12 Meteorological data handling

12.1 Introduction

Meteorological data is commonly supplied as time series meaning large data amounts. There is a large range of data sources, from local measurements to refined mesoscale model data. Where the local measurements often have gaps or erroneous data and are typically for shorter periods, the model data are more often than not complete and available for long term periods back in time, whilst at the same time, not being so accurate.

Different data sources complement each other and efficient tools for comparisons, substitutions etc. are essential for preparing the dataset representing the long term meteorological parameters at the specific project site. In windPRO the tools for importing, screening, comparing, repairing and validating meteorological data can handle most situations thanks to decades of development.

This chapter describes **two** main components:

The **METEO object** : For import, screening, analyzing, synthesizing, merging, wake cleaning (along with PARK calculation), etc. a single point (Mast, Lidar, Model point etc.) with one or more heights.

The **Meteo Analyzer** : For comparison of multiple Meteo object data series (same mast or different masts), featuring cross prediction, substitution, gap filling and latest RSD (Remote Sensing Device) verification.

In both components, the SCALER function can be used. See details in Chapter 3 Energy on this comprehensive model-based transport of one data time series to another for comparison and thereby also evaluation/calibration of the model.

Finally, it's worth mentioning the ON-Line data service, where data all over the world can be downloaded into the Meteo objects with only on a few mouse clicks (subject to license conditions). It is probably the most easy-to-use and comprehensive service to find in the business.

12.2 METEO object: the wind data container

The Meteo object is the input object for wind data and other measurements or model 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 AEP based on just a simple mean wind speed and a Raleigh distribution (Weibull where k=2)

To the very advanced form:

- 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, The Meteo object importer can also read from compressed files, such as .ZIP directly. Finally, it can read the NRG logger files (.RWD) directly (although it is processed through the NRG data retriever software that must be installed).

When loading directly from .RWD files, 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. This information is NOT included unless you obtain it from the mast operator, or you enter it yourself. There can, therefore, be a risk of using the wrong calibration factors when importing directly from .RWD files.

The measurements can be used directly (i.e. without use of models) for AEP calculations in the calculation module METEO. The most common method of use, however, is with MCP for long-term correction (see

Chapter 3) and using these data and terrain information to generate a wind statistic. Then the wind statistics can be used to calculate AEP with ATLAS, WAsP interface or (most commonly) using the PARK module.

Data from other loggers must first be converted to ASCII files (such as .txt or .csv) with proprietary logger software tools. Additionally, windPRO has an automatic filter for Zephir lidar data files so that all definitions for all channels are filled out automatically.

A newer option is to load data directly from databases through an API. This is currently established for Ammonit's online system. At a later stage more systems can be added on request.

12.3 METEO object – tab by tab

12.3.1 Guide – including on-line data description

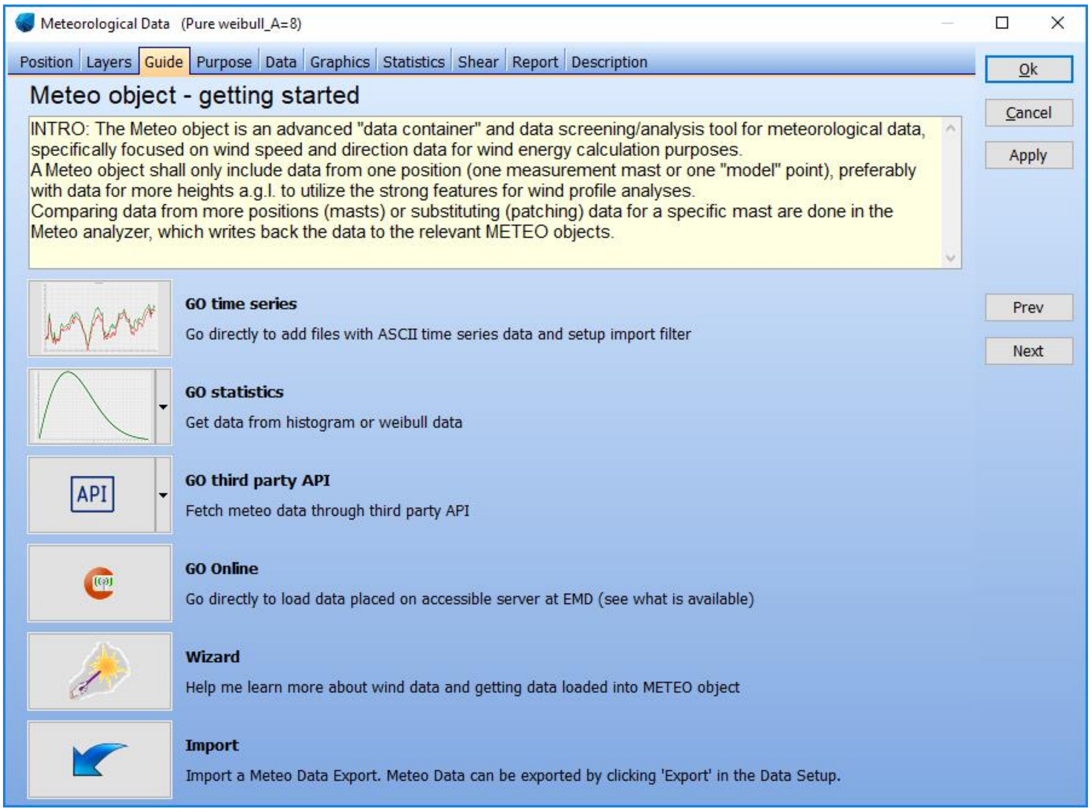
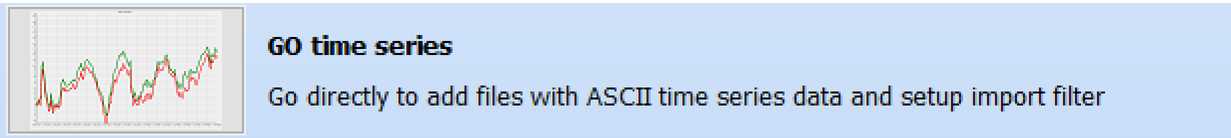
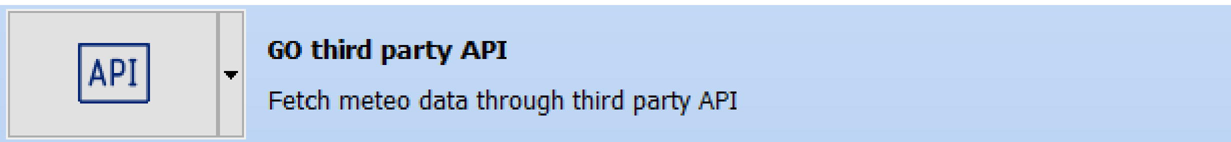


Figure 1 Guide in Meteo object

The different options for getting started are explained in window above.



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.



Third party API makes it possible to download measurement data from external data servers. Currently, it's only possible to log into Ammonit servers. More sources are expected to come.

GO Online

Go directly to load data placed on accessible server at EMD (see what is available)

Online data gives access to data on the EMD On-line server, where EMD adds free data for fast and easy download. Also, data for purchase is available, where the EMD server re-links to commercial data servers. Click 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 like this:

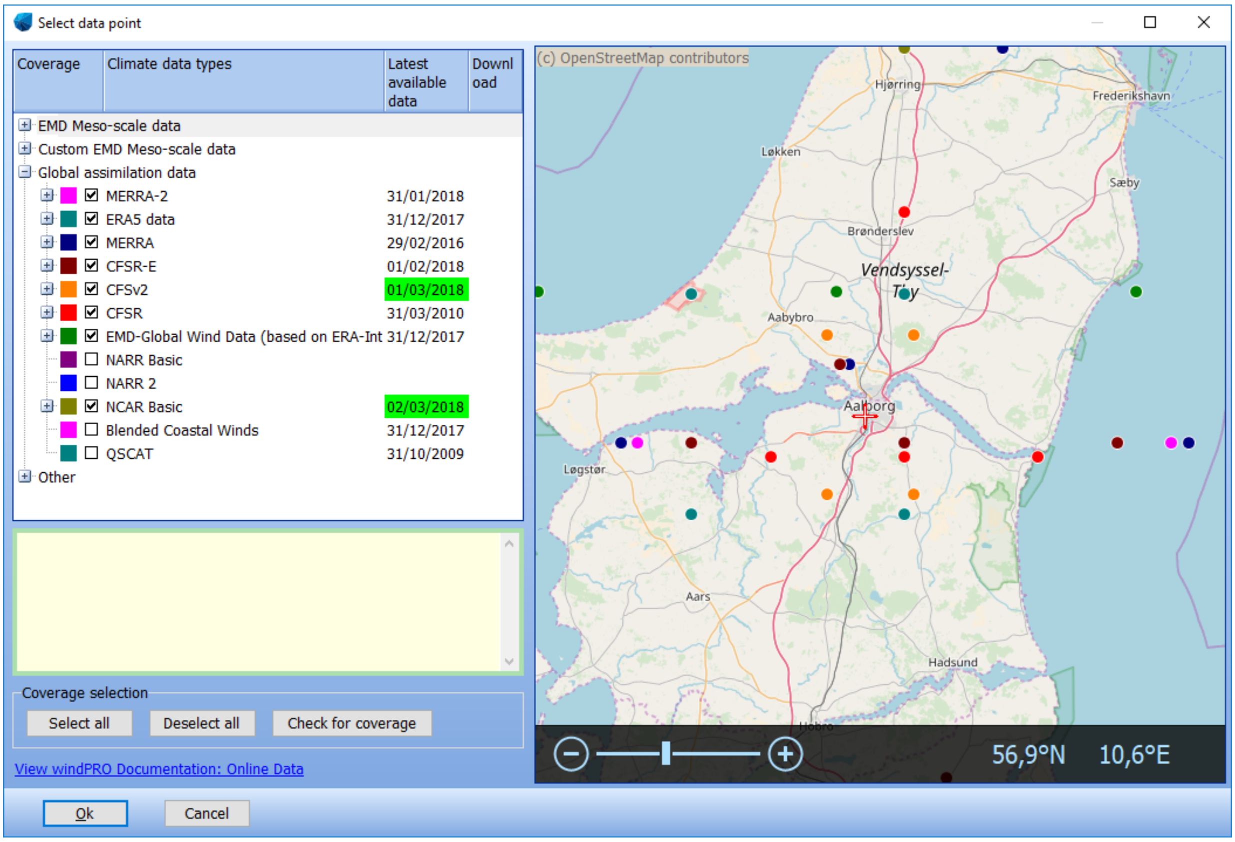


Figure 2 On-line data download in Meteo object – with coverage check

The first screen shows the list of possible datasets for download. It’s possible to check relevant datasets to test if there is coverage near the site. The most recent data date is shown.

The list below shows some of the datasets available. The focus is on wind, but several data sets have several other climate parameters:

- Global: EMD-WRF Global Meso On-Demand
- Europe: EMD-ConWx Europe Meso Data
- Middle East: EMD-WRF Middle East Meso Data
- South Korea: EMD-WRF South Korea Meso Data
- South Africa: EMD-WRF South Africa Meso Data
- India: EMD-WRF India Meso Data
- Indonesia: EMD-WRF Indonesia Meso Data

- EMD-Global Wind Data (based on ERA-Interim)
- ERA5 Data
- MERRA Data
- MERRA-2 Data
- CFS- and CFSR Data
- NCEP/NCAR Global Reanalysis Data

- North American Regional Reanalysis Data
- QuikScat Offshore Wind Dataset
- Blended Coastal Winds
- METAR Data
- SYNOP Data
- Danish Wind Index Data

The datasets are regularly updated, and the latest information about the data can be found here: help.emd.dk/mediawiki/

After coverage check, dots on the map and radio buttons in the list show locations for possible datasets:

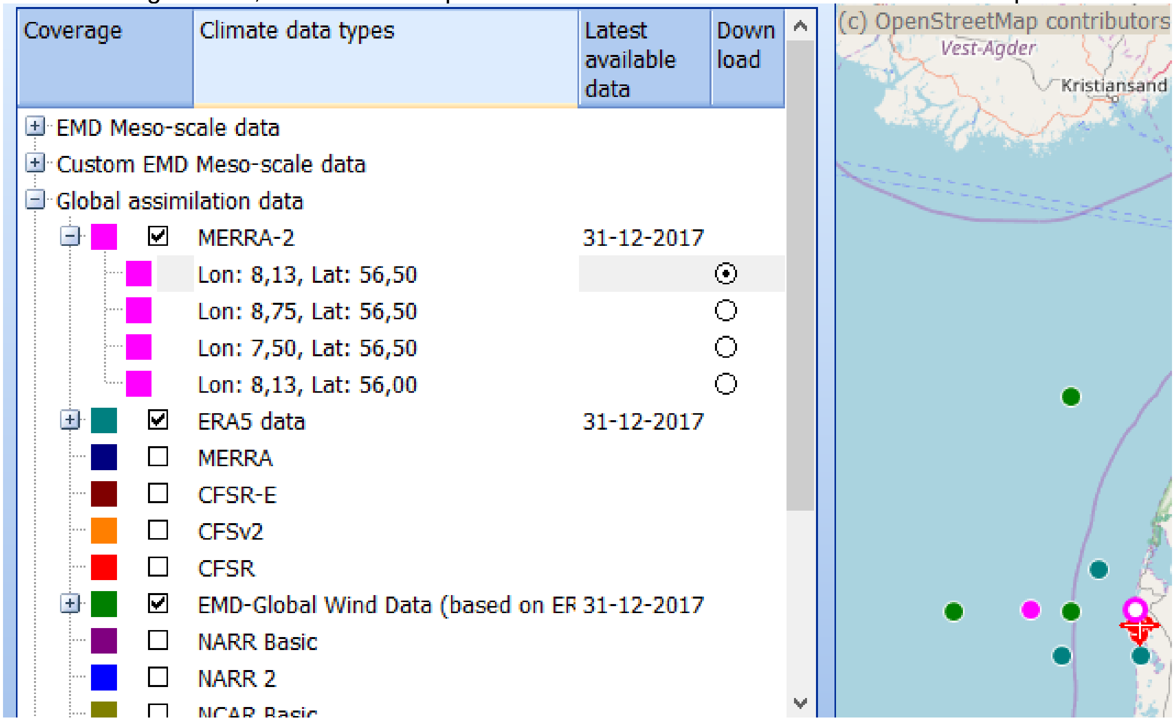


Figure 3 Selection of data set for download.

Click on one of the dots to see which dataset it refers to. With **Ok** the selected dataset will be downloaded. The data will automatically be imported in the Meteo object, ready for analyses.
Note that it is possible to download more datasets at a time from Meteo Analyzer. Users have the choice of filtering the download period according to the available data and their own requirements.

12.3.2 Purpose

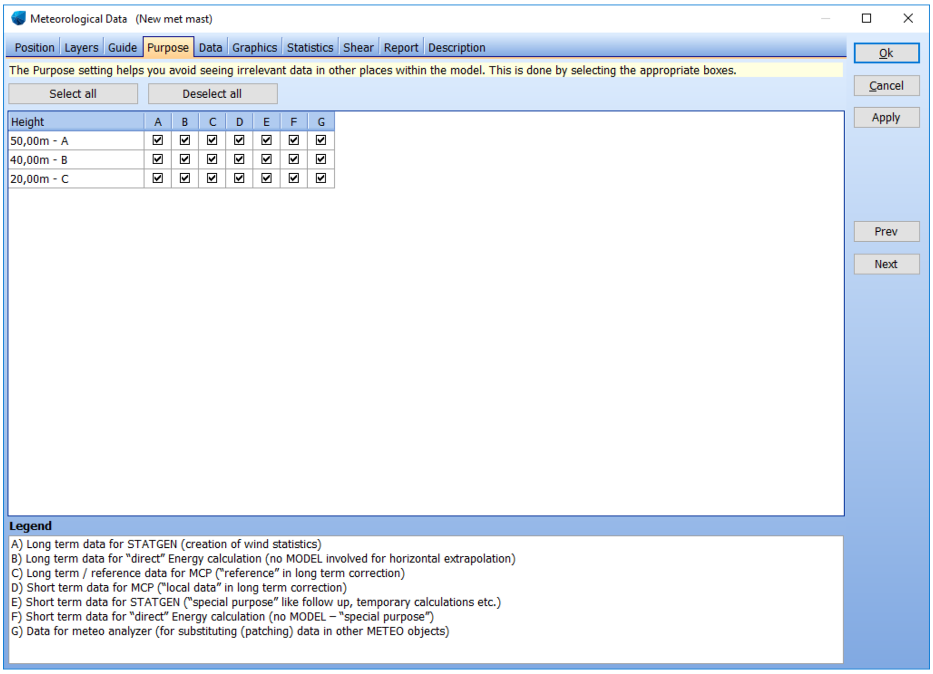


Figure 4 "Purpose" settings help to structure the data.

If there are several wind measurement data in a windPRO project, it can give a better overview to give the data purposes. Only the relevant data based on the purpose settings will be selectable from appropriate places in windPRO.

12.3.3 Data

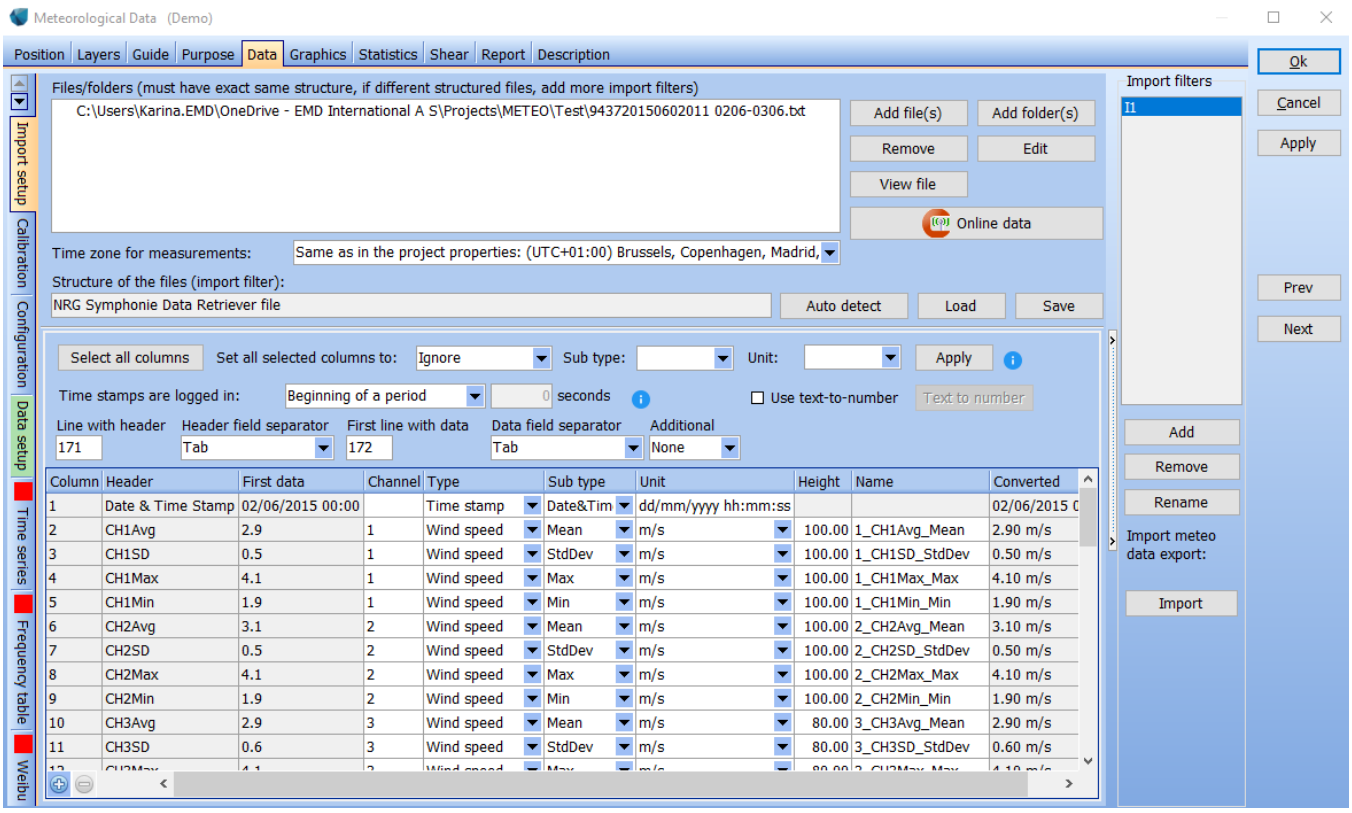


Figure 5 The Data tab - import setup

The Data tab controls:

- Import setup (identifying file structure(s)),
- Calibration (applying correction to the data)
- Configuration (input of configuration of the measuring equipment and check against standards)
- Data setup (setting up the signals required for each height)

and after importing data:

- Time series (raw data table, can be sorted by any signal)
- Table data (binned by direction sector and wind speed)
- Weibull data (Weibull fit per direction sector)
- Turbulence data (binned by direction sector and wind speed)

Below, each function in this tab is explained.

12.3.3.1 Import setup

File types supported: Only ASCII files can be imported. This means raw logger files, Excel files or database files must be converted to text files before data can be imported. Compressed text files are supported (.zip, .rar or other compressed files).
Add file(s): point out the files with the data to import. Note, these **MUST** all 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 different files in the folder, it is possible to set a mask, e.g. "*.txt", so only relevant files are used.

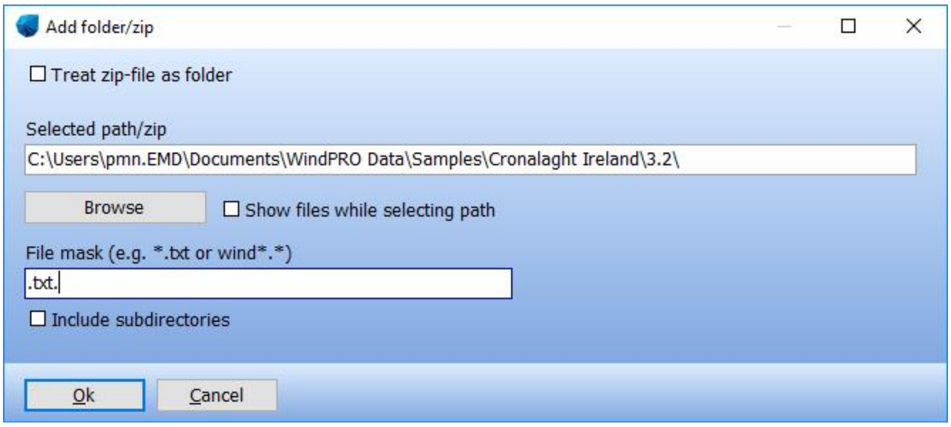


Figure 6 Adding folders in meteo object

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 METEO or MCP module) - start a communication with EMD server (see help.emd.dk/mediawiki/index.php?title=Category%3AWind_Data).
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 types of files are often used in different projects. If you do not have an import filter saved, use the "auto detect" feature.
Auto detect; is a powerful feature that can recognize the "base structure" of many types of wind data files.

Use text to numbers: converts, for example, wind direction described as N, NNE, ENE, etc., to numbers.

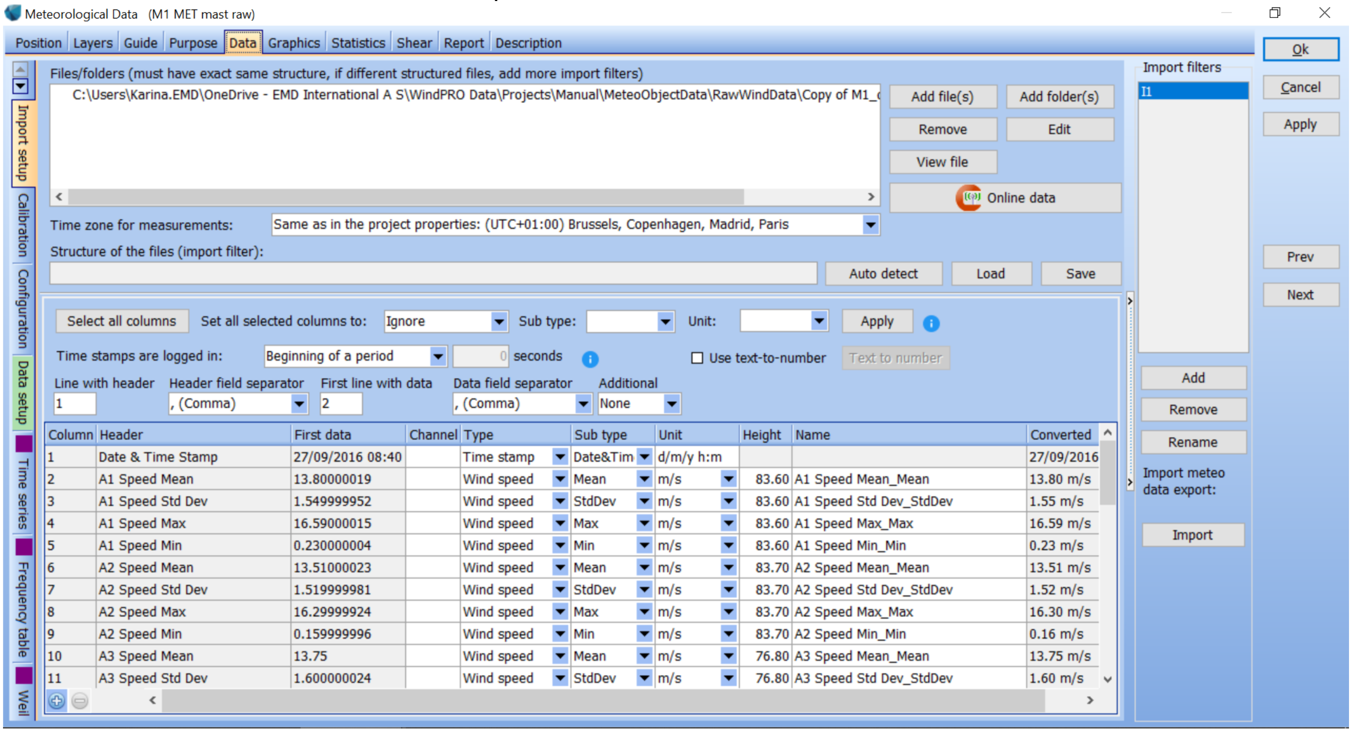


Figure 7 Setting up import filter in meteo object

When "auto detect" is used, the lower part of the form is filled in automatically. In the example above, an NRG Symphonie™ logger file is used, and everything is auto detected. Several other standard logger output files can be automatically detected, and new types are continuously added. Some file formats, however, must be manually set up, if they, are, for example, user defined excel exports, etc.

Import setup: Manual adjustment of “auto detection”

There must be an entry for each data signal which will be used in the object. The signals not used will just be ignored if the option “ignore” is chosen. Signals can always be set up and used at a later stage.

1. Choose “type” in the dropdown list, such as “Time stamp” or “wind speed” (note that the standard deviation (StDev) of a wind speed signal is also classified as a wind speed).
2. Choose “sub type”, such as “year” or “mean” etc.
3. Choose “unit” – note that non-metric units (e.g. mph, knots, Fahrenheit) will be automatically converted to metric units in the object.
4. Choose “height” – this must be in meters. Files set to “feet” will be auto converted to meters. Always check that height is correct.

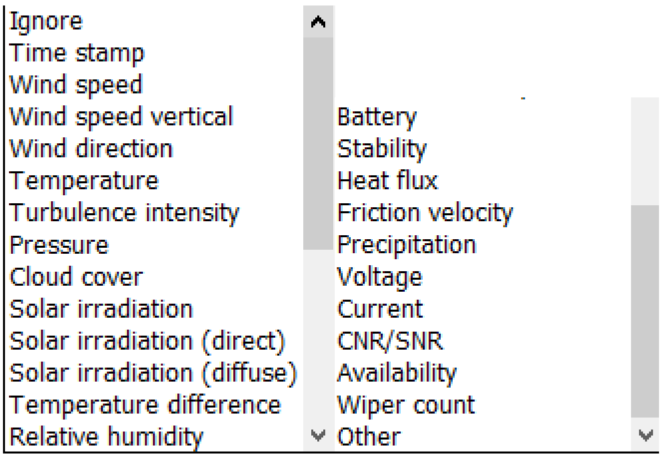


Figure 8 The signal types available currently.

The signal type list is expanded when new demands occur. Above the status of predefined types are shown. Some types have sub types and more units to choose from. And some types will have a special status. E.g. the Solar irradiation is dedicated to irradiation on horizontal plane, the only type that can be used in Solar-PV calculations at present, where direct and diffuse just can be used for evaluations.

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

12.3.3.2 Calibration

The Calibration tab is used to:

1. View the scale and offset parameters input in the logger, when available in a file format recognized by windPRO.
2. Input correction or recalibration parameters (scale and offset) to be applied to the data when necessary. This can be relevant when the values from the data logger differ from the values from calibration certificates. Knowing the official values from calibration certificates, windPRO can automatically calculate the needed correction to be applied on the “wrongly” logged data.
3. Check the average magnetic declination value valid at the position of the meteo object for the middle of the data period. Wind direction data can be then corrected for magnetic declination if necessary
4. Provide documentation of data treatment, through the Report (see 12.3.8)

The tab consists in two main parts: the Calibration table and the Timeline. The Calibration table and timeline are automatically created from the Import setup tab. If files are added at a later stage, these will be detected, and the table will be amended accordingly.

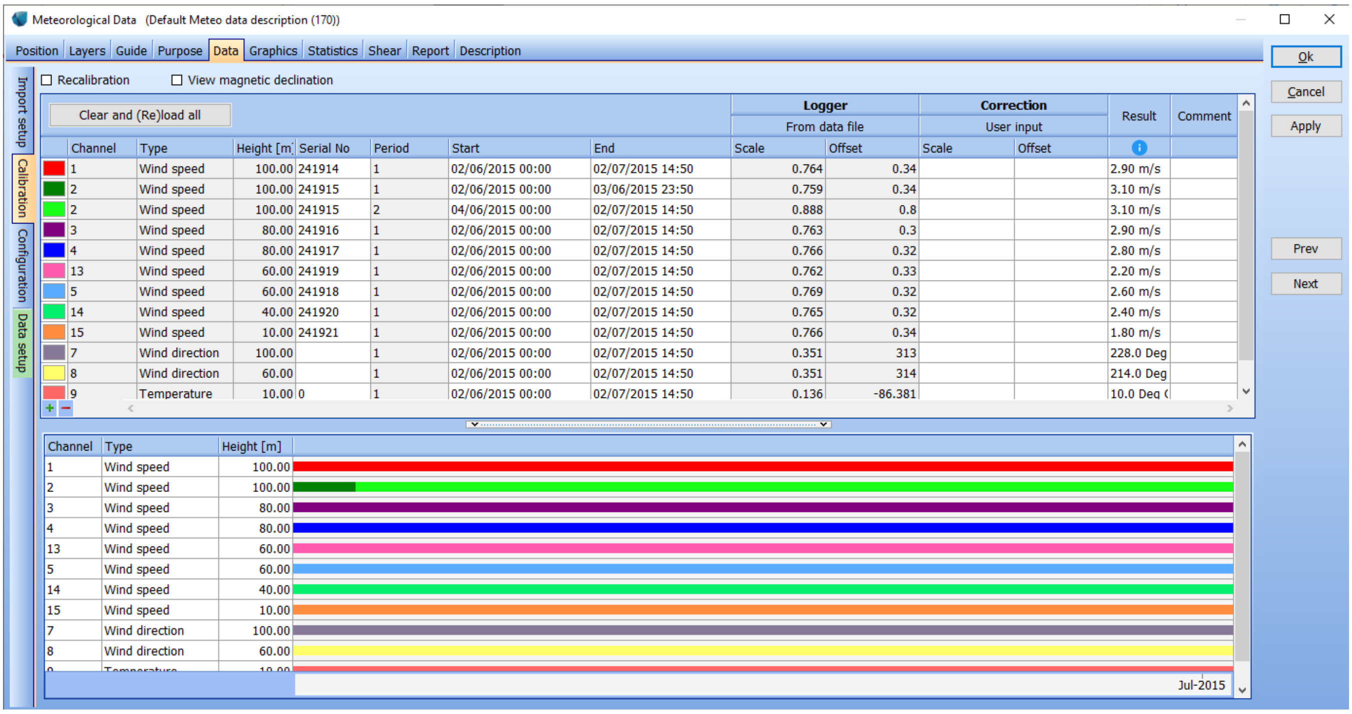


Figure 9 Calibration tab

Calibration table

Each line of the calibration table relates to a calibration period of a given sensor.
A calibration period is defined as an interval of time for which a specific set of scale, offset and magnetic declination relating a specific dataset from a given sensor. A given sensor can have more than one calibration period, for example when it has been recalibrated as recommend by Measnet after 2 years.

The calibration periods are firstly automatically created by windPRO after screening all data files defined in Import setup.

A calibration period is created for each time interval with constant Channel (if available), serial number (if available) AND constant 2 scale/offset values (if available), for any Type of data (speed, direction, temperature …) with sub type defined as “Mean” in the import filter.

Please note that windPRO detects only one calibration period per file. It is therefore not recommended to gather all data into one data file if several calibration periods are covered.

The calibration periods can also be created manually using the + at the bottom of the table or a right click on the line and select Duplicate line. An existing line can be split in 2 lines to allow the user to identify distinctive periods for different calibration factors in case this has not been detected automatically. Alternatively, right click on a line of the table.

The columns **From data file** under the header **Logger** relate to the Scale and Offset values read from the file (if available).
The columns **User input** under the header **Correction** allows the user to decide which scale and offset to apply to a dataset. The same correction is applied to all signals under the same channel, like mean wind speed, min and max wind speed. The standard deviation is however only using the scale factor, not the offset.
The **Result** column shows the result of the correction of first data of the first file loaded under the given Import filter. It can be useful to make a sanity check of the result to expect. In the rare case when several calibration periods are created from files under a same import filter (occurring if the scale and offset information from the files changes in raw data files), then it is only the result of the first file which is shown and not the result for each file.
The **Comment** column is available for user text input.

Recalibration table

The Calibration table can be extended to a more advanced table by checking the checkbox **Recalibration** in the upper left corner. The recalibration table is used to:

- Provide documentation of the calibration values applied to the data
- Calculate the corrections to apply to data in case of mismatch between the logger and official values

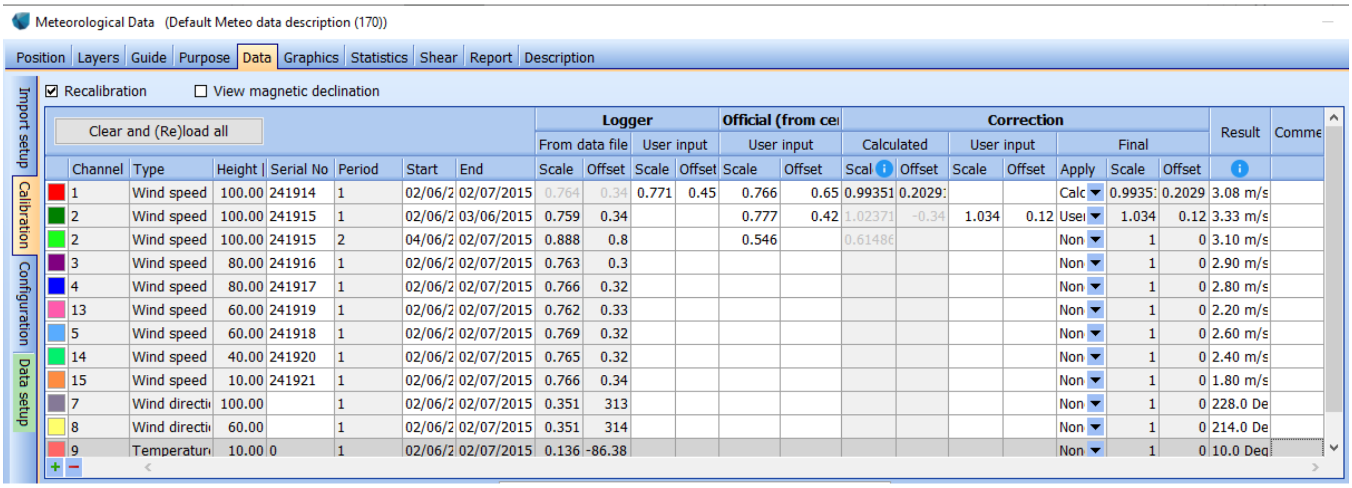


Figure 10 Recalibration table

The columns **User input** under the Logger header allows to manually enter the scale and offset as setup in the logger, when these are not available or properly detected.
The columns under the header **Official (from certificates)** give the option to input the scale/offset values as presented in the calibration certificates documents.
Under the Correction header, the **Calculated** columns are automatically filled when data is available in the Logger columns and the Official (from certificates) columns.
The calculated correction for scale is calculated as: Scale(official)/Scale(logger).
The calculated correction for offset is calculated as: Offset(official)-(scale(official)/scale(logger))xOffset(logger)
When both logger values are available in the From data file or User input columns, only User input is used for the Calculated correction columns. If a cell of User input is left blank, the value 1 is assumed for scale data and 0 for offset data.

The Final columns under the Correction header consists firstly in the selected of the correction to apply, that is either the calculated one as presented in the Calculated columns, or the User Input ones or none. Then to the right of the **Apply** column a final visual check of the correction selected and used later on in windPRO can be made.

Note that some EMD on-line data have calibration factors for heatflux automatically input in the table while downloading.

Timeline

The Timelines gives an overview of the different calibration period(s) for each sensor as defined in the Calibration table. This feature is especially useful when a sensor is concerned by several calibration periods. If a sensor has been (re)calibrated over time, a new calibration period is created on the same line in a lighter color. Clicking on a line will mark the corresponding line in the table and vice versa.
Note that the function of the timeline is to provide a view of different calibration periods, not of the data availability. If there are holes in the time series, they will not be reflected here but for example under Graphics tab, Recovery.

Magnetic declination

By checking **View magnetic declination**, it is possible to see the magnetic declination as provided by the International Geomagnetic Reference Field, 13th Generation, released in December 2019 (http://geomag.bgs.ac.uk/data_service/models_compass/igrf_calc.html). The value is calculated at the position of the meteo object and for the central date of the whole measurement period.

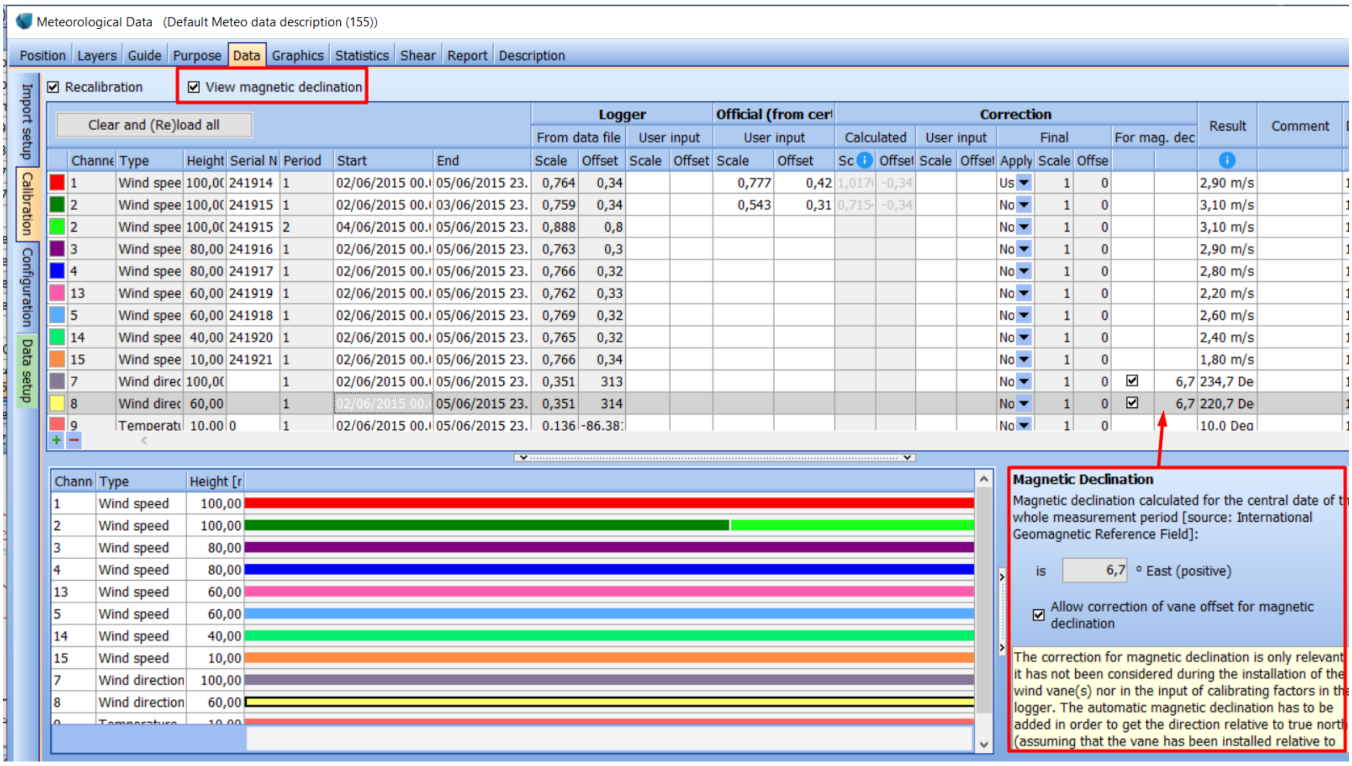


Figure 11 Magnetic declination

If needed, the direction data can be corrected for the magnetic declination by checking **Allow correction of vane offset for magnetic declination**. The correction for magnetic declination is only relevant if it has not been considered during the installation of the wind vane(s) nor in the input of calibrating factors in the logger. The value of magnetic declination is added to the direction data in order to get the direction relative to true north (assuming that the vane has been installed relative to the magnetic north). The final correction applied to the data can be seen in the Calibration table, where it can also be deselected or changed manually.

12.3.3.3 Data: Configuration

The Configuration tab is used to:

- Document the configuration of the sensors installation on a typical mast used for the wind data measurements
- Evaluate the compliancy of this configuration to standards for wind data measurements (at the moment IEC 61400-12-1 ed 2.

