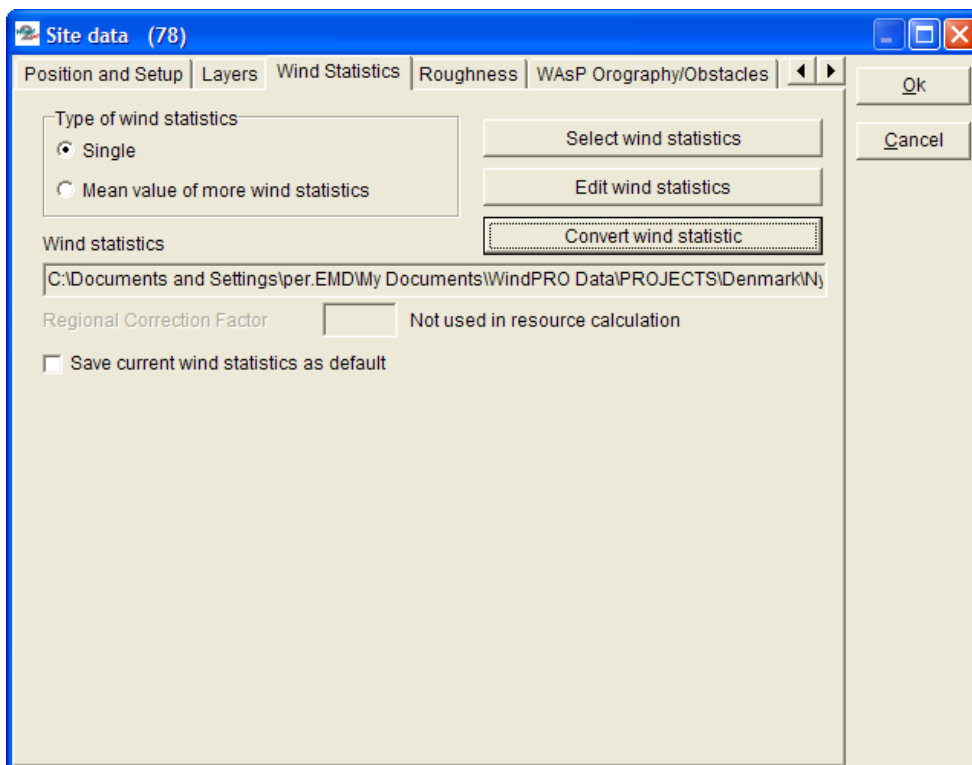
Figure 40 Choosing "Convert wind statistic" from a site data object gives the dialogue shown in Figure below.

Figure 41 A wind statistics with energy correction factor can be loaded and converted to wind speed correction based on a specific power curve, hub height and roughness.

With "Compare to clipboard" the original and converted data can be pasted to excel so the changes can be evaluated.

3.4.5.3 Danish "regional corrections" DK'92 – DK'07 wind statistics

For calculations in Denmark, WindPRO has used a regional correction factor applied to the Wind statistic DK'92 automatically based on individual WTG positions.

This wind statistic has three problems:
1. It assumes a standard air density, whereas WindPRO now calculates a default site specific air density, giving 2-3% higher results;
2. It does not take into account the adjusted long time wind energy level (7-8% in 2006). Therefore, with an automatically calculated air density, the result of a calculation will be approximately 10% too high. It can be even more optimistic if the new turbines are tall or placed in high wind areas due to the previously described built-in bias in the energy correction factor.
3. It uses an energy scaling based on regional correction factors, not a wind speed scaling.

These 3 problems are fixed in the DK'07 wind statistic that now is recommended for use in Denmark.

3.4.6 Printing and reading reports

3.4.6.1 Printing
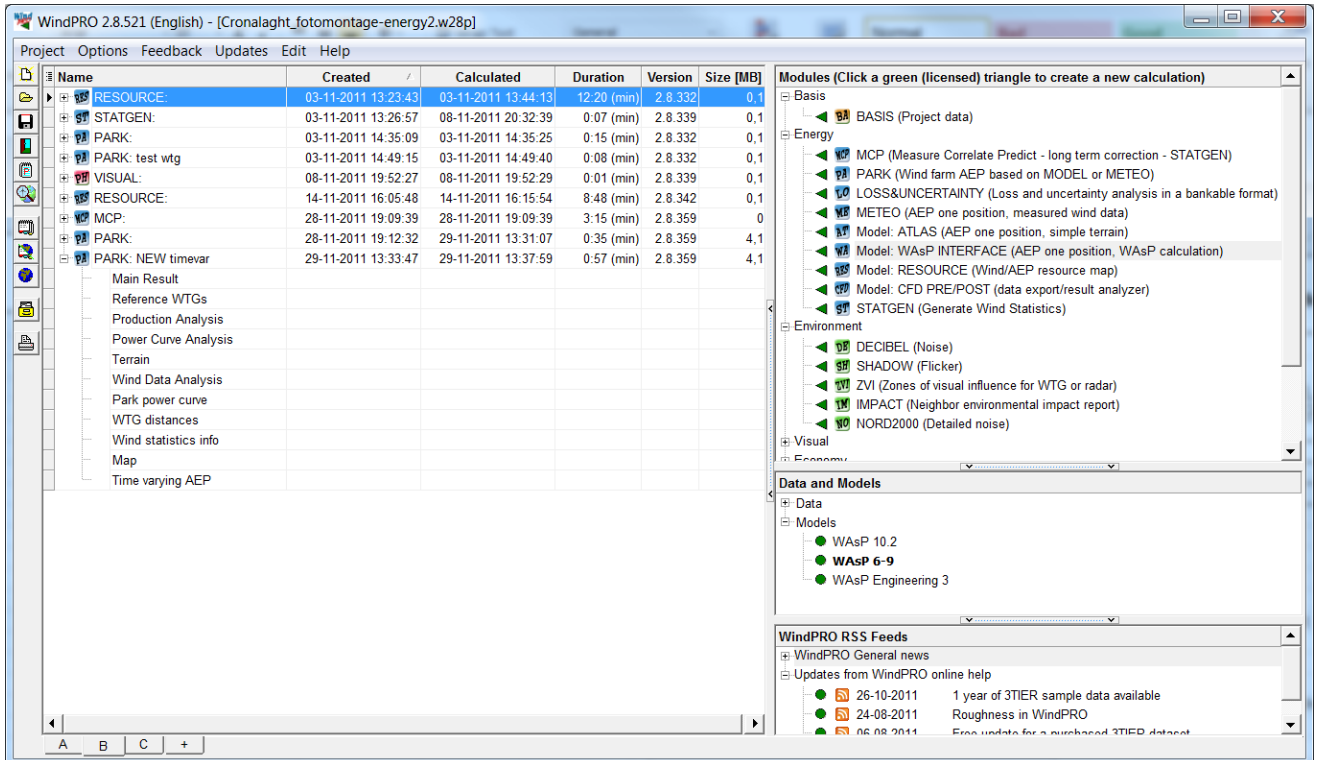
When the calculation has finished, the window shown above will appear, listing the available reports that can be printed.

There will be info columns telling when a calculation was created, last calculated, the duration, with which version and the size of result data included in the WindPRO project file.

A sub-level report will automatically pop up on the screen if you double-click on a sub-level report name. The sub-level report has its own right-click options. When you right-click on the calculation header or on one of the calculation reports, you gain access to the following features:
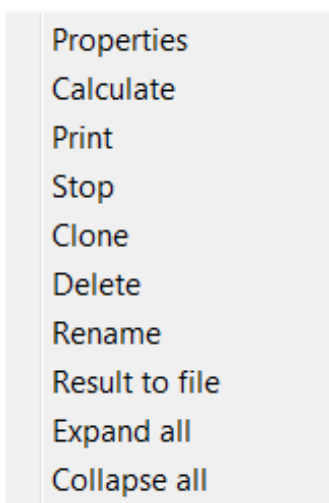
Properties - Edit calculation setup for recalculating (or view calculation setup).

Calculate - Recalculate (e.g. if positions of WTG have changed, but the calculation setup is unaltered).

Print - Show the print options with the possibility of making changes (e.g. map scaling).

Stop - To stop a running calculation.

Clone - Make a copy of the calculation. This is useful if a calculation, based on changed object information, is required with the present calculation setup without overwriting the former calculation.

Delete: Removes the actual calculation report.

Rename: For changing the calculation name, description, and uncertainty reduction percentage without recalculating

Result to file: Makes it possible to save results to a file or copy to clipboard.

Expand/collapse: Work on all performed calculations in the window.

From the "Print" option, the following screen will appear:
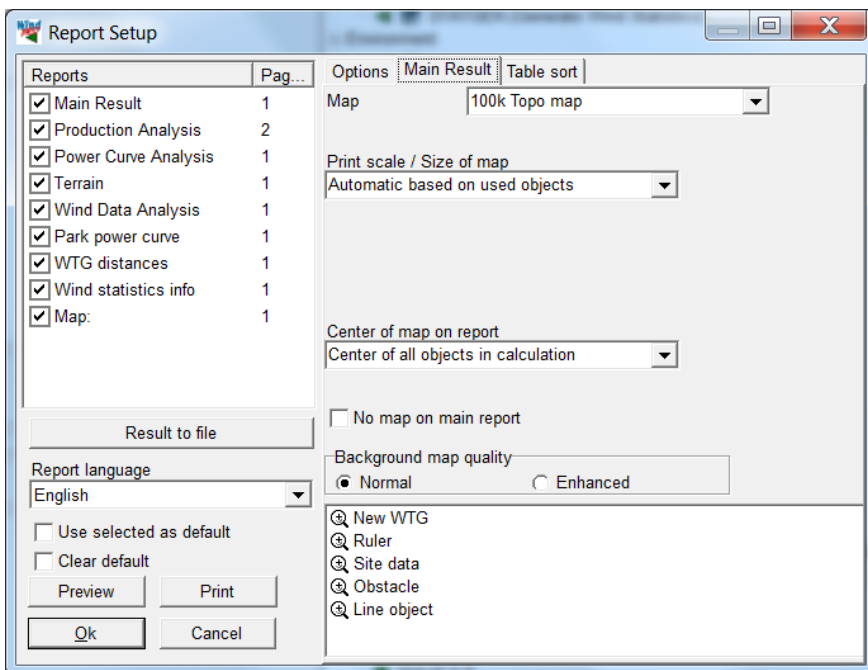
There are a number of options available for changing printouts. When you select a report, the right half of the screen offers you different setup options, depending upon the report.

NOTE: The object settings (label size etc.) can only be changed when the "Map" report is selected.

For more details on printing reports, see Chapter 2, BASIS.

3.4.6.2 Reading reports from Energy calculations

Examples of reports are given in Chapter 1. Below, a few samples from reports will be shown and some of the key figures will be explained. New in version 2.5, you can print calculated wind profiles for each wind direction sector (only from WAsP Interface calculation).

Wake Model   N.O. Jensen (RISØ/EMD)

Calculation Settings
Air density calculation mode   Fixed for all WTGs (Based on Std. Atmosphere Model)
Result for site center elevation+key height   1,225 kg/m³
Air density relative to standard   100,0 %
Hub altitude above sea level (asl)   0,0 m
Annual mean temperature at hub alt.   15,0 °C

Wake Model Parameters
From angle   To angle Terrain type   Wake Decay Constant
   [°]   [°]
   -180,0   180,0 Open farmland   0,075

Wake calculation settings
Angle [°]   Wind speed [m/s]
start end   step   start end step
 0,5 360,0 1,0   0,5 30,5 1,0

Wind statistics   IE Malin Head, 1970-79.wws

WAsP version   WAsP 6-9 for Windows RVEA0011 1, 0, 0, 13
WAsP parameters   Non-default WAsP parameters - detailed information at the
                                       end of "Main results"

The assumptions for the energy calculation concerning the Wind Statistic(s) chosen, air density, wake decay constant and WAsP version, are shown above.

Key results for height 50,0 m above ground level

Terrain	IG	East	North	Name of wind distribution	Type	Wind energy [kWh/m²]	Mean wind speed [m/s]	Equivalent roughness
	A	186.373	424.102	Malin Head	WAsP (WAsP 6-9 for Windows RVEA0011 1, 0, 0, 13)	9.152	9,9	0,2

Key results are based on the position where the Site Data Object is placed and the hub height specified in the calculation setup.

