USER MANUAL

Version 2.0

November 2020

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Contents

CERTIFICATE

ZERTIFIKAT ◆ CERTIFICATE ◆ 認証書 ◆ СЕРТИФИКАТ ◆ CERTIFICADO ◆ CERTIFICAT

TÜV SÜD
Industrie Service

CERTIFICATE

Testing Laboratory for Wind Energy
TÜV SÜD Industrie Service GmbH
Ludwig Eckert Str.8
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confirms for

Etulos Solute SL
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Spain

that

Furow 1.3
Modules Wind Ressource and Micro Siting

was compared with results using industry standards
and features comparable and verified results.

This certificate is based on test report no. 1707-036-ES_Rev.0

This certificate is valid until November 15th, 2021

Regensburg, 2017-11-15

Peter Meier
Head of testing laboratory

Jürgen Hahn
Project Manager

TÜV®

Version history of the document

Date	Observations	Name	Responsibility	Ver.	Comments
November 2020	Created by	ATR	Wind Resource and Site Assessment. Project Manager	1	

1 Purpose and Scope

In this document, the functionalities and the structure of **FUROW** software for version **v2.0** are presented, as well as the main rules to work inside the program. This software is a result of several years of work, partially under the ETSWIND PROJECT, developed by **SOLUTE Ingenieros** and partially financed by CDTI (Centro para el Desarrollo Técnico Industrial).

FUROW is a software program developed by **SOLUTE Ingenieros** and created with the aim of providing the user a single tool to perform a complete wind farm analysis including the analysis of meteorological data from many sources, wind resource evaluation and micro-siting. **FUROW** is characterized by a simple architecture and complex calculations are performed quickly and in an easy way for the user. Methodologies and results for wind and energy calculations are similar to others present in other wind farm analysis programs of the sector.

The information presented hereafter covers all what is needed to work within **FUROW**.

2 General description of FUROW

Along this section, the general description of the program **FUROW** is presented.

2.1 General characteristics

The main purposes of **FUROW** are the following:

1) To serve as wind data analyzer to determine the meteorological characteristics of a site and provide useful information of wind behavior of that site.
2) To serve as a wind resource calculator at different heights for a specific area.
3) To study the energy production and suitability of wind turbines for a wind project as well as to analyze the economic viability of a wind farm.

Some of its specific functions are:

- ✓ **Load meteorological data** in general from meteorological masts dataloggers, reanalysis and mesoscale data, SODAR and LIDAR.
- ✓ **Graphic representation of meteorological variables** attending to diurnal, seasonal and spatial characteristics.
- ✓ **Analyze meteorological variables time series** and describe wind distributions, wind profiles and the behavior of other variables.
- ✓ **Calculate wind resource** at any height and at any given point of an area from a map when contour levels and roughness change lines of a site are provided.
- ✓ **Layout optimization** considering restrictions and maximum energy production
- ✓ **Estimate energy production of a wind farm** including the estimation of wake losses and other losses
- ✓ **Class and subclass verification** for each wind turbine position attending to several parameters.
- ✓ **Noise and shadow flicker calculations** for environmental analysis purposes.
- ✓ **Financial analysis** to study the economic viability of a wind project.

2.2 Functionalities

The application is divided logically in several modules according to the main purposes defined for **FUROW**. Those modules are:

1) <u>Wind Measurements:</u> within this module, the following actions can be executed
   - ✓ Raw data loading and appending from data-loggers, reanalysis and mesoscale data (.nc files) SODAR and LIDAR.
   - ✓ Modification of raw data properties.
   - ✓ Data inspection, flagging with rules and filtering.
   - ✓ Generation of new data from existing variables.
   - ✓ Meteorological data vertical extrapolation.

- ✓ Graphic analysis with different plot modes.
- ✓ Correlation with reference data through MCP methods
- ✓ Data analysis: availability, Weibull distribution, fitting analysis, wind shear, turbulence, long term analysis, extreme winds, atmospheric stability, inflow angle, wind hysteresis and wind transitions analysis, temperature losses and energy production.
- ✓ Energy output calculator.
- ✓ Export time series, .tab files and others
- ✓ Another applications connector.

2) <u>Wind Resource:</u> within this module, the following actions can be executed
   - ✓ Loading files of elevation and roughness
   - ✓ Downloading bathymetric maps
   - ✓ Grid generator for elevation, roughness and bathymetry
   - ✓ Maps viewer
   - ✓ Loading of .tab files, and others related to wind distribution and turbulence
   - ✓ Wind and turbulence map calculator for multiple heights
   - ✓ Discrete wind resource calculations
   - ✓ Correction of wind maps using multiple CLIMA objects
   - ✓ Extreme wind map calculation
   - ✓ Atmospheric parameters (temperature, pressure and density) calculator for multiple heights.
   - ✓ Relocation of time series (wind speed and direction, turbulence intensity and atmospheric parameters) for any point at the site.
   - ✓ Relocation of CLIMA objects for any point at the site.
   - ✓ Profile inspection
   - ✓ Management of .WRG files.
   - ✓ Export wind speed maps in .kml format

3) <u>Micrositing:</u> within this module, the following actions can be executed
   - ✓ Import and work with wind maps.
   - ✓ Select and create wind turbines.
   - ✓ Create wind farms by defining the appropriate boundaries.
   - ✓ Wake effects calculator through different methods.
   - ✓ Wakes visualization.
   - ✓ Wind farm layout optimization
   - ✓ Wind farm energy production estimation.
   - ✓ Energy losses estimation
   - ✓ Wind sector management calculation
   - ✓ Evaluation of uncertainties

- ✓ Wind assessment at turbine sites and class verification
- ✓ Wind farm power curve calculator
- ✓ Wakes site distortion
- ✓ Noise calculation
- ✓ Shadow flicker analysis
- ✓ Financial analysis

2.3 Basic workflow

The following diagram (Figure 1) shows the basic workflow of the application, these tasks are done by a user through the GUI.

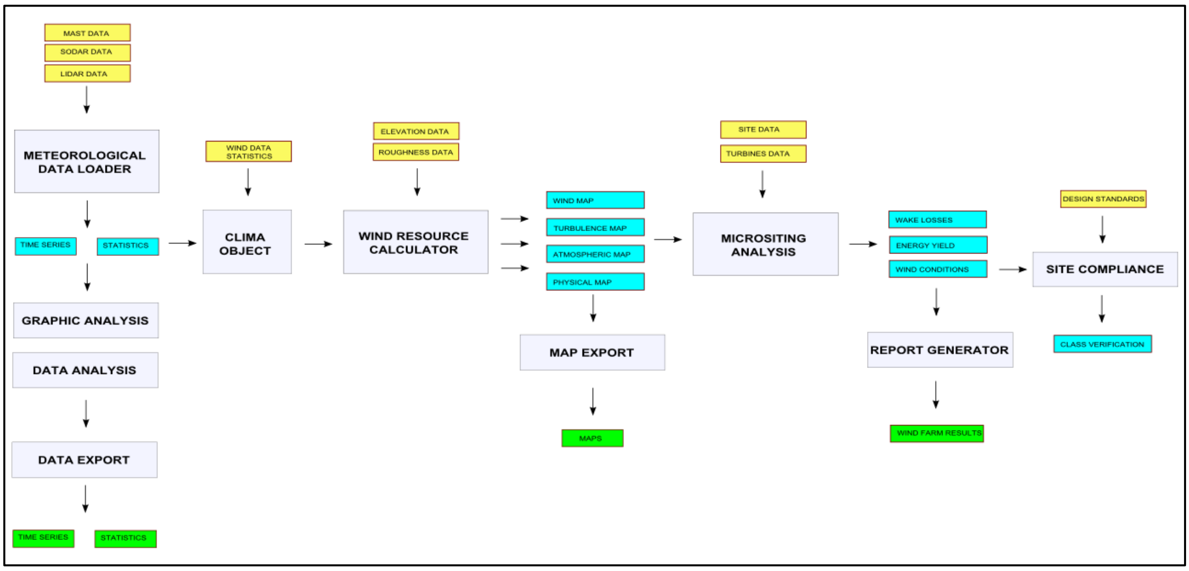


Figure 1: Workflow of the program

2.4 Logic of the application

FUROW has been designed to work connected among all modules, while the user follows the typical sequence in the analysis of wind resource and energy production.

The program is based on tree structure with objects having different properties depending of their topology. Moreover, objects are positioned in the tree according to a degree of hierarchy, which is defined through the properties that are shared by one or several objects.

On the other hand, the program is designed in a way that the user follows the standard procedure established in the wind energy sector to perform correct wind resource analysis and energy production calculation.

The tree structure of the data and results with all objects is one shown on Figure 2. The description of every object will be shown on next sections.

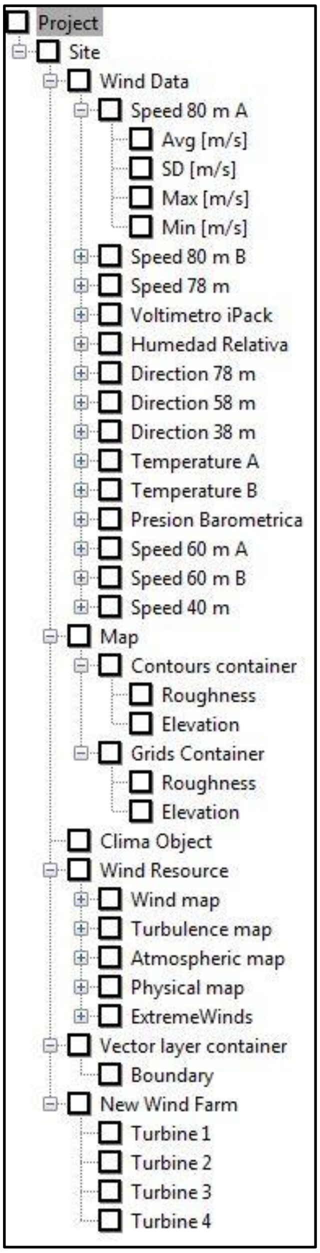


Figure 2: Tree structure of the program

2.5 Interface and GUI

All user actions are done through a Windows-like GUI. The GUI is the main interface. It is a resizable window that can be maximized to get the best user experience by using all the space that their display devices can offer. Minimum display size is set to 1024x768 pixels, but this tool is not guaranteed to work properly in lower resolutions. GUI interactions are performed by using a keyboard and a mouse.

2.6 Runtime environment, distribution and deployment

FUROW is intended to be a closed-source tool, so clients that buy it have no access to source code. **FUROW** is packed and distributed by a single installable file (.exe). Any additional required software is also provided.

Machine architectures supported are x64 (if required architecture x86 can be provided). This application shall run in personal computers running one of the following operating systems (when they have the required software installed):

- Microsoft Windows XP (some incompatibility issues have been found)
- Microsoft Windows Vista
- Microsoft Windows 7
- Microsoft Windows 8
- Microsoft Windows 10

English (EN-us) is the main language of this tool. This application must adapt its GUI and output text files to the operating system regional configuration.

SWS is the extension of the files that this tool can natively manage, and they must have their own icon to distinguish them from the rest of files.

Projects can be managed correctly with computers with at least an installed RAM memory of 4.0GB, but 8.0GB is desirable to exploit software capabilities to its maximum.

3 FUROW structure

The project window of **FUROW** has the structure shown on Figure 3.

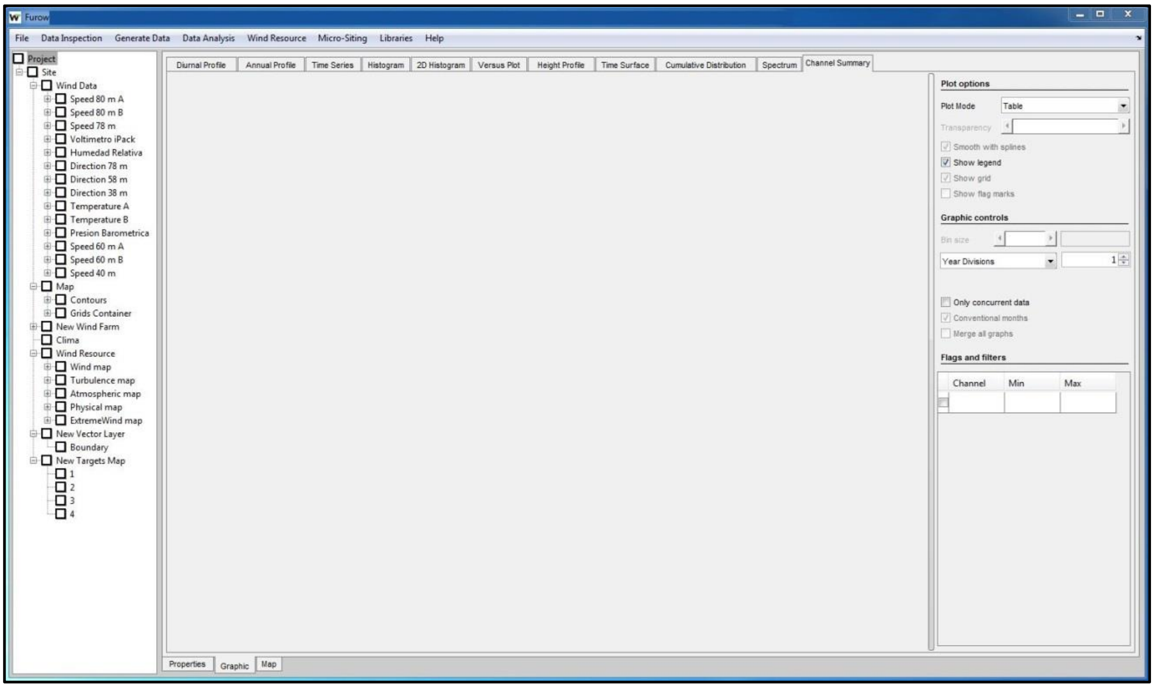


Figure 3: FUROW structure

Several working areas are identified in the program window:

1) Menus and toolbars
2) Tree panel
3) Window area
4) Plot options and filters

3.1 Menus and toolbars

The different menus in the application are:

- File: allows opening all types of files supported by the application, save **FUROW** projects, download Reanalysis data, capture images from the window area and close projects. Additionally, the settings of the program can be modified by changing the preferences (see Figure 4).

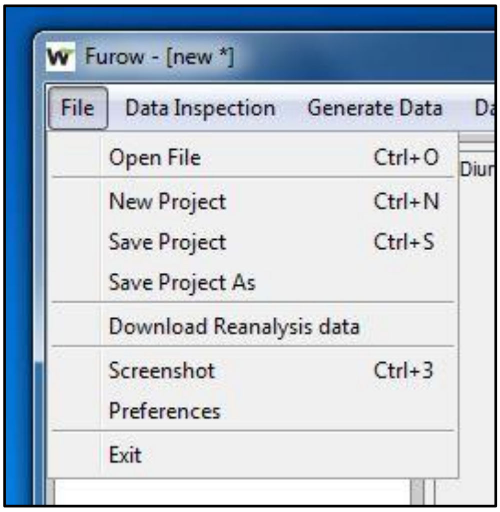


Figure 4: File menu

- Data Inspection: allows the user to view raw data coverage as well as it provides tools for the process of data screening by flagging data, analyzing the possible influence of the mast tower in the measurements, changing the time intervals and modifying raw data by changing calibration parameters (see Figure 5).

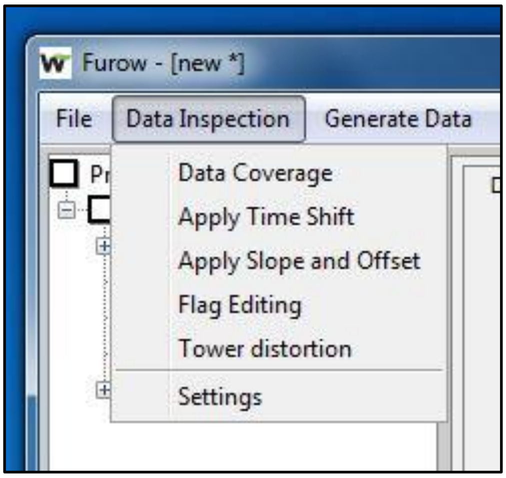


Figure 5: Data inspection menu

- Generate Data: allows creating new data from raw data or flagged data, by combining channels, extrapolating variables or correlating with some reference channels. It is also possible to fill gaps using different channels and methods through MCP window (see Figure 6).

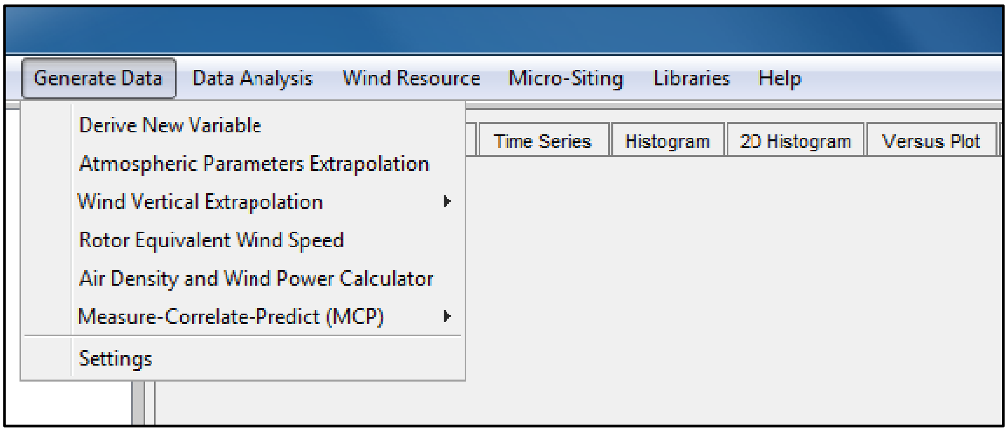


Figure 6: Generate data menu

- Data Analysis: once data have been filtered and new variables have been synthesized, it is possible to make specific analyses. These analyses include the following: Availability, Weibull Fit, Scatter Plot and Fitting, Turbulence, Wind Shear, Long Term, Extreme Winds, Atmospheric Stability, Inflow Angle, High Wind Hysteresis, Wind Transitions, Temperature Losses and Energy Production (see Figure 7).

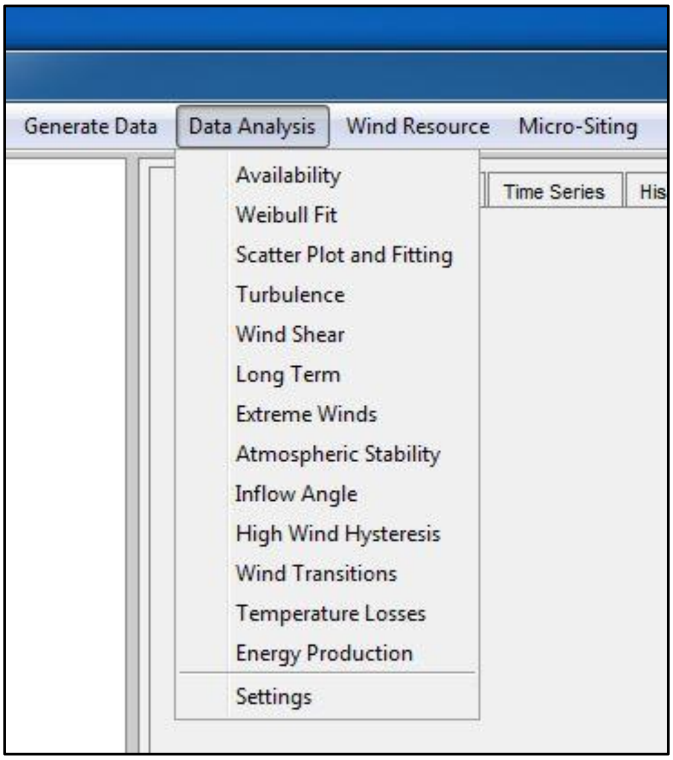


Figure 7: Data analysis menu

- Wind Resource: once wind speed and direction and other variables have been properly characterized at the mast position though a CLIMA object; the elevation and roughness grids are created, wind speed, turbulence and atmospheric maps can be calculated for the whole map. Additionally, a map for extreme wind conditions can be calculated (see Figure 8).

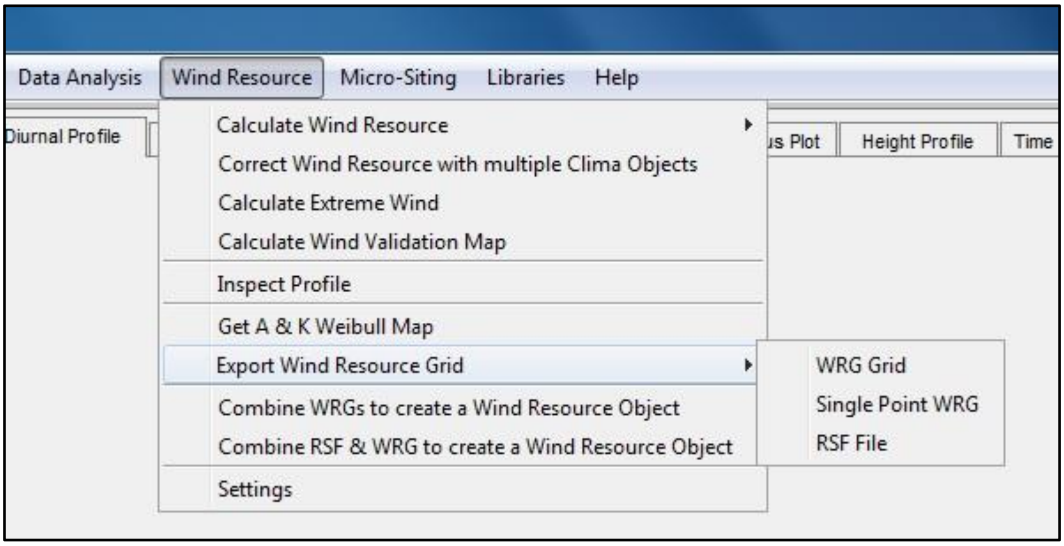


Figure 8: Wind resource menu

- Micro-siting: allows inserting wind turbines and boundaries of the wind farm for the estimation of energy production using different wake models. Wind speed deficits with different wake models can be shown for a given configuration. Moreover, wind conditions at each turbine point can be determined and class and subclass of each wind turbine can be verified (see Figure 9)

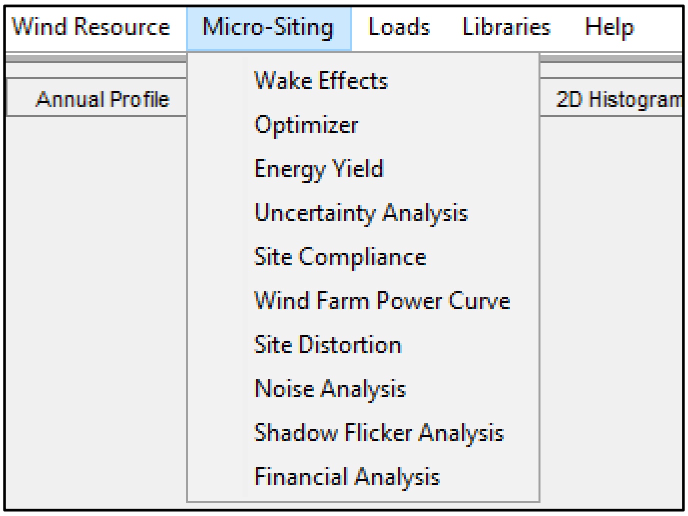


Figure 9: Micro-siting menu

- Libraries: under this menu, wind turbines technical specifications can be edited. It is possible to add wind turbines to the existing databases or create new ones through an Excel template (see Figure 10).

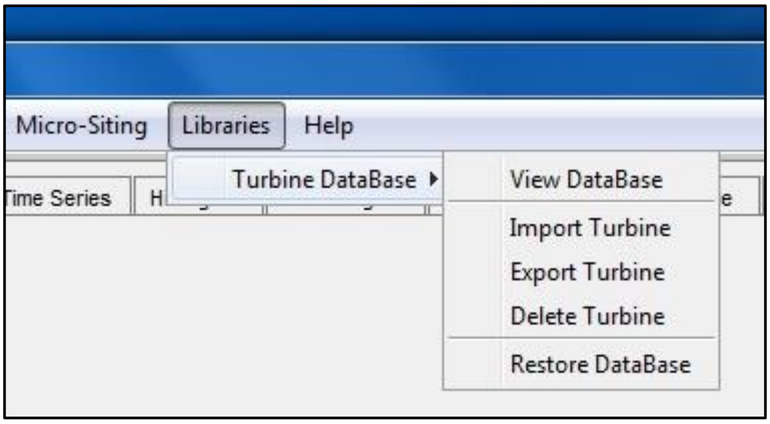


Figure 10: Libraries menu

- <u>Help:</u> under this menu, the user can view the current version of the program and the license status and terms (see Figure 11).

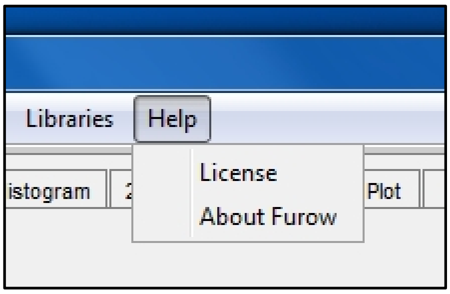


Figure 11: Help menu

3.2 Tree panel

On the tree panel, the user can keep track of all information inserted into the program as an independent object, as well as new objects generated through calculations.

3.3 Window area

The *Window area* is divided into 3 different parts:

1) At the bottom, the program has 3 tabs (*Working mode tabs*) to choose from:
    a. *Properties tab*: properties of each object can be edited or visualized when this tab has been clicked.
    b. *Graphic tab*: with this tab activated, the program shows graphs derived from plotting meteorological data
    c. *Map tab*: within this tab, all kinds of maps can be viewed, but not edited.

2) At the top, the program shows multiple tabs (*Tool tabs*) depending on the *Working mode tab*:
    a. Within the *Properties tab*, tabs for each type of object show up. At each tab, the properties of each object belonging to each class can be edited.

b. Within the *Graphic tab*, tabs for each type of representation for time series are shown
c. Within the *Map tab*, just one tab is present.

3) The center of the window has the main graphing and plotting area, being available both for the *Graphic tab* and the *Map tab*, that is, time series representation in different manners and maps representation of each type.

3.4 Plot options and filters

This area is oriented to visualize graphs with different types of plots or using filters to visualize graphs accordingly to the filters chosen.

This area is divided depending on the actions to be performed by the user:

1) Plot options area: the user can change the type of representation in the *Graphic tab* by changing to the following plot modes. Moreover, transparency can be adjusted for each graph, and splines can be used to smooth each one of them.
   a. **Line:** connects points of the graph
   b. **Area:** shows the area under the line connecting the points
   c. **Bar:** shows each point as a bar with the height equals to the value
   d. **Surface:** shows 3D surface adding a third dimension to be represented
   e. **Boxplot:** shows statistical values (mean, 25% and 75% percentile by default)
   f. **Table:** shows numerical values on a table

2) Graphic controls area: the user can change the time step or the bin size for the representation of any channel, and also decide whether to use or not concurrent data. At this area the user can also split the representations according to:
   a. **Year divisions:** values of variables are separated in different groups (months of the year). Once these divisions are done, all graphs can be merged in one through the checkbox "*Merge all graphs*". "*Conventional Months"* can be used with the checkbox.
   b. **Day divisions:** values of variables are separated in different groups within one day and with different time length. Additionally, the starting hour to form the groups can be modified. Once these divisions are done, all graphs can be merged in one through the checkbox "*Merge all graphs*".

3) Filters area: the user can define a specific interval of time to work with including variable ranges of dates, or specific years and months. The user can also determine specific ranges of a given channel to represent other channels on the *Graphic tab*. Finally, the user can select which data to represent on the *Graphic tab* depending on the flag type marked.

3.5 Preferences

There is a dialogue in the program where the user can set the preferred options to operate with the program including all modules subjected to have default conditions (i.e. number of sectors, vertical gradient of properties, default wake model, etc.).

There are some general options which are related to the working directories, some preferences for loading data and the time step of the project, options related to data export and graphic options such as the box plot percentiles.

Under the File menu it is possible to take screenshots from the *Graphic tab* or the *Map tab*, and on Preferences dialogue it is possible to set the working folder where these screenshots will be saved.

The original default options of **FUROW** can be restored by clicking on "*Restore default settings*".

On Figure 12 general settings of the program are shown.

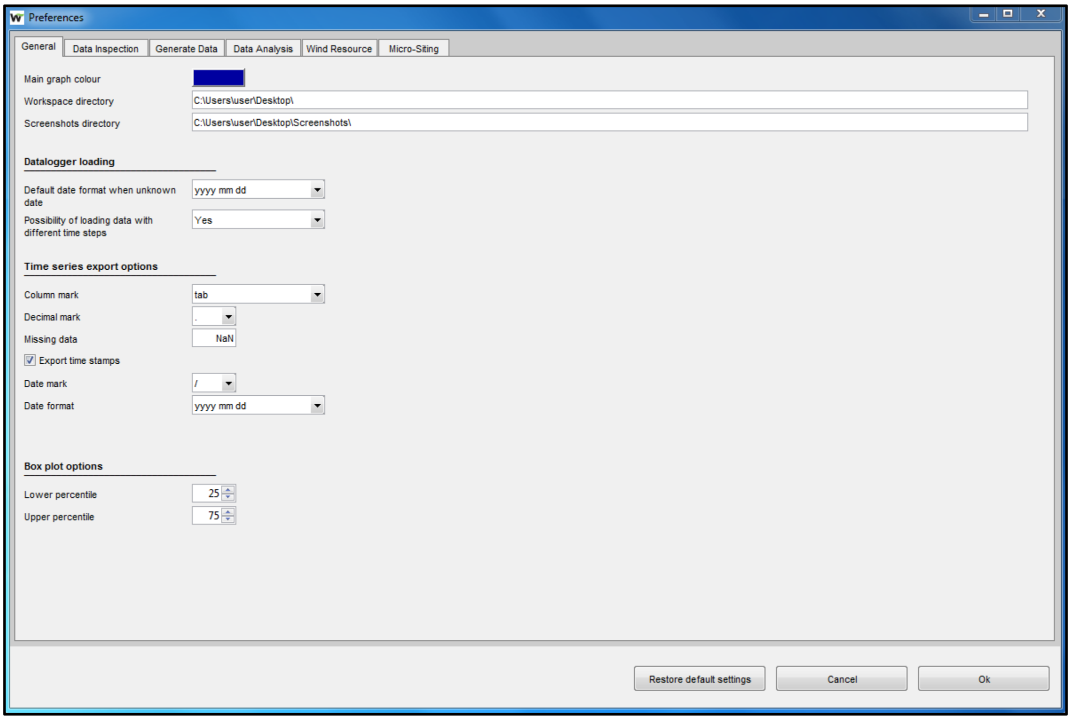


Figure 12: Preferences dialogue

4 FUROW objects

Within a project, there are different objects the user can create, modify or remove. Next, all objects are explained:

1) Object PROJECT: This object contains the name of the project and a possible description of the project entered by the user. Only one project can be managed in one window, although several projects can be opened at once in different windows.

2) Object SITE: This object contains information about the site at which one or several wind farms will be developed. Also, if WIND DATA objects have been loaded already, the position of all of them will be shown on a Google map.

3) Object WIND DATA: This object is created provided some meteorological time series are loaded into the program. Input meteorological data can be mast data (from a data-logger), SODAR data or LIDAR data. The program also supports loading files from NWP models (or other scientific data source) on .nc format. Each WIND DATA object has a unique position, in a way that it is possible to have several objects of this type.

   There are different properties such us the coordinates of geographic position, elevation above sea level, time step, meaning of time stamp, measuring system type (MAST/SODAR/LIDAR/Reanalysis node/Mesoscale node) and model and data-logger type. All sensors (once they have been added correctly) can be represented on a schematic of the measuring device (either mast, SODAR or LIDAR).

4) Object SENSOR: this object determines what kind of variable is being measured by an actual instrument (wind speed, wind direction, temperature, pressure, etc.) or hypothetical instrument as a result of combination of different variables (turbulence intensity, wind power, air density, etc.). All sensor names can be changed from original name interpreted from data-logger file.

   The height of the instrument and the units must be set. **FUROW** offers a database of common sensors to choose from, to have a better idea of the sensor configuration. Since sensors can be represented, boom orientation can be set to have an approximate idea of their layout. Finally, calibration and slope parameters can be set on the "*Apply slope and offset dialogue*" in order to make appropriate changes if important differences between calibration parameters and data-logger parameters exist.

   In the case of a SODAR or LIDAR, the sensor (i.e. wind speed) does not have a specific height since all channels (each of them at one different height) are inside of this sensor. This allows reducing the size of the tree.

5) Object CHANNEL: this object contains properties such as the height (inherited from the sensor property), color and the type of statistic is represents (average, standard deviation, maximum, minimum and coverage). The statistic coverage is used specifically for the channels created as an availability channel.

6) Object CLIMA: a CLIMA object has all the statistical information about the meteorology of the site based on information about wind speed, wind direction, turbulence, pressure, temperature, humidity and atmospheric stability. This object is necessary to create all wind, turbulence and meteorological maps. This object can be created from existing channels or from existing files exported from **FUROW** itself or other software.

7) Object MAP: This object has the general information about the topographical aspects of the site. Among others, it has information about Map Projection, Datum and Time Zone.

8) Object CONTOURS CONTAINER: This sort of object is like an "empty" object which contains information of the boundary coordinates of the map, that is, minimum and maximum coordinate of both maps of height contours and roughness.

9) Object CONTOURS: These types of objects represent contour levels of a scalar field, such as elevation or roughness length.

10) Object GRIDS CONTAINER: This sort of object is also an "empty" object which contains information of the grids below it (maximum and minimum coordinates of the map). In this case, this object has a type associated to it such as: topographic, wind, turbulence, atmospheric, etc.

11) Object GRIDS: Grids are the scalar fields over a part of the map derived from calculations such as the grid calculation, wind resource estimation and others. As properties, the type of the grid is considered, as well as the boundary coordinates, the grid resolution and the calculation heights. Maximum and minimum values of the scalar fields are also shown. Finally, the color scales can be edited: either an *Auto color* scale can be used (depends on the visible layer on the Map tab, being this option the default) or a user defined color scale with a minimum and a maximum value (which is constant for all layers belonging to that specific grid).

12) Object WIND RESOURCE: this object acts as a container of all grids generated when performing the wind resource calculation. It also contains some of the key parameters to perform the calculations such as the calculation method for wind speed and turbulence, forest parameters and others.

13) Object WIND FARM: this object contains as children wind turbines of different types.

14) Object WIND TURBINE: Each object of this kind has among its properties the following information: coordinates, wind turbine model, rotor diameter, hub height, class and subclass.

15) Object VECTOR LAYER CONTAINER: This sort of object is also an "empty" object which contains vector layers such as polygons, lines and others.

16) Object VECTOR LAYER: Vector layers are polygons, lines and other kinds, whose type can be selected, as well as the buffer for affecting the positioning of wind turbines.

17) Object IMAGE: images are downloaded from Google for a specific area.

18) Object TARGET POINTS CONTAINER: This sort of object is also an "empty" object which contains target points where magnitudes are going to be calculated

19) Object TARGET POINTS: target points are specific locations with coordinates and height where magnitudes are calculated, being the noise level or the geometrical characteristics for shadow flicker calculations the included properties on this version.

4.1 Project files

All information related to the project is well saved keeping the tree structure of the objects as well as any other information necessary for the files to be opened correctly. All **FUROW**'s files are saved with the extension **.sws**.

5 Raw data loader

Time series are written by data-loggers. **FUROW** can read several file formats that are written by widely-used data-loggers, and through an algorithm, **FUROW** will extract the most of the file content automatically to free the user to enter manually the maximum amount of data. The goal of the data loader is to identify the period of measurements and the time series, but it will also try to extract the type of each channel and the measurement height. All information extracted is written on the *Properties tab* depending on the object, and missing information should be entered by the user depending on the action.

When information regarding to starting dates and hours, and time steps cannot be deducted from the raw data file, a pop-up menu will show up and will allow the user to indicate the starting date and hour as well as the time step.

There can be gaps between consecutive timestamps larger that the habitual sample rate of the file and these cases are processed like periods in which measurements have been taken but all values are missing.

Files may have unsorted data. Once read, data in time series are sorted by its time stamp. If there are repeated instants only the last of them is accepted, and the rest are rejected.

Once files are read, the program generates a structure of objects: WIND DATA, SENSOR and CHANNEL (See Figure 13).

In this new version the user can move the elements of any wind data, including sensors or channels, so the order is decided by the user. In order to move a sensor or channel, the user must highlight it and while doing left click with the mouse, drag the tree node to another position of the tree. Once a node is moved, the new order is updated on the *Properties* tab. It must be remarked that when a channel is moved to another sensor, if a filter with that channel had been created, it is automatically removed, so it is convenient to arrange the tree structure first and then create the filters.

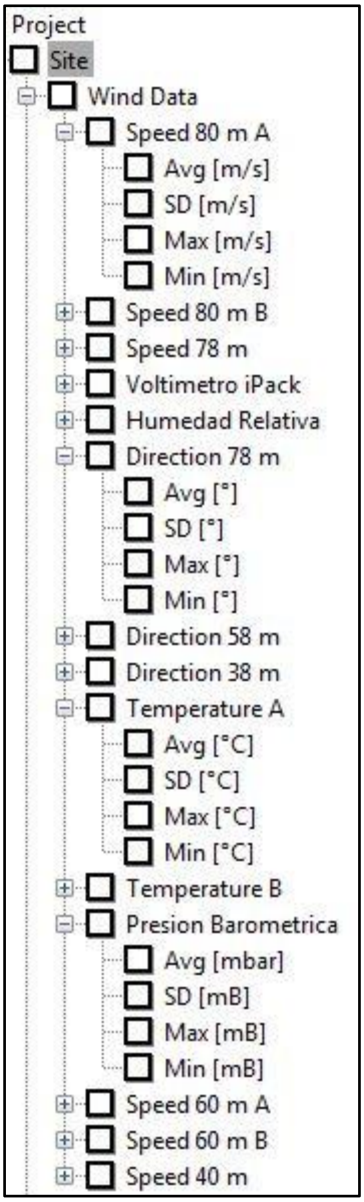


Figure 13: WIND DATA structure

5.1 Data appending

If files are written on daily, weekly or monthly basis, it is possible to append new data, being the program able to recognize channels of the same kind. The assumptions made when appending are the following:

- Measurement period is the least period that covers the old measurements period and the measurements period of the just appended data. If there are gaps in between, they are considered as missed samples.
- Channels from existing project and just loaded data shall be linked:
    - Channels existing in the project but not in the new data will have as missing value every value in the measurement period of new data.

- Channels not existing in the project but existing in the new data will have as missing value every value in the old measurement period.
- Channels existing in both will be merged: result channels will have the data of both origins. If periods overlaps and at the same instant there is only one measurement, that will be taken as valid value; if there are two values at the same instant, the value from the new data is considered as valid by default.

5.2 File formats

File formats which can be interpreted by **FUROW** are the following:

- **.txt** files from any type of data-logger, SODAR or LIDAR
- **.dat** files from any type of data-logger, SODAR or LIDAR
- **.xls** files from any type of data-logger, SODAR or LIDAR
- **.csv** files from any type of data-logger, SODAR or LIDAR
- **.xlsx** files from any type of data-logger (excel 2007 needs to be installed in the computer)
- **.nc** files from meteorological data

5.3 Time steps

One of the characteristics of **FUROW** is that the project allows loading data from different time steps working with both WIND DATA objects simultaneously. Therefore, it is now possible to work with measured data and Reanalysis data for example to perform MCP analyses.

It is important to remark that every WIND DATA has an associated time step, so it is not possible to append new data with different time step on a given WIND DATA object.

FUROW works internally with the minimum time step, so it is important to be aware that long term time series with a time step larger than 10 minutes can take up a lot of space when analyzed together with measured data and slow down operations. However, when measured data (typically with smaller time step) is removed and remaining data has a larger time step, then the whole internal data matrix is restructured with a new time step, thus making calculations faster.