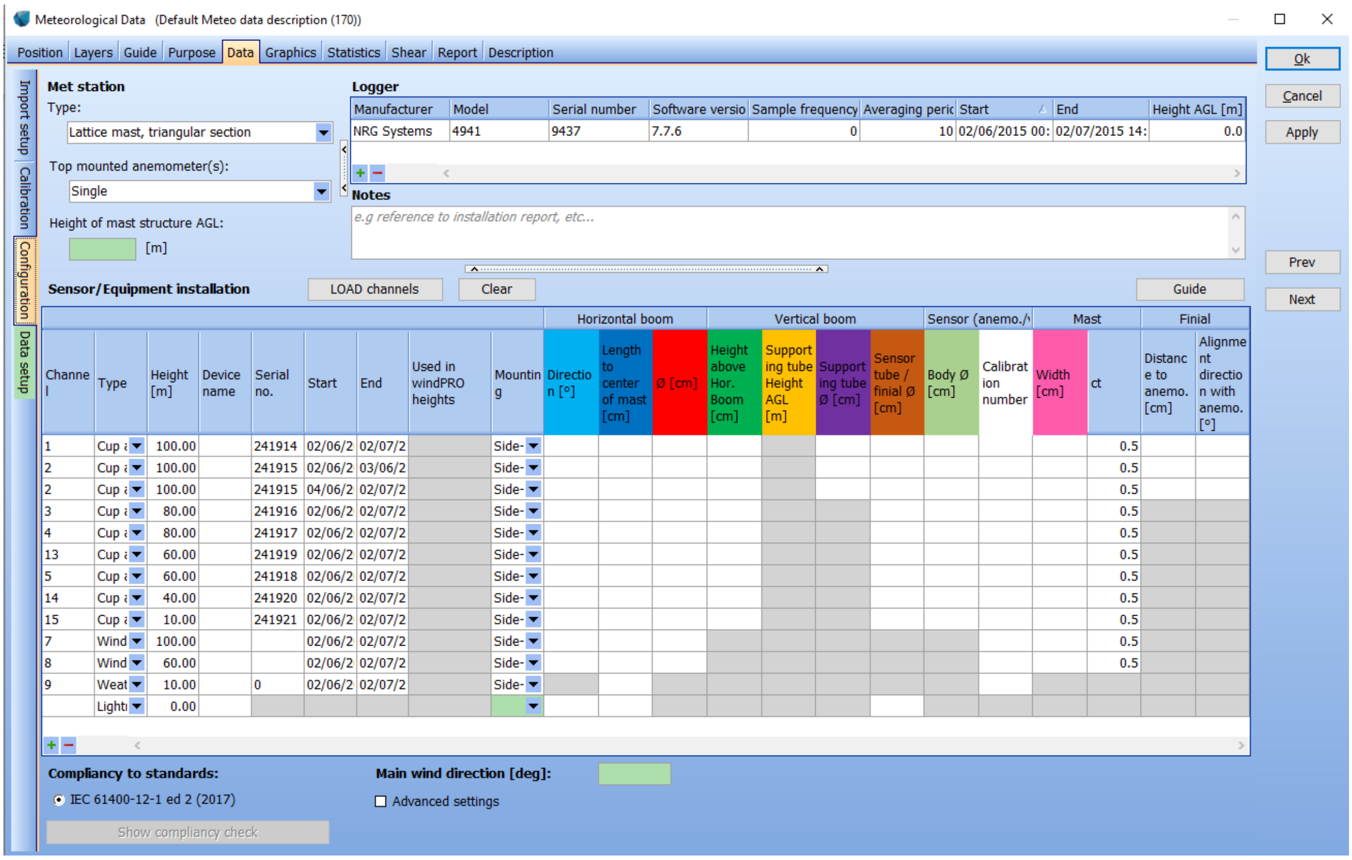


Figure 12 Configuration tab

Met station

It is possible to define the type of Met station between Lattice mast, (triangular or square section), tubular mast, SODAR or LIDAR. The difference between lattice (whatever section type) and tubular has an influence on the IEC check for the distortion from the mast (involving Ct value or not, cf below). For SODAR or LIDAR, no configuration table nor compliancy check is available at present.
It shall be specified if the top mounted anemometer(s) is single or side-by-side since this is relevant for the IEC checks.
The height of mast structure AGL is the total height of the lattice or tubular mast from bottom to top.

Logger

If available in the raw data file, information on the logger, such as the manufacturer, Model, serial number … is presented automatically. It is also possible to input the information manually and to add a line if a new logger has been changed over the measurement campaign.

Notes

This field is available for user defined text for documentation purposes. It could be relevant to input the reference to various installation and maintenance reports related to the installation and operation of the measurement mast.

Sensor/Equipment installation
The sensor/Equipment installation table lists the various sensors involved in the measurement campaign of the data defined in Import filter and allow to input the dimensions relevant for the compliancy check to standards. The relevant input concerns:

- the horizontal booms (direction, length from mast center and diameter)
- the vertical booms, that is both the smaller tube directly attached to the sensor and the supporting tube. The supporting tube is the additional tube used to stabilize the smaller tube attached to the body of single or side-by-side top anemometers
- The body diameter of the sensor
- The calibration number from the certificates (for documentation purposes)
- The mast width and thrust (Ct), the latter only in case of lattice tower
- The distance to anemometer and the alignment with the anemometer of the lightning finial.

The dimensions of certain sensor/equipment type are not relevant for compliancy check and therefore not available for input in the table (grey cell).
The cells of the table can be filled in from the Clipboard (preferably from a Copy from Excel) using Paste relative to currently selected cell will.

The dimensions are presented in the diagram below, using the same color as the headers of the table.

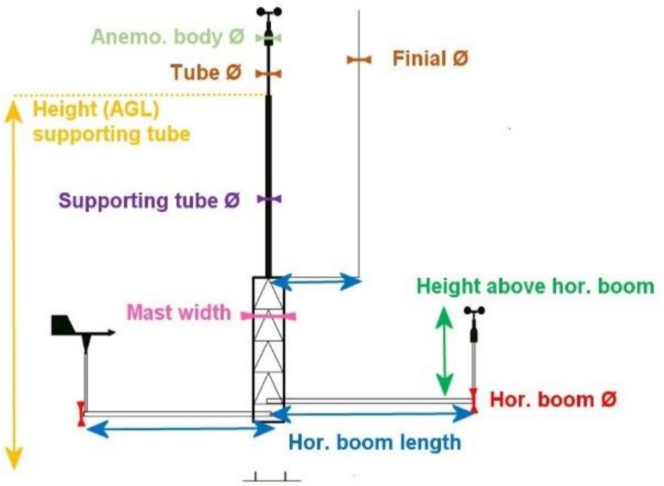


Figure 13 Diagram of the dimensions to input in Sensor/Equipment installation table

This diagram is also available under the Guide button.

The table is based on the Calibration table but changing the data type (wind speed, wind direction, …) to corresponding sensors (anemometer, wind vane, …). Wind speed signal is by default assumed to come from a cup anemometer. It is possible to change the Type of sensor to sonic anemometer in the drop-down menu of the Type column. The data such as temperature, pressure or humidity are reported as belonging to a sensor type called Weather station.

Loads Channels: (Re) Load the Sensor/equipment installation table based on the Calibration tab.

If 2 calibration periods have been defined for a data type in the calibration tab, two sensor lines will be created in the configuration table matching each period and assuming that the configuration between the two periods could be different. If this is not the case, lines can be manually deleted (with the – at the bottom of the table) or modified; the Start and End date can also be manually changed.

At the bottom of the list, a line is added for a lightning finial.

Mounting
The mounting is relevant for the IEC compliancy checks. The mounting is filled in automatically as a first best guess. It is recommended to check that it corresponds to the mast configuration at stake. The mounting of the top anemometer(s) and of the lightning finial require user input. The different types of mounting are:

- Single-top: The top anemometer is placed on the top of the mast and centered on the cross section
- Side-mounted: The sensor is placed on a horizontal boom

- Shared boom: The sensor is placed on a horizontal boom together with another sensor (at the same height and direction)
- Top (Lightning finial): The lightning finial is placed on the top of the mast and centered on the cross section
- Boom (lightning finial): The lightning finial is placed on horizontal boom

Used in windPRO heights
This column is automatically filled once the data have been setup and loaded under the data setup tab. It refers to the heights that are defined and used in the Meteo object from the Data setup tab. It can be used for traceability of the data.

Lightning finial, distance, and alignment
The horizontal distance between the finial and a given top anemometer is calculated automatically in windPRO for most of the common combination of anemometer and finial mounting, as presented in the following table.

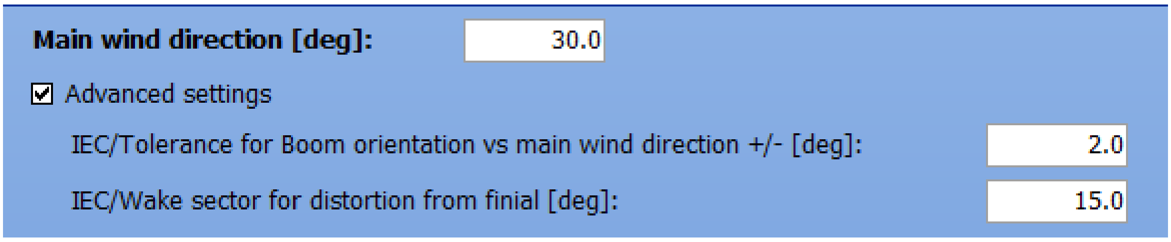
Table 1. Automatic input of distance and alignment direction between finial and anemometer in Sensor/Equipment installation table used for the IEC checks about distortion from finial

Combinations of anemometer and finial		Automatic input in Configuration table	
Anemometer mounting	Finial mounting	Distance to anemometer	Finial-anemometer alignment direction
Single, top (centred)	On a boom	Length of finial boom	direction of finial
Single, side mounted	Top (centred)	Length of anemometer boom	180 + direction of anemometer boom
Single, side mounted	On a boom	-	-
Side-by-side, top	Top (centred)	Length of anemometer boom	180 + direction of anemometer boom
Side-by-side, top	On a boom	-	-

The calculated distance or alignment can be modified manually in the table (“Distance to anemo.” Column).

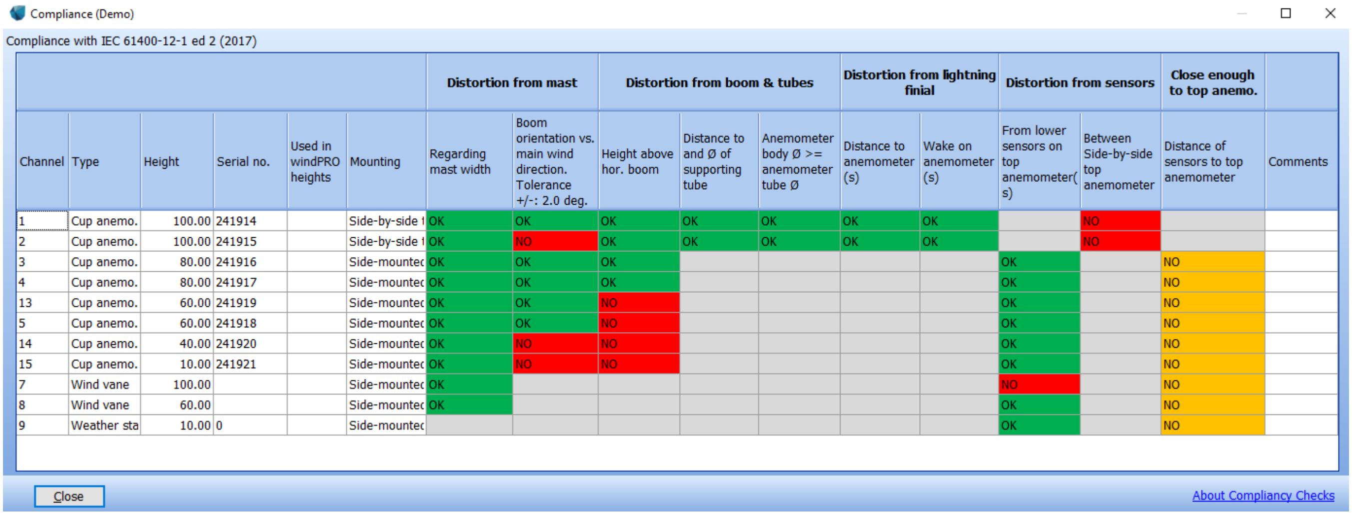
Main wind direction
The input of main wind direction is used for the check of the mast distortion and of the lightning finial giving wake in compliance with IEC 61400-12-1 Ed 2.

Advanced settings
Checking the advanced settings, gives access to tolerance values used in some Compliancy checks. The IEC/Tolerance for boom orientation vs main wind direction gives a margin (+/-) around the ideal orientation of the boom that will return OK to compliancy.
The tolerance IEC/Wake sector for distortion from finial is the wind direction sector in which the finial is supposed to give wake, assuming that it is centered on the finial.
The default values are arbitrary and can be changed.



Compliancy check
The input made in the Sensor/equipment installation table is used to check the configuration of the mast to the most important requirements defined in Annex G of the IEC standard 61400-12-1 Ed.2.0 Wind energy power generation systems – Part 12-1: Power performance measurements of electricity producing wind turbines.

Once the table is filled and provided that there is an input in all the green cells (Height of mast structure, Main wind direction and Mounting of lightning finial), the Compliancy check can be launched clicking on the button **Show compliancy check**.



Compliance (Demo)

Compliance with IEC 61400-12-1 ed 2 (2017)

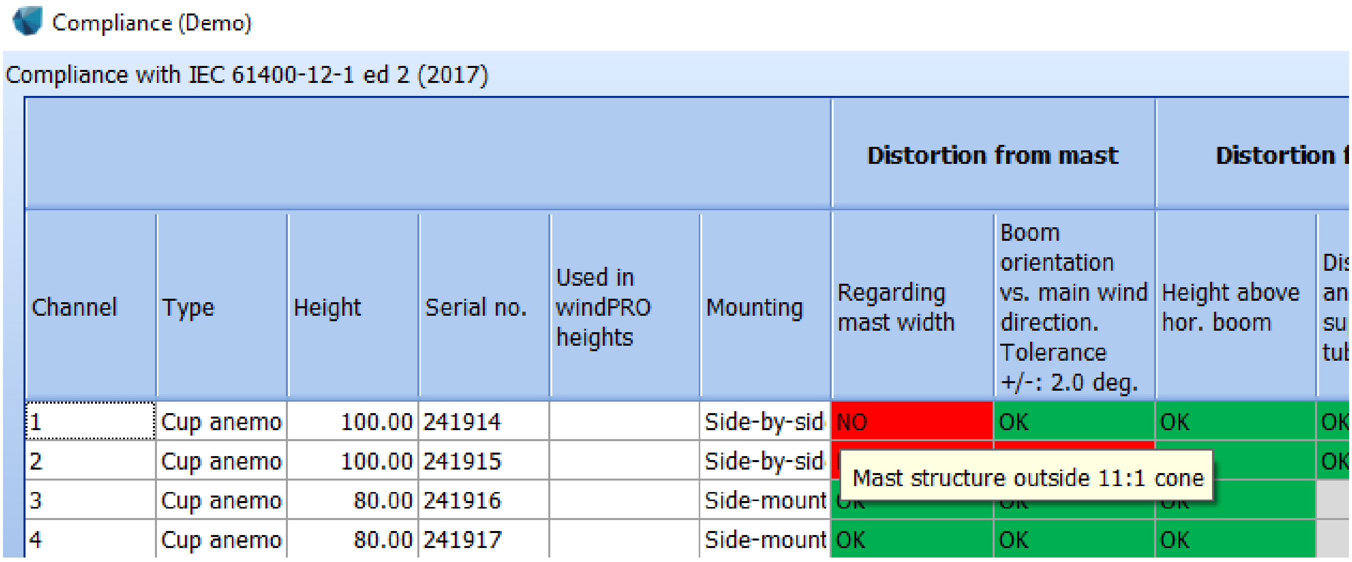
						Distortion from mast		Distortion from boom & tubes			Distortion from lightning finial		Distortion from sensors		Close enough to top anemo.	
Channel	Type	Height	Serial no.	Used in windPRO heights	Mounting	Regarding mast width	Boom orientation vs. main wind direction. Tolerance +/-: 2.0 deg.	Height above hor. boom	Distance to and Ø of supporting tube	Anemometer body Ø >= anemometer tube Ø	Distance to anemometer (s)	Wake on anemometer (s)	From lower sensors on top anemometer(s)	Between Side-by-side top anemometer	Distance of sensors to top anemometer	Comments
1	Cup anemo.	100.00	241914		Side-by-side t	OK	OK	OK	OK	OK	OK	OK		NO		
2	Cup anemo.	100.00	241915		Side-by-side t	OK	NO	OK	OK	OK	OK	OK		NO		
3	Cup anemo.	80.00	241916		Side-mountec	OK	OK	OK					OK		NO	
4	Cup anemo.	80.00	241917		Side-mountec	OK	OK	OK					OK		NO	
13	Cup anemo.	60.00	241919		Side-mountec	OK	OK	NO					OK		NO	
5	Cup anemo.	60.00	241918		Side-mountec	OK	OK	NO					OK		NO	
14	Cup anemo.	40.00	241920		Side-mountec	OK	NO	NO					OK		NO	
15	Cup anemo.	10.00	241921		Side-mountec	OK	NO	NO					OK		NO	
7	Wind vane	100.00			Side-mountec	OK							NO		NO	
8	Wind vane	60.00			Side-mountec	OK							OK		NO	
9	Weather sta	10.00	0		Side-mountec								OK		NO	

Close

About Compliancy Checks

For more detail about the conducted checks, please refer to the online documentation: https://www.emd-international.com/files/windpro/210629_Notes-compliancy%20check.pdf, also available from the Compliancy Check window through the link in the bottom right corner in the window.

A color code is used to give a quick overview of the result of the compliancy check. Green color is used for compliancy, red for non-compliancy and orange for a non-critical non compliancy. When a check involving two condition is not passed, the result is NO. It is possible to see which condition is not fulfilled by mouseover the cell, as shown in the example below.



Compliance (Demo)

Compliance with IEC 61400-12-1 ed 2 (2017)

						Distortion from mast		Distortion f	
Channel	Type	Height	Serial no.	Used in windPRO heights	Mounting	Regarding mast width	Boom orientation vs. main wind direction. Tolerance +/-: 2.0 deg.	Height above hor. boom	Dis an su tul
1	Cup anemo	100.00	241914		Side-by-sid	NO	OK	OK	OK
2	Cup anemo	100.00	241915		Side-by-sid				OK
3	Cup anemo	80.00	241916		Side-mount	OK	OK	OK	
4	Cup anemo	80.00	241917		Side-mount	OK	OK	OK	

Mast structure outside 11:1 cone

Figure 14 Example of explanatory text in case one condition is not met

In case of missing data, the checks cannot be performed. The required input from the configuration table is listed for each check in the online documentation

Note that it is possible to select whether all or only some compliancy checks shall be presented in the final report (See 12.3.8).

12.3.3.4 Data setup

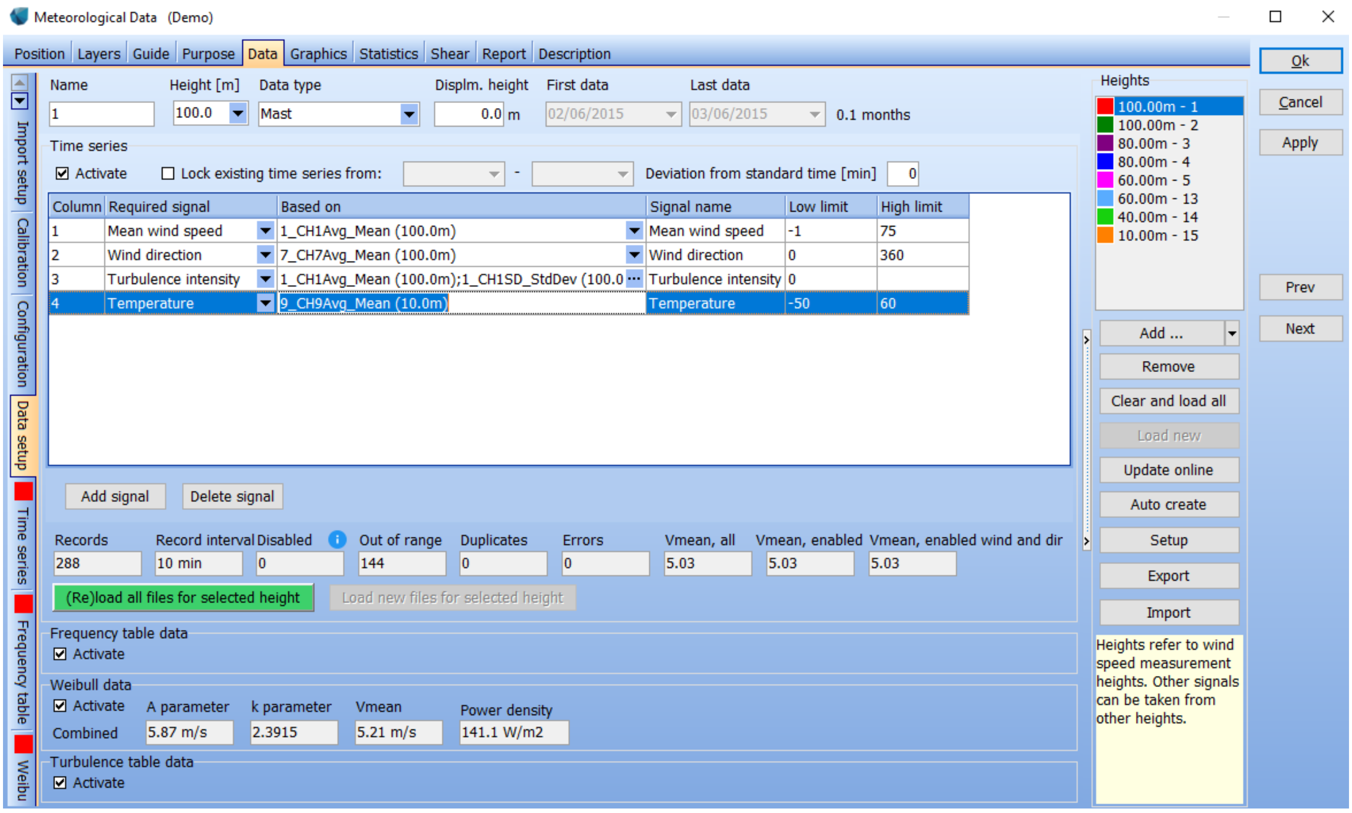


Figure 15 Define signals in "data setup" for heights

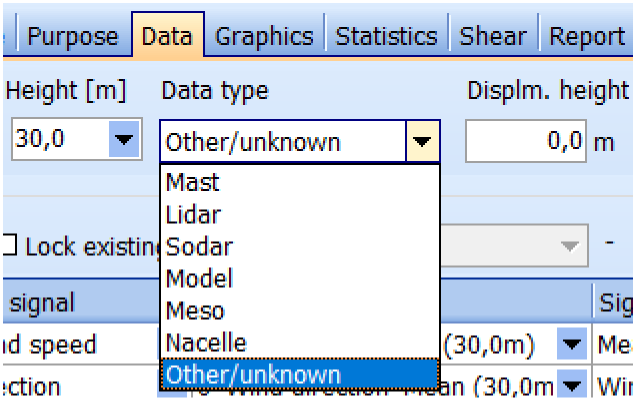


Figure 16 Data type and displacement height

It is possible to set a displacement height, if the mast is, for example, in a forest (positive disp. height) or on a very narrow rock (island) (negative disp. height), which is NOT included in the elevation data. The data type, mast, Lidar, etc. can be specified. This information can be used by modules like PARK and SITE COMPLIANCE, and is used in the later explained graphic wind profile. The data type Mast, Lidar etc. can be selected and is used for relevant purposes. For example, for downscaling Meso data in Scaler the data type must be Meso. Creating a wake cleaned wind speed signal will be handled differently if the datatype is Nacelle or Mast. If Nacelle, the turbine nearest the Meteo object is not included in calculation. It is although checked there is a turbine object within 5 m distance.

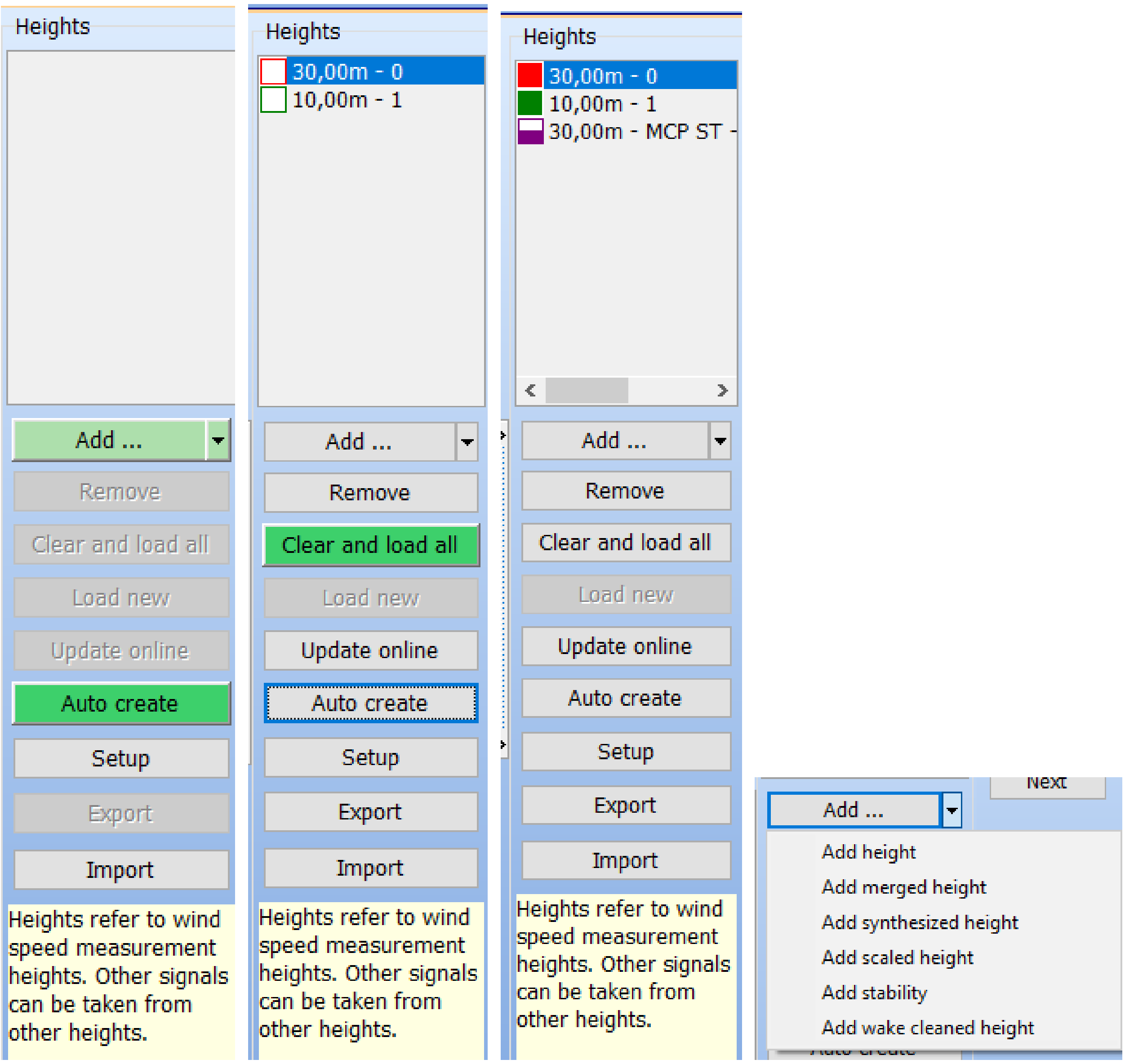


*Figure 17 The data panel in the Data setup tab . (1) Click **Auto-create**, to create signals in available heights. (2) Click **Clear and load all** to load data into the height signals. (3) Click **Add…** to add more heights. (4) Select the kind of height signal.*

The "**Auto Create"** button is, by default, green, as this will be the typical starting point. This will automatically create all the wind speed measurement heights in the import setup, providing the file can be read by windPRO. The signals created by default are:

- Wind speed
- Wind direction
- Turbulence intensity

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

Clear and load all will in case of already loaded data, clear those. If new data have been added to the import filter, the **Load new** will make sure the already loaded data are maintained with flagging, disabling etc.

Add adds a new height. The button also has more sub menus:

Add merged is a flexible way to merge two or more measurements, typically used to take out the tower shading when two sensors are at the same height (see example at the end of this section).
Add synthesized gives access to an advanced shear calculator that is used to scale measured data to another height (see example at the end of this section).
Add scaled creates a new data series, which can be, for example, a downscaled MESO series (if EMD meso data are loaded) but can also be a scaling where a Model and one or more measurement

heights creates a new height. Or it can by using the direction post calibration in scaler simply add tower shading or… there are many possible scenarios here due to the high flexibility of the Scaler tool.
Add stability can create an “artificial” stability classification based on user defined classes for day, night and season. This is for use in later more refined models that includes stability handling.
Add wake cleaned is based on a PARK model (which must be pre-run), which cleans the data series for calculated wake reductions. The methodology has the improvement relative to use of for example, the Scaler, in that it respects the wind speed dependent wake reductions.

Update online refreshes data previously loaded from On-line data (updates with most recent months and has the option to extend data back in time where data are available)
Setup allows setting of rules for concurrency, disabling of turbulence and rules for use of data for the turbulence table. Also, a special feature is available for very high time resolution data.
Export exports all or selected data into a flat text file format. The flag definitions included in the export (see explanation in the text file). Below is an example where 80m and 60m data are exported:

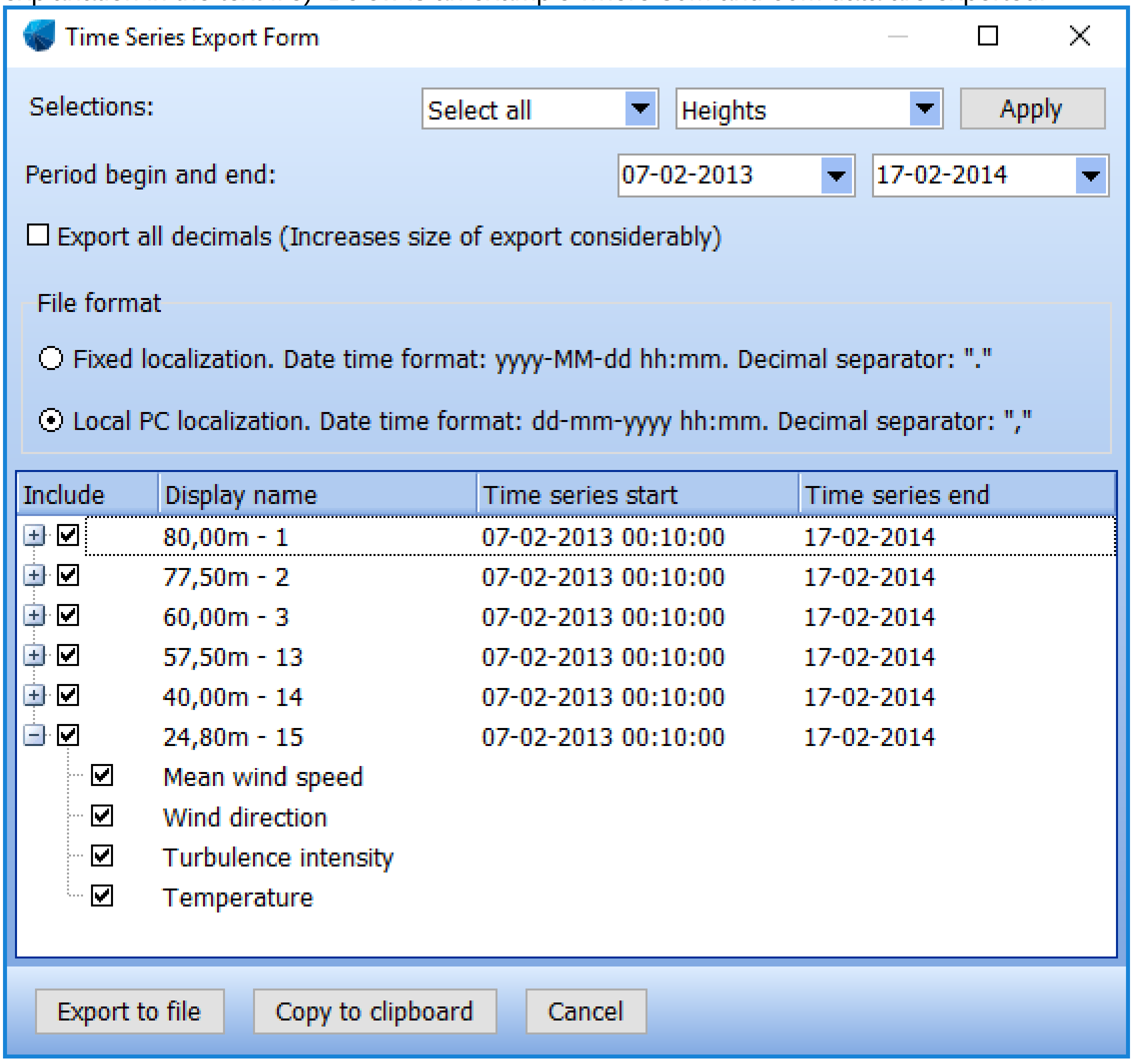


Figure 18 Export selections

Geographical Coordi	Longitude:	-87,22	Latitude:	13,9										
Local Coordinates: (l	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	DirectionUID_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	DirectionUID_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

Figure 19 Export format from METEO object

Status values are binary coded, so the sum in the status columns can be decoded for precise identification of, for example, "disabled", "out of range"(this means that multiple 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 it 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 around the world.

Import Imports data from the export file. Note: a full object export can be performed from the object list. An import of this full METEO object is done from the "Guide" tab.

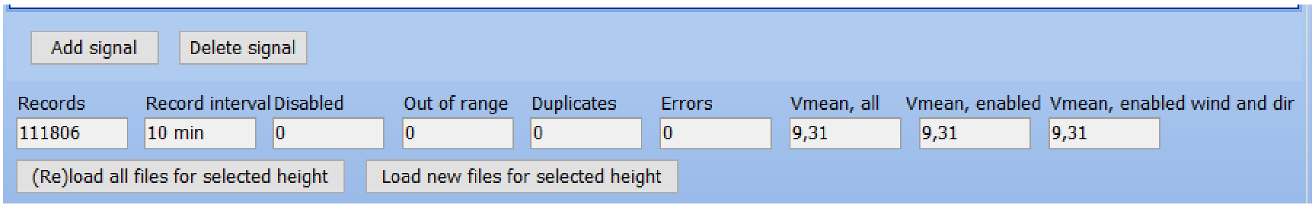


Figure 20 Data panel below signals in Data tab

Add signal is used for adding other signals, for example, temperature or "max. wind speed". Having more import filters, there are full flexibility in composing a given "height" with signals from different import filters. See examples below. **When using multiple import filters: Always check the dropdown buttons below "based on" to see if the signals from the different import filters are correctly included.** The range of signals that can be included is from time to time expanded, see in drop down list.

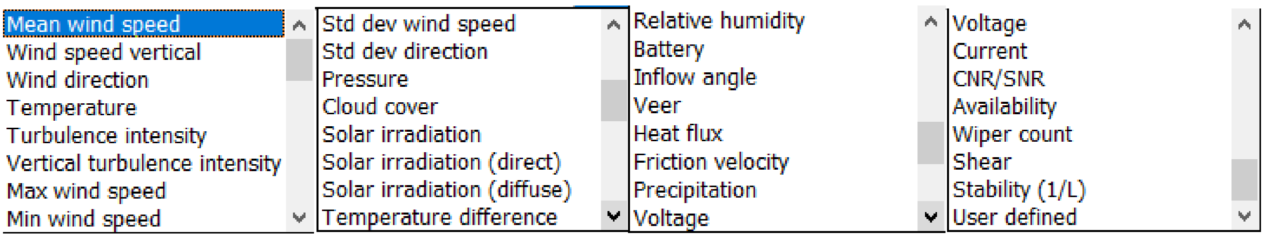


Figure 21 Current predefines signals.

The signal s available match the import filter types + sub types and some extra signals, calculated from more signals, e.g. Turbulence Intensity, which requires wind speed as well as Std.dev wind speed.

Delete signal removes unwanted signals from a height.

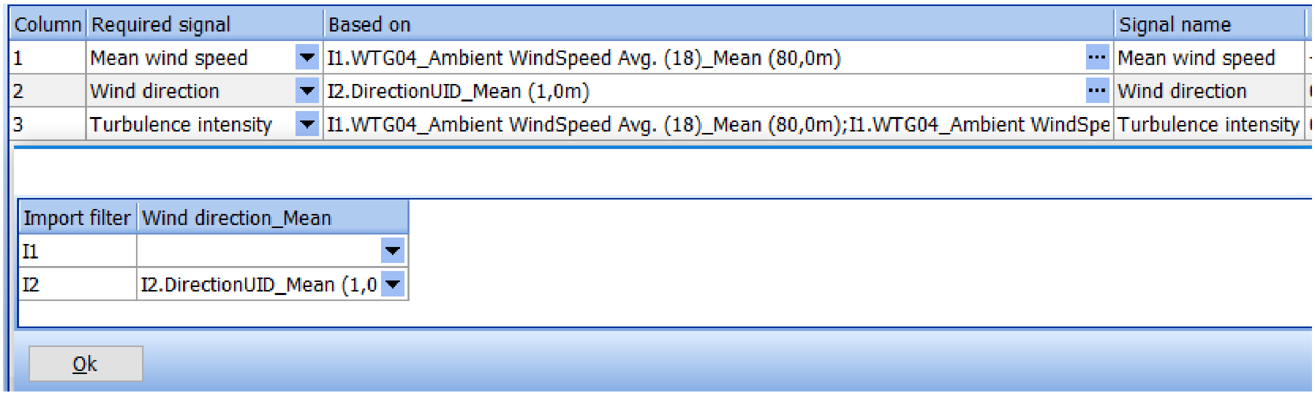


Figure 22 Combining wind speed and direction from different data series

Above is shown how the import filter takes wind speed from a Scada data file with nacelle measurements, and combines it with direction data from a Mesoscale file.
There is much flexibility. For example, shear can be added as a signal, giving options for comprehensive analyses of shear within the Graphics tab. While shear requires more heights, these can be selected in drop down buttons as illustrated in next figure:

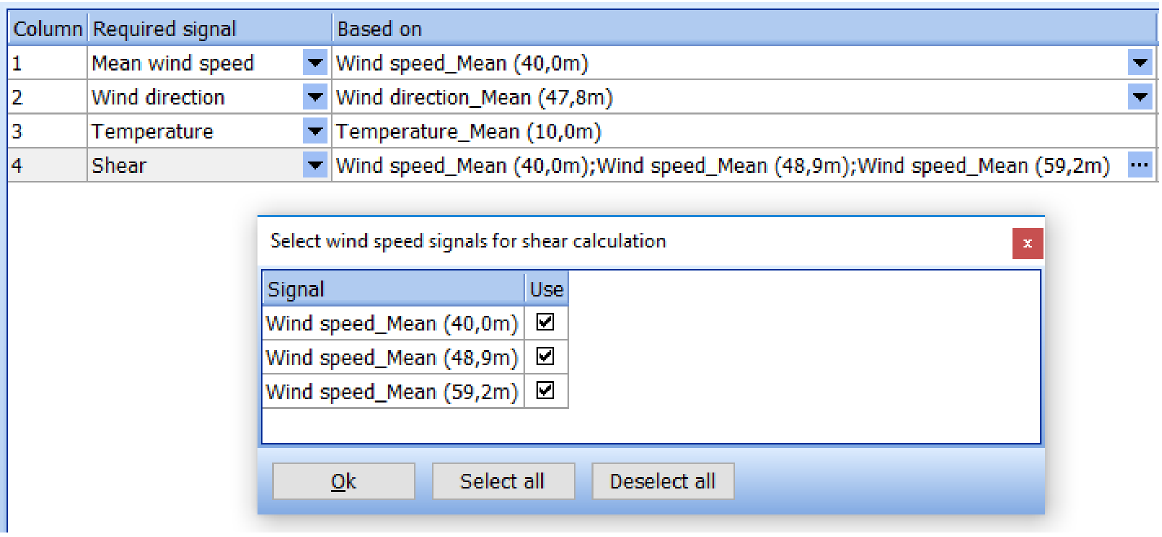


Figure 23 Setup of shear calculation

When adding shear, the user has full flexibility on which height will be used to calculate the shear time series (minimum of 2 heights is needed).

(Re)load all/new files for selected signal loads the data from the files via the import filter into a time series for the selected height only. The right side button (new) only loads new files added after the last load operation. The Reload button keep the disabled data points– these are not kept by the “Clear and load all” presented earlier.

Low/high limit (next to the signals’ names) is used to set the data record “out of range” data in the time series. By default the low limit for wind speed is -1. Pay attention to the calibration of the raw measurements not making the “0” or very low wind speeds negative. To avoid these being set 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.

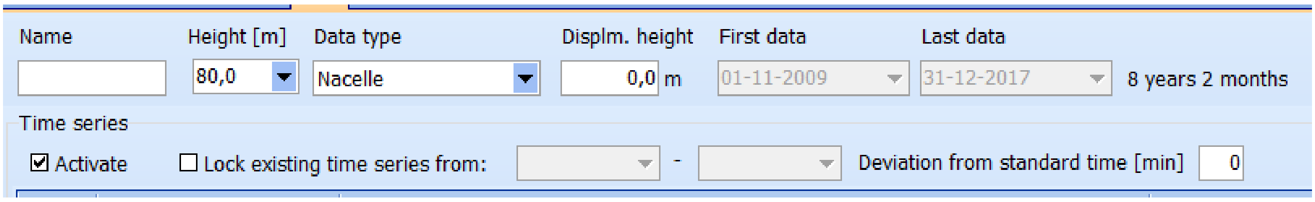


Figure 24 Features in the top of the form

Activate activates the different types of data presentation including showing the Weibull or Turbulence tab. If you have no intention of using the Weibull distribution, or you have table data but no time series data, this feature is still useful.

[ ] Lock existing time series is used when new data are 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 or previous versions. Basically, adding new data requires intact import filters and files for all data except when older data series are locked.

12.3.3.5 Remove tower shading – add merged

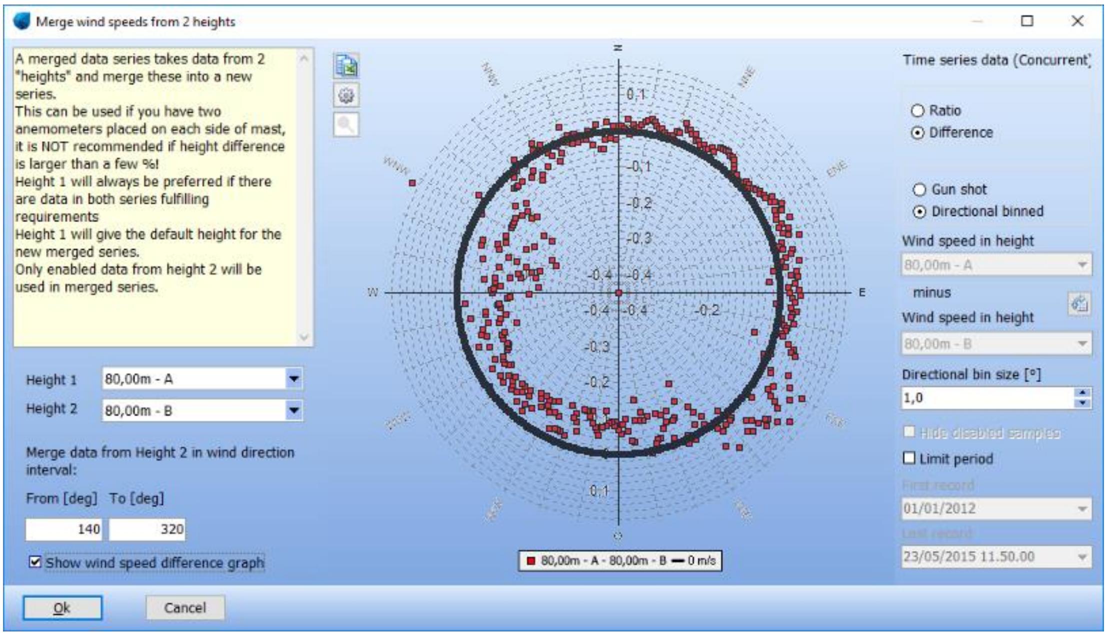


Figure 25 Compare wind speeds by direction

When two wind speed measurements are at the same height, the desire is often to use both measurements to remove the influence of tower shading and thereby get the “clean” signal. A typical setup is shown above. Here, wind speed data from “Height 1” is used as “base” and wind speed data from “Height 2” is merged into the “base” data within the given sector defined by “From [deg] - To [deg]”. Only enabled wind speed data from “Height 2” is used for the merging. The merging is not performed if the direction data of “Height 1” is disabled (in this case, the disabled wind direction data can advantageously be replaced by other wind direction data from another wind vane using Substitute in Meteo analyser prior to the merging with “Add Merge”). Looking at the data above, it is obvious that wind speed data from “Height 2” measures higher values from 140 degrees to around 320 degrees (the difference, ”Height 1” minus ”Height 2”, is negative).. Click on **OK** and the following screen appears:

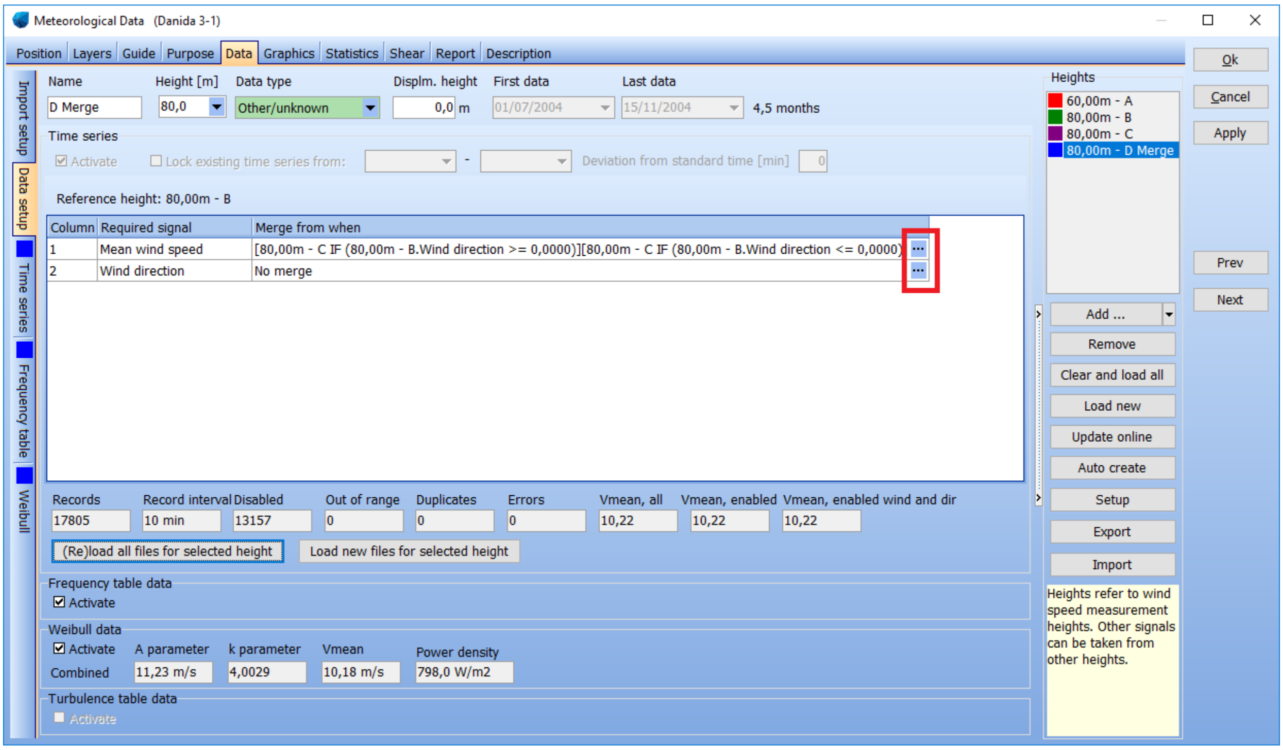


Figure 26 Merging data from more sensors

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.