Equivalent roughness is the roughness class in flat terrain with no obstacles that would give the same calculated energy production. This can vary with the chosen hub height for key results if there are obstacles or orography, while the reduction/speed up from obstacles/orography varies with height. Also it can change based on the WAsP version, due to differences in the model before and after WAsP 10.0, see "Wasp model differences".

Calculated Annual Energy for Wind Farm

				Specific results¤)				
WTG combination	Result PARK [MWh/y]	Result-10,0% [MWh]	GROSS (no loss) Free WTGs [MWh/y]	Park efficiency [%]	Capacity factor [%]	Mean WTG result [MWh/y]	Full load hours [Hours/year]	Mean wind speed @hub height [m/s]
Wind farm	20.405,2	18.364,7	21.049,2	96,9	42,1	2.295,6	3.688	9,6

¤) Based on Result-10,0%

Calculated Annual Energy for each of 8 new WTGs with total 5,0 MW rated power

		WTG type					Power curve		Annual Energy		Park	
Terrain	Valid	Manufact.	Type-generator	Power, rated [kW]	Rotor diameter [m]	Hub height [m]	Creator	Name	Result [MWh]	Result-10,0% [MWh]	Efficiency [%]	Mean wind speed [m/s]
1 A	No	VESTAS	V39-600	600	39,0	40,5	User	Manufactor 05-03-2000 1.225 30.00 0.00	2.369,2	2.132	97,1	9,69
2 A	No	VESTAS	V39-600	600	39,0	40,5	User	Manufactor 05-03-2000 1.225 30.00 0.00	2.407,5	2.167	95,8	9,89
3 A	No	VESTAS	V39-600	600	39,0	40,5	User	Manufactor 05-03-2000 1.225 30.00 0.00	2.479,9	2.232	95,8	10,10
4 A	No	VESTAS	V39-600	600	39,0	40,5	User	Manufactor 05-03-2000 1.225 30.00 0.00	2.275,2	2.048	97,7	9,36
5 A	No	VESTAS	V39-600	600	39,0	40,5	User	Manufactor 05-03-2000 1.225 30.00 0.00	2.230,3	2.007	98,0	9,22
6 A	Yes	VESTAS	V47-660	660	47,0	40,0	EMD	Level 0 - calculated - - 07-2001	2.867,2	2.580	97,3	9,39
7 A	Yes	VESTAS	V47-660	660	47,0	40,0	EMD	Level 0 - calculated - - 07-2001	2.848,4	2.564	97,1	9,32
8 A	Yes	VESTAS	V47-660	660	47,0	40,0	EMD	Level 0 - calculated - - 07-2001	2.927,4	2.635	96,8	9,56

In the report sample shown above, it must be noticed that the specific results all are deducted, here with 10% covering expected losses and uncertainty. The wind speeds shown are free wind speeds (no wake reduction). The column with the deduction of xx% is controlled by the user when setting up the calculation. Wind farm efficiency is a measure of how much each single turbine produces, taking the wake losses into account relative to the gross production.

Capacity factor is the percentage of hours in a year that the WTGs would need to operate at rated capacity, to obtain the same production as calculated.

For example: A 600 kW WTG is estimated to produce 2,643 MWh/year. Dividing the annual production by WTG's rated capacity of 600 kW: 2,643,000 kWh / 600kW = 4,405 hours. Since there are 8,760 hours in a year, 4,405 / 8,760 yields a capacity factor of 50.3%.

Calculated Annual Energy for each of 5 reference WTGs with total 3,0 MW rated power

	WTG type						Power curve		Calculated prod. without new WTGs	Actual wind corrected energy	Goodness Factor
Terrain	Valid	Manufact.	Type-generator	Power, rated	Rotor diameter	Hub height	Creator	Name			
				[kW]	[m]	[m]			[MWh]	[MWh]	[%]
1 A	No	VESTAS	V39-600	600	39,0	40,5	User	Manufactor 05-03-2000 1.225 30.00 0.00	2.384,5	2.383,0	100
2 A	No	VESTAS	V39-600	600	39,0	40,5	User	Manufactor 05-03-2000 1.225 30.00 0.00	2.455,5	2.501,0	102
3 A	No	VESTAS	V39-600	600	39,0	40,5	User	Manufactor 05-03-2000 1.225 30.00 0.00	2.546,0	2.632,0	103
4 A	No	VESTAS	V39-600	600	39,0	40,5	User	Manufactor 05-03-2000 1.225 30.00 0.00	2.300,4	2.346,0	102
5 A	No	VESTAS	V39-600	600	39,0	40,5	User	Manufactor 05-03-2000 1.225 30.00 0.00	2.242,9	2.321,0	103

When using existing WTGs in a calculation, WindPRO provides a report called "Control WTGs", where the calculated yield is compared to the actual yield that is entered in the "Statistics tab sheet" in the Existing WTG Object. The "Goodness Factor" in the right-most column is described below.

Goodness factor = Actual yield (long term corrected) / calculated yield

Where the actual yield is assumed to be corrected to long-term conditions by the wind index method, and the calculated yield is based on wind data that is parallel to WTG operation. In both cases, a Goodness Factor of 100% indicates that there is an exact match between the predicted and actual production. If the Goodness Factor is less than 100%, e.g. 90%, then the actual WTG production is 10% less than predicted. This may be due not only to an inaccurate calculation. It could also be due to grid losses and availability. For this reason, the actual yield entered in existing WTG Data Object should be corrected for losses and availability.

PARK - Production Analysis
Calculation: PN-test - WAsP **WTG:** All existing WTGs, Air density: 1,225 kg/m³

Directional Analysis

Sector		0 N	1 NNE	2 ENE	3 E	4 ESE	5 SSE	6 S	7 SSW	8 WSW	9 W	10 WNW	11 NNW	Total
Roughness based energy	[MWh]	379,1	158,6	171,0	500,9	1.050,8	1.164,1	1.062,3	769,0	1.025,2	1.351,7	956,8	496,7	9.086,3
+Increase due to hills	[MWh]	122,9	44,9	66,6	191,1	304,2	414,0	329,6	206,5	256,0	434,4	422,8	267,4	3.060,3
-Decrease due to array losses	[MWh]	8,3	7,1	3,2	1,0	30,2	40,1	21,5	28,4	12,2	2,0	38,1	25,5	217,5
Resulting energy	**[MWh]**	**493,7**	**196,4**	**234,4**	**691,1**	**1.324,8**	**1.538,0**	**1.370,5**	**947,1**	**1.269,0**	**1.784,1**	**1.341,4**	**738,7**	**11.929,2**
Specific energy	[kWh/m²]													1.997
Specific energy	[kWh/kW]													3.976
Increase due to hills	[%]	32,4	28,3	38,9	38,2	29,0	35,6	31,0	26,9	25,0	32,1	44,2	53,8	33,68
Decrease due to array losses	[%]	1,7	3,5	1,4	0,1	2,2	2,5	1,5	2,9	1,0	0,1	2,8	3,3	1,79
Utilization	[%]	25,5	29,2	27,5	21,9	16,3	19,2	24,0	28,1	25,8	21,4	19,8	23,3	21,7
Operational	[Hours/year]	348	226	307	527	658	840	826	696	739	885	767	526	7.346
Full Load Equivalent	[Hours/year]	165	65	78	230	442	513	457	316	423	595	447	246	3.976

In the "Production Analysis" report, the results of the energy calculations for any or all WTGs (new, existing, or individual WTG) can be printed for further analyses. In the figure above, the directional calculation data is shown. The changes due to orography, obstacles, and array losses are provided in absolute figures as well as percentages. This can help to give you a sense for the importance of the different modeling elements and lead you to ideas for optimizing the layout.

The last three lines from the printout shown above are explained below:

Utilization – The percentage of the total wind energy in the available swept-rotor area that is utilized. For high-wind sites, this figure will be much lower than for low-wind sites. The figure does not directly indicate the quality of the site, but may be more useful for comparing different WTG types on a specific site.

Operational – The number of hours per year that the WTG will operate with the given power curve and wind data. The maximum will be 8,760 hours (total number of hours in a year). For example, the information can be used in flicker calculations.

Full Load Equivalent – The number of hours required to produce the calculated energy if the WTG(s) are operating at rated capacity.

NOTE: If the report is printed for a specific WTG, in addition, the Weibull A, k and frequency parameters will be shown for each direction.

PARK - Power Curve Analysis
Calculation: Using Local Wind data - WAsP   **WTG:** 6 - VESTAS V47 660 47.0 !O! Manufactor 24/8-2000 1.225 25.00 0.00, H

Name: Manufactor 24/8-2000 1.225 25.00 0.00
Source: Manufactor 24/8-2000

Created by Stop wind speed Power control CT curve type
                    [m/s]
EMD   25.0   Pitch   User defined

HP curve comparison

Vmean	[m/s]	5	6	7	8	9	10	10.2 (Current site)
HP value	[MWh]	855	1,368	1,876	2,350	2,781	0	0
VESTAS V47 660 47.0 !O! hub: 40.0 m	[MWh]	848	1,362	1,885	2,371	2,795	3,143	3,214
Check value	[%]	1	0	0	-1	-1		

Power curve

Original data from Windcat, Air density: 1.225 kg/m3

Wind speed	Power	Ce	Wind speed	Ct curve
[m/s]	[kW]		[m/s]	
3.0	0.0	0.00	3.0	0.00
4.0	3.0	0.04	4.0	0.92
5.0	44.0	0.33	5.0	0.89
6.0	97.0	0.42	6.0	0.88
7.0	166.0	0.46	7.0	0.88
8.0	252.0	0.46	8.0	0.83
9.0	350.0	0.45	9.0	0.81
10.0	450.0	0.42	10.0	0.75
11.0	538.0	0.38	11.0	0.66
12.0	600.0	0.33	12.0	0.57
13.0	635.0	0.27	13.0	0.40
14.0	651.0	0.23	14.0	0.31
15.0	657.0	0.19	15.0	0.24
16.0	659.0	0.15	16.0	0.20
17.0	660.0	0.13	17.0	0.17
18.0	660.0	0.11	18.0	0.14

Power, Efficiency and energy vs. wind speed

Data used in calculation, Air density: 1.203 kg/m3

| Wind speed	Power	Ce	Interval	Energy	Acc.Energy	Relative
[m/s]	[kW]		[m/s]	[MWh]	[MWh]	[%]
1.0	0.0	0.00	0.50- 1.50	0.0	0.0	0.0
2.0	0.0	0.00	1.50- 2.50	0.0	0.0	0.0
3.0	0.0	0.00	2.50- 3.50	0.3	0.3	0.0
4.0	2.9	0.04	3.50- 4.50	5.6	5.9	0.2
5.0	43.2	0.33	4.50- 5.50	24.8	30.7	1.0
6.0	95.3	0.42	5.50- 6.50	60.5	91.2	2.9
7.0	163.0	0.46	6.50- 7.50	111.1	202.3	6.4
8.0	247.5	0.46	7.50- 8.50	173.7	376.0	11.9
9.0	343.7	0.45	8.50- 9.50	239.3	615.3	19.4
10.0	442.1	0.42	9.50-10.50	295.2	910.6	28.8
11.0	529.9	0.38	10.50-11.50	328.7	1,239.3	39.2
12.0	592.5	0.33	11.50-12.50	333.0	1,572.3	49.7
13.0	628.6	0.27	12.50-13.50	311.8	1,884.1	59.5
14.0	646.1	0.23	13.50-14.50	274.9	2,159.0	68.2
15.0	653.7	0.19	14.50-15.50	232.3	2,391.3	75.6
16.0	657.3	0.15	15.50-16.50	190.3	2,581.6	81.6

The Power Curve Analysis can be printed for each WTG in the calculation. The columns on the left side show the original power curve, including the Ct curve (for array loss calculation). The columns on the right side show the power curve converted to actual air density conditions (the one used in calculations). The calculated energy (for a specific site) divided into wind speed bins, and accumulated energy are also shown. This indicates what percent of the total calculated energy production is produced at wind speeds below 5.5 m/s (in this case, 1%).

The HP curve comparison in the printout indicates what the WTG would produce at different mean wind speeds, calculated based on a normalized power curve. This can often be a better estimate than a measured power curve, since a power curve measurement involves considerable uncertainty. When no HP values are shown, as in the example above (Current site), the HP lookup table does not have information for this extreme wind speed region (or for some WTGs with extreme specific power (kW/m^2 rotor area), no information is available). The HP values are based on a study of several power curves grouped into specific power. The sub-groups are:

- Stall regulation with 1 generator and 1 speed
- Stall regulation with 2 generators or variable speed
- Pitch regulation (2 generators or variable speed assumed)

(See also Section 3.5.2).