5.4 Types of sensors and channels

There are several instruments which are used on wind measuring which produce different outputs. Some of those which should be included are described below:

- Wind speed
  - Channels: mean, stdv, max, min
  - Units: cm/s, m/s, km/h, mph, knots
- Vertical wind speed
  - Channels: mean, stdv, max, min
  - Units: cm/s, m/s, km/h, mph, knots

- Wind direction
    - Channels: mean, stdv, max, min
    - Units: º, rad
- Temperature
    - Channels: mean, stdv, max, min
    - Units: ºC, ºF, K
- Pressure
    - Channels: mean, stdv, max, min
    - Units: Pa, hPa, kPa, mbar, atm, psi, mmHg
- Relative humidity
    - Channels: mean, stdv, max, min
    - Units: %
- Radiation
    - Channels: mean, stdv, max, min
    - Units: W/m^2, $MJ/\ m^2/day$, $kWh/\ m^2/day$
- Precipitation
    - Variables: mean
    - Units: mm, inch, l/m^2

Other sensor types can refer to other types of variables derived from the program itself or imported from a file such as: turbulence intensity, wind power, air density, inflow angle, noise, quality, battery voltage, power production, Obukhov length and Richardson number.

On Figure 14 an example of a sensor table in the Properties tab is shown.

	ID	Sensor type	Units	Height
Wind Data Speed 80 ...	Speed 80 m A	Wind speed	m/s	80
Wind Data Speed 80 ...	Speed 80 m B	Wind speed	m/s	80
Wind Data Speed 78 ...	Speed 78 m	Vertical wind speed	m/s	78
Wind Data Voltimetr...	Voltimetro iPack	Battery voltage	V	10
Wind Data Humeda...	Humedad Relativa	Relative humidity	%	80
Wind Data Direction...	Direction 78 m	Wind direction	deg	78
Wind Data Direction...	Direction 58 m	Wind direction	deg	58
Wind Data Direction...	Direction 38 m	Wind direction	deg	38
Wind Data Tempera...	Temperature A	Temperature	ºC	80
Wind Data Tempera...	Temperature B	Temperature	ºC	10
Wind Data Presion B...	Presion Barometrica	Pressure	hPa	10
Wind Data Speed 60 ...	Speed 60 m A	Wind speed	m/s	60
Wind Data Speed 60 ...	Speed 60 m B	Wind speed	m/s	60
Wind Data Speed 40 ...	Speed 40 m	Wind speed	m/s	40

Figure 14: Sensor table

It must be remarked that for every channel of a sensor, a new availability channel can be generated. This new channel has values which are 0 or 1 if the data exist or not. In that way, the availability of a given period can be obtained when averaging time series in the *Graphic tab*. Figure 15 shows how to create availability channels from a sensor, and how the tree looks like after creating them. Moreover, availability channels are linked channels, so, if some data are flagged or filtered, then they are automatically updated to provide consistent values. Additionally, availability takes into account the time step of each WIND DATA object.

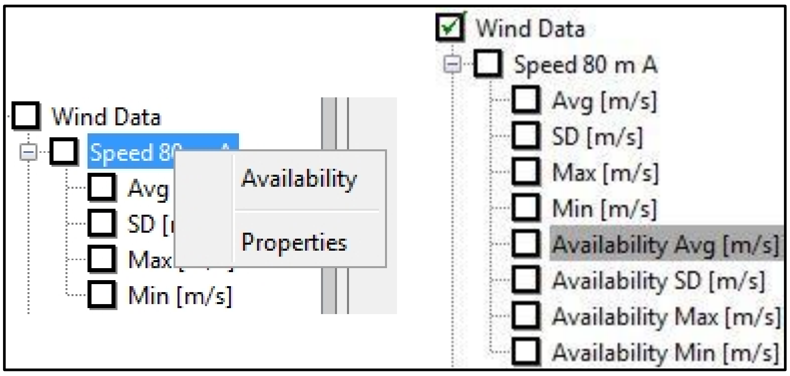


Figure 15: Availability channel

<u>Note:</u> currently, the units for each sensor are merely descriptive, as FUROW works with International System as the reference. That is, even if sensors have other units, FUROW will interpret them to be in “correct” units. Thus, if the user wants to proceed with calculations and obtain consistent results, it will first be necessary to convert every channel to International System units.

Units considered for wind resource calculations are:

- **Wind speed → m/s (both for mean wind speed and standard deviation)**
- **Vertical wind speed → m/s**
- **Wind direction → degrees**
- **Temperature → ºC**
- **Pressure → hPa**
- **Relative humidity → %**

5.5 Download Reanalysis data

On this new version, a new module to download Reanalysis data has been included. This module allows downloading meteorological data from five different Reanalysis models: MERRA, MERRA-2, ERA-INTERIM, ERA-5 and CFSR. Each one of the models has different variables, including wind speed and direction, temperature and pressure; also time steps are different and available period of time are also different.

Wind speed, direction and temperature are extracted at different heights, being in meters for MERRA and MERRA-2, whereas for ERA-INTERIM and CFSR, some are provided in meters and others are referred to the sigma levels (although its approximate conversion to meters is shown). On the other hand, pressure is defined at sea level so arbitrarily a height of 0m has been selected (although the user may change it under properties tab).

The user will be able to interpolate any variable at any pair of coordinates as long as the *"Spatial interpolation"* check button is marked. Otherwise, the selected coordinates will coincide with the model nodes (which have different resolution depending on the model selected). In order to select selected the point, **FUROW** can show some google maps (satellite, terrain, road and hybrid) or a map with the average wind speed calculated for a 20 year period of time. Finally, when the selected model is the ERA-INTERIM it is possible to make a temporal interpolation from 6 hour to 1 hour step. The interpolation is done through a Piecewise Cubic Hermite Interpolating Polynomial.

An example of the interface is shown on Figure 16.

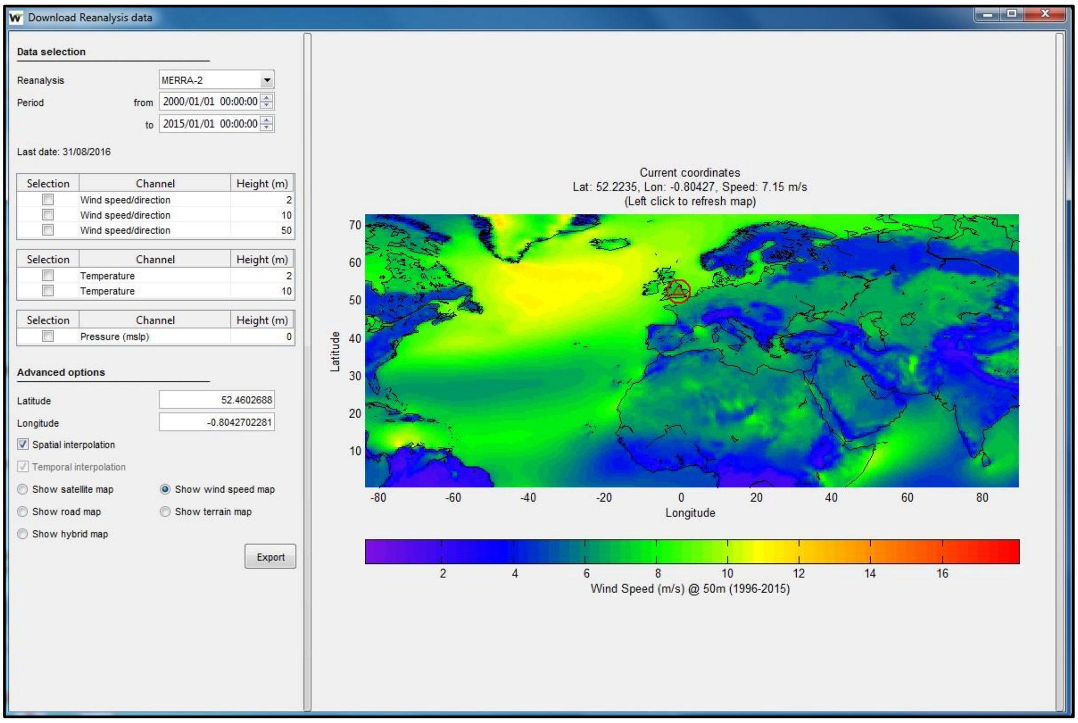


Figure 16: Download Reanalysis data module

6 Graphics

At the *Graphic Tab* many representations can be performed.

It is possible to modify the plot mode options, increase or decrease the transparency level, smooth data with splines and show or remove grid and legends. The graphic representation can be done through lines, areas, bars, surfaces, boxplots and tables. Not all kinds of representations are available for each tab, except for the table mode as it allows exporting the data the user is viewing all the time.

At the *Graphic Options* area, the user can modify the time step of representation (depending on the action), acting as a filter. Moreover, the user can change the number of divisions per year and per day, to have a greater insight of what is happening with any atmospheric variable within the year or the day. "*Concurrent Data"* checkbox can be selected if there are large discrepancies among levels to compare in identical conditions and when "*Conventional Months"* checkbox is clicked, divisions taking into account the length of each month are performed. If the user wants all graphs to be represented in one window, then the option "*Merge all graphs"* should be clicked.

It must be highlighted that when two different sensor types are selected, the program will display two axes, so the user will be able to compare several magnitudes in one single graph.

In general, all mode options allow the user clicking and inspecting each point represented on the window.

Finally, at the *Filters* area, it is possible to determine which data the user wants to view or exclude, applying temporal filters, and filters by direction and by any variable. Flags created on the "*Flag with Rules"* dialogue can be marked to ignore those elements included on the flag.

6.1 Representations

6.1.1 Diurnal profile

This representation allows plotting the average evolution of an atmospheric variable along the day. In all plot modes (except on surface mode), the x axis represents time (whose step can be modified) whereas the y axis represents the magnitude of the variable. On the surface mode, if selected channels have one height assigned, the y axis will represent the height, and the variable magnitude will be represented by the color scale. As indicated on the ***Theory Manual*** wind direction averages are performed differently than a scalar magnitude. On Figure 17 a diurnal profile of 4 wind speed channels is shown using a surface mode. It is noticeable how wind speed increases during the day in lower levels.

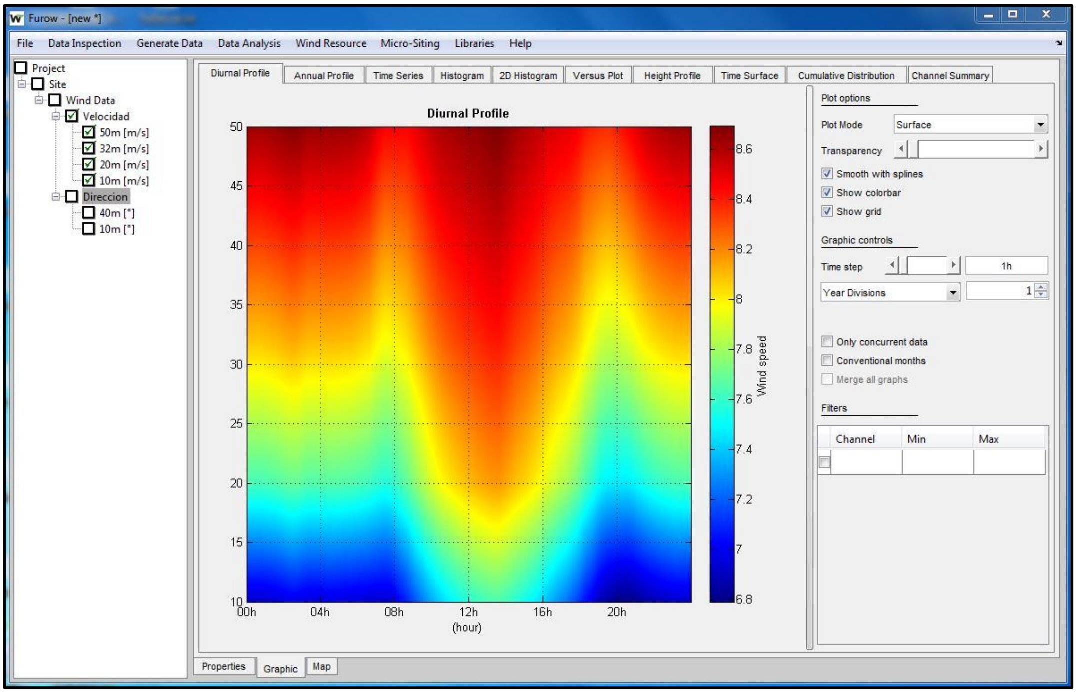


Figure 17: Diurnal profile

6.1.2 Annual profile

This representation shows how any variable changes in average throughout the year. If *"Conventional Months"* option is used, just 12 values are available (one for each month). However, time step can be modified to obtain for instance an annual profile of each day of the year. On Figure 18 the annual profile for 4 wind speed channels is shown.

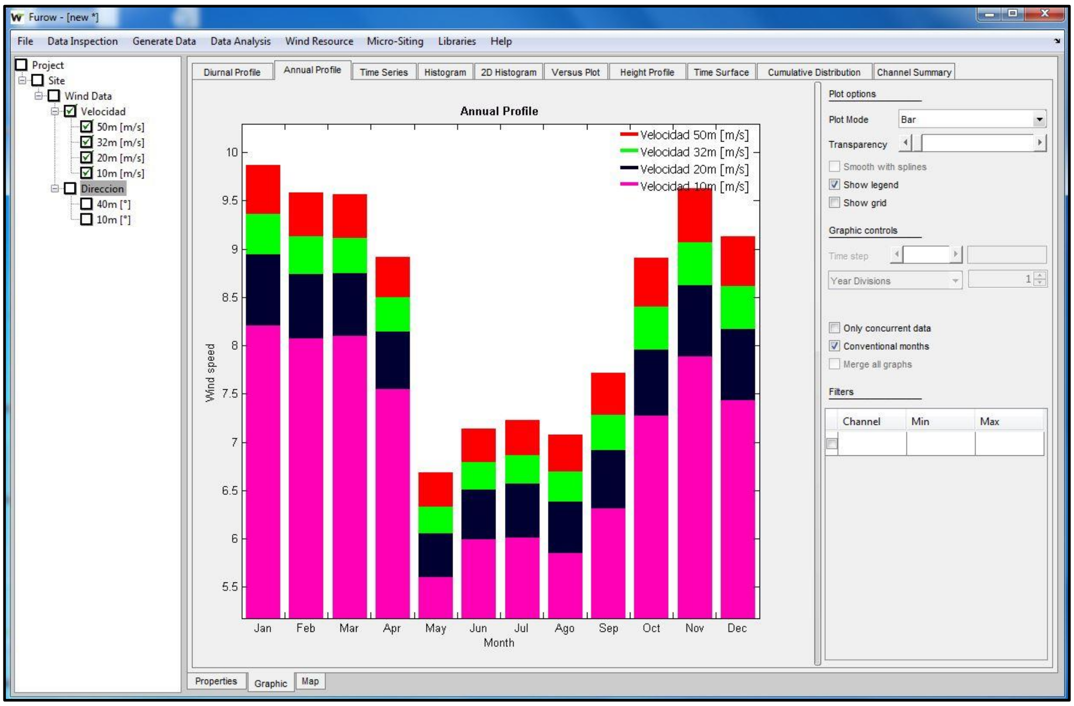


Figure 18: Annual profile

6.1.3 Time series

It shows the actual data loaded into the program. However, the time step can change and make averages on different lengths. Again, 2 axes are possible when several sensor types are being represented. On Figure 19, time series of wind speed at 50m and wind direction at 40m are shown.

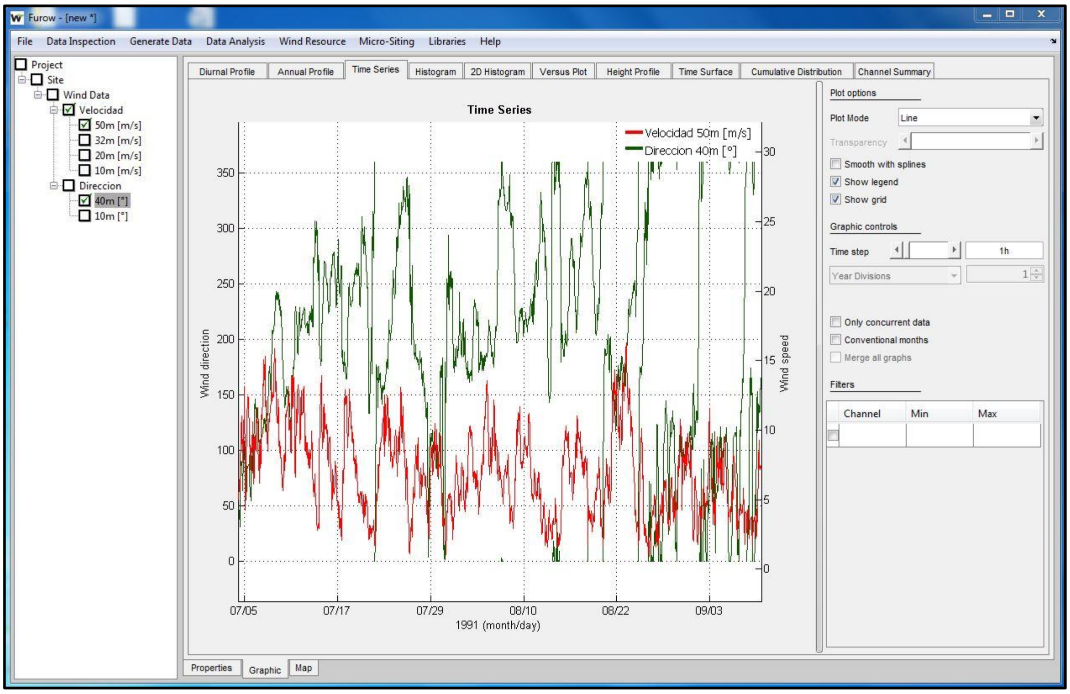


Figure 19: Time series

6.1.4 Histogram

On this representation, relative frequencies of occurrence are shown as a function of the magnitude value to be represented. On Figure 20 the histogram for each month of the year is shown for a wind speed at 50m. Changes on the Weibull distribution due to seasonal variations are well appreciated on this figure. If just one direction channel is selected, then wind roses appear with the frequencies corresponding to each sector. The number of sectors can be modified to discretize as much as desired. On Figure 21, wind roses for 4 periods of the year are shown for a wind direction at 40m high.

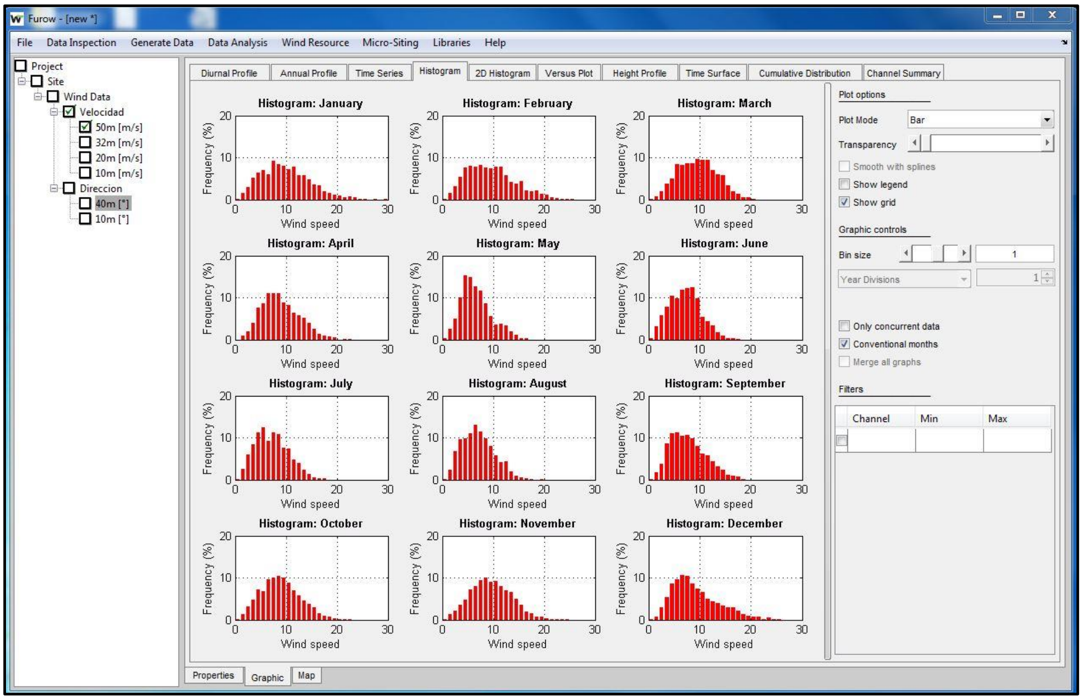


Figure 20: Histogram

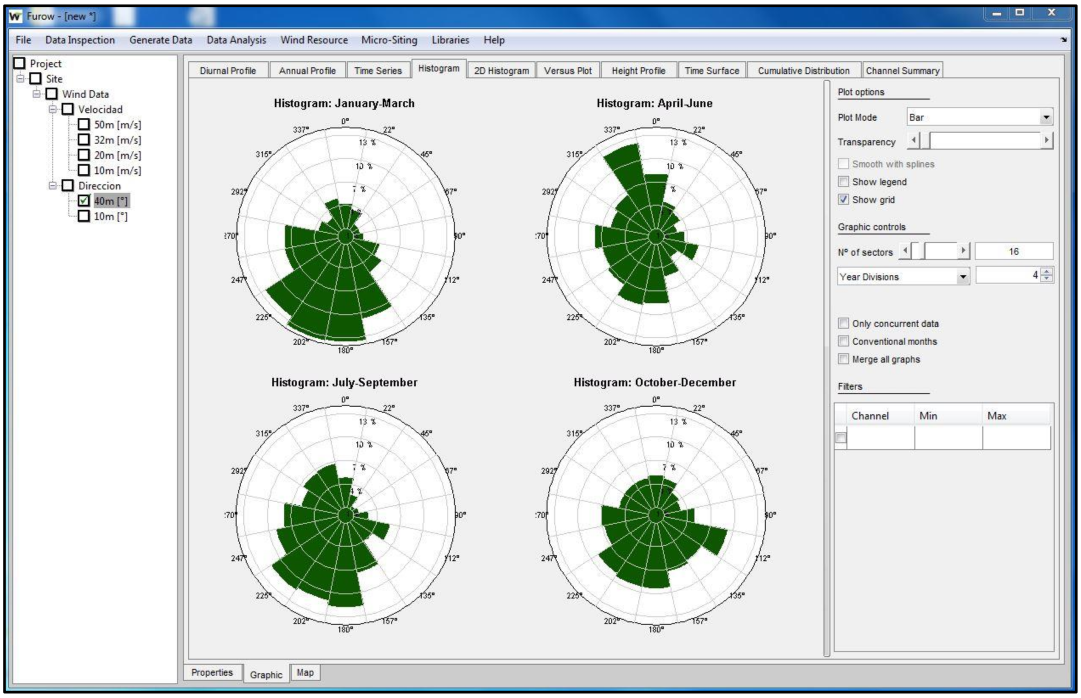


Figure 21: Wind Roses

6.1.5 2D Histogram

This type of representation allows us to calculate the relative frequencies of occurrence between 2 channels selected on the tree. The x axis will be the first marked variable attending to the tree order and the y axis the second variable. If the user wants to change the order, it is necessary to mark again the channel and a green square will appear on the channel which will be on the x axis. On

Figure 22, wind speed at 10m is compared with wind speed at 50m, being the wind speed at 10m the independent variable. Thus, on table mode the reference axis will correspond to wind speed at 10m, varying in this case every 1m/s. If the independent variable is the wind direction, then the circle is divided in sectors, and radially also in the same number of sectors (see Figure 23).

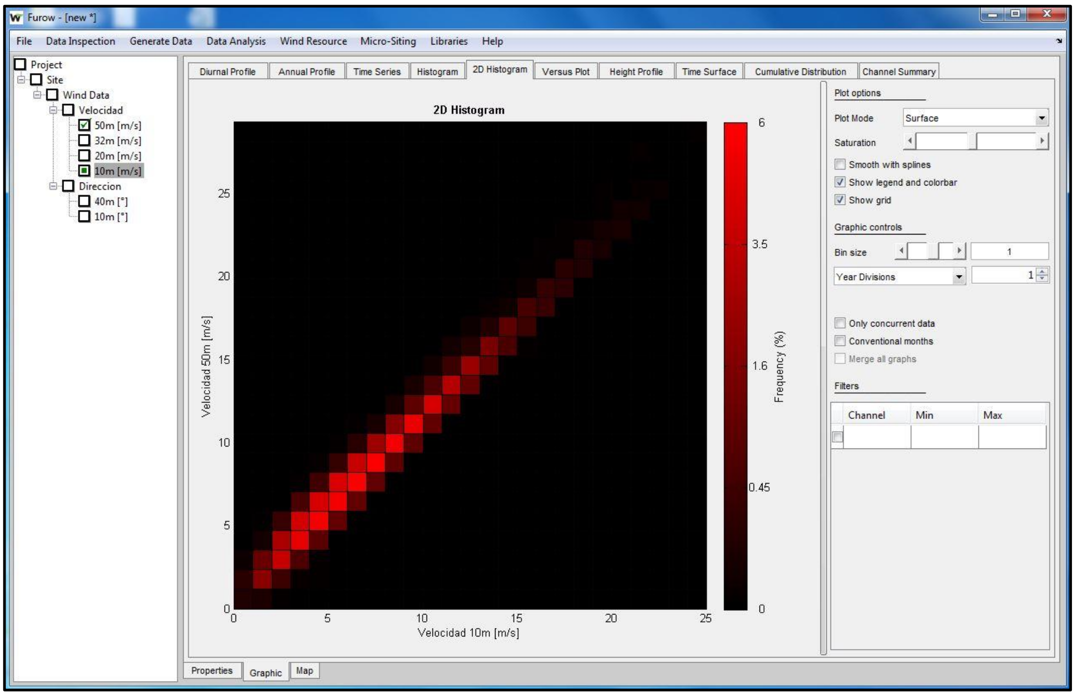


Figure 22: 2D Histogram

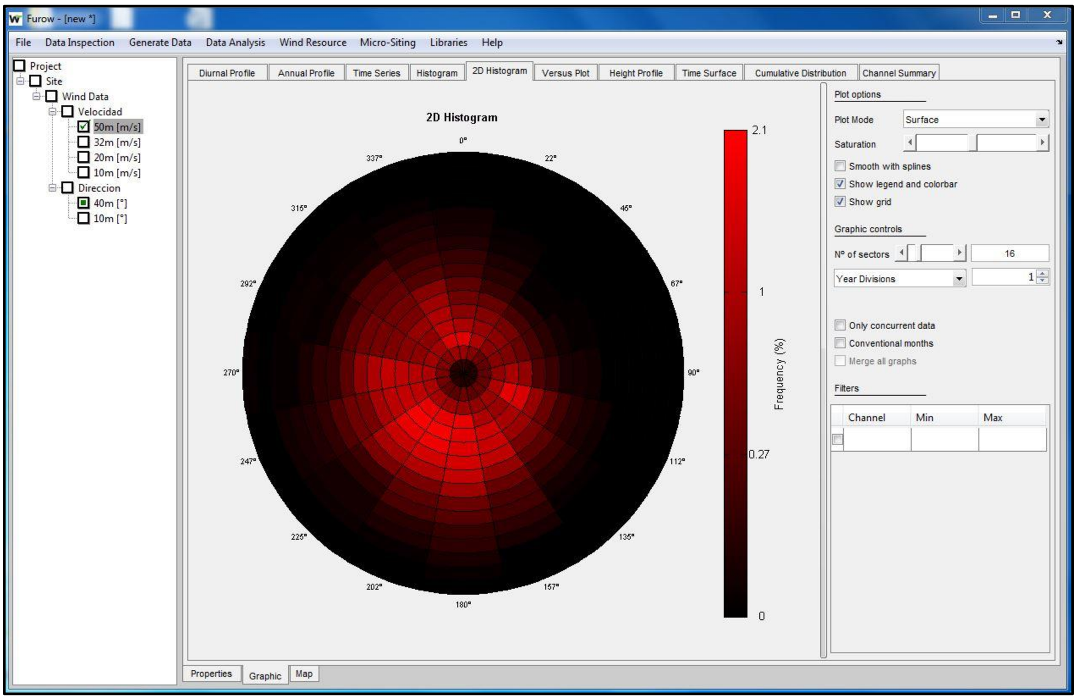


Figure 23: 2D Histogram with wind direction

6.1.6 Versus plot

This type of figures allows plotting the mean value of two variables. The reference axis works in the same manner as the 2D Histogram. On Figure 24 the versus plot is shown every 1m/s taking the 10m wind speed as the reference. Again, if the independent axis is a wind direction, then the plot is a polar plot, as seen on Figure 25.

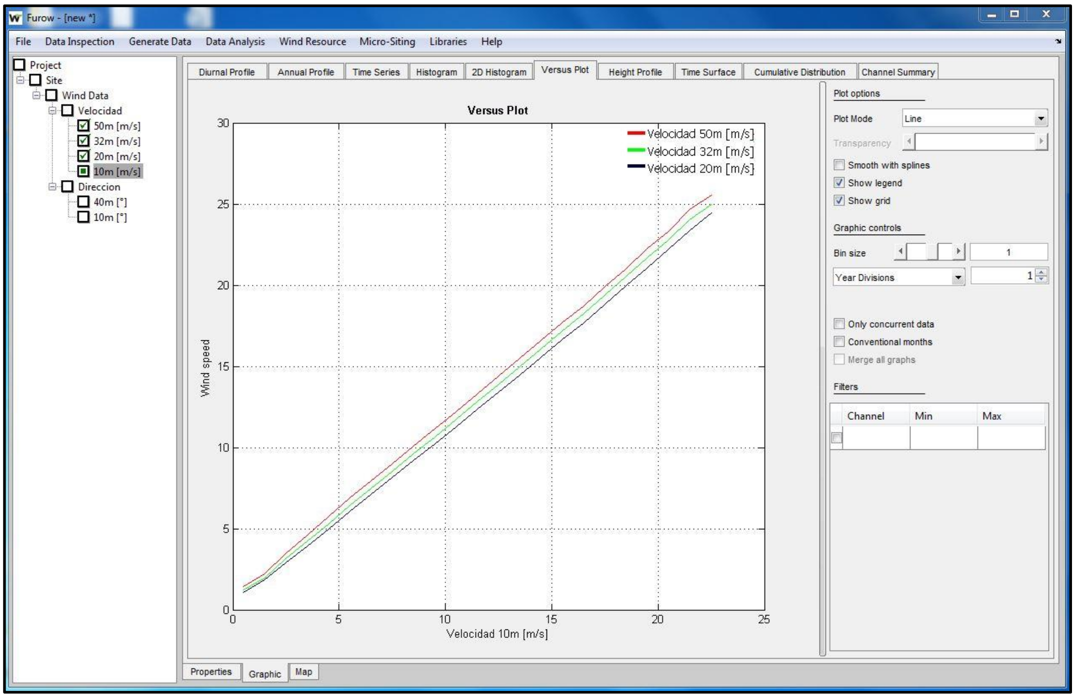


Figure 24: Versus plot

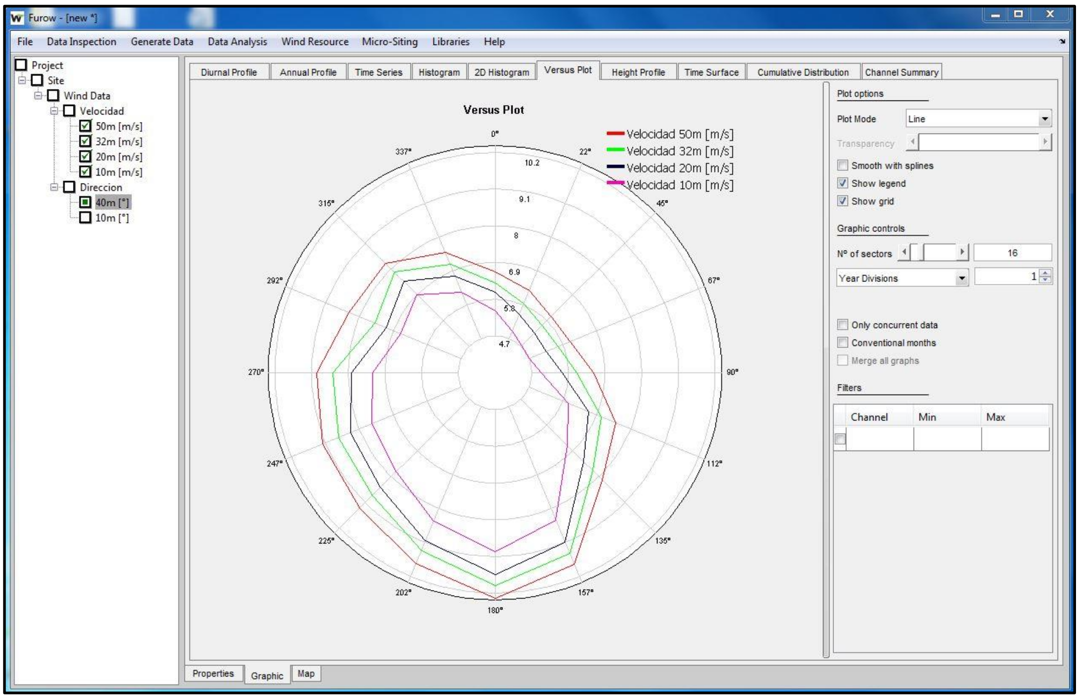


Figure 25: Versus plot with wind direction

6.1.7 Height profile

The height profile allows calculating the mean value of a channel and be represented at its height, thus having an idea of the vertical profile of a given magnitude. Very interesting is to analyze the vertical profile attending the hour of the day. On Figure 26 the vertical profile between 10m and 50m is shown every 4 hours and merged in one graph. For bar and boxplot modes, the vertical axis do not show the height but the same of the channel.

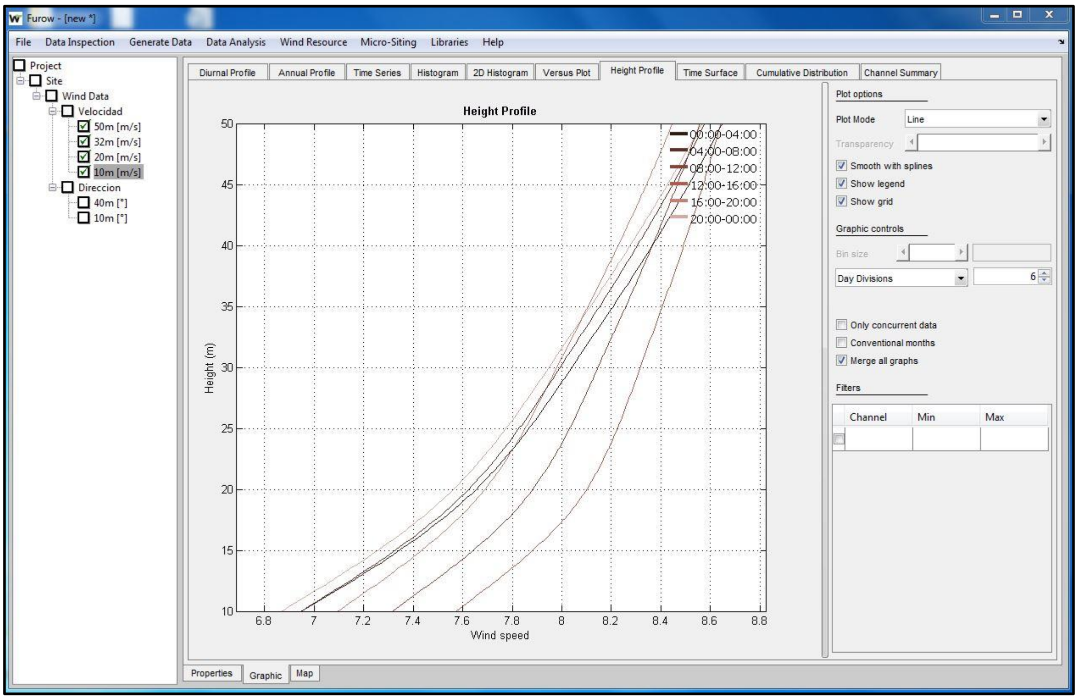


Figure 26: Height profile

6.1.8 Time surface

When using the time surface mode, the user can obtain the average value of any variable in a 2D axis, where the vertical axis represents the time of the day and the horizontal axis the time of the year (or months). When the "*Conventional months"* option is marked there will be 12 divisions on the x axis, and time of the day step can be changed. If this option is unmarked, then, the number of divisions on both axes depends on the number of divisions chosen for the vertical axis. On Figure 27 the time surface plot of wind speed at 50m is shown. On the table mode, all values are shown according to the divisions selected (see Figure 28).

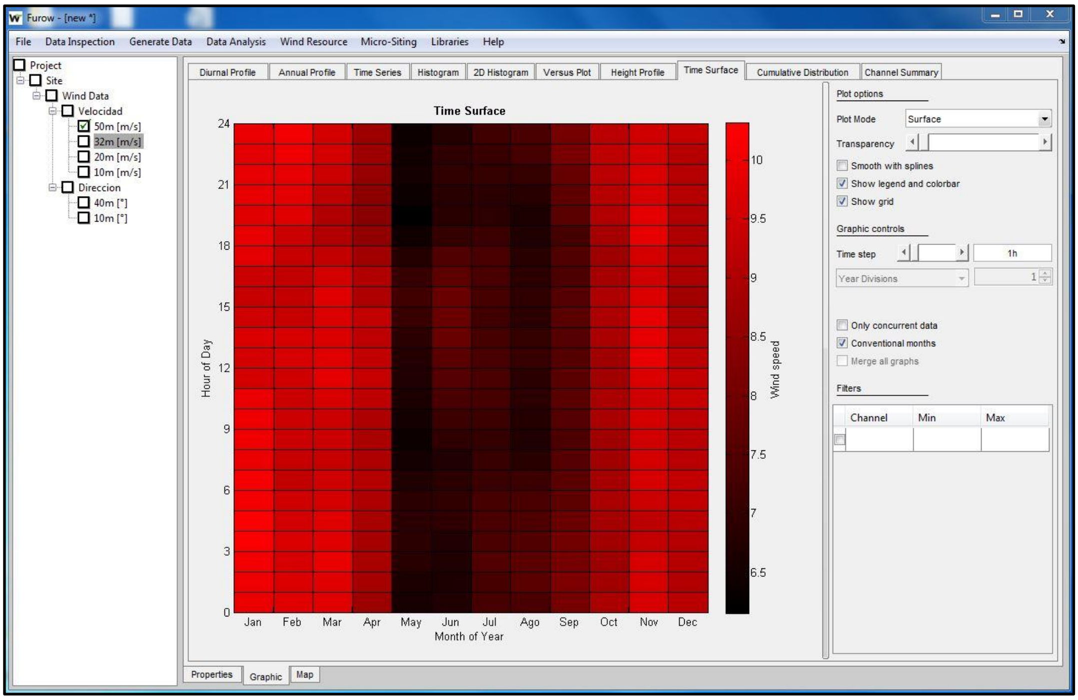


Figure 27: Time surface

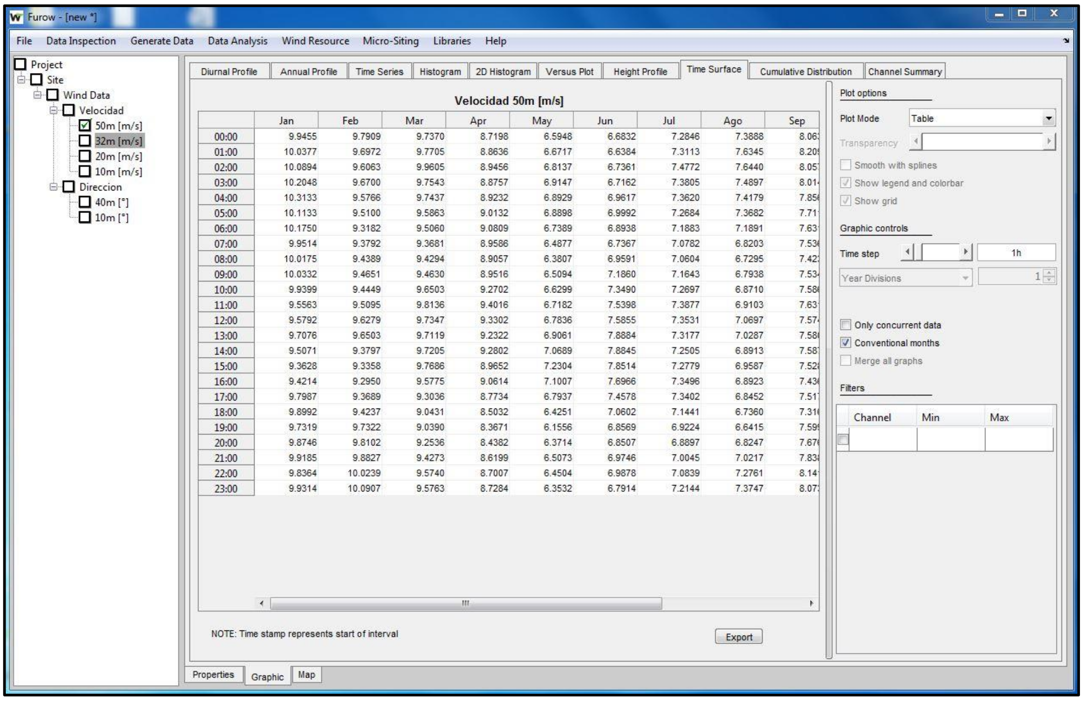


Figure 28: Time surface on Table mode

6.1.9 Cumulative distribution

This representation shows for every channel its cumulative frequency as a function of its value. On Figure 29 the cumulative frequencies for 4 wind speed channels are shown.