12.3.3.6 Add synthesized – creates shear matrix – scale to new height

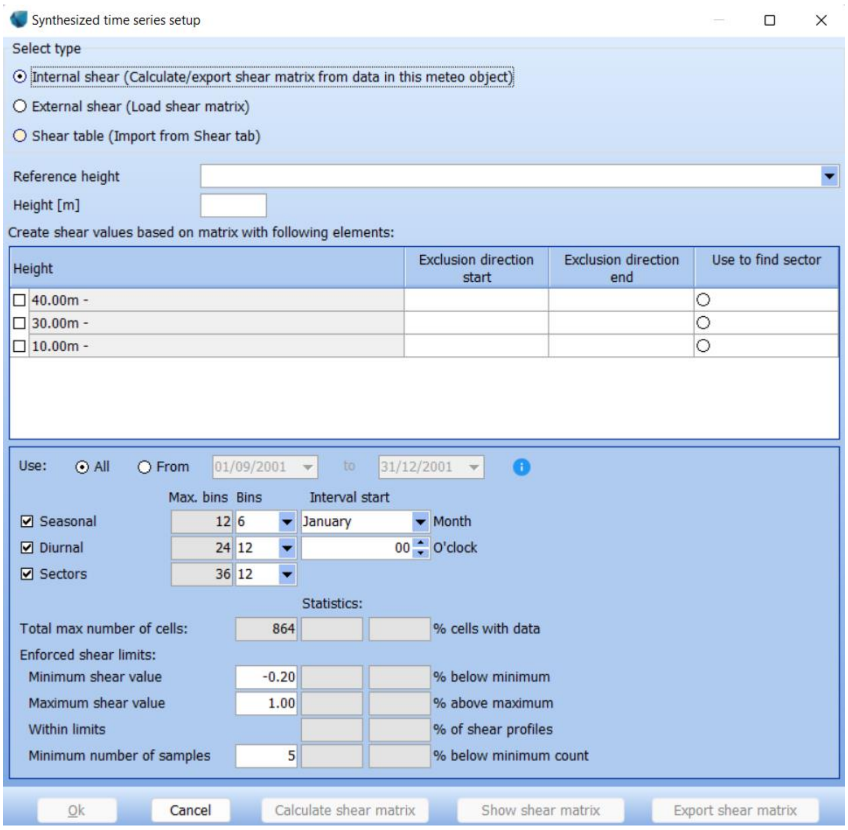
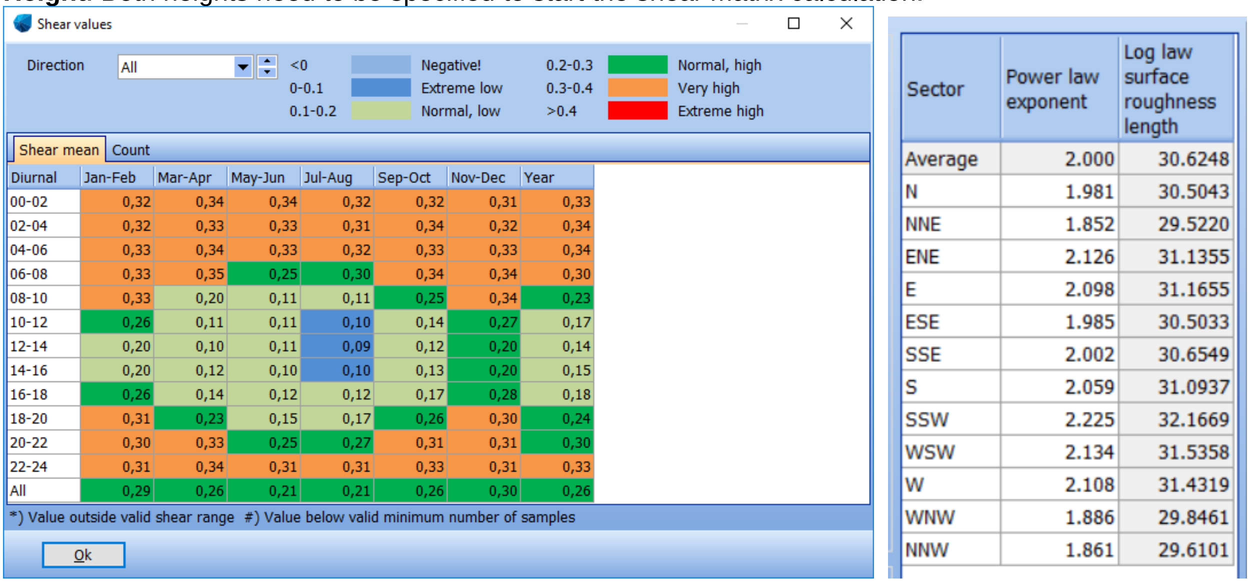


Figure 27 Create synthesized data

Data can be scaled to a new height based on a shear extrapolation. The two first options **Internal shear** and **External shear** rely on a shear matrix, calculated within the current meteo object in the first case or calculated and exported from another meteo object in the second case. The third option uses a shear table from the shear tab of the current meteo object (see 12.3.6 about the shear tab).

The **Reference height** is the height which wind speed will be extrapolated to the target height specified in **Height**. Both heights need to be specified to start the shear matrix calculation.

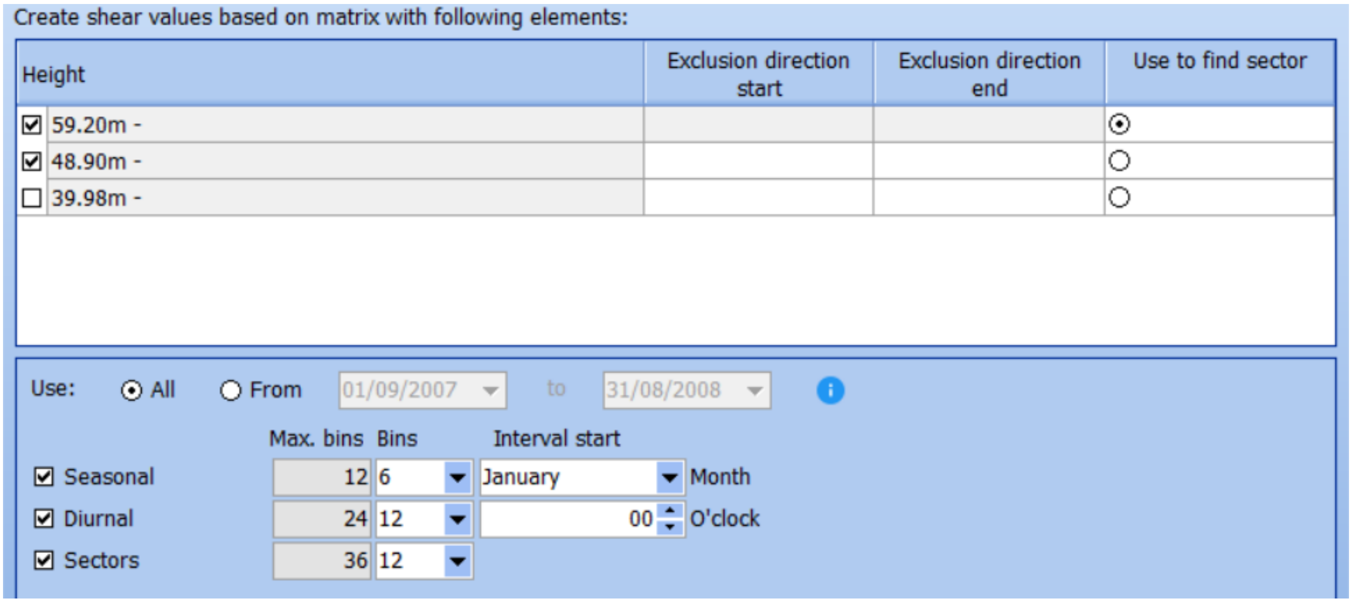


Diurnal	Jan-Feb	Mar-Apr	May-Jun	Jul-Aug	Sep-Oct	Nov-Dec	Year
00-02	0,32	0,34	0,34	0,32	0,32	0,31	0,33
02-04	0,32	0,33	0,33	0,31	0,34	0,32	0,34
04-06	0,33	0,34	0,33	0,32	0,33	0,33	0,34
06-08	0,33	0,35	0,25	0,30	0,34	0,34	0,30
08-10	0,33	0,20	0,11	0,11	0,25	0,34	0,23
10-12	0,26	0,11	0,11	0,10	0,14	0,27	0,17
12-14	0,20	0,10	0,11	0,09	0,12	0,20	0,14
14-16	0,20	0,12	0,10	0,10	0,13	0,20	0,15
16-18	0,26	0,14	0,12	0,12	0,17	0,28	0,18
18-20	0,31	0,23	0,15	0,17	0,26	0,30	0,24
20-22	0,30	0,33	0,25	0,27	0,31	0,31	0,30
22-24	0,31	0,34	0,31	0,31	0,33	0,31	0,33
All	0,29	0,26	0,21	0,21	0,26	0,30	0,26

Sector	Power law exponent	Log law surface roughness length
Average	2.000	30.6248
N	1.981	30.5043
NNE	1.852	29.5220
ENE	2.126	31.1355
E	2.098	31.1655
ESE	1.985	30.5033
SSE	2.002	30.6549
S	2.059	31.0937
SSW	2.225	32.1669
WSW	2.134	31.5358
W	2.108	31.4319
WNW	1.886	29.8461
NNW	1.861	29.6101

Figure 28 Shear matrix (shown here for all directions) and shear table

The shear matrix contains shear values in several bins: monthly bins (yearly variation), hour bins (daily variations) and directions.



Height	Exclusion direction start	Exclusion direction end	Use to find sector
☑ 59.20m -			◉
☑ 48.90m -			○
☐ 39.98m -			○

To calculate the shear matrix at least two heights must be selected and one of these selected also to define the sector.

The shear matrix is calculated from Weibull fitted mean wind speeds in each bin (season, time of day and direction) and will, thereby, partly represent stability conditions. For example, a lot of solar heating of the Earth's surface will give low shear due to mixing of the air. The extrapolation to a new height will then be based on the individual bin values for shear. Note: In complex terrain, on a smooth hill, or in a forest, very inaccurate extrapolations can occur. Using a model, such as WAsP (or better, WAsP-CFD, when terrain is really complex) for the extrapolation, will be the better choice.

The shear matrix can be more or less detailed, depending on how good and long-term period of data is available.

If there is too little 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. Annual value for the direction and diurnal period.
2. Mean value for the nearest two directions
3. Overall mean

For instance, if a direction has almost no data, not even a year's worth of values might be present for a certain diurnal bin, then the two nearest directions are used. If those (or just one of them) also have too little data, the algorithm moves to step 3. Note that these substitutions are not very critical, since they will basically represent bins where wind is rarely experienced.
Note that if a fixed displacement height is input in the Meteo object, the displacement height is applied to the height used to create the shear values as well as to the reference and target heights. If the met mast is experiencing a displacement height, it is recommended to include the displacement height to calculate the shear matrix.

Once the shear matrix has been calculated, it can be viewed (and/or exported) and finally used to synthesize the data (clicking OK).

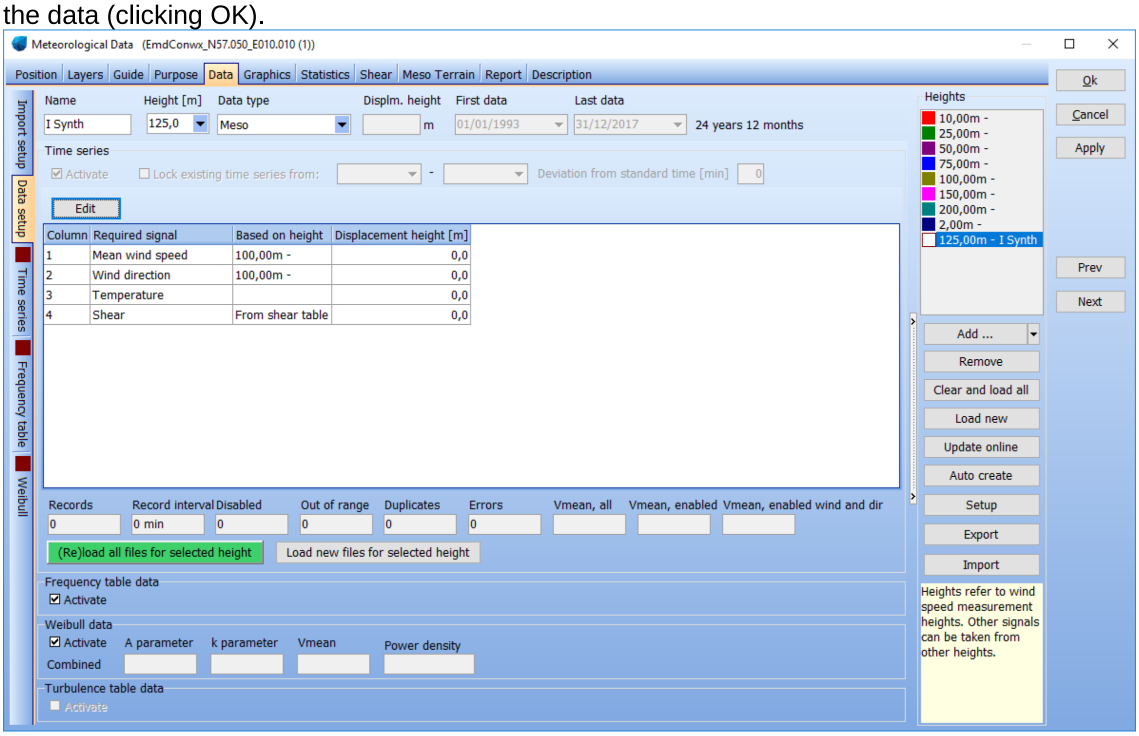


Figure 29 Load synthesized data

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.

In the case of exported shear matrix, a .shearmat file is created. This file contains all the needed information to replicate the matrix in another meteo object (or the same). This option can be useful especially for co-located remote sensors (Lidar, Sodar). Care must be taken that an imported shear matrix is representative (for example concurrent in time or same terrain or stability conditions) of the data that it is going to be applied to.

12.3.3.7 **Add Scaled height**

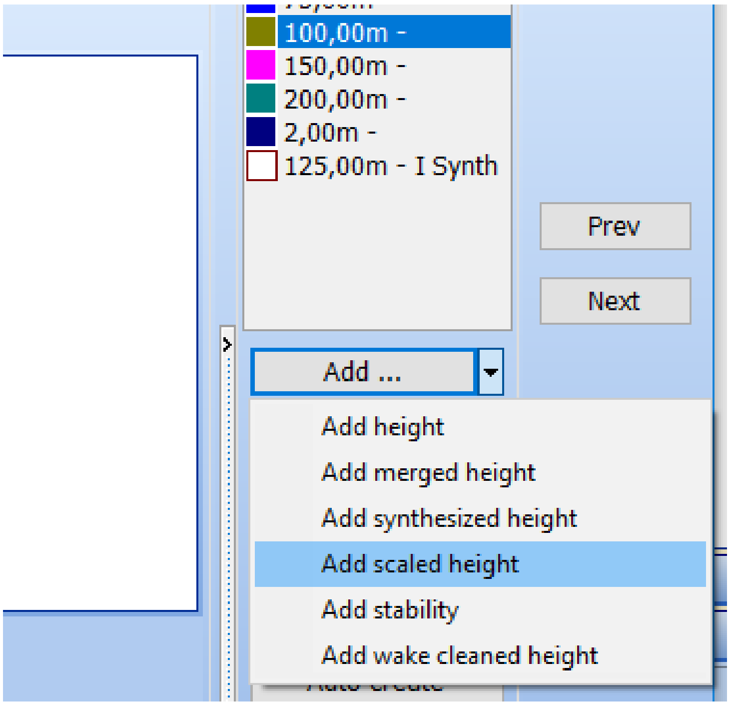


Figure 30 Add scaled height in meteo object

Here, the SCALER is used to create a scaled (e.g. downscaled mesoscale data) time series within the meteo object. Then, it is easy to directly compare the scaled data to the non-scaled data within the meteo object.

It is important to note that the data is scaled to the same position as the current object position. Thereby, it is possible to move the mesoscale data based meteo object to a position where an "artificial mast" is required. The mesoscale based meteo object knows its original position and uses the mesoscale terrain from this position, only the micro terrain is used for the new current position.

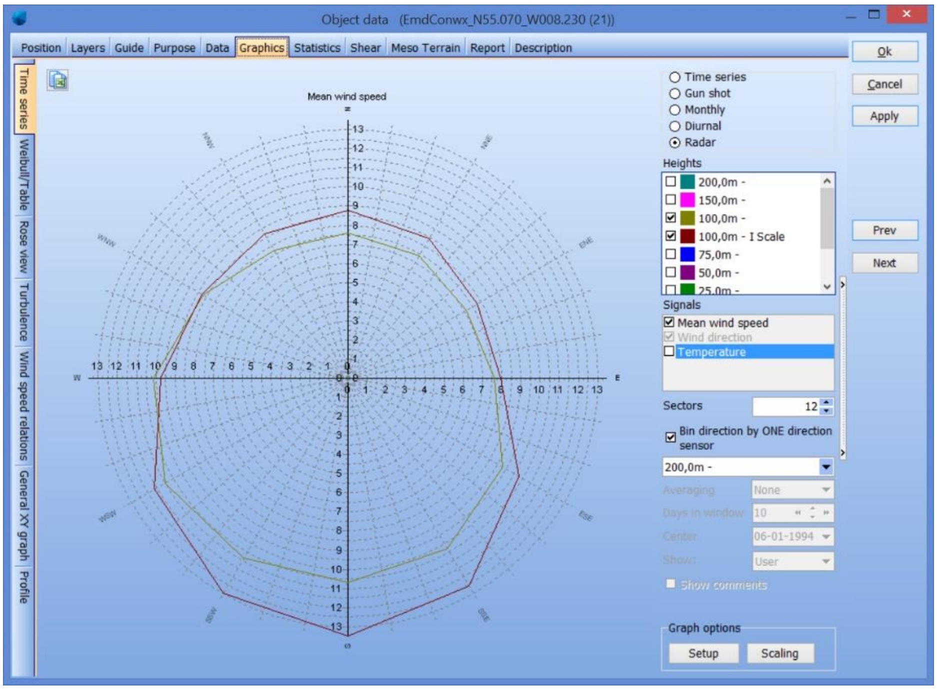


Figure 31 Radar graph comparison

Here is illustrated how a downscaled mesoscale data series compares to the original. The hill impact in the N-S directions gears up the wind speed in the downscaled data compared to the original data, which only sees the hill very approximately due to the low resolution of the elevation data in the mesoscale model.

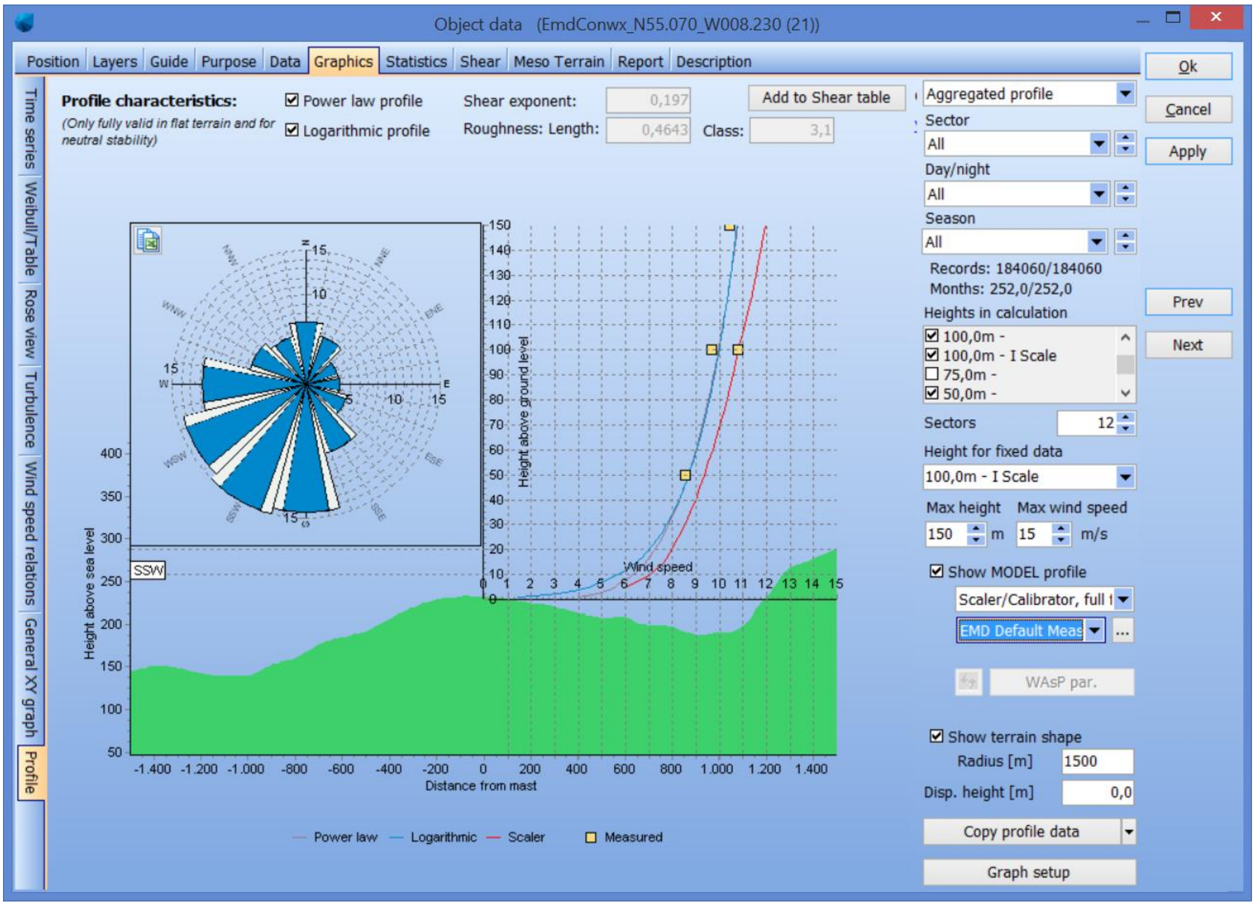
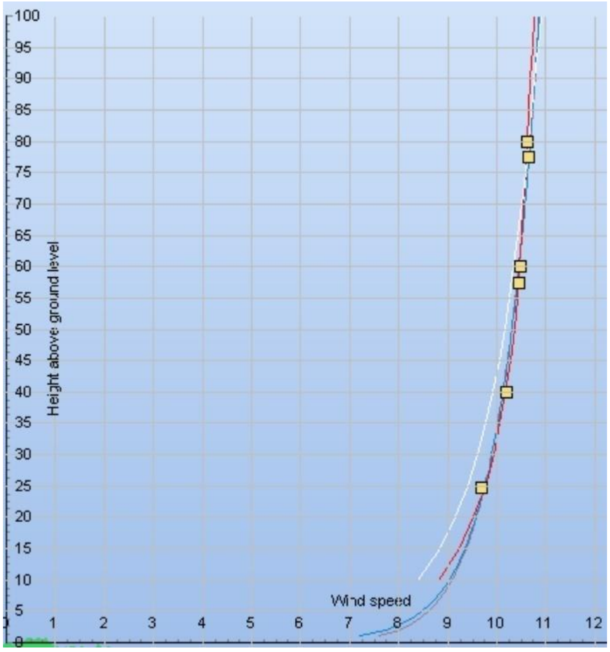


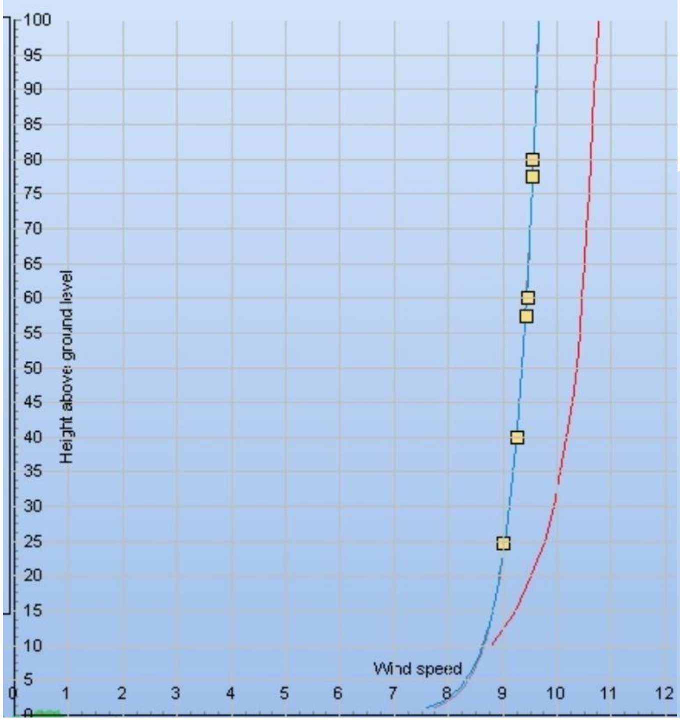
Figure 32 Profile based on SCALER calculation

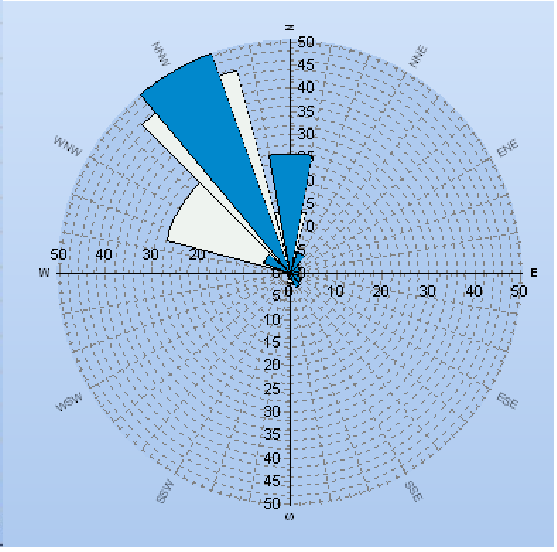
Another feature is the use of the SCALER for establishing the wind profile. This is interesting because the calculated profile is no longer just one profile by direction sector. When aggregating by season, only the, calculated summer profile, for example, is compared to the measured summer profile. In other words; while the scaler calculates for each time step, aggregations of calculated values can be directly compared to measurements. With the "traditional" (annual average) WAsP profile, only the annual mean profile is available for comparison to, for example, the measured summer profile. The Scaler based profile thereby gives closer comparison between measurements and calculations. Although, it must be mentioned that the variation of stability in time is NOT handled (yet) by this. This will require different WAsP stability parameters in the time domain (an upcoming feature). It must also be noted that ONLY the SCALER set to WAsP method (measured data) for profile calculation based on only ONE height is available here. The Mesoscale downscaling method requires more heights as input, which the profile viewer shown above is not prepared for. But, by adding more scaled heights, it is possible to view the shear of the downscaled data based on specific heights.

Below, an illustration of the power of the Scaler based profile versus the WAsP average profile from a real site, where it was difficult to understand why there were so large deviations between measurements and model calculations by direction sector:

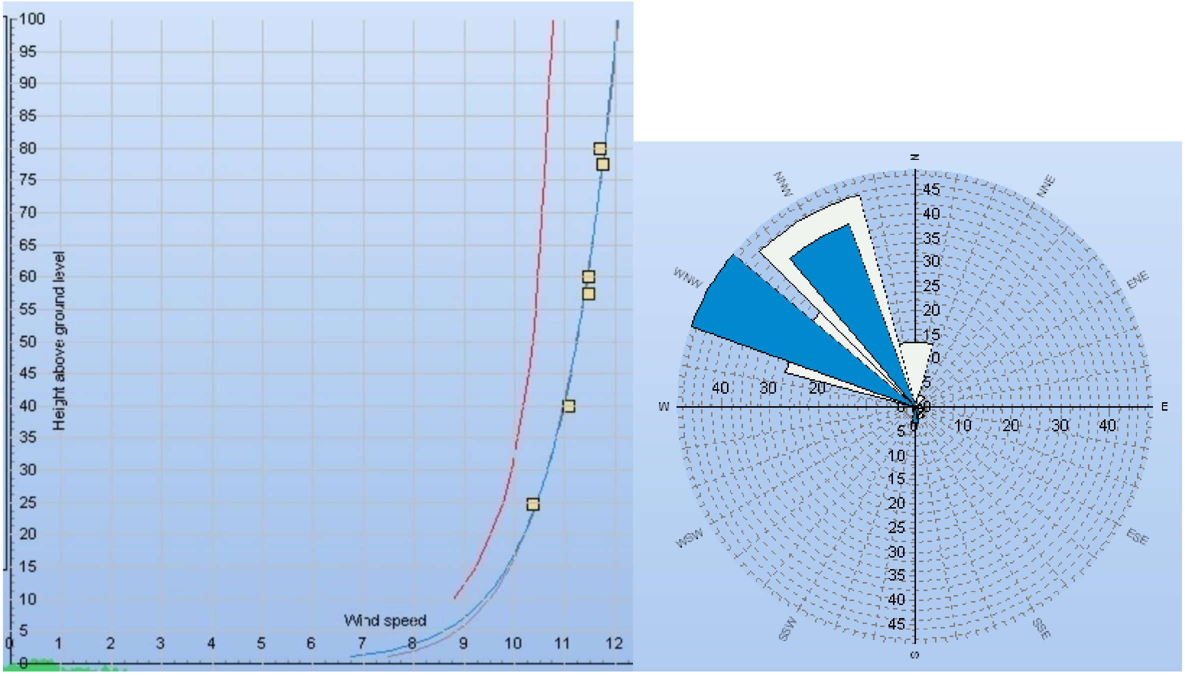


The average measured (yellow points and in blue and grey lines the best fit based on power law and log. law) and WAsP calculated (in red) profile from 80m.
The white graph shows the WAsP calculated without stability correction (neutral)





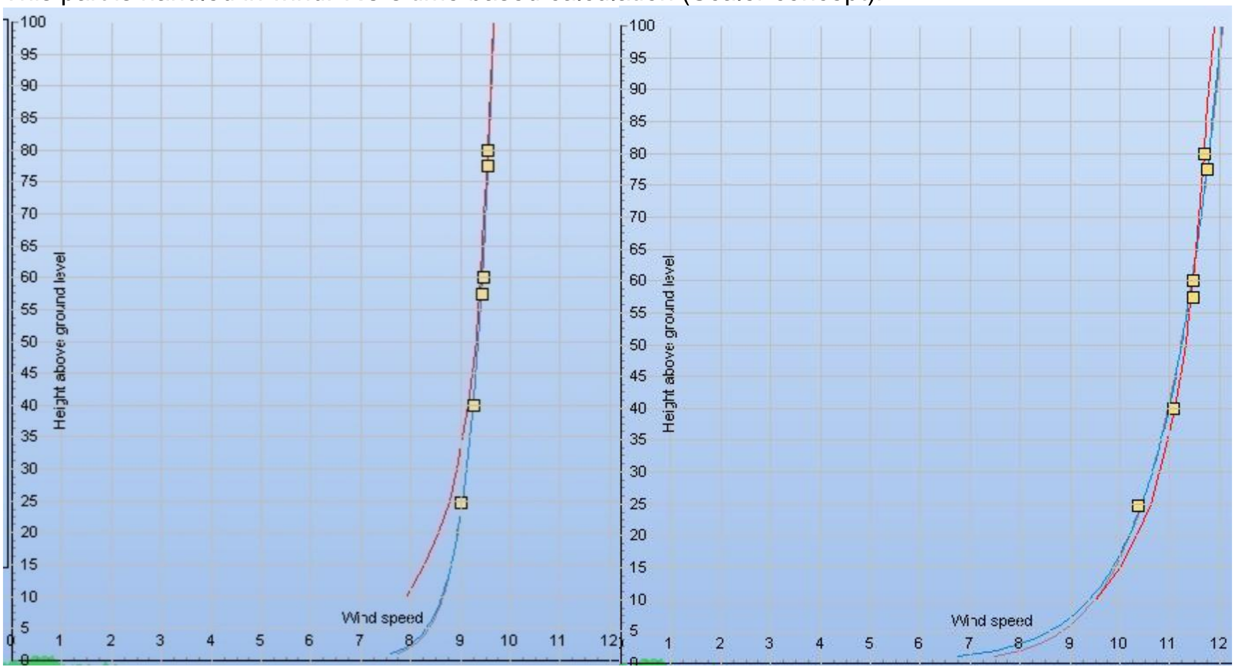
Measured only for day hours. (red WAsP profile still for all data) – to the right blue show day direction distribution, white all data.



Measured only for night. (red WAsP profile still for all data)

It seems quite obvious that there will be benefits from handling stability in the time domain.
At this site, however, it is also worth noticing that the day/night differences are heavily related to the direction distribution. At night wind comes from the mountains, during the day from the more open desert.

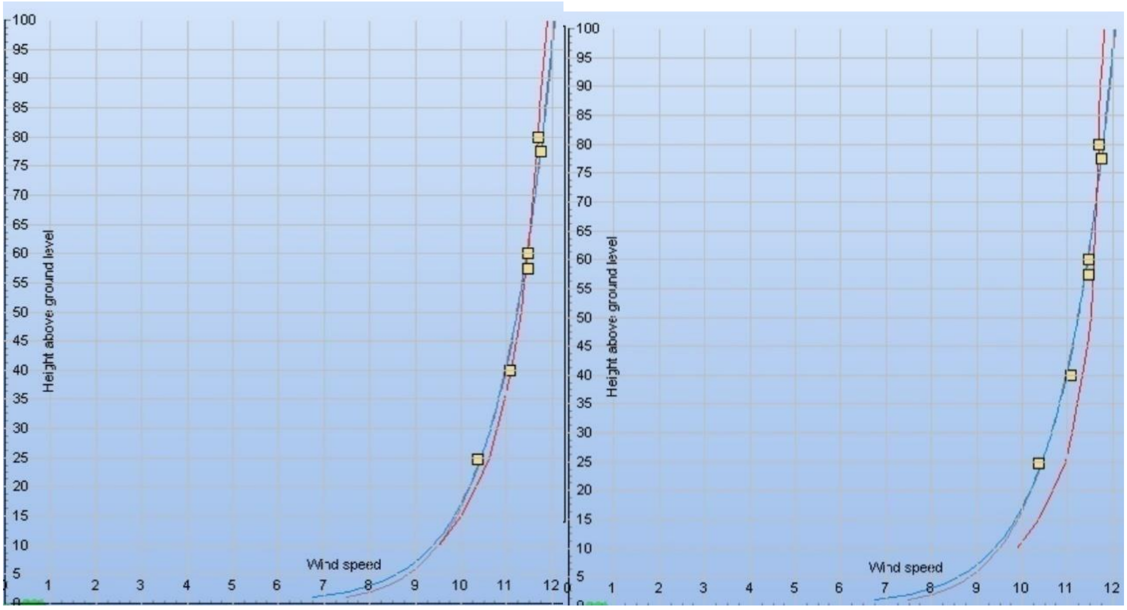
This part is handled in windPRO’s time based calculation (Scaler concept):



Left day, right night. The WAsP reproduction day-night is much better, because the time step-based calculation aggregates the day calculations and then only compare these to daytime measurements etc.

Thereby the issues due to different directions, and day-night can be solved in the graphic evaluation of the model performance. There is still a problem as the WAsP stability parameters, however, which are the same in day-night calculations. This is although a much smaller issue here than the direction problem.

Another feature since windPRO 3.2 is the wind speed dependent stability correction in the Scaler calculation (see also manual Chapter 3). The rightmost graph below shows how much worse it was before this improvement.



Both graphs show the night profile. The right side is without wind speed dependent stability correction. As seen the wind speed dependent stability correction illustrates a major improvement in reproducing measured profiles.

12.3.3.8 Stability information import and view in graphs.

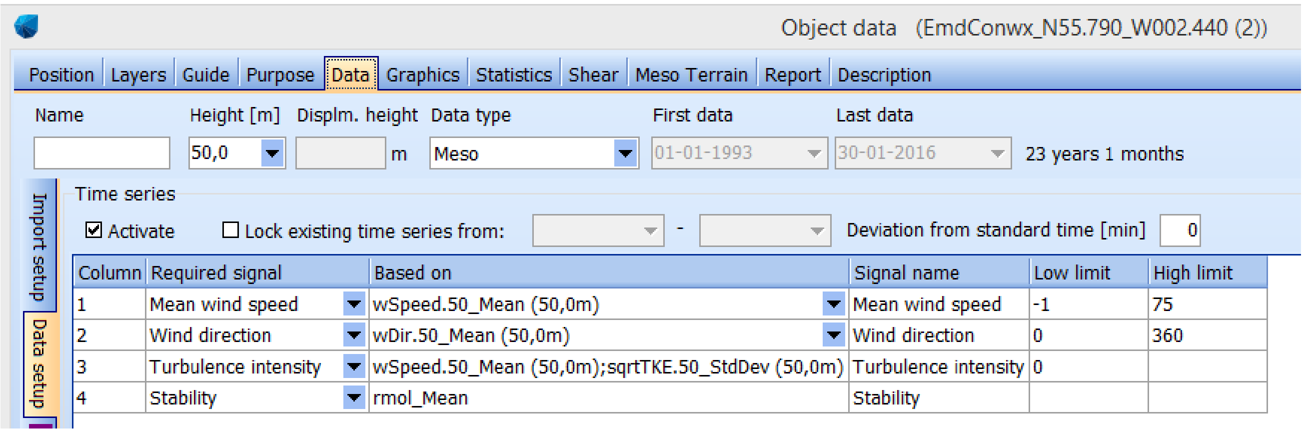


Figure 33 Stability can be imported in meteo object.

Above, EMD-ConWx Europe mesoscale data. The “rmol_mean” signal is the inverse Monin Obukov length available in this data set. Stability can be viewed in Graphics tab under Stability View:

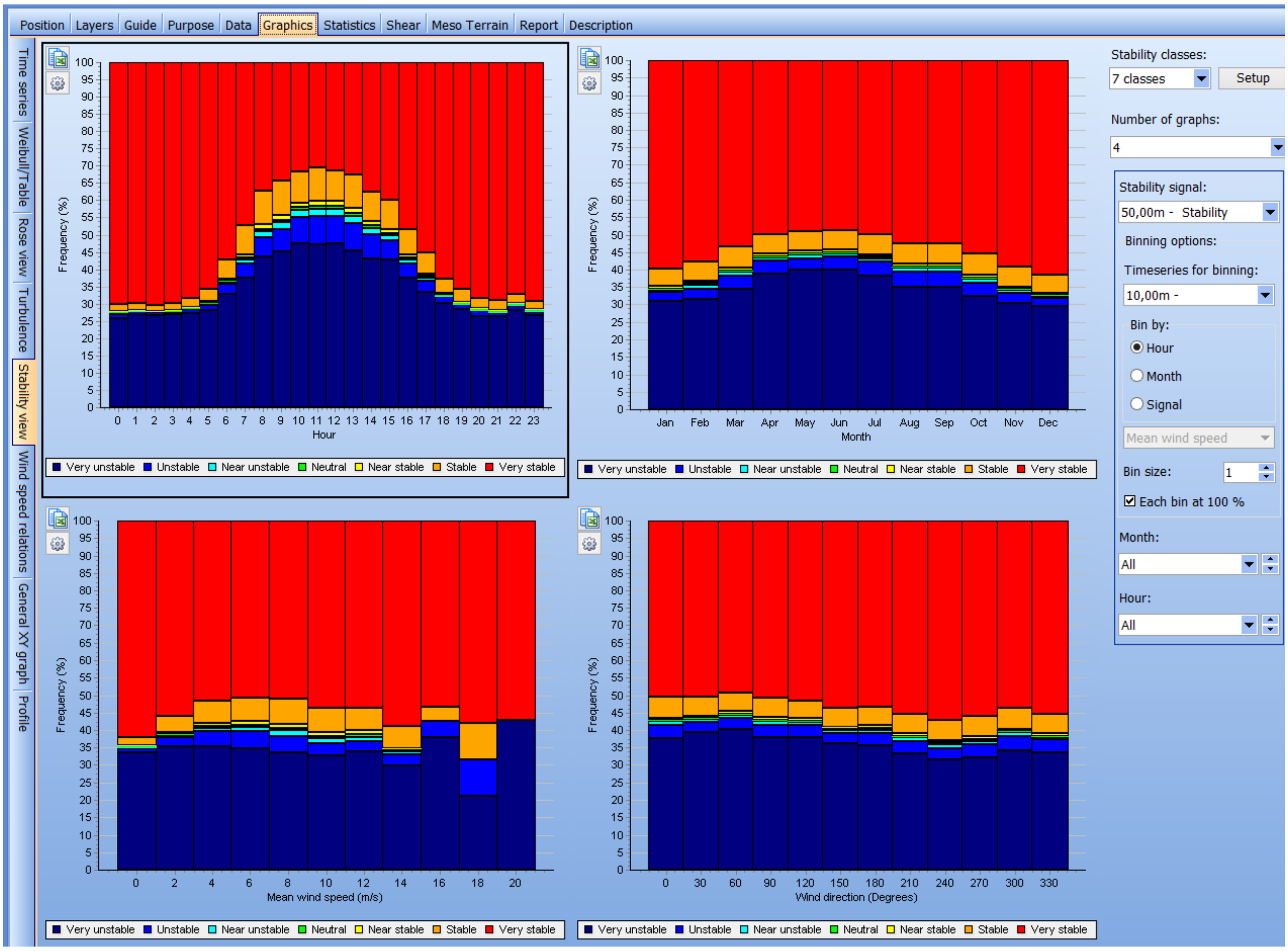
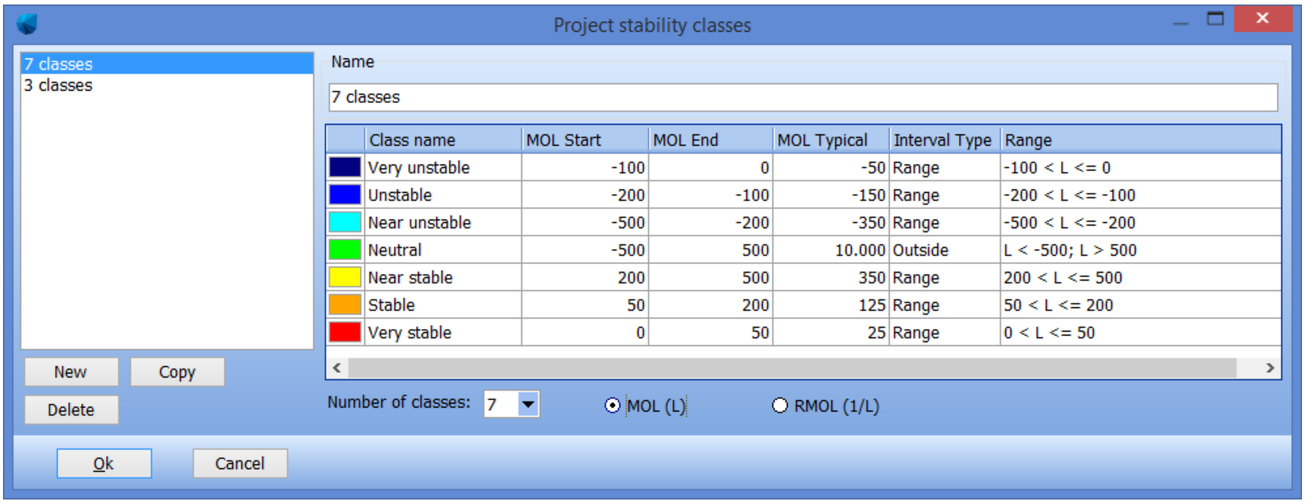


Figure 34 graphic view of stability classes.