NOTE: If a noise-reduced version of a power curve is used, the HP check should be performed on a non-reduced power curve, since the noise-reduced curve will always produce higher positive check values.
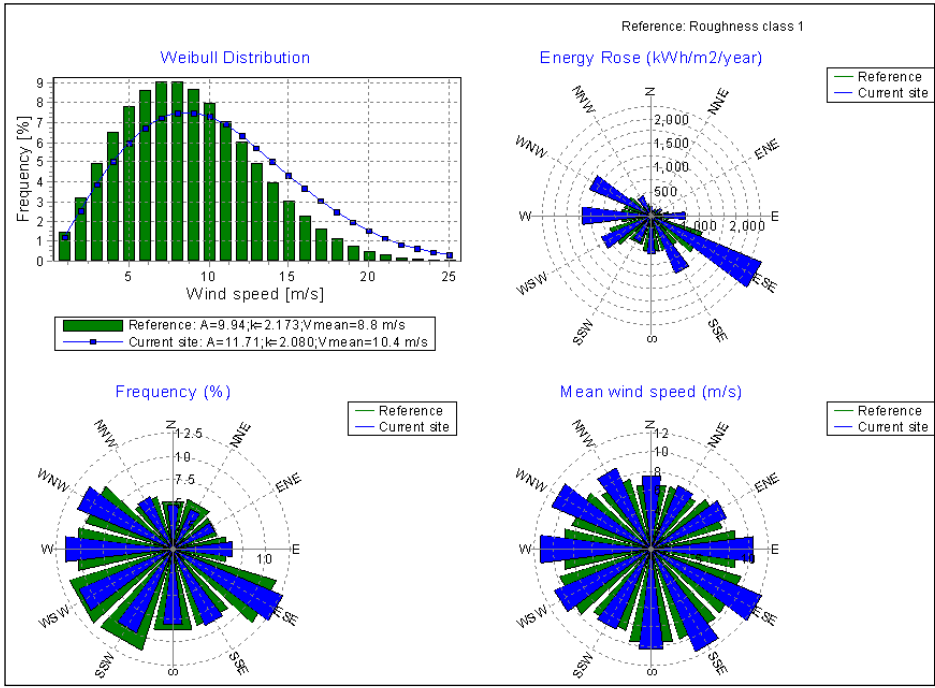
In the printouts, wind data can be compared with a reference, which is associated with flat terrain and a roughness class of 1. This reference is chosen because it is the best onshore condition, and, thereby, the effects of a coastline near the site, or a hilly site, etc. can be clearly seen. In the example above, the site benefits greatly from the local orography in most sectors, and they all result in much more energy than a flat roughness class 1 site.
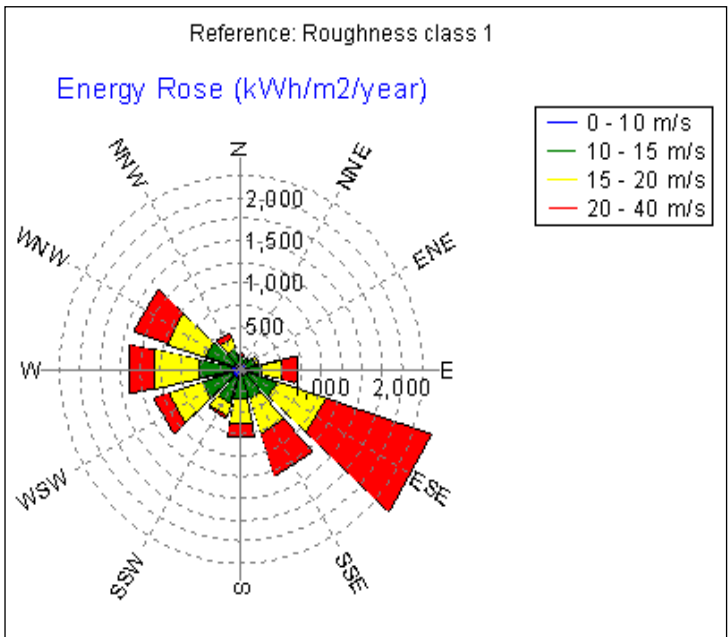
As an alternative to a comparison with a flat reference, a more detailed color setup can be made where the roses for energy and frequency are divided into wind speed intervals.

PARK - WTG distances

Calculation: Using Local Wind data - WAsP

WTG distances

	Z	Nearest WTG	Z	Horizontal distance	Distance in rotor diameters
	[m]			[m]	[m]	
1	326	5	287	238	6.1
2	333	3	344	218	5.6
3	344	2	333	218	5.6
4	289	5	287	242	6.2
5	287	1	326	238	6.1
6	296	7	292	219	4.7
7	292	8	306	209	4.4
8	306	7	292	209	4.4

This is an example of the WTG distance report. The nearest WTG to each WTG is determined and the distance calculated, and then reported in meters as well as in rotor diameters. In the case of unequal rotor diameters between the two nearest WTGs, the larger rotor diameter is used (which yields the lowest rotor diameter distance).

PARK - Wind statistics info

Calculation: Calculation of the AEP using WAsP

Main data for wind statistic

File	E:\Users\Per.EMD\Documents\WindPRO Data\PROJECTS\USA\Wichek_PN\Local wind data long term corrected.wws
Name	Wishek met mast 7/01 to 6/02 (Regression MCP using Linton NDAWN)
Country	United States
Source	USER
Mast coordinates	UTM WGS84 Zone: 14 East: 450.366 North: 5.110.713
Created	07-02-2008
Edited	07-02-2008
Sectors	12
WAsP version	

Comments
From MCP
The used wind statistic is generated from an older WindPRO version (before 2.8) or from another tool (WAsP) – therefore not all detailed informations are available.

Note
Note that to get most correct result, the wind statistic should be generated with same WAsP version as used in calculations. For WAsP versions before WAsP 10 although there will be no differences.

The wind statistic info page document the wind statistic used. Only wind statistics generated as.wws files from ver. 2.8 will have the full information saved with the wind statistic.

Report pages on turbulence are described in the wake and turbulence model appendix.

3.4.6.3 Printing data to a file (Results to file)

This option is very useful, especially if the PARK calculation results will be further analyzed. When you click on "Results to file" the following window appears:

Results from the Park calculation (all park calculation results) as well as WTG distances and wind speeds inside the wind farm can be printed in a structured format to a file for import in e.g. Excel. The information can also be copied to the clipboard and then be pasted into an Excel or other spreadsheet application.

Park results
A table with all relevant information from the PARK calculation is very efficient for post processing in spreadsheet. An overview of all information in the file is shown below.

NOTE: The table shown below is a transposed version of the output.

Label	Example	Explanation
WTG num	1	WTG numbered from 1 with lowest system label first
WTG type	New	New or existing
LIB file	ES Munesia-40m1.lib	Windstatistic
East	318.391	Coordinate
North	4.540.176	Coordinate
Z	581	h.a.s.l
Valid	Yes	Refer to power curve
Manufact.	DUMMY	Refer to power curve
Type		Refer to power curve
Power	3.500	Refer to power curve
Diam.	100	Refer to power curve
Height	95	hub height
Row data/Description	126.6°, 200.0 m	If row of WTGs the angle and distance else description field
Creator	USER	Refer to power curve
Name	Constructed based on 3MW expirience	Refer to power curve
User label	WTG#1	User label
Result	7.027,10	Calc. result incl park efficiency, no uncertainty withdrawn
Efficiency	97,1	Park efficiency
Regional Correction Factor	1	Refer to wind statistic
Equivalent roughness	2,1	is the roughness class in flat terrain with no obstacles that would give the same calculated energy production
Mean wind speed	6,3	Calculated at hub height
HP result (std. air density)	7.023,00	Calculation result based on HP table lookup instead of "real" power curve
Calculated prod. without new WTGs	0	Calculation of existing WTG without new
Actual wind corrected energy	0	Actual production from "statistics" of existing WTG
Goodness Factor		Actual/calc. for exisitng WTG
A (Sum)	7	Weibull A-parameter, all sectors
k (Sum)	1,72	Weibull k-parameter, all sectors
A (0)	9,1	Weibull A-parameter, sector 0 (North)
k (0)	1,93	Weibull k-parameter, sector 0 (North)
f (0)	9,3	Frequency, sector 0 (North)
A (1)	5	As above, sector 1
k (1)	1,92	As above, sector 1
f (1)	5,8	As above, sector 1
For all following sectors the same as abowe		

New from ver. 2.8:

Label	unit	Example	Explanation
Air density	[kg/m³]	1,242	The air density used for the specific turbine
Displacement height	[m]	0	The subtraction in hub height used for the specific turbine
Decrease due to obstacles	[%]	0	The reduced production due to local obstacle effect
Increase due to hills	[%]	2,68	The increased production due to local hill effect
Sensitivity	[dAEP/dWS %]	1,79	The change in AEP per change in wind speed, both as percentages

The last one, sensitivity is useful when calibrating production based on reference turbines. These will often have a lower hub height and thereby lower sensitivity. The sensitivity can be used to convert the AEP bias for reference turbines (actual/calculated) to wind speed bias and thereby find the relevant AEP correction for the new turbines.

Also the coordinate system is included in the header.

Park result sector wise
A report almost similar to the above, but with sector wise AEP. Wake efficiency, obstacle reduction and hill speed up. This can be used for e.g. post processing of results where noise reduction is performed different for different direction sectors.

Wind speeds inside wind farm
First, you can define the wind speeds, angles, and for which sites the data is to be extracted.
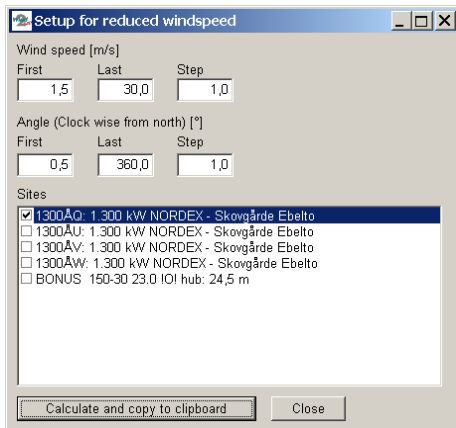
You also specify where and in what resolution the data is needed.

Explanation:		Wind speeds - first row the "unreduced" (center value for interval), below in table the reduced									
		UTM ED50 Zone: 32 East: 603066 North: 6225290 1300ÅQ: 1.300 kW NORDEX - Skovgårde Ebelto									
Directions:		1,5	2,5	3,5	4,5	5,5	6,5	7,5	8,5	9,5	10,5
(center of	0,5	1,5	2,5	3,5	4,5	5,5	6,5	7,5	8,5	9,5	10,5
direction	30,5	1,5	2,5	3,5	4,5	5,5	6,5	7,5	8,5	9,5	10,5
interval)	60,5	1,5	2,5	3,5	4,5	5,5	6,5	7,5	8,5	9,5	10,5
	90,5	1,5	2,5	3,5	4,5	5,5	6,5	7,5	8,5	9,5	10,5
	120,5	1,5	2,5	3,5	4,5	5,5	6,5	7,5	8,5	9,5	10,5
	150,5	1,49	2,49	3,42	4,24	5,17	6,1	7,07	8,04	9,03	10,04
	180,5	1,46	2,44	3,26	3,77	4,33	5,08	5,81	6,64	7,54	8,48
	210,5	1,5	2,5	3,5	4,5	5,5	6,5	7,5	8,5	9,5	10,5
	240,5	1,5	2,5	3,5	4,5	5,5	6,5	7,5	8,5	9,5	10,5
	270,5	1,5	2,5	3,5	4,5	5,5	6,5	7,5	8,5	9,5	10,5
	300,5	1,5	2,5	3,5	4,5	5,5	6,5	7,5	8,5	9,5	10,5
	330,5	1,5	2,5	3,5	4,5	5,5	6,5	7,5	8,5	9,5	10,5

The table shown above contains the extracted data, which can be used for cleaning measurements in a wind farm. This requires some "reverse engineering" in order to do this. The Lookup function in Excel is used for this purpose.

Park power curve, Turbulence inside wind farm, and Wake wind speeds from a single turbine.
These results are discussed in detail in the appendix on wake and turbulence models.