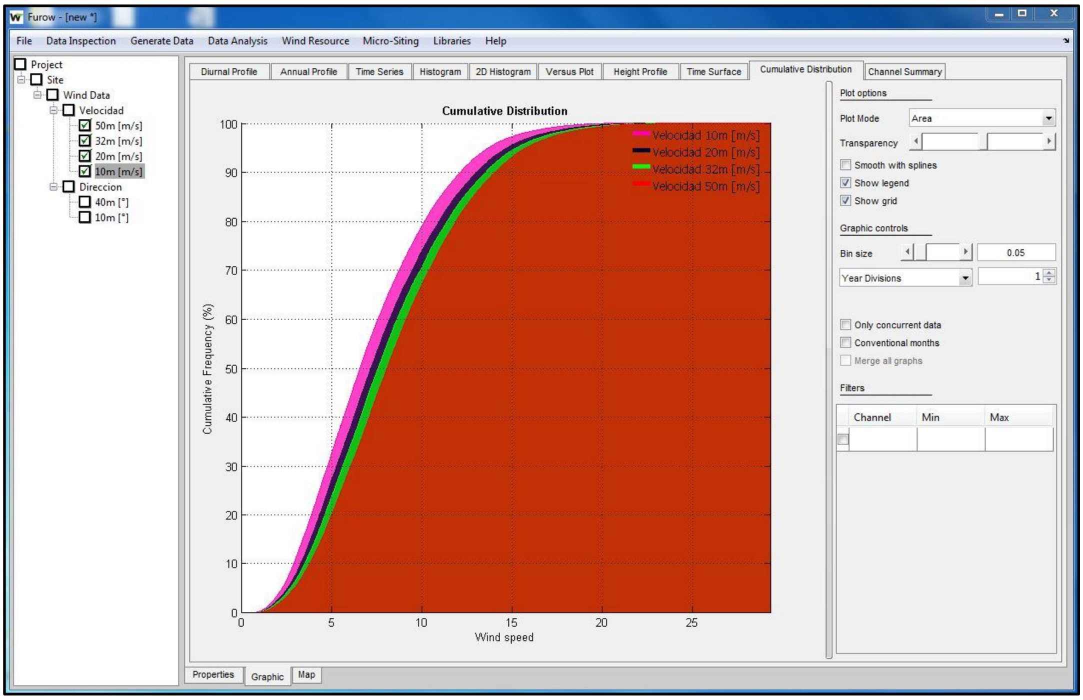


Figure 29: Cumulative distribution

6.1.10 Spectrum

On this tab the user can calculate the spectrum amplitude of any variable selected on the tree. This quantity is obtained even if the time series contains gaps as a special procedure has been developed to manage this issue. Figure 30 shows an example of the frequency spectrum for a wind speed channel, on which the diurnal pattern is evident as well as other cyclical variations.

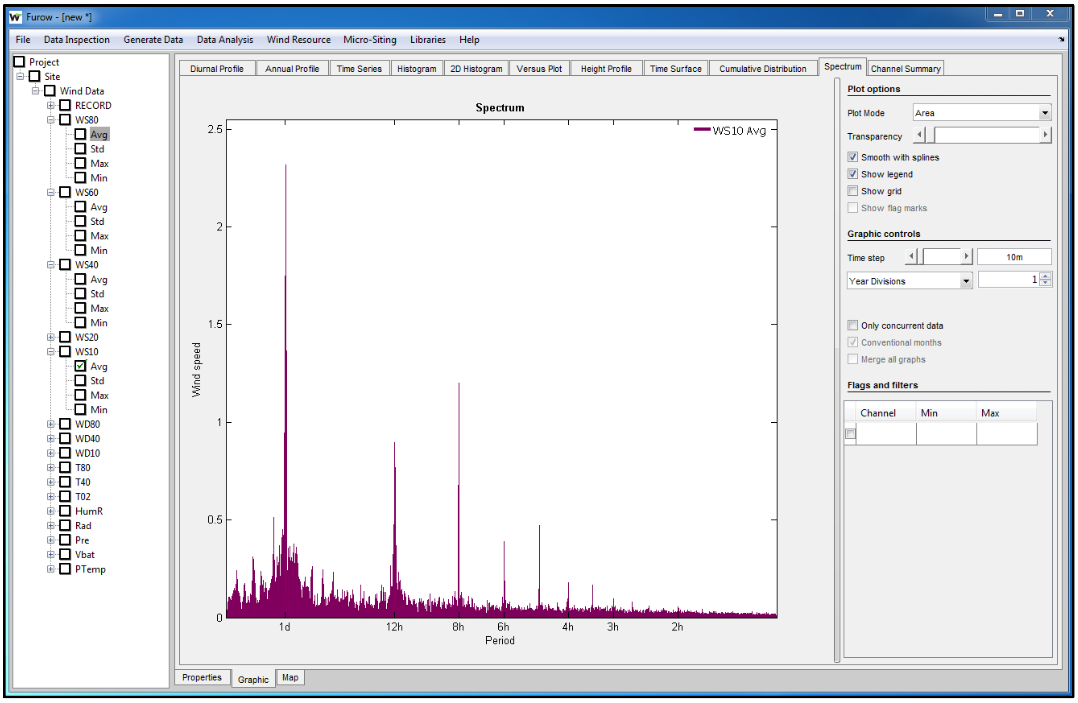


Figure 30: Spectrum

6.1.11 Channel summary

This tab only allows representing a table with the main statistics of each channel: mean value, standard deviation, maximum value and when it occurred and minimum value and when it occurred. When changing the number of divisions, tables are updated, as well as if time filters are applied. Figure 31 shows an example of the main statistics for 4 wind channels.

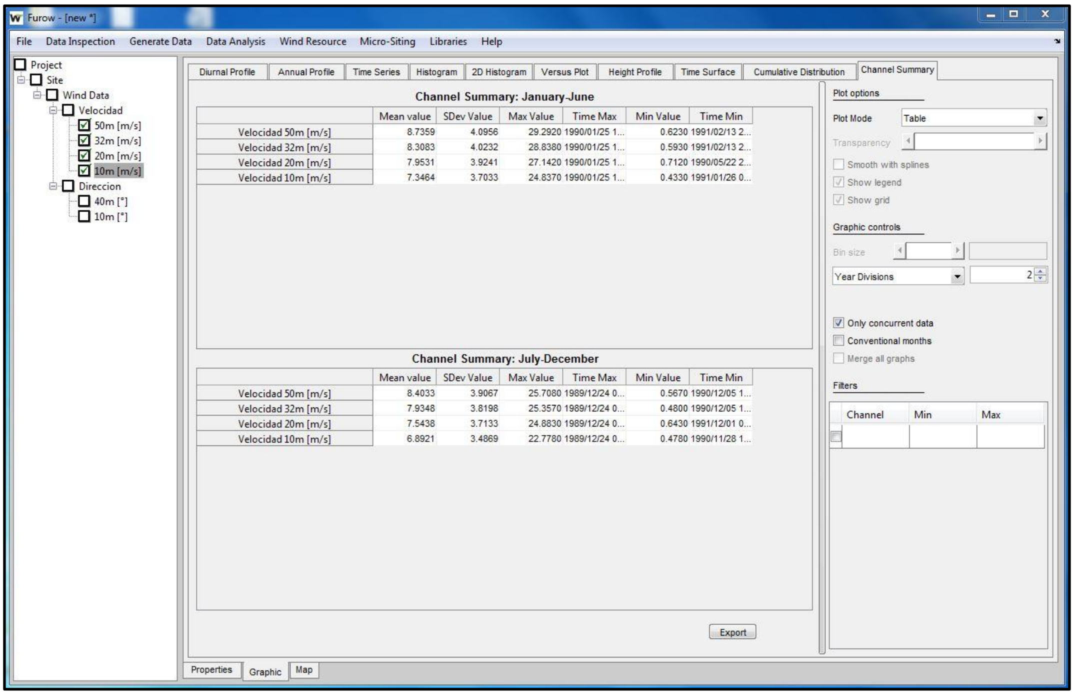


Figure 31: Channel summary

6.2 Filters and flags on the Graphic tab

On this section, the use of filters and flags applied to Graphic representation will be explained.

6.2.1 Filters

There are two main types of filters the user can create:

1) <u>Time filters:</u>
    a. **Time:** it selects data from one date to another (See Figure 32)
    b. **Annual:** it selects data from one day and hour of the year to another (for the whole data range if no other filters are applied simultaneously) (See Figure 33)
    c. **Diurnal:** it selects data from one hour of the day to another (for the whole data range if no other filters are applied simultaneously) (See Figure 34)
2) <u>Channel filters:</u> this filter is directly applied to any other channels which are being represented. For example, on Figure 35, wind direction at 40m has been filtered between 90º and 180º. Automatically, when clicking on the wind speed channel at 50m, only values within this direction range are represented.

Filters can be deleted by doing right click on top of the filter. It must be remarked that the application of a filter does not modify the availability of the channel in any of the representations, unlike the flags which are considered to represent erroneous or invalid data.

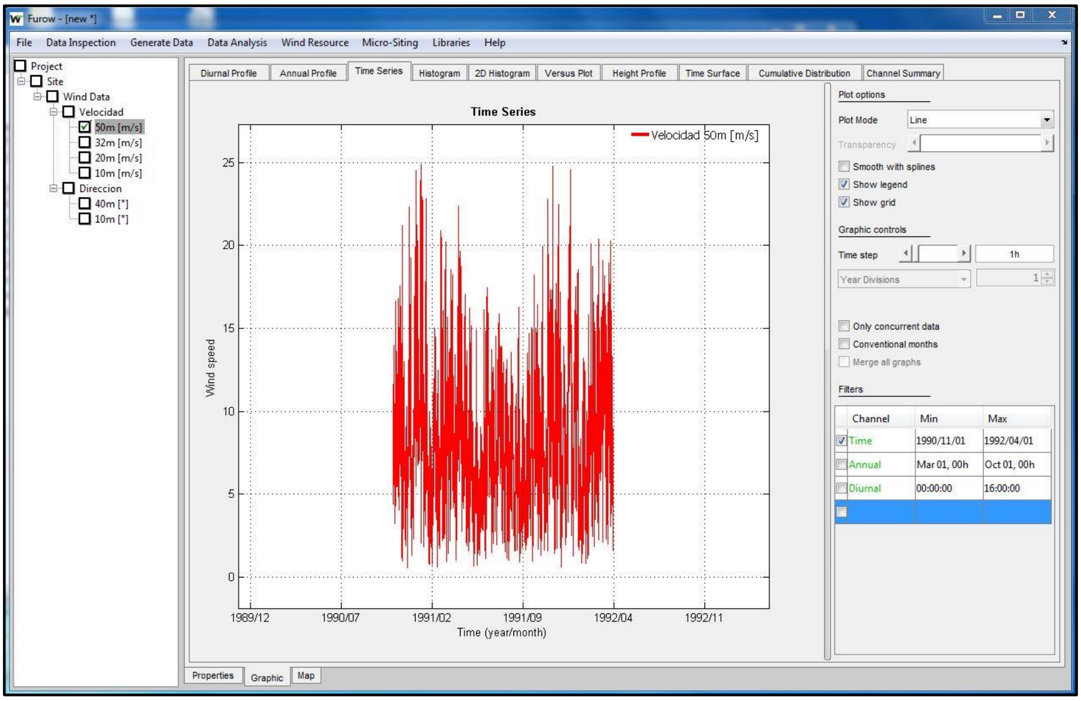


Figure 32: Application of time filter "Time"

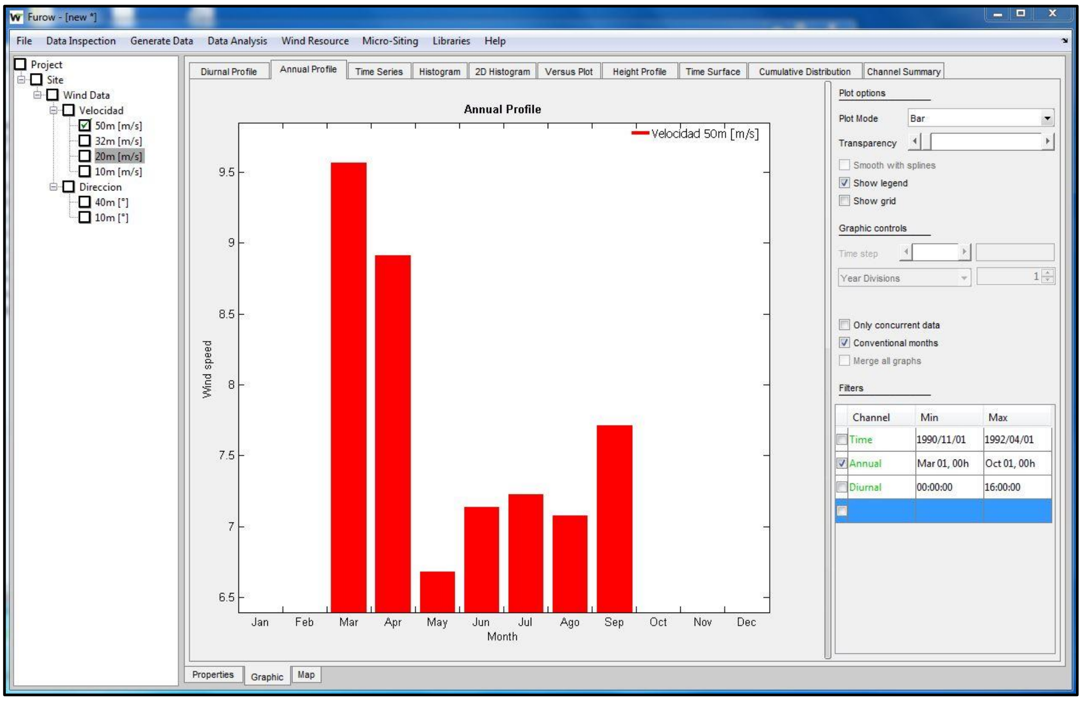


Figure 33: Application of time filter "Annual"

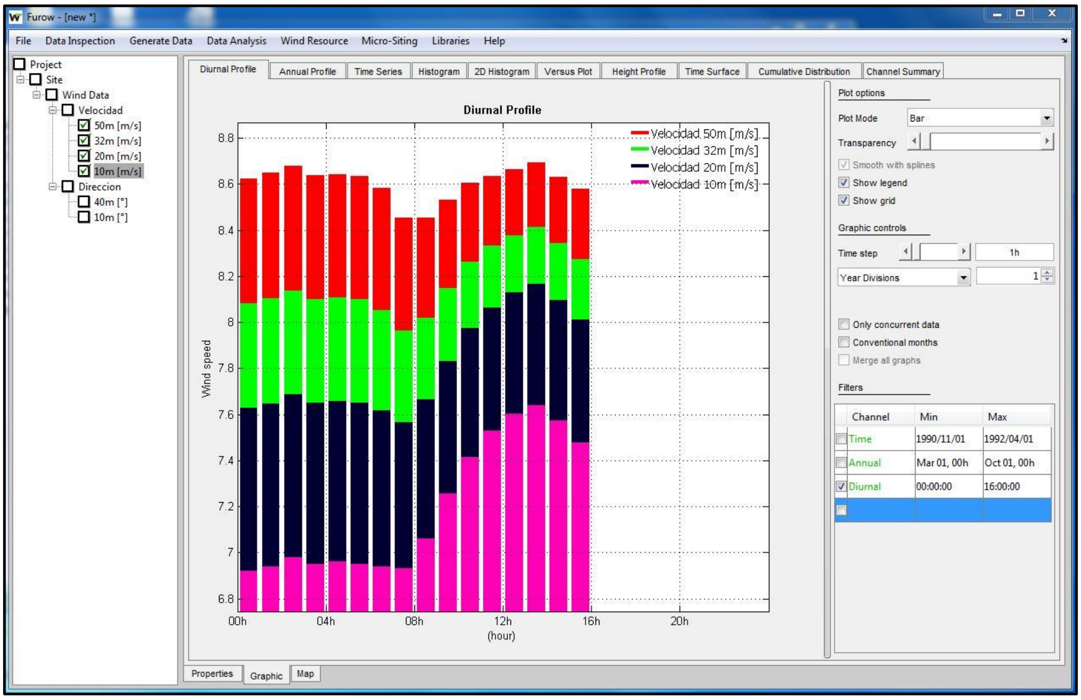


Figure 34: Application of time filter "Diurnal"

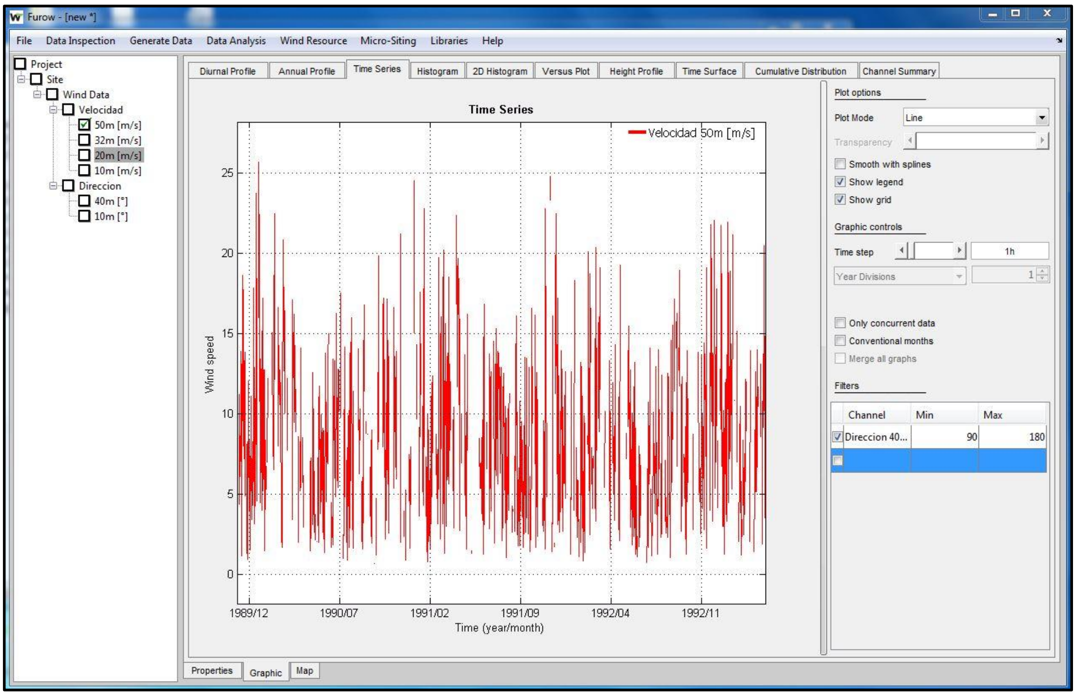


Figure 35: Application of channel filter

6.2.2 Flags

a) <u>Flags with rules</u>

Flags are created on the "*Data Inspection*" menu, under the "*Flag Editing*" dialogue. Once a flag is created, it is automatically loaded on the Filters table. Flags are loaded as "*Ignore Flag*", which means that it removes all data that fulfills with the rules associated with the flag. Within the module, flags are created on the *"Create and edit flags"*, being also possible to change the color of the flag marks. The procedure is the following: first, the rules are created and then channels to apply the rules are marked; after the button *"Set flag"* is clicked and the flag is created. Flags only affect the channels involved in the definition of the flag and thus, concurrent data of other channels will not be affected on the representation.

The deletion of the flags must be done from the same module under the *"Inspect and delete flags"* and cannot be deleted from the filters table. There are two options: either the whole flag is removed, or individual elements are removed.

As an example of flagging with rules (see Figure 36), a flag has been created on which the affected channel is the wind speed at 50m. The value rules are:

- Wind speed at 10m is less than 5m/s, and
- Wind direction at 10m is within range of 270º and 90º

It is easy to see how when wind parameters at 10m are coincident with the rules, automatically the wind speed at 50m is discarded.

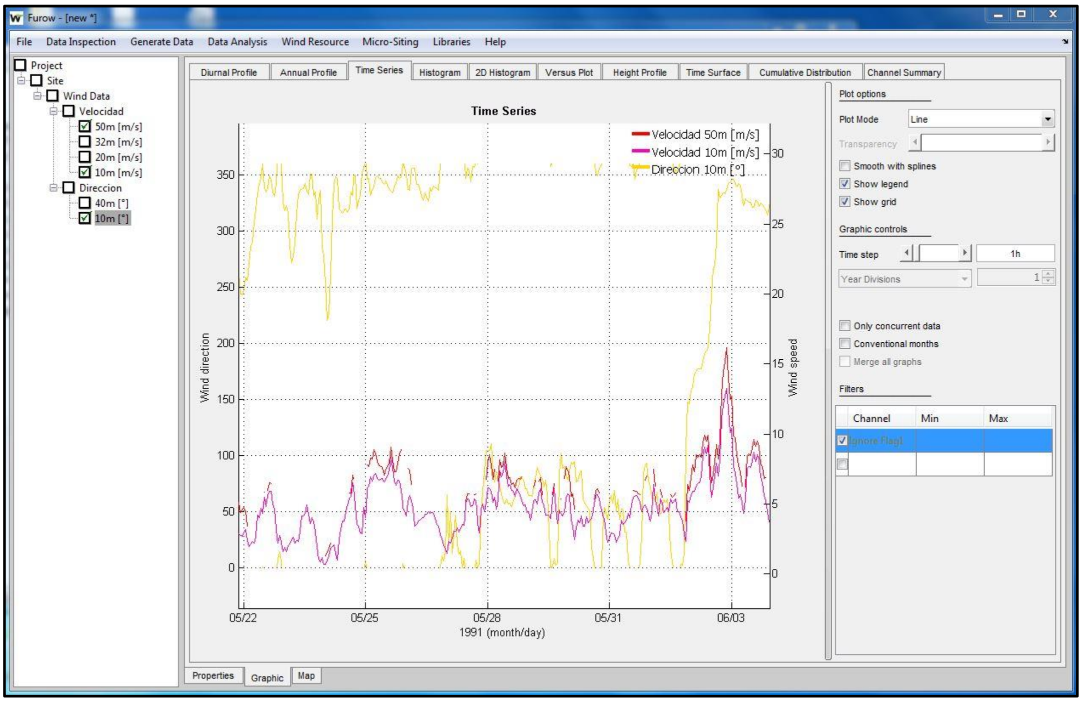


Figure 36: Application of flags

It is also possible to generate *"Time rules"* in order to remove periods of time whose data are subjected to be discarded. The application logic is the same as with values.

b) <u>Flags manually</u>

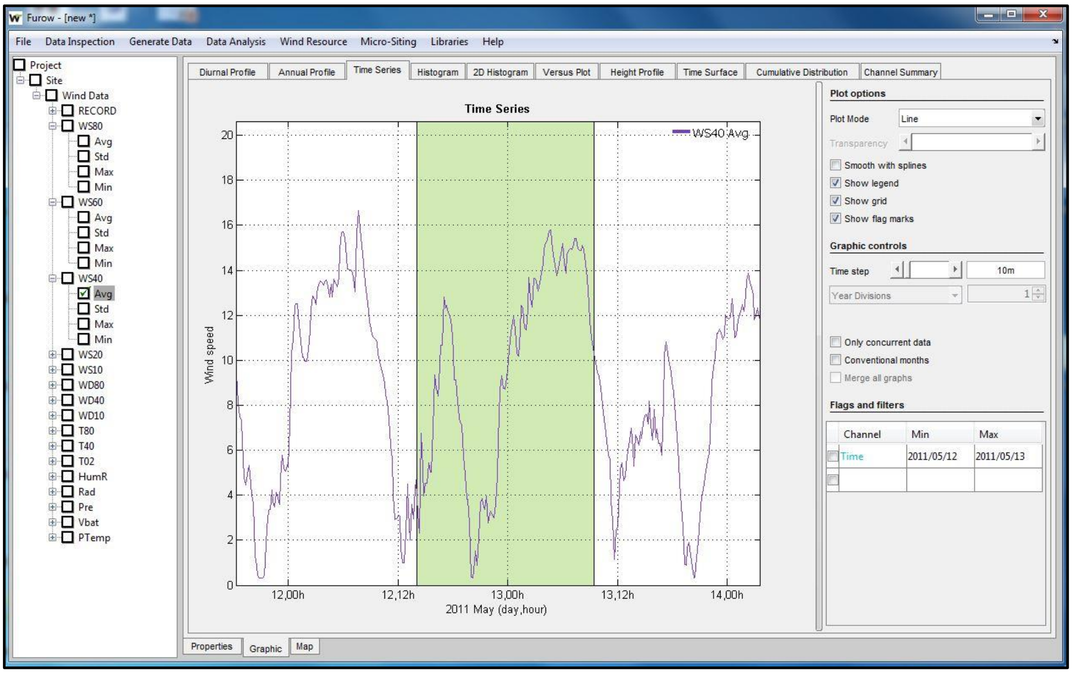
This new version of **FUROW** includes the possibility of flagging data on the *Graphic* tab. The manual flagging can be performed on the following representations: Diurnal Profile, Annual Profile, Time Series, Histogram (including the polar plot), Versus Plot and Cumulative Distribution.

To activate the flagging the user must left click and press the Left Shift key and then drag to select the desired data. While dragging, a light green rectangle will show up indicating the selected interval and then the selected points are marked with black dots (see Figure 37). Once data has been marked, the user must right click on top of any selected dots and there are three options: 1) Remove flag; 2) New flag; 3) Existing flag. The first option allows excluding the selected data from the existing flag. With the second one, the user sets up a new name and color and creates a new flag with one or several elements which internally have flagging rules. Finally, the third option allows adding new selected data to an existing flag increasing the number of data affected. Manual flagging can be applied to one or several channels simultaneously. When applying a manual flag, the filter table shows a temporary filter which covers the range of values selected in the independent axis.

Once the flag is created the user can go to *"Flag editing"* module to inspect the elements which have been created after performing the manual flagging. Also, it will be possible to change the colors of the created flags.

In the Time Series tab, the user can visualize all the flag marks by clicking on the checkbox *"Show flag marks"* whereas if the user wants the data to be removed from the screen and not be taken into account for calculations, it is necessary to go to the *Filter*s table and click on the appropriate *"Ignore Flag"*. Finally, if the user wants to select several intervals of data to be flagged then the keys CTRL+Left Shift must be held together while dragging with the mouse.

For the moment, manual flagging with multiple divisions or with the *"Merge all graphs"* option is not allowed in this version.



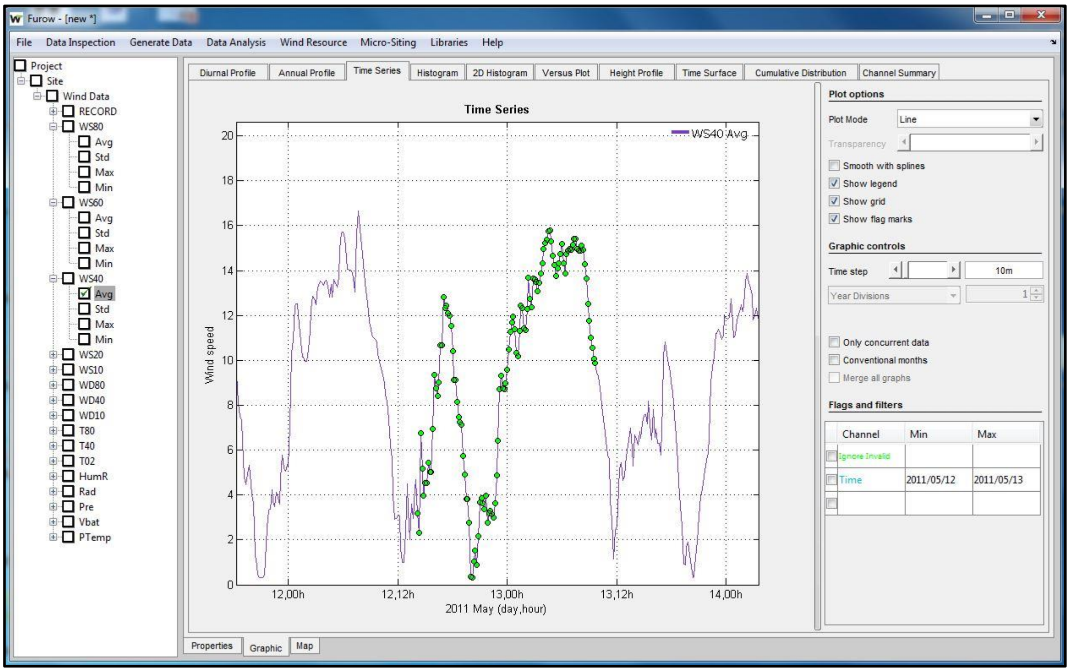


Figure 37: Flagging rectangle and flagged data

7 Data inspection

With the modules which will be described below, the user can inspect and modify data.

FUROW allows, with a quick view, having an idea of the data coverage of the measuring campaign, being possible to determine the coverage on different time frames. Additionally, it is possible to apply time shifts to the Wind Data objects, as well as changing the slope and offset parameters of each of the sensors within this object.

When there are potential erroneous values, and they can be identified through some rules, the user can program them to potentially discard those values on calculations. At the end, data can be cleaned from systematic errors. Finally, if erroneous values come from the distortion generated by the tower on different sectors, the user can filter them on the specific dialogue by comparing time series of anemometers at the same height.

7.1 Data coverage

By opening this dialogue the user can determine the data coverage of every channel loaded on the tree. If the tree has several WIND DATA objects, each of them can be selected from the pop-up menu, and coverage is calculated in relation to the time length of that WIND DATA. When the pop-up has the option *"All"* then the coverage is measured taking into account the whole period covered by all WIND DATA objects. Moreover, the coverage can be inspected depending on the year, month and hour. An example is given on Figure 38. Additionally, the coverage of each channel depends on the WIND DATA time step and the filters and flags.

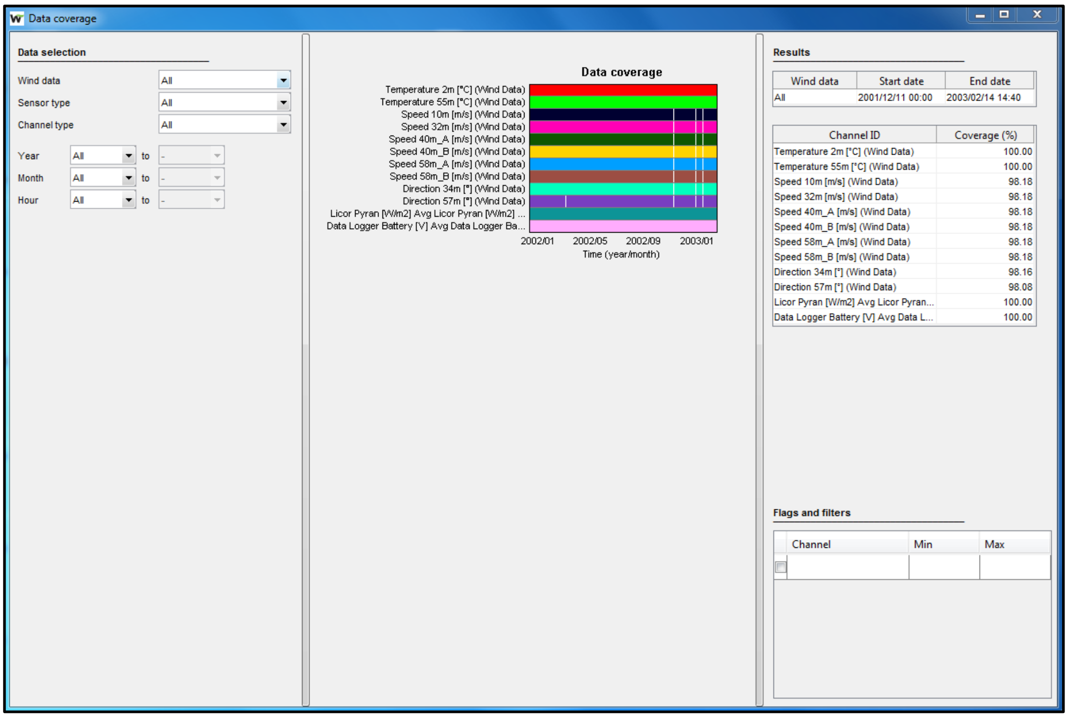


Figure 38: Data coverage dialogue

7.2 Time shift

This option allows shifting the time series of a whole WIND DATA object a given number of time steps or defining the new start or end dates. Current start and end date can be seen on grey to compare with the new ones (see Figure 39).

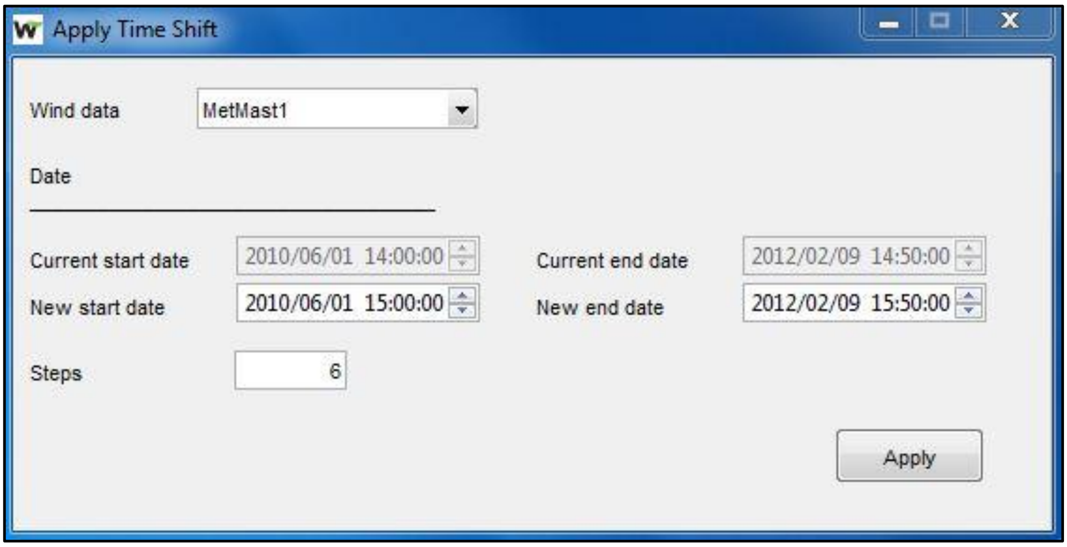


Figure 39: Time shift dialogue

7.3 Slope and offset

This module allows the user changing the slope and offset values with which wind data have been stored on the datalogger. For some reason, values introduced in the datalogger may be different from those of calibration process, or even, data may have been recorded in terms of frequency.

In any case the user can select any sensor, set the old and new parameters, and click "*Correct*" to apply the new parameters. Automatically, the status of the channel changes to "*Corrected*". If for any reason the parameters are not correct, the user can always restore the original values through the *"Restore"* button. In this case, the status becomes "*Not corrected*" (see Figure 40).

On this new version, the slope and offset can also be modified on a given time range. This allows using different calibration curves as it is typical that sensors may be replaced during the wind campaign.

When correcting the values of each sensor, standard deviation channels are treated differently from the rest of the channels in terms of the mathematical formulae (see ***Theory Manual***). In the case of availability channels (with statistic coverage) no correction is performed.

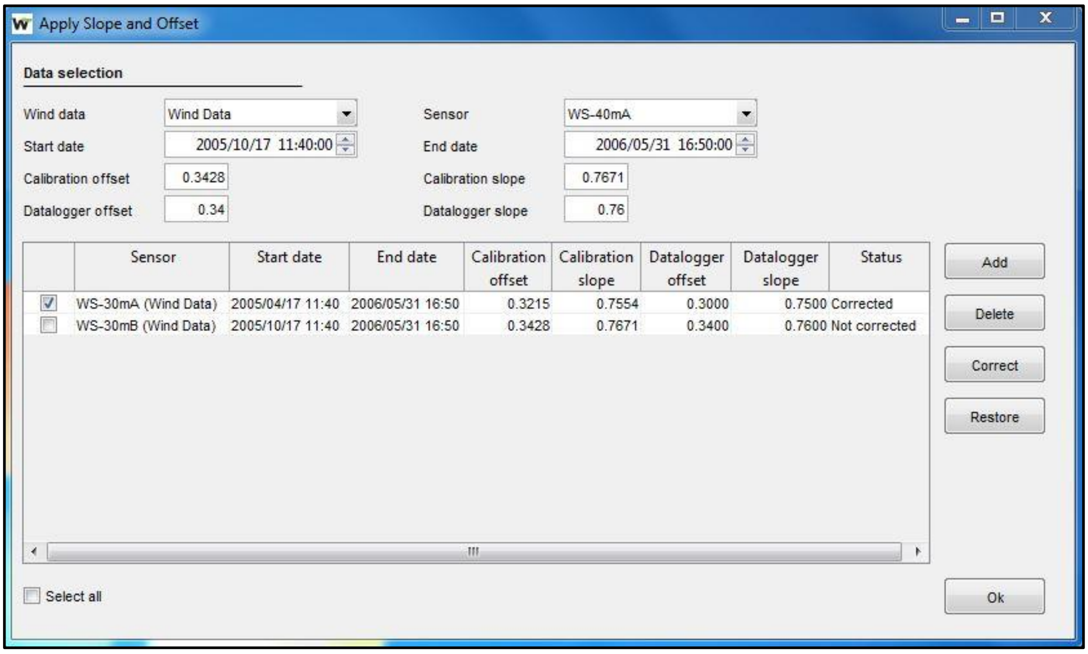


Figure 40: Slope and offset dialogue

7.4 Flag with rules (Flag Editing)

FUROW allows creating rules in order to flag data which are subjected to be discarded or used in special manner (within the module Flag Editing). Each flag can contain different rules which are applied to one or several channels, being each flag identified with a name given by the user. Under the description box, the user can give an explanation about the rules which will be implemented below.

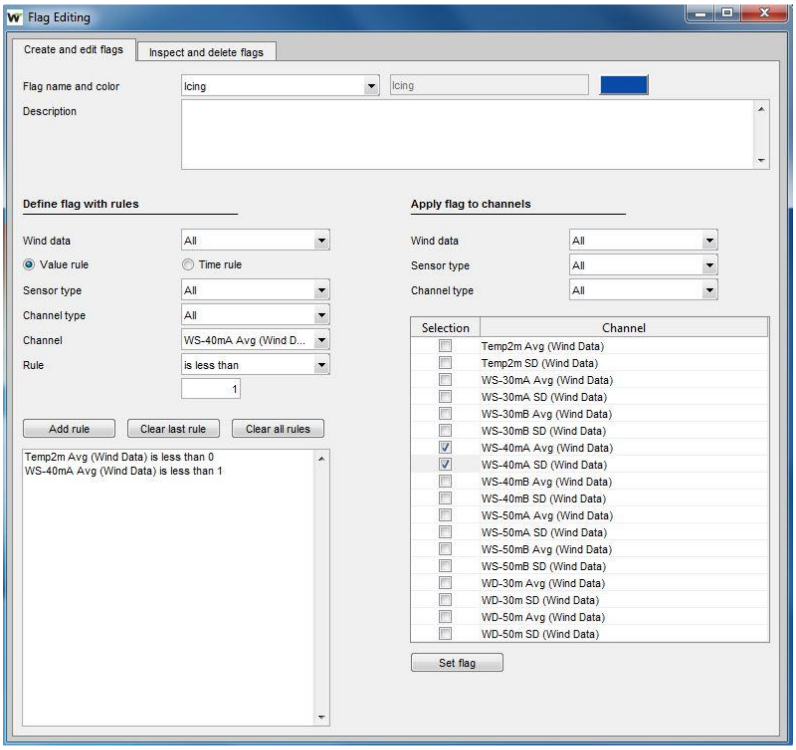
It must be noted that one flag can have several elements, understanding element as a set of rules that are applied to one channel. Thus, if several rules are applied to several channels, there will be as many elements in the flag as the number of channels affected. All simultaneous rules within an element are treated as an AND condition, that is, the intersection among them.