Different settings are available. The graphic view is the first step; in future versions of windPRO, the Stability information will be included in calculations.



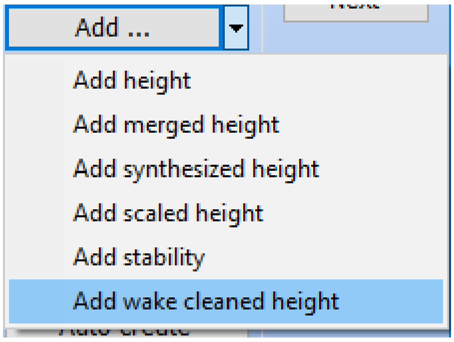
Class name	MOL Start	MOL End	MOL Typical	Interval Type	Range
Very unstable	-100	0	-50	Range	-100 < L <= 0
Unstable	-200	-100	-150	Range	-200 < L <= -100
Near unstable	-500	-200	-350	Range	-500 < L <= -200
Neutral	-500	500	10.000	Outside	L < -500; L > 500
Near stable	200	500	350	Range	200 < L <= 500
Stable	50	200	125	Range	50 < L <= 200
Very stable	0	50	25	Range	0 < L <= 50

Figure 35 Setup of stability legend.

In the legend above, the grouping of the stability classes can be user defined. Note in EMD-ConWx mesoscale data, it is the reverse Monin Obukov length (1/L) that will be imported, in the definition above it is the Monin Obukov length, L that is shown, with option for showing 1/L.

12.3.3.9 Wake cleaning measurements

It is possible to load a PARK calculation and remove the wakes caused by the turbines to generate a wake-clean time series:



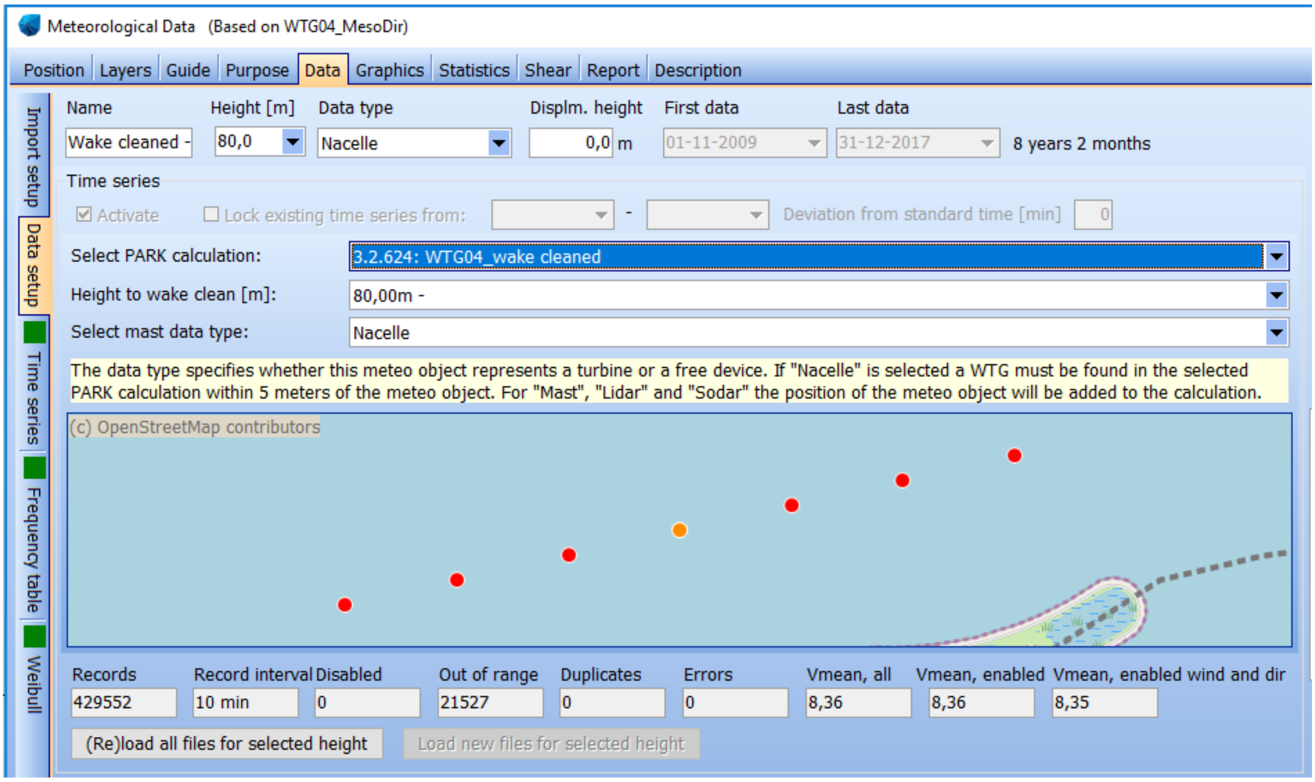


Figure 36 Select PARK calculation for wake cleaning

Wake cleaning can be for:

- Measurement device
- Nacelle wind

If the first, the measurement devise coordinate is auto insert in the selected PARK calculation.
If Nacelle wind, the software checks if there is a WTG object in the PARK calculation within few meters from the meteo object used, if not, calculation cannot be performed. If there is, this WTG object is automatically taken out of the PARK calculation.

The Wake cleaning is based on calculation of a wake wind speed reduction matrix with 1-degree direction step and 1 m/s wind speed step. Based on the selected wake model and settings in the PARK calculation. Although following apply:

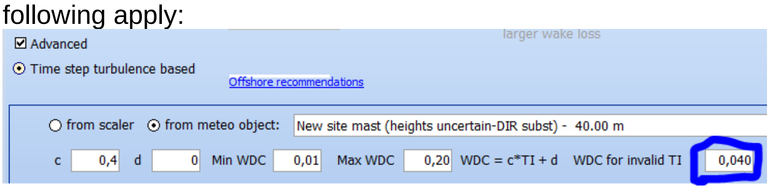


Figure 37 Advanced wake settings are not included in wake cleaning.

Using like time step TI to control the WDC, will not be included in the wake cleaning. The WDC for invalid TI will be used. Similar curtailment settings will not be included.

When the wake reduced wind speed matrix is calculated, the method is: For each time step; a look up in the matrix from the wake reduced wind speed, identifies the free wind speed, and replaces the recorded value with this in the wake cleaned time series.

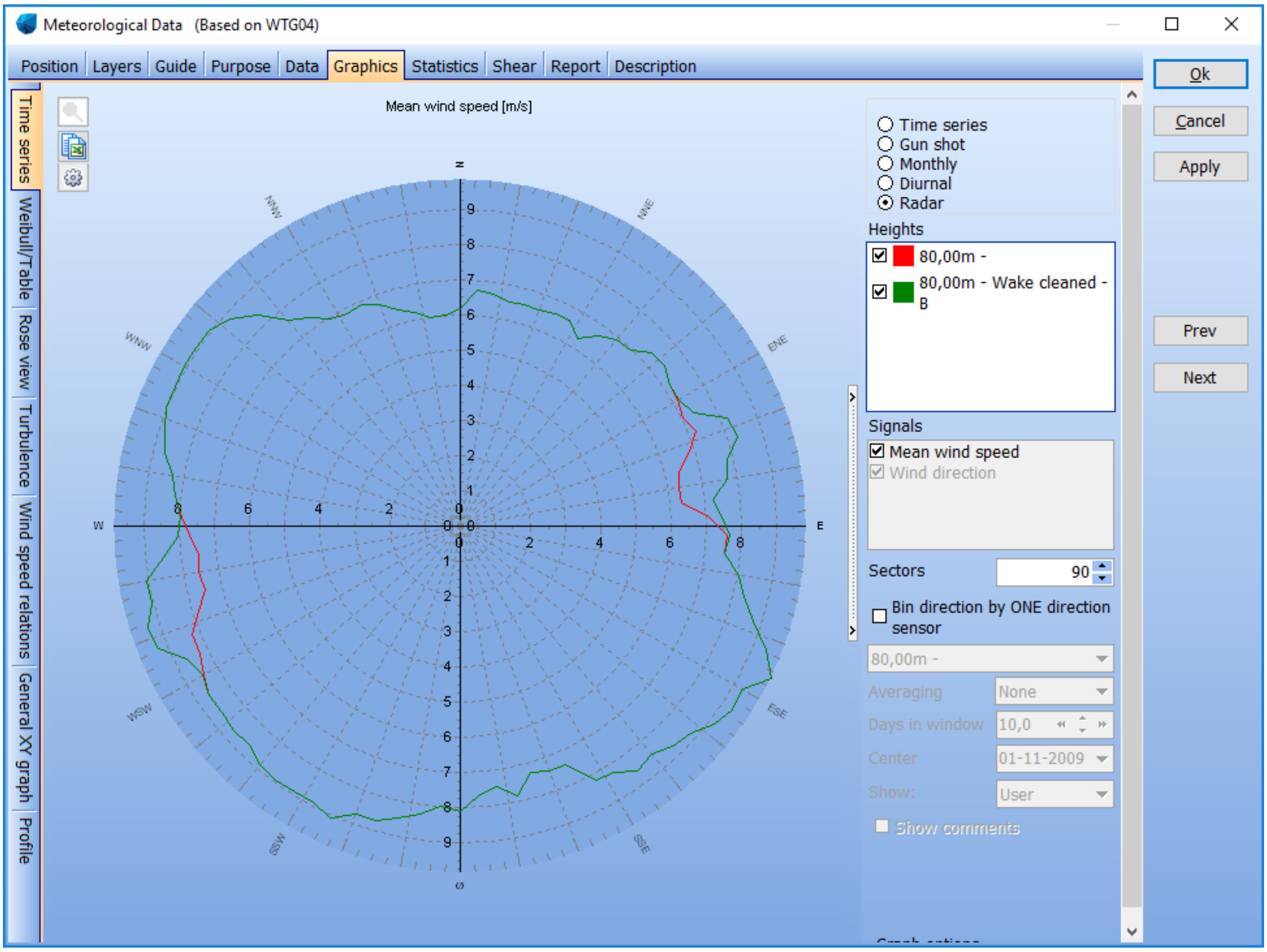


Figure 38 The radar graph illustrates effect of wake cleaning

As seen above, the result is as expected. In the directions with turbines, the wind speeds become higher.

It is, of course, of high importance that the wake model settings are correct, and that the wake model does a reasonable job.

The advantage with this method compared to e.g. a simple scaling, is that the wind speed reduction dependency on wind speed is handled correct.

12.3.3.10 Turbulence from Mesoscale data in meteo object

Although the turbulence from Mesoscale modelling might not be too precise, it can be convenient to take turbulence data from this to at least have some turbulence data. Our experiences with different meso scale model runs are that where the former EMD_ConWx data set typically has too high TI, the new EMDWRF data sets typically have too low TI. This is seen by comparing to measured data for round 300 measurement masts. The change in bias can have large impact, if a user has found a good way compensating within the former data set, then this process now must be redone. As an example, on a random test site, the new Meso data has 40% lower TI than the former. Using this for controlling the Wake Decay Constant, the new Meso data set will calculate 13% higher wake loss due to the lower TI for a random test example, just to illustrate the size order of the impact.

For the new EMD_WRF meso scale datasets, turbulence signals are auto created when downloading data.

To get the turbulence information from the EMD-ConWx mesoscale data requires a little work:

27	snowDepth	0.0					0,00	snowDepth	
28	vis.s	24206.91					0,00	vis.s	
29	sensHeatFlux.s	-49.59					0,00	sensHeatFlux.s	
30	totPrecip.s	0.00					0,00	totPrecip.s	
31	downShortWaveFlux.s	0.000					0,00	downShortWaveFlux.s	
32	totalCloudCover.a	98.71		Ignore			0		
33	convCloudCover.a	9.93		Ignore			0		
34	4LFTX	0.46					0,00	4LFTX	
35	rmol	0.174					0,00	rmol	
36	znt	0.050					0,00	znt	

Figure 39 Establish turbulence data in Meso meteo object

Looking at the import filter, in this case the last row is 36 (depends on when data were downloaded, in later downloads the next shown columns are included). This need to be expanded by clicking the little **+** to add lines:

36	znt	0.050					0,00	znt	
37	sqrtTKE.10	2.001		Ignore			0		
38	sqrtTKE.25	1.793		Ignore			0		
39	sqrtTKE.50	1.635		Ignore			0		
40	sqrtTKE.75	1.543		Ignore			0		
41	sqrtTKE.100	1.477		Wind speed	StdDev	m/s	100,00	sqrtTKE.100_StdDev	1,48 m/s
42	sqrtTKE.150	1.385		Ignore			0		
43	sqrtTKE.200	1.329		Ignore			0		
44	cloudWater.100	0.000		Ignore			0		
45	cloudIce.100	0.000		Ignore			0		

Figure 40 Establish turbulence data in Meso meteo object (2)

The extra rows include the standard deviation; sqrtTKE in all heights. Set, for example, the 100m Type, to wind speed and sub type to “StDev.” and the height to 100m.

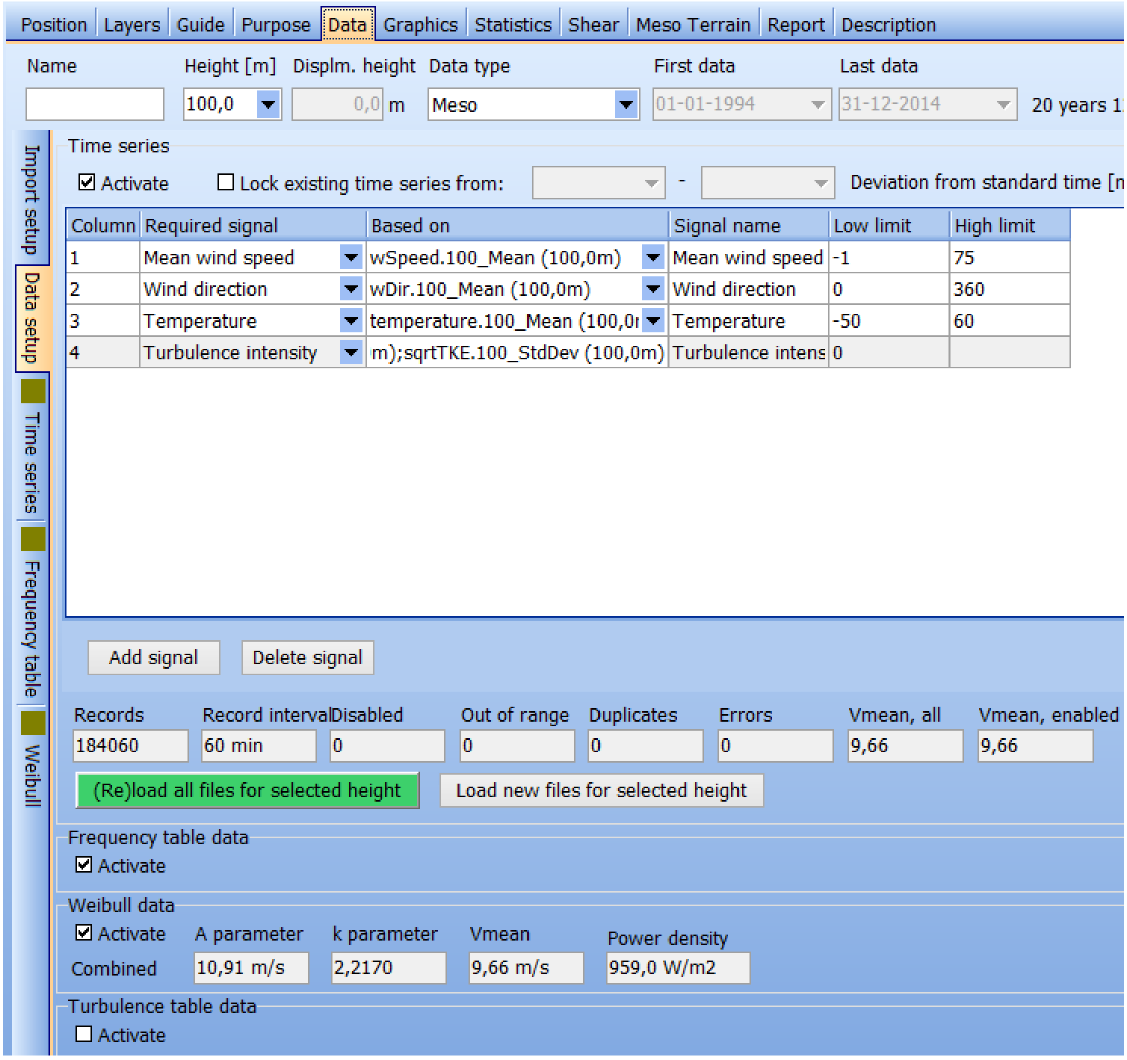


Figure 41 Establish turbulence data in Meso meteo object (3)

On the Data setup tab, click **Add signal** and choose *Turbulence intensity*. This will then be composed from wind speed and StDev. Double check this by clicking on the small down-arrow to the right making sure the values are taken from the correct signal sources.

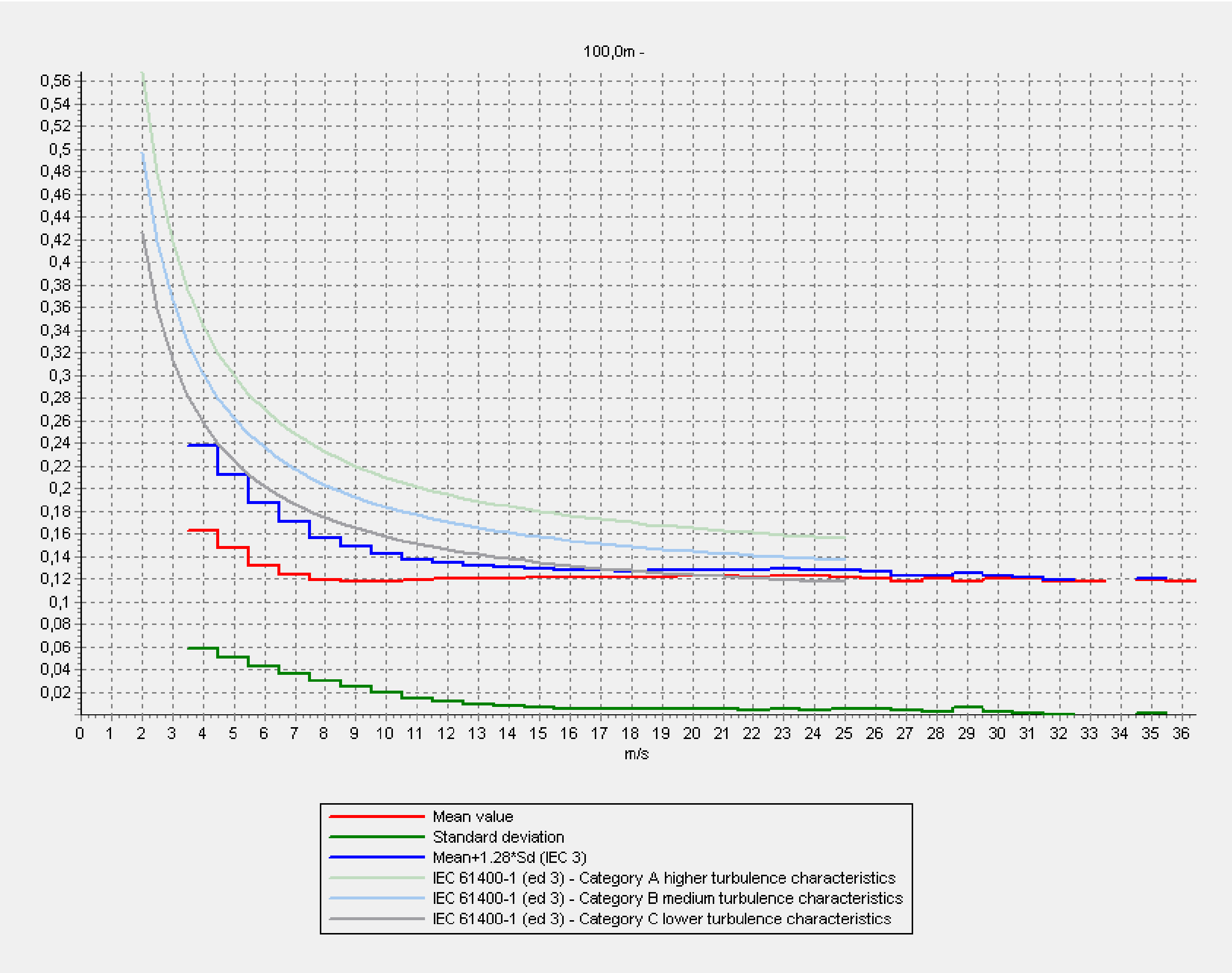


Figure 42 Graphic view of turbulence

The graphic presentation above shows the turbulence from the mesoscale data, in this case, it matches the IEC 61400 ed. 3 Category C very well (which is expected for this site). EMD is still in the process of evaluating turbulence from Meso scale data. One special concern is that the added turbulence due to forestry or urban areas will probably not be reflected sufficiently in mesoscale data turbulence.

12.3.3.11 Time series

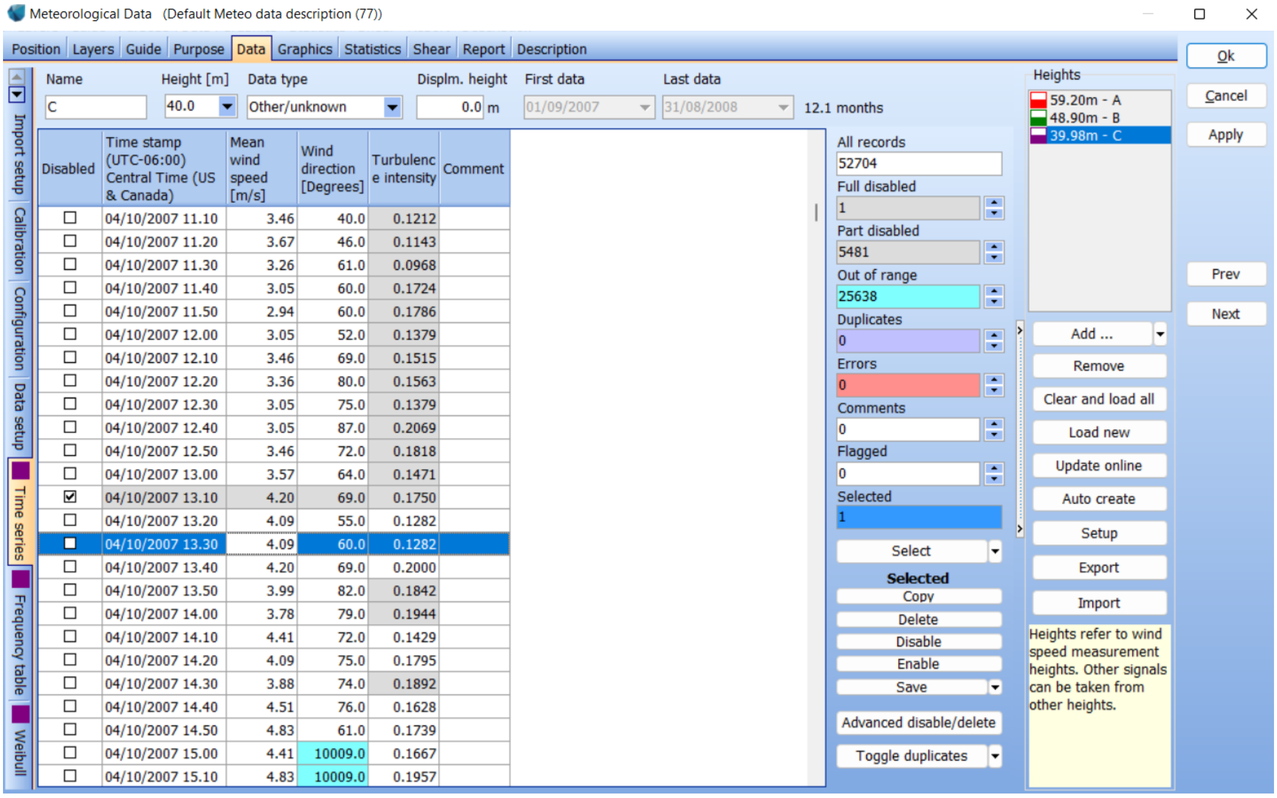


Figure 43 Time series data

With color background, data characteristics such as “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.

Select: can select “enabled” data – selection can also be performed “manually” by dragging the mouse in the list.

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

Enable/disable: can be performed manually in the list by checking the checkbox next to the time stamp, or the “Advanced” feature can be used.

Advanced disable/delete
This option allows to disable or delete the data according to different specified conditions.

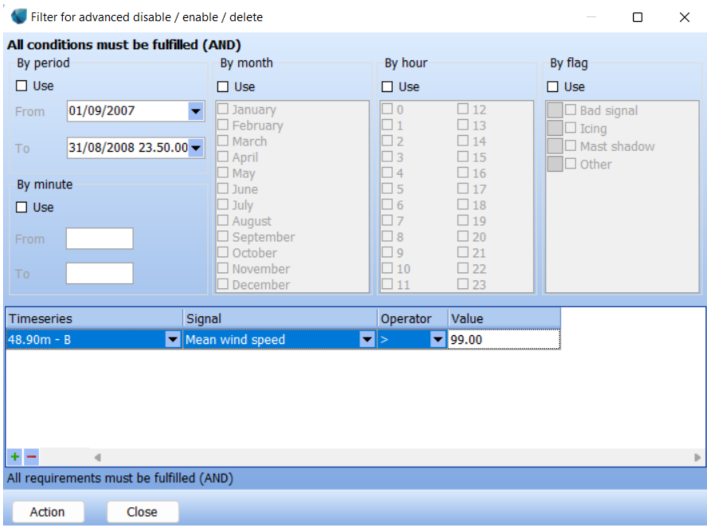


Figure 44 Advanced disable/enable/delete

Pressing the "Action" button (shown in Figure 44) gives access to the advanced disable/enable/delete feature for ALL heights (with same time stamp or within +/- 5 min.) that fulfill the conditions in the filter settings.

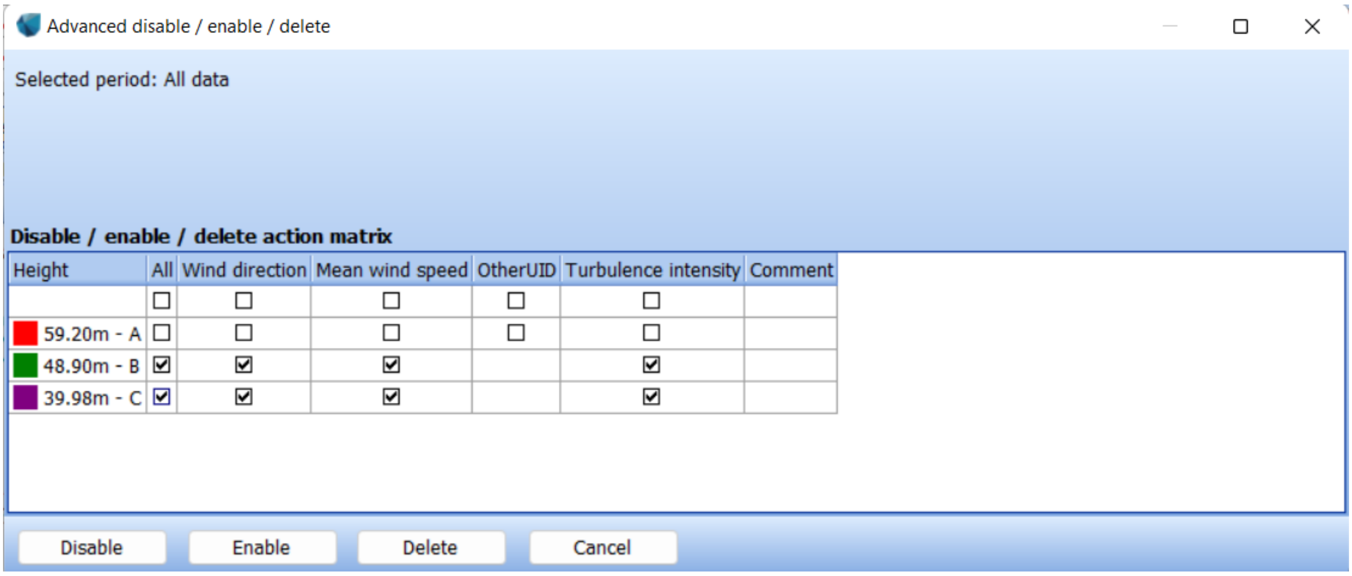


Figure 45 Advanced disable/enable/delete feature for ALL heights

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

12.3.3.12 Frequency table

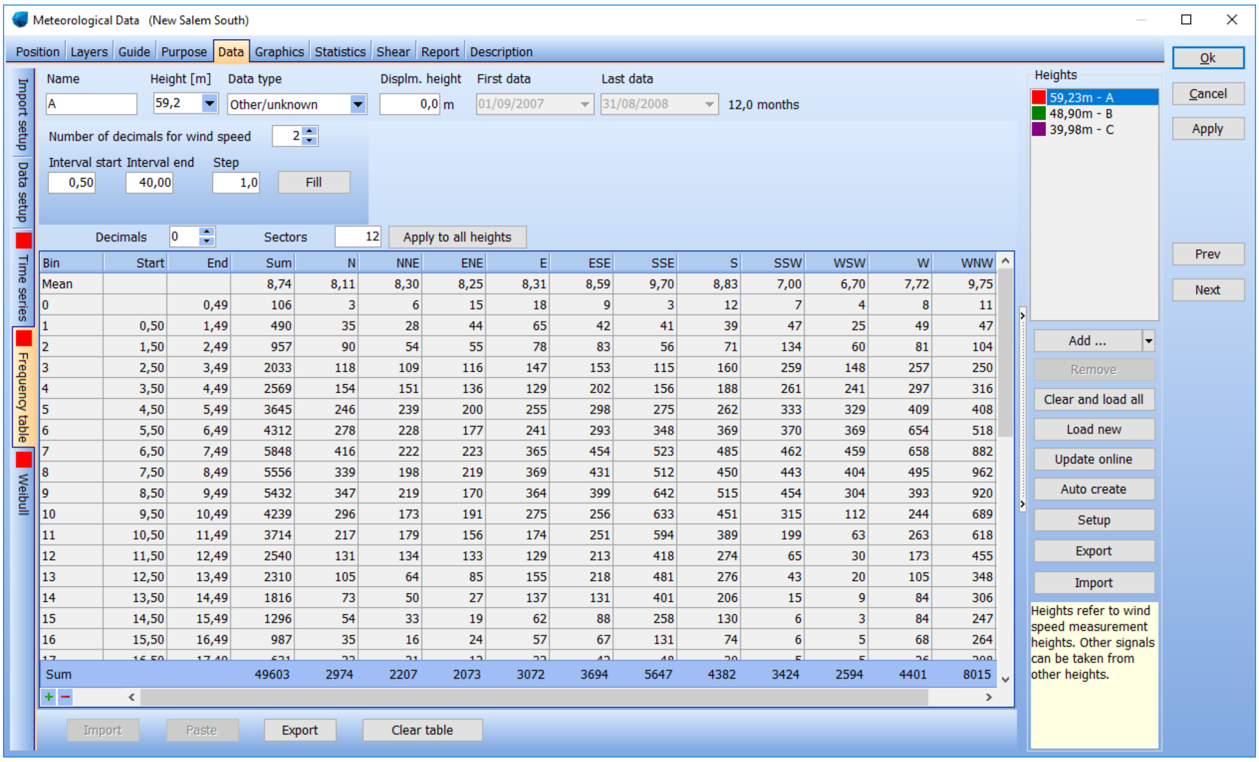


Figure 46 Data frequency table

12.3.3.13 Weibull

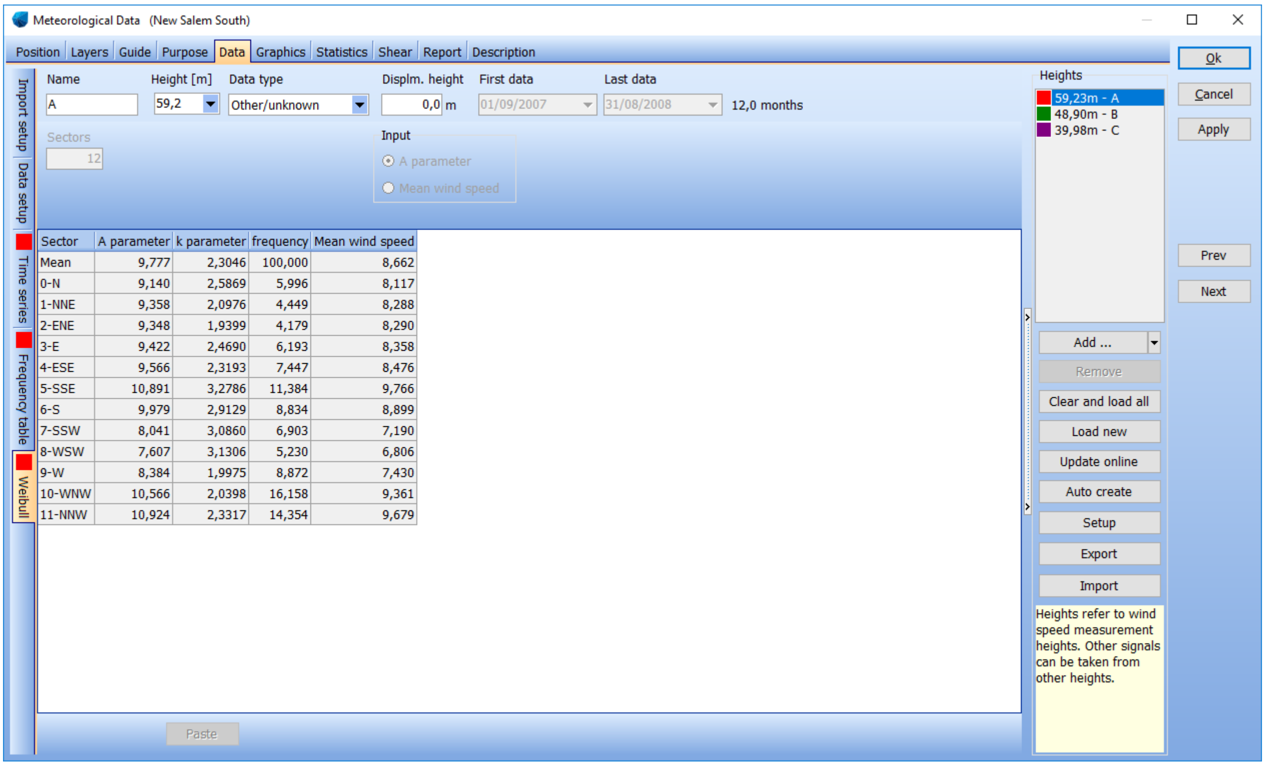


Figure 47 The Weibull fitted data.

The method for Weibull fit is energy weighted by the same method as DTU/Risø's WAsP uses, as described in the "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.

12.3.3.14 Turbulence

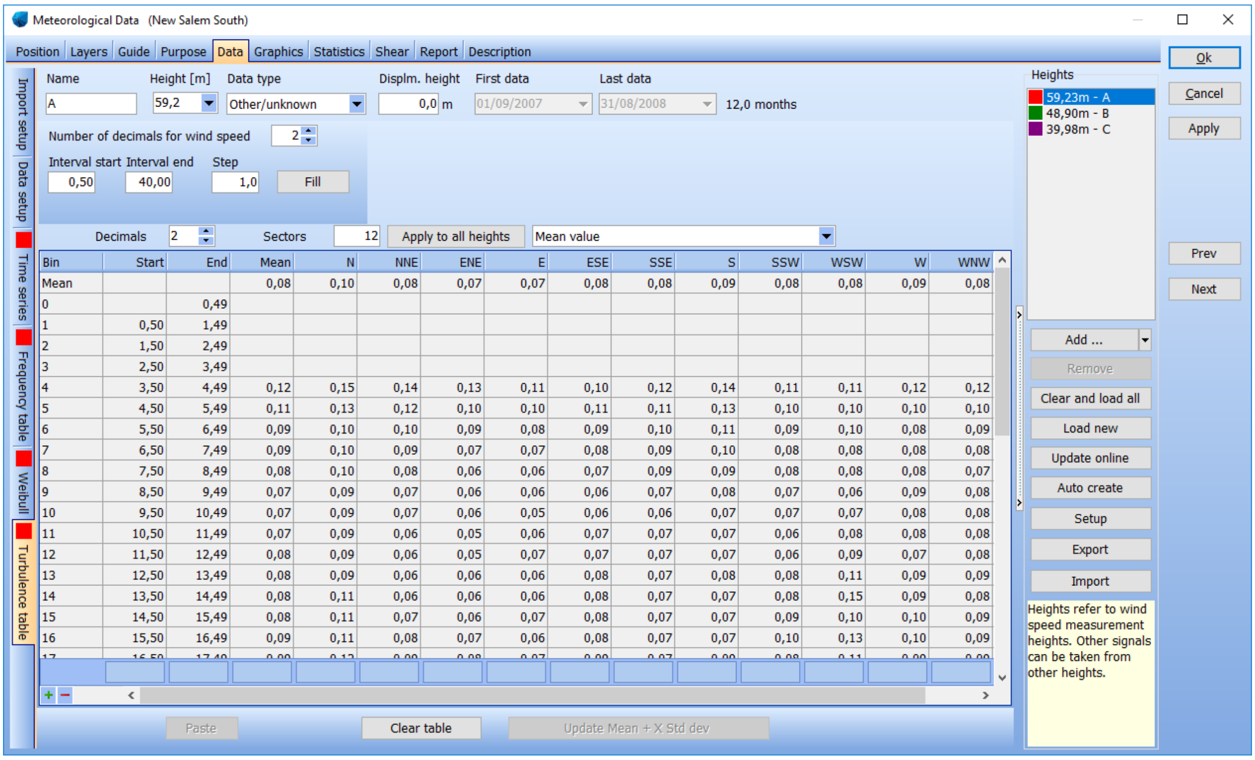


Figure 48 Turbulence data

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).

12.3.4 Graphics

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

The Graphics tab has 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 as the others should not need any further explanation.

12.3.4.1 Time series

Figure 49 The time series view

The time series view is efficient for finding erroneous data – simply right click in the graph at the start and end of erroneous data to disable that particular section. You can also add comments (right click) and these can be reported in a separate report. Zoom by mouse drag is possible as well.

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

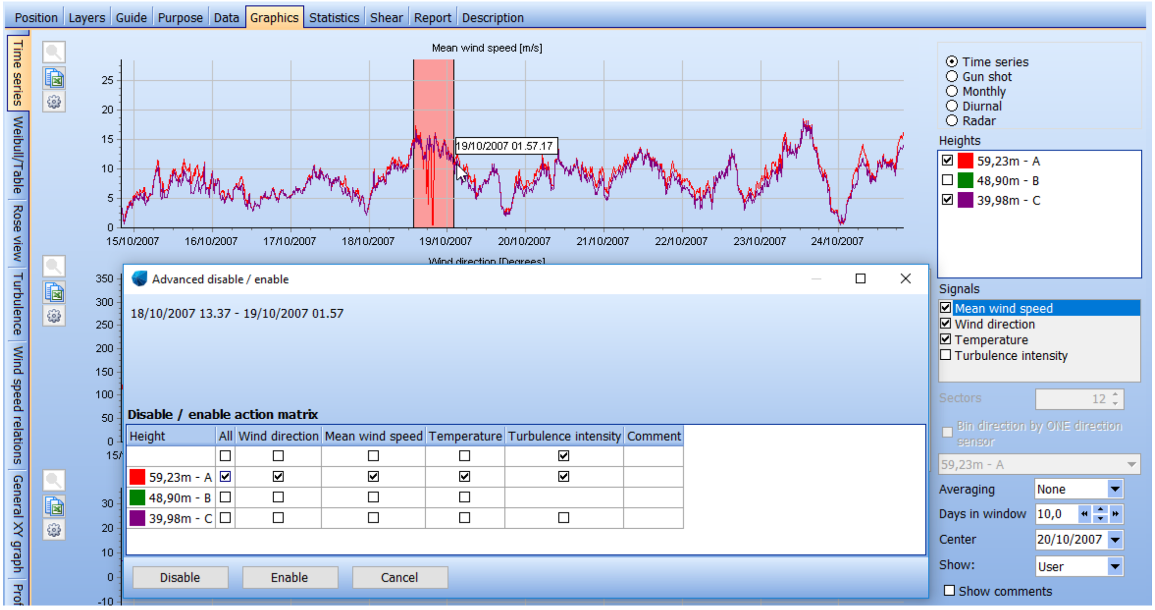


Figure 50 Disable by right-clicking and dragging the mouse along the time series graph.

Furthermore, data can also be highlighted with flags based on logical expressions. See section 12.6.

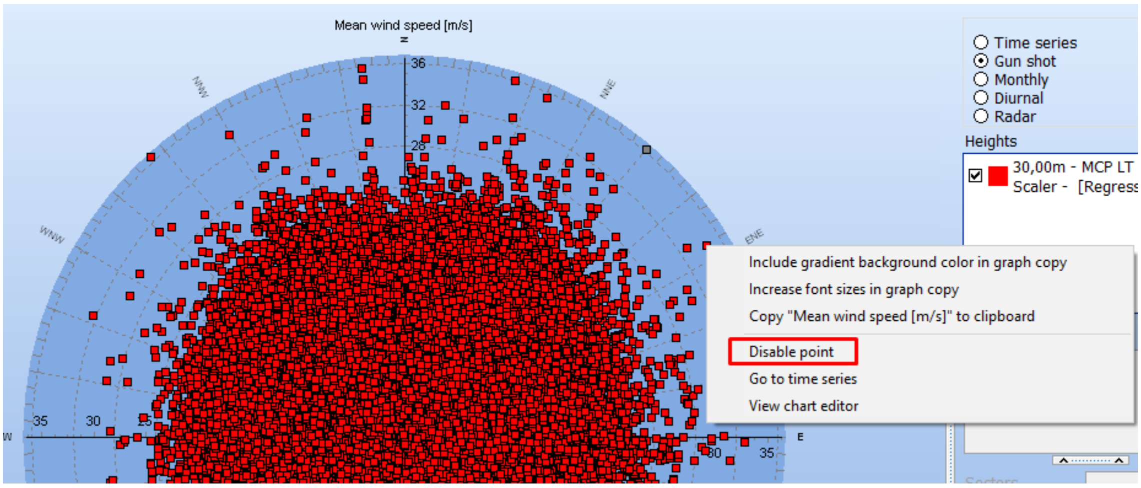


Figure 51 In point view graphs, disabling available by right click.