3.5 ENERGY – Losses, Uncertainty, and Checking

3.5.0 Introduction to Losses, Uncertainty, and Checking

To carry out a production calculation by using a modern computer program is a worthwhile exercise. However, since large-scaled investments are usually involved in wind energy projects, it's important that the user of the program be able to check to see whether the results are realistic or not. The many detailed printouts from WindPRO are useful for this purpose.

A detailed loss and uncertainty evaluation has become more and more important the recent years, while the margins for financial feasibility have become smaller. Therefore there is now a separate module in WindPRO for performing this evaluation. We, therefore, highlight some of the more important issues in this chapter and refer to chapter 12 Loss and Uncertainty.

3.5.1 Losses and Uncertainties

3.5.1.1 Losses

Losses must be estimated and deducted from the calculated results. It is highly recommended to use the WindPRO Loss and Uncertainty module (Chapter 12) for this purpose. If this is NOT used, a rough guideline would be to subtract 5-15% from the wake loss calculated AEP, much dependent on site location. Some of the more important losses are reviewed below:

Wake losses – Included in PARK calculation.

Grid – (Can be calculated by the eGRID module in WindPRO). It's important to remember the losses in the built-in transformer in the WTG (for large WTG's), since the power curve is typically measured before the transformer losses. Grid losses will typically be round 2% including the transformer, where 1% typically are lost in the build-in step-up transformer.

Availability – Typically, modern WTGs have availability losses of approximately 3-5%. It is very dependent upon manufacturer guarantees and service/maintenance agreements. In some countries, grid down-time is quite common and losses can be high, but in most industrialized countries, grid availability is normally considered to be close to 100%.

Blade degradation, icing, and extreme temperatures – This can be a problem in some regions, requiring a more specific analysis.

High-wind hysteresis – If the wind speed is above the shut down speed for WTG (at least once per year), there will be some time before the WTG resumes operation. This is not included in the production calculations and must be deducted manually. From our experience in Denmark, approximately 0.3% of annual production will be lost each time this happens (this is only a rough estimate).

Operation mode losses – Turbines may operate at reduced levels for different reasons such as turbulence (closely-spaced WTGs stopped in certain wind directions), flicker (during hours when the nearest neighbors experience significant flicker) or noise reduced mode (e.g. during night time). At present, the user must account for deductions manually.

Lastly, there may be some bias due to RIX (see chapter 3.4.3.1 RIX calculation) or power curve experience that should be corrected for before the net production figure is obtained

Note: See the detailed loss list in Chapter 12.

3.5.1.2 Uncertainties

As for losses, it must be mentioned that in Chapter 12 a far more comprehensive description is given. But for the users without this module, we maintain the rough guidelines for a simpler calculaiton here.

The following uncertainties are usually present in a production calculation (figures in brackets indicate estimated uncertainties under good conditions):

- The wind data/ Wind Statistics (5%)
- The long term correction of the wind data (MCP) (5%)
- The model extrapolation (vertical and horizontal) based on Terrain Description, i.e. roughness, hills and obstacles (5%)
- The Power Curve (5% if verified, see Section 5.2)

For very large wind farms, an essential extra contribution can come from the wake loss model

A commonly used method of estimating the joint uncertainty of independent, uncorrelated uncertainties is to calculate the RMS value, i.e.:

Joint uncertainty = $SQRT(5^2+5^2+5^2+5^2) = SQRT(100) = 10\%$

A more recently typical included uncertainty is the future wind climate. Previous (before 2005) it was quite common to accept 10 years as sufficient long-term data. In northern Europe, practical experience has shown that this is much too short a period, due to special climate conditions in this region. Different analyses pinpoint that approximately 30 years seems to be needed period to characterize a long-term wind climate. But even with this, the next 20 years, when the wind farm is expected to be in operation, might be 5% below the long-term average. Therefore, the latest recommendation is to add an extra 5% uncertainty for the future wind climate.

NOTE: If the predicted uncertainties are treated as standard deviations, and the uncertainty is assumed to be 10% (= 1 st.dev), this means that there is a probability of 84% that the calculation results (minus losses) of less than 10% will be achieved. This is also called the P(84) case(or 84% probability of exceedance). If a P(90) probability of exceedance is desired based on the same uncertainty assumptions, 12.8% must be deducted. (the uncertainty multiplied with 1.28). This is based on the characteristics of the normal distribution (see figure below).
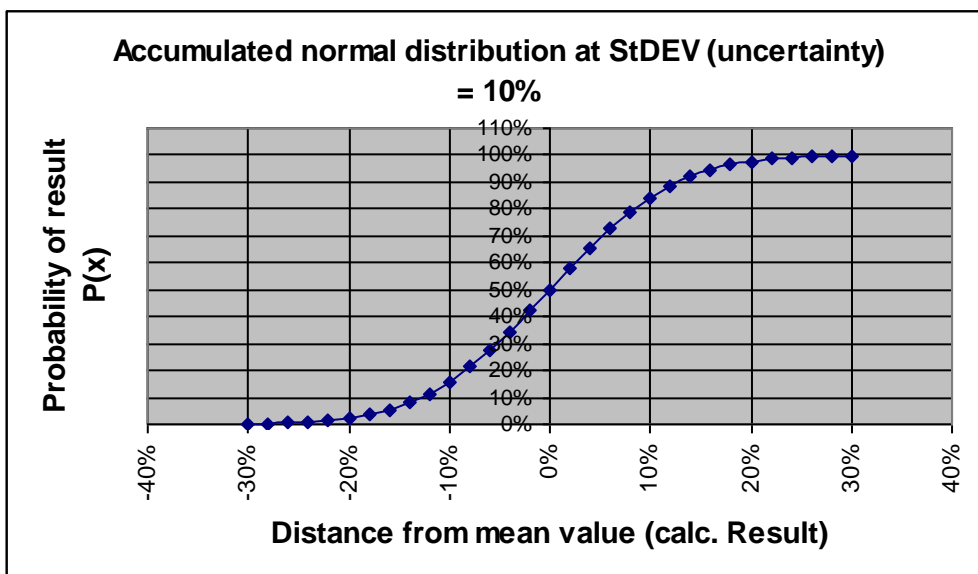
When the calculated production is verified with the actual production, it's important to be aware that there is an uncertainty in establishing the production corrected to a "normal year", e.g. the long-term scaling of actual production figures. The following uncertainties are based on experience from WTGs in Denmark:

- With one year of production data   +/- 10%
- With two years of production data +/- 5%

It's generally assumed that a good production estimate can be made with an uncertainty of +/-8% (Danish or similar conditions, with many reference turbines).

This seems to be the case for about 95% of all calculations carried out in Denmark over the previous years.

Two things are especially important in order to achieve a small uncertainty:

- Experience with turbine installations in the area which have been running for some years
- Experience in using the calculation method and regular checks on how your calculations perform compared to real experience.

One would therefore expect that 95% of the production estimates that have been made by an experienced user/consultant in Denmark and Germany lie within +/-10%.

For new regions where there is no experience, a significant increase in the uncertainty should be expected, especially in complex terrain. It's not possible to set any guidelines for these uncertainties. But local measurements of cause can reduce the uncertainties. The more masts, the higher masts and the longer measurement period will all bring the uncertainty lower.

NOTE: Uncertainty is one thing, but errors are quite another. If data is erroneous, there is no upper limit for how incorrect the estimated production can be compared to the actual production.

3.5.2 Checking the Power Curve

A key parameter when checking the power curve is the non-dimensional C_e curve, which can be used for direct comparison of different power curves. If the maximum C_e value exceeds 0.45, either the power curve is incorrect or the manufacturer has developed an extremely efficient WTG. Although efficiency has improved later years, up to 0.49 is seen, but not validated sufficient – but round 0.47-0.48 is probably possible to reach today. The improvements are a mix of better blade design, permanent magnets, and better control systems.
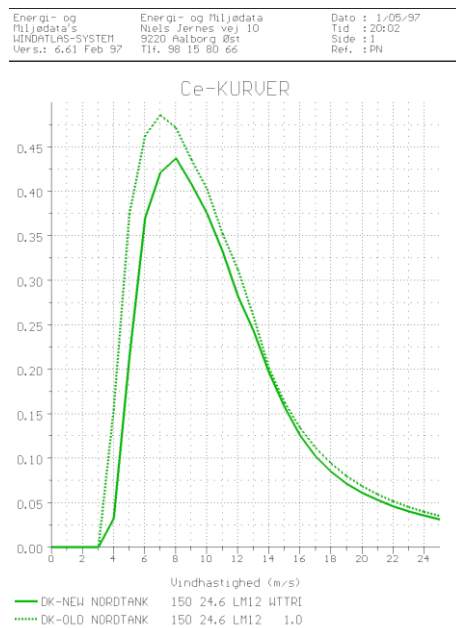
Comparison of C_e curves from WTGs of similar construction and size is also a good way to look for possible overestimations of the power curve. The figure above shows a power curve measurement that should have been rejected in the first place due to an unrealistically high C_e value.
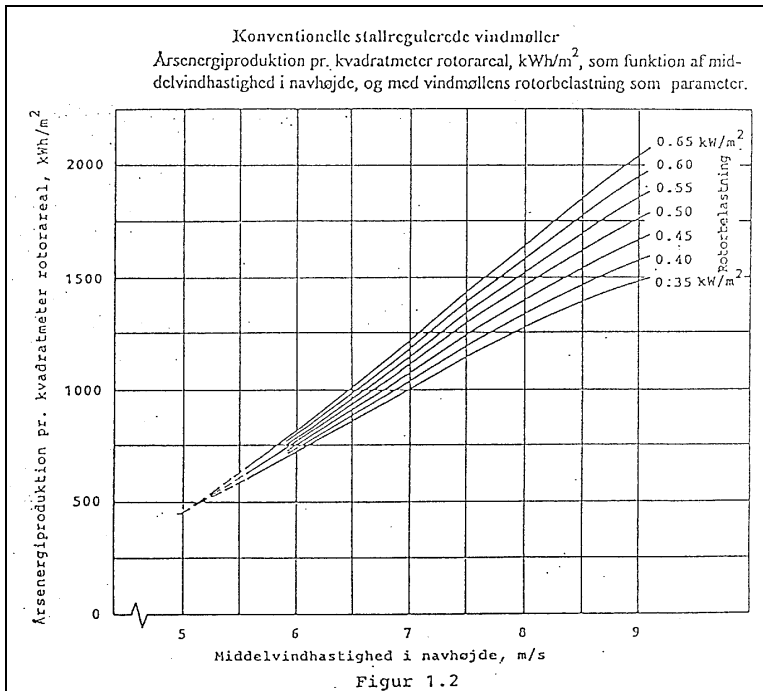
Another possible method of verification is to compare the estimated production by using the "Helge Petersen" (HP) curves with the production based on the power curve. The HP curves are shown in the above figure. These curves show key figures based on a large number of rather new turbines ranging from 150 kW to 2 MW. These curves have been updated in 2001, and a printout from the WTG Catalog will give the values from these curves for the specific WTG. Comparisons with actual power curve calculations are performed. A portion of the printout from the WTG catalogue is shown below.

HP curve comparision

Vmean		[m/s]	5	6	7	8	9	10
HP value		[MWh]	206	331	464	578	665	754
WT/TRIPOD 1.225 25.00 -0.80		[MWh]	206	331	457	572	671	749
Check value		[%]	0	0	2	1	-1	1

From version 2.4, the HP values have been improved with the following:

WTGs smaller than 150 kW are given reduced HP values based on experience, so that:

- 50-149 kW is reduced to 90% for 50 kW, and linearly reduced up to 100% at 150 kW.
- WTGs below 50 kW are reduced to 90%.
- 1 generator, pitch-regulated WTGs are reduced by 4% for mean wind speeds below 7 m/s.

With these corrections, the HP values will be more accurate for all WTG sizes.

From version 2.8 further improvements are made. There are now 5 check tables:

Stall – 1 generator	Pitch – 1 generator
Stall – 2 generator/variable	Pitch – 2 generator (updated 2012)
	Pitch – variable speed (NEW 2012)

NOTE: It is when using the HP check VERY important that field in the turbine catalogue "Generator type" is correct filled. From ver. 2.8 there 2-generator and variable speed means two different check tables, where the "variable speed" version more reflect the 2000-12 generation of modern turbines.