The number of rules created for each flag is unlimited, and they can be all deleted using the button "*Clear all rules*". Also, the last rule created can be deleted using the button *"Clear last rule".* Once created, the user selects which channels the flag is applied to. In the example below (see Figure 41), and Icing Flag is created: 1) Wind speed is below 1m/s; 2) Temperature is below 0ºC. This flag is applied to several wind speed channels including the standard deviation is such way that when representing these channels, time series and others will change when the Ignore Icing is checked on the Filters table. As it can be seen on the *"Inspect and delete flags"* four elements with two rules have been created.

If the rules are time rules, it must be remarked that if two time ranges are selected, but they do not intersect, as the AND operation is applied then no data are flagged. So, in order to flag two periods of time which do not intersect, the *"Set flag"* button must be clicked twice, each one with each individual time range.

Finally, it is possible to mix *"Value rules"* with *"Time rules"* provided both rules intersect.

At the "*Inspect and delete flags*" tab, the description of each element is available. The *"Delete flag"* button allows removing any flag and all its elements, whereas if any of the elements belonging to a given flag want to be deleted individually it can be performed using the "*Delete Elements*" button.



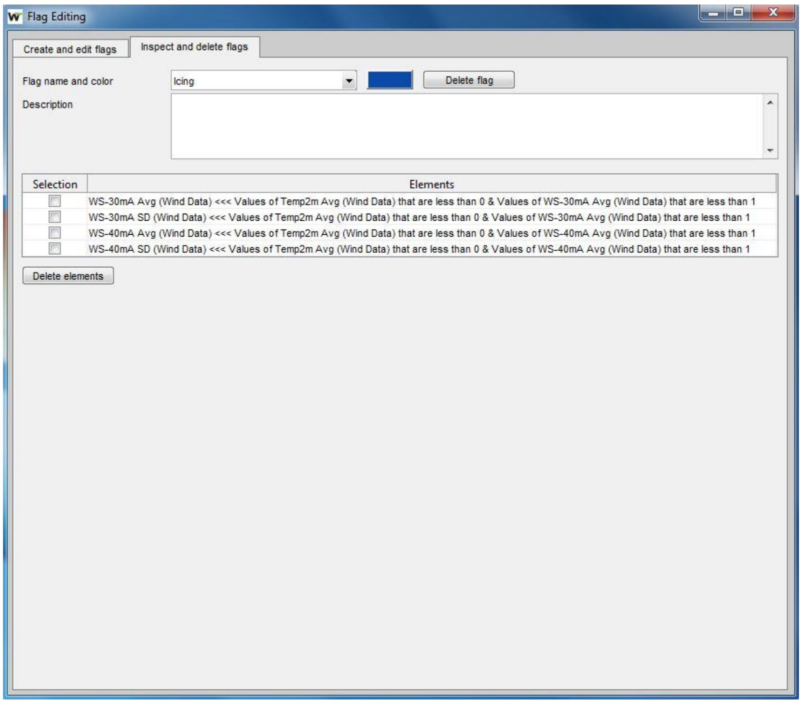


Figure 41: Flag with rules dialogue

7.5 Tower distortion

When a met mast has redundant anemometers, it is possible to quantify the distortion of wind speed measurements for different direction sectors. Flow distortion not only affects average wind speed but also its standard deviation. For this reason, this module accepts wind speed channels with these two statistics (see Figure 42).

Once the analysis is performed, the results can be viewed on "*Polar axis*" or *"Cartesian axis"* to identify the distorted sectors. The program automatically detects the 2 most distorted angles and highlights them together with its values and a width of 30 degrees by default. When making the analysis it is possible to limit the ration between channels, to avoid obtaining scatter and distortion factors not representative.

Finally, the user can export the flags with the tower distortion criteria, as well as the "cleaned" time series of average wind speed and standard deviation. For the time series, the user can select either the first or the second channel, or even a combined channel with a time series that is the result of averaging both filtered channels, except for the distortion sectors for which the undistorted channel is used.

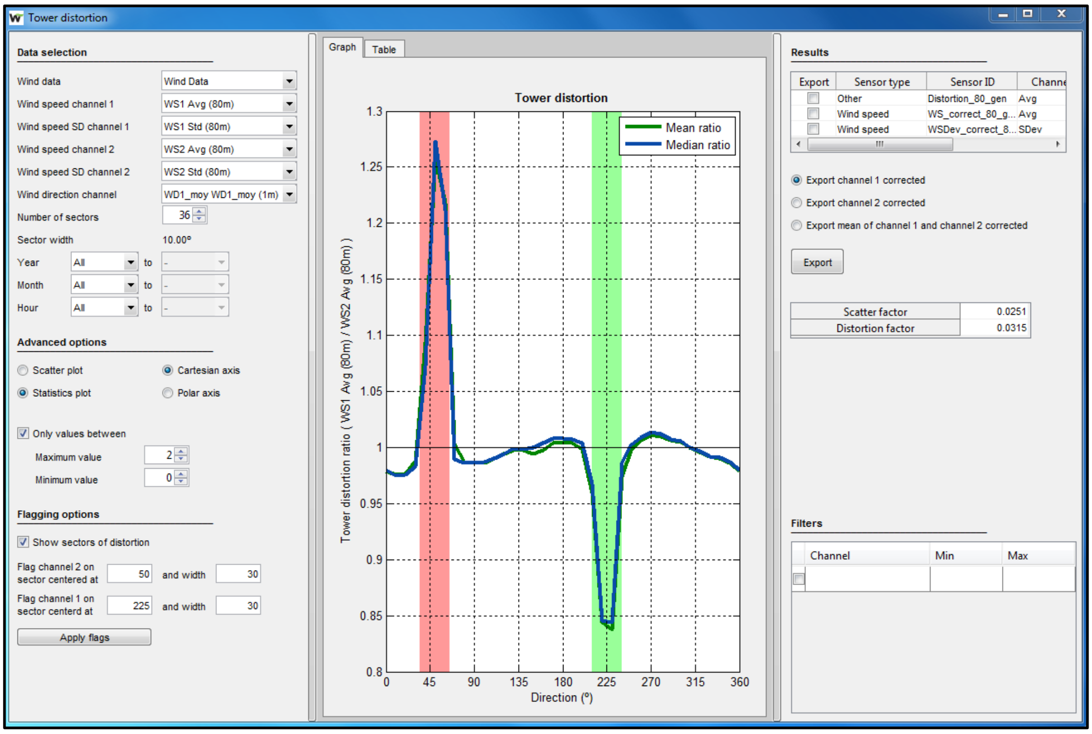


Figure 42: Tower distortion module

8 Data generation

FUROW counts with several tools to produce synthetic data based on existing measurements, so that time series can be either completed or extrapolated to other heights.

This completion of data from the same measuring device or from nearby weather stations allows better estimation of the wind climate of the site at a particular level. In the case of the MCP technique, it allows the reconstruction of wind speed and direction when long term measurements from nearby weather stations are available together with concurrent measurements at a site.

Extrapolation of atmospheric parameters as well as wind speed and direction related variables can be of great importance to reduce the uncertainty in wind resource assessment. For most of flow modelling techniques, it tends to be more accurate to extrapolate in height the wind climate at the measuring position and then perform a horizontal extrapolation, rather than allowing wind flow models to extrapolate vertically.

Finally, within **FUROW**, it is possible to generate new variables by using existing channels.

8.1 Derive new variable

New variables can be generated in **FUROW** combining existing channels. Thus, differences between channels, changing of units, generation of new parameters (such as stability parameters) can be produced with this dialogue. New generated variables are placed on the tree depending on the ranking of the channels used to generate the new variable: if they are channels of the same sensor, the new variable will be a child of the same sensor, whereas if channels used belong to different sensors, then a new sensor is created. On Figure 43 you can see how the difference between two wind speed channels at the same height is created.

It is common to have wind data from reanalysis models. In this case, wind speed components **U** and **V** are given. This dialogue also helps the user to generate a wind speed and wind direction sensor from **U** and **V** provided both channels are labeled as wind speed sensors (see Figure 44).

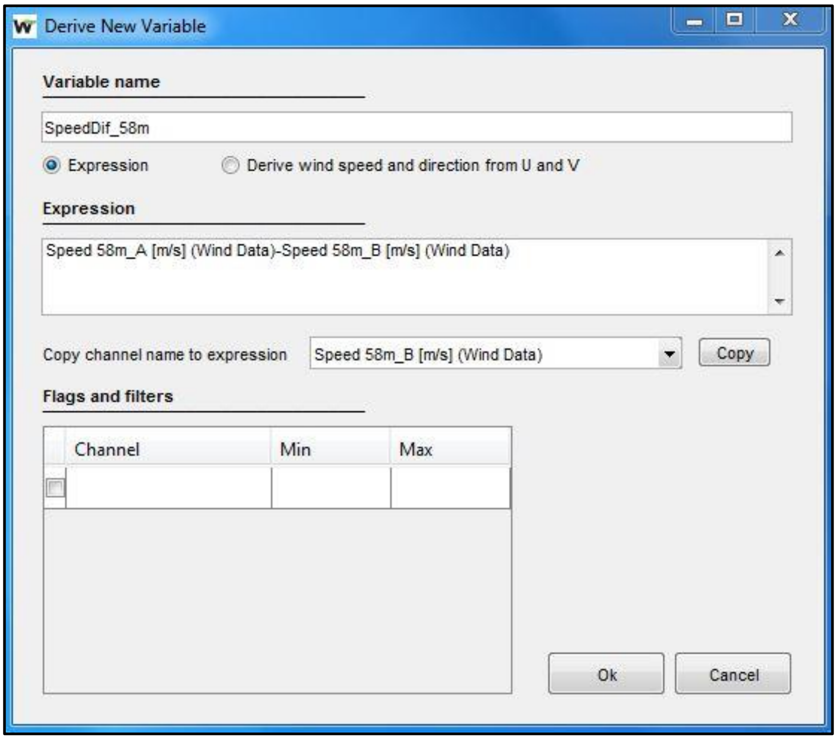


Figure 43: Derive new variable module

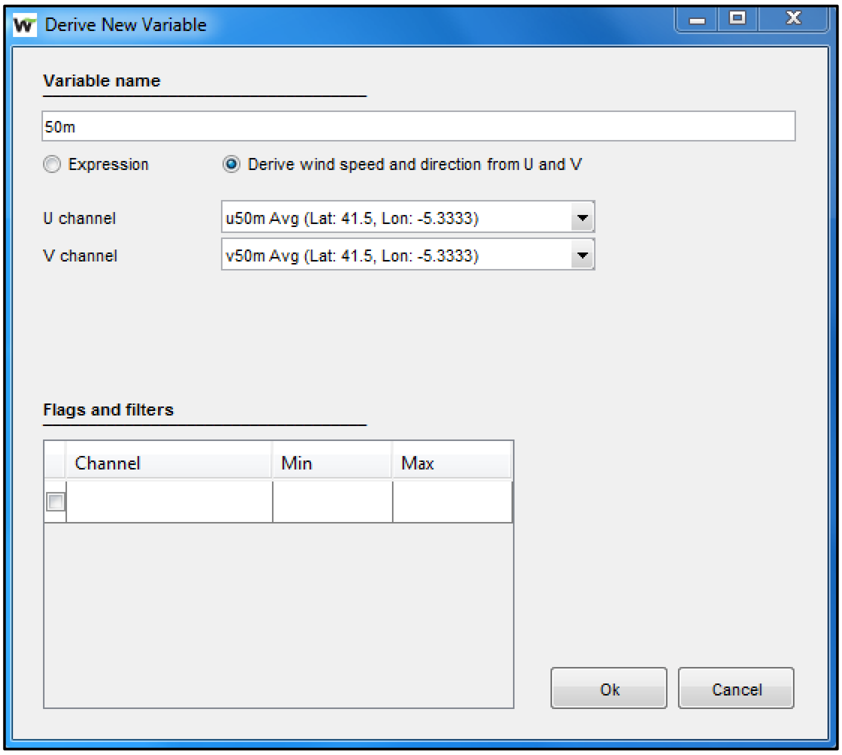


Figure 44: Derive new variable module for U and V

8.2 Atmospheric parameters extrapolation

As explained on the ***Theory Manual***, atmospheric parameters like temperature, pressure and relative humidity can be extrapolated to another height. The user must set the target height as well as the vertical gradients if just one sensor is available. When there are two sensors, it calculates the gradient at each time step and extrapolates from the nearest level. New extrapolated channels can be exported to the tree (See Figure 45). On this new version, when one channel is selected temperature gradients by hour, direction, etc. can be used.

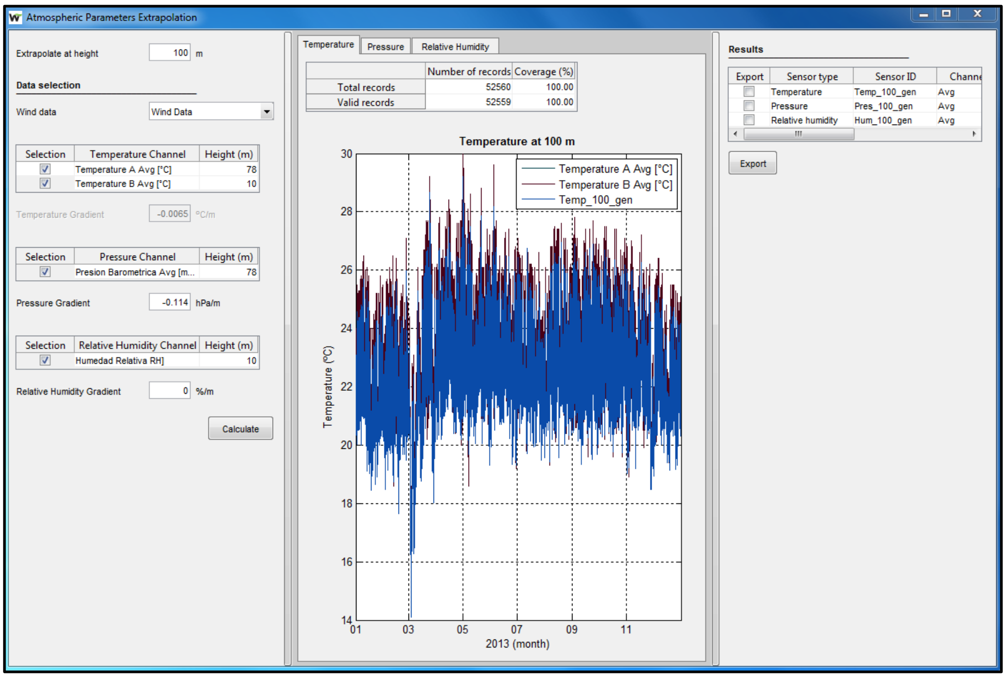


Figure 45: Atmospheric parameters extrapolation module dialogue

8.3 Wind vertical extrapolation

8.3.1 Wind speed vertical extrapolation

This module shows many possibilities for extrapolating a wind speed channel to any height. As mentioned on the ***Theory Manual***, there are four types of extrapolation laws which can be used: *power law*, *log law*, *log-linear law* and *log-log2 law*.

When just one height is available or selected, then the power law or log law can be applied by setting a table with the values of power law exponent or roughness length as a function of the wind direction, month, hour of day, etc. That table can be copied from the wind shear analysis dialogue.

When two channels are selected, an extrapolation for every step is carried out, again using only power law or log law. When extrapolating it is possible to discard those values whose fitted R^2 does not reach a certain threshold (by default 0.8). For power law, the user can choose to discard those values of alpha which exceed a given range, and thus wind speed is not extrapolated. Within this previous range, the user can decide to fix very high or low values of alpha to a given threshold (see Figure 46). When using the log law, it is possible to discard values with negative friction velocity values (which in some case they may be numerous), but it is also possible to fix the value of roughness length to a very low value when friction velocities are very low. Negative values of friction velocity yield into a lower wind speed, so the idea of using a very low value of roughness length when extrapolating is to obtain a wind speed profile which barely increases with height in order not to overestimate the wind speed but keeping the physical meaning of friction velocity.

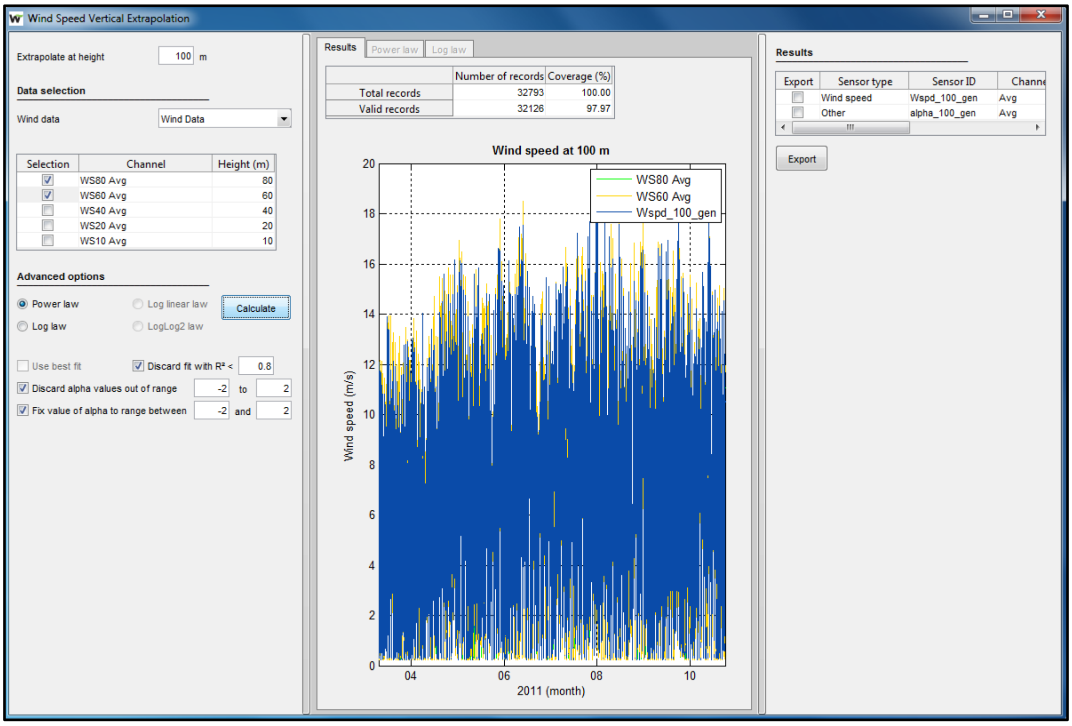


Figure 46: Wind speed vertical extrapolation module with 2 channels

When there are three channels, then all fitting profiles are available, being the options for power law and log law the same as explained before. In this case, the user can employ the "*Use best fit*" option to calculate in each time step the extrapolation law which produces the best estimation at the highest wind speed level, but only with power law and log law.

When there are four or more channels, the best fit algorithm can be applied using all extrapolation laws. It is always possible to discard those fittings whose coefficient of determination is below a given value (see Figure 47). It must be remarked that when the highest level is not available the program uses the highest of the remaining to validate.

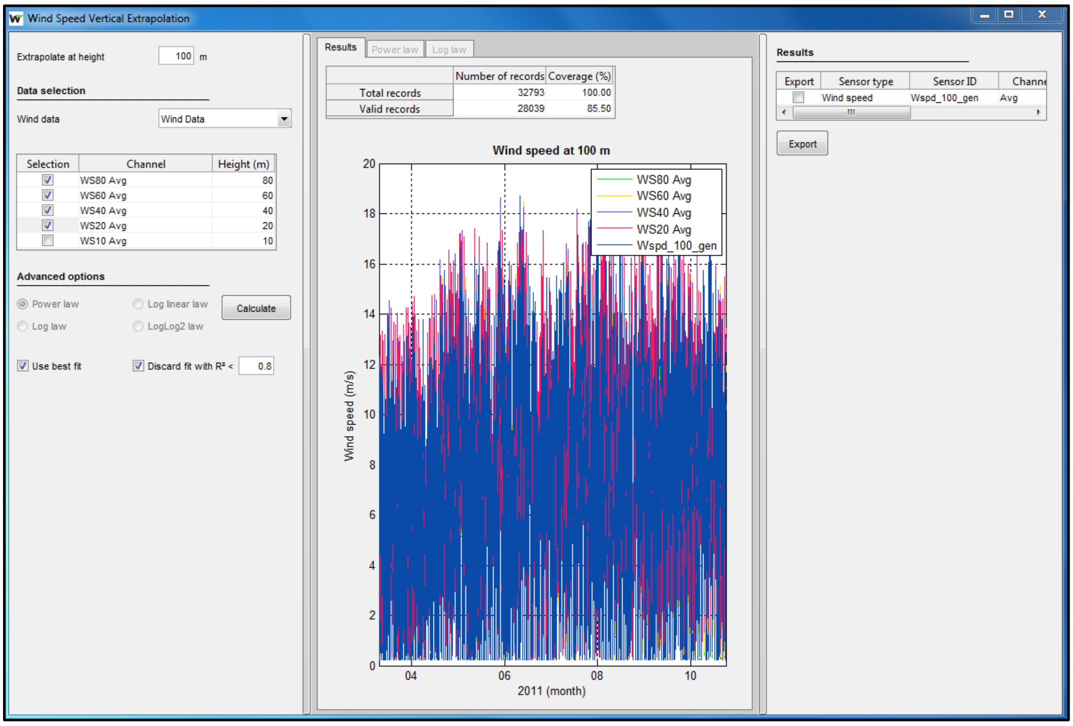


Figure 47: Wind speed vertical extrapolation module with 4 channels

8.3.2 Wind direction vertical extrapolation

For the extrapolation of wind direction, a lineal gradient is applied using the two closest wind direction channels to the extrapolated height (see Figure 48). If known, a value for vertical gradient can be set which is applied to all time steps.

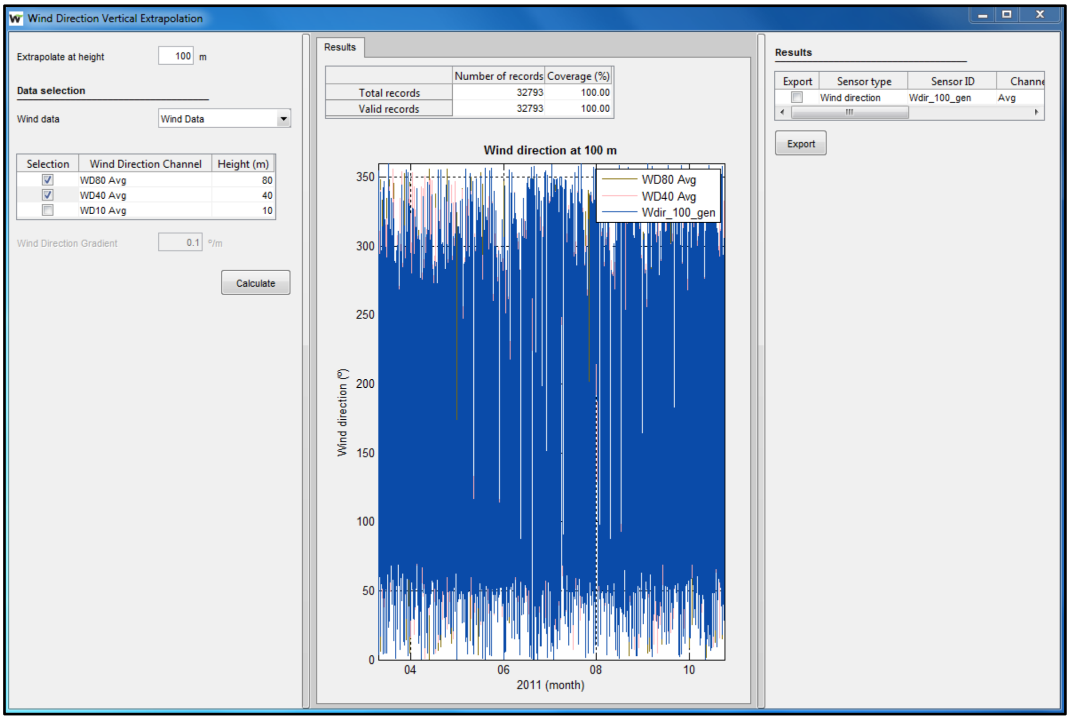


Figure 48: Wind direction vertical extrapolation module

8.3.3 Wind speed standard deviation vertical extrapolation

For this calculation, the vertical gradients for each time step are used between the two closest measurements to the height the extrapolated values are calculated (see Figure 49). If a constant value is used, this is also applied to all time steps.

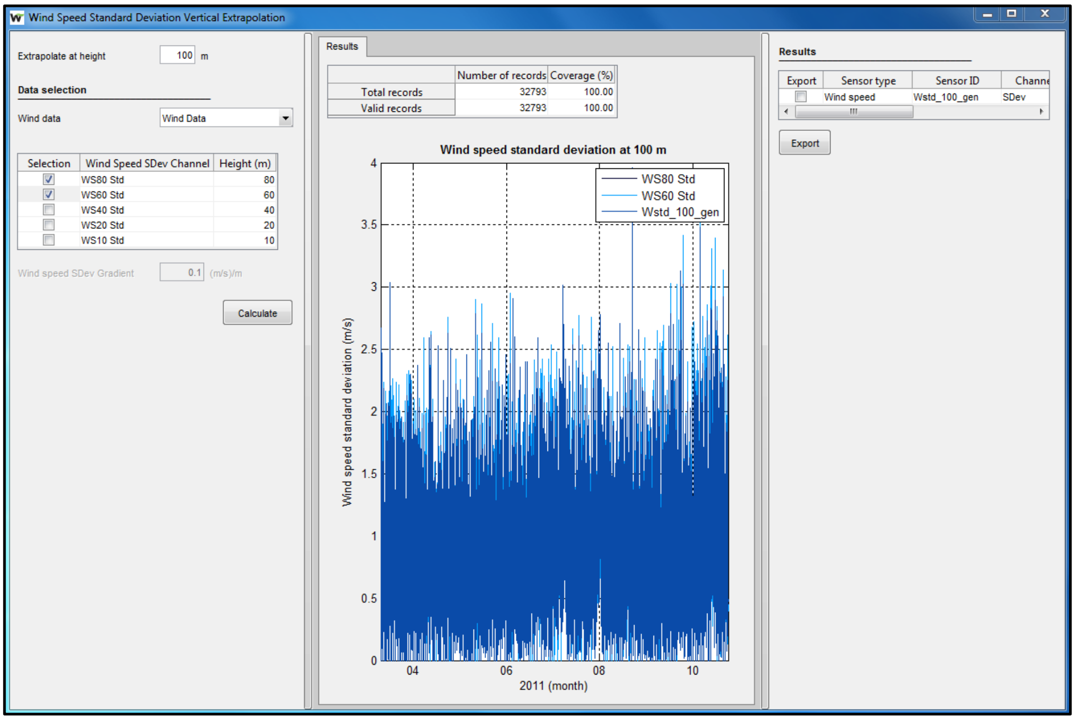


Figure 49: Wind direction vertical extrapolation module

8.4 Rotor equivalent wind speed

As explained on the ***Theory Manual***, the so-called Rotor Equivalent Wind Speed (REWS) is an equivalent wind speed which takes into account the wind speed flux across the whole rotor area.

In **FUROW**, for the moment, the user can select the wind speeds with which a fitting is performed on 10-minute basis (using the same options described on the wind speed extrapolation module) and then calculated the REWS by diving the rotor on several slices (selectable by the user) and weighting (with a given exponent) the wind speed with the amount of area of each slice. On this version **FUROW** can also use the measured wind profile without performing any fitting. The user can select the turbine model as well as the hub height.

Finally, the user can compare the difference of the average wind speed as if all time steps had been calculated with a constant alpha shear exponent (by default 0.2).

The new REWS time series can be exported and used in the program as a regular wind speed channel.

Figure 50 shows the REWS module with all the options.

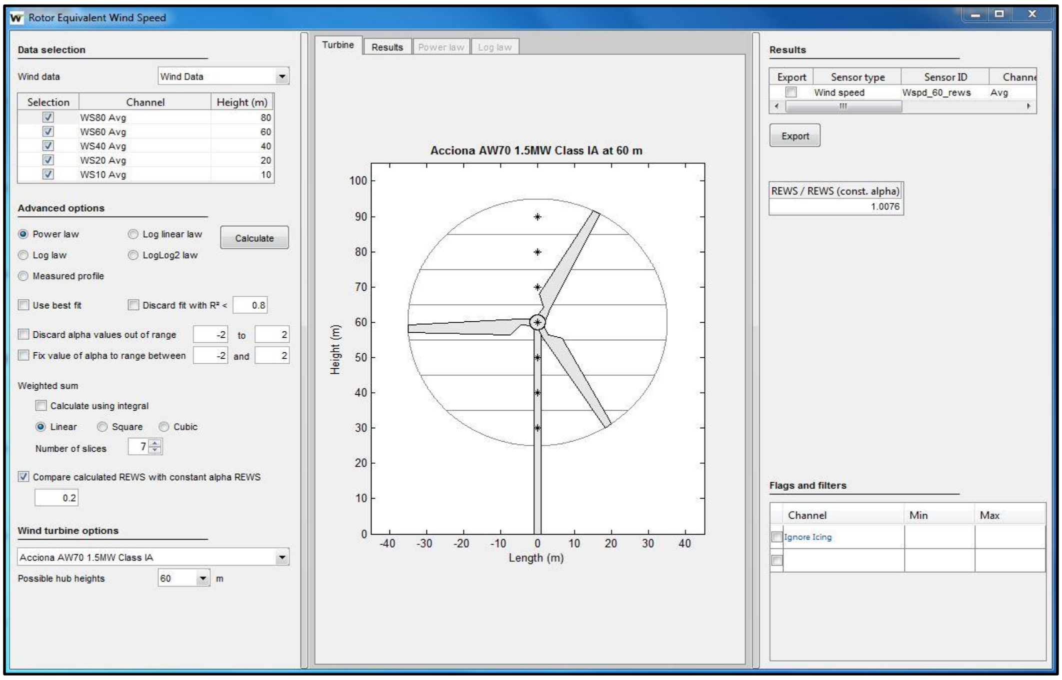


Figure 50: Rotor equivalent wind speed module

8.5 Air density and wind power

Within this module, air density at any height and wind power density can be calculated, as long as sensor channels or constant values are selected. New channels can be exported to the tree (see Figure 51). When all channels are not at the same height, the program still calculates air density and wind power density but it issues a warning on the right panel. On this version, altitude above sea level can be used to derive the pressure using standard atmosphere.

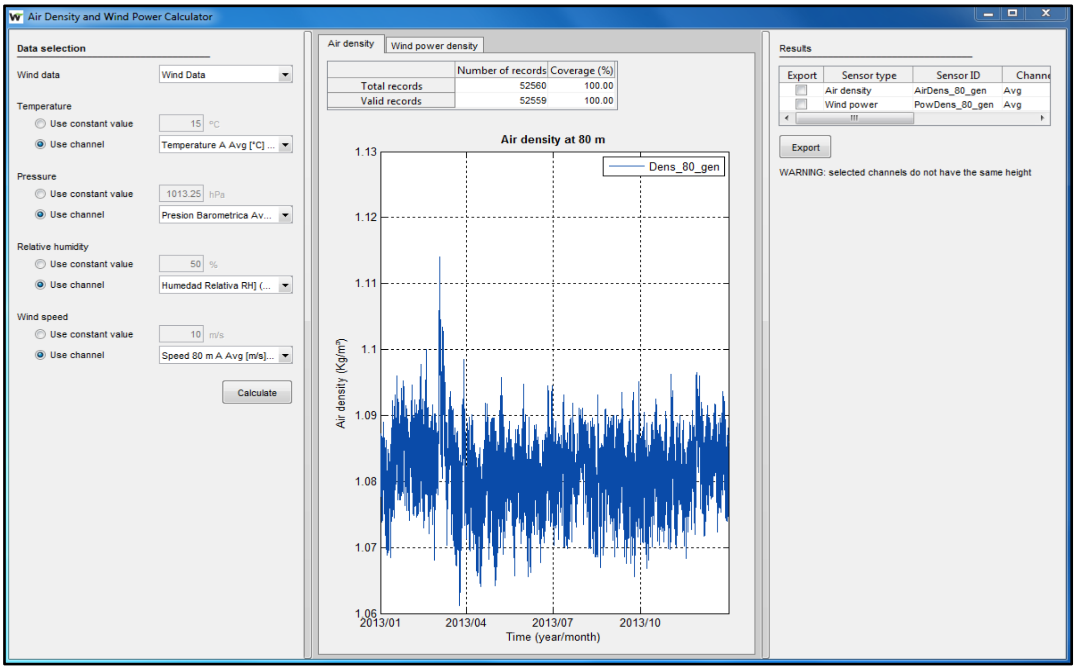


Figure 51: Air density and wind power module

8.6 MCP (Measure-Correlate-Predict)

The *"MCP module"* allows comparing the degree of correlation between two time series which can be from the same met mast or several different met masts. As a result, time series of the new channels can be exported, and/or information from score parameters can be obtained.

FUROW MCP dialogue allows correlating not only wind speeds, but also temperature, pressure, radiation and power production channels. Every magnitude is correlated sector-wise by selecting reference and target wind direction channels.

As explained on the ***Theory Manual,*** there are 5 algorithms to perform the correlations between channels, and one method to obtain the wind direction shifts. Every directional fit for the 5 algorithms can be viewed by changing the wind direction on the sector pop-up.

In **FUROW** there is the possibility of performing the MCP based on a single reference or multiple references:

8.6.1 Single reference MCP

Correlations between two time series can be done on the wind data time step basis, or by moving the slider, calculations can be done on larger time steps such as 1 hour, 1 day or even conventional months. When using larger time steps, it is recommended that the number of sectors is reduced to 1, as for large periods the idea of average wind direction makes less sense. Additionally, the user can discard data (for any time step) whose availability is lower than a given threshold. It is important to remark that there is an option of using *"Spot measurements",* which means that correlation will be performed only on concurrent instants when time steps of the target and reference channels are different.

On the Advanced options, the cross-validation method to be used can vary according to the user's preferences. Thus, score parameters can be quantified on alternating daily basis, halves of the concurrent period or the whole concurrent period. All score parameters are the result of comparing data of the validation period with the generated data based on the MCP fit.

For all the details above see Figure 52.

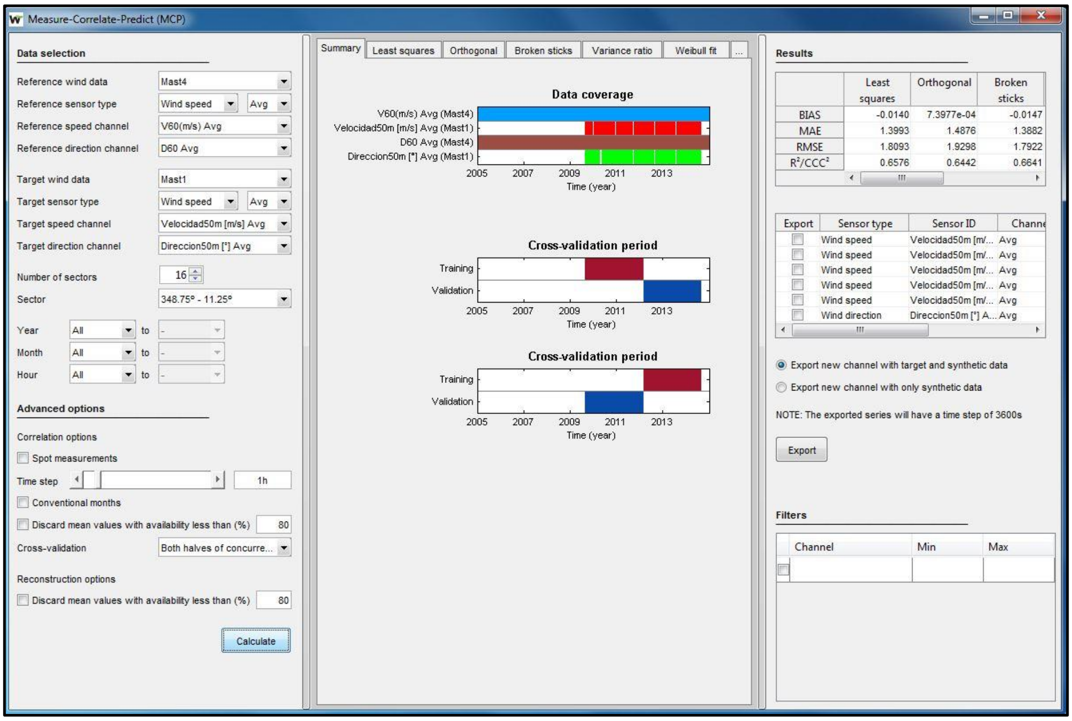


Figure 52: Single Reference MCP (Measure-Correlate-Predict) module

Finally, it is important to remark that new reconstructed channels can be exported to the tree. The step of the reconstructed data is the largest between the target and the reference. When exporting time series, the user can choose either to export the original data together with the synthesized data, or export just the synthesized data. It is also possible to discard data whose means do not fulfill with the criteria of minimum availability. The fitting coefficients used for the reconstruction are calculated on the time step selected by the time step slider.

8.6.2 Multiple reference MCP

When there are several WIND DATA objects, **FUROW** counts with a new module to use the information of multiple references to reconstruct the longest possible time series. The user must add all the references before making the calculations, taking into account that the reconstruction can be performed using series of different time step (knowing that the exported time series will be on the largest step).

This module does not perform a multiple regression but it ranks all references attending to the correlation coefficient in order to reconstruct always with the best available reference. References with a correlation coefficient lower than a given threshold (by default 0.6) are discarded directly on the ranking algorithm. The rest of options are the same as for the Single reference MCP, except for the cross-validation options which are not available here. For this last reason, the score parameters presented on the results are obtained directly by comparing the target data and the reconstructed data.

All the options and the structure of the module is shown on Figure 53.

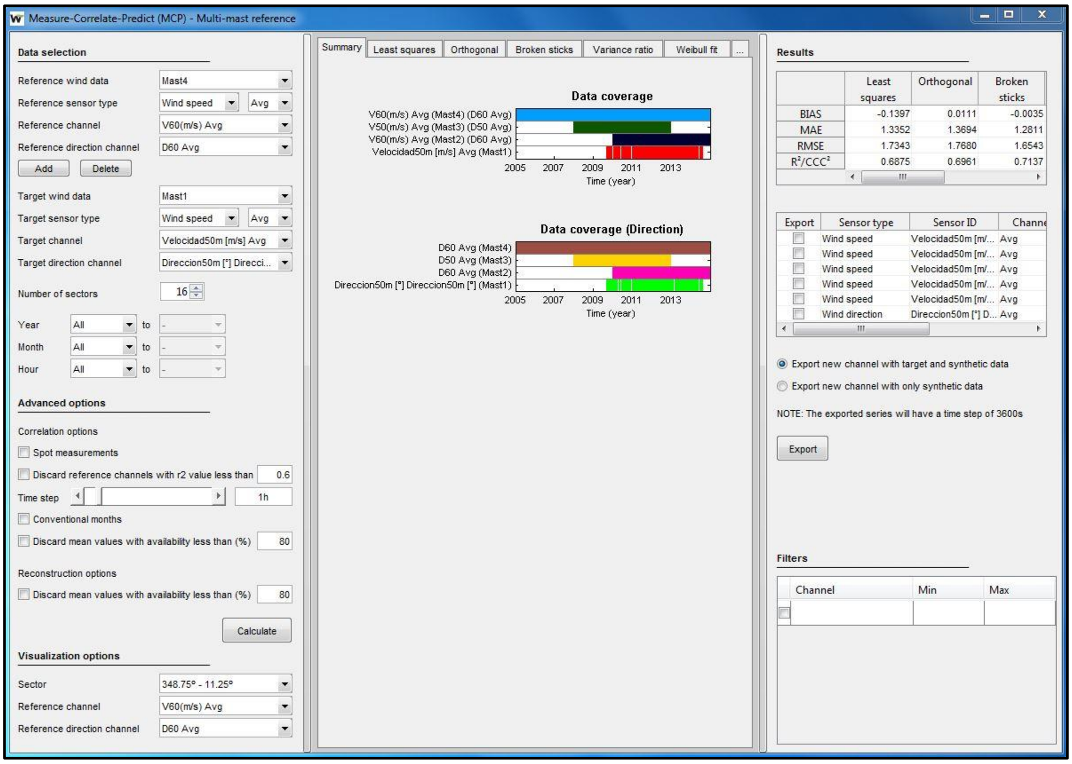


Figure 53: Multiple Reference MCP (Measure-Correlate-Predict) module

9 Data analysis

At the "*Data Analysis*" dialogues the following analyses can be performed.