The graphs showing the individual data points, like the gun shot and X-Y graph, data points can be disabled by right click on the data point. Thereby obvious outliers can be eliminated.

12.3.4.2 Weibull/table

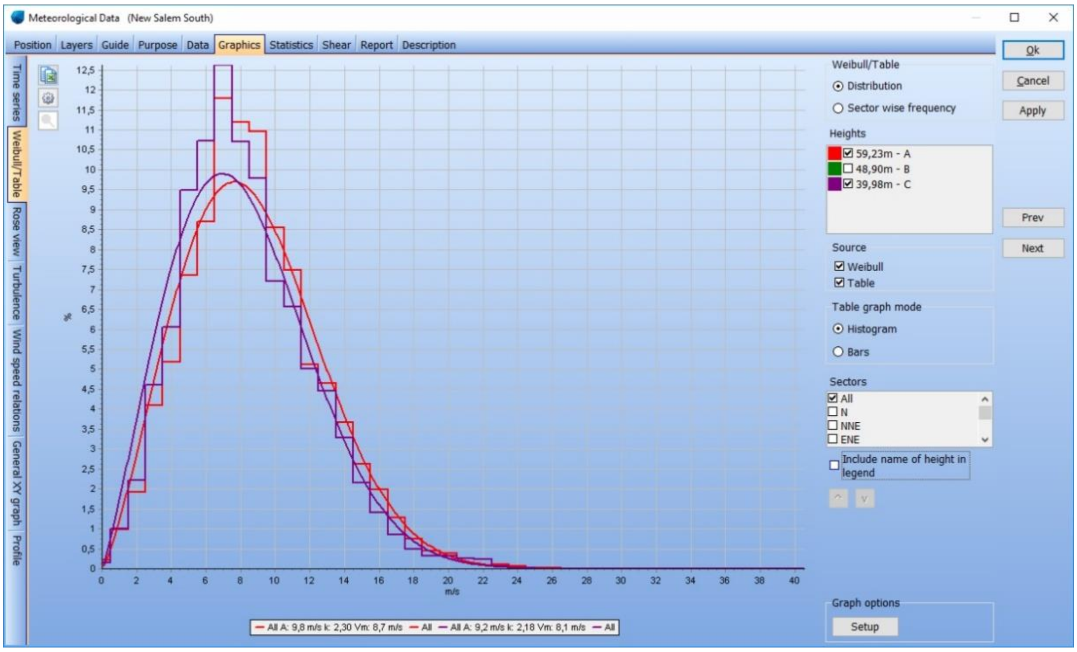


Figure 52 The Weibull/table graphs

The Weibull/table graphs are shown here for two heights. Note that the axis can be scaled manually by the “Edit graph” feature, activated by double clicking on the graph.

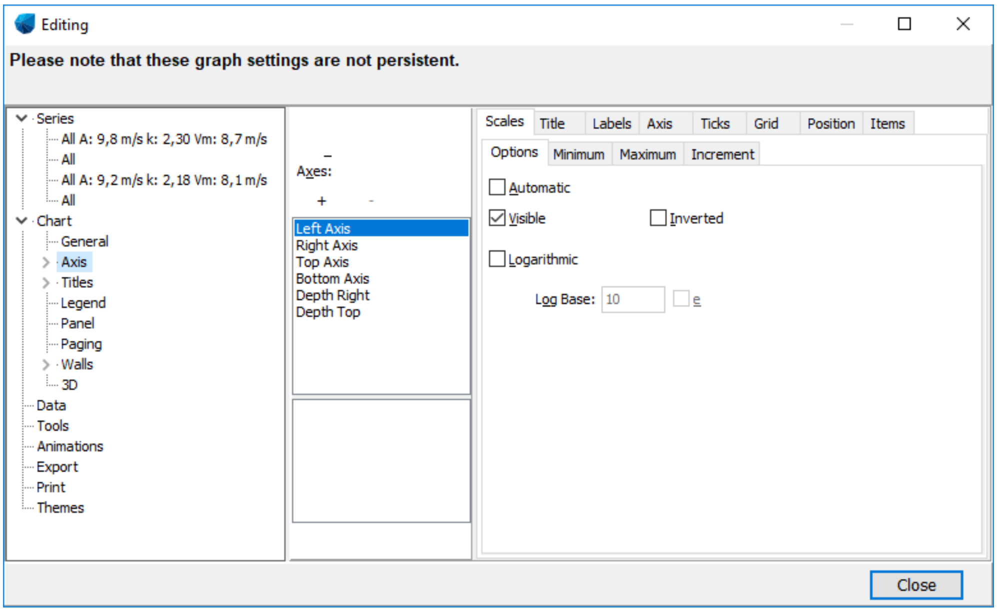


Figure 53 Advanced editing of the graph setup

Double clicking on a graph gives access to advanced editing of the graph setup. Above is shown the dialog box for manually adjusting the x-axis.

12.3.4.3 Turbulence

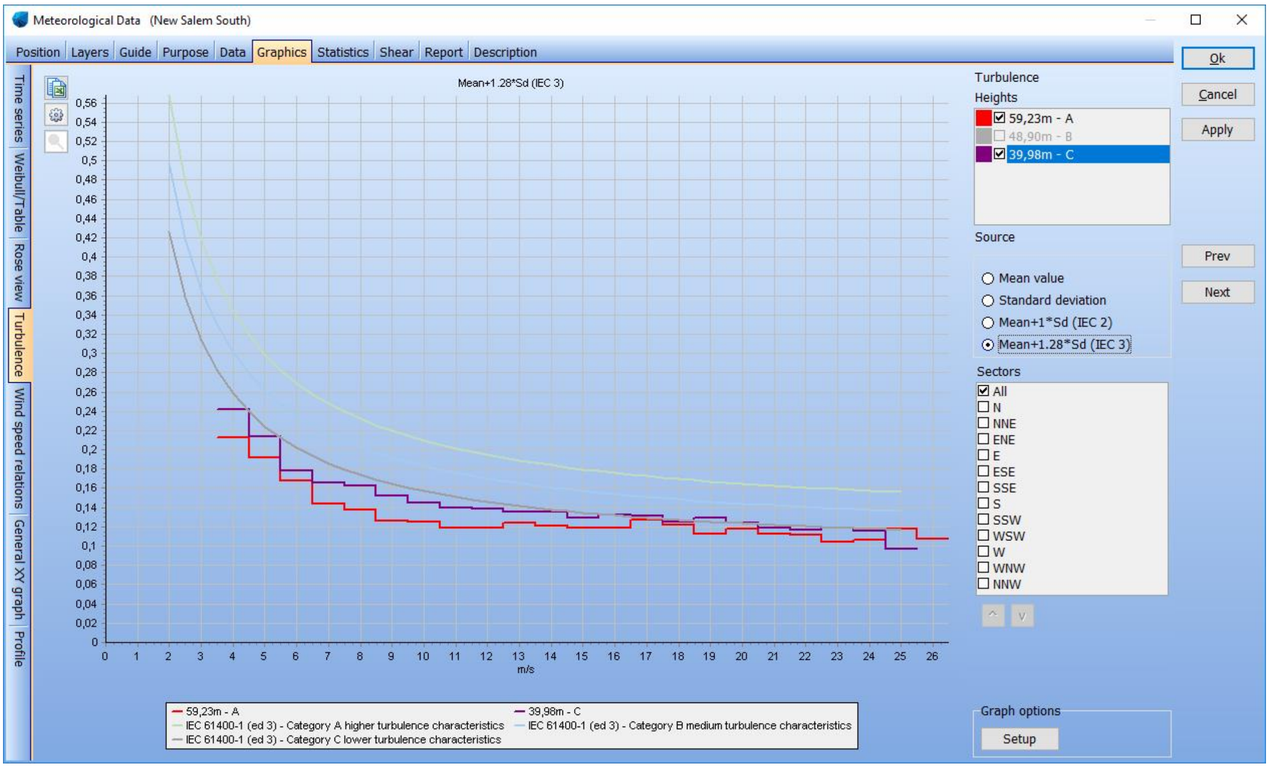


Figure 54 Turbulence graphs

The Turbulence graphs are shown above 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.

12.3.4.4 Rose view

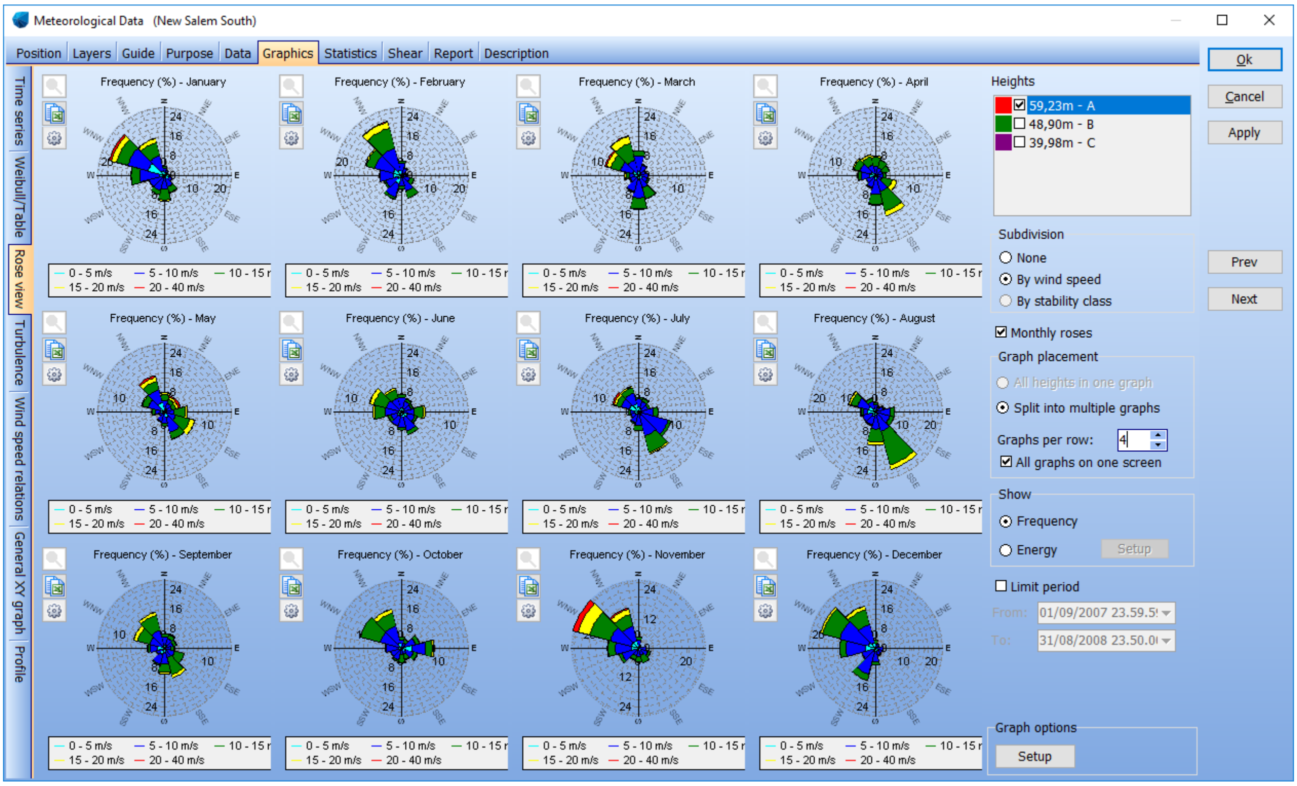


Figure 55 The Rose graphs

The Rose graphs are shown above for one height, displaying the option of month by month. The layout can be changed to contain a user-defined number of graphs at a time.

12.3.4.5 Wind speed difference

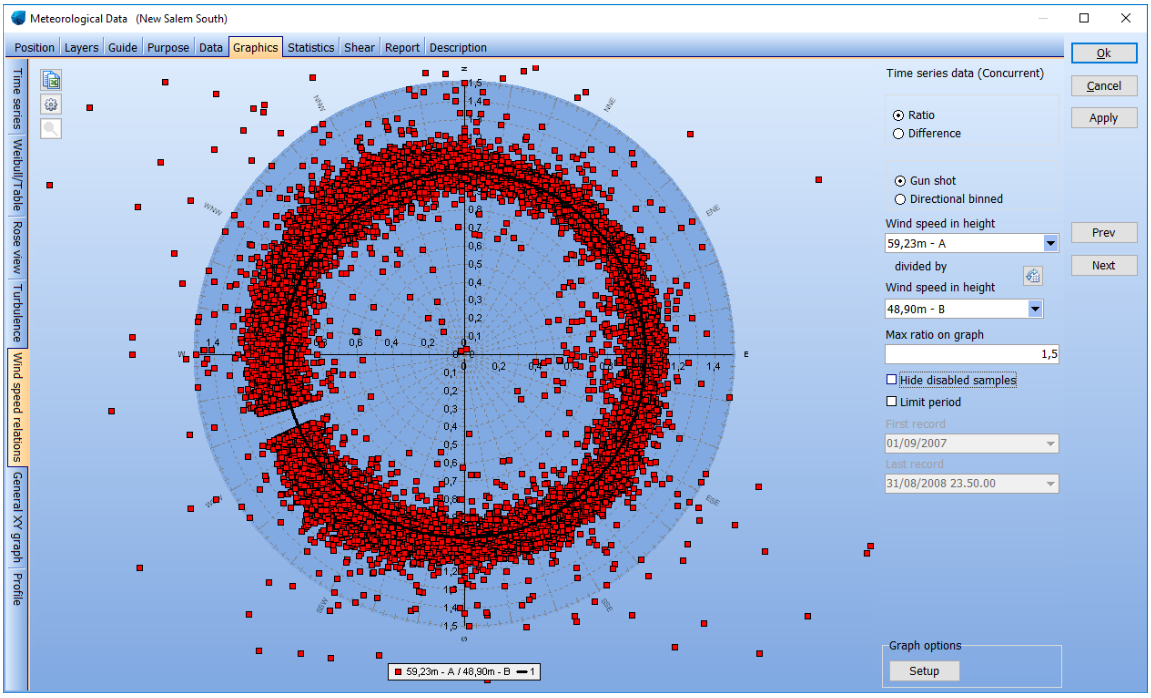


Figure 56 Difference plot

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, the difference as a ratio can be selected, and the data can be binned. Flags can be defined and shown on the graph as well.

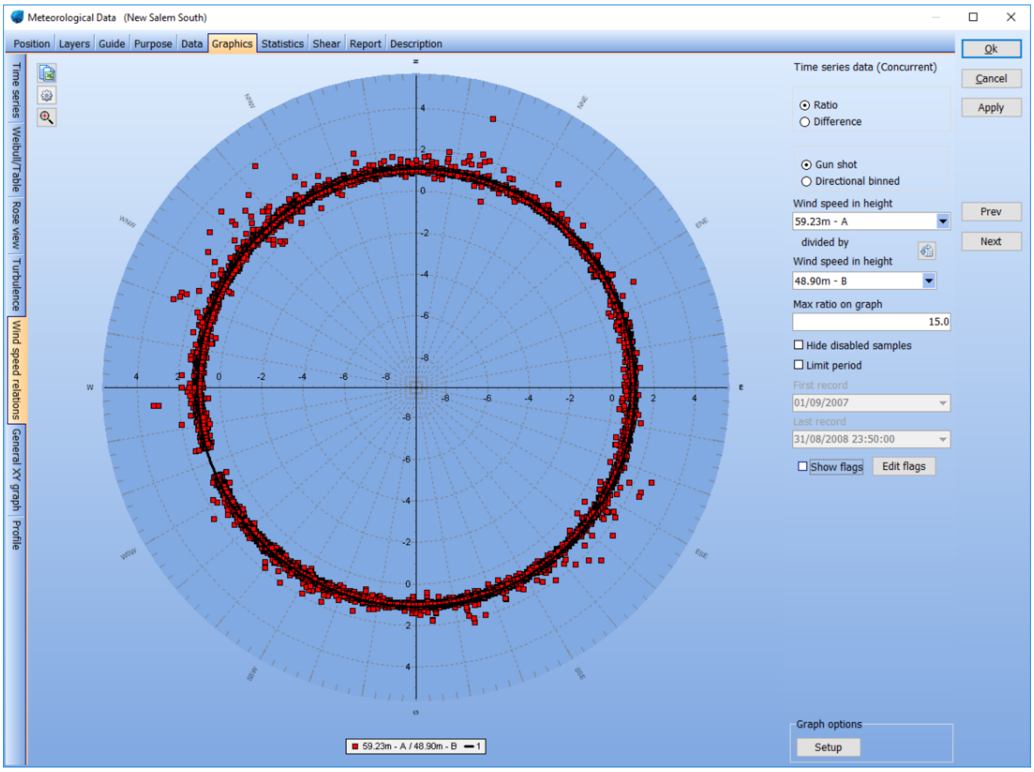


Figure 57 Showing wind speed ratio between two heights in a gun shot

12.3.4.6 General X-Y graph

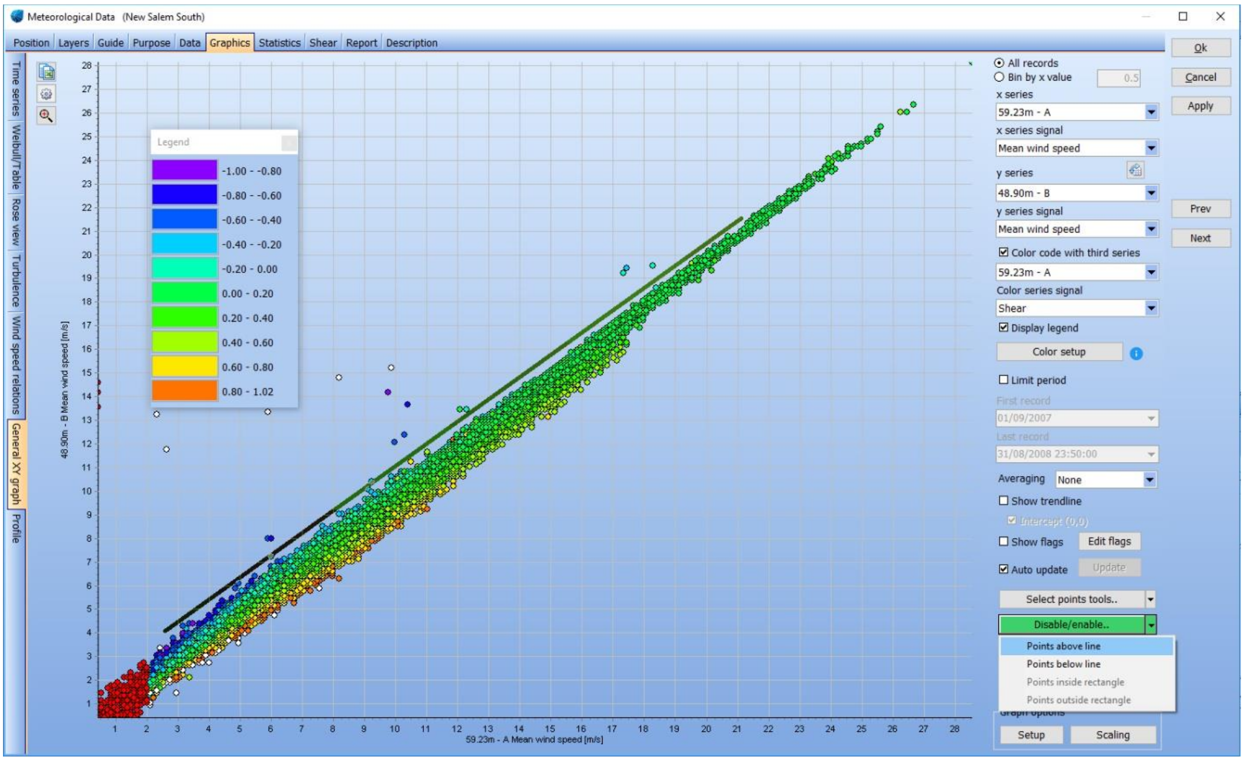


Figure 58 General X-Y graph

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 that point to disable or use the “disable/enable line” to disable a “block” of outliers in one operation. It is also possible to color code the data points with a third time series. Flags can also be created and shown on the XY graph (See section 12.6)

12.3.4.7 Profile

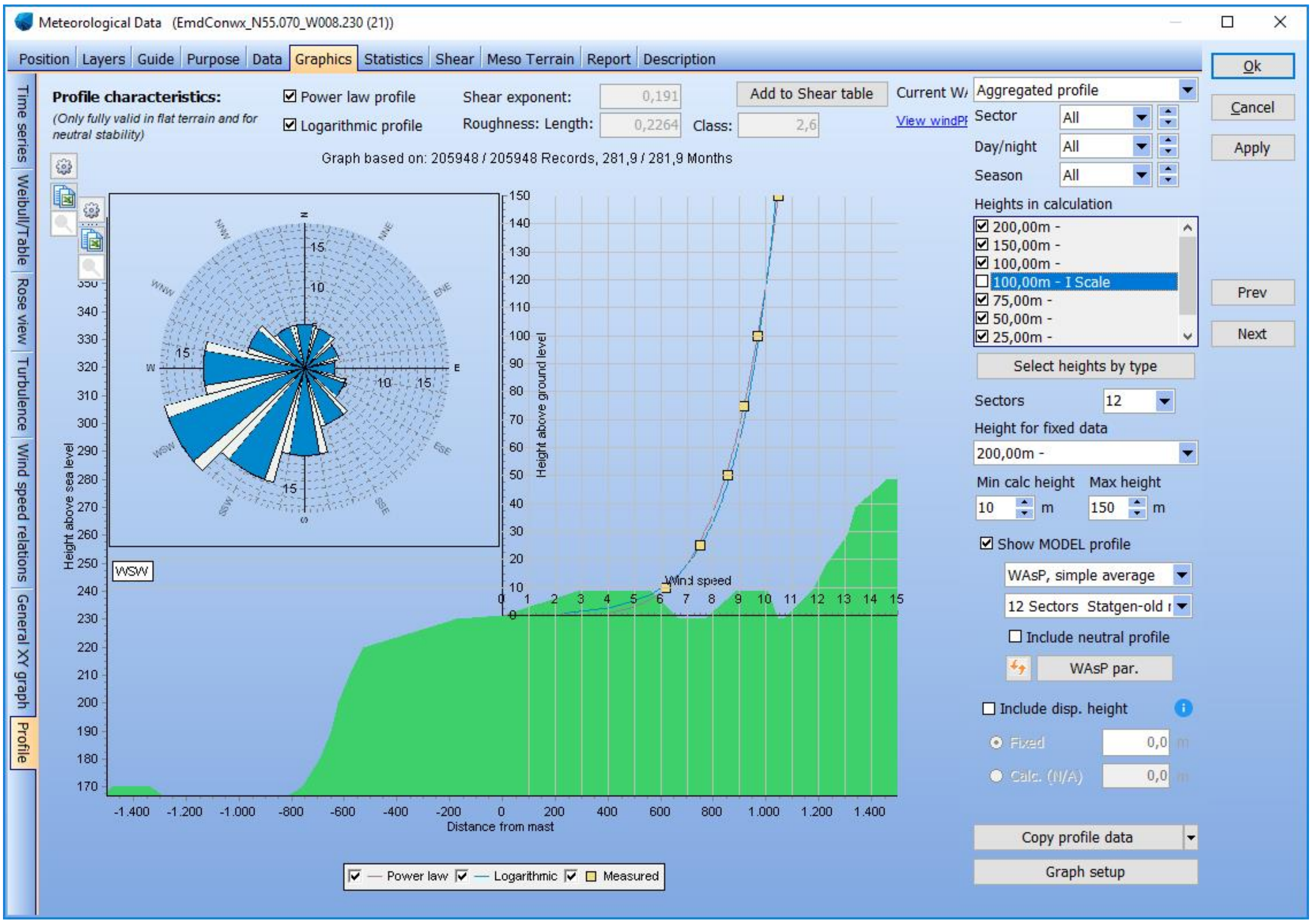


Figure 59 The profile viewer

The profile view shows the terrain profile as well as the wind speed profile. This is an efficient tool to analyse the data and compare to model calculations.

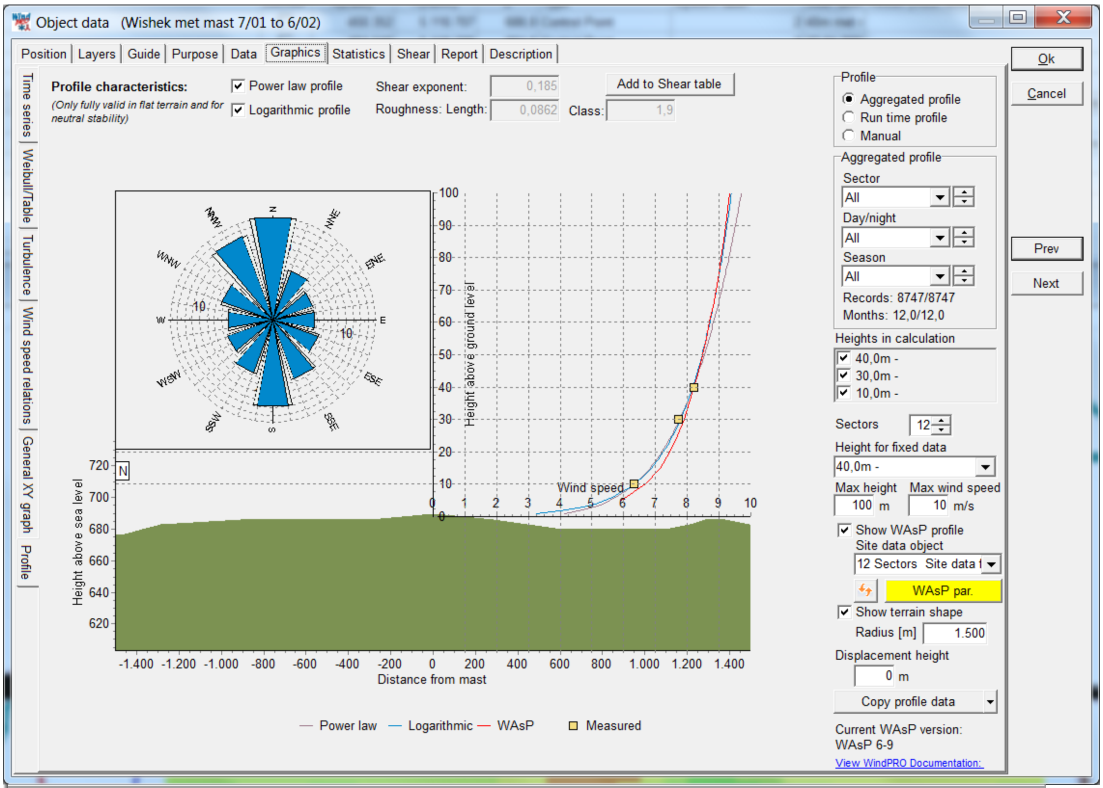
The profile viewer illustrates how the measured wind profile looks by showing the best fit of both power law profile and logarithmic profile. Also, a WAsP-calculated profile can be shown.

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 a 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, the power or logarithmic profiles can 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.

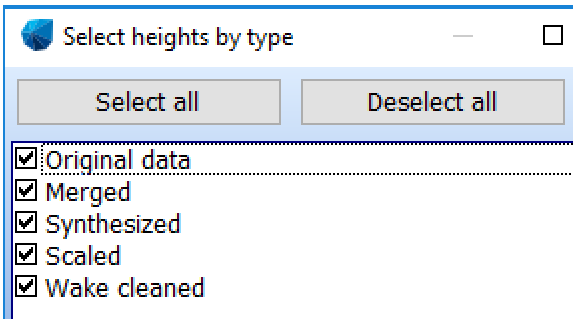


WAsP wind modelling (Non-default parameters: 1)				
Avg. offset over land from neutral at z=P2	0,01	0,25	0,11	0,11
Azimuth resolution in BZ model [°]	1	15	5	5
Decay-length for roughness area size	1000	1000000	10000	10000
Depth of daily variation over land	50	100	100	100
Depth of daily variation over 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

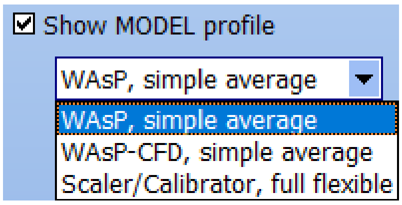
Figure 60 WAsP heat flux parameter changes shear profile

To illustrate the capability of the tool, above, one of the WAsP parameters is changed (Heat flux offset). This modifies the calculated WAsP profile (compare to previous graph).. 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 essential.

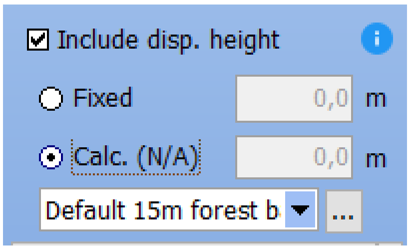
The profile view window holds many detailed options. To mention the more important ones:



Select height by type – here it is quicker to show e.g. only the original data, so the calculated shear values not are influenced by other “artificial” data. Or only to show wake cleaned to get the free wind flow expected shear.



Model profile – As well the WAsP based on annual average (by direction sector) as similar, but using WAsP-CFD, and finally the Scaler calculated profile.
The Scaler calculated profile has the advantage that it has a calculated time series “behind”, and thereby showing like day/night compares measures day data to calculated day data etc.
See more detailed review of this in paragraph: **Add Scaled height**



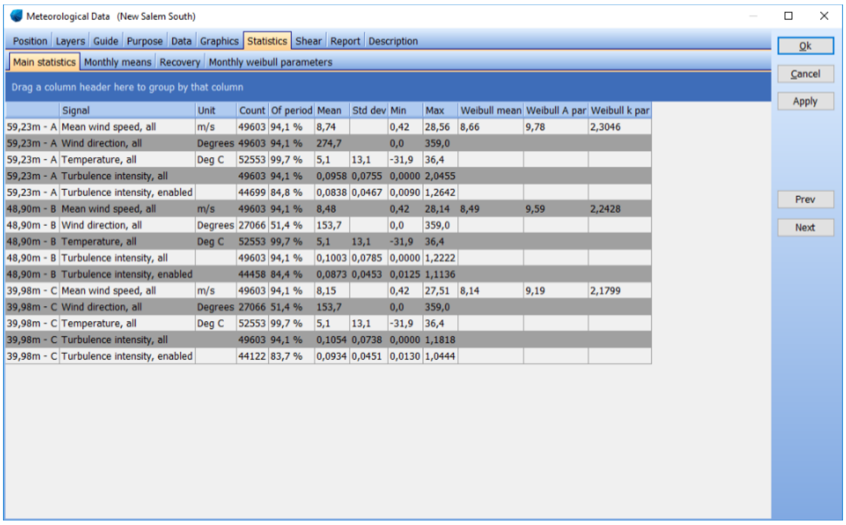
Displacement height – can be included by displacement height calculator giving individual heights by direction sector. Fully implemented from windPRO 3.2 and onwards to work with as Scaler as well as with WAsP. Also shown in terrain profile by direction sector – a very powerful visualization.

Copy profile data – includes information such as meteo object name and displacement height

12.3.5 Statistics

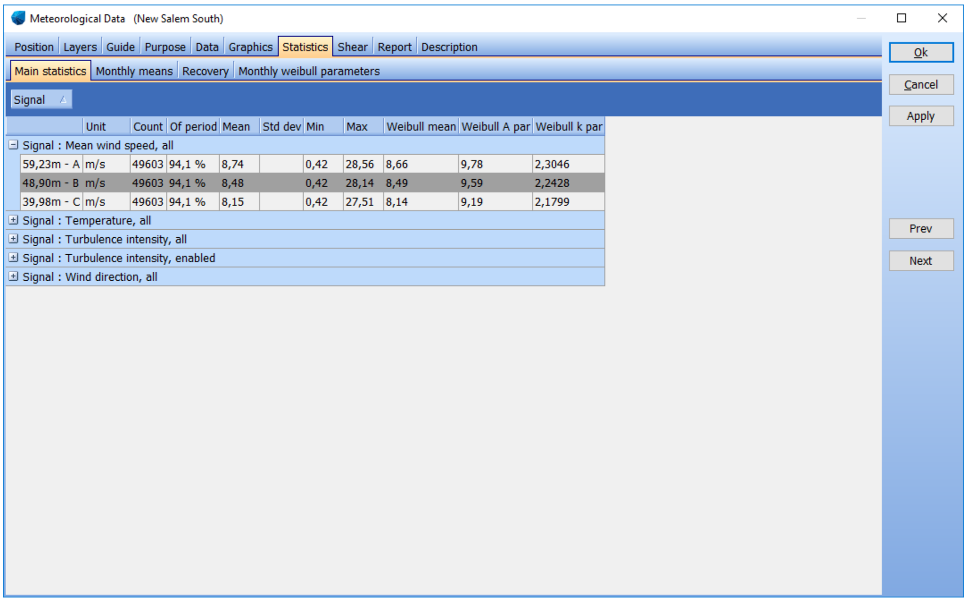
There are three different tabs for statistics:

- Main statistics
- Monthly means
- Availability (data recovery)



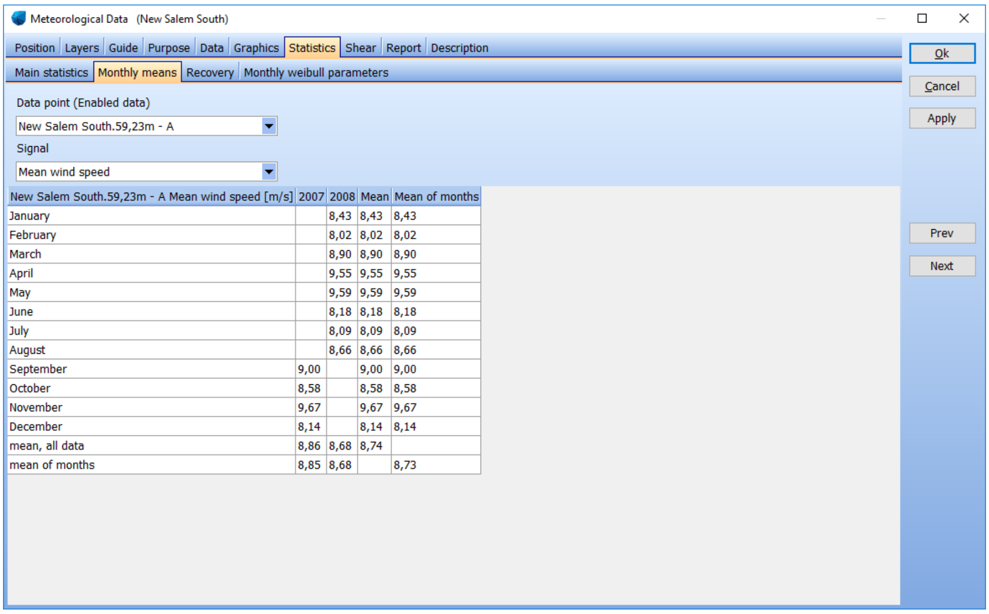
	Signal	Unit	Count	Of period	Mean	Std dev	Min	Max	Weibull mean	Weibull A par	Weibull k par
59,23m - A	Mean wind speed, all	m/s	49603	94,1 %	8,74		0,42	28,56	8,66	9,78	2,3046
59,23m - A	Wind direction, all	Degrees	49603	94,1 %	274,7		0,0	359,0			
59,23m - A	Temperature, all	Deg C	52553	99,7 %	5,1	13,1	-31,9	36,4			
59,23m - A	Turbulence intensity, all		49603	94,1 %	0,0958	0,0755	0,0000	2,0455			
59,23m - A	Turbulence intensity, enabled		44699	84,8 %	0,0838	0,0467	0,0090	1,2642			
48,90m - B	Mean wind speed, all	m/s	49603	94,1 %	8,48		0,42	28,14	8,49	9,59	2,2428
48,90m - B	Wind direction, all	Degrees	27066	51,4 %	153,7		0,0	359,0			
48,90m - B	Temperature, all	Deg C	52553	99,7 %	5,1	13,1	-31,9	36,4			
48,90m - B	Turbulence intensity, all		49603	94,1 %	0,1003	0,0785	0,0000	1,2222			
48,90m - B	Turbulence intensity, enabled		44458	84,4 %	0,0873	0,0453	0,0125	1,1136			
39,98m - C	Mean wind speed, all	m/s	49603	94,1 %	8,15		0,42	27,51	8,14	9,19	2,1799
39,98m - C	Wind direction, all	Degrees	27066	51,4 %	153,7		0,0	359,0			
39,98m - C	Temperature, all	Deg C	52553	99,7 %	5,1	13,1	-31,9	36,4			
39,98m - C	Turbulence intensity, all		49603	94,1 %	0,1054	0,0738	0,0000	1,1818			
39,98m - C	Turbulence intensity, enabled		44122	83,7 %	0,0934	0,0451	0,0130	1,0444			

Figure 61 Raw views of main statistics.



	Unit	Count	Of period	Mean	Std dev	Min	Max	Weibull mean	Weibull A par	Weibull k par
Signal : Mean wind speed, all										
59,23m - A	m/s	49603	94,1 %	8,74		0,42	28,56	8,66	9,78	2,3046
48,90m - B	m/s	49603	94,1 %	8,48		0,42	28,14	8,49	9,59	2,2428
39,98m - C	m/s	49603	94,1 %	8,15		0,42	27,51	8,14	9,19	2,1799
Signal : Temperature, all										
Signal : Turbulence intensity, all										
Signal : Turbulence intensity, enabled										
Signal : Wind direction, all										

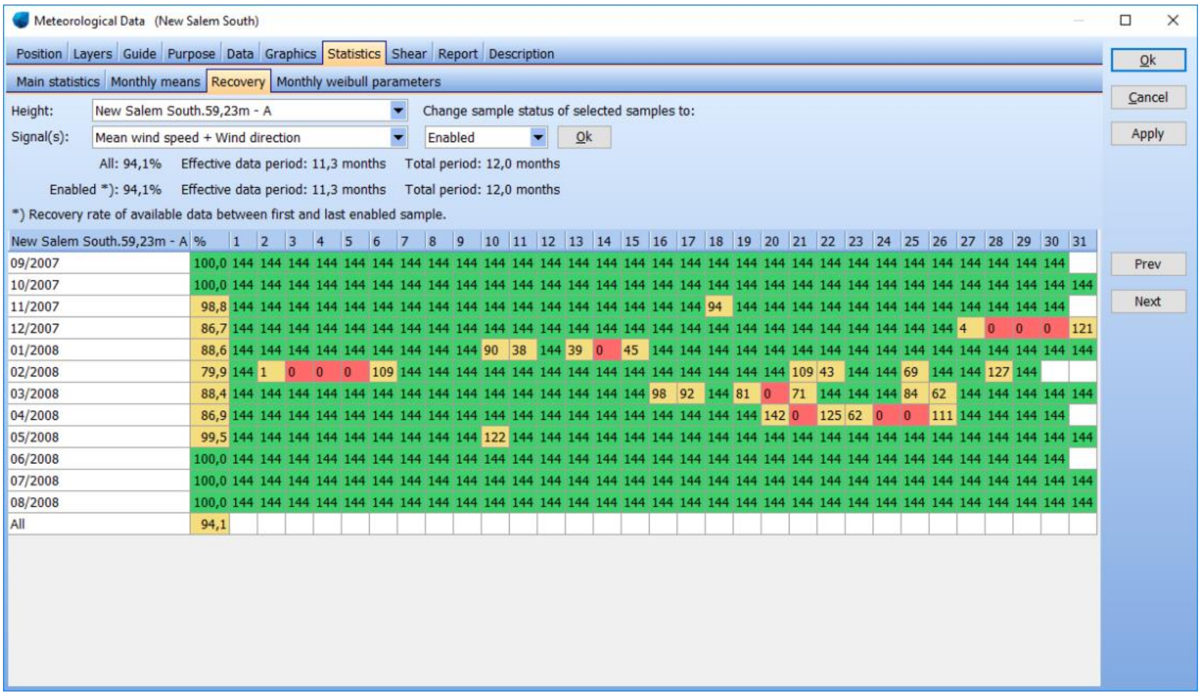
Figure 62 Dragging "Signal" up into the header bar area change views



New Salem South.59,23m - A Mean wind speed [m/s]	2007	2008	Mean	Mean of months
January		8,43	8,43	8,43
February		8,02	8,02	8,02
March		8,90	8,90	8,90
April		9,55	9,55	9,55
May		9,59	9,59	9,59
June		8,18	8,18	8,18
July		8,09	8,09	8,09
August		8,66	8,66	8,66
September	9,00		9,00	9,00
October	8,58		8,58	8,58
November	9,67		9,67	9,67
December	8,14		8,14	8,14
mean, all data	8,86	8,68	8,74	
mean of months	8,85	8,68		8,73

Figure 63 Monthly means

Monthly means can be shown signal by signal – by right clicking, the tables can be copied to the clipboard and easily integrated into documentation.



New Salem South.59,23m - A	%	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
09/2007	100,0	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	
10/2007	100,0	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144
11/2007	98,8	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	94	144	144	144	144	144	144	144	144	144	144	144	144	
12/2007	86,7	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	4	0	0	0	121
01/2008	88,6	144	144	144	144	144	144	144	144	144	90	38	144	39	0	45	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144
02/2008	79,9	144	1	0	0	0	109	144	144	144	144	144	144	144	144	144	144	144	144	144	144	109	43	144	144	69	144	144	127	144		
03/2008	88,4	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	98	92	144	81	0	71	144	144	144	84	62	144	144	144	144	144
04/2008	86,9	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	142	0	125	62	0	0	111	144	144	144	144	
05/2008	99,5	144	144	144	144	144	144	144	144	144	122	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144
06/2008	100,0	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	
07/2008	100,0	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144
08/2008	100,0	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144
All	94,1																															

Figure 64 Data recovery view

Data recovery can be shown height by height and for a signal alone or a combination of two signals. If both wind speed and direction are selected, the data is only considered available if both signals are available. The day is shown in the horizontal axis and the month and year on the vertical. The table shows the percentage of available data in the first column ("%") and then the number of samples enabled per day ("1","2","3", etc).

Color coding gives a fast overview of the availability. Green shows that no samples are missing nor disabled. The cells in red show that all samples are missing or disabled, and yellow is in between.
The effective data period equals the total period x recovery rate.
The results presented for "Enabled*) data is relative to the enabled period. In this case, if data is disabled at the start or the end of the measurements, the recovery is calculated between the first and last enabled data.

Change sample status of selected samples allows to select data form the recovery table and change its status to enabled/disabled.