The updates are based on comprehensive analyses by Per Nielsen based on 23 reasonable new power curves (2000-12 turbines). These are divided into Specific power classes and analyzed part by part (foot, leg, shoulder and arm) and are basis for establishment of "artificial power curves", which then are basis for calculation of the "HP-table values".
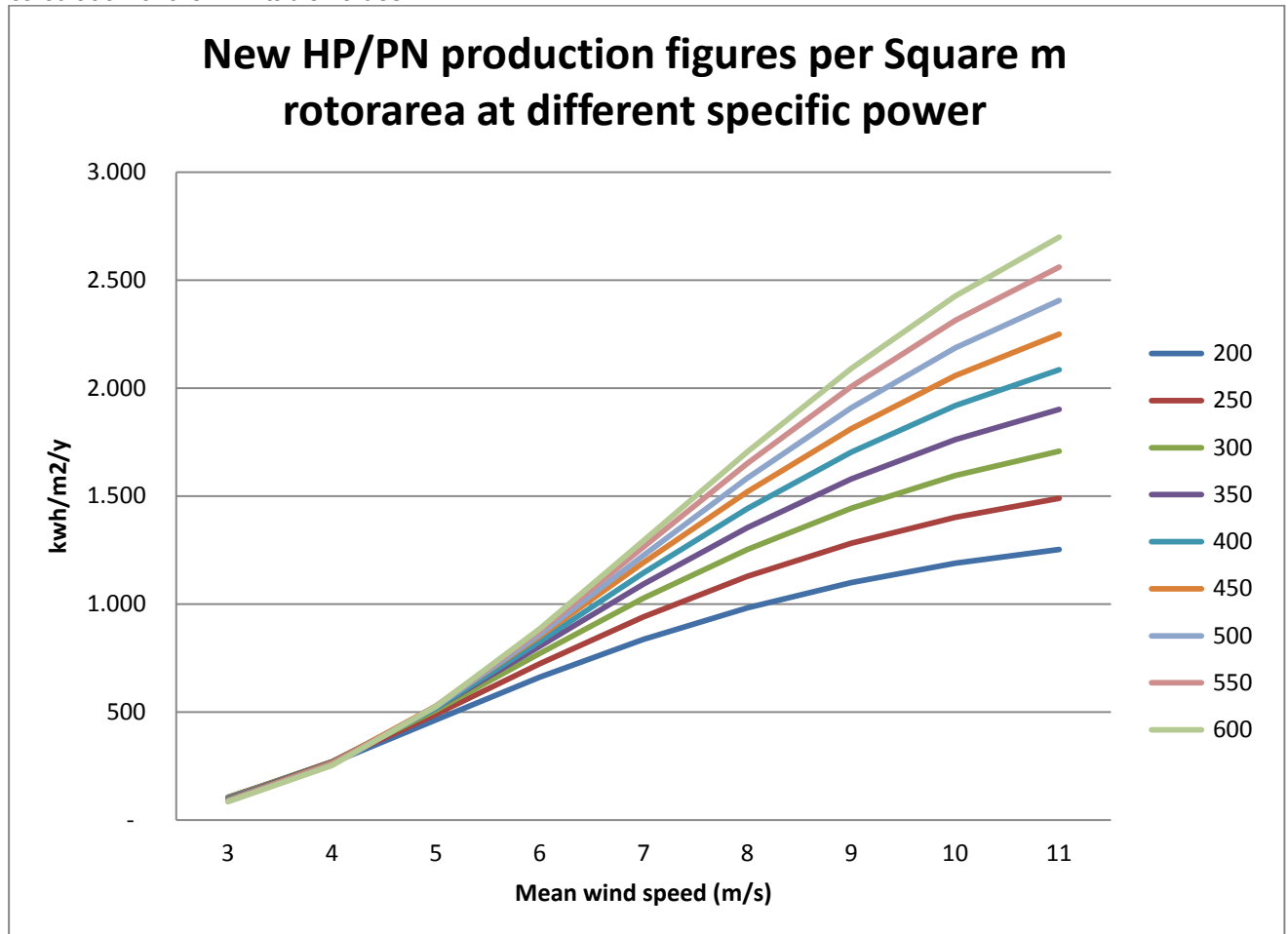
The results of the analyses for the Pitch-variable speed modern 2000-12 turbine.

A more comprehensive documentation will be available at WindPRO help desk at a later stage.

3.5.3 Verification by using existing WTGs

The best check is to use production information from other WTGs in the area for which reliable information is available. Information on the energy production and the power curve is essential. Regarding the production, it's important to adjust data from short measuring periods (less than 3 years) to long-term wind conditions (normal year). For Denmark, Holland, and Germany, there are good wind energy indices available. Please note the comments at the end of this section regarding possible errors when making production verifications. In other countries where no energy indices are available but where several WTGs have been installed, you can establish your own index based on the WTGs with more than 3 years of operational data. But note that the 3 years is only valid if there is sufficient long-term data to correct the production. Latest experience shows that in e.g. Northern Europe, even 25 years is not enough to establish reliable long-term wind expectations. Up to 50 years may be required.

Performing the production check involves performing a production calculation for the existing WTGs while using the same assumptions and data as used for the new WTGs (adjusted to the existing terrain conditions if the terrain of the existing sites vary from the terrain conditions of new site). If the calculated production differs by more than approximately 5%, you should be able to find the explanation.

Possible reasons for errors in the production check for shorter production periods (less than 3 years):

1. The wind direction

The production of a WTG sited in terrain with very different roughness in the different direction sectors will be very sensitive to the prevailing wind directions during the reference period.

2. Seasonal variations
A WTG sited in an area with many crossing hedges and/or high roughness will produce much less of its annual production during the summer with relatively weak wind than a coastal or offshore WTG, which, on a relative basis, does not benefit as much from the strong winter storms as the low-wind sited WTG, even when both WTGs would be running at their maximum output.

3. Geographic differences
Even over distances of a few hundred kilometers in simple terrain, there can easily be significant differences in the geostrophic winds.

4. The Power Curve
The ratio between the swept rotor area and the nominal generator rating will have significant influence on the production check, as will the power regulation system (stall or pitch regulation). During a period with high winds, some WTGs with pronounced stall characteristics will only produce approximately 2/3 of their rated power, while other WTGs may produce even 1/3 above their rated power. Lastly, some WTGs will have lower cut-out wind speeds than others.

3.5.4 Verification by using additional wind data

If no reference turbines are available in the area, then verification calculations on the basis of other wind data will give a good indication of the level of uncertainty by a simple comparison of results. One should generally never base production estimation on only one set of wind measurements unless these have been verified through other measurements. The risk of not noticing errors is simply too high. EMD has made a more comprehensive study regarding the checking of existing wind farms energy production against calculations, where many different investigations have been performed. The complete study can be downloaded from EMD's home page: www.emd.dk.

Below main result graphic is shown.

3.5.4.1 Overview of the case studies and main specifications

Case Id	Country	Place	Terrain	Wind farm	Start	Meteorological mast on site	Meteorological mast near site	Measurement height	Wind speed at 40 m on site *)	Goodness, "standard" calculation	Highest goodness	Lowest goodness	NCAR based Goodness
01	DK	Klim Fjordholme	Flat, open, inland, close to fjord	35 x 600 kW Vestas	1996	No	Parallel	10	7.0	1.00	1.02	0.98	-
02	DK	Torrild	Hilly, inland	15 x 150 kW Bonus	1989	Parallel	0	30	6.2	1.05	1.10	1.05	
03	DK	Torrild, Windsim	Hilly, inland	15 x 150 kW Bonus	1989	Parallel	0	30	6.2	1.15	-	-	-
03	DK	Avedøre (København)	Harbour, close to large city	12 x 300kW Bonus	1993	No	Parallel	0	6.9	1.02	1.02	0.80	0.90
03	DK	Lynetten (København)	Harbour, close to large city	7 x 600kW Bonus	1996	No	Parallel	0	6.4	1.00	1.05	0.70	0.90
03	DK	Dragør (København)	Flat, close to large city and sound	8 x 95 kW Tellus	1989	No	Parallel	0	6.3	0.98	1.00	0.74	0.90
03	DK	Middelgrunden	Offshore, close to large city	20 x 2 MW Bonus	2001	No	Non parallel	50	6.9	0.96	-	-	-
04	DK	Tunø knob	Offshore	10 x Vestas 500 kW	1995	No	No	0	7.8	1.03	1.04	1.00	-
05	DK	Knebel	Hilltopp, coastnear, local obstacle	4 x 55 kW Nordtank + 150 kW NTK	1982	No	No	0	7.5	0.98	1.10	0.97	-
06	DK	Brokilde	Coastal open flat land	12 x 600 kW Vestas	1996	No	Parallel	10	7.2	1.05	1.05	0.91	1.15
07	DK	Silstrup	Hilly, inland, close to fjord	3x 225kW Vestas	1990	Parallel	jan-00	10	7.2	0.98	1.02	0.83	-
08	SE	Göteborg	Fjord with skerries, close to open sea	3 x 225 kW Vestas + 6 x 600 kW Vestas	1996	No	No	0	7.0	0.83	1.02	0.83	0.85
09	FIN	Pori	At open sea, flat, skerries	7 x 1 MW Bonus + 300 kW NTK	1999	Parallel	0	38, 62, 87	6.2	1.01	1.20	0.90	0.81
10	DE	Fehmern	At open sea, flat, dikes	Mixed; Bonus, Enercon, HSW, Vestas	1987	Parallel	0	10, 30	7.8	0.93	1.07	0.89	-
11	DE	Knull	Complex obstacles, medium mountainous	Tacke, Enercon E18 + E40	1993	Parallel	0	10	6.0	0.85	1.24	0.78	-
12	DE	Hartmansheim	Complex obstacles, medium mountainous	Mixed, Bonus, Tacke, Enercon, HSW, Enron	1993	Parallel	0	10, 30	6.0	0.73	0.85	0.70	-
13	NL	Rotterdam	At large fjord, flat, dikes	Mixed	1999	No	No	0	6.5	1.00	1.05	0.89	-
14	FR	Port La Nouvelle	Coast near, hilltop	4 x Vestas V39 (+1 x V25)	1993	No	No	0	7.5	0.90	1.20	0.85	1.99
15	EIRE	Cronalacht	Coast near, hilltop	5 x Vestas V39 600 kW+ 3 x Vestas V47	1997	Non parallel	0	10, 30	9.6	1.00	1.00	0.94	1.04
16	POR	Sines	Coastal, gentle hill, close to city	12 x 500 kW WindWorld	1995	No	No	0	6.0	1.54	1.80	0.59	1.47
17	GR	Sitia, Modi	Flat plateau in complex mountainous region	17 x 600 kW Bonus	1998	Parallel	0	40	9.0	0.97	1.04	0.92	2.60
18	TR	Cesme	Coast near, mountain region	12 x Vestas V44 + 3 x Enercon	1999	No	Parallel	10, 20, 30	7.2	0.92	0.94	0.86	-
19	AUS	Esperance	Coast near, hilly	9 x Vestas V27, 225 kW	1994	Non parallel	0	10, 30	7.5	0.93	1.05	-	1.26
20	USA	Fargo, Minnesota	Flat inland	2 x NEG-Micon 750 kW	1999	Parallel	0	30, 40	6.1	1.08	1.10	0.94	1.00

*) The expected "real" mean wind speed at site based on all gained experience — 0

The table shown above provides an overview of the various case studies.

The goodness is defined as: actual wind farm production divided by the calculated production, corrected for differences in the wind energy index for the production period and the wind data period, if they are non-parallel.

The column "Standard calculation" corresponds to what we would consider as the calculation based on the best-available data for the site but not necessarily the calculation that yields the most accurate results.

Many different calculations and parameter variations have been tested in each case. The highest and lowest goodness values give an indication of the uncertainty in each case, and are due to the very different setups in each case; they are not directly comparable. In some cases, the lowest and highest goodness values are based on individual differences from WTG to WTG, but in most cases, the lowest and highest goodness values are based on using different wind data for the calculations. The "NCAR based goodness" is based on calculations using the nearest NCAR upper-air data taken down to the specific site by the WAsP model.

3.5.4.2 Examples of wind data uncertainties

The two following examples illustrate how uncertain the basis for the production calculation can be when working in new areas where WTGs with some years of operation are not yet available and where the quality of measured data is poor.

Portugal

A wind energy project was established based upon on-site wind measurements.

The actual production turned out to be only half of the estimated production. The following errors and uncertainties were found:

- The wind measurements were based on instant readings, which were taken at irregular intervals and written down by hand. There were no guarantees that the data was representative. For example, the

readings were carried out primarily during the day, which may cause large error margins since wind often blows less during the night.
- The measurement equipment was not calibrated and the measurement height was only 8 m agl.
- The measurements were made on a hilltop where the conversion of wind data from measuring height to hub height can be quite uncertain.
- The use of the Wind Statistics from the nearest meteorological station would have given much more precise results. However, this station was rejected in the first place due to its complex location close to the ocean and the city.