9.1 Availability

Within this module, the user can select the periods which show higher data availability in case the number of gaps on the time series is significant. In such way, if there are several years of data, they could all be represented by smaller period of time whose availability is the highest and its mean value is very close to that off the long term.

For example, on Figure 54 there were 10 years of data at 70m high, and the user wants to select the best period of 3 years. **FUROW** runs a step-by-step moving window of 3 years to determine the availability of each period and represents a graph with the information. On the *Table tab*, the user can see all periods with highest availability. If besides the availability, the user wants to determine if that period is also consistent on average, it is possible to set a threshold above which period is considered invalid in terms of representativeness. It is remarkable that this availability calculation can be used combining several channels, such as wind speed and wind direction, or even another one like turbulence. The selection of the threshold for the mean value depends on the channel selected by the user.

Also, for this new version the availability calculation for a so-called typical year has been included. It allows determining the months with the highest availability, and, if enabled by the user, the average value of the month can be taken into account to discard outliers.

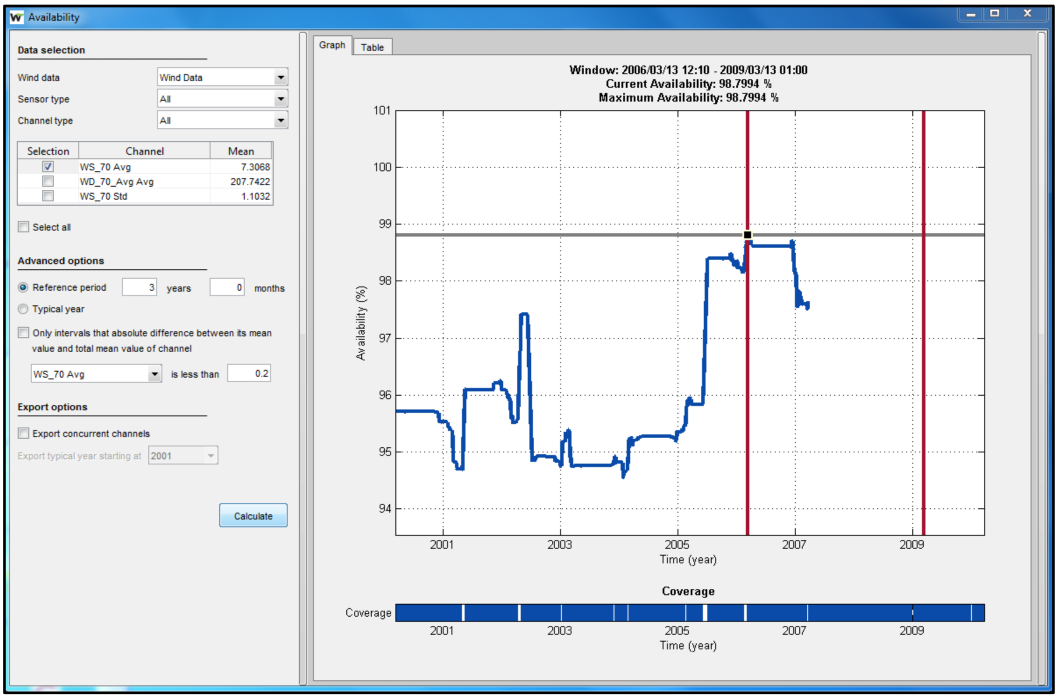


Figure 54: Availability module

9.2 Weibull Fit

This dialogue allows the user estimating the Weibull distribution parameters (A and K) associated to a wind speed time series. There are several methods used to derive these parameters and the results are always followed by the R^2 of the fitting. Moreover, other parameters like the mean value, standard deviation, etc. are shown on a different table (see Figure 55).

There is an option called *"Weibull merge"* which calculates Weibull distributions by sector or by month, and then adds all of them up to obtain a function which is not a Weibull distribution but fits better a hypothetical non-Weibull distribution such as a bimodal distribution.

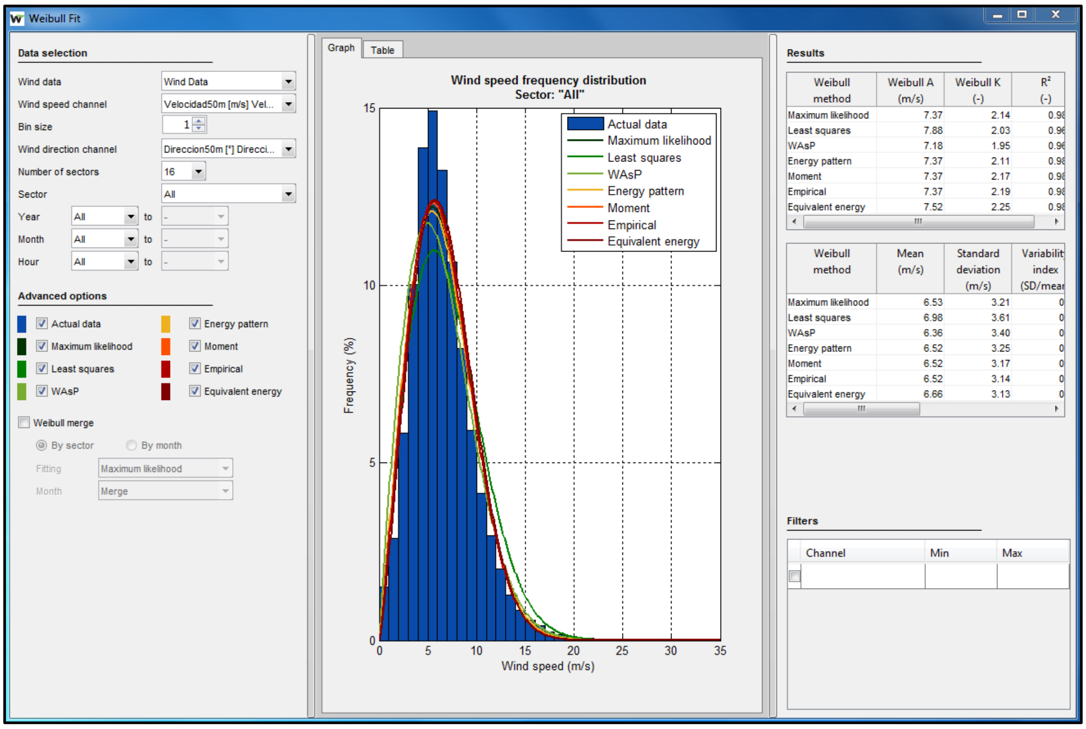


Figure 55: Weibull Fit module

9.3 Scatter Plot and Fitting

This tool allows the user comparing two channels and establishing the degree of linearity between them. Several types of fit are available, even forcing the regression to zero (making the offset equals to 0), and showing the confidence intervals (set to a given level, being 95% the default). See Figure 56 for an example.

The number of sectors can be chosen, and thus the score parameters are obtained for every sector. Besides, the time step for the fitting can be modified and then score parameters will also change. The time step also depends on the time step of each channel which can be different. The option of conventional months can also be used on this tool.

When there are discrepancies on the linearity between two channels of the same magnitude within a mast, because some measurements are clearly outside of the fitting line, it may indicate that some of them may have been retrieved incorrectly or might be affected by special issues which cause disagreement. This could happen when comparing anemometers, one of them is affected by icing problems, overspeeding or even tower distortion. On those cases, specific time steps can be removed by using the *"Scatter Plot and Fitting"* dialogue under the *Data Analysis* menu. In order to flag the wrong data the Shift key is pressed while dragging with the mouse left key. Once the points are selected (through a rectangle for the moment), three options show up: 1)Flag both channels, 2)Flag channel X, 3)Flag channel Y. Thus, depending on which channel contains the wrong data, the flag is applied to the one selected by the user. Figure 57 shows an example of the rectangular box to flag some outliers.

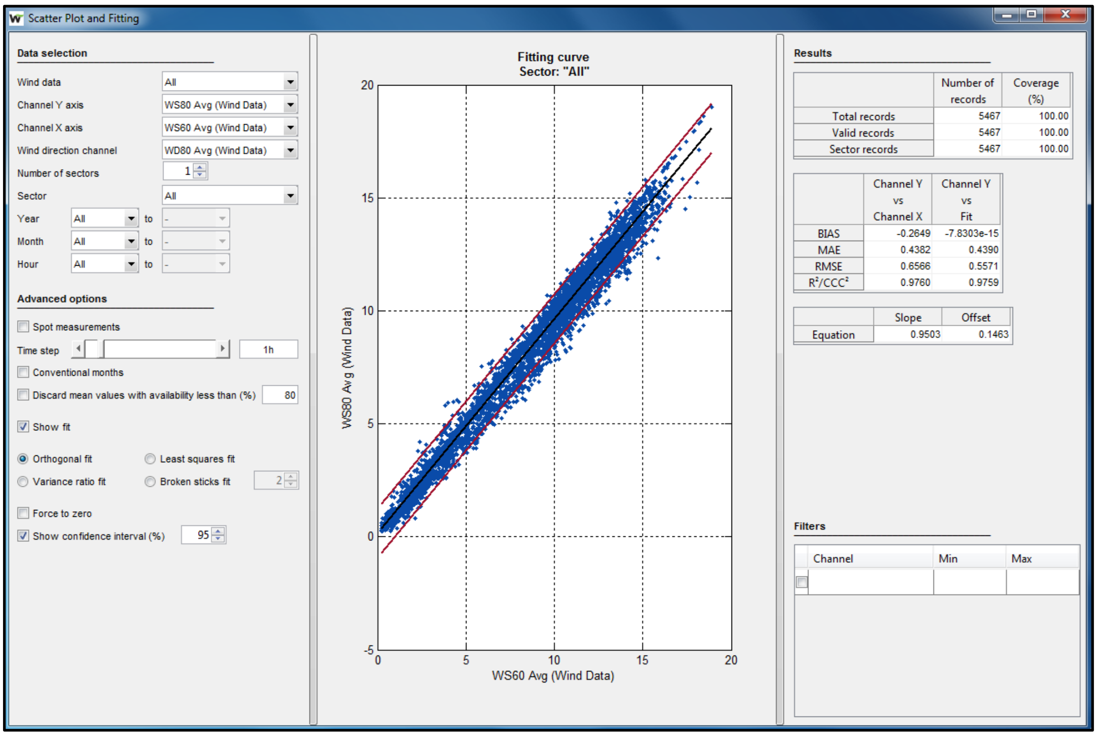


Figure 56: Scatter Plot and Fitting module

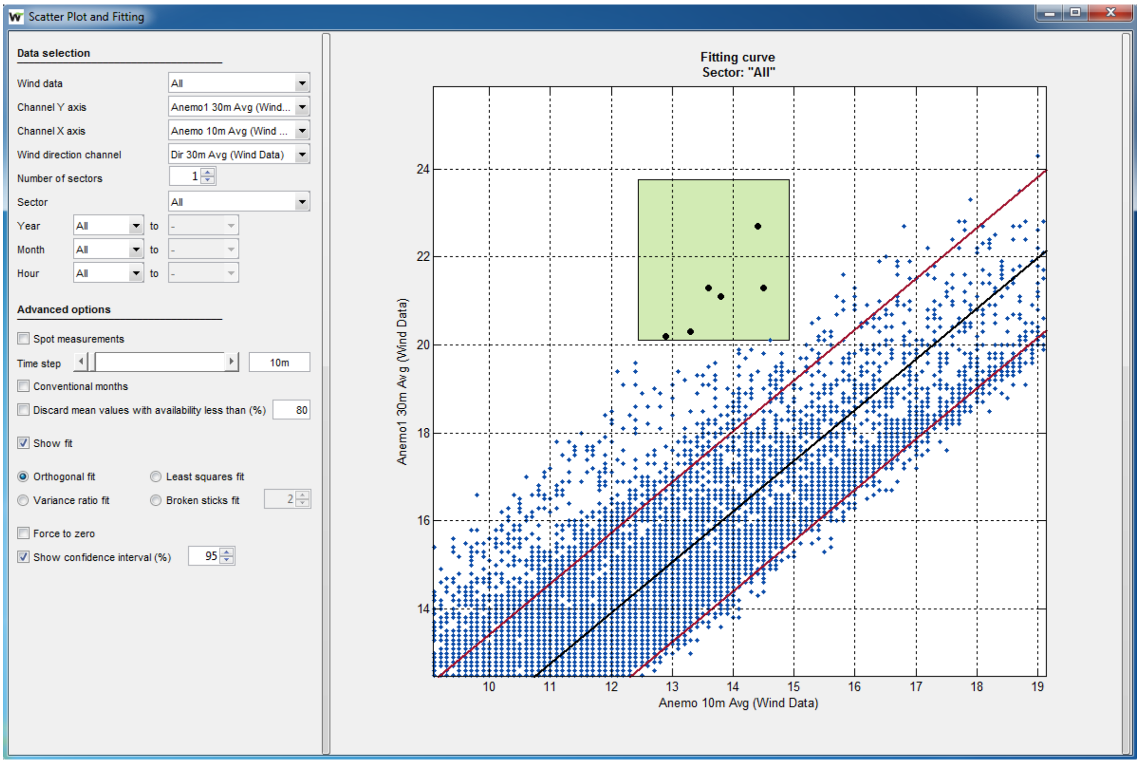


Figure 57: Flagging with Scatter Plot and Fitting dialogue

9.4 Turbulence

On this module, one average wind speed channel, one wind speed standard deviation channel and one direction channel are needed to calculate all the statistics related to turbulence analysis. The bin size is controlled by the user, as well as where to start the first bin. Sometimes, the user wants to have a smaller first bin, for example of 0.5m/s instead on 1m/s. In this case, the option *"First bin half the bin size"* must be selected. Regardless of which option is chosen for binning, the wind speed value which appears on the table tab always denotes the center of the bin, with the associated number of records and the turbulence intensity statistics. On the *Graph tab* the turbulence intensity curves are plotted and can be changed for every wind direction (see Figure 58).

On the advanced options, the user can choose the IEC Edition to work with, as well as the graphs corresponding to IEC Editions under normal conditions or extreme conditions. The extreme TI graphs only apply to IEC 3rd Edition.

Finally, in order to calculate the TI15, **FUROW** gives two options: either the interpolated value at 15m/s or the weighted average value from 10m/s up to maximum wind speed

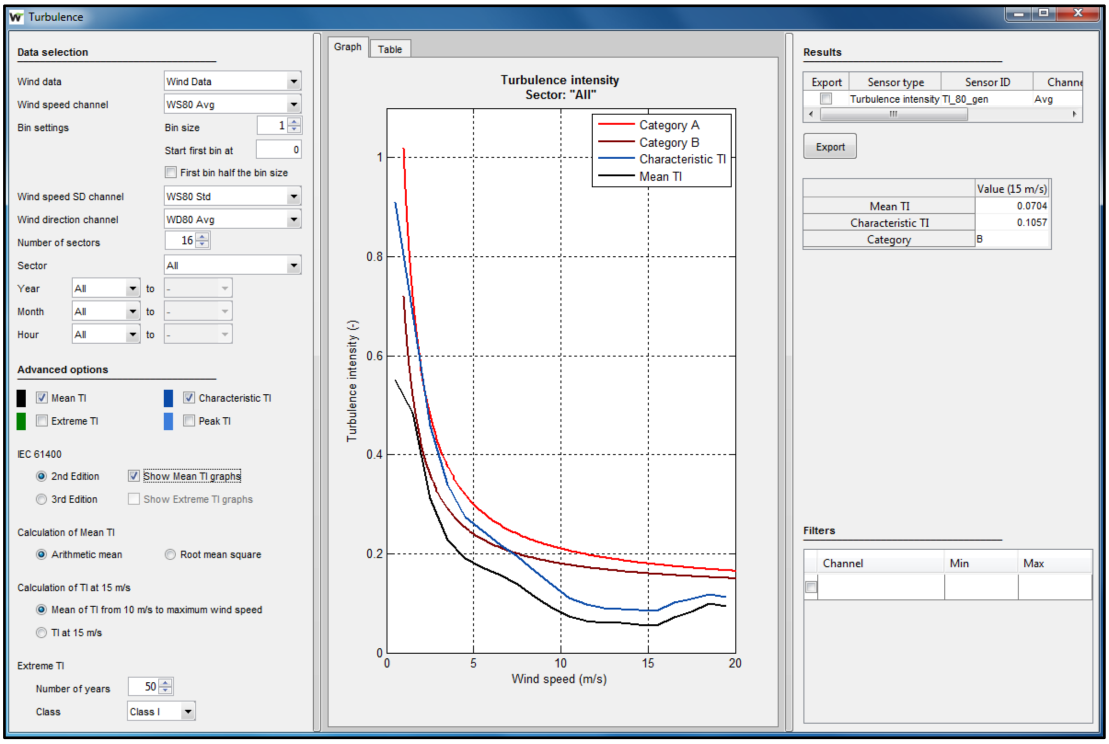


Figure 58: Turbulence module

9.5 Wind shear

The wind shear module allows calculating how the wind changes with height using four different laws as explained on the ***Theory Manual***. The *power law* and the *log law* are available with just two channels, whereas the *log-lineal* and *log-log2* are available with at least three channels selected. On the *Graph tab* the vertical profiles with all the fittings are plotted and can be changed for every wind direction (see Figure 59).

When moving to the *Table tab*, all the results for every sector and every fitting are shown, including all the coefficients from the regressions. Additionally, the value of R^2 is shown for every fit.

On the *Results panel*, the user can view the average wind speed value at all selected heights, as well as the mean value of alpha, roughness length and friction velocity.

For some applications, it may be interesting to create a matrix of values of alpha attending to the wind speed (at the highest channel) and the wind direction channel selected on the pop-up. In this case, **FUROW** allows exporting this matrix according to two different procedures. The bin size of the wind speed interval can be modified if desired.

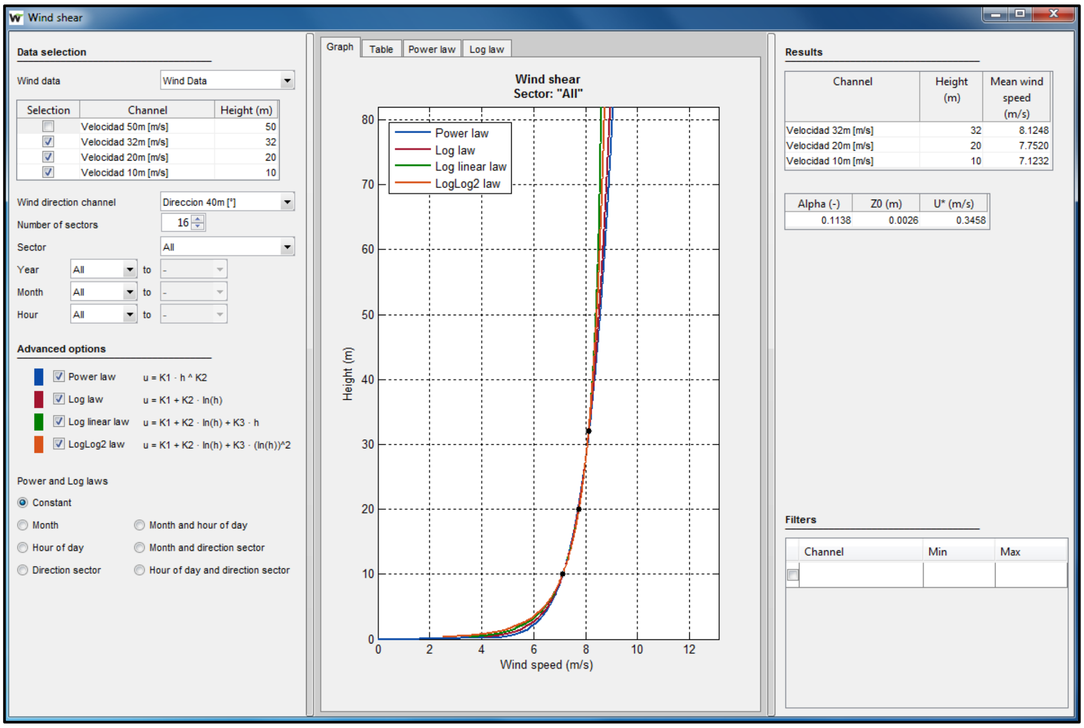


Figure 59: Wind shear module

9.6 Long term

With this tool, the user can inspect the annual evolution of a magnitude such as wind speed and power production to derive potential trends which may appear on the time series. For this purpose, the program fits a straight line through a linear regression and calculates the slope of the straight line as well as the determination coefficient of the fitting. The higher the correlation coefficient, the higher is the confidence to ensure that there is a potential trend on the behavior of the magnitude. It is possible to exclude those years whose recovery rate is below a given threshold. The user can also select specific periods of time to perform the analysis.

By applying a moving average of N years, the possible cycles maybe identified and linked with large climate forcing phenomena such as El Niño, NAO, etc. This is the case shown on the Figure 60 and Figure 61 for wind speed and power production time series (reconstructed) for a site in Mexico where cycles of 20 years are identified by making moving averages every 5 years.

On the *Results panel* the program quantifies the wind speed or power production average and standard deviation values, as well as its variability in percentage, as defined on the ***Theory Manual***.

Numeric results are on *Table tab*, whereas the cumulative variability is quantified on another tab. The cumulative variability may indicate potential inconsistencies of the time series.

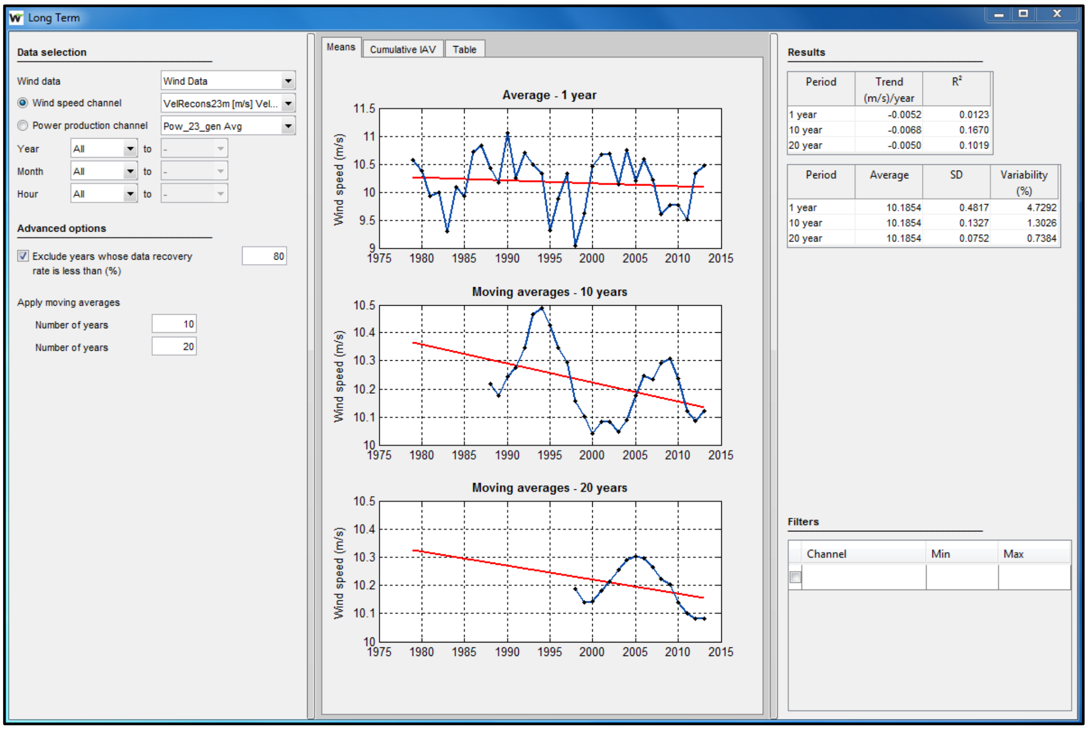


Figure 60: Long term module for wind speed channel

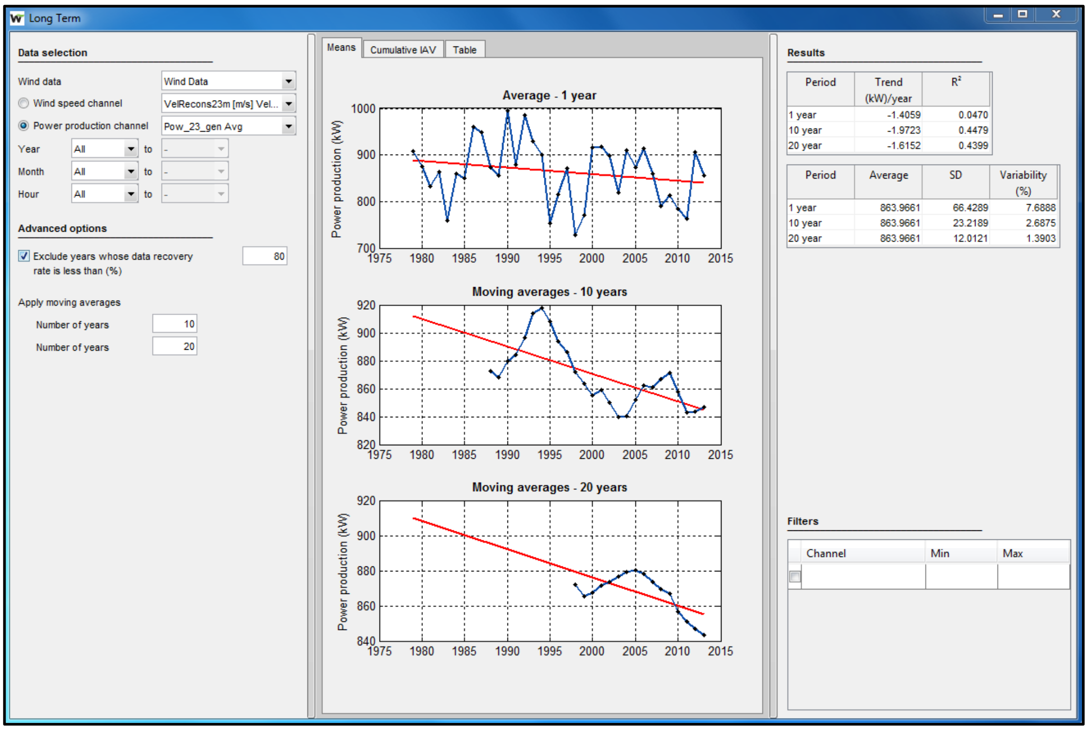


Figure 61: Long term module for power production channel

9.7 Extreme Winds

The extreme winds tool allows calculating the so-called V_{ref} provided data are on 10 minute time step (also the V_{ref} for a different period than 50 years can be calculated) as well as its uncertainty.

There are three methods to derive this extreme wind speed as described on the ***Theory Manual***. With the *"Periodic Maxima method"*, only one time step is selected on every period, whereas on the *"Independent Storms method"*, all time steps above a certain threshold and as long as they are separated by a given number of hours are selected. The "*EWTS II method*" is based on Weibull distribution and it is accurate when Weibull K is close to 2.

As a result of the calculations, on the Table tab it is always possible to find the exact date and time of the selected maxima by each method. If channels such as standard deviation, air density and Monin-Obukhov length are available, then for each maximum concurrent values of these variables are shown on the table together with the wind direction. This information is very useful when running an "*Extreme Wind map"* since it is possible to obtain the value of turbulence intensity and air density for the selected V_{ref} at all turbine positions. On the *Results panel*, the user can see at all times the values of V_{ref} calculated for every method, as well as the mean wind speed and Weibull K parameter being used on the EWTS II method.

In this new version, it is possible to correct with a scaling factor the maximum wind speeds selected to calculate V_{ref} when the time step is different from 10 minutes.

An example of the calculation of V_{ref} for a specific site with more than 5 years of data is shown below on Figure 62 and Figure 63. On Figure 62, it can be seen how "*Periodic Maxima"* yields a higher value of V_{ref} in comparison with Independent Storms method. However, the uncertainty is a little higher as the number of data points is smaller. For the Figure 63, values of other variables are shown when maxima are found. It is interesting to remark that high wind speeds are usually connected with very neutral atmospheres as it is visible on the last column of the table.

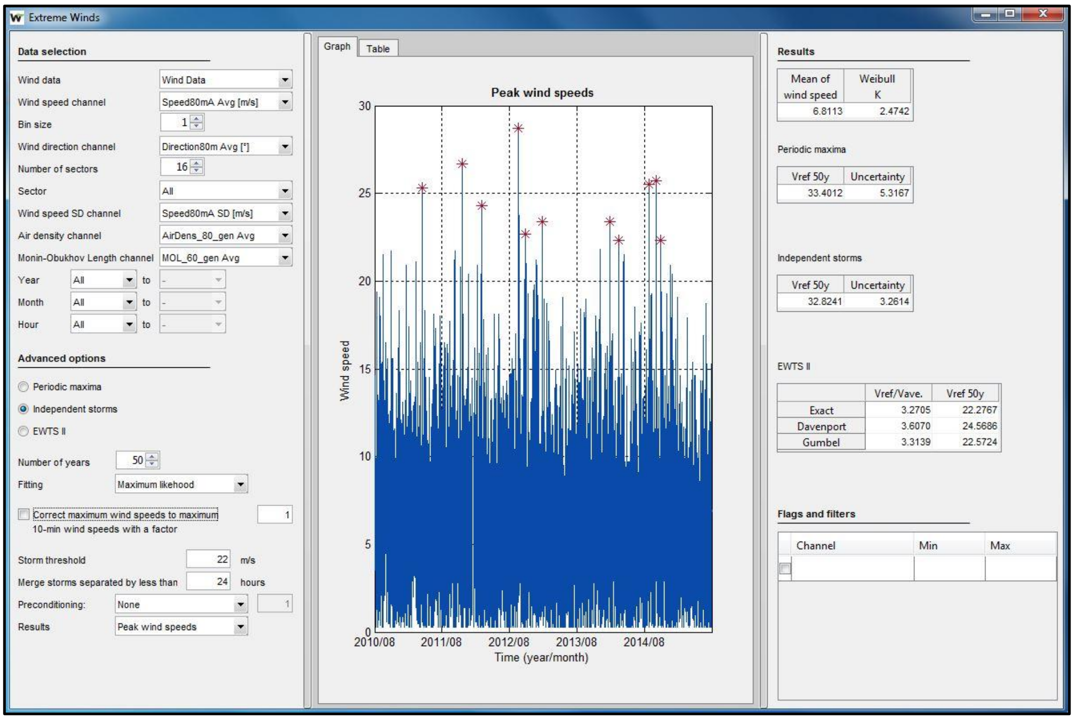


Figure 62: Extreme winds module using Independent storms method

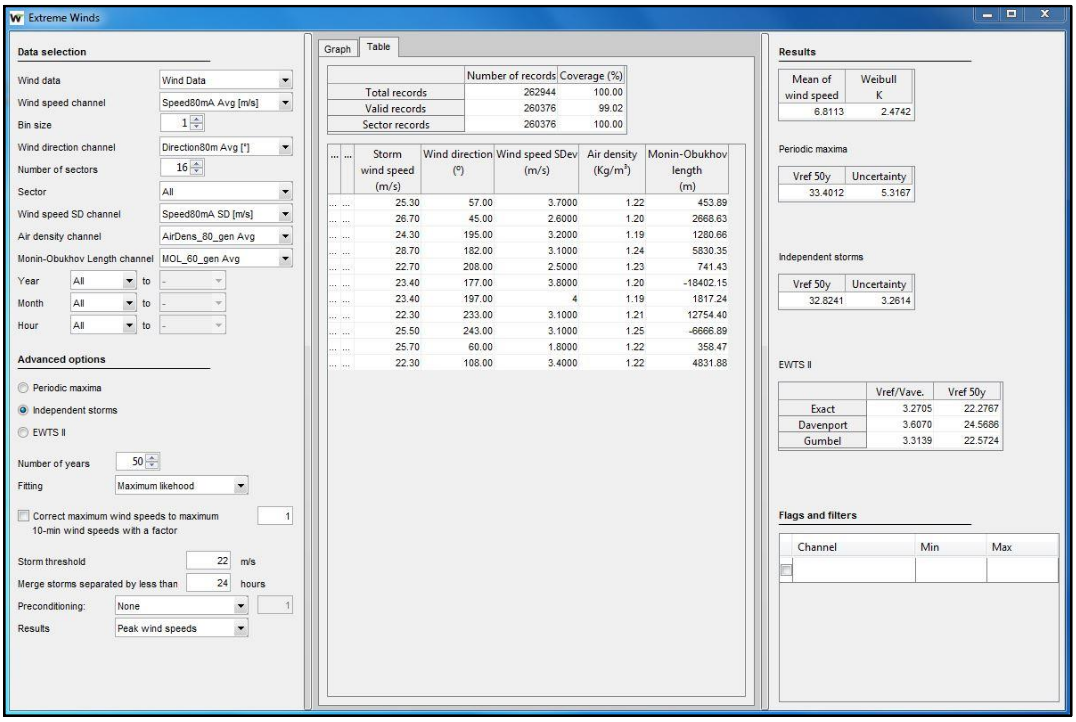


Figure 63: Extreme winds module showing the results on a table

On this new version, SOLUTE has developed a new tool which allows estimating the extreme wind speeds at a place affected by hurricanes. This new functionality does not need information about the wind speed at the site as it is based on the hurricane tracks and meteorological data derived from the NOAA databases. With that information and taking into account the formulation described on the ***Theory Manual*** it is possible to estimate the value of V_{ref}.

In order to do so, in the *Extreme winds* module the user can select **Hurricane database** by clicking on that radio button and then clicking on the button "Select hurricane database wind speed series" (see Figure 64). After clicking on this button another window shows up (see Figure 65) where the user can select the coordinates of the mast, the period of time to compute the effects of different hurricane tracks, the search radius (by default 500km) and the category of hurricanes to be taken into account for the estimation of the extreme events. Once all of this is defined the user must click on the "Extract hurricane data" button and then all hurricane tracks appear on the screen. The circles indicate the position of the hurricane every 6 hours when it is at a distance less than the search radius. On the Table tab the user can visualize all the events with the following variables: geographical coordinates, eye pressure, eye wind speed and distance to the mast.

Once all tracks have been identified with their properties, it is time to click on the "Calculate and export" button in order to perform all the necessary calculations to obtain the maximum wind speeds at the mast position. Calculation options for the estimation of maximum wind speeds can be modified according to Figure 64, where the user can change the terrain type (which modifies the conversion factor), the wind shear and the extrapolation height (hub height). From there, it is possible to calculate V_{ref} by applying the Independent Storms Method

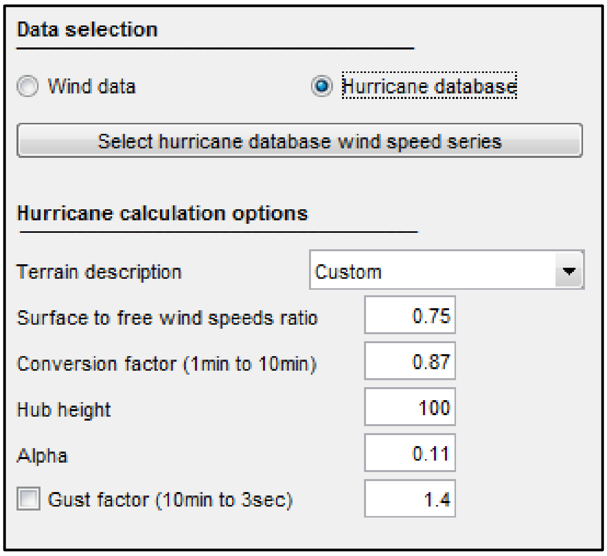


Figure 64: Selection of hurricane database and calculation options

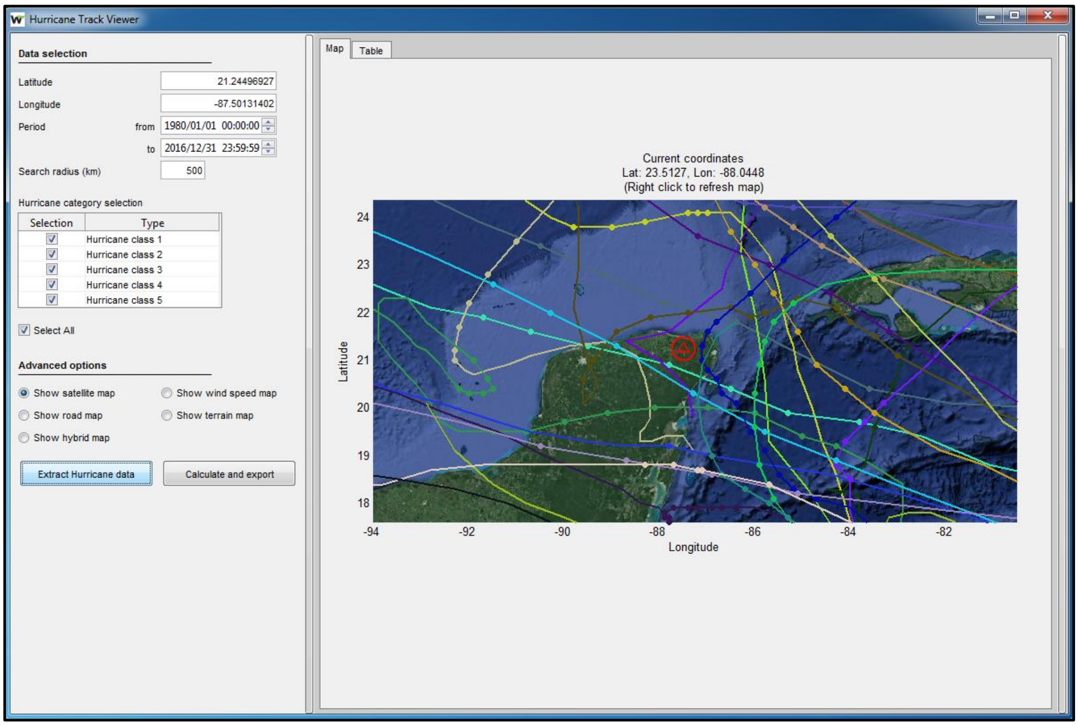


Figure 65: Visualization of the hurricane tracks

9.8 Atmospheric stability

In order to work in atmospheric stability module, it is necessary to have information of the temperature and wind speed at two heights. Additionally, wind direction may be used to better calculate the Richardson number. However, if a Monin-Obukhov length has been previously loaded, the module also works and provides as output the Richardson number and the stability histogram.

When calculating the Richardson number, the formula involves calculating the wind shear. When wind speeds are almost identical at two heights, then the Richardson number becomes very large and results may not be accurate. For this reason, it is possible to discard calculations when wind speed differences are below a certain threshold.

Some sites have very stable or unstable conditions which cause the Monin-Obukhov length to be extremely low in absolute value. Very low values may be somewhat noisy in terms of wind flow simulations. For this reason, **FUROW** allows fixing Monin-Obukhov length to a certain threshold when it is below this threshold. Also, the user can discard Monin-Obukhov length values when they are outside of a given range.

Once the Monin-Obukhov length time series is created, **FUROW** can plot a stability histogram where the x-axis is wind speed and y-axis the frequency per wind speed bin. The user can divide the atmospheric stability in 7 ranges as wished, and each one of them is shown with a different color (see Figure 66). If a wind direction channel is available, then the stability histogram can be viewed for each sector.

On this new version of **FUROW** it is also possible to make a first estimation of the boundary layer height by fitting the wind profile and using the Monin-Obukhov length.

Finally, many channels can be exported from this module: temperature difference between two levels, temperature gradient, potential temperature gradient, Richardson number and Monin-Obukhov length.