12.3.6 Shear

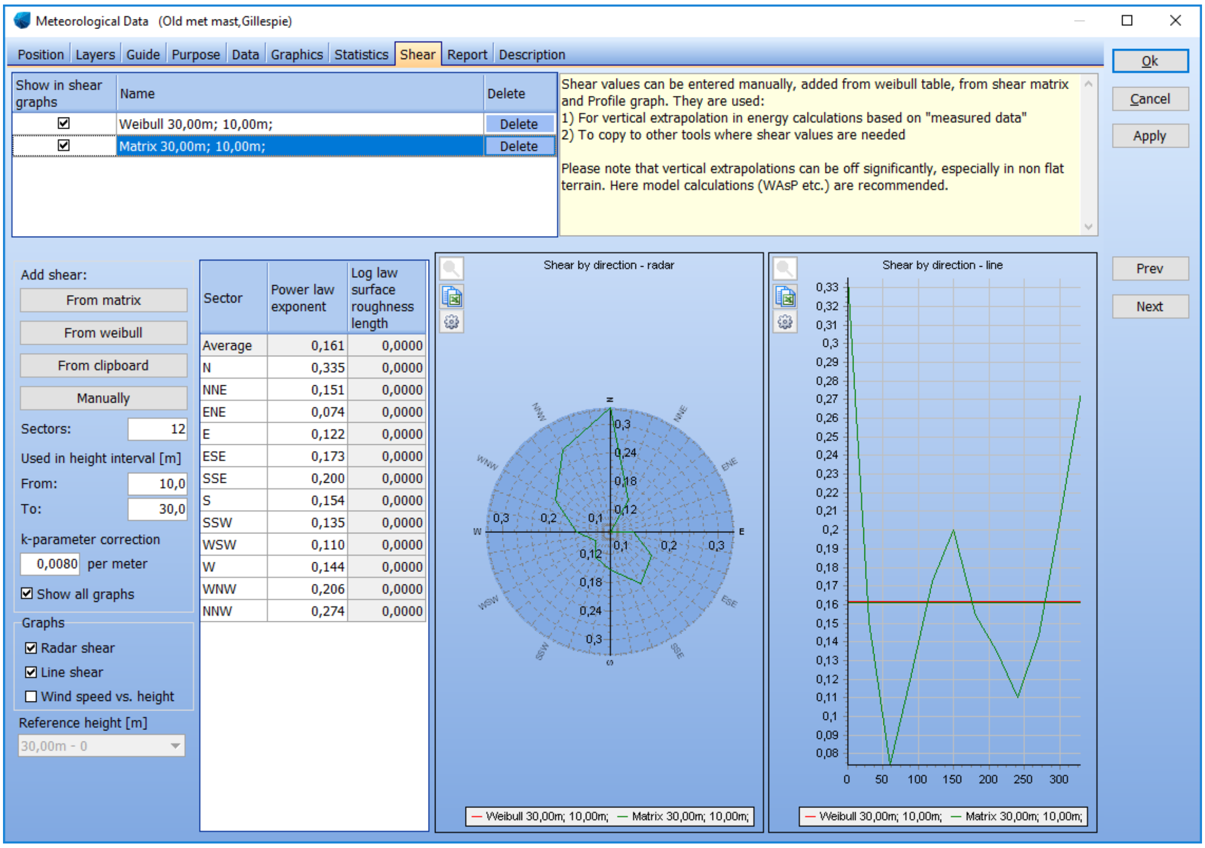
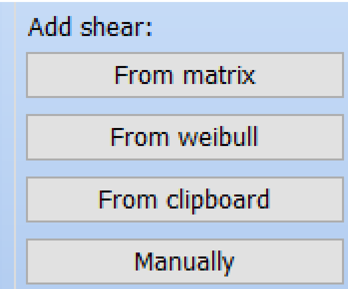


Figure 65 Shear for simple METEO calculations and evaluations

In the graph above, two different shear calculation options are tested against each other.
When doing a METEO AEP calculation based on Meteo object, the shear tables available can be selected as input for the calculation.

Shear can either be manual input or calculated based on more calculation variants:



From matrix is probably the most robust, and this also adds value analyzing the data. Below an example of a shear matrix calculation:

Shear values

Direction	All				
<0	Negative!	0.2-0.3	Normal, high		
0-0.1	Extreme low	0.3-0.4	Very high		
0.1-0.2	Normal, low	>0.4	Extreme high		

Shear mean | Count

Diurnal	jan	feb	mar	apr	maj	jun	jul	aug	sep	okt	nov	dec	Year
00	0,16	0,15	0,18	0,17	0,18	0,22	0,20	0,21	0,24	0,20	0,17	0,16	0,19
01	0,16	0,17	0,18	0,19	0,19	0,19	0,19	0,22	0,25	0,21	0,16	0,16	0,19
02	0,15	0,16	0,19	0,21	0,21	0,20	0,20	0,21	0,25	0,20	0,17	0,17	0,19
03	0,15	0,16	0,18	0,21	0,20	0,20	0,19	0,23	0,24	0,19	0,17	0,16	0,19
04	0,15	0,17	0,18	0,21	0,20	0,21	0,20	0,22	0,25	0,18	0,16	0,16	0,19
05	0,15	0,18	0,18	0,21	0,18	0,21	0,19	0,24	0,23	0,18	0,18	0,17	0,19
06	0,16	0,17	0,16	0,18	0,16	0,18	0,18	0,22	0,22	0,18	0,18	0,17	0,17
07	0,17	0,16	0,16	0,17	0,15	0,16	0,15	0,18	0,21	0,17	0,17	0,19	0,16
08	0,15	0,17	0,16	0,17	0,12	0,14	0,14	0,14	0,19	0,17	0,17	0,17	0,16
09	0,14	0,17	0,14	0,16	0,11	0,13	0,13	0,12	0,14	0,16	0,16	0,15	0,15
10	0,14	0,17	0,13	0,14	0,11	0,13	0,13	0,11	0,14	0,15	0,14	0,14	0,14
11	0,16	0,15	0,13	0,13	0,09	0,13	0,11	0,11	0,13	0,15	0,13	0,15	0,14
12	0,14	0,15	0,14	0,13	0,09	0,13	0,12	0,10	0,13	0,14	0,14	0,14	0,14
13	0,15	0,15	0,12	0,13	0,09	0,12	0,12	0,11	0,14	0,13	0,15	0,14	0,13
14	0,17	0,17	0,14	0,12	0,10	0,12	0,13	0,11	0,13	0,15	0,14	0,14	0,13
15	0,15	0,15	0,14	0,11	0,09	0,12	0,12	0,11	0,13	0,16	0,13	0,16	0,14
16	0,15	0,16	0,15	0,13	0,10	0,13	0,12	0,11	0,16	0,16	0,15	0,16	0,14
17	0,16	0,16	0,15	0,14	0,09	0,12	0,14	0,13	0,16	0,17	0,15	0,17	0,14
18	0,17	0,16	0,17	0,17	0,10	0,13	0,15	0,13	0,20	0,19	0,15	0,17	0,15
19	0,15	0,16	0,18	0,18	0,13	0,15	0,14	0,18	0,22	0,17	0,16	0,17	0,17
20	0,16	0,16	0,19	0,19	0,18	0,15	0,20	0,21	0,22	0,16	0,16	0,17	0,18
21	0,16	0,15	0,18	0,19	0,18	0,20	0,22	0,21	0,24	0,18	0,16	0,18	0,19
22	0,17	0,15	0,17	0,18	0,19	0,21	0,20	0,19	0,23	0,18	0,17	0,16	0,18
23	0,15	0,16	0,18	0,19	0,19	0,21	0,20	0,21	0,24	0,19	0,17	0,15	0,19
All	0,15	0,16	0,16	0,16	0,14	0,16	0,16	0,16	0,19	0,17	0,16	0,16	0,16

Figure 66 Seasonal and diurnal shear values for all direction sectors

The shear calculation is binned by direction, season and hour. The bin sizes can be specified.
The shear matrix is partly a good tool to understand the wind on the site, partly to identify data problems. Normally low shear will be seen mid-day in summer, where the sun heats up the ground and creates turbulence which gives low shear. At this site this is not seen so clearly due to low measurement heights and a relatively cold climate.

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

The shear calculations based on Weibull method use the Weibull mean wind speed. Only direction from one height is used, so the mean Weibull wind speed used is based on concurrent time records. This is a change implemented first in windPRO v2.7, where the calculation, previously, was based on each height's own direction sensor, if present. This change was found to be more correct and robust as direction sensor problems were often seen, leading to unrealistic shears in some directions, and leading to unrealistic results using the shears.

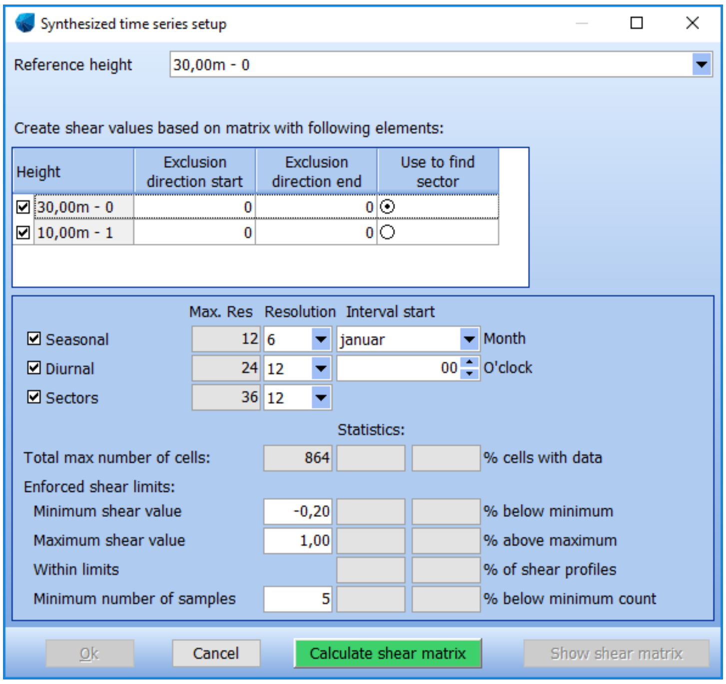


Figure 67 Shear calculated binned (matrix method)

Shear calculation based on the Matrix method only using one direction sensor. There are settings that ensure unrealistic values are omitted. In bins with too few data, substitution is performed, by taking the calculated annual value within the same hour and direction bin.

12.3.7 Mesoscale terrain

Another addition is the tab "Mesores", which contains the EMD-WRF mesoscale result data:

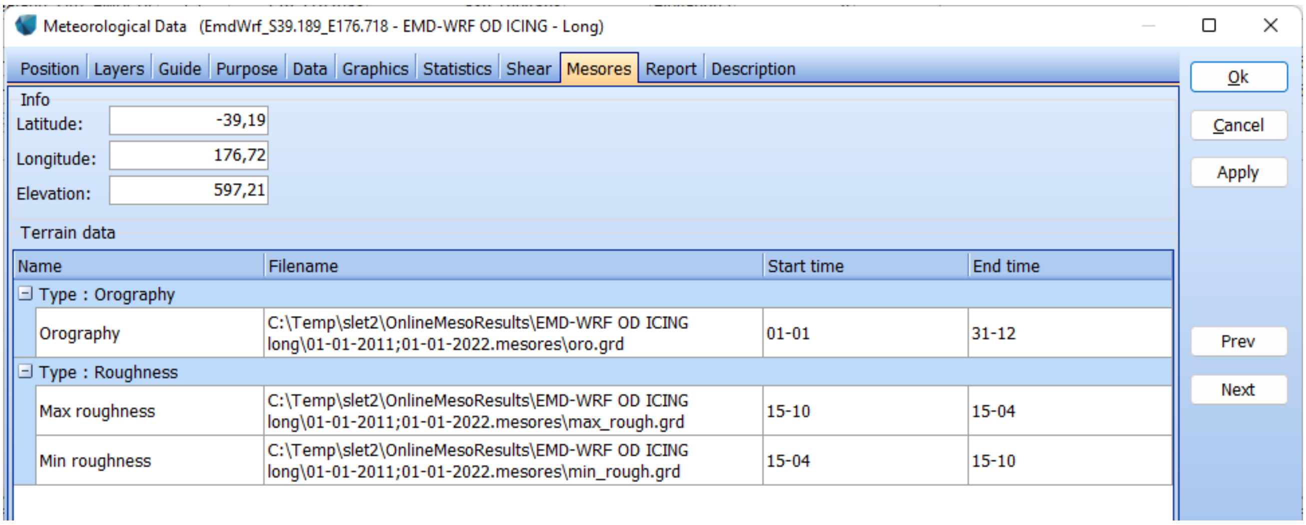
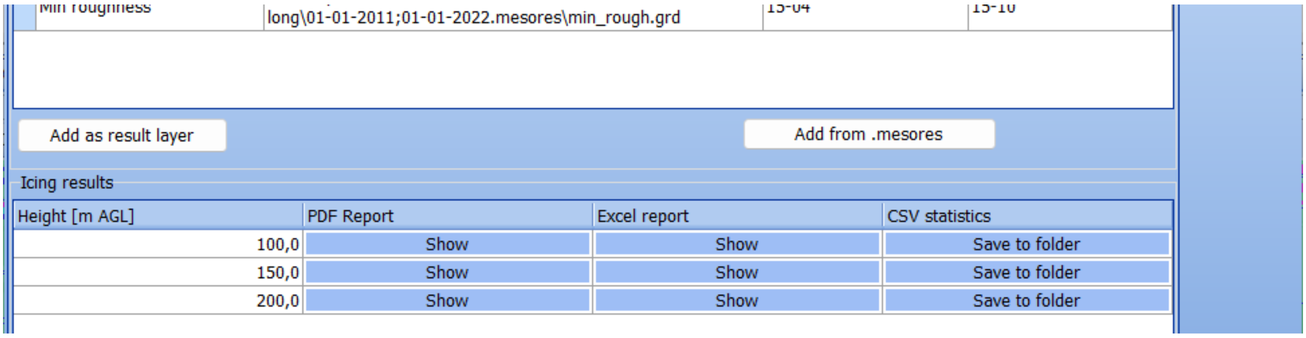


Figure 68 Mesoscale terrain in Meteo object

Here, the mesoscale terrain is included when downloading EMD mesoscale data. **Note**: there are two different roughness files - a min. (winter) and a max. (summer). The mesoscale model uses seasonal varying surface roughness. When "lifting off" the mesoscale roughness, the min. by default is used all year. In the user defined SCALER settings, the max can be used or even a seasonally dependent choice.

From windPRO 3.6 onwards it is possible to order and download EMD-WRF ICING calculations. This establishes a meteo object with regular EMD-WRF time series including additional parameters such as icing intensity, ice load, instrumental icing and meteorological icing. If at least 10 seasons are included in the icing calculatuion, additional reports are included as well. These can be accessed in the lower part of the window:



The mesoscale terrain map and icing maps can be added as a result layer by clicking “Add as result layer”.

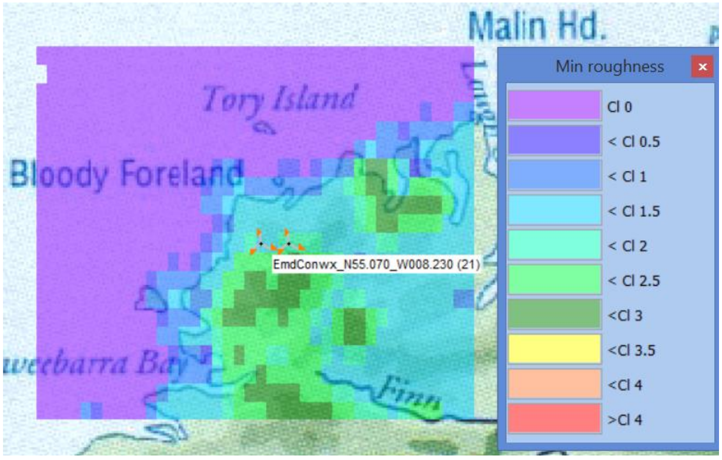


Figure 69 Mesoscale minimum roughness in result layer shown on map

12.3.8 Report

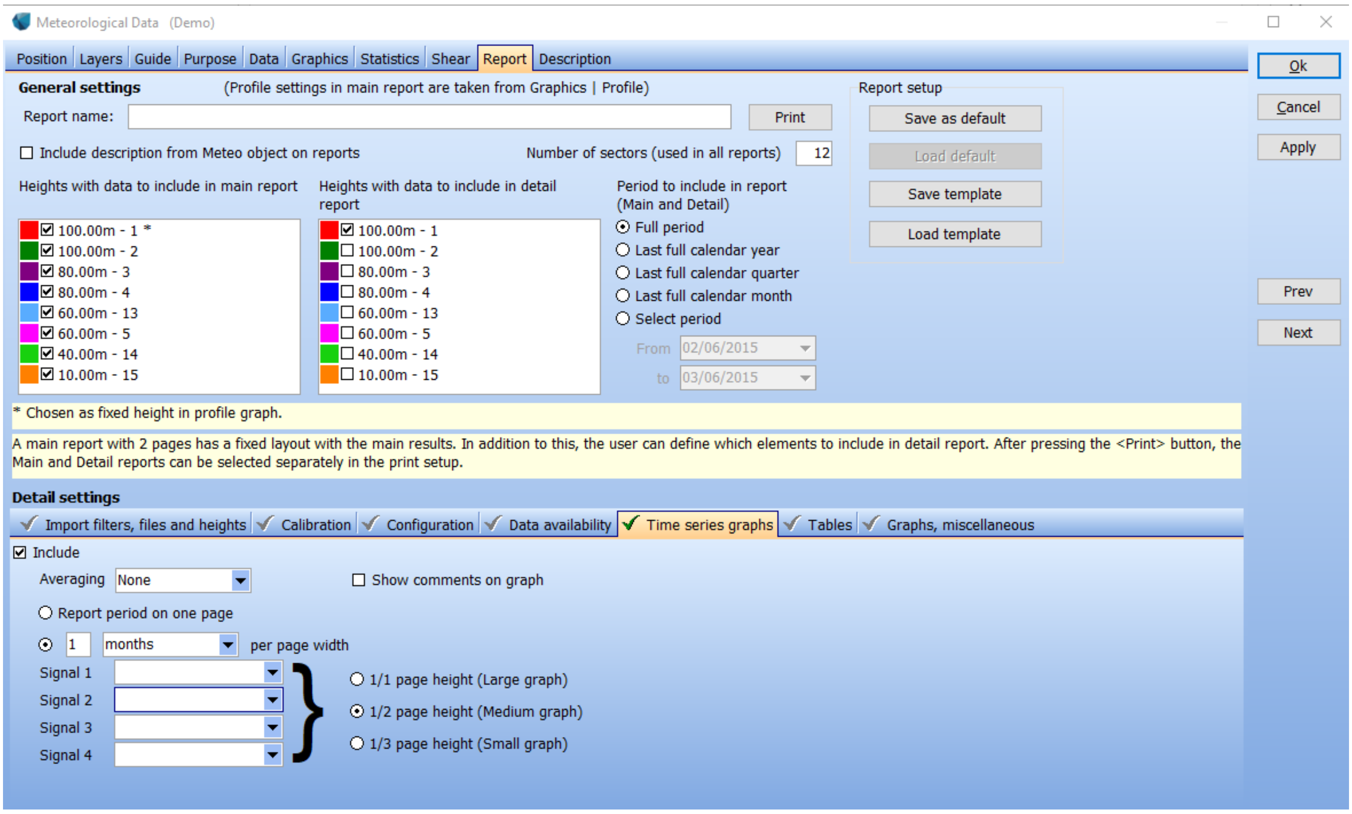


Figure 24 Reports from METEO object

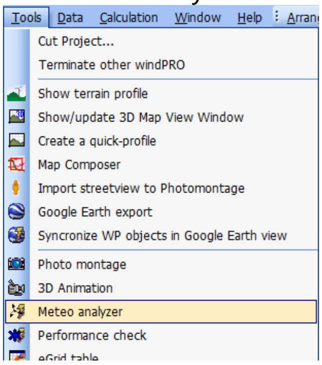
The Report tab allows for setting up a report, where a number of optional tables and graphics can be selected. A template with preferred setup can be saved for later use.

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 Windstatistic using WAsP, you must create 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 is used, which holds additional information).

12.4 Meteo analyzer

The Meteo Analyzer is a tool started from the tool bar  or the tool menu.



The Meteo Analyzer works directly on the data in the Meteo data objects. The Meteo Analyzer works on data from multiple 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 multiple Meteo data objects (measurement masts/Model data).
Disable/enable concurrent data from multiple masts.
Substitute / Fill data from one signal to another – scaling optional!
Cross predictor to 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 hold a complete one year data file with user defined time resolution for use in time varying PARK calculations or for detailed Loss calculations.
Scaling creates new time series based on SCALER – for immediate comparison with measurements (e.g. downscale MESO data to a measurement mast and compare the two signals. This can then be used for post calibration of the Scaler to get a match with measurements in concurrent data period).
RSD verification (Remote Sensing device) verification based on IEA Wind Expert Group recommended practices.

12.5 Meteo analyzer: tab by tab

12.5.1 Data: overview and selection of data

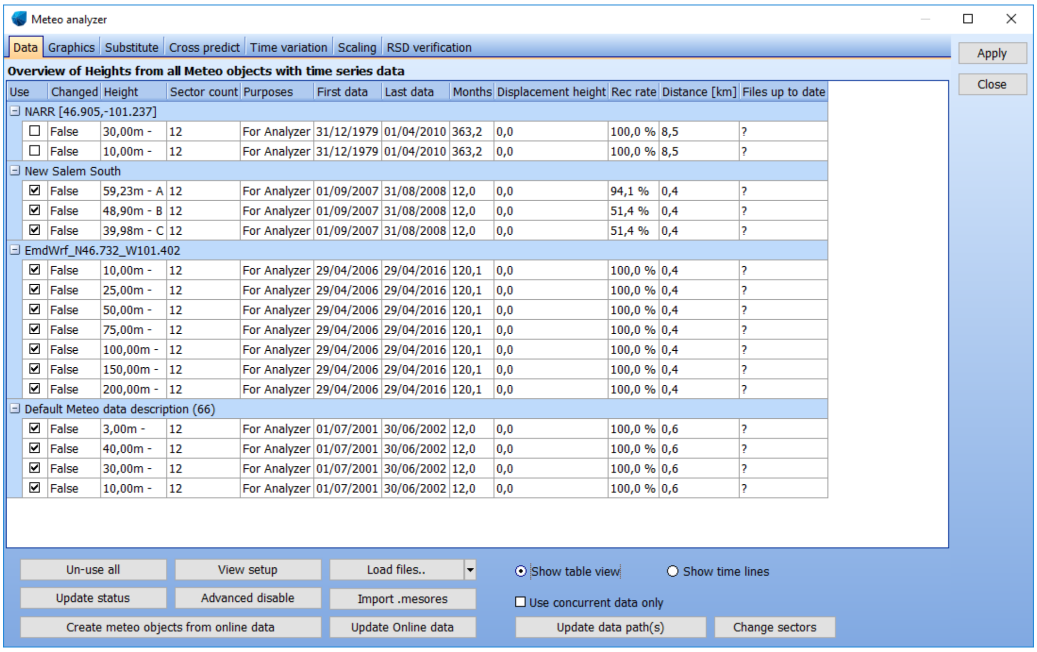


Figure 25 Selection of data in Meteo Analyser

Selection of data - here the data you do not want to use for "analyzing" can be deselected (Un-used).

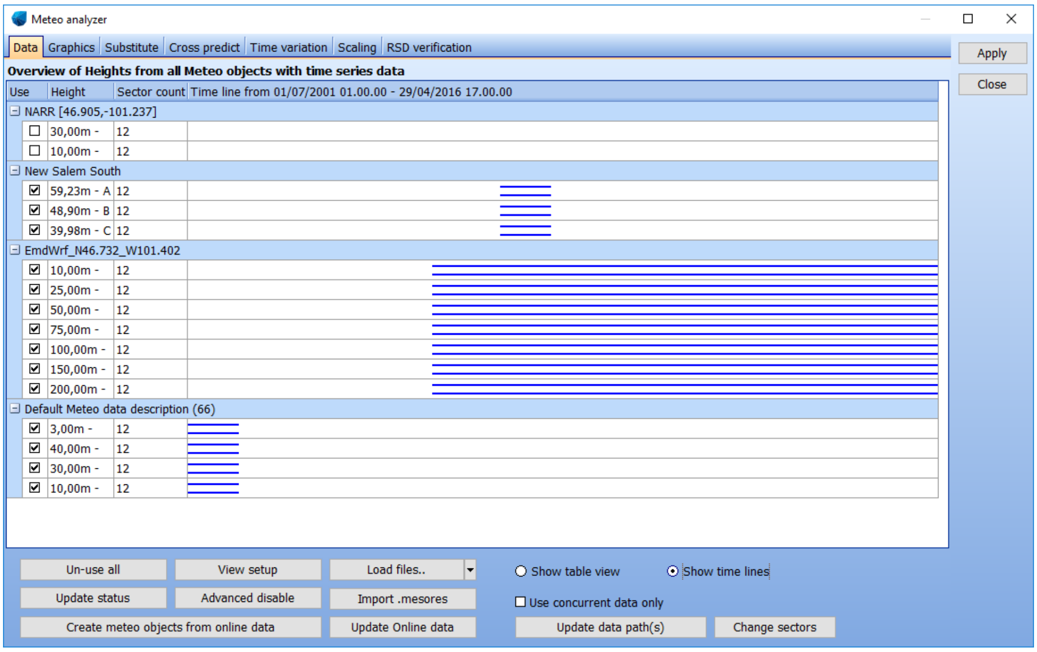


Figure 26 "Show time lines" gives a nice overview of selected data.

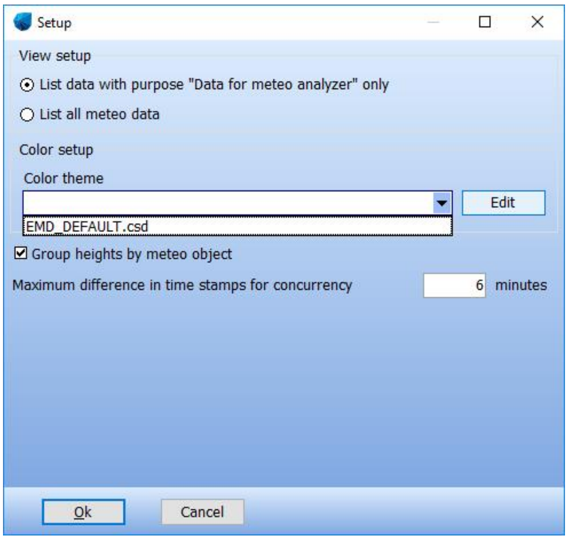


Figure 27 The view setup gives access to showing time lines with different settings.

12.5.2 Graphics: Compare time series

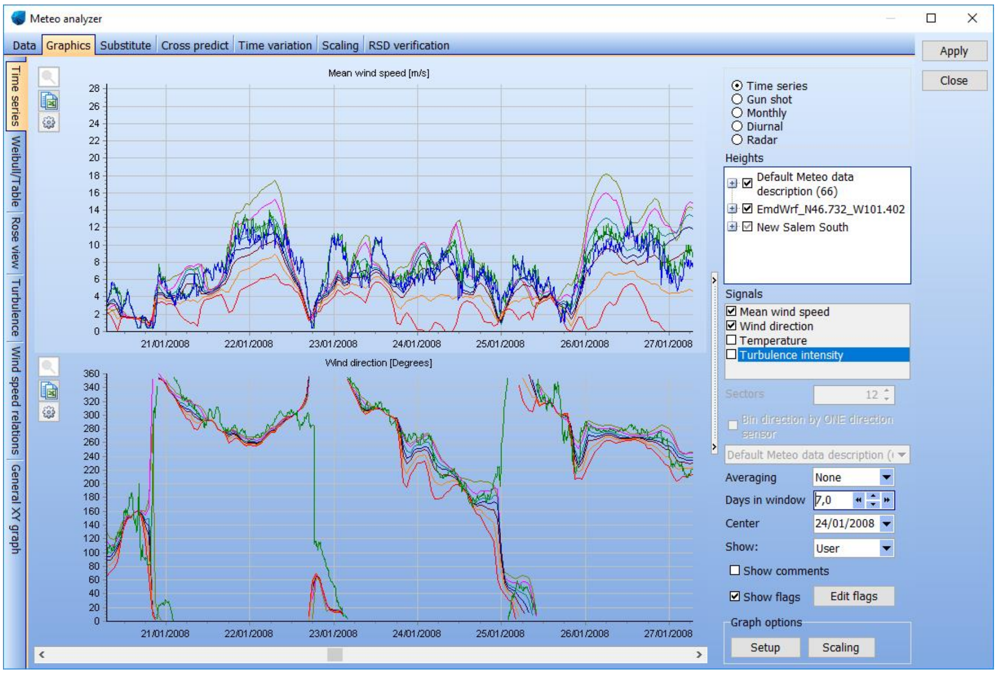


Figure 28 Graphic comparison of more Meteo object data.

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

12.5.3 Substitute: 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.

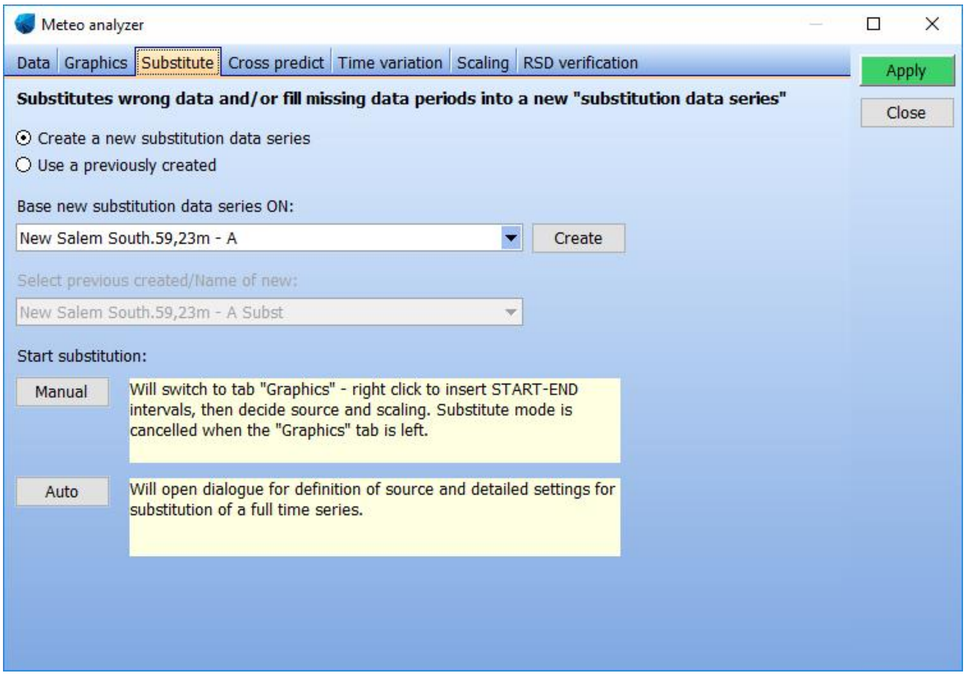


Figure 29 Substitution of data

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 will be placed.

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.

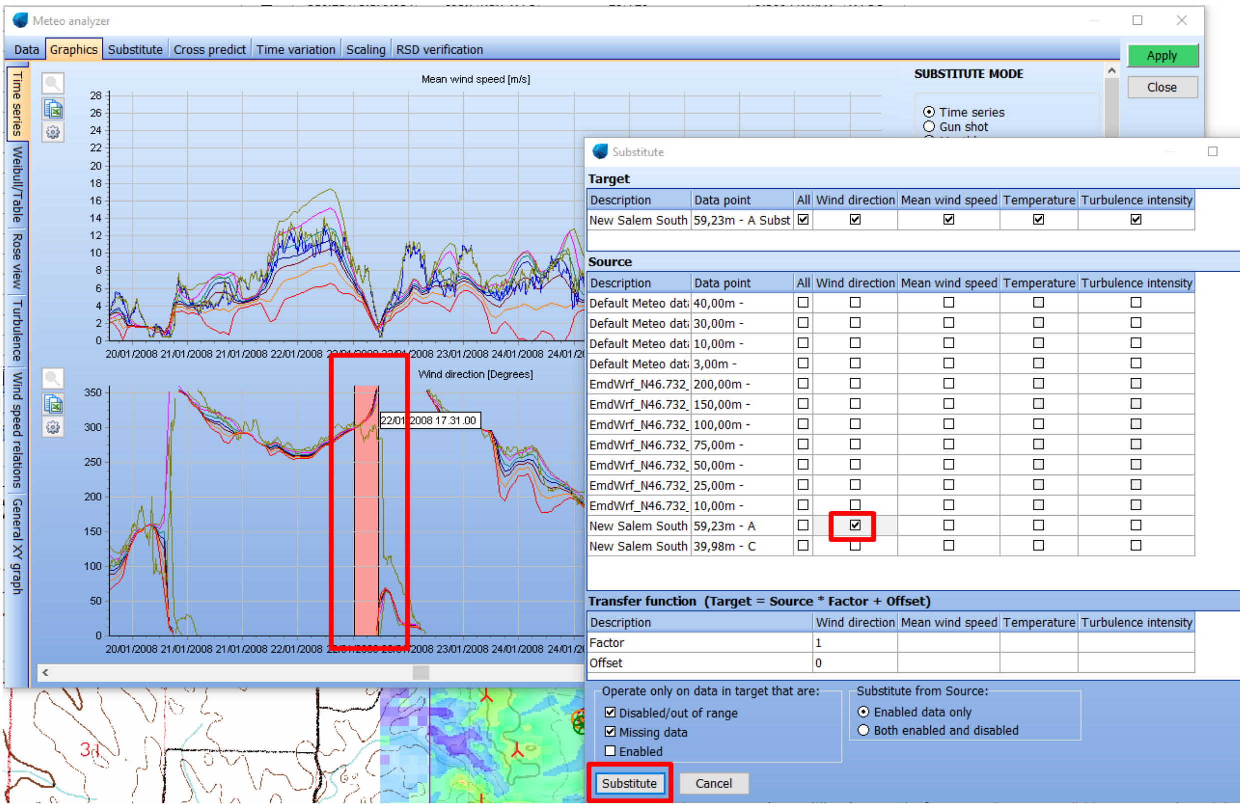


Figure 30 Manual substitution

Manual substitution: select "start" and "end" of interval by right clicking, 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).

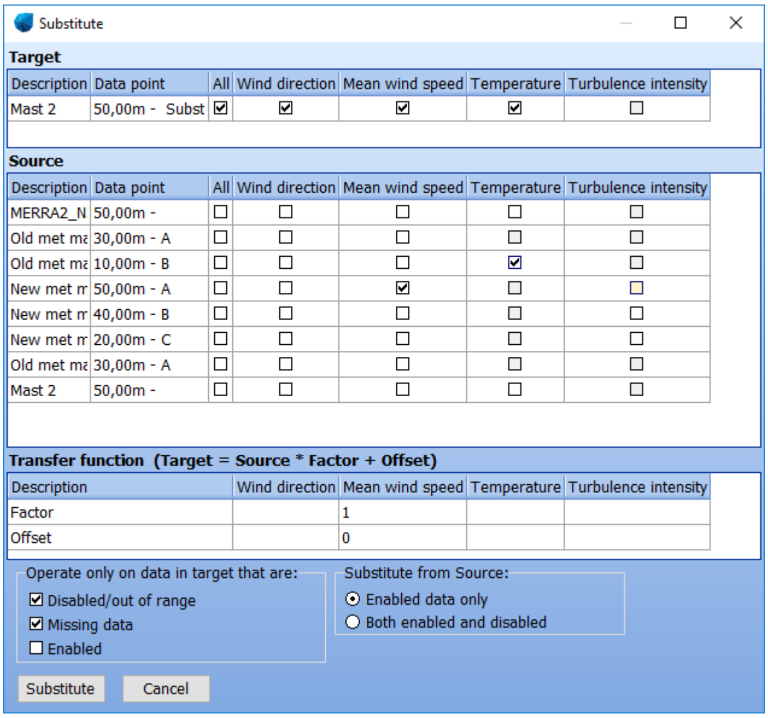


Figure 70 Auto substitution

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 are used for the substitution.

12.5.4 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 few mouse clicks - and some waiting time for the calculations.

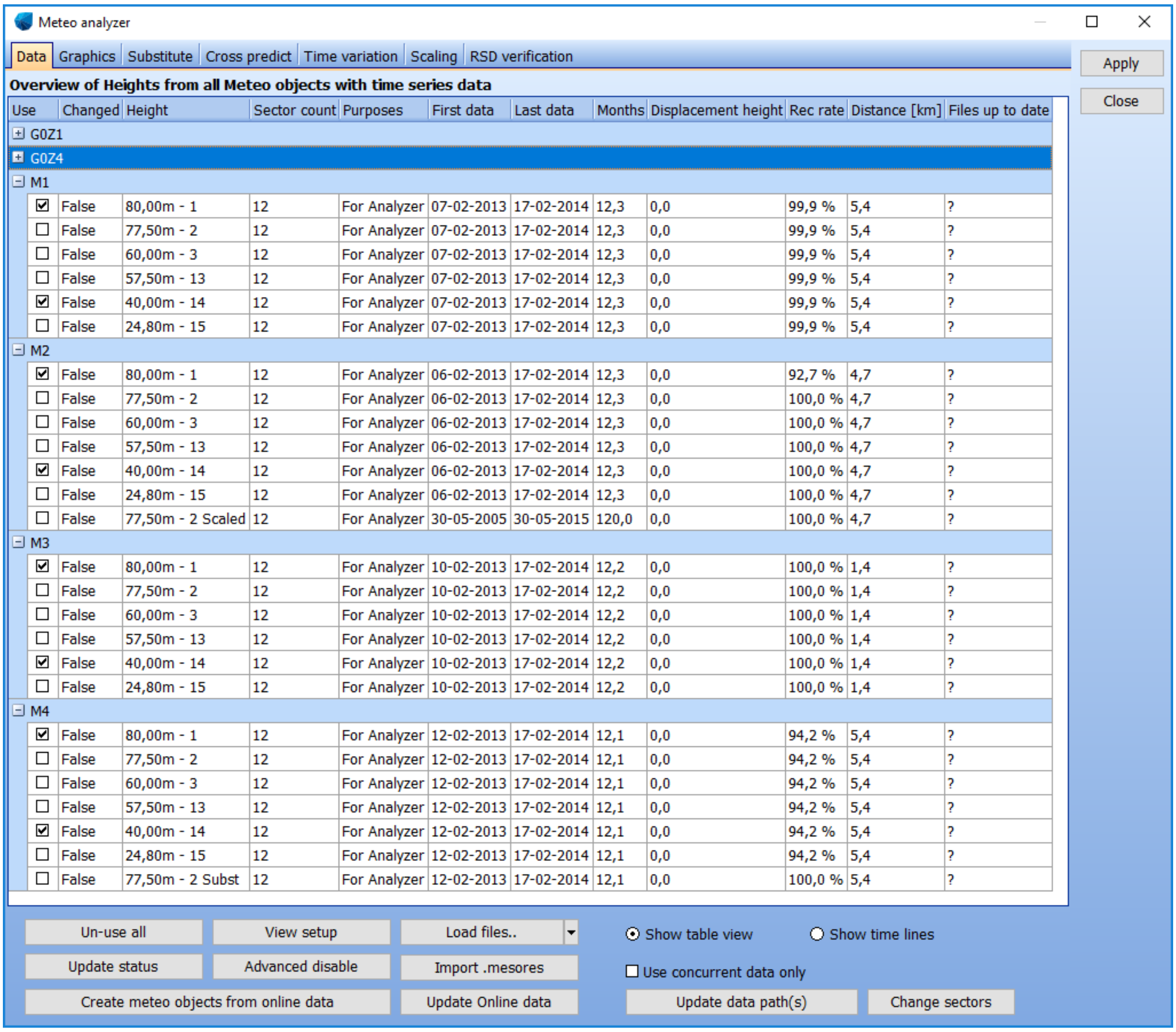


Figure 71 Selecting the masts and heights to be included

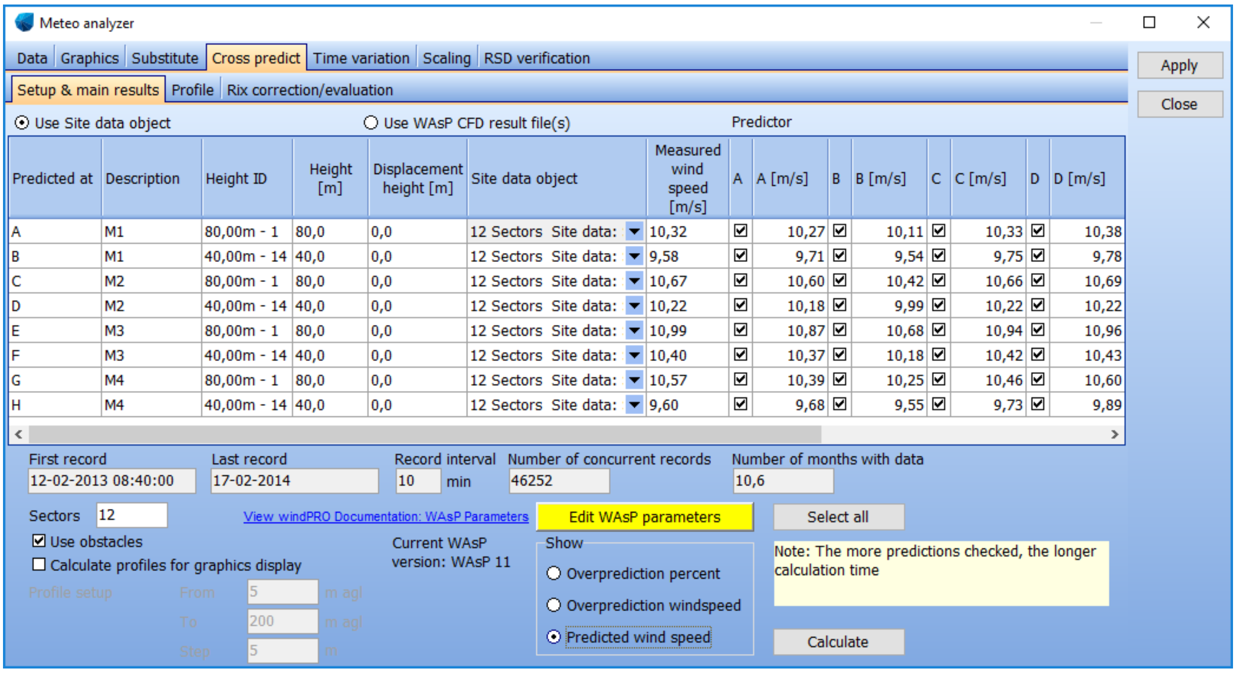


Figure 72 results of 64 cross predictions

The WAsP model capabilities of horizontal as well as vertical extrapolation of data are tested in one process on concurrent data. Above is a calculation where, 64 cross predictions based on almost one year of measurements is tested. This takes less than one minute.

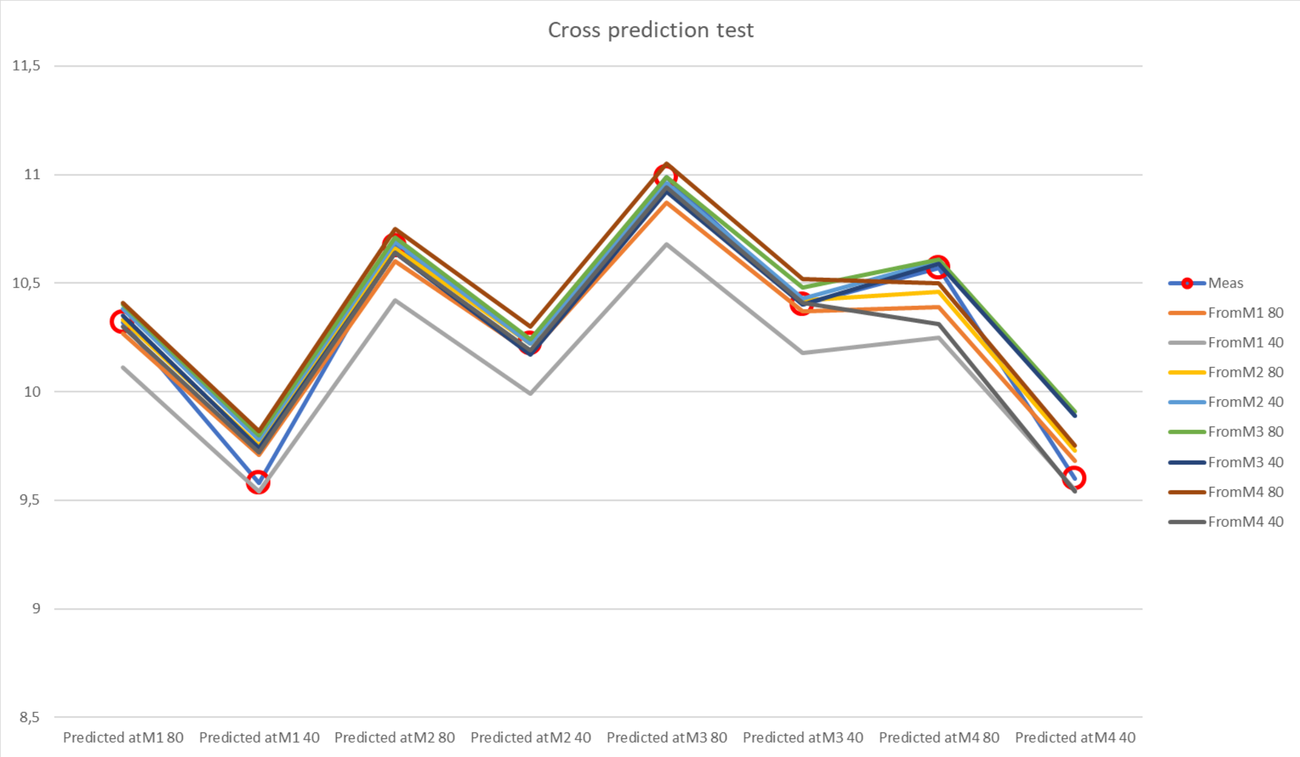


Figure 73 Cross prediction results into an Excel graph

When performing so many cross predictions, a graphic view is essential. The table can be copied to clipboard and inserted into Excel. This illustrates in this example that there is a problem with M1 40m, and that there are quite some deviations for M4. This might lead to further screening of the 40m data or possible roughness modification near M1. For M4 position (which has some more complex terrain than the other mast locations) it must be concluded that uncertainty in AEP calculations ´for turbines in the region near this is higher. Eventual a CFD calculation could improve these results.