Ireland

In connection with a project, on-site measured data was received from the client. Data from the European Wind Atlas was available from 3 stations, all within about 70 km from the site.

The calculations based on the data from the European Wind Atlas and the on-site measurements respectively gave the following results:

Data origin	Relative calculated production
Station 1	100%
Station 2	92%
Station 3	56%
On-site measurements	163%

It can be seen that the deviations are large (a factor of 3 from lowest to highest production). This clearly indicates that one should never rely on only one set of data unless it is very well documented.

3.5.4.3 Verification by using additional Wind Atlases for a large area

If a large number of Wind Atlases (Wind Statistics) are available for a large area (e.g. a country or a province), you can verify these by calculating the energy production on the basis of the same WTG and the same assumptions (e.g. Roughness Class 1 in all directions), and calculate the associated production indices (using the average of all the production figures). The resulting indices (e.g. in percent) are marked at the corresponding geographic positions on a map. You can then try to fit smooth curves through points of equal or close to equal indices. In general, the geotropic wind (which the Wind Atlases should represent) will only change a little over a certain area. It should therefore be possible to fit smooth curves without sharp bends. This exercise will often reveal an incorrect Wind Atlas.

The next figure shows a check of some Swedish Wind Atlases. As supporting data for the curve fitting around Denmark, the actual production from a number of turbines was also used.
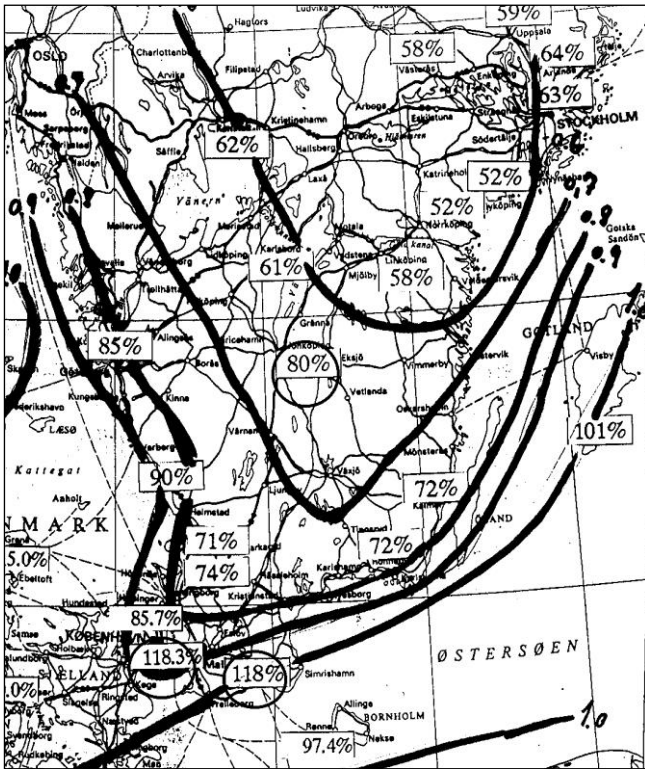
3.6 ENERGY - Wind Resource Maps

3.6.0 Introduction to Wind Resource Map

A wind resource map is a useful tool, which has many purposes, for example:

- Planning of wind energy projects, where the search for good sites is a part of the process.
- Evaluation of the wind energy potential in a region or a country.
- Support for wind farm layout, where the best sites within a certain area are desired. This can be automated from the OPTIMIZE module, see chapter 8.

A wind resource map where you just want to find the best spots can be established for very large areas as well as small areas.

With WindPRO, you can handle very large areas in one process. The software can handle an unlimited number of .map files (roughness and orography), and it can automatically work with several Wind Statistics that will be changed and weighted according to the distance to the sites in question. WAsP is used as the calculation engine.

It is also possible to calculate RIX corrected resource maps. Thereby the optimization of the layout can consider the bias, the differences in ruggedness gives.

3.6.1 Background Data for the Wind Resource Map

The following data is needed to generate a Wind Resource Map:

- One or more digitized roughness maps covering the calculation area plus the additional area extending approximately 10-20 km beyond the Wind Resource Map area.
- One or more digitized height contour line maps covering the calculation area plus the additional area extending approximately 5-10 km beyond the Wind Resource Map area, depending on the terrain complexity at the site.
- One or more Wind Statistics valid for the calculation area. Weighting can be automatically based on distance to wind statistics.
- Optional: Obstacles in the area. These are often not taken into account when calculating wind resource maps, but it's possible via WindPRO.

3.6.1.1 Digitized Roughness Map

You can create a digital roughness map in the following ways:

Manual digitizing
This involves a combination of field studies and map studies, followed by digitizing in WindPRO. In WindPRO you can digitize directly by using the Line Object, or indirectly by using an Area Object followed by exporting to roughness lines. The Area Object is strongly recommended for larger areas or complicated areas since this avoid problems such as crossing lines or discontinuous lines, which can cause dramatic errors in the WAsP calculation.

Automatic generation
You can generate roughness maps based on information from databases which contain information on land use, or GIS systems. In this case also, the Area object should be used. EMD did use a more refined processing method when we made a detailed roughness map of the entire country of Denmark for calculating a detailed wind resource map. Please check On-line data in Area object or contact us for further information on the subject.

(see also Basis, Section 2.8, Line object for further information).

3.6.1.2 Digital elevation data

This data will often be available from public sources, check the On-line data from the line object or elevation grid object. As an alternative, you can digitize manually from maps (see Basis, Section 2.8, Line object or 2.10 Elevation grid for further information).

3.6.1.3. Wind Statistics

For more information on Wind Statistics, see Section 3.2.1.2 and 3.2.4. A unique feature in the RESOURCE module is that it can change Wind Statistics automatically and weight them during the calculation.

3.6.1.4. Local Obstacles

Local obstacles can be added to the calculation as described in Section 3.1.5. It should be noted that the calculation speed will be reduced significantly by adding just one local obstacle. The reason for this is that WindPRO calls a "normal" WAsP calculation for each calculation point in order for it to be able to treat the obstacle correctly. If no obstacles are included, the WAsP resource option is called, which operates much faster.

3.6.2 Entering data for the calculation

When the data has been established it must be attached to a Site Data Object.

First select the Site Data Object that is to be used in RESGEN. It's of minor importance where the object is positioned.
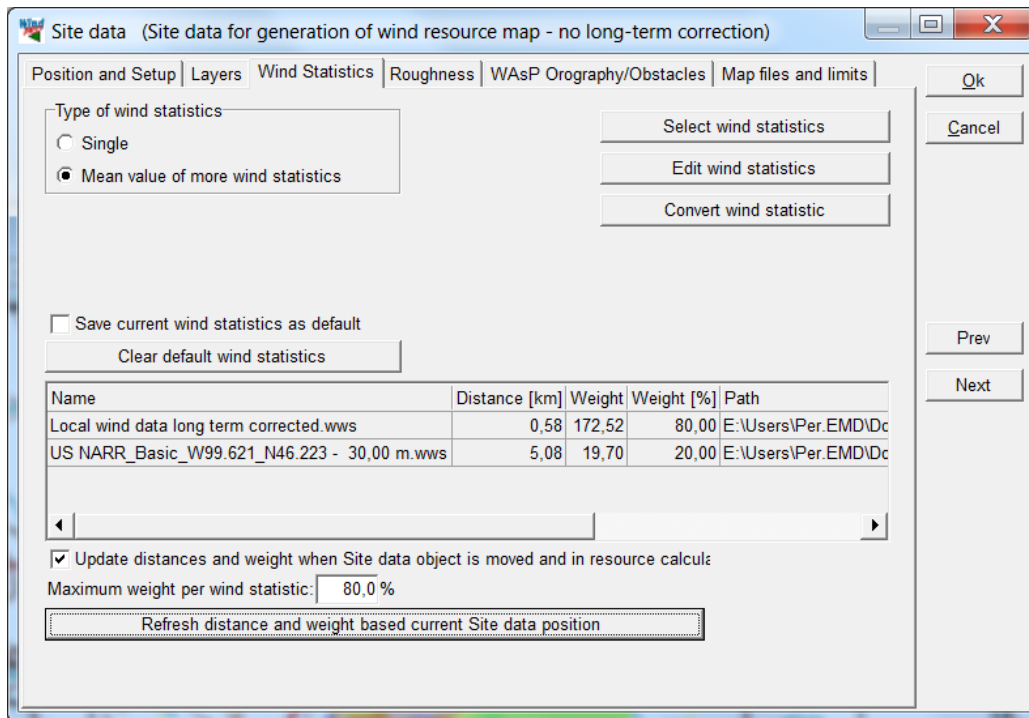
The wind statistic selection – in the example, "mean value of more wind statistics" is chosen, and it is set to update distance weight when moving from one calculation point to the next. A maximum weight per wind statistic of 80% has been set. Thereby you can avoid small local minima or maxima just around the wind statistic points, and you can decide to trust more an partly average than fully trust one wind statistic.

After having selected the Wind Statistic(s) (see the previous comments) and added information regarding obstacles, you add the maps and define map limits for the calculation area.

The important setting in the form above is the "Radius read from map files in each calculation". By limiting the radius, combined with "tiled calculation" (WindPRO divides the resource map calculation in tiles like 1 x 1 km squares), unlimited large resource maps can be calculated, and the calculation can be shared on more processors. The radius limit is to avoid sending too large map files to WAsP calculation for each tile. So, if the map file contains a lot of points (high point density), it might be necessary to limit the radius for reducing the map area sent to a WAsP calculation. Below is shown the capability of the different WAsP versions. The form below will, at present, only be available when site data object purpose is set to WAsP calculation (or

STATGEN). To get some help for analyzing if the WAsP capabilities seem to be violated by your file sizes, change the purpose to WAsP calculation temporarily and press the calculator button.

Pressing the **?** gives info on the WAsP:
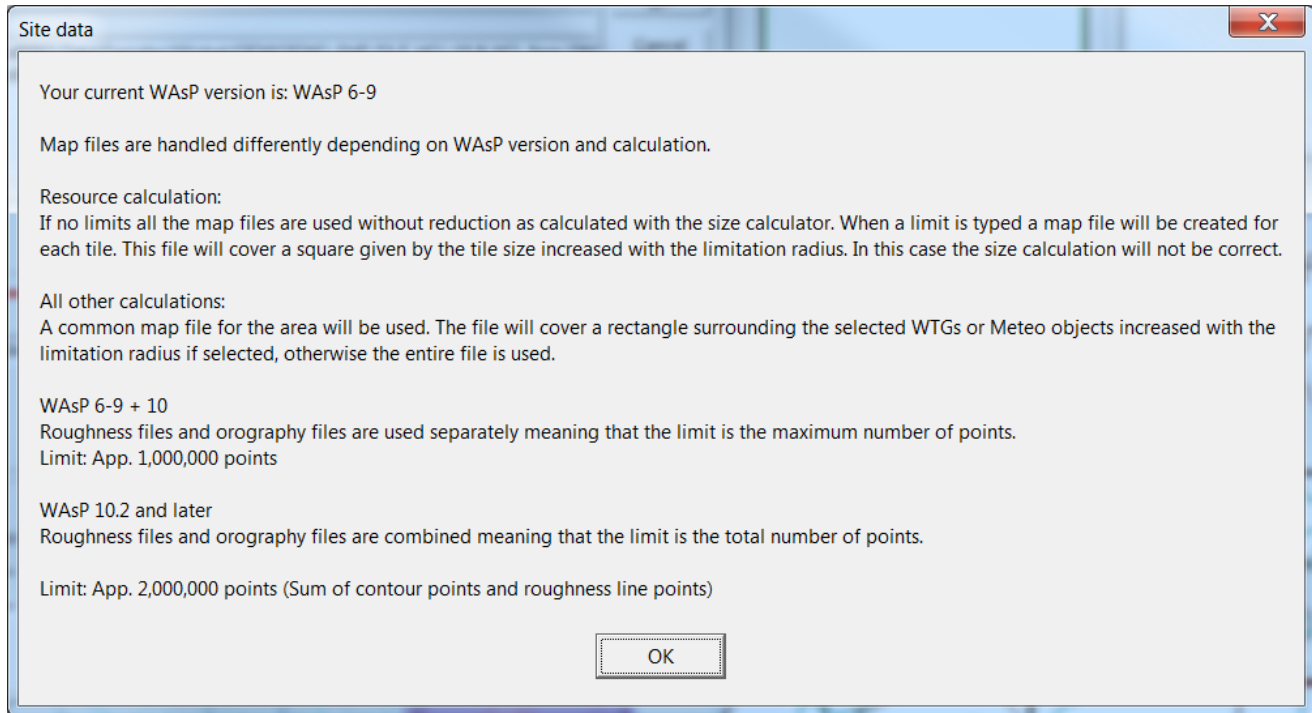
With the "pick tool" you can set the calculation region directly on the background map.