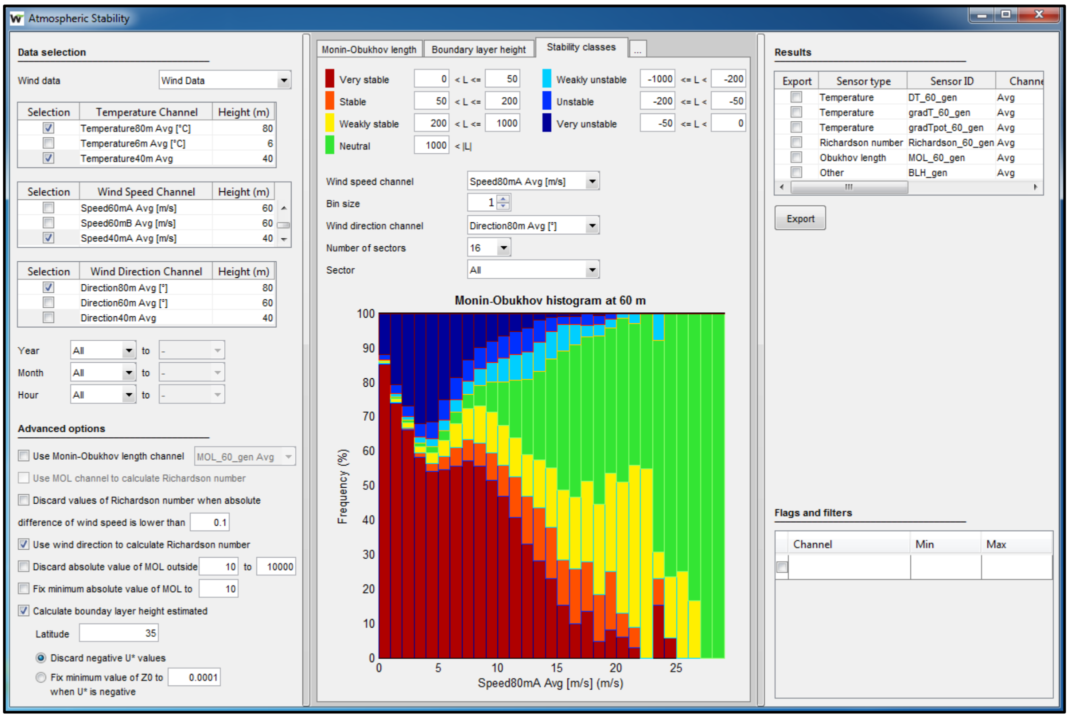


Figure 66: Atmospheric stability module

9.9 Inflow angle

Inflow angle can be calculated from an average wind speed channel and a vertical wind speed channel. The inflow angle can be viewed on *Cartesian axis* or *Polar axis*, and the number of points on the plot depends on the number of sectors chosen for the representation (see Figure 67). In any of previous ways of representation, the user can choose to perform a scatter plot or a statistics plot.

On the Table tab, the inflow angle for each sector is shown. There is also an option called *"Histogram"* which allows calculating the frequency of the inflow angle for a number of sectors. Finally, the inflow angle channel can be exported to the tree structure.

In this new version, a parameter called *Inflow ratio* is also calculated. This parameter gives an idea of the approximate inflow losses in energy production a wind turbine would have if it had been placed at the mast position. For that purpose the user must select a wind turbine from the drop-down list.

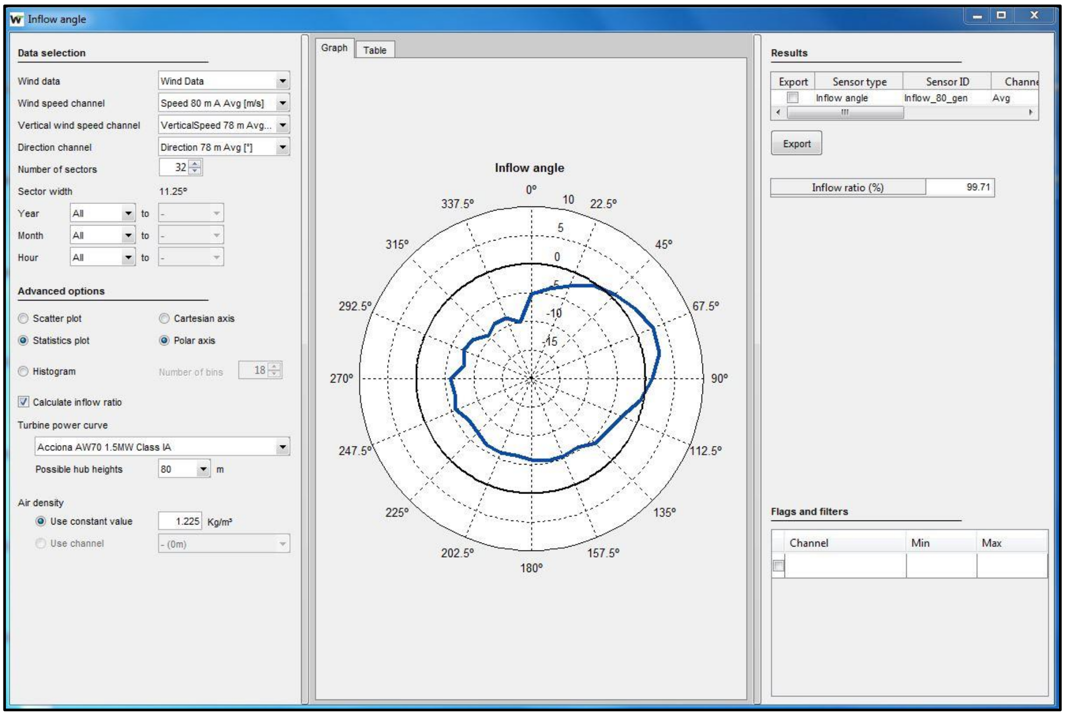


Figure 67: Inflow angle module

9.10 High Wind Hysteresis

The idea with this module is to be able to calculate the losses due to high wind hysteresis, that is, the number of steps the wind turbine is stopped within a range in which the turbine could be operating if the cut out wind speed had not been surpassed.

Thus, in order to quantify these losses, the cut out wind speed and the rearming wind speed after the hysteresis should be an input. Additionally, a filter in seconds have been implemented in order to determine a possible situation in which wind speed remains for a given time within the hysteresis range and does not go below it. In this case, it is possible that some manufacturers will set a time to re-start the wind turbine if wind speed is below the cut-out wind speed sustained for a certain amount of time. On the contrary, if the wind turbine has to wait until the wind speed has gone below the hysteresis level, then the maximum losses time filter should be set into a very large number.

As a consequence of the behavior described above, red colored time steps show the instants when the wind turbine is stopped and black colored time steps show the losses time steps as a consequence of applying the hysteresis (see Figure 68). The *Results panel* shows the number of time steps included on those losses as well as a percentage, which could be used as a first approximation to estimate the high wind hysteresis losses on the energy yield assessment. On the Table tab, the time intervals including stops and losses are shown, also including the average wind direction of the interval and the wind direction standard deviation.

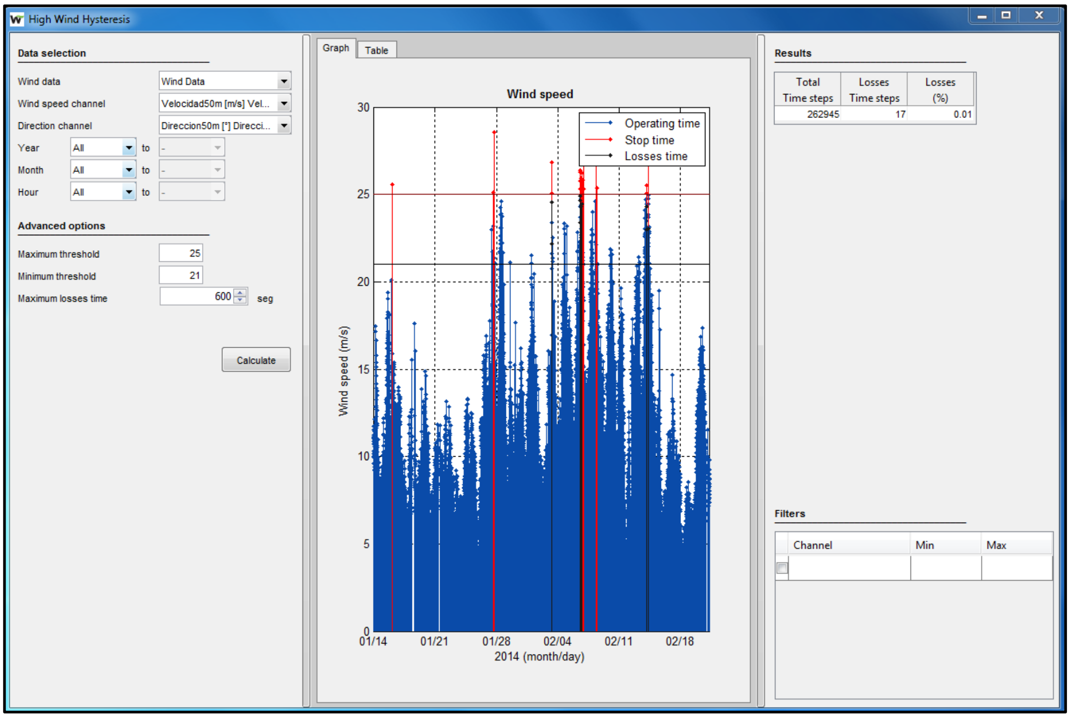


Figure 68: High Wind Hysteresis module

9.11 Wind transitions

Within this module, based on a wind speed and wind direction channel, the transitions of wind speed and wind direction based on some thresholds can be calculated. Moreover, coincident transitions can be calculated to find the worst instants when abrupt changes are occurring.

Time distance can be modified through the time frame box. If the time step is 10 minutes, but the transitions are wanted every hour, then the time frame should be 3600 seconds.

On the *Table tab*, all transitions fulfilling the conditions set on the thresholds are shown to clearly identify the time steps.

Figure 69 shows all the options of this module.

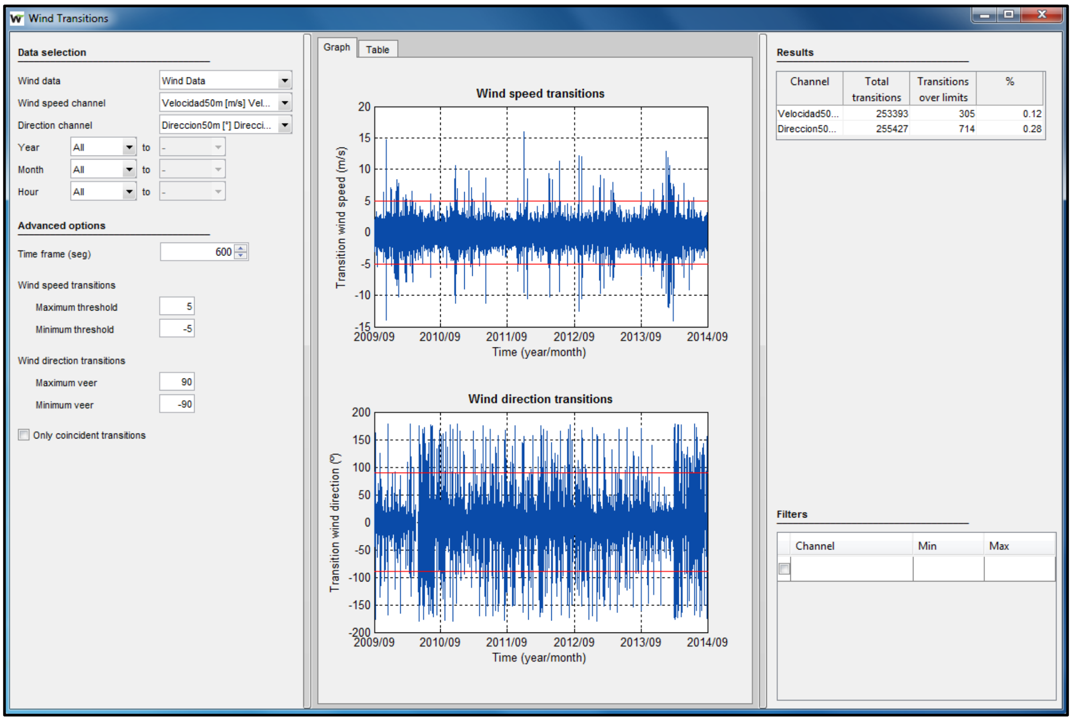


Figure 69: Wind transitions module

9.12 Temperature losses

This new module implemented in **FUROW** allows calculating the energy losses as a consequence of temperature data above or below the maximum and minimum temperature thresholds which are usually the maximum and minimum operating temperatures for a wind turbine.

In order to calculate the energy losses, wind speed, air density and temperature information is required, together with the power curve of a wind turbine or a wind farm. Additionally minimum and maximum operating temperatures are required.

For the example shown on Figure 70, operating temperatures have slightly modified in order to show the effect of potential temperature losses. Values in red will be those on which the turbine would be stopped and values in blue on which it would be operating. So, in order to calculate the losses, power curve is applied for the time steps plotted on red color and then divided by the overall energy produced in order to get a percentage which is shown on the *Results panel* on the right side of the screen.

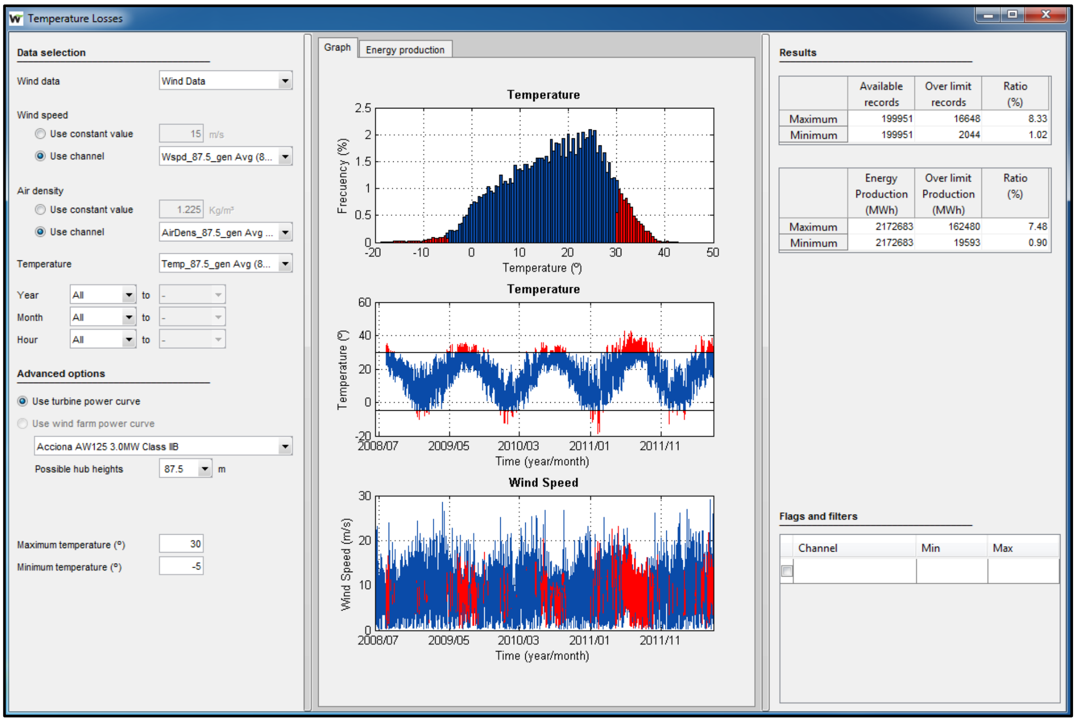


Figure 70: Temperature losses module

9.13 Energy production

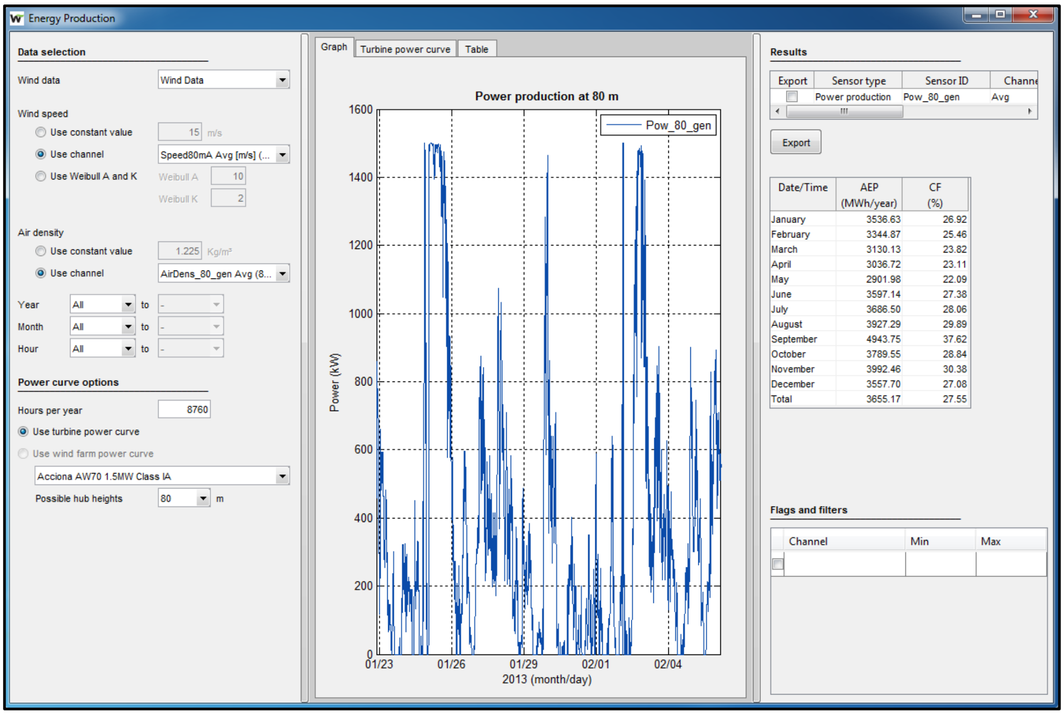
The energy production module allows estimating the energy production of a site in a quick manner by just providing a source of wind speed distribution and a power curve of a wind turbine.

Wind speed inputs come from either a constant value, a Weibull distribution (A and K parameters) or a channel. In the first case, a constant value derived from the interpolation within the power curve is obtained. When providing a Weibull distribution, a power production histogram is obtained. Finally, when a wind speed channel is selected, then a time series of power production is calculated. On the *Results panel*, the user can see the estimated energy production and the capacity factor. When the input is a time series, then a power production time series can be exported to the tree (see Figure 71).

Air density is another parameter which is used to decide on which power curve to interpolate, or in the case the value is outside the range for the power curve, to apply the appropriate corrections depending on the power regulation type of the wind turbine (pitch or stall). Air density can be a constant value or a channel. If the availability of the air density channel is different from that of the wind speed, then the time series will have an availability which will be the minimum of both channels.

Finally, the power curve of a wind turbine is necessary for all calculations. If the energy yield has been calculated, then the wind farm power curve is available, so the power production of the wind farm can be obtained in terms of time series. Wind farm power curve only includes losses due to wake effects.

If wind speed comes as a time series, then it is possible to inspect energy production estimates or capacity factor on year basis, monthly basis or hourly basis.



Date/Time	AEP (MWh/year)	CF (%)
January	3536.63	26.92
February	3344.87	25.46
March	3130.13	23.82
April	3036.72	23.11
May	2901.98	22.09
June	3597.14	27.38
July	3686.50	28.06
August	3927.29	29.89
September	4943.75	37.62
October	3789.55	28.84
November	3992.46	30.38
December	3557.70	27.08
Total	3655.17	27.55

Figure 71: Energy production module

10 Clima object

A CLIMA object shows a summary of the meteorology of the site to do all wind resource calculations useful for energy production calculation and micrositing. It is easy to create a CLIMA object by selecting under the SITE object the appropriate inputs of wind speed, wind direction, wind speed standard deviation, pressure, humidity and temperature.

Whereas in the first version there were two ways to generate a CLIMA object, on this version they have been unified in just one dialogue, which is called *"Create Clima Object"* under the SITE object (see Figure 72).

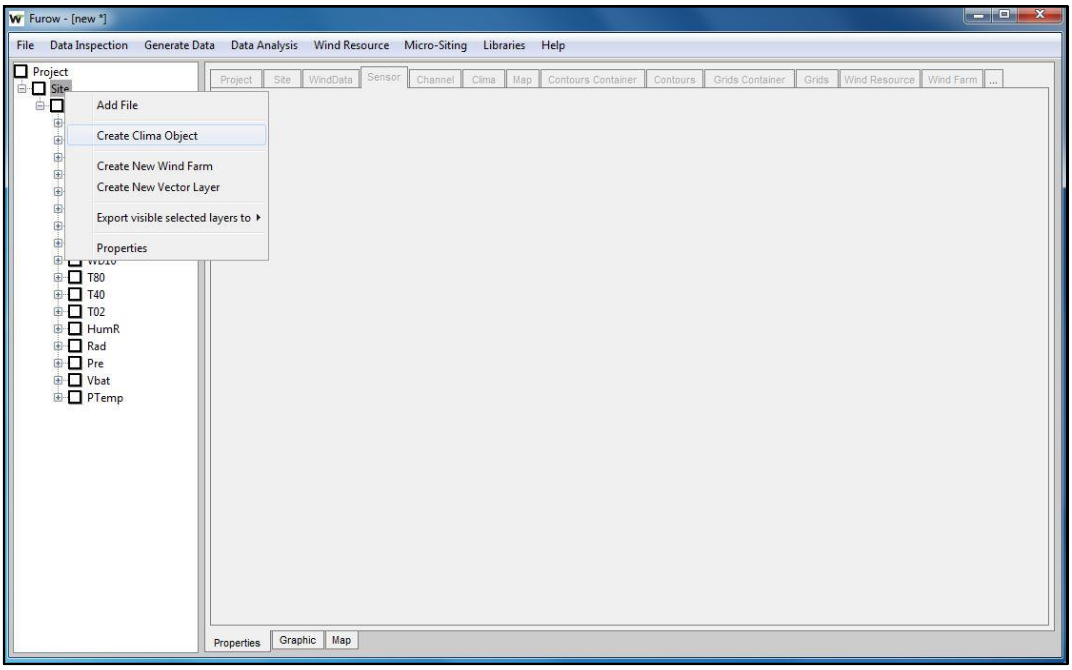


Figure 72: Create CLIMA object from tree

When the CLIMA object dialogue is opened, the user can input data through different ways: by using a file previously created on **FUROW** or in other programs, by selecting constant values or distributions (by sector, wind speed or both) or by using channels from any WIND DATA object. As the user enters all necessary information, tabs change their colors alternating red (inactive tab), yellow (active tab) and green (calculated tab). When loading information though the three ways described above, if existing, **FUROW** stores information about latitude and longitude, as well as the height, number of sectors or wind speed bin size.

Depending on the tab, there are several representations which are shown to provide more information about what is being loaded.

- Wind speed frequencies: table format, wind rose, Weibull parameters for directional distributions and global distribution, and a 2D histogram by sector and wind speed.

- Wind speed SD: table format, polar plot of wind speed SD, turbulence by wind speed and turbulence polar plot.
- SD wind speed SD: table format and polar plot.
- Monin-Obukhov length: table format and polar plot.
- Atmospheric parameters: table format and vertical profile.

A general view of the CLIMA object dialogue is shown on Figure 73.

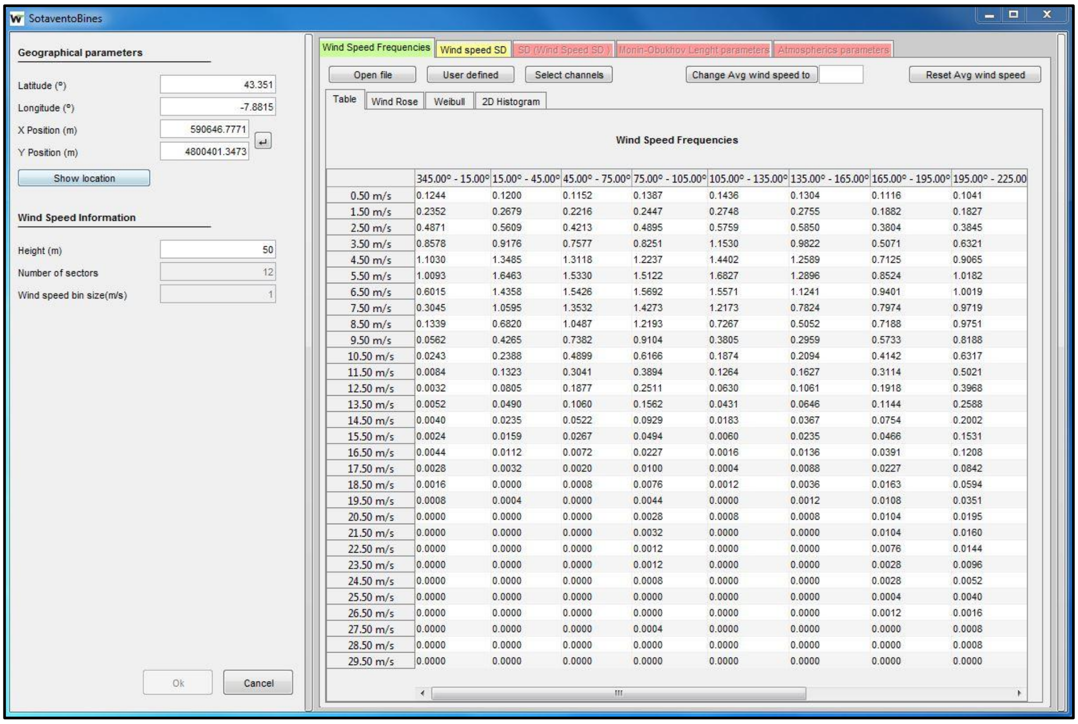


Figure 73: General view of CLIMA object from tree

a) Open file

The user can load statistics tables when they come from external files or even if they are user defined/calculated distributions generated somewhere else. When time series information is not given, then typical **.tab** files and specific files with turbulence intensity, atmospheric stability and atmospheric parameters information can be provided.

FUROW can import files with extensions **.owf** (wind frequencies adding all of them 100%), **.sdw**, **.sdw2**, **.mol** and **.atm** which can be generated by **FUROW**, but also can be easily created with a text editor or Excel. On Figure 74 the typical format of **FUROW**'s files can be seen, in particular the .sdw file. Additionally, WAsP .tab files can also be read with this dialogue.

The files **.atm** have a different structure as they show in one table and by order the following fields: “Atmospheric variable (air density, temperature, pressure and relative humidity)”, “Height”, “Vertical gradient”. If for one variable there is information about more than one height, then the gradient field is empty.

35 16 ← Number of wind speed bins and sectors
22.45286 -83.782 ← Latitude and Longitude
213672 2485616 ← X and Y coordinates
50 ← Height

0.5	0.129	0.125	0.1325	0.1405	0.1395	0.148	0.1645	0.156	0.159	0.166	0.153	0.134	0.143	0.135	0.138	0.137
1.5	0.222	0.2325	0.261	0.2955	0.324	0.333	0.3135	0.291	0.2835	0.2295	0.261	0.306	0.3435	0.2685	0.234	0.2175
2.5	0.3025	0.3	0.3775	0.4275	0.4675	0.44	0.44	0.3375	0.315	0.4125	0.4275	0.4525	0.56	0.4025	0.33	0.2975
3.5	0.42	0.35	0.4375	0.5355	0.56	0.5355	0.518	0.4095	0.4305	0.434	0.6685	0.609	0.756	0.5495	0.4165	0.392
4.5	0.5625	0.4545	0.5265	0.6795	0.675	0.6435	0.621	0.5895	0.621	0.63	0.8055	0.7785	0.9585	0.6795	0.5535	0.486
5.5	0.6435	0.605	0.6435	0.8525	0.8195	0.7535	0.7315	0.7975	0.737	1.045	0.9955	0.9405	1.3365	0.8635	0.7425	0.6105
6.5	0.7475	0.7085	0.7345	1.053	0.962	0.8125	0.871	1.027	0.7475	1.0595	1.3455	1.4885	1.5665	1.053	0.91	0.7995
7.5	0.8625	1.395	0.8475	1.23	1.11	0.96	1.035	1.1175	0.8925	1.47	1.635	1.395	1.68	1.3575	1.095	0.9525
8.5	1.173	0.867	1.0115	1.4195	1.173	1.1645	1.105	1.479	1.3175	1.6405	1.7935	1.4875	2.1165	1.5725	1.275	1.19
9.5	1.539	0.9785	1.2255	1.5865	1.292	1.387	1.425	1.5865	1.8335	0	2.223	1.7765	2.3655	1.748	1.3965	1.368
10.5	1.785	1.2285	1.2915	1.6485	1.407	1.533	1.5435	1.974	1.596	0	1.323	2.1735	2.94	1.8375	1.6065	1.575
11.5	1.886	1.1845	1.518	1.955	1.6445	1.817	1.7365	1.978	1.8745	1.5985	0	2.0125	3.358	1.8975	1.6905	1.656
12.5	2.4375	5.175	2	1.825	1.6875	2.0125	1.8625	2.35	2.5625	2.0375	1.975	2.475	3.5625	1.825	2.0125	1.875
13.5	0	2.646	1.7415	2.295	0	0	1.9305	2.6325	2.4165	0	2.0115	2.457	3.105	1.9035	2.133	1.89
14.5	0	3.3785	2.755	0	2.1315	0	2.088	2.7115	0	0	0	2.7115	3.828	3.248	0	2.784
15.5	0	0	5.859	0	0	0	2.3715	3.038	3.627	3.255	0	0	4.402	0	0	2.294
16.5	0	0	0	0	2.9535	0	2.3595	3.2505	0	0	0	0	0	3.7455	0	3.0525
17.5	0	0	0	0	0	0	2.45	3.0975	0	0	3.5875	0	0	0	2.205	0
18.5	0	0	0	0	0	0	2.849	3.293	0	0	0	0	4.8655	0	0	3.2375
19.5	0	0	0	0	0	0	2.9835	3.2175	0	0	0	0	0	0	2.964	3.627
20.5	0	0	0	0	0	0	3.116	0	0	3.649	4.469	0	5.535	7.4825	0	0
21.5	0	0	0	0	0	0	4.0205	5.1385	0	3.5905	0	5.1815	0	0	3.5475	4.085
22.5	0	0	0	0	0	0	0	0	0	0	0	4.68	0	8.1225	3.9825	0
23.5	0	0	0	0	0	0	0	0	0	0	0	0	6.7915	0	3.8775	0
24.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4.067	0
25.5	0	0	0	0	0	0	0	0	0	0	0	0	6.1965	4.488	4.4625	0
26.5	0	0	0	0	0	0	0	0	0	0	0	6.042	0	0	4.3725	0
27.5	0	0	0	0	0	0	0	0	0	0	0	0	5.665	0	4.2625	0
28.5	0	0	0	0	0	0	0	0	0	0	0	0	0	4.9305	0	0
29.5	0	0	0	0	0	0	0	0	0	0	0	0	0	7.375	0	0
30.5	0	0	0	0	0	0	0	0	0	0	0	0	0	7.4725	0	0
31.5	0	0	0	0	0	0	0	0	0	0	0	0	0	7.686	0	0
32.5	0	0	0	0	0	0	0	0	0	0	0	0	0	8.19	0	0
33.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

↑ Wind speed bins

↑ Data

Figure 74: Example of .sdw file

b) User defined

For any of the variables of the CLIMA object, the user can input self-defined values in order to represent any distribution of frequencies, turbulence intensity, stability or atmospheric parameters (this last one just for constant values and vertical profile).

This user defined distribution can be defined as (see Figure 75):

- Constant value
- Value changing by sector (for wind speed frequencies, the total sector frequency and the Weibull parameters shall be given)
- Value changing by wind speed
- Value changing by sector and wind speed

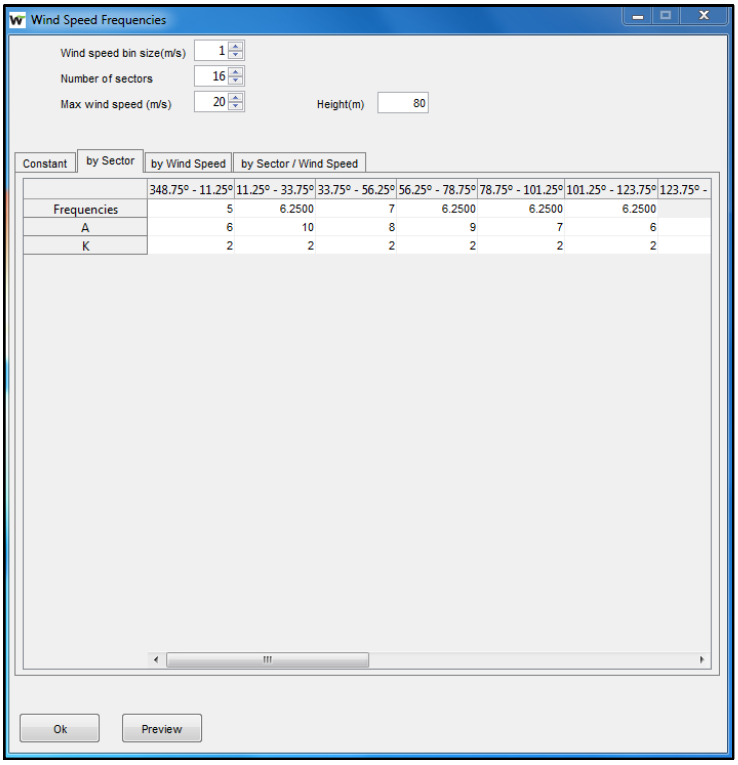


Figure 75: Create CLIMA object from user defined values

c) Select channels

The user can create a CLIMA object through time series channels under any WIND DATA object. In this case, wind speed and wind direction channels are mandatory, whereas the others are optional and can be set to a constant or a fixed distribution if data do not exist. If exist, the wind speed standard deviation channel can be used to complete the second and third tab and a Monin-Obukhov channel can be used to complete the fourth tab. In this case, it is not needed to select channels again, but click on *"Use channels"* in order to use the channels selected on the *"Wind Speed Frequencies"* tab.

In order to create the statistics, the number of sectors and the bin size must be user defined. When creating the CLIMA object this way, the user can apply time filters to select the period of time on which the statistics are desired (i.e. the user can create 12 CLIMA objects corresponding to conventional months as to later calculate the wind resource for each month). In order to calculate the wind speed SD per bin and its average, FUROW proposes two options whose differences are explained on the ***Theory Manual***. Finally, when time series do not cover complete years, seasonal bias can be removed using the *"Remove Seasonal Bias"* check. See Figure 76 for the creation of the CLIMA object using channels.

It is important to remark that wind speed and sector bins without data are completed with a filling algorithm. This algorithm takes nearby data to synthesize empty bins.

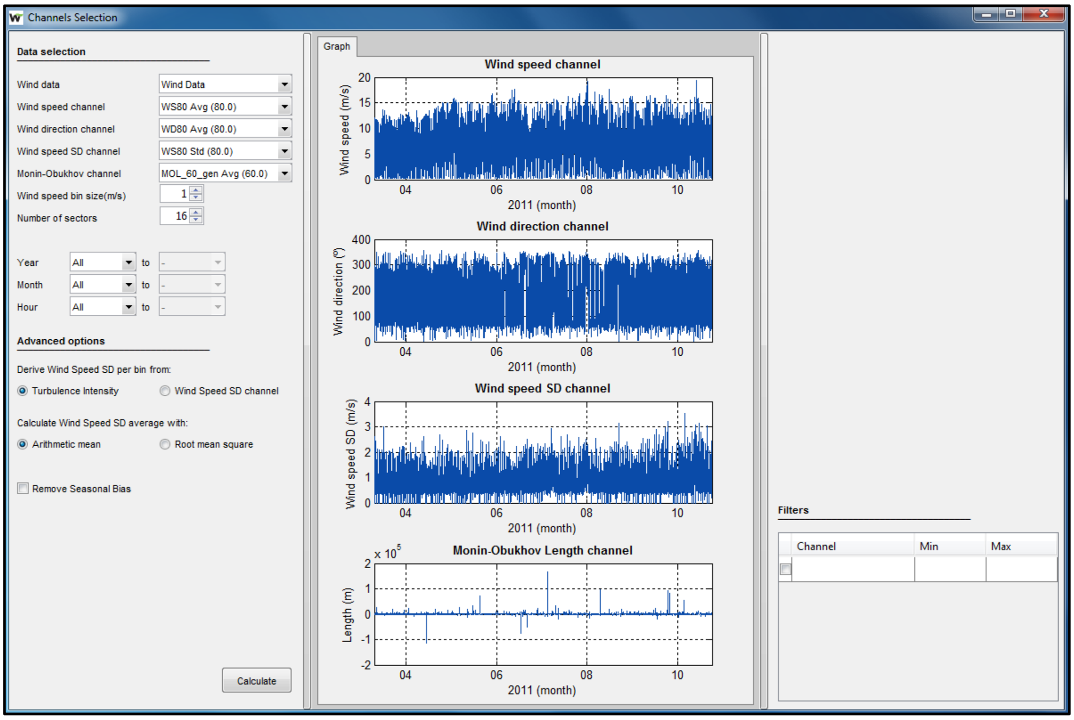


Figure 76: Create CLIMA object from channels

When dealing with atmospheric parameters, the output is not a distribution by wind speed and wind direction, but a mean value at any height of each atmospheric variable together with a mean vertical profile. The user can decide to work only with air density or with temperature; pressure and relative humidity to calculate their profiles and eventually the air density profile (see Figure 77). Channels of each variable are loaded on individual windows and the *"Remove Seasonal Bias"* check can also be used to correct the average value.

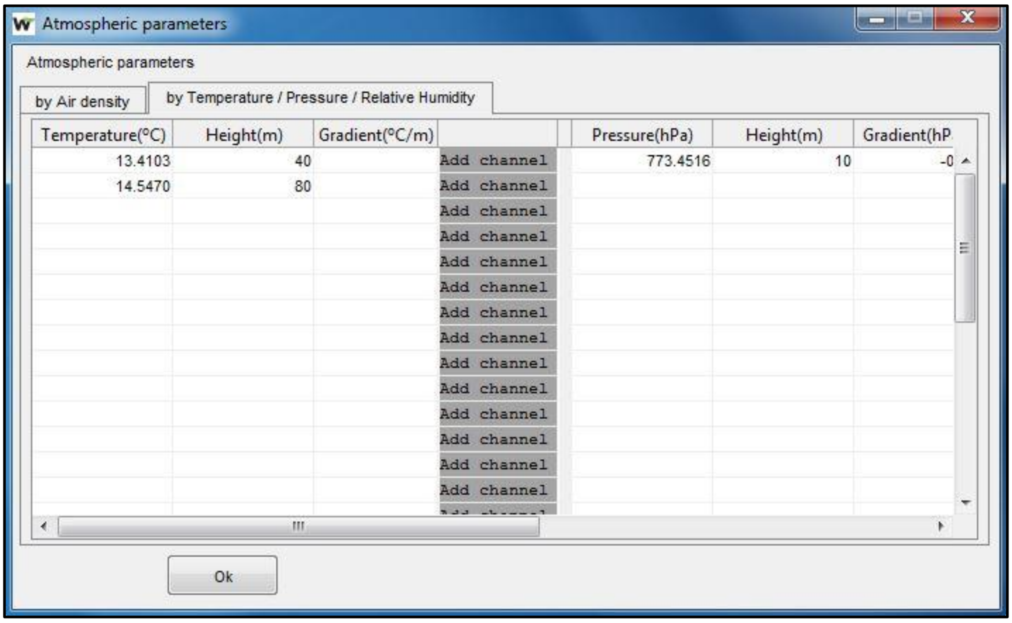


Figure 77: Selection of atmospheric variable channels

The vertical profile of each variable is observed on the fifth tab as shown on Figure 78.

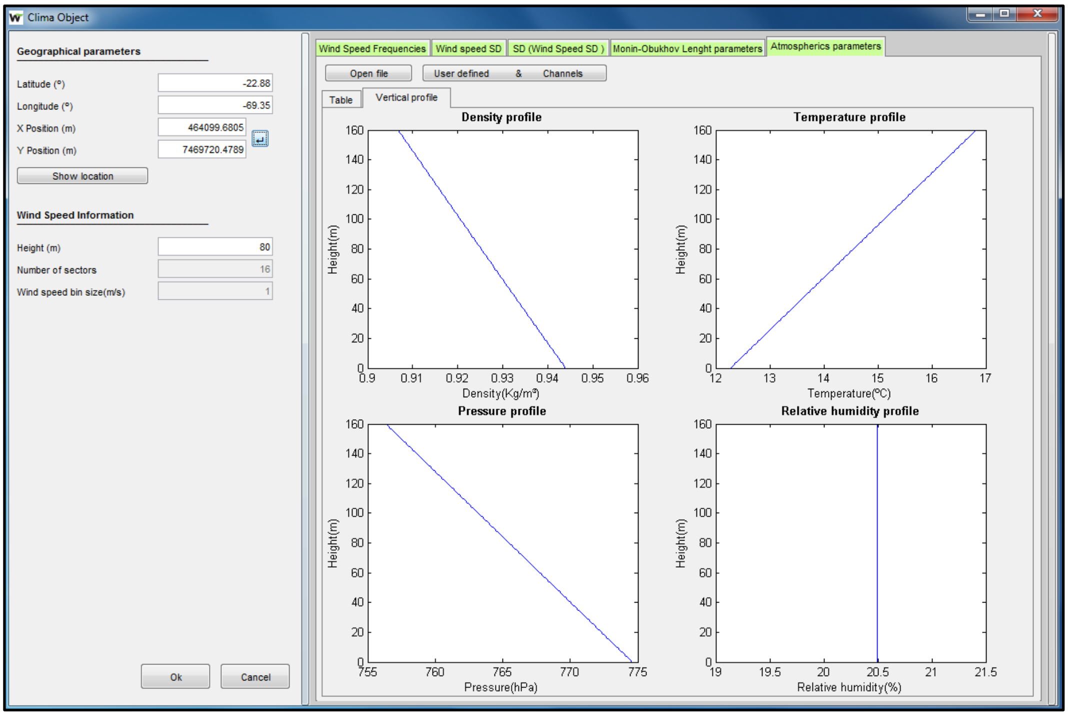


Figure 78: Vertical profile of each atmospheric variable

Once wind speed and direction data have been selected and the frequencies have been calculated, it is possible to correct the distributions in order to match a given value of wind speed. This turns out to be useful to correct wind speed distributions to adjust the measured data distributions to long term distributions and fit the long-term wind speed. To perform this change, the user must set the long-term value and click on *"Change Avg wind speed to"*. If the user wants to restore the measured distribution, the option *"Reset Avg wind speed"* must be used.