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 the clipboard by selecting the cells to copy and right clicking.

If cross predictions are poor, there can be several reasons:

1. Measurement equipment is poorly calibrated
2. Masts are wrongly positioned in the terrain
3. Terrain is not described well enough (roughness, height contours, summit detail, local obstacles)
4. The wind climate is not the same at the different masts (and thereby the model cannot cross predict since the model assumes the wind climate is the same across the site). This could be if one mast is close to a mountain ridge that causes mesoscale 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 steepness 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).

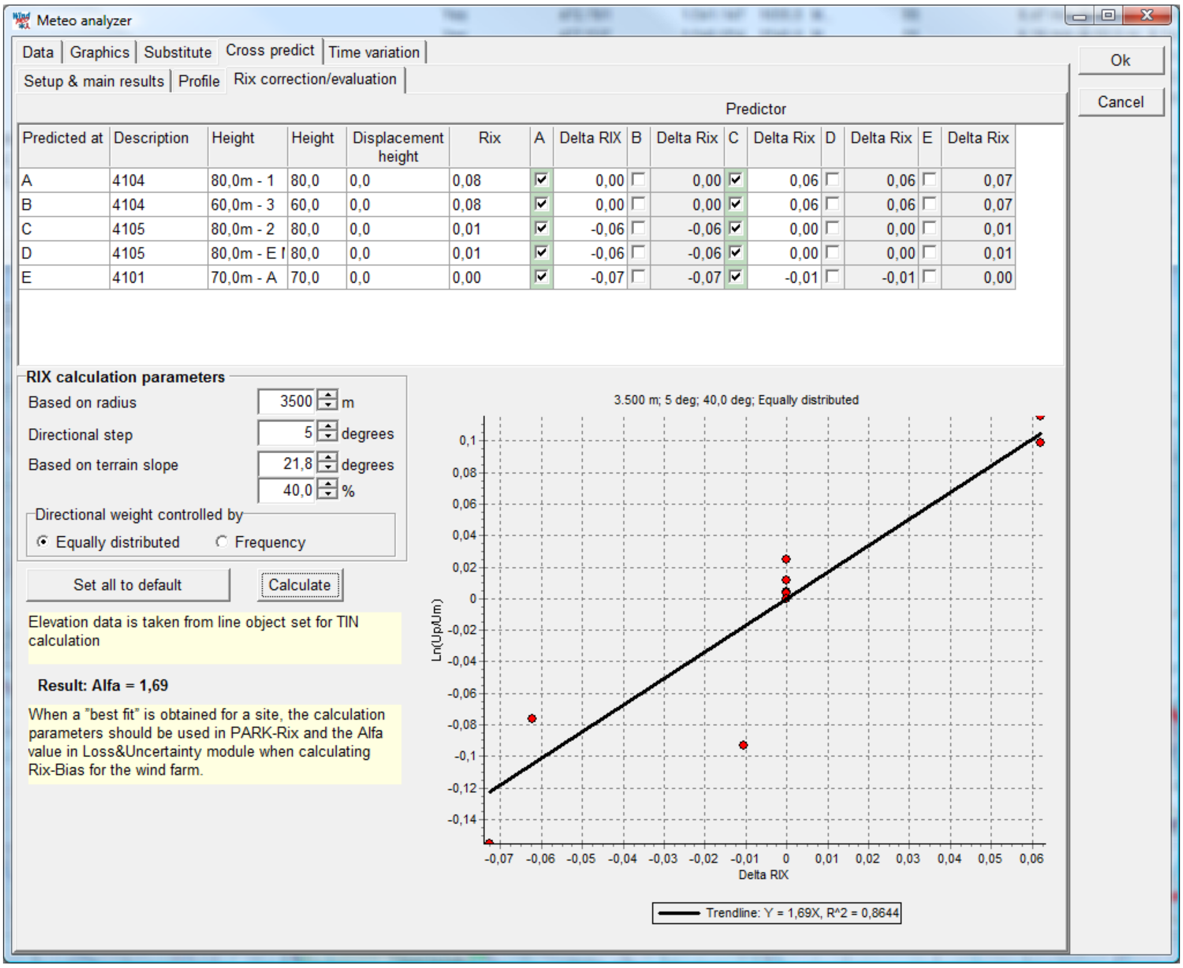


Figure 33 The RIX correction/evaluation tool

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. In the graph above, it seems reasonable that RIX can explain the cross prediction errors (all points on a reasonably straight line). The implied value for Alpha of 1,69 would be the choice in the RIX correction, which can be performed in the Bias part of the LOSS & UNCERTAINTY module.

Only the cross predictions calculated on the previous tab can be used in the Rix evaluation. See further documentation on RIX calculation in 3.4.11 RIX calculation or in the LOSS & UNCERTAINTY manual section on Bias.

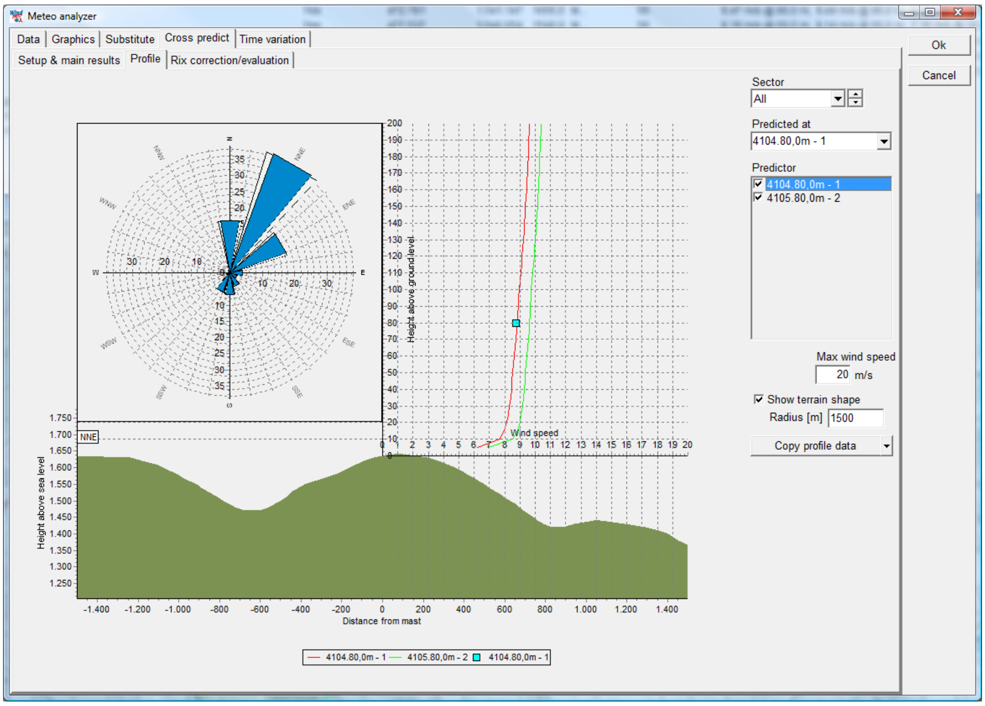


Figure 34 Prediction versus measurement inspected in the profile viewer

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”. However, 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 image below).

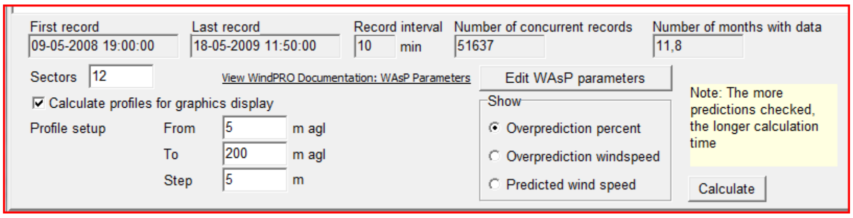


Figure 74 Check for profile calculation

12.5.5 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.

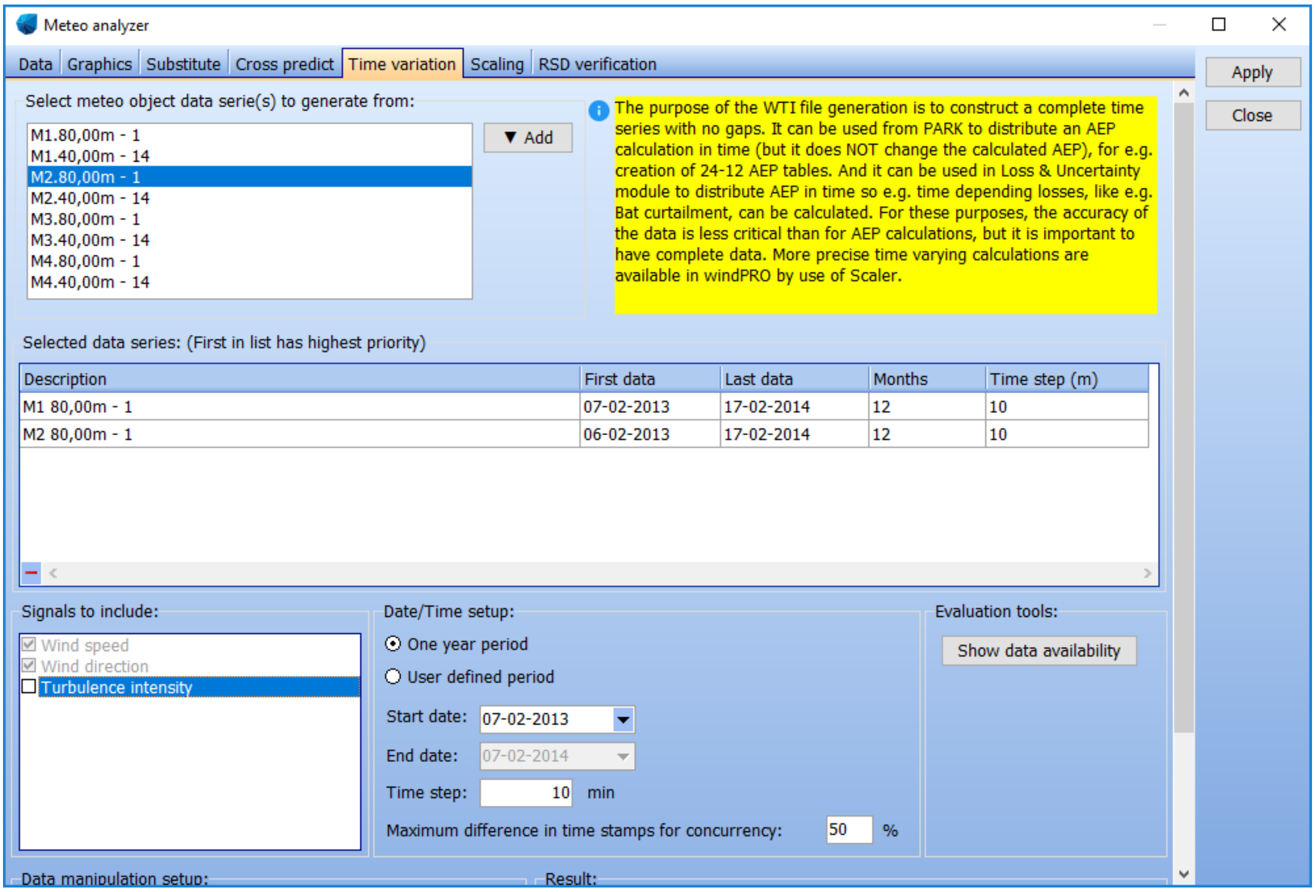


Figure 35 Generation of complete time series with no gaps

The setup for generation of a complete wind data series. This can be used for the calculating a "complete" time varying AEP and/or detailed loss calculation.

The basic idea with the tool for generating a complete wind data file is that, for some purposes like calculation of the expected AEP variation in time (as, for example, 12-24 tables for PPA negotiation), an often seen problem is that half a month of data is missing. Therefore, no production will be calculated for 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. In this case, the WTI generator is convenient since it 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, for example, the loss due to shut down below -20ºC 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 20ºC. If the temperature sensor was not working all the time (1 year), or simply not present, data can be substituted from a nearby met station or MESO scale or Model data into the basic measurement so that all relevant time stamps' variables are filled after the data has been processed by the WTI generator.

Basically three methods are available for filling gaps:

- Take from other measurement (other height, other mast or a dataset like NCAR)
- 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)

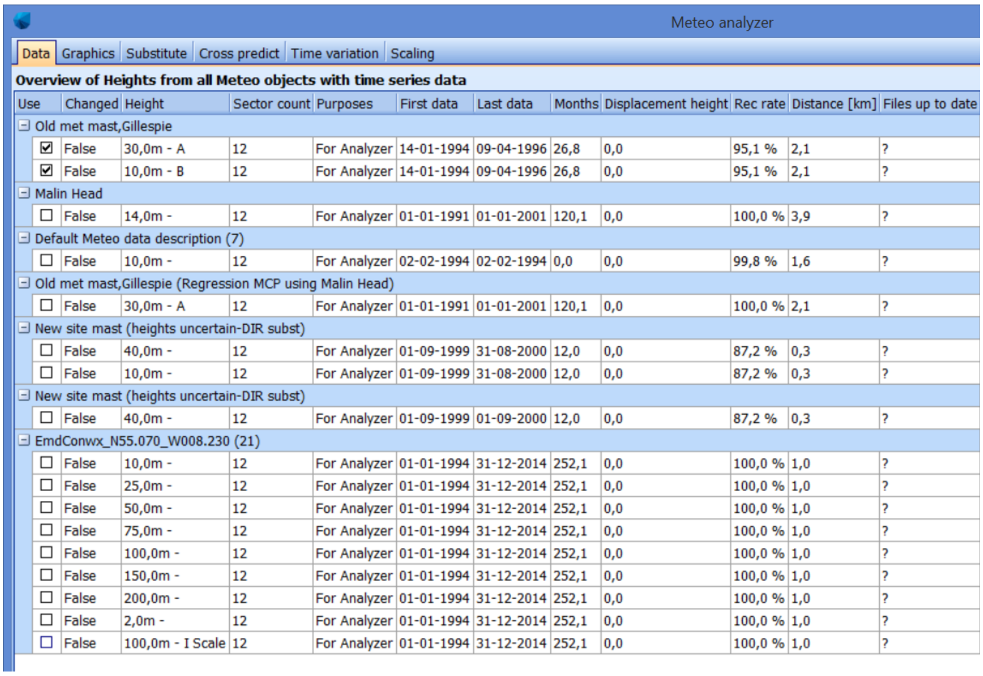
The three methods can be used in combination. Data will be “resampled” to any user defined time resolution, but, typically, a 10-minute or 60-minute resolution should be used. NOTE: taking data from another mast does not include any scaling options. Eventually, scaling is needed to bring the two masts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

The .WTI file is, by default, saved in the project folder and can be selected from PARK time varying calculation or from the LOSS & UNCERTAINTY module. The wind speed data is automatically scaled to the calculated mean wind speed for the actual site in order to have as correct of 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.

12.5.6 Scaling – create a new scaled time series using the SCALER.

The scaling can be used on measurements as well as model data. The most logical way is to scale meso data to a mast position for comparison. This approach is described here.

The procedure is to compare downscaled mesoscale data (cleaned using mesoscale terrain and applied with local microscale terrain) to actual measurements. If the match is not perfect, the downscaled data can then be forced to fit in an iterative procedure using scaling factors on directional, diurnal and monthly wind speeds. The following is a demonstration of the procedure:


Meteo analyzer

Data | Graphics | Substitute | Cross predict | Time variation | Scaling

Overview of Heights from all Meteo objects with time series data

Use	Changed	Height	Sector count	Purposes	First data	Last data	Months	Displacement height	Rec rate	Distance [km]	Files up to date
⊟ Old met mast,Gillespie											
☑	False	30,0m - A	12	For Analyzer	14-01-1994	09-04-1996	26,8	0,0	95,1 %	2,1	?
☑	False	10,0m - B	12	For Analyzer	14-01-1994	09-04-1996	26,8	0,0	95,1 %	2,1	?
⊟ Malin Head											
☐	False	14,0m -	12	For Analyzer	01-01-1991	01-01-2001	120,1	0,0	100,0 %	3,9	?
⊟ Default Meteo data description (7)											
☐	False	10,0m -	12	For Analyzer	02-02-1994	02-02-1994	0,0	0,0	99,8 %	1,6	?
⊟ Old met mast,Gillespie (Regression MCP using Malin Head)											
☐	False	30,0m - A	12	For Analyzer	01-01-1991	01-01-2001	120,1	0,0	100,0 %	2,1	?
⊟ New site mast (heights uncertain-DIR subst)											
☐	False	40,0m -	12	For Analyzer	01-09-1999	31-08-2000	12,0	0,0	87,2 %	0,3	?
☐	False	10,0m -	12	For Analyzer	01-09-1999	31-08-2000	12,0	0,0	87,2 %	0,3	?
⊟ New site mast (heights uncertain-DIR subst)											
☐	False	40,0m -	12	For Analyzer	01-09-1999	01-09-2000	12,0	0,0	87,2 %	0,3	?
⊟ EmdConwx_N55.070_W008.230 (21)											
☐	False	10,0m -	12	For Analyzer	01-01-1994	31-12-2014	252,1	0,0	100,0 %	1,0	?
☐	False	25,0m -	12	For Analyzer	01-01-1994	31-12-2014	252,1	0,0	100,0 %	1,0	?
☐	False	50,0m -	12	For Analyzer	01-01-1994	31-12-2014	252,1	0,0	100,0 %	1,0	?
☐	False	75,0m -	12	For Analyzer	01-01-1994	31-12-2014	252,1	0,0	100,0 %	1,0	?
☐	False	100,0m -	12	For Analyzer	01-01-1994	31-12-2014	252,1	0,0	100,0 %	1,0	?
☐	False	150,0m -	12	For Analyzer	01-01-1994	31-12-2014	252,1	0,0	100,0 %	1,0	?
☐	False	200,0m -	12	For Analyzer	01-01-1994	31-12-2014	252,1	0,0	100,0 %	1,0	?
☐	False	2,0m -	12	For Analyzer	01-01-1994	31-12-2014	252,1	0,0	100,0 %	1,0	?
☐	False	100,0m - I Scale	12	For Analyzer	01-01-1994	31-12-2014	252,1	0,0	100,0 %	1,0	?

Figure 75 List of data sets (Meteo objects) in meteo analyser

The METEO objects in the project are shown above. You only need to check the datasets used for the operation – the METEO object that the meso data shall be “scaled to” - in this case, the Old met mast datasets. Then proceed to the Scaling tab:

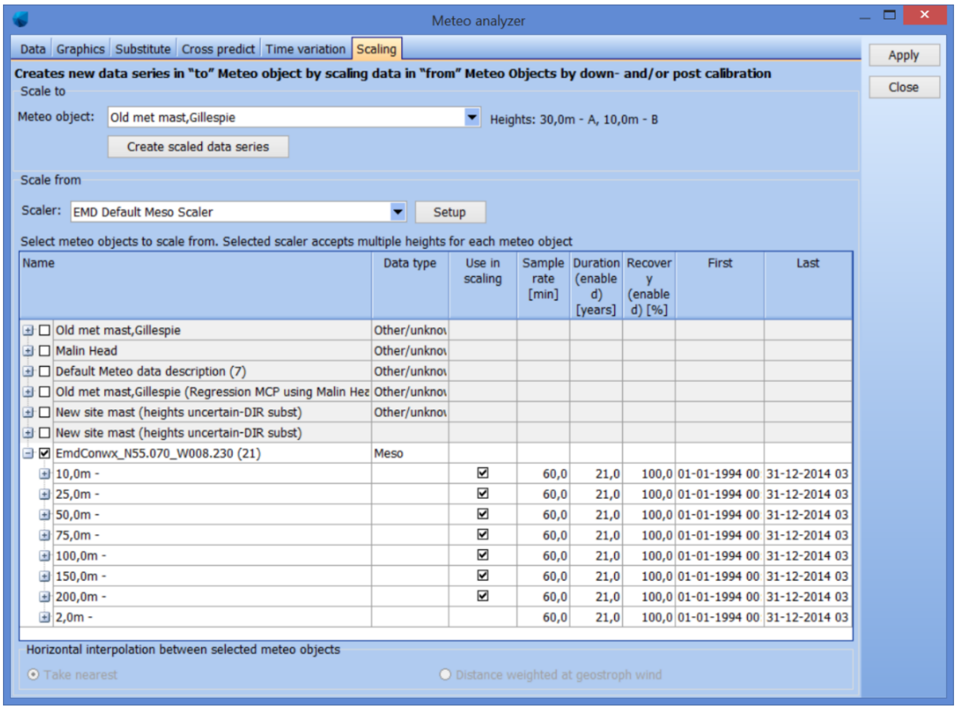


Figure 76 Scaling setup in meteo analyser

The only METEO object that appears in the “Scale to” METEO object is the one selected previously in the Data tab.

“Scale from” is where the SCALER setup is partly defined and the METEO object(s) is partly selected. Here, the EMD-ConWx mesoscale data near the mast is selected to scale from. Click the **Create scaled data series** and the transfer function created by the SCALER creates a time series based on the meso data at the mast position.

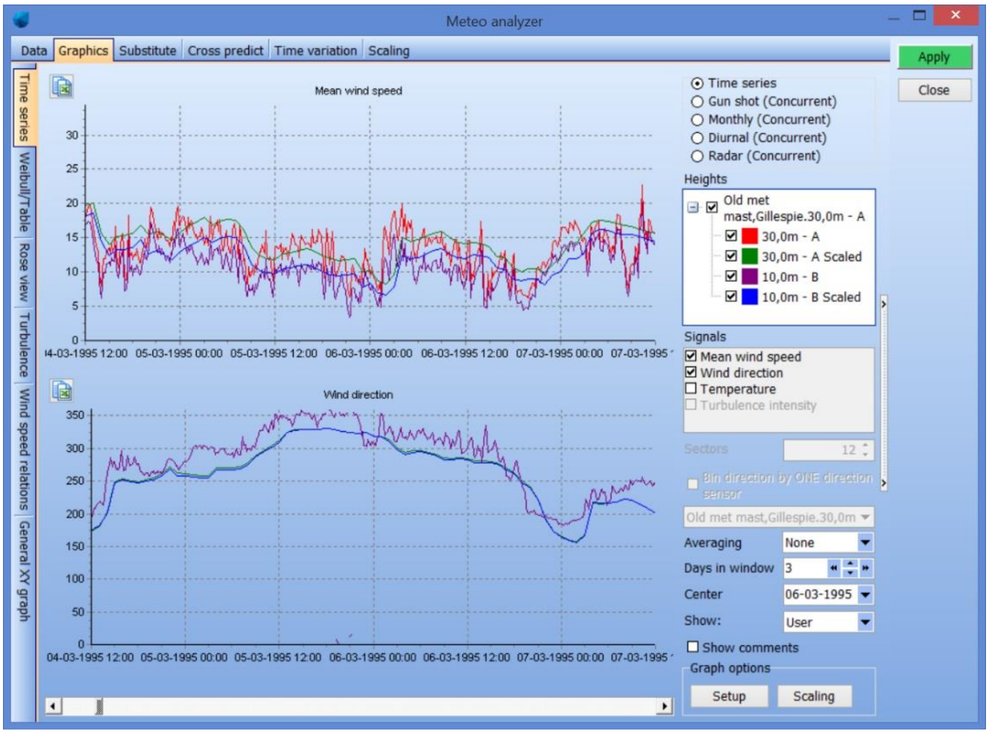


Figure 77 Compare scaled to measured, time series

Here, the time series are seen together: partly the 10 min. measurements, partly the 1 hour scaled meso data at the mast position. If the time series looks reasonable, the real evaluation will be on the aggregated presentations of concurrent data.

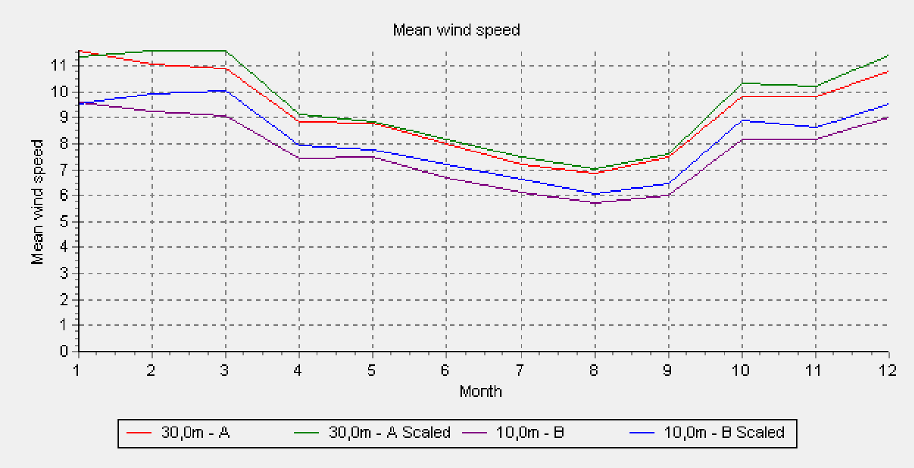


Figure 78 Monthly comparison scaled and measured

Looking at the monthly wind speeds, it is seen the monthly variations and the variation by height match reasonably well, although not perfect.

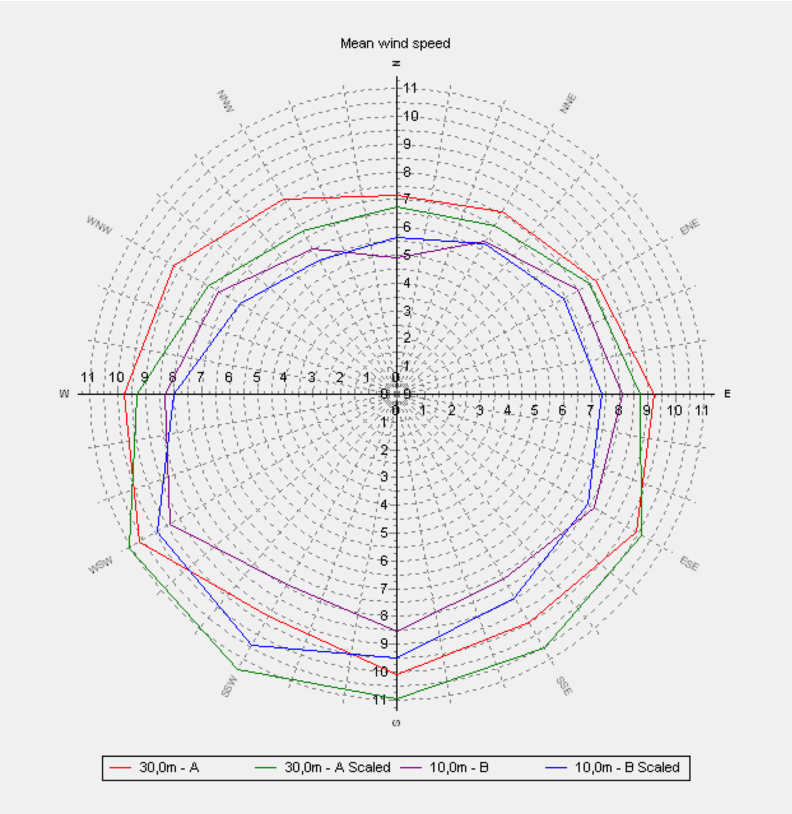


Figure 79 Direction comparison scaled and measured

One of the most interesting evaluations is by direction. It is known that the mesoscale model data can have some directional bias. In Northern Europe, it is often seen that the E-NE directions give too low wind speeds in mesoscale data, where they often are too high in SW directions. This is what is seen here. A reason for this observed bias can be direction inaccuracies. Measurements can often be wrongly calibrated by direction or have periods with offsets due to the measurement equipment.

It is, therefore, recommended to check “Bin direction by ONE direction sensor”, which means that the comparisons by direction is made on concurrent time stamps.

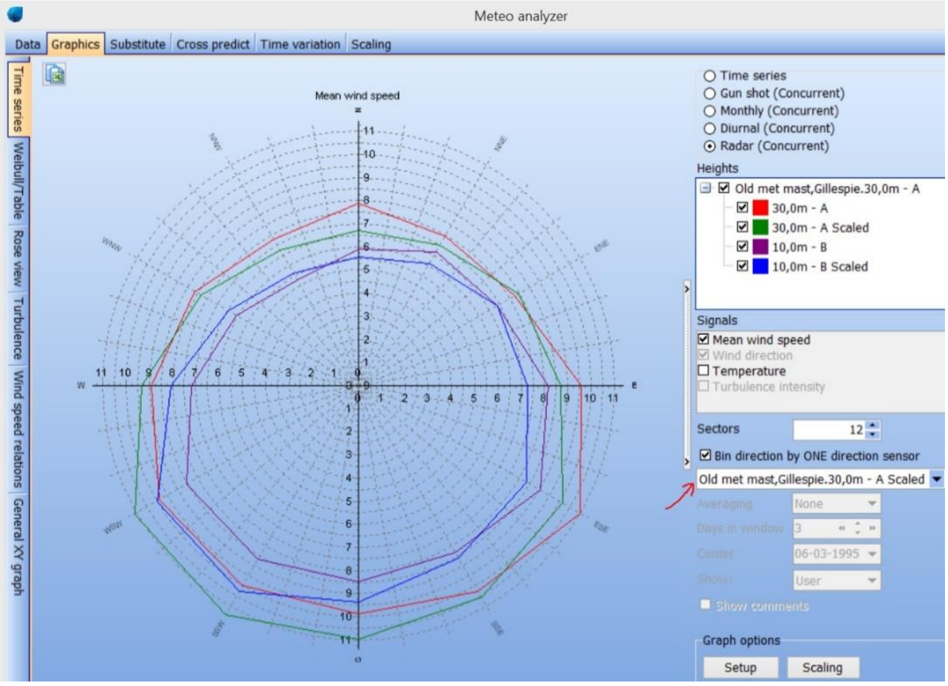


Figure 80 Direction comparison scaled and measured, one direction sensor

Here, only the scaled (meso data based) 30m wind direction is used for the evaluation. This also means that concurrent time steps are compared – and the relations now look better (more smooth).
If we want a perfect match, the post calibration can be used.

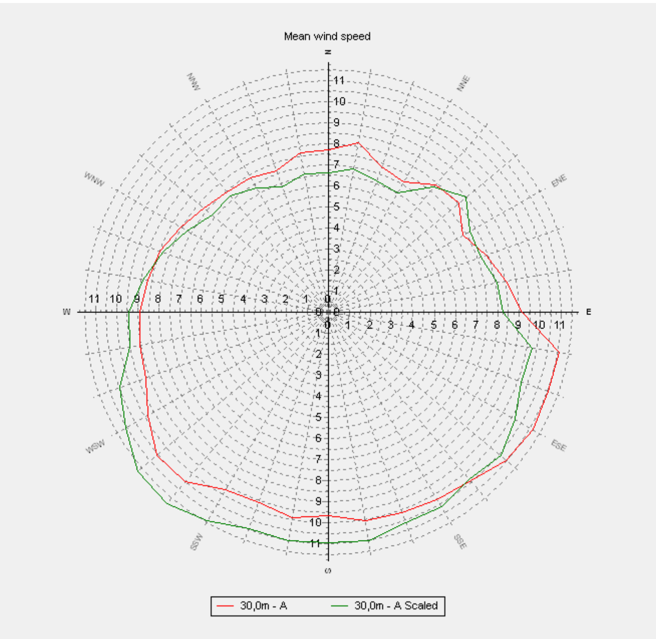


Figure 81 Ratios of measured/scaled for post calibration

The number of sectors is increased to 36 and only the 30m data is used. It is clearly seen here how E and N are under predicted by the Meso data, while SW is over predicted.

Table 2 establishment of direction post calibration in Excel

Real dir.	Angle	30,0m - A	Angle	30,0m - A Scaled	Measured/ Scaled

0	360	7,698769	360	6,606075	1,17
10	350	8,16588	350	6,886537	1,19
20	340	7,337907	340	6,645956	1,10
30	330	7,142952	330	6,558915	1,09
40	320	7,901548	320	7,757147	1,02
50	310	8,058771	310	8,476159	0,95
60	300	7,30944	300	7,720281	0,95
70	290	7,896954	290	7,651225	1,03
80	280	8,524108	280	8,081497	1,05
90	270	9,121071	270	8,234601	1,11
100	260	11,04795	260	9,767339	1,13

The data are copied to Excel, and the ratio measured/scaled is established (only first 11 lines of 36 shown above). Note the angle shown is mirrored. This is just how the graphic tool works: do not get confused about this. The order of the direction sectors are always N – E – S – W.
Now, return to the SCALER tab and open the "setup" of the SCALER:

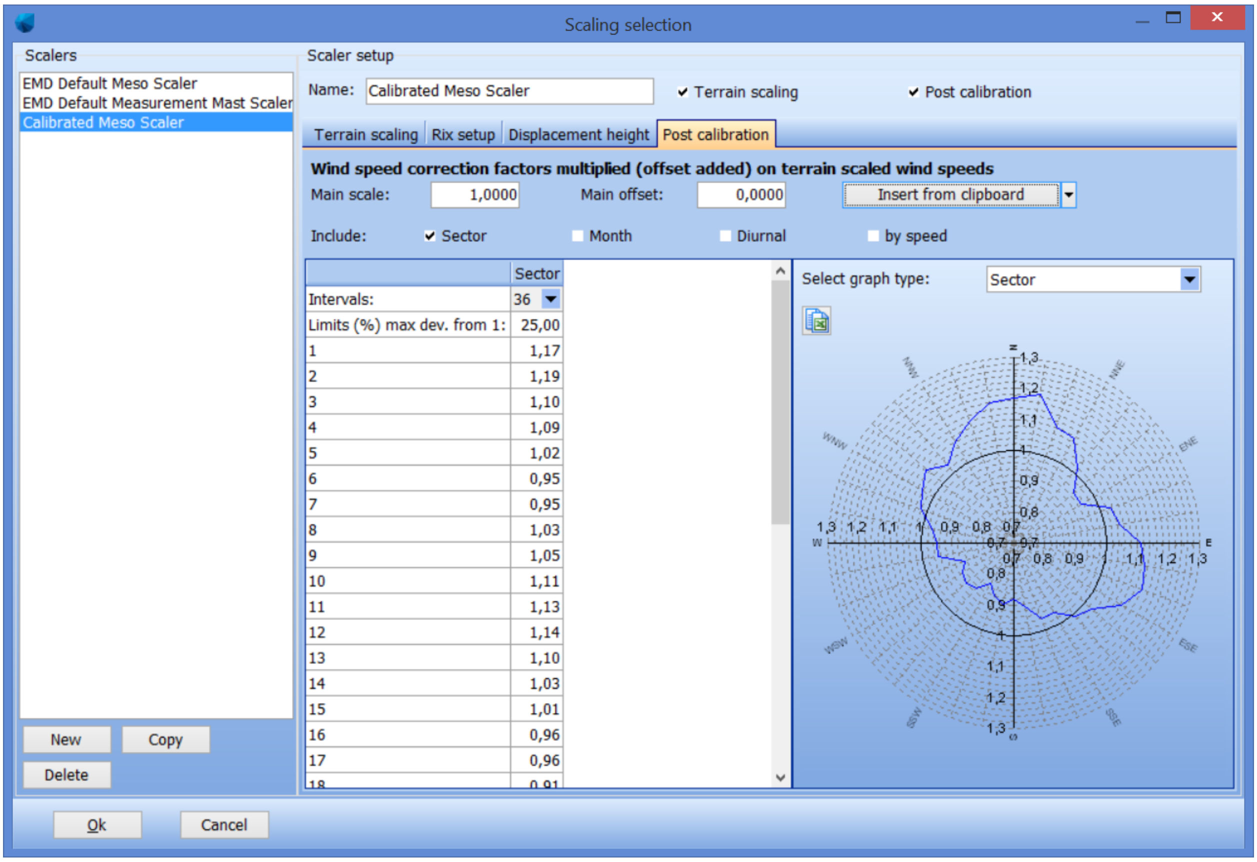


Figure 82 Insert the post calibration data in the SCALER

Here, the ratios are inserted from excel via the clipboard in the Post calibration tab.
A new SCALER is created by "copy" and renamed to "calibrated mesoscaler". This "SCALER" is now a part of the project and can be used from other places, like PARK calculations.

Now, the "create scaled data series" is rerun and the result is:

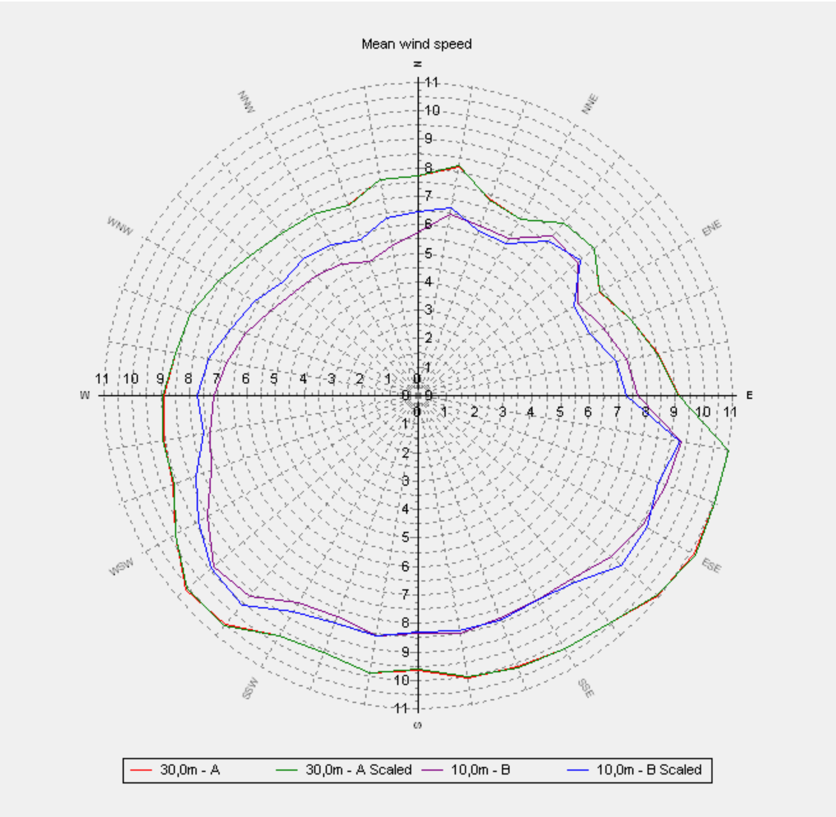


Figure 83 Compare post calibrated scaled data to measured

A perfect match for 30m is seen between measurements (red) and scaled (green) Meso data. The directional bias is removed. For 10m, the match is not completely perfect, especially in the NW sector where the meso data is higher. This could be due to a mast shadow in these directions. It is assumed the 30m anemometer is top mounted and, therefore, has no mast shadow.
Now, other aggregated results can be evaluated.

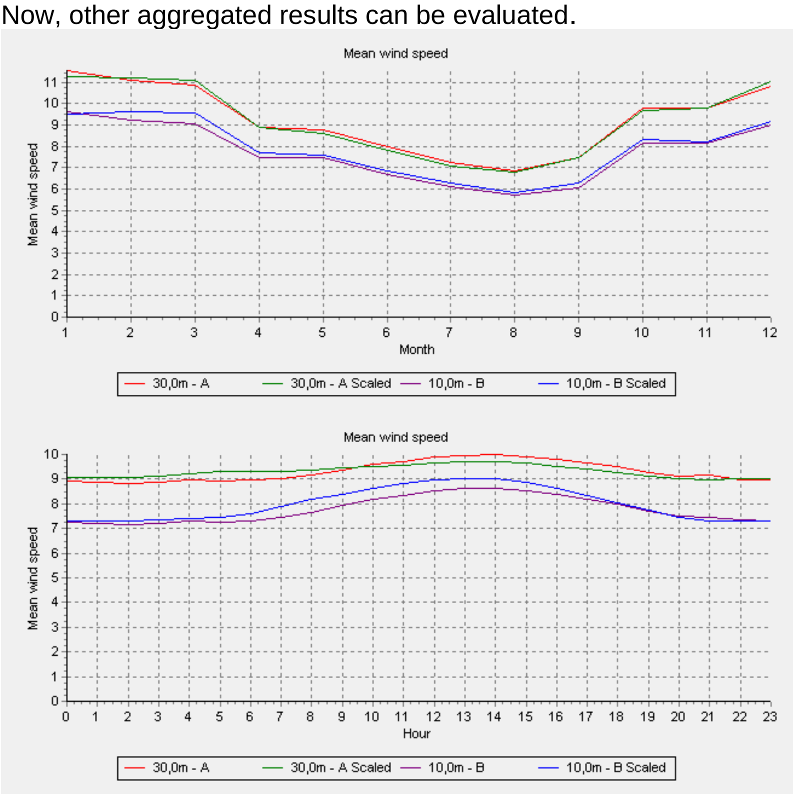


Figure 84 Monthly and diurnal comparison of measured and scaled data

Monthly as well as diurnal have a very fine match – another indicator that removing the bias by direction worked well. Sometimes a seasonal bias should be removed. This can be related to how the surface roughness varies during the year.

What is important to notice is that the scaling can sometimes be a compensation for how well the calculation model handles the terrain. If the hill speed up is over/under estimated, this can be compensated for with the scaling. This compensation would not then work for all of the site, only at the parts of the site that have similar speed up errors. Therefore, the scaling must be handled very carefully, especially in complex terrain. Having more masts to test the SCALER settings will, of course, be the best method since it gives a more detailed feedback.

When the Meteo Analyzer session is finalized, the “apply” button writes the modifications to the METEO objects. For example, the generated scaled series from the “old mast” object will be written to that object, and the data can be used in calculations as a long term artificial mast.

12.5.6.1 Structured establishment of main scale and offset

One of the wishes when post calibrating Meso data to match local measurements is to have a similar Weibull distribution. This can be established by following procedure in MCP module:

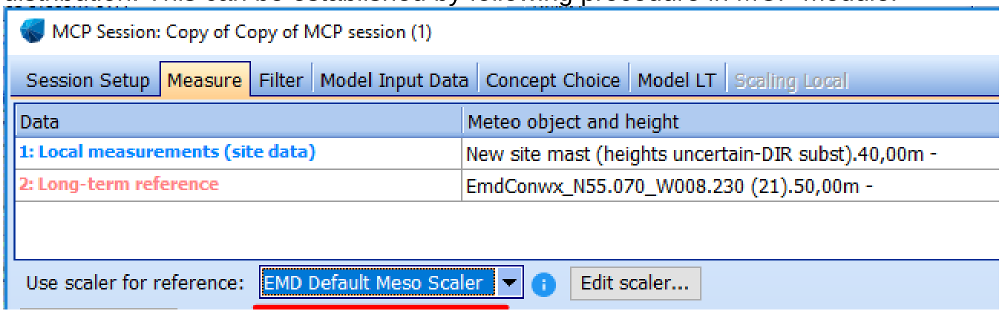


Figure 85 Downscaling in MCP module

Use a default MESO scaler (no post calibration). The MESO data will then be downscaled.