NOTE: At calculation time you can decide to let a WTG-area decide the area to be calculated and the selection in the site data object is thereby overruled.

3.6.3 Calculating a Wind Resource Map

Click the green button (arrow): ◀ 🖼 Model: RESOURCE (Wind/AEP resource map)
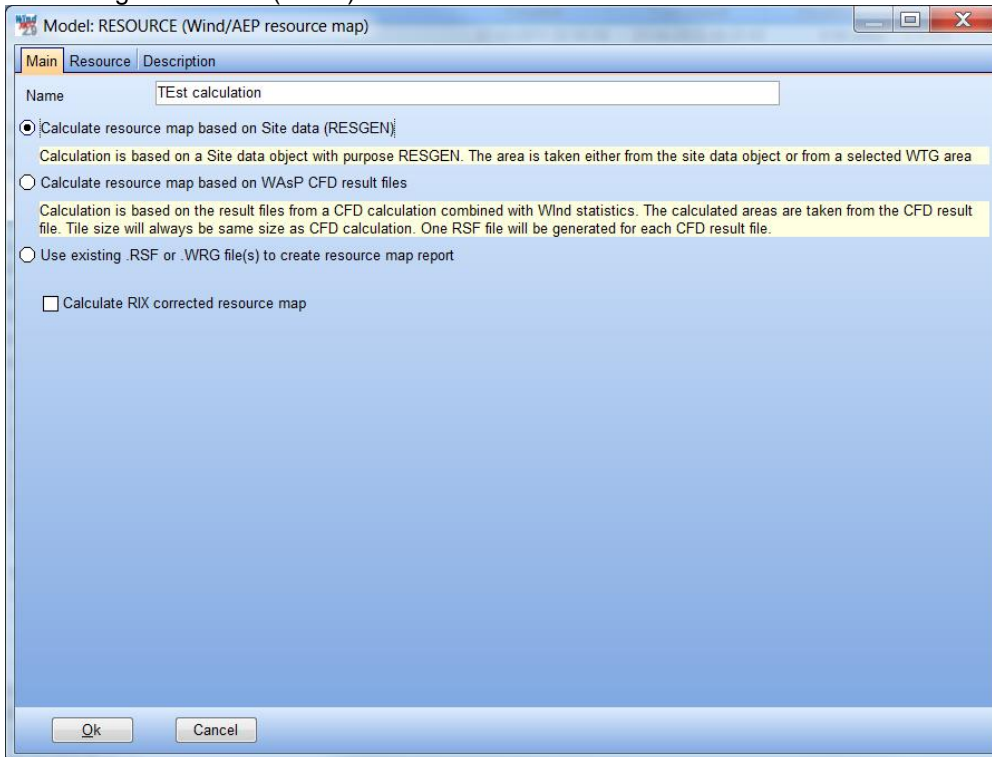
Resource map can be based on WAsP-CFD result files, in that case Rix correction option is not available. You can choose to use a previously calculated resource file, which basically give you the option to utilize the features of the resource module (presentation etc.), but based on an "external file", that could come from a another CFD calculation.
You have the option to chose to calculate RIX corrected resource map. A RIX tab then appear.
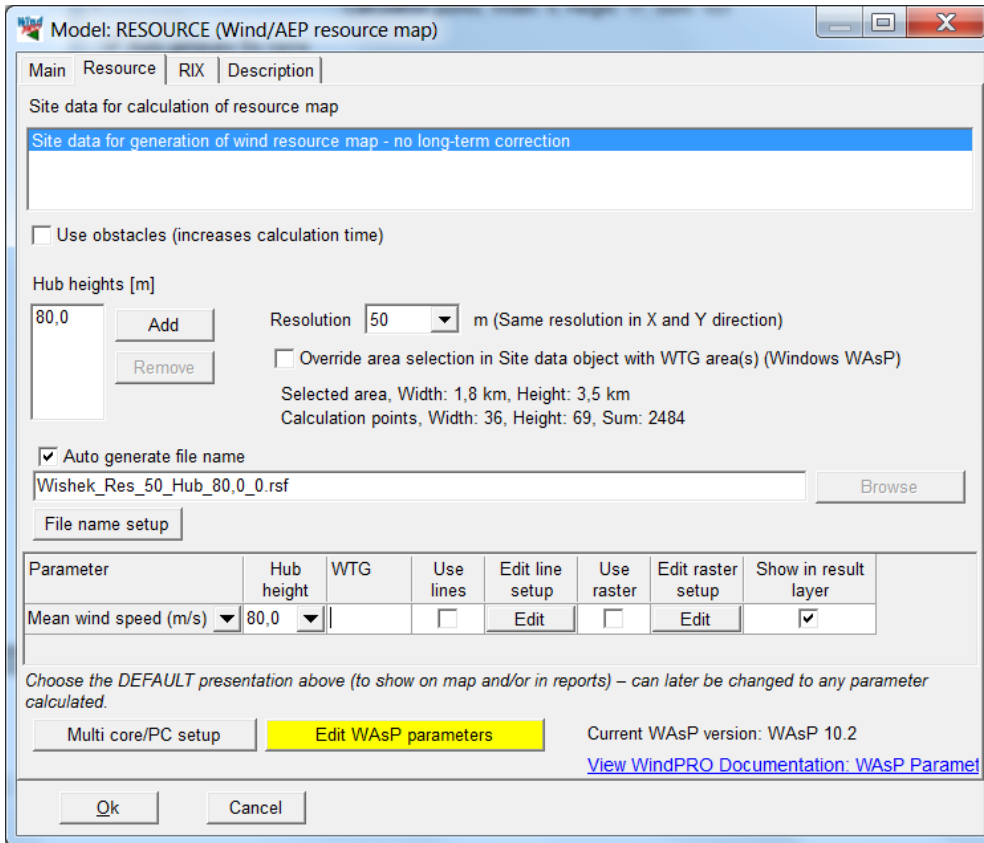
In the Resource tab sheet, you start to specify up to five different hub heights (heights above terrain level) to be calculated and the grid resolution. Other settings are optional.

You can "Override area selection in Site Data Object with WTG Area". Instead of using the rectangle defined in the Site Data Object, a freely definable area digitized in a WTG Area Object can be used. This has two advantages:

1. You do not need to calculate a lot of unnecessary points which saves calculation time.
2. You can get a nicer presentation. For example, if a map is calculated for a municipality, only the municipality is covered by the resource map.

### 3.6.3.1 Multi core / PC setup

With the multi core/PC setup, more cores in the local processor as well as other processors in the network can be used in helping to calculate the wind resource map. This will make calculations much faster. All functionality should be explained by the above shown screen. NOTE: There must be a WAsP license on each PC that takes part in the calculation. There are no requirements for a WindPRO installation, just the WaspResCalc program mentioned on the screen above.
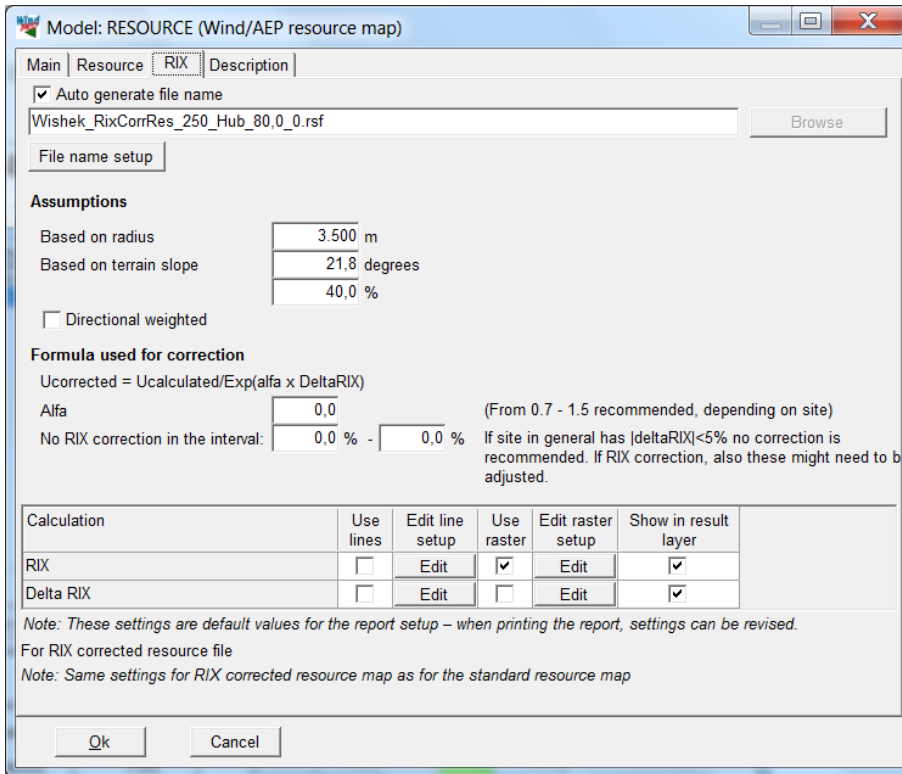
RIX setup, read more about the parameters in 3.4.1.3 PARK RIX calculation.

Note you can include as well RIX as delta RIS map as result layers on your map.

3.6.4 Printout of Wind Resource Map
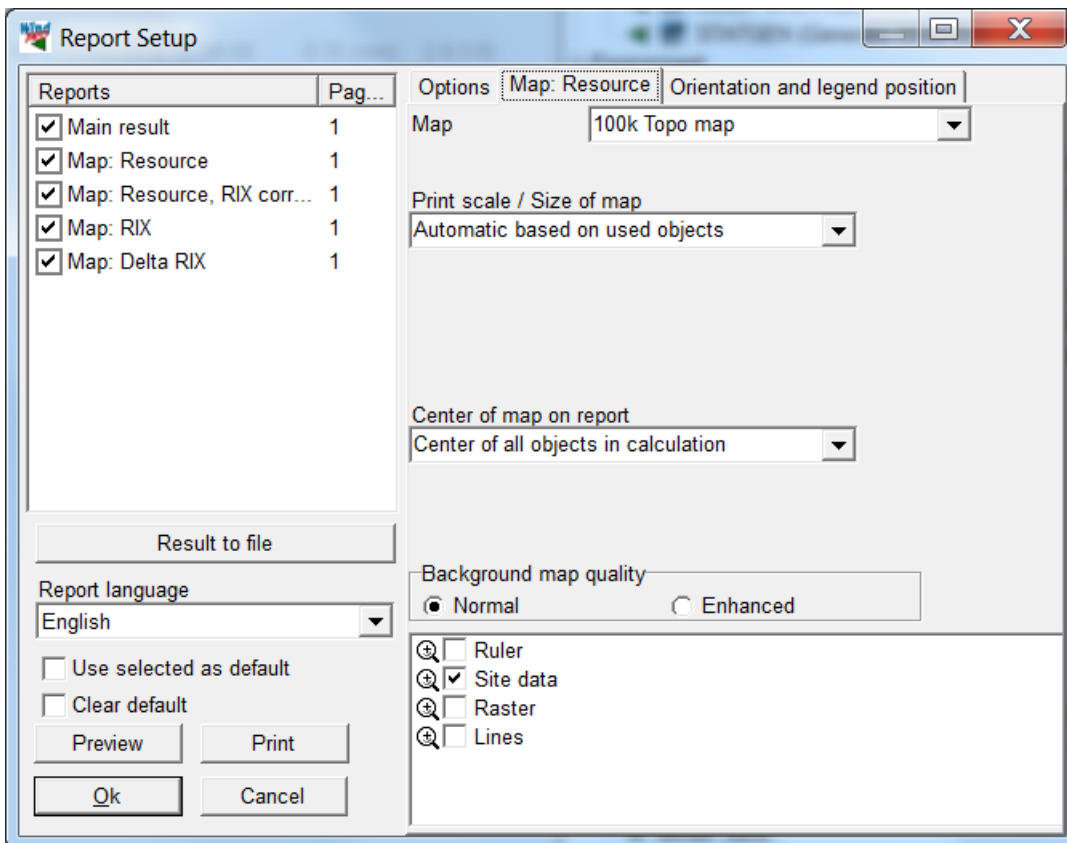
After the calculation has been performed, the new resource map is ready for printing. At this point, you can select parameters for presentation (resolution, colors, etc). If WTG production is chosen for presentation, they will not be air density corrected – production figures as "wind resource maps" will only be seen as relative figures.