Once created, the CLIMA object is created as another object on the tree structure, and its content can be viewed by right clicking on the object on *"View Clima Object".* Then, the same window (as when the creation) shows up and the user can view many inputs as the wind speed distribution or turbulence intensity curve among others (see Figure 79 and Figure 80). They can also be viewed by each sector.

It is important to remark that once created, the CLIMA object cannot be edited, so if new changes need to be done, a new CLIMA object must be created.

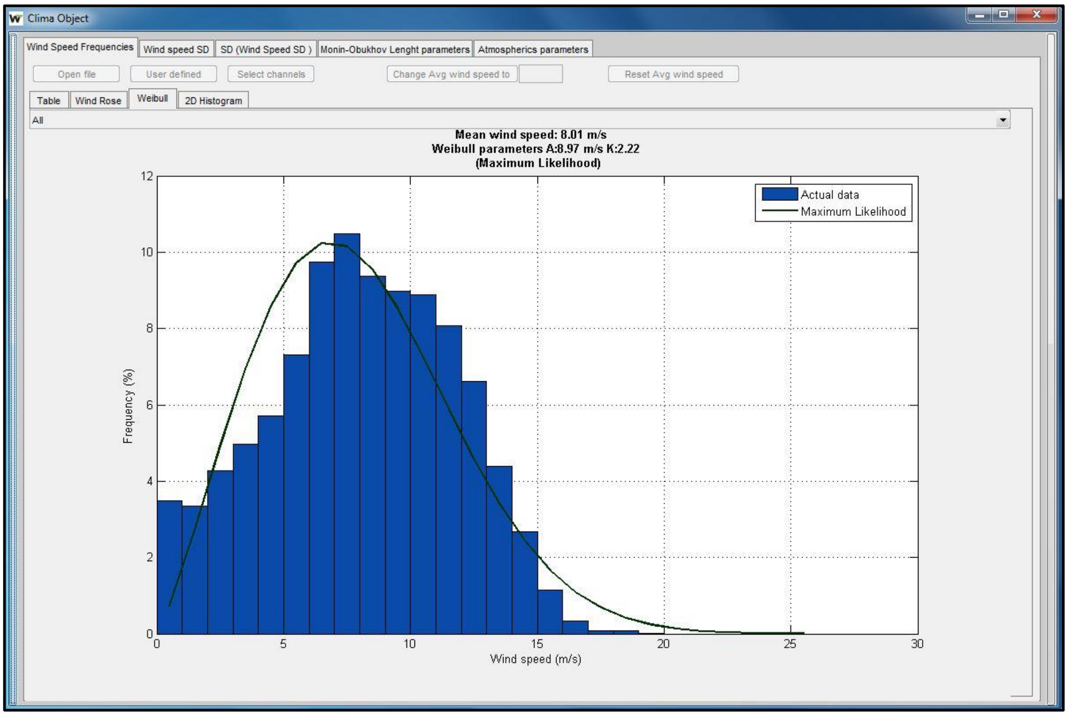


Figure 79: Wind speed distribution for the CLIMA object and Weibull parameters

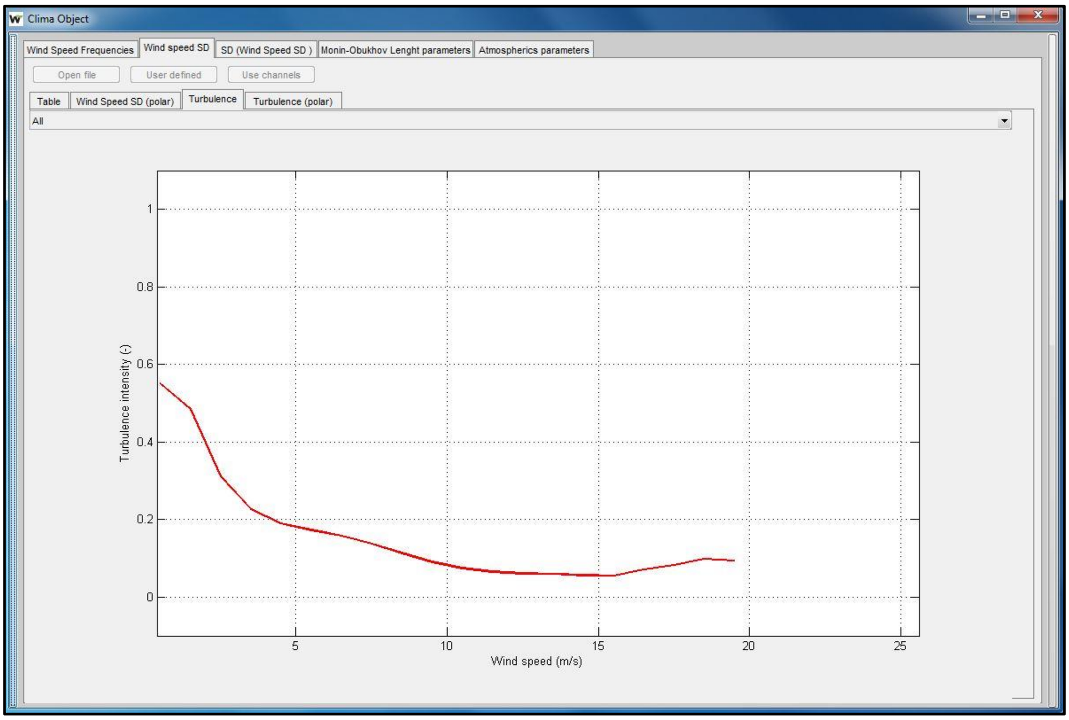


Figure 80: Turbulence intensity distribution for the CLIMA object

Finally, information on the CLIMA object can be exported on ASCII files with different file extensions (the same as those described on the type of files **FUROW** can read). For this purpose, right click on the CLIMA object under *"Export Clima Object"* and select the type of file to be exported (see Figure 81). In this version it is possible to export all of them at once.

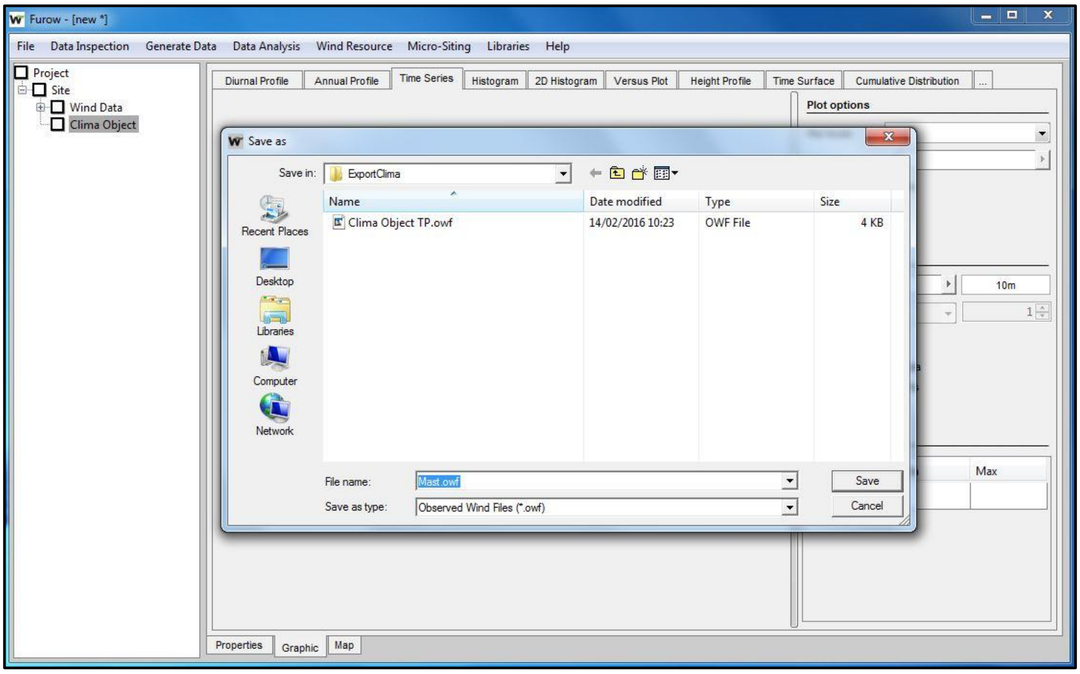


Figure 81: Export CLIMA object

11 Map loader and grid generator

FUROW can load different types of maps with different extensions representing elevation and roughness of terrain. File formats which can be interpreted by **FUROW** are the following:

- **.map** files (from WAsP) with orography alone
- **.map** files (from WAsP) with roughness change lines alone
- **.map** files (from WAsP) with orography and roughness change lines combined
- **.xyz** files (raster files) with orography or roughness
- **.dtm** files (raster files) with orography or roughness
- **.asc** files (raster files) with orography or roughness
- **.grd** files (raster files) with orography or roughness

After any of the previous files is loaded, the structure of a MAP object is created. This MAP object can contain contour lines, raster grids and grids generated by the user (described on next section). The typical structure of a MAP object is shown below (See Figure 82).

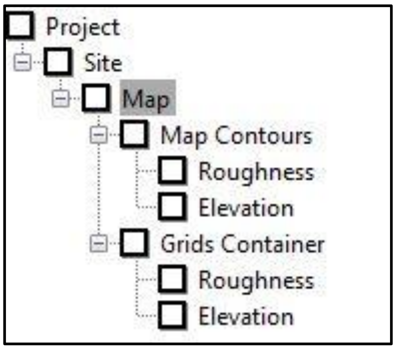
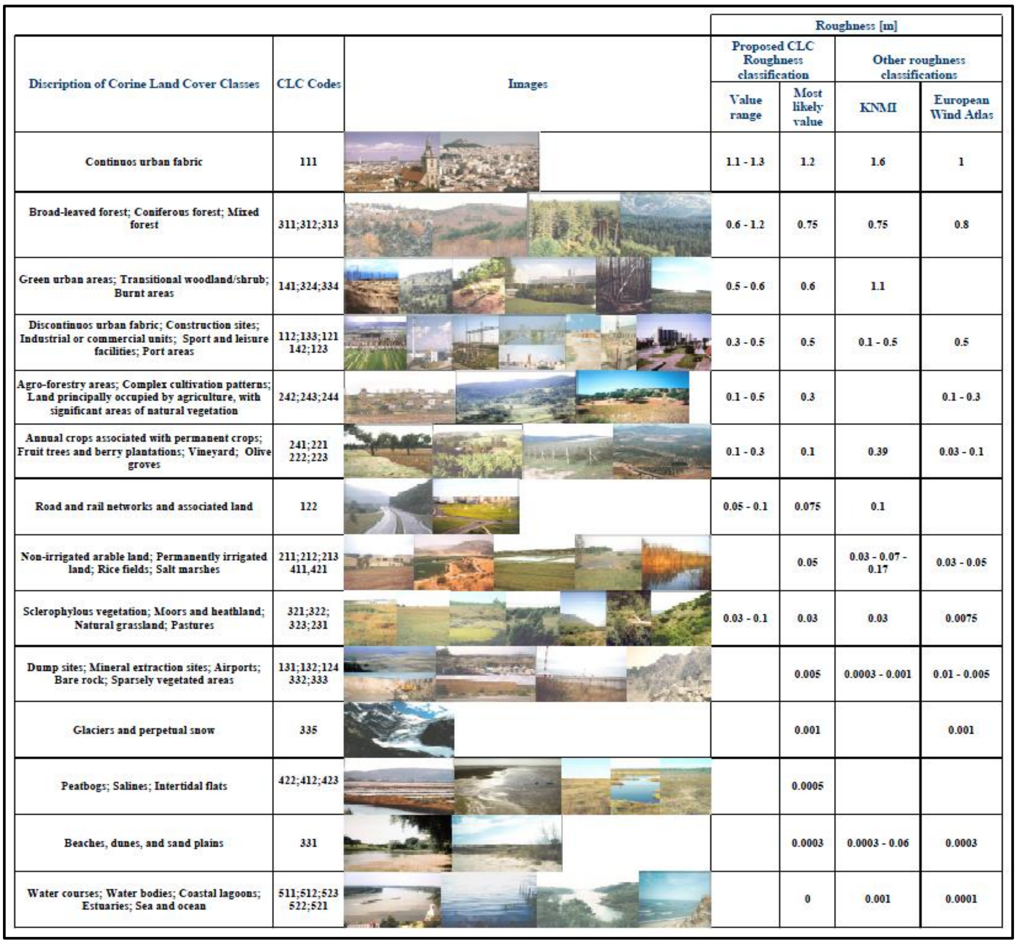


Figure 82: MAP structure

The user can download data from CORINE LAND COVER (CLC) database in **.txt** format (extension must be changed to **.xyz**). The information contained in these files is the RGB codes for every grid point depending on the land cover type. SOLUTE has used a conversion between CLC codes and roughness length proposed by MEGAJOULE on the following article: *"Roughness Length Classification of Corine Land Cover Classes"* (See Figure 83). It is also possible to load data from the National Land Cover Database (NLCD) prepared on different dates (2001, 2006 and 2011) which is a 16-class land cover classification scheme that has been applied consistently across the United States at a spatial resolution of 30 meters. In order to be able to interpret both CLC and NLCD in terms of roughness length, **FUROW** uses a .txt file which codifies RGB codes and roughness length and can be modified by the user (this file can be found under the folder *template/land cover codification* located in the installation folder). An example of this codification is shown on Figure 84. On this new version, also files downloaded from GlobCover 2009 can be read provided a codification file is used.

Additionally, it is possible to load Google Images once contours or raster grids are generated and one CLIMA object is selected. For that purpose, right click on MAP object (while selecting a CLIMA

Object with latitude and longitude and one Contours container object) and select *"Load Image from Google".* Then choose the type of Image: Road Map, Satellite, Terrain and Hybrid. See Figure 85 with a hybrid image (roads and terrain) of a given site together with elevation and roughness contours. It must be remarked that in order to use this option, the user must have Internet connection. Moreover, Google images are in UTM WGS84, so if the world projection and datum of the maps are different, Google image may not fit correctly the map contours.



Discription of Corine Land Cover Classes	CLC Codes	Images	Roughness [m]			
			Proposed CLC Roughness classification		Other roughness classifications	
			Value range	Most likely value	KNMI	European Wind Atlas
Continuos urban fabric	111		1.1 - 1.3	1.2	1.6	1
Broad-leaved forest; Coniferous forest; Mixed forest	311;312;313		0.6 - 1.2	0.75	0.75	0.8
Green urban areas; Transitional woodland/shrub; Burnt areas	141;324;334		0.5 - 0.6	0.6	1.1	
Discontinuos urban fabric; Construction sites; Industrial or commercial units; Sport and leisure facilities; Port areas	112;133;121 142;123		0.3 - 0.5	0.5	0.1 - 0.5	0.5
Agro-forestry areas; Complex cultivation patterns; Land principally occupied by agriculture, with significant areas of natural vegetation	242;243;244		0.1 - 0.5	0.3		0.1 - 0.3
Annual crops associated with permanent crops; Fruit trees and berry plantations; Vineyard; Olive groves	241;221 222;223		0.1 - 0.3	0.1	0.39	0.03 - 0.1
Road and rail networks and associated land	122		0.05 - 0.1	0.075	0.1	
Non-irrigated arable land; Permanently irrigated land; Rice fields; Salt marshes	211;212;213 411,421			0.05	0.03 - 0.07 - 0.17	0.03 - 0.05
Sclerophylous vegetation; Moors and heathland; Natural grassland; Pastures	321;322; 323;231		0.03 - 0.1	0.03	0.03	0.0075
Dump sites; Mineral extraction sites; Airports; Bare rock; Sparsely vegetated areas	131;132;124 332;333			0.005	0.0003 - 0.001	0.01 - 0.005
Glaciers and perpetual snow	335			0.001		0.001
Peatbogs; Salines; Intertidal flats	422;412;423			0.0005		
Beaches, dunes, and sand plains	331			0.0003	0.0003 - 0.06	0.0003
Water courses; Water bodies; Coastal lagoons; Estuaries; Sea and ocean	511;512;523 522;521			0	0.001	0.0001

Figure 83: Land Cover Classes

The MAP object has certain properties which for the moment do not have many implications on the program, as they are merely descriptive. Only the map datum is relevant when exporting files to **.kml** format. Map datum can be "WGS84" or "ED50 Spain", so in the case coordinates of the project are in ED50 Spain, when they are exported to **.kml**, **FUROW** makes an internal conversion to convert X and Y coordinates into WGS84 to be correctly represented on Google Earth.

```
071 107 161 0.0001000000    c11OpenWater
207 220 246 0.0010000000    c12PerennialIceSnow
222 201 201 0.3000000000    c21DevelopedOpenSpace
217 148 130 0.5000000000    c22DevelopedLowIntensity
237 0   0   0.7500000000    c23DevelopedMediumIntensity
171 0   0   1.2000000000    c24DevelopedHighIntensity
179 173 163 0.0500000000    c31BarrenLand(RockSandClay)
105 171 99  0.6000000000    c41DeciduousForest
028 099 48  1.0000000000    c42EvergreenForest
181 201 143 0.8000000000    c43MixedForest
175 150 60  0.0300000000    c51DwarfScrub
204 186 125 0.1000000000    c52ShrubScrub
227 227 194 0.0500000000    c71GasslandHerbaceous
209 209 130 0.0300000000    c72SedgeHerbaceou1ls
163 204 81  0.0100000000    c73Lichens
130 186 158 0.0050000000    c74Moss
219 217 61  0.0750000000    c81PastureHay
171 112 41  0.1000000000    c82CultivatedCrops
186 217 235 0.6000000000    c90WoosyWetlands
112 163 186 0.2000000000    c95EmergentHerbaceousWetlands
```

Figure 84: Land Cover codification example (NLCD 2011)

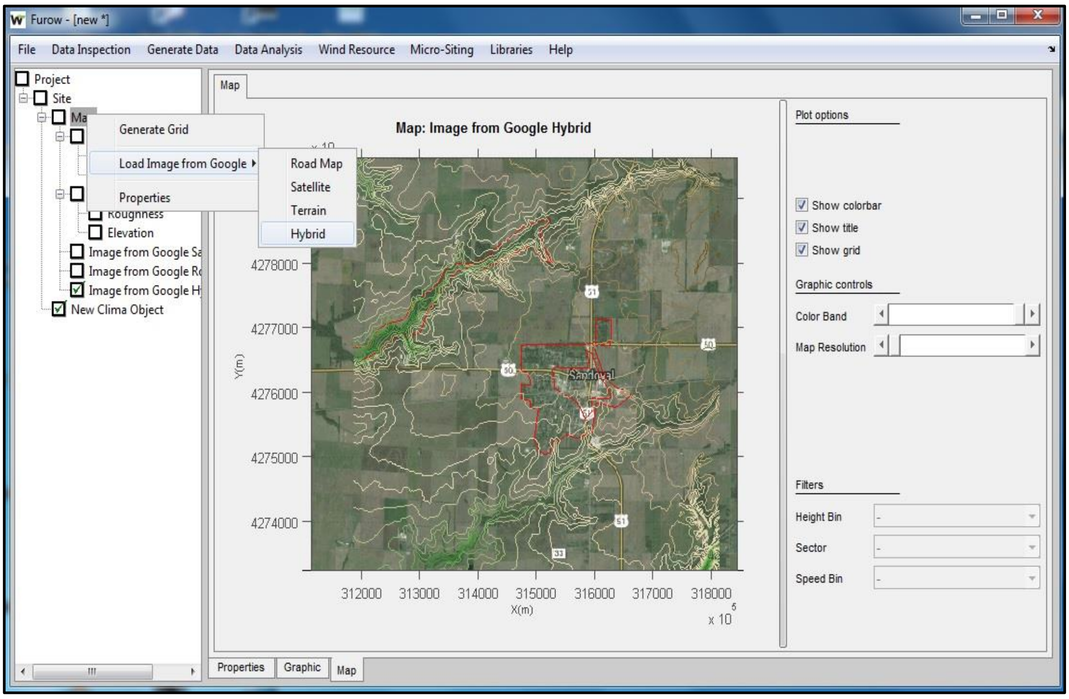


Figure 85: Google image

Once contours or raster grids are input in the tree structure, a unified grid of the whole area or just part of it can be generated through a grid generator. There, it is possible to set the area, define X and Y resolution of the grid, and even enter a default value in the event that any of the maps is unknown (i.e. roughness length is sometime missing, so a constant value can be set for preliminary calculations). If several grids or contour maps of elevation or roughness are present, the user can choose which one to use to generate the grid (See Figure 86). By default, grid resolution is 25m, but can be finer if desired (the finer the longer time it takes to generate the grid and calculate the wind resource).

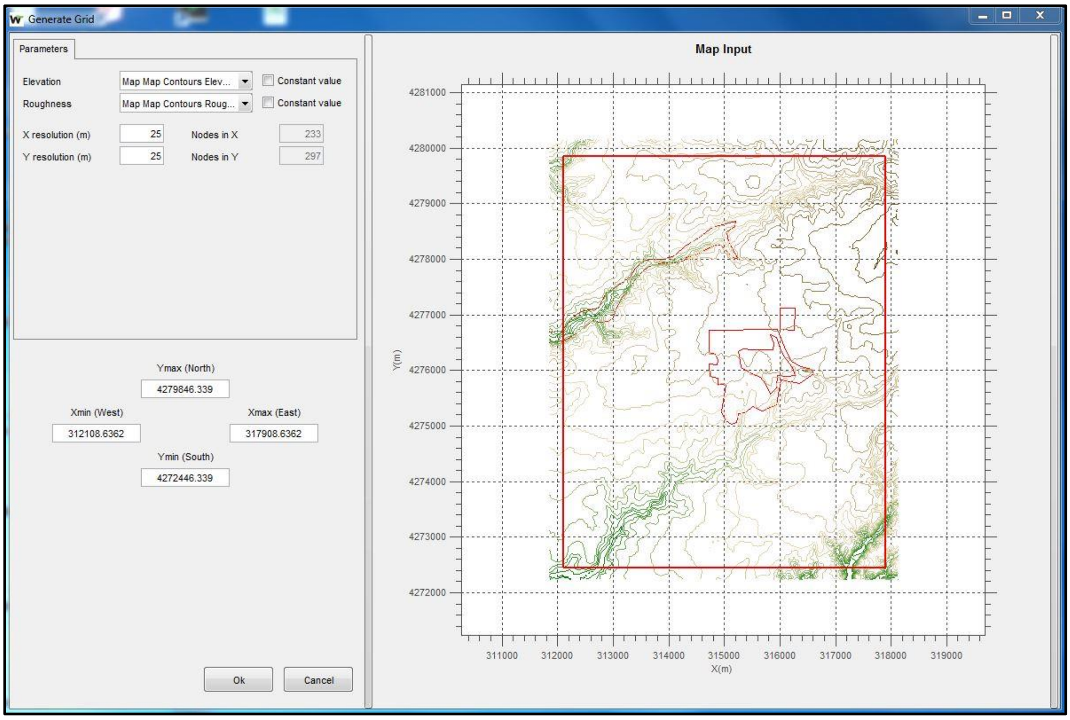


Figure 86: Grid generator menu

On Figure 87, the elevation grid node is represented together with the roughness and elevation contours.

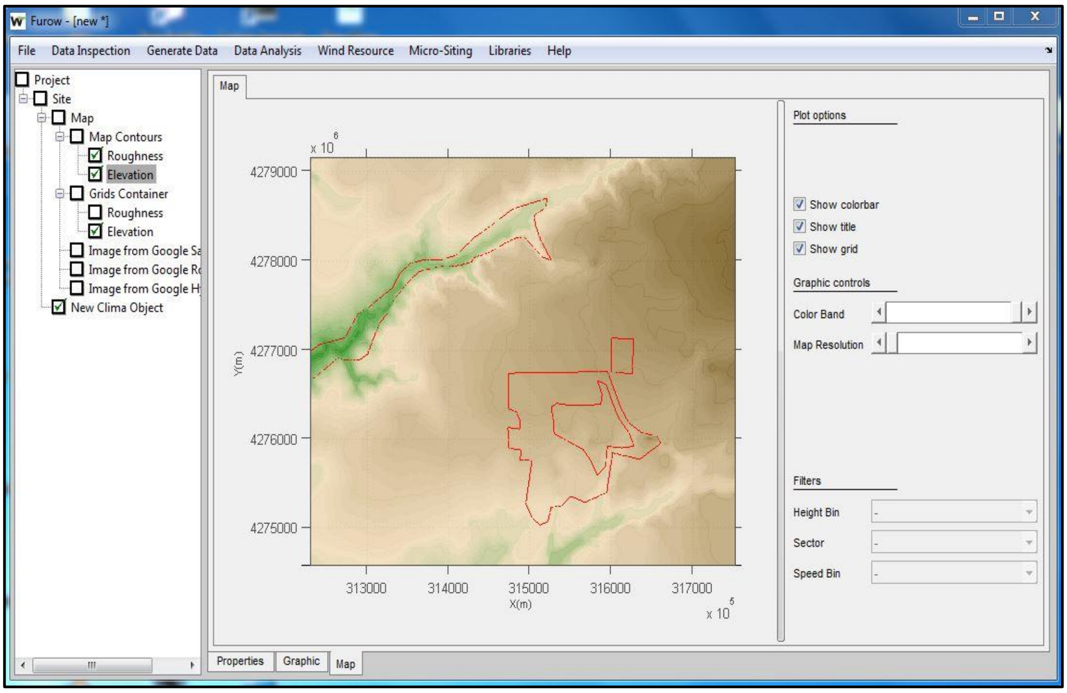


Figure 87: Elevation grid node

There are two new functionalities in this new version of **FUROW** in relation to topographic grids creation. This first one is the possibility of downloading a bathymetry grid, that is, the underwater topography for oceans and seas. The bathymetric maps were downloaded from the NOAA website and correspond to the database ETOPO1 with a resolution of 1 arc-minute. This includes information of the global relief of earth's surface, but in **FUROW** information with an elevation above 0 meters is set to 0 meters as it is assumed only bathymetry data is relevant for the user. The projection and datum for these bathymetry maps are UTM WGS84.

In order to create a bathymetry map, the user must right click on the MAP object and then click on *Load bathymetry map*. After this action, a new window will show up and the user will be able to select the boundary coordinates of the site to download the bathymetry, or use the mouse to delimit the coordinates (see Figure 88). Once selected, click on *Download* to export the map and it will be placed directly on the tree under the MAP object (see Figure 88)

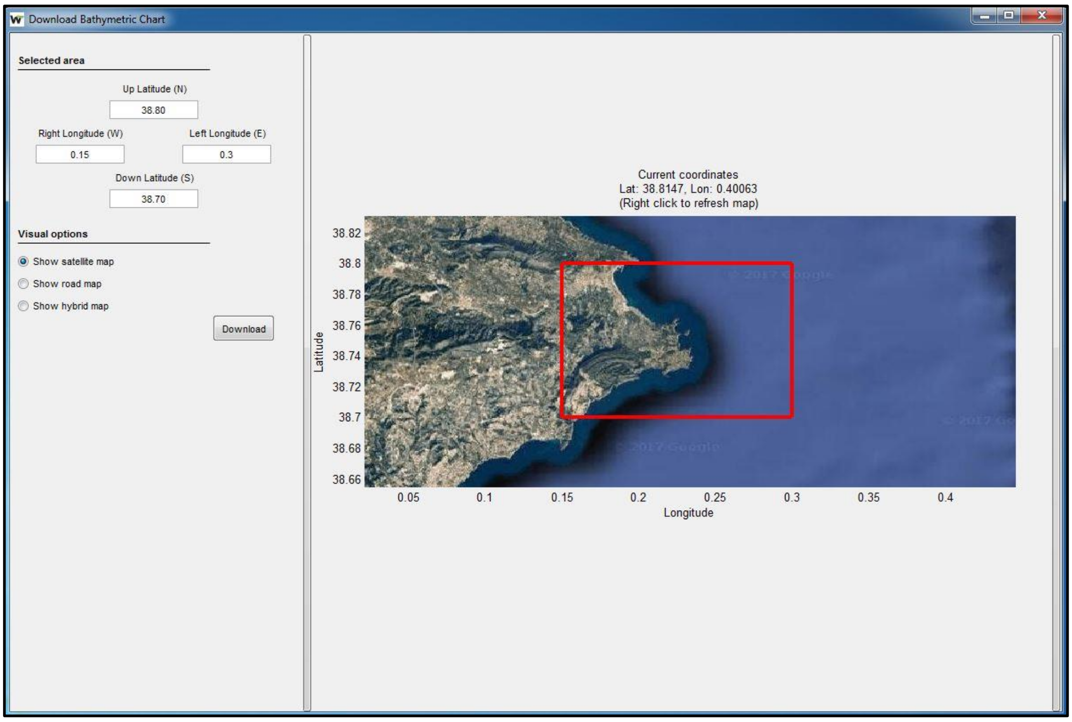


Figure 88: Download bathymetry map

The second new functionality is the possibility of creating a roughness map through the edition of roughness areas on which the user must define the roughness within an area. To proceed right click on a MAP object and select the option *"Create roughness map"*. By using the left mouse button and dragging the user can create contours which in the end turn into areas by clicking on *"Add surface contour"*. Additionally new contours can be created by importing a vector layer, a **.kml** or a **.shp** file. Finally, if elevation contours are available the user can select those contours to create roughness contours as well. Lines can be deleted with the **Backspace** key whereas last created points are removed with the **Delete** key. When assigning roughness values, the user must assign only the inner values of the patch which is created not being necessary to define the outer value. There is always a background roughness which must be set in advance. An example of a few roughness lines created on this module is shown on Figure 90.

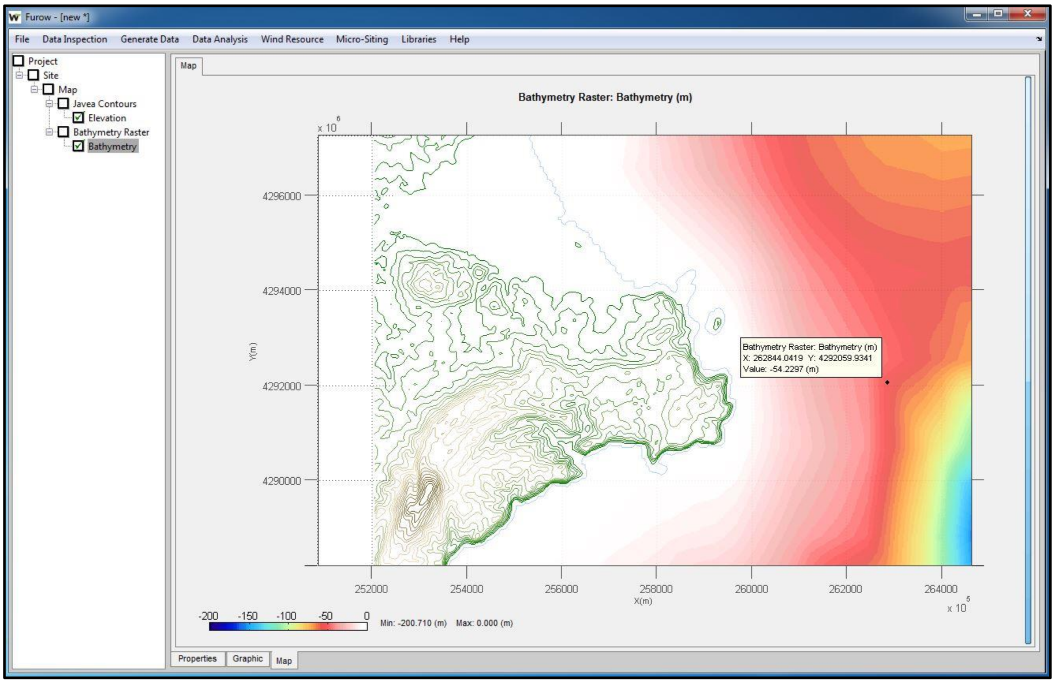


Figure 89: Bathymetry grid

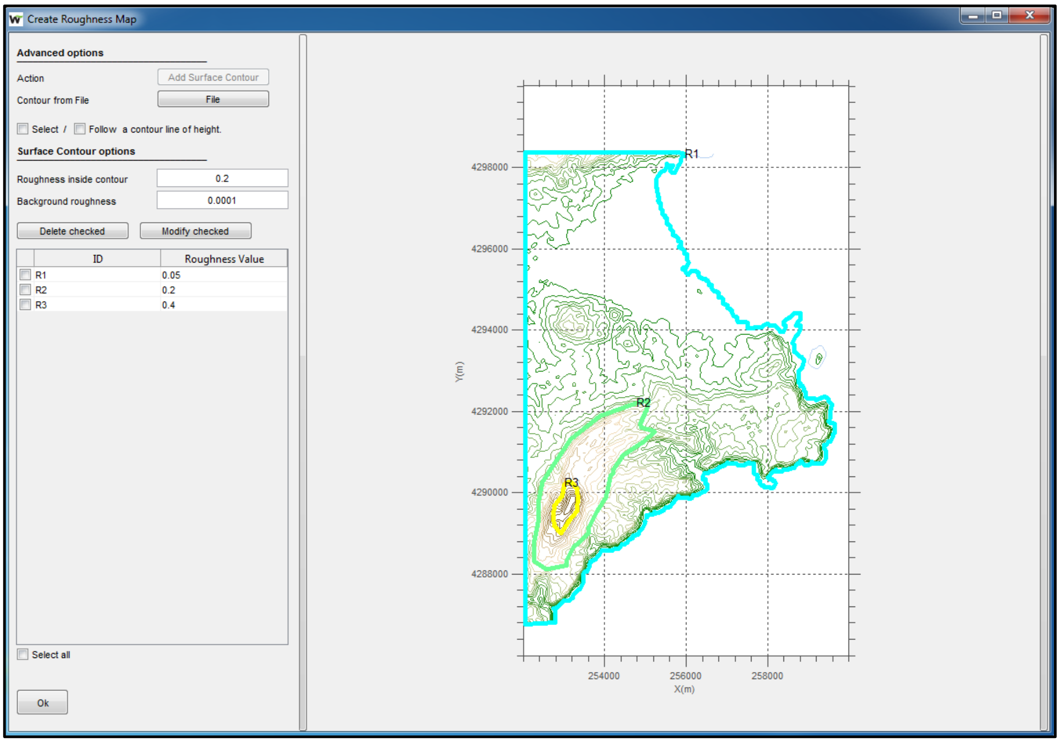


Figure 90: Create roughness map

12 Wind resource calculator

FUROW has its own wind resource calculator, allowing the user to get all necessary maps to make a correct wind resource assessment of a given site. All calculations can be performed at several heights depending on the needs of the user.

12.1 Calculating a wind resource object (map)

In order to generate all wind resource maps, the user must select one CLIMA object and one TOPOGRAPHIC GRID CONTAINER object (see Figure 91) and then go to *Wind Resource/Calculate Wind Resource/Map*. Then, a new window allows the user to select the parameters to perform the calculation such us the grid resolution, the number of heights and the height step. Wind speed bins and direction sectors used in computations are derived from the CLIMA object. The boundaries of the polygon to calculate the wind resource can be given by introducing the coordinates of the most southwest point and the most northeast point, or by selecting the calculation area with the mouse (first clicking and then dragging) (See Figure 92).

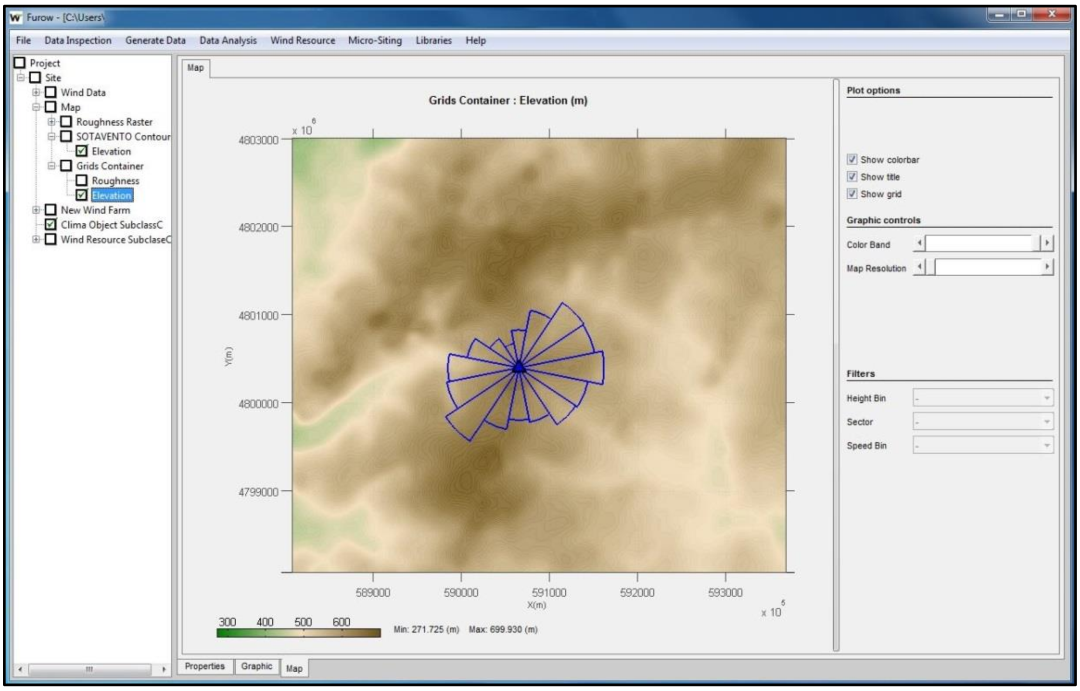


Figure 91: Nodes selection for calculating the wind resource

When launching wind resource calculations, the user must also select the calculating method:

1) <u>Complete method:</u> speed-ups with respect to the CLIMA object position are calculated for all wind speed bins and directions, each on with its profile according to the Monin-Obukhov length.
2) <u>Simplified method:</u> speed-ups are calculated for every wind direction with the wind speed bin closest to the average wind speed of the CLIMA object.

The description of the model and the theoretical background is described in detail on the ***Theory Manual***.