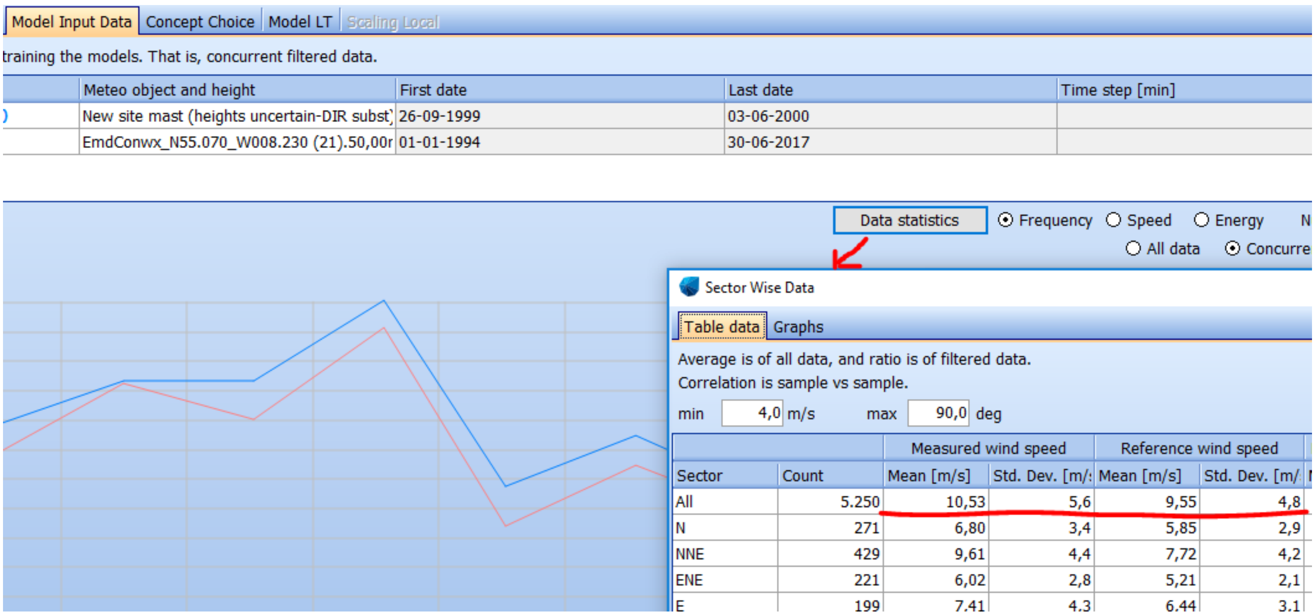


Figure 86 Statistical output from MCP

On the Model Input data page, under “Data statistics”, find the Mean and st.dev for the measurements and the downscaled reference.

Now use the formulas from next figure.

Based on the assumption that the cumulative distributions of the modelled data shall be the same as the measured, this equation is used:

$$\frac{Umodel - Umean{,}model}{StDev{,}model} = \frac{Umeas - Umean{,}meas}{StDev{,}meas}$$

From this following formulas for needed Post calibration can be derived:

Scale = Stdev.Measured/Stdev.Modeled

Offset = Mean.measured - ((Stdev.Measured/Stdev.Modeled) x Mean.Modeled)

	Meas	Model			
Mean	6,23	7,72		Scale	Offset
St.dev	2,86	3,48		**0,82**	**-0,11**

Figure 87 Establish calculation in Excel or similar tool.

And calculate the Scale and offset.

	Meas	Model			
Mean	10,53	9,55		Scale	Offset
St.dev	5,6	4,8		1,17	-0,61

Results from shown example.

Based on the MCP2005:
Create a scaled series in Meteo analyser based on “Default meso scaling” (no Post calibration)
Read the measured and scaled series in MCP module, load data, go to “correlate” and load concurrent data:

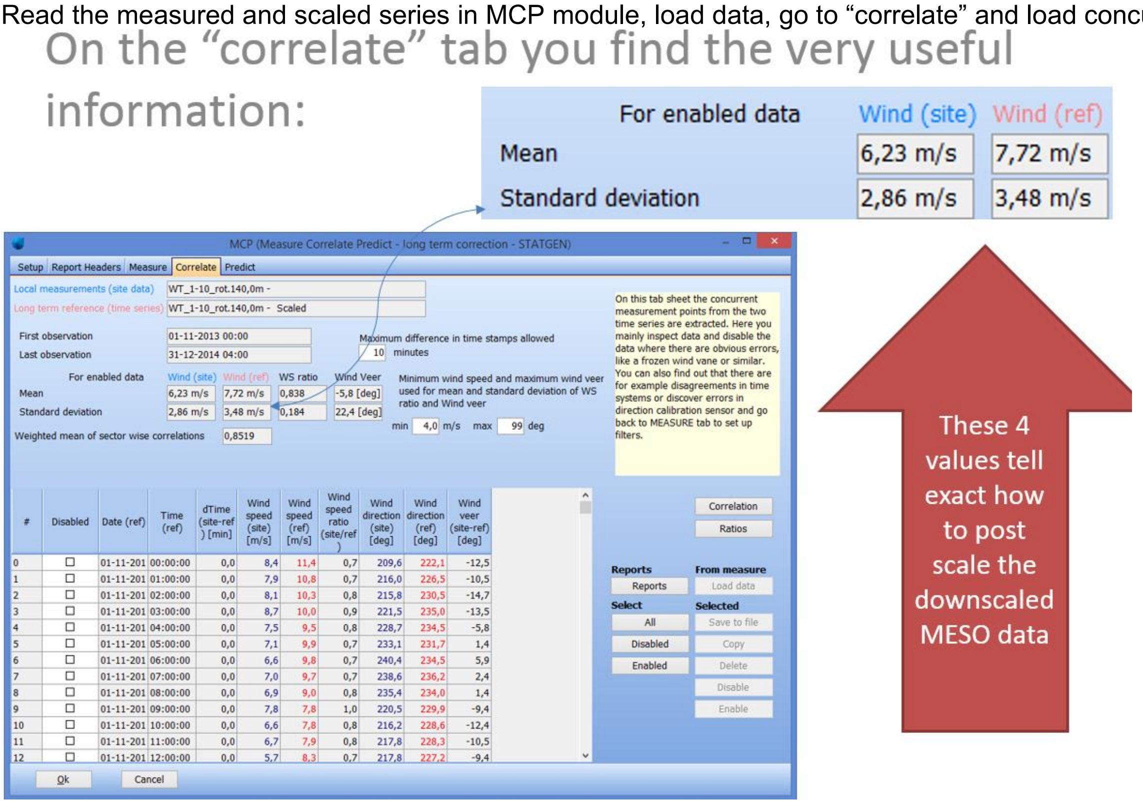


Figure 88 The correlation tab in MCP2005 gives mean and st.dev for both series

Note also the wind Veer. If this is high (here only based on wind speeds > 4 m/s), it is most likely that the measurement mast has a direction sensor calibration problem. This should be fixed by recalibration before later directional calibration.

The formulas given in figure “*Establish calculation in Excel or similar tool.*” tells how Scale and Offset are calculated to give the best possible Weibull fit between measured and scaled. This is a very good “basis calibration” to start with. Afterwards more refined Post calibrations can be performed as described in previous paragraph.

12.5.7 RSD verification

Remote sensing devices will often be installed next to a traditional measurement mast to evaluate the quality of the device. An expert group has established recommendations:

iea wind

EXPERT GROUP STUDY ON
RECOMMENDED PRACTICES

15. GROUND-BASED VERTICALLY-PROFILING REMOTE SENSING FOR WIND RESOURCE ASSESSMENT

FIRST EDITION, JANUARY 2013

Submitted to the Executive Committee
of the International Energy Agency Implementing Agreement
for
Co-operation in the Research, Development, and Deployment of
Wind Energy Systems

January 2013

These recommendations have been programmed to establish the tables and graphs from the recommendations. There is a link to the document from the RSD verification tab. Here all are described, so no further info here.

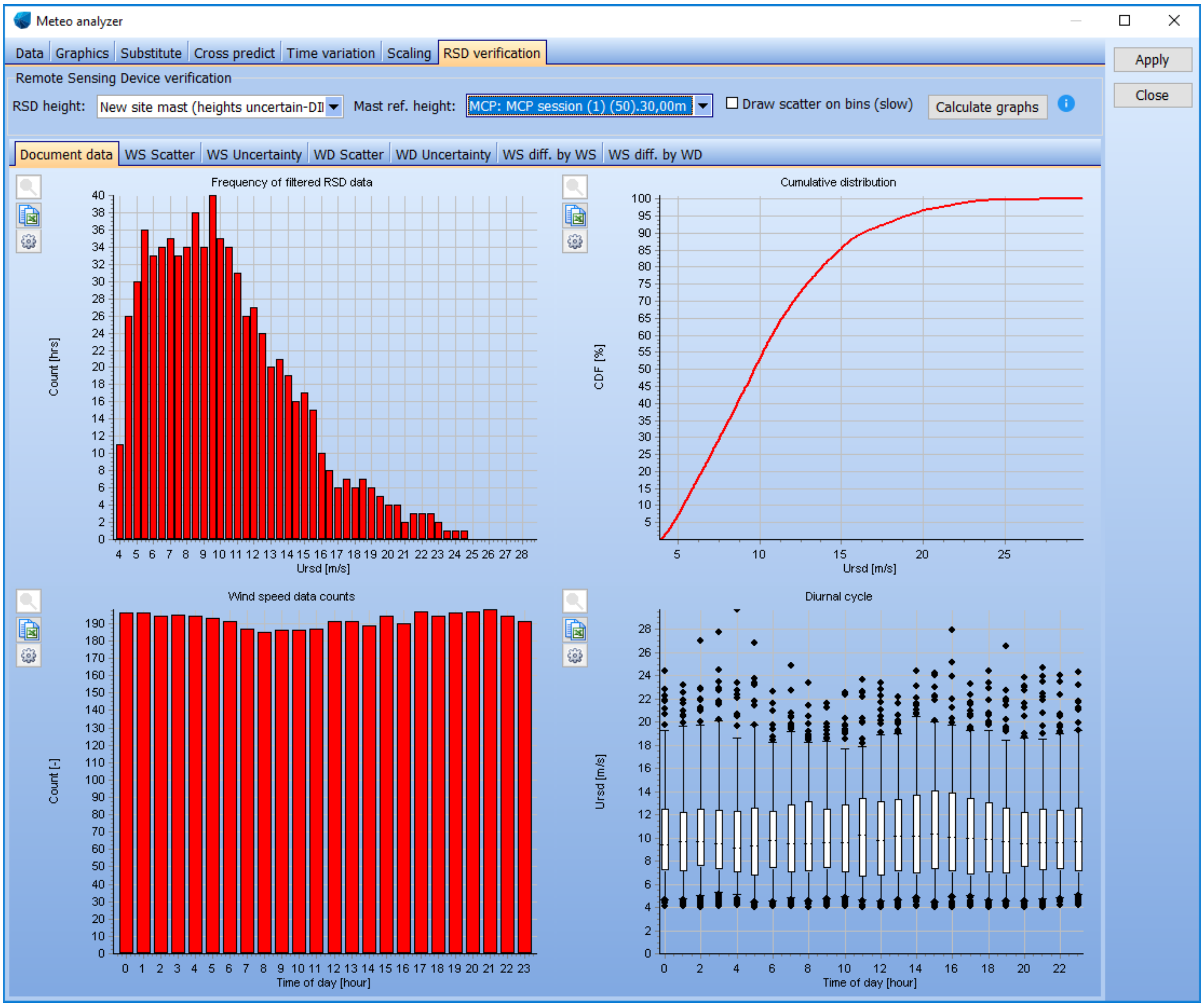


Figure 89 Example graph from RSD verification tool

Basically, all graphs and tables are generated, ready for copy paste into documentation.

12.6 Flagging and data screening

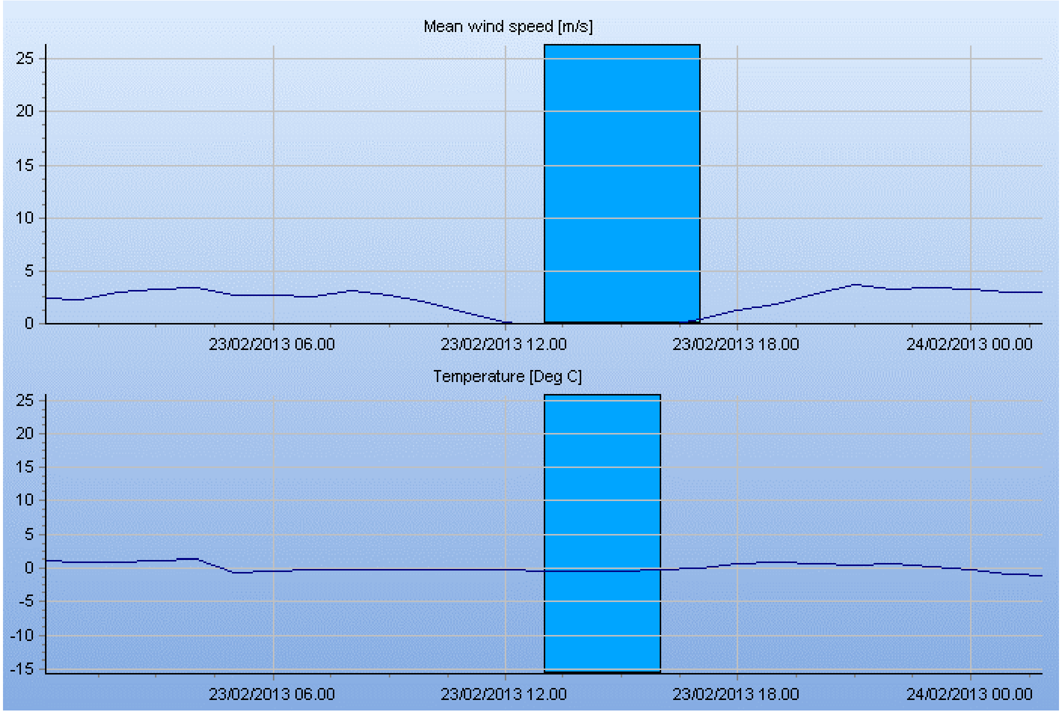
From windPRO 3.2 onwards it is possible to visually highlight data which meets a set of logical expressions. The purpose is to assist you in screening and cleaning measurement data without having to scroll through multiple signals simultaneously to spot problematic data.
For information about how to use flags, see: [Quick guide – Cleaning Data with flagging in meteo]
The following section goes into details about the flagging system.

12.6.1 What is a flag?

A flag is a set of logical expressions which can be used to define certain measurement phenomena such as icing, spiking and faulty sensors (or any other required trigger). A simple example could be the one below:

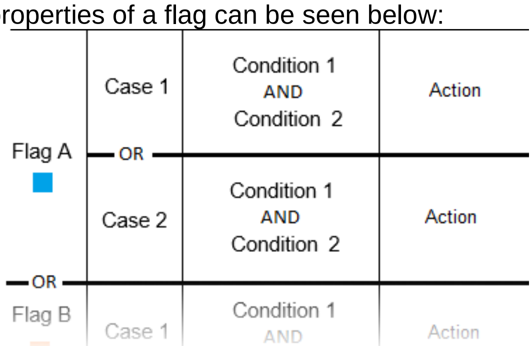
If	(“Wind speed” is less than 0 AND “Temperature” is less than 0)
OR	(“Wind direction” changes less than 2° AND “Temperature” is less than 0)
Then	Show a blue flag at the time where the above conditions are met.

Such a set a of conditions will result in a flag being displayed in the background of the time series graph, XY graph or wind speed relations graph:



Flags do not directly influence or change the data in any way but are stored as metadata. Flagging can however be used to disable some or all the highlighted data. Any changes to the original data only occur when you actively decide to disable data.

A flag consists of a name and color. A flag can contain multiple cases, which group conditions together. The properties of a flag can be seen below:



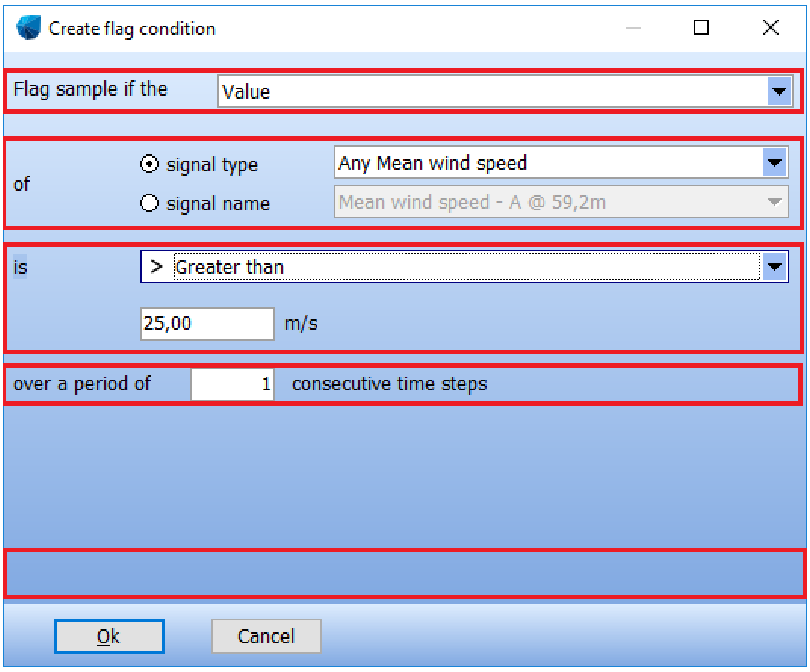
Notice the "Action" property. This allows you to create a flag which looks at the temperature but applies the flag to the wind speed signal. The signals used in a condition may thus not be the same as the signals being flagged.

12.6.2 Building conditions:

To add a new flag, open your Meteo object from the object list or the map or open it in Meteo Analyzer. Select the "Graphics" tab and click on the "Edit flags" button. This will open the flag editor window. windPRO comes with four pre-defined categories of flag: Icing, Bad signal, Mast shadow and Other. You can edit these flag categories or create your own.

When adding a condition, the following window appears, consisting of five parts:

Type of data to evaluate



Signals to evaluate

Operator and threshold to evaluate data against

Duration for which condition should stay true

Special considerations

In the following section the properties of the different parts are explained

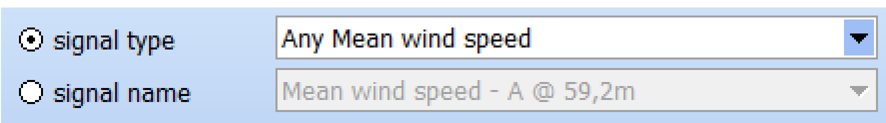
Type of data to evaluate

The first condition property to define is the type of data to evaluate. The choice of data type influences the options available further on. The formulas of the types of data to evaluate can be found below:

Type of Data	Example	Mathematical expression
Value	A is equal to 0.5	If
Difference	Difference between A and B is equal to 0.5	If
Absolute difference	Absolute difference between A and B is equal to 0.5	If
Ratio	Ratio between A and B is equal to 0.5	If You can decide if data should be flagged when B=0 using the “Condition met if second signal is zero”
Shear	Shear between A and B is equal to 0.5	if You can decide if data should be flagged when B=0 using the “Condition met if second signal is zero”
Change in time	Change in time of A is equal to 0.5	If

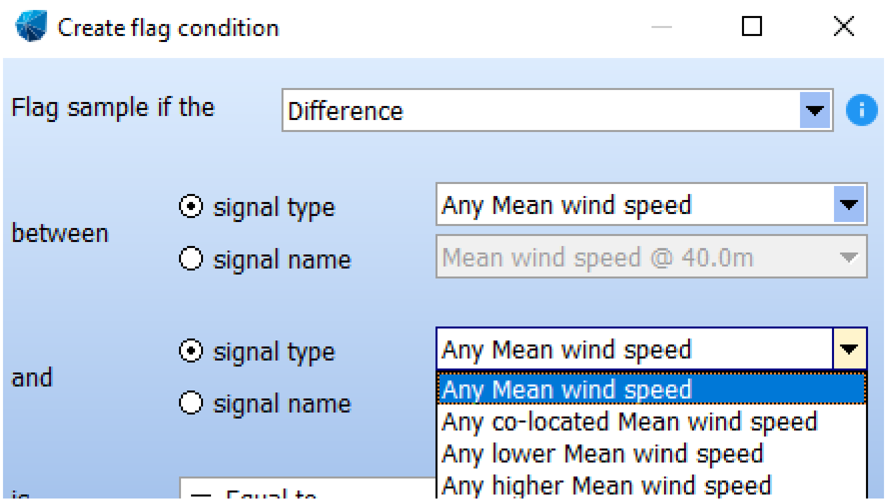
Signals to evaluate

Next step in the condition building process is to select which signal(s) to evaluate. You can decide to evaluate a specific signal with a name (e.g. the unheated anemometer at 60m), or all signals of a certain type (e.g. any mean wind speed sensor):



In the above example, the conditions will be tested against all the signals categorized in the Data setup as “Mean wind speed”. If just one of the mean wind speed signals meets the conditions, then the condition will be true.

Bear in mind, that you can flag another signal than the one used in the condition. For instance, you can use the Turbulence Intensity signal in a condition, and then display a flag only on a wind speed signal.
When you chose a type of data involving the evaluation of two signals, you can use the “signal type” to evaluate against any other signal of the same type, but at lower, same or higher height. This can for instance be used for identifying wind speed inversions.



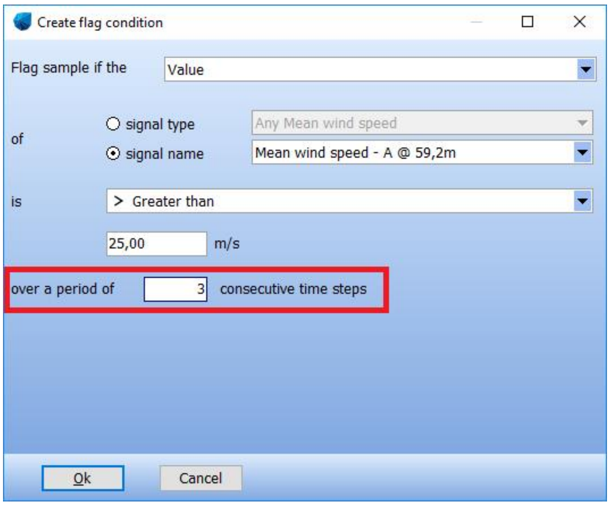
Operator and threshold to evaluate data against

A number of operators are available to compare the signal to a threshold. For example, consider a wind speed signal with the following values: 0,5,10,15,20. The conditions will then be true for the data below:

If value of wind speed @80m is	Equal to	10	Then the condition is true for	10
If value of wind speed @80m is	Not equal to	10	Then the condition is true for	0;5;15;20
If value of wind speed @80m is	Less than or equal to	10	Then the condition is true for	0;5;10
If value of wind speed @80m is	Greater than	10	Then the condition is true for	15;20
If value of wind speed @80m is	Greater than or equal to	10	Then the condition is true for	10;15;20
If value of wind speed @80m is	Within interval	5 and 15	Then the condition is true for	5;10;15
If value of wind speed @80m is	Outside interval	5 and 15	Then the condition is true for	0;20
If value of wind speed @80m is	Missing	-	Then the condition is true for	-

Condition over multiple consecutive time steps

When building a condition, it is possible to specify for how long this condition must stay true before the flag is applied to the data.



The conditions are evaluated differently over time depending the type of data being evaluated:

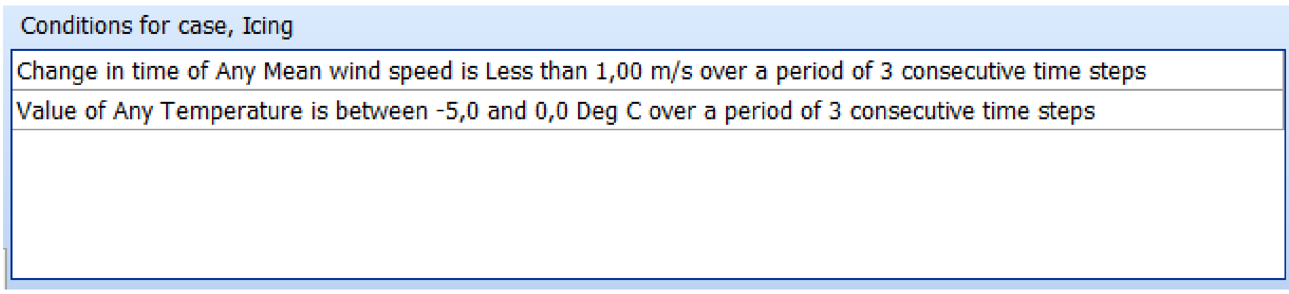
Example Type of Data	Flag data
Value of A is equal to 0.5 over 2 consecutive time steps	If AND
Difference between A and B is equal to 0.5 over 2 consecutive time steps	If AND
Absolute difference between A and B is equal to 0.5 over 2 consecutive time steps	If AND
Ratio between A and B is equal to 0.5 over 2 consecutive time steps	If AND
Shear for A and B is equal to 0.5 over 2 consecutive time steps	if AND
Change in time of A is equal to 0.5 over 3 consecutive time steps	If AND No missing samples between and

Special considerations

If a condition involves dividing numbers there is a chance that the denominator is zero. How to handle division by zero can be controlled using the “Condition met if second signal is zero”. Checking it means the condition is considered true, even if there is no value due to division-by-zero.

12.6.3 Multiple conditions

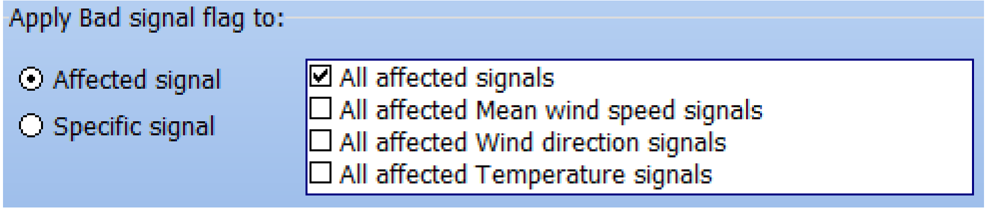
A case can contain multiple conditions. All conditions must be met before a flag can be applied to the time step.



12.6.4 Actions for flags

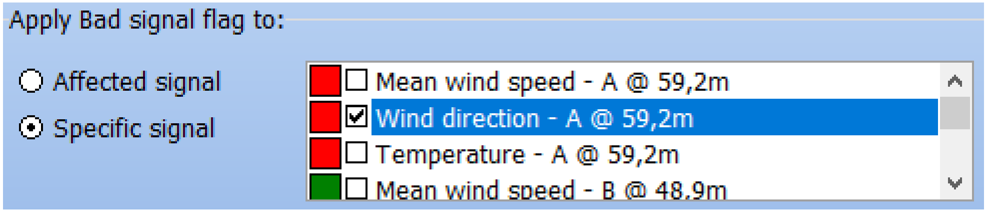
Once the conditions have been defined, it is time to decide which signals to flag. Per default, the flag will be applied to all signals used in the condition builder, but this can be changed. There are two ways of specifying which signals should be flagged:

“Affected signal”: Flag (some of) the signals which are used in the conditions.
“Specific signal”: Flag whatever signal you want, no matter which signals are used in the condition.

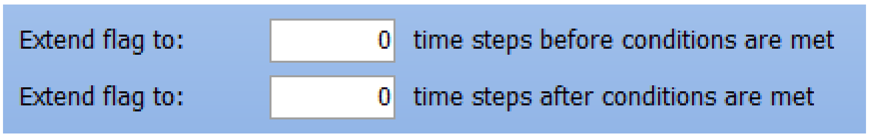


Example: Create a case with two conditions: One involving temperature, and another involving wind speed. You can specify what should happen when these two conditions are met:

- **All affected signals**: The flag will be applied to the temperature signal and wind speed signal used in the condition at the time steps where both conditions are met.
- **All affected Mean wind speed signals**: The flag will only be applied to the wind speed signal used in the condition at the time steps where both conditions are met. The flag will thus not be applied to the Temperature signal.
- If you select both **All affected Mean wind speed signal** and **All affected Temperature signals**, this will be equal to selecting **All affected signals**.
- If you select **Specific signal**, you can specify that the flag should be applied to a signal, regardless of the signals used in the conditions.



You can decide if the flag should be applied to more data than just the data which meets the conditions:

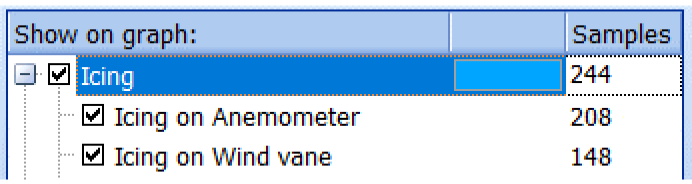


For example, the data surrounding an icing event is often suspicious. Then it’s possible to extend the flag, so it is applied to more data than meets the conditions:

Time steps where conditions are met:								
Time steps to flag:								

These extensions can also be negative numbers, so fewer time steps are flagged.

The actual number of flagged samples can be seen in the left side window:



Each case applies a flag to a number of samples. Since multiple conditions can be met at the same time, the total number of applied flags is not necessarily the sum of samples meeting the conditions of the cases. In the image above, the two cases flag data in many of the same time steps.

12.6.5 Flags in Meteo Analyzer

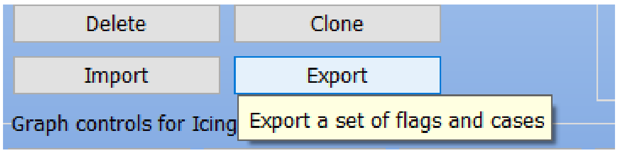
The flagging feature is used in the same way in the Meteo Analyzer as in the Meteo object.
When creating conditions in Meteo Analyzer, the list of available signals depends on the selection of Meteo objects in the Data tab.

No flags created in the Meteo Analyzer are added to the individual Meteo objects. Likewise, flags created in the individual Meteo objects are not added in Meteo Analyzer. It is therefore possible to define one set of flags in the individual meteo object, and another set of flags in the Meteo Analyser. As always, any disabling made in Meteo Analyser is applied to the individual Meteo object.

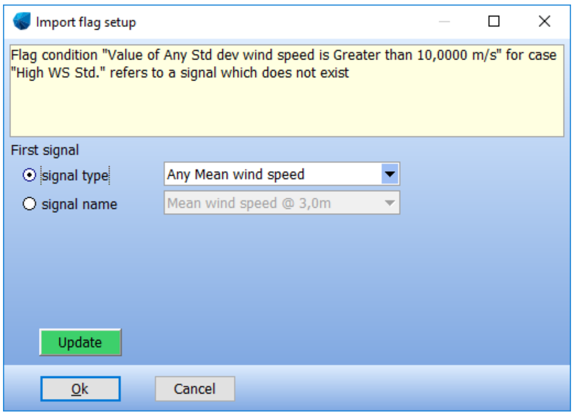
Flagging data with different resolutions
Often in Meteo Analyzer, you will have data at different temporal resolutions, e.g. one dataset in 1-hour time-steps, and another in 10-minute time-steps. If you create a condition which applies the flag to both datasets, then it is not possible to see which dataset the flag is applied to, as the flags for each dataset will be merged on the graph. When using the disable or enable features in the flagging window, the two time-series will be treated individually, however this cannot be distinguished when viewing the graph.

12.6.6 Import/Export flags

Flags can be exported from the “Edit flags” window by clicking the **Export** button:

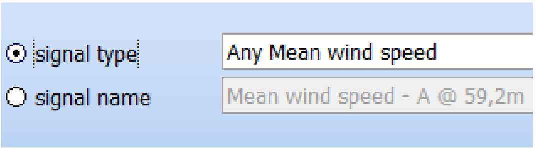


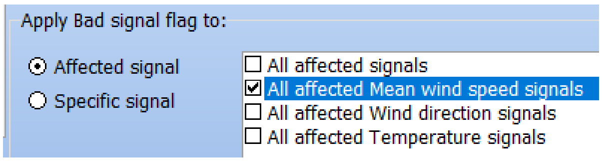
The entire flag setup (flag names, colors, cases, conditions and actions) is saved in a XML file in a user-defined location. The exported flag definition can be used in different Meteo objects, projects, and in Meteo Analyser.
To Import a flag setup, click the **Import** from the **Edit flags** window. Any existing flag definitions will be overwritten.
If you import flag definitions from a Meteo object which does not contain the same signals as the Meteo object you are exporting to, you will be asked to re-assign the signals in the conditions:



Considerations for creating templates:

Using the import/export functionality, you can create templates for use in other projects. When creating such a template it is recommended to always define the conditions using the “signal type” conditions, and then apply the flag to an “Affected signal”:

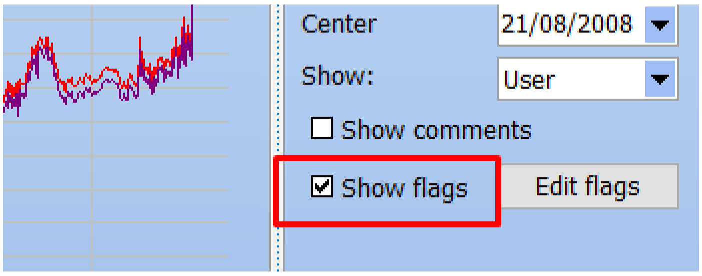




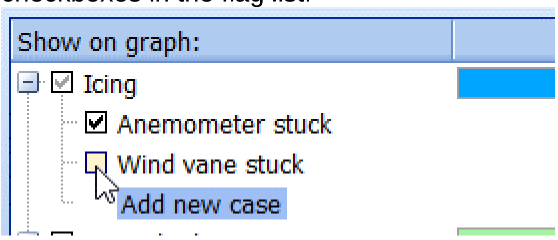
This way, the template can be used in any Meteo object without having to reassign any missing signals. This strategy can also be useful when re-using flag definitions for multiple Meteo objects in the same project.

12.6.7 Showing flags in time series graph

Flags can be shown in three graphs: the time series graph, XY graph and wind speed relations graph. They can also be shown in the Time series table (Data tab).
To see the flags in the Time series graph, make sure the “Show flags” checkbox is ticked.

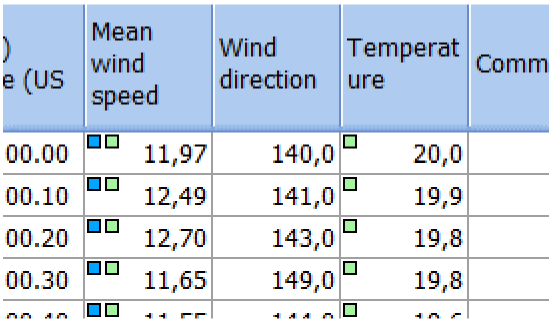


If you only want to display some of the flags or cases, you can open the flag window and untick the relevant checkboxes in the flag list:



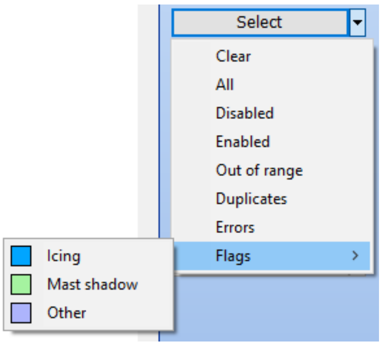
12.6.8 Showing flags in time series table

Flags are shown in the time series table found in the Data tab. The flags are shown as a small square next to the values flagged:



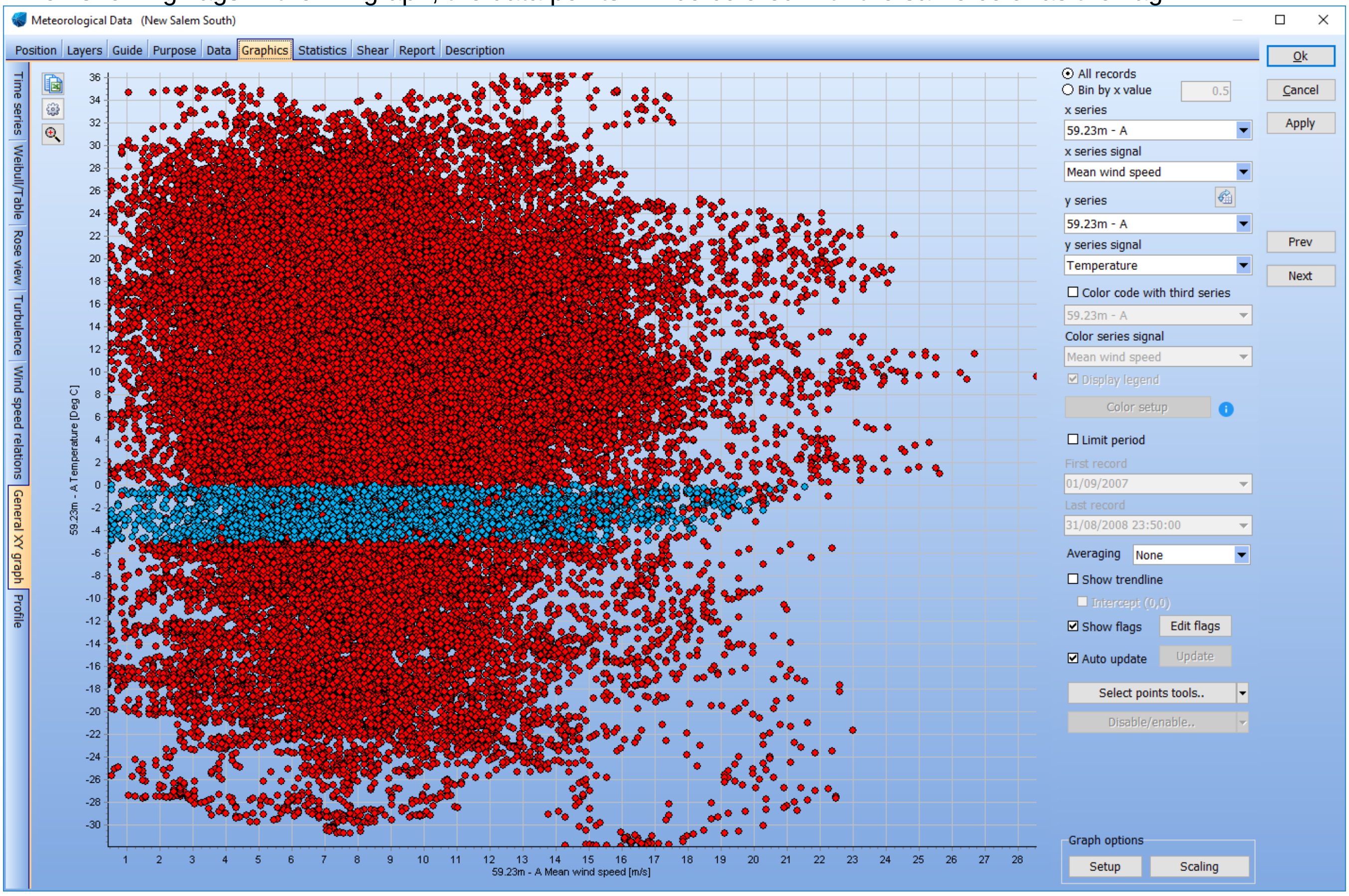
) e (US	Mean wind speed	Wind direction	Temperat ure	Comm
00.00	11,97	140,0	20,0	
00.10	12,49	141,0	19,9	
00.20	12,70	143,0	19,8	
00.30	11,65	149,0	19,8	

Hover the mouse over a flag to display the flag name.
The flags shown in the time series table reflect the choice of visible flags in the “Edit Flags”.
You can select all data with a certain flag using the **Select** button in the right-hand side:

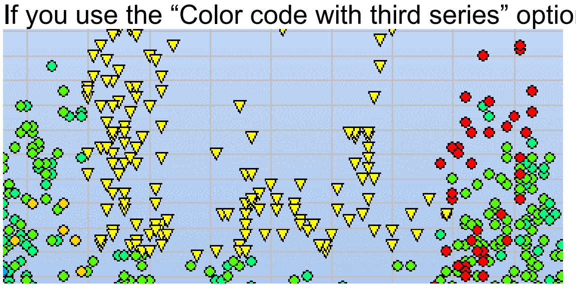


12.6.9 Showing flags in XY graph and Wind Speed Relations graph

When showing flags in the XY graph, the data points will be colored with the same color as the flag:

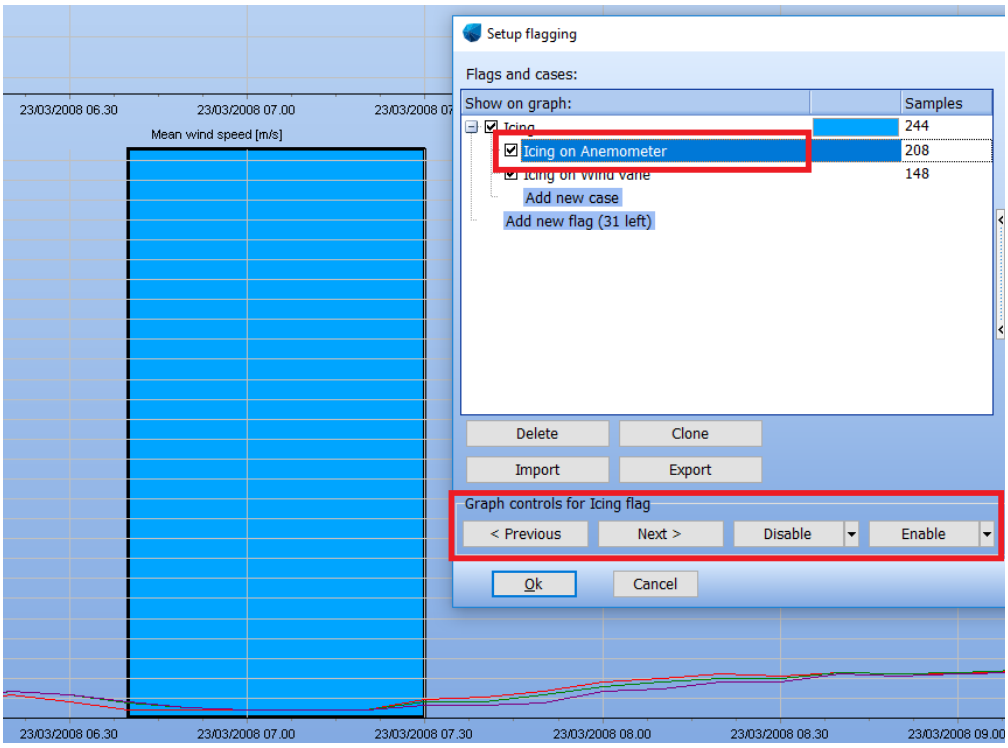


If you use the "Color code with third series" option, the flagged samples will be shaped as triangles



12.6.10 Cleaning data with flags

There are two ways to disable data with flags.
One way is to use the graph controls in the bottom of the "Edit flag" window. The graph setup can be used without having to close the "Edit flags" window. You can jump between flagged data segments using the **Next** or **Previous** buttons in the "Edit flags" window, when showing the time series graph. You can control which flags to jump between by highlighting a flag in the list of flags.



To disable the flagged data which has been highlighted in the graph, simply click the **Disable** button. If you want to speed up your disabling process, you can click the small Disable menu, and select **Automatically move to next flag, after disabling**. Then the next flag will be highlighted.
Alternatively, you can disable the traditional way using the select “Advanced Disable/enable” functionality, see section 12.3.4.1.

Currently, flags are completely independent from disabling, so any changes to the flag will not influence the disabling and vice versa. It is not yet possible to print a report of the amount of data disabled due to a flag.