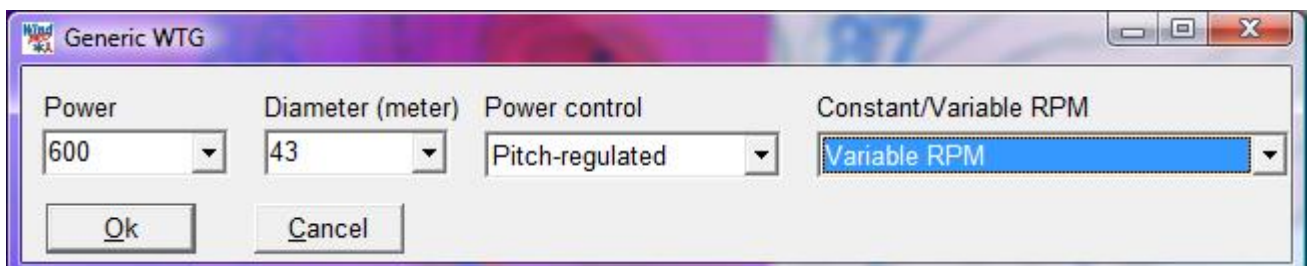Raster and or line presentations can be specified, see Basis, 2.11.2.3 Color scheme editor.

## 3.6.5 Analyze site with roses on Wind Resource Map
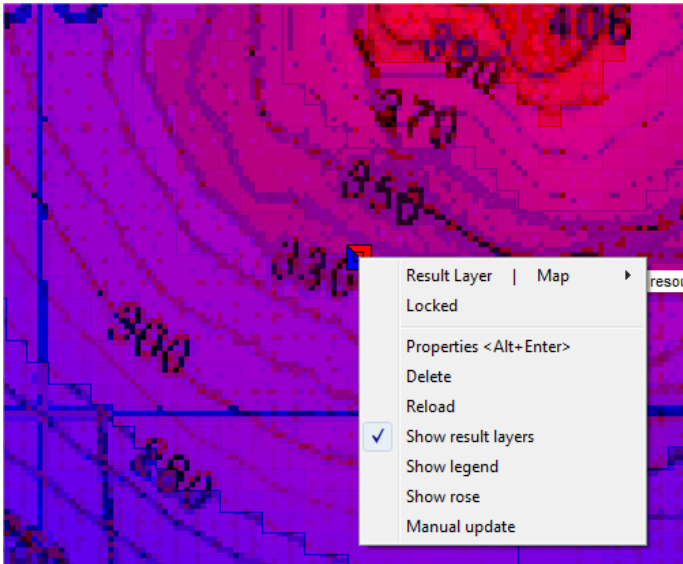
Right click on the result layer object and click on the "show rose".
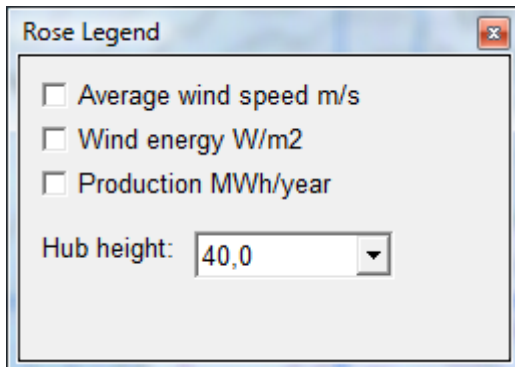
In the rose legend, wind speed as an average, as energy, or as production can be chosen


When production is chosen, a generic turbine can be selected. The HP-standard power curve values will be used. Note: they will not be air density corrected – production figures as "wind resource maps" shall only be seen as relative figures.
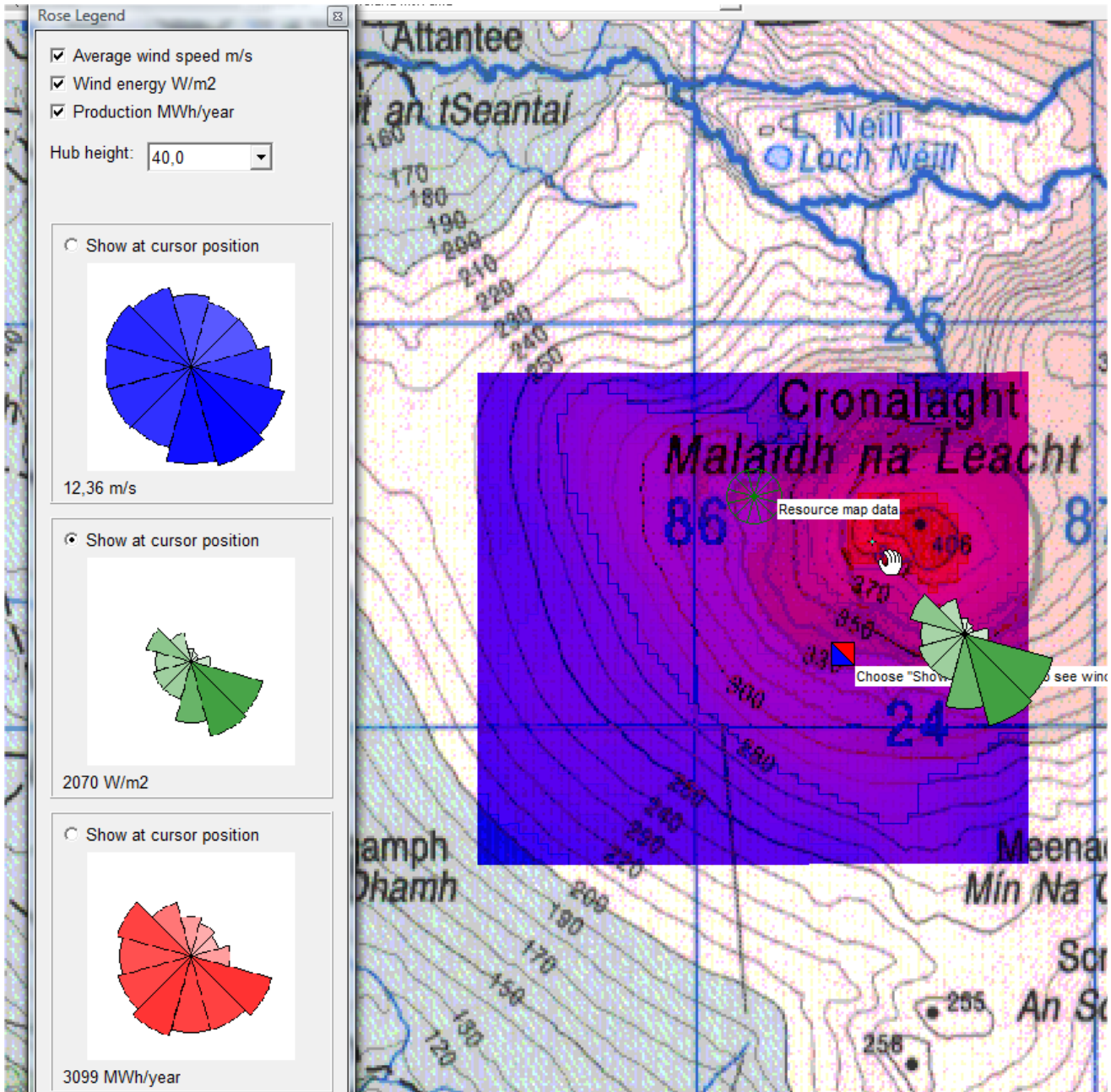
The legend shown here contains all three options. The energy (green) here is selected for "show at cursor position". When the cursor is moved around on the resource map, the three legends are updated and the roses are shown for the cursor position. And, on the map itself, the selected one is shown for the cursor position. This is an efficient tool to analyze a resource map and see how wind conditions changes on the site. Note: The example shown pertains to the position where the little crosshair is located NW of the hand symbol.

3.6.5.1 Roses at site data objects

A special variation of the above example is explained here to show roses at site data objects. When more site data objects are shown on map and the option (right click at site data object) "show energy rose" is chosen, the wind energy rose is calculated based on the specifications in the site data object. This can e.g. be used if there are more measurement masts on the site, to establish an energy rose for each of them based on concurrent data for each of the masts. Then it can be visually inspected if the masts seem to agree, and eventually errors in data for specific masts can be identified – or changes in the wind flow over the site can be seen. See example below.
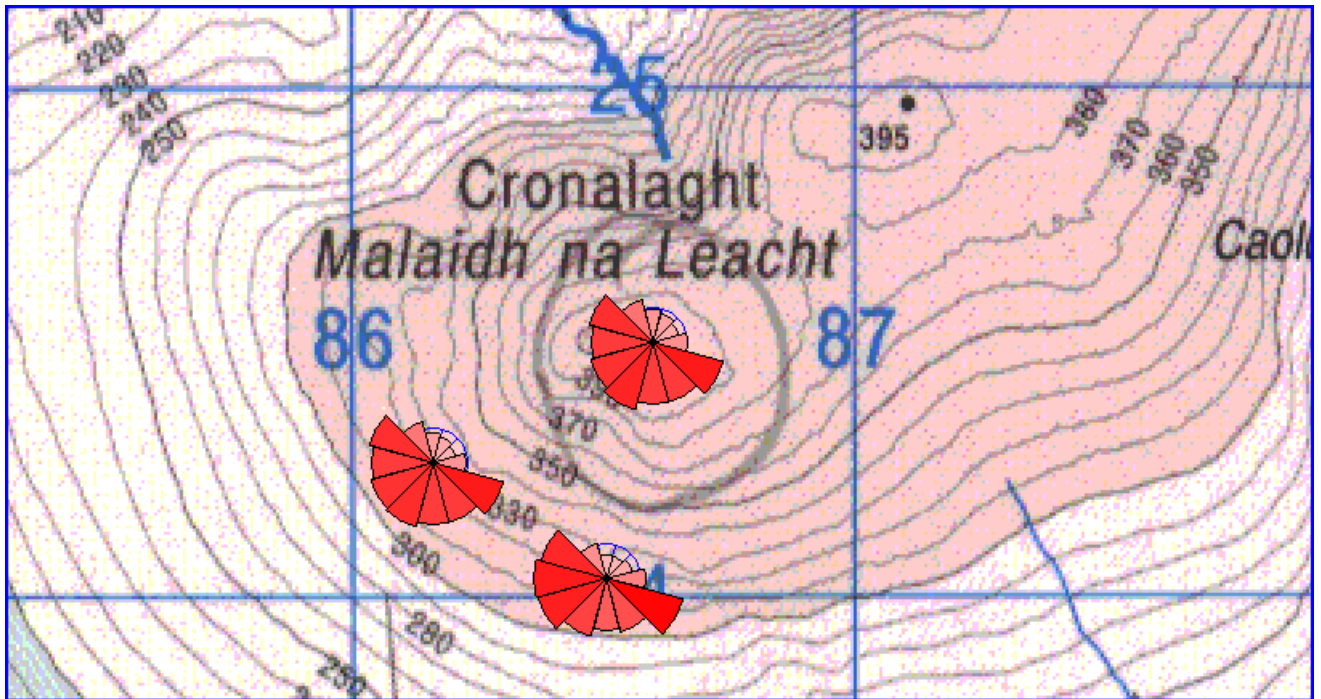
Energy roses at 3 site data objects. For an update (if e.g. more are added), you must deselect the "show energy rose" and select it again.

[i] Ross, Sheldon M.: *Introduction to Probability And Statistics For Engineers and Scientists*, John Wiley & Sons, 1987.

[ii] Efron, Bradley & Robert J. Tibshirani: *An Introduction to the Bootstrap*, Chapman & Hall, 1998.

[iii] Cramér, Harald: *Mathematical Methods of Statistics*, Princeton University Press, 1946.

[iv] Troen, I & E.L. Petersen, *European Wind Atlas*, Risø National Laboratory, 1989, ISBN 87-550-1482-8.