In relation to turbulence intensity calculations, there are three options which are described on the ***Theory Manual***:

1) From extrapolation model
2) From measured SD
3) From roughness

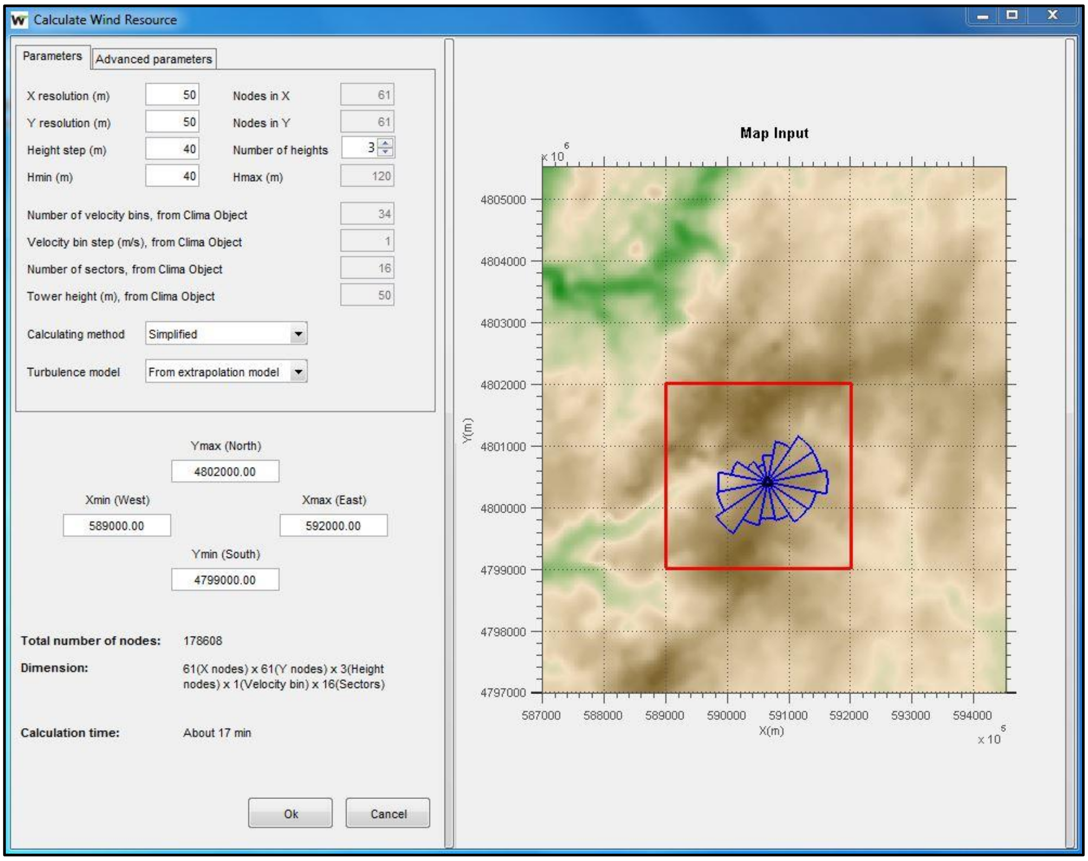


Figure 92: Parameters for calculating the wind resource

Other advanced parameters can be modified such as the decay length when weighting the effects of roughness length around a particular point and sector, as well as the type of decay rule. Also, the way of calculating the height of the forest, the forest density and its influence in the wind profile can be modified. Finally the RIX typical parameters can be adjusted as well as the parameter called *"Independent hills distance"* which gives an idea of the minimum distance to consider hills which are treated as independent to modify the wind flow around them (see Figure 93). For example, if this parameter is set to 2000m, then the program selects local hill maxima in west to east directions and north to south directions keeping at least a distance of 2000m between closest maxima. Thus, selected hills are the ones determining the characteristic hill length and height.

Finally, on this new version, another option has been added to *Advanced Parameters* which is the possibility of considering the CLIMA object as a climatology derived from mesoscale or Reanalysis data. In that case this option must be selected with the implications described on the ***Theory Manual.***

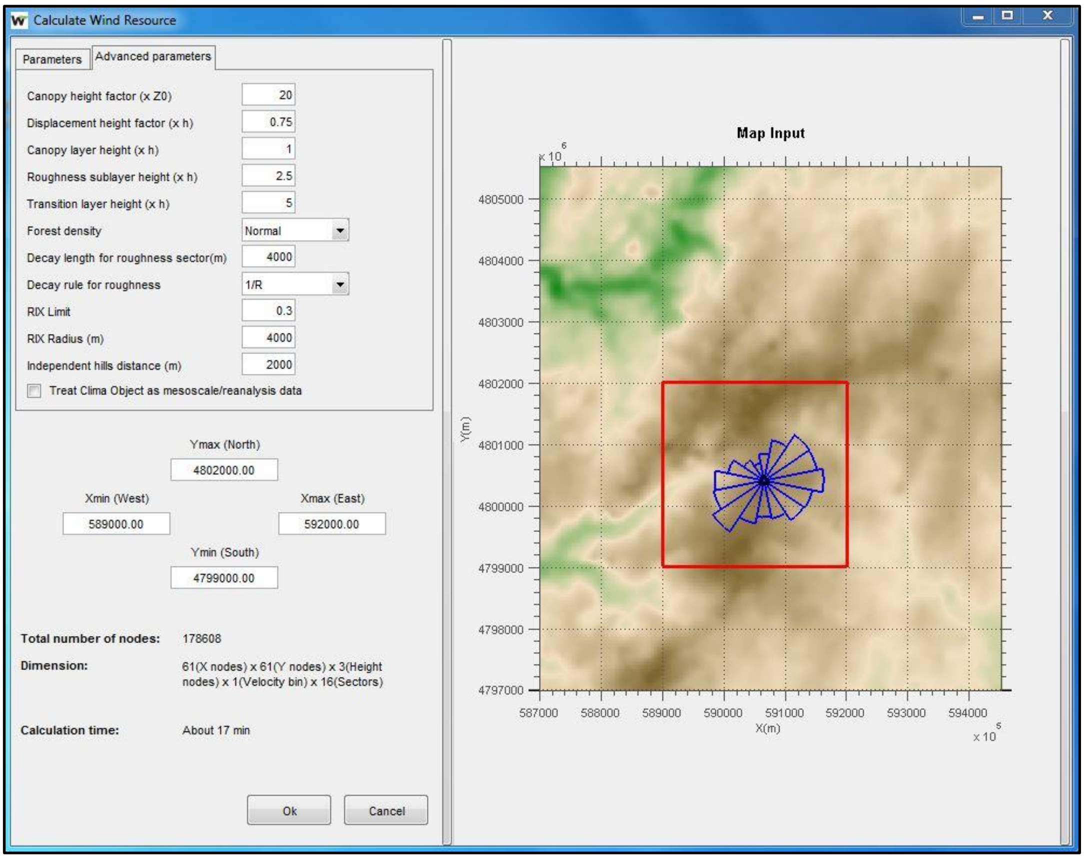


Figure 93: Advanced Parameters for calculating the wind resource

Once parameters have been set and the area to perform the calculation is selected, the calculation starts by clicking on OK. In this version of **FUROW**, calculations are parallelized, so there is a parallel window (see Figure 94) which indicates that the wind resource is running, while the user can keep working with the project.

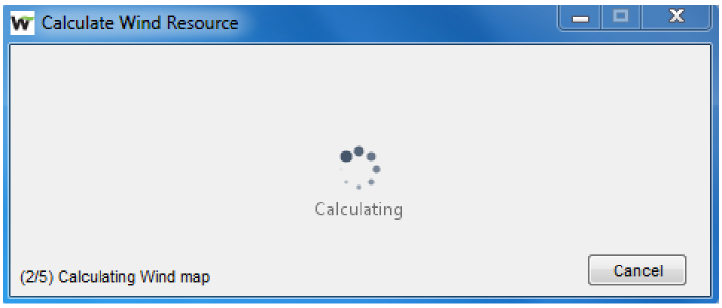


Figure 94: Window indicating wind resource is being calculated

Once all calculations have been made, grids are placed on the tree structure. It is possible to visualize all the grids on the tree structure organized in the following manner (See Figure 95). When air density is the only variable on the CLIMA object, then temperature and pressure maps are not created.

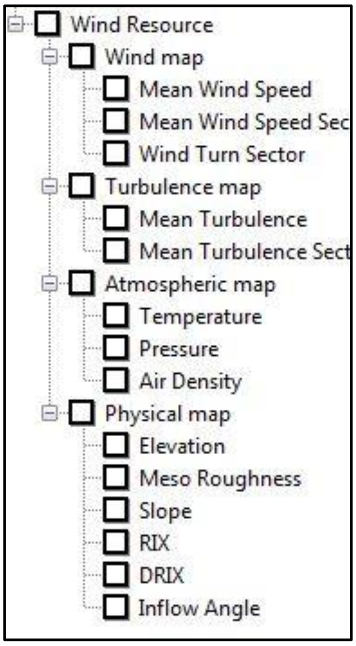


Figure 95: Wind resource maps structure

On the one hand, the wind maps show all information related to the mean wind speed at a particular point of the grid, including the maps by sector, as well as topographic turn of the wind vector in relation to the met mast position.

Turbulence maps object is comprised by a grid representing mean ambient turbulence of the site and the mean ambient turbulence by sector. All grids are created for the selected heights.

Atmospheric maps object is comprised by a grid representing temperature, pressure and air density, except if in the CLIMA object, only air density parameter has been assigned which in that case only the air density map is created. All grids are created for the selected heights.

Finally, the physical maps object contains information about physical features of the area selected for calculations:

- Elevation grid
- Meso-roughness grid (by sector)
- Slopes grid (by sector)
- RIX grid (by sector)
- DRIX grid (by sector)
- Inflow angle grid (by sector and depending on the calculation height)

12.2 Calculating a wind resource object (discrete)

When the calculation of the wind resource is not for an area, but for a number of discrete points, then besides selecting a GRIDS CONTAINER and a CLIMA object, a WIND FARM object must be selected. In that case, the calculation options are the same but are limited to the positions of the wind turbines and the heights selected by the user. Figure 96 shows the wind resource dialogue and how it looks like when the calculation is performed on discrete positions.

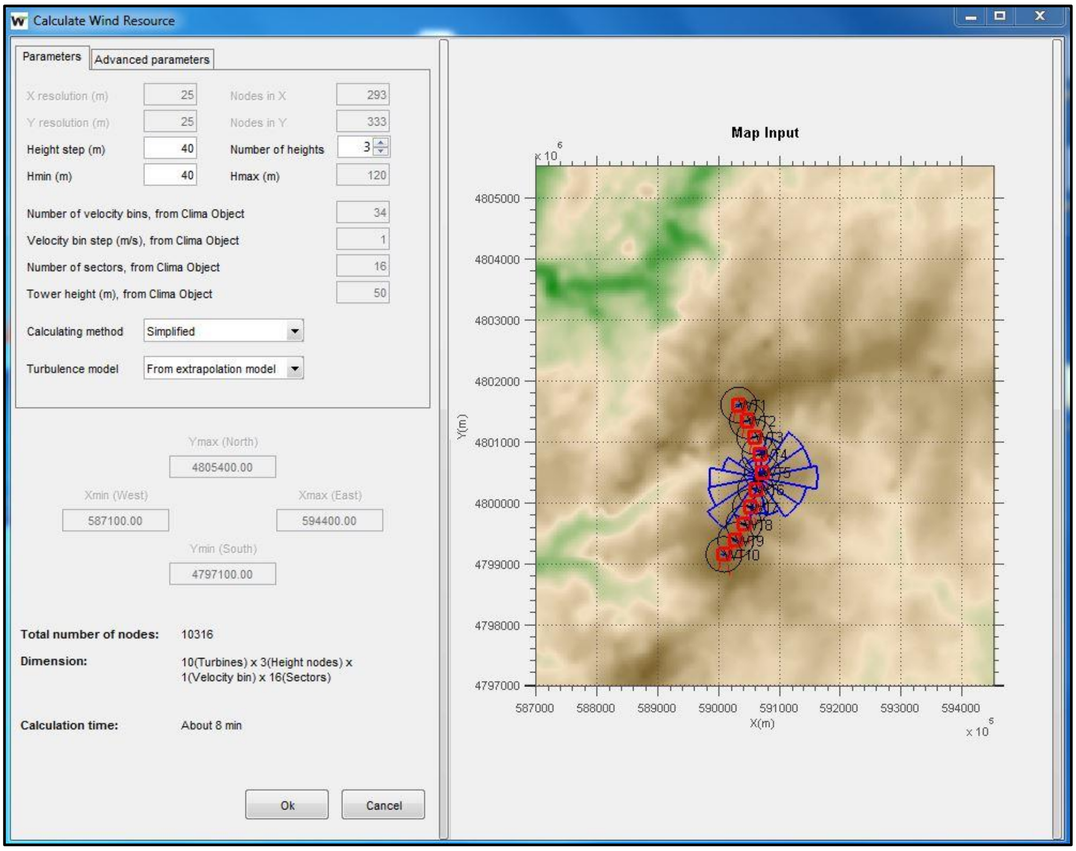


Figure 96: Wind resource dialogue for discrete positions

12.3 Managing a wind resource object

Once the wind resource object has been created the user can inspect its properties going to the *Properties tab*. There, all calculation hypotheses are reflected as to be able to track the differences between simulations in terms of inputs. Under the *Grids Container tab*, the user can view the coordinate of the selected grids as well as the resolution. Finally, under the *Grids tab*, the user can see the minimum and maximum values of each grid type, calculation heights and the color scales (see Figure 97).

In relation to the color scales, when the option *"Auto color scale"* is checked, then the colors are adjusted automatically from minimum to maximum. However, when it is unchecked, the user can fix the minimum and maximum value for the colors in the map.

When working in **FUROW** several grids (layers) can be viewed at the same time. However, the object marked in blue is the current layer and is viewed on top of the rest of the checked grids. On Figure 98, the mean wind speed layer of a site can be viewed. If the "map resolution" wants to be changed, the user can use the slider on *Graphic controls*. The same, if the user wants to have a color scale defined in distinguished colors according to the range, which in this case the "color band" slider must be used. Finally, as several heights in a calculation are possible, all of them can be viewed by changing the height at *Filters*. The same will apply to the maps which depend on the sector.

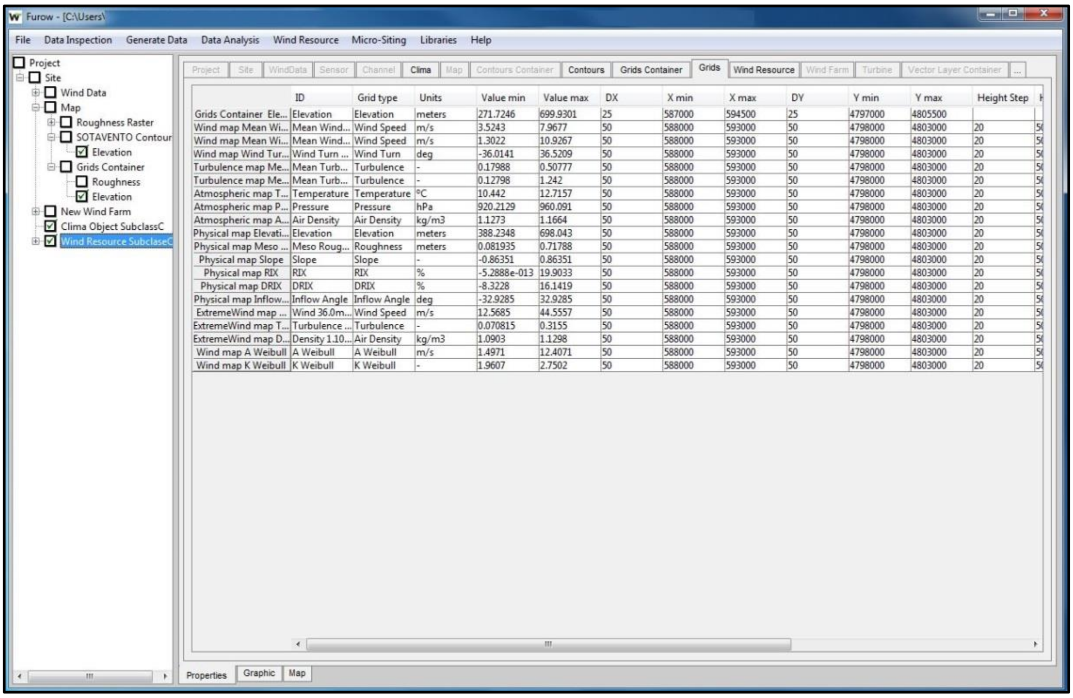


Figure 97: Wind resource grids properties

12.4 Wind resource calculation using multiple CLIMA objects

In this new version of **FUROW** it is possible to use several CLIMA objects to perform the wind resource calculation. For this purpose, a normal wind resource calculation must be performed using one CLIMA object assuming that this first CLIMA object is the most representative in terms of frequencies distribution. Once created, the user must check the rest of CLIMA objects together with the WIND RESOURCE object and the same GRIDS CONTAINER object, and then go to *Wind Resource/Correct Wind Resource with multiple Clima Objects*. Once selected, a window called *Parameters* will show up (see Figure 99) and the user must define both the interpolation order and the weighting decay exponent for performing the calculations as described on the ***Theory Manual***. Common weighting decay exponents will range between 0.5 and 3, tending to use higher exponents when the wind resource domain is large and lower for smaller domains. After clicking on OK the calculations will proceed and the result will be another WIND RESOURCE object with a regular tree structure.

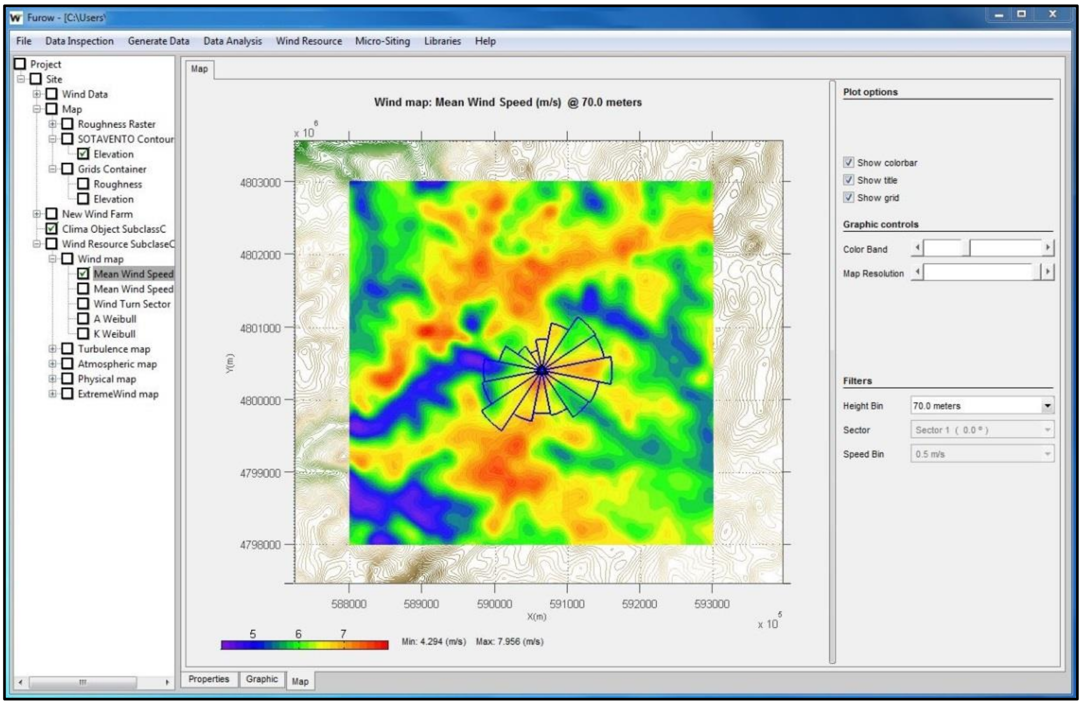


Figure 98: Mean wind speed layer

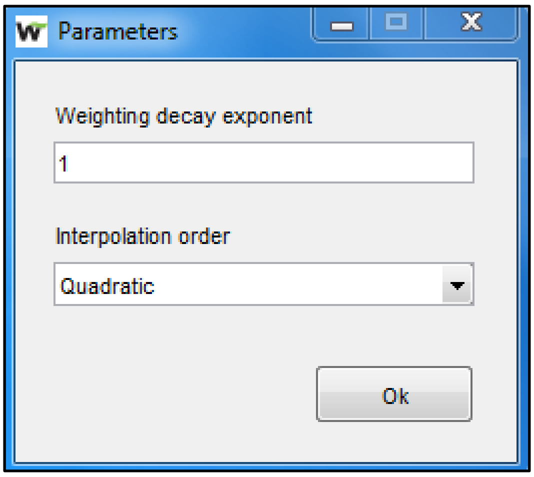


Figure 99: Parameters window for multiple CLIMA objects wind resource calculation

12.5 Extreme wind

In the same way calculations were performed for all wind speeds and directions for a given CLIMA object, it is possible to calculate the extreme wind map of wind speed and direction given these two values from a previous calculation of V_{ref} (for example in the *Extreme Winds module* of **FUROW**). Furthermore, air density of the site for that particular event (and its vertical gradient), wind speed standard deviation and Monin-Obukhov length can be also an input in order to calculate the specific value under extreme events (see Figure 100 for the inputs window). To calculate an *Extreme wind map* the user must select a CLIMA object, a WIND RESOURCE object and a TOPOGRAPHIC GRIDS CONTAINER object.

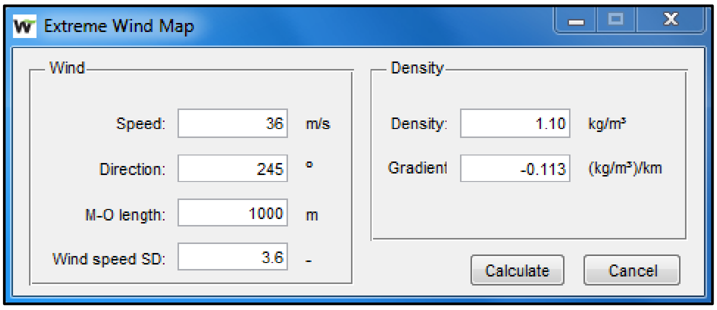


Figure 100: Extreme wind map inputs

As a result of the calculation, an extreme wind map for all the heights of the wind resource selected is available under the WIND RESOURCE object. Under this object hang a wind map, a turbulence map and an air density map (see Figure 101). This calculation has also been parallelized for better performance of the program.

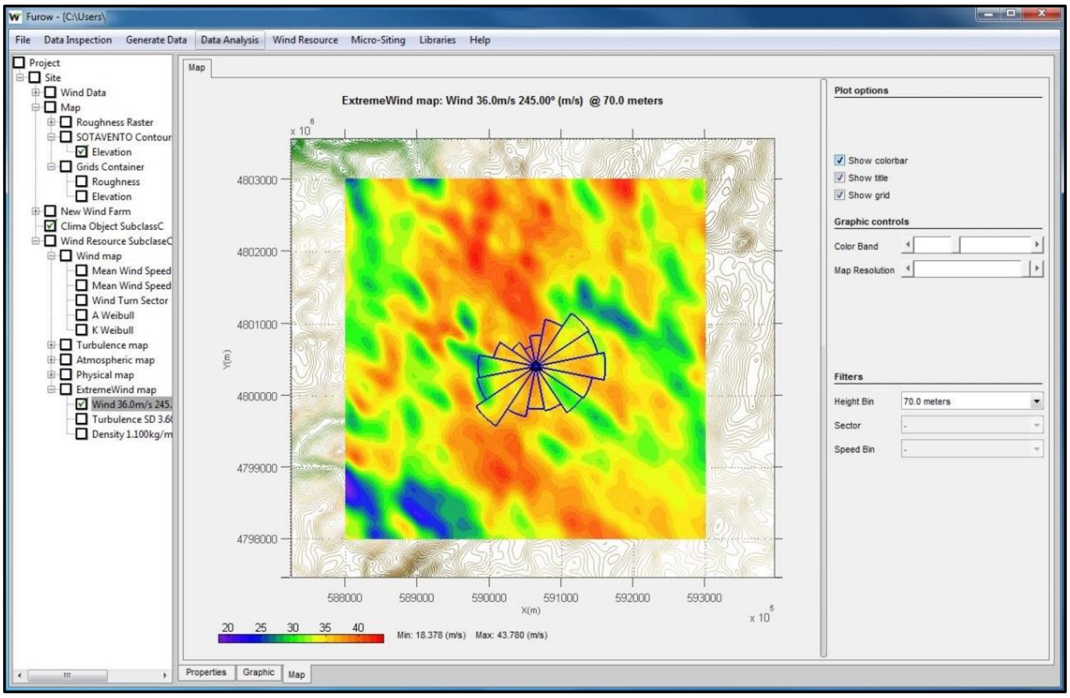


Figure 101: Extreme wind map

<u>Note:</u> It must be remarked that extreme wind map calculations cannot be performed with multiple CLIMA objects on this version.

12.6 Wind validation map

In **FUROW** it is possible to test specific conditions measured or simulated at a given point. For that purpose, wind speed, wind direction, wind speed standard deviation and Monin-Obukhov length shall be defined for a given height and coordinates (see Figure 102). If a CLIMA object is selected, then the coordinates are obtained from the object, but they can be changed.

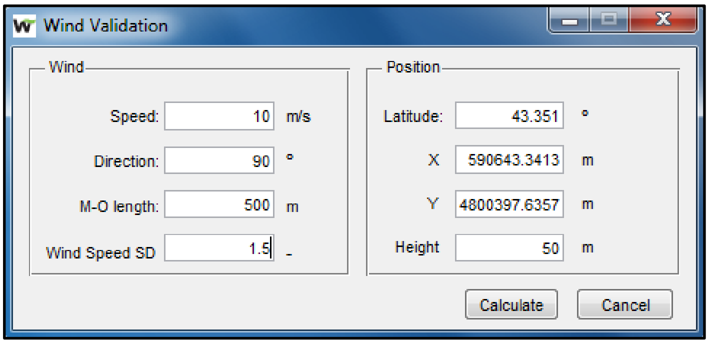


Figure 102: Wind validation map dialogue

Once the conditions are set, the same window as the wind resource calculation shows up to define the calculation options as well as the area to make the calculation and the heights. As a result, the wind speed map and the turbulence map are calculated as seen on Figure 103. Calculations have also been parallelized.

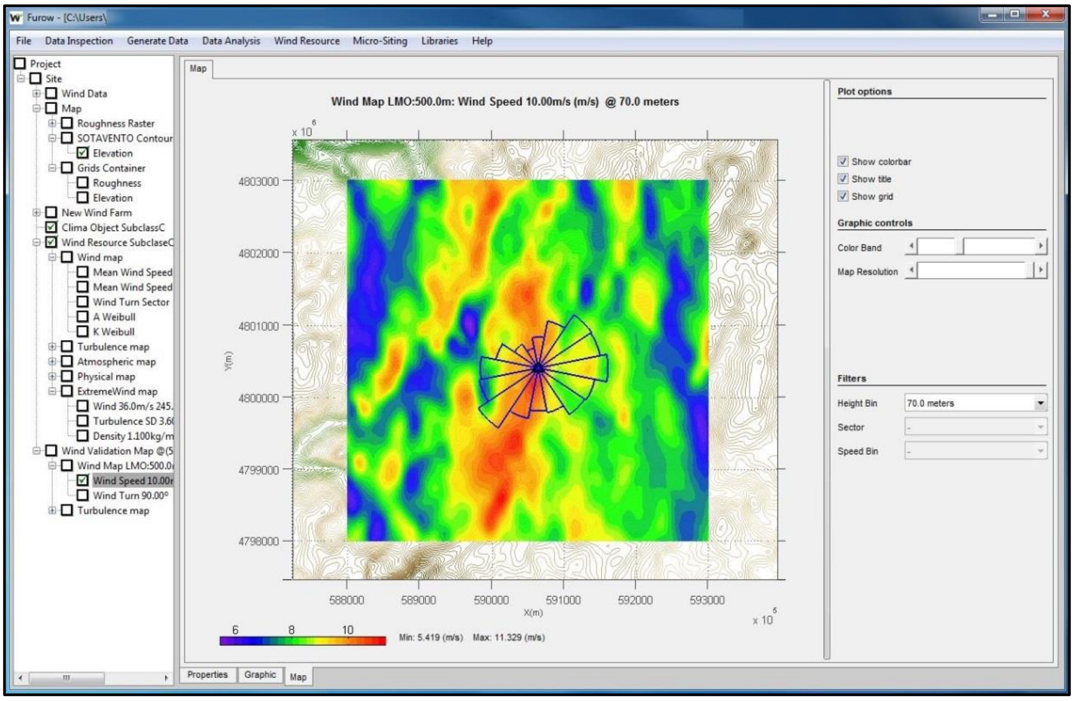


Figure 103: Wind validation map

<u>Note:</u> It must be remarked that wind validation maps cannot be performed with multiple conditions at different grid points.

12.7 Inspect profile

Once wind, turbulence and atmospheric maps are created at several heights, the user can inspect their vertical profiles. Within this dialogue it is possible to compare simulated wind flow with measured wind flow at mast positions, in particular for the vertical distribution (wind shear), to quantify how accurate the wind model is and rely on it for vertical extrapolation.

The user can select the point to obtain the profiles by clicking on the map or introducing the coordinates. By switching the tabs, the user can inspect several variables and from the sector pop-up the profile for each sector is shown. There is also a Table tab where all numerical results can be seen. Additionally, a polar profile for each height can be viewed (see Figure 104).

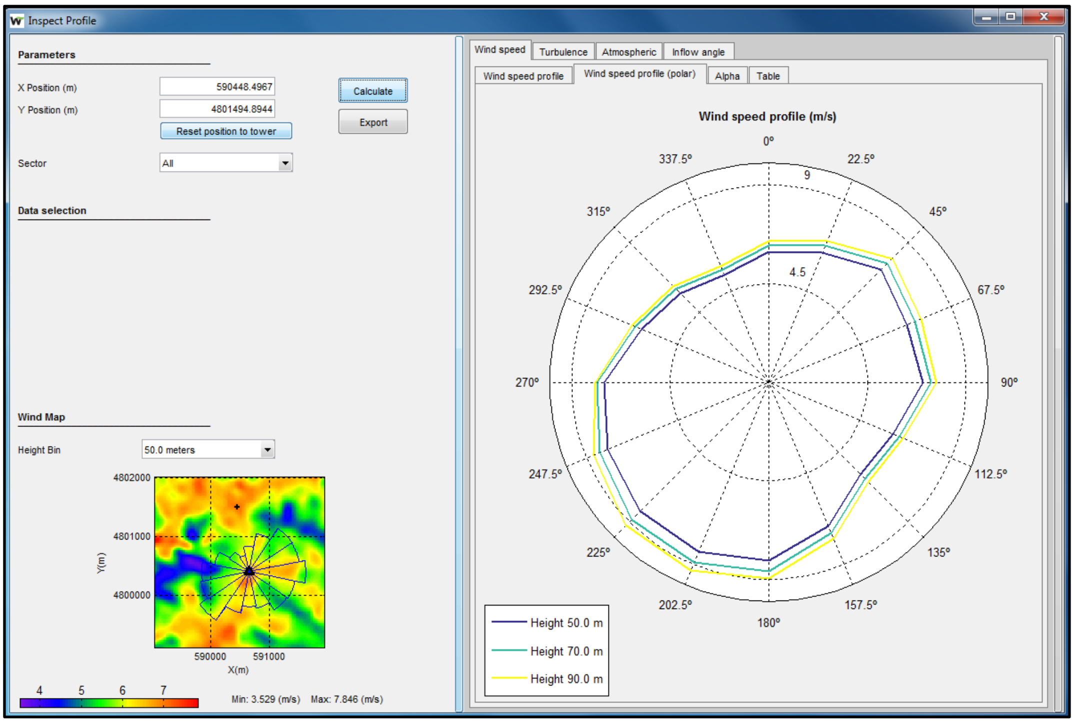


Figure 104: Inspect profile module

12.8 WRG files

It is common in the wind energy sector to work with **.wrg** files. Those files, unlike the wind grids calculated by **FUROW**, contain information of Weibull parameters for each sector as well as their frequencies of occurrence. For this reason, before exporting a **.wrg** file, it is necessary to generate the Weibull A and K grids. This action can be performed from the Wind Resource menu under *"Get A&K Weibull Map"* (see Figure 105). If the wind resource has been created with a very high resolution and there are many heights, this calculation can take several minutes. However, if it is a discrete calculation, it will take much less time.

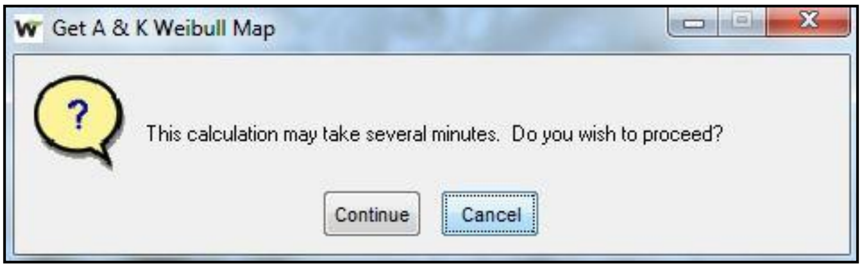


Figure 105: Weibull parameters calculation dialogue

Once calculated, the A and K maps are appended to the WIND MAP object inside of the WIND RESOURCE object.

If a **.wrg** file wants to be exported, this can be done under "*Wind Resource* and *Export Wind Resource / WRG Grid"* as seen on Figure 106. The height of the WRG must then be selected (any between the minimum and maximum calculation heights) and then search for the path to save it.

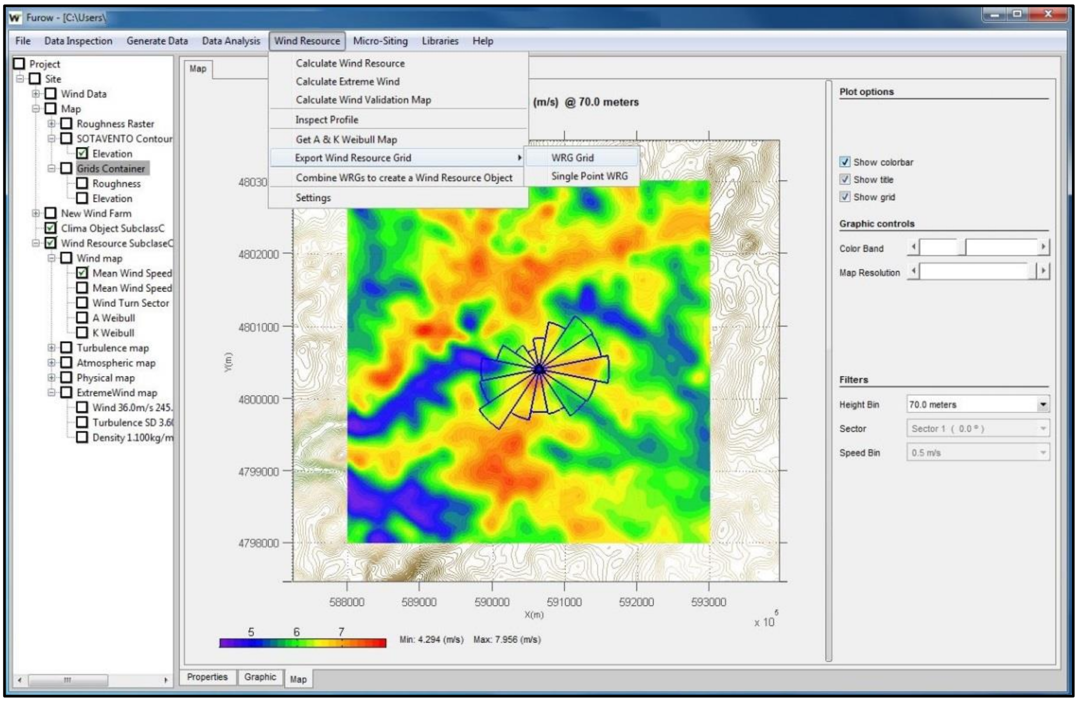


Figure 106: Export .WRG file

Finally, if a Single Point **.wrg** wants to be exported, the procedure is the same as for the **.wrg** but the position of the Single Point is also selected. Remember that to generate this Single Point **.wrg** the calculation grid must cover its coordinates.

On this new version, as it is possible to calculate discrete WIND RESOURCE maps, it will be possible to export the so-called **.rsf** files as well, that is, the wind conditions at turbines hub height.

When calculating in other programs through the association method, the Single Point **.wrg** must be created at the same height as the **.tab** file (or CLIMA object in **FUROW**).

FUROW can also accept **.wrg** files created from another source such as WAsP. In order to be able to use the **.wrg** the association method must be followed to create a WIND RESOURCE Object. In order to do this, the user must follow the following steps:

- Load a **.wrg** at a given height
- Load a single point **.wrg** at the CLIMA object height
- Open CLIMA object and load files or insert constant values
- Go to *Wind Resource* and select *"Combine WRGs to create a Wind Resource Object"*

Once the new WIND RESOURCE Object is created, then energy calculations can be performed. The structure of required objects is shown on Figure 107.

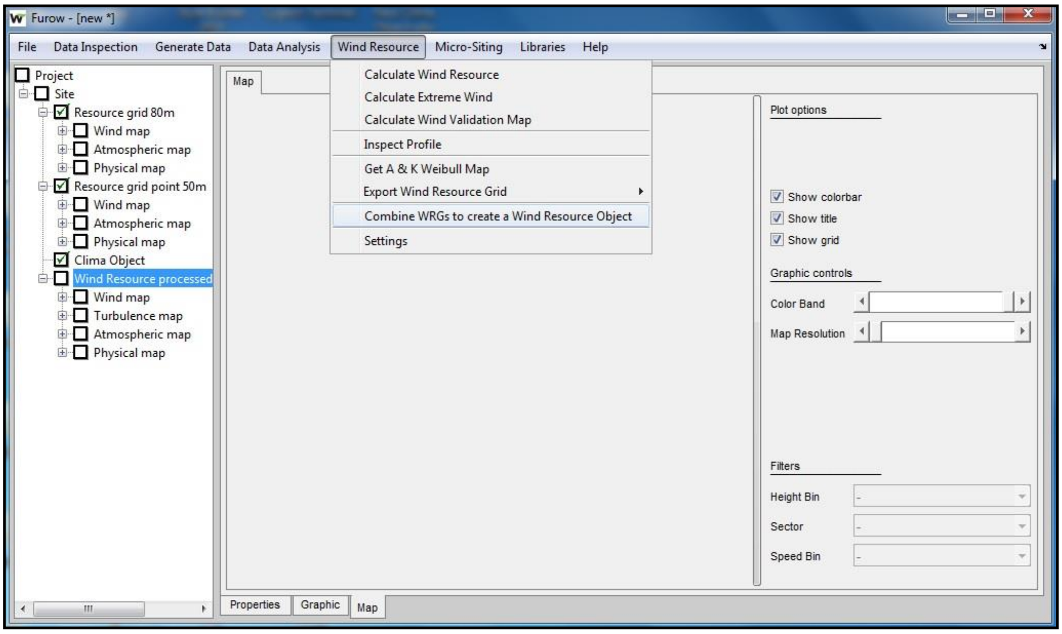


Figure 107: Create wind resource object from WRGs

12.9 Relocate CLIMA object

Once the wind resource is calculated, the hypothetical CLIMA object can be obtained at any point of the site. For doing so, while having selected the reference CLIMA object, the user must right click on the Wind resource object, choose *"Relocate Clima Object"* and then select if the action wants to be done for any point of the site or at turbine positions (see Figure 108).

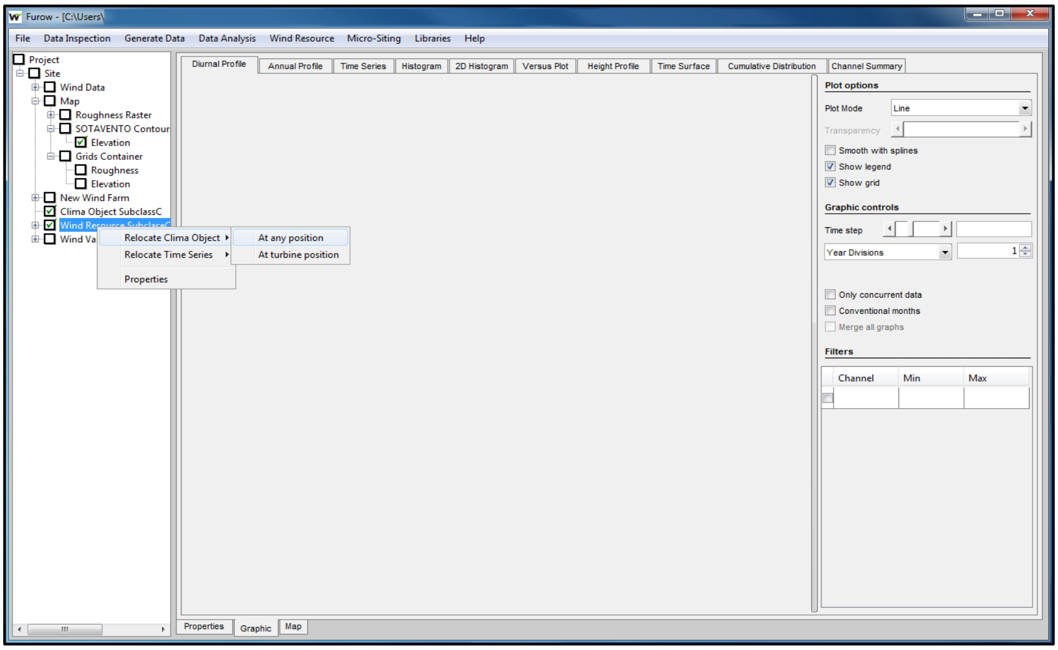


Figure 108: Relocate CLIMA object from tree

When the option selected is *"At any position",* then the user can select the exact position for calculation by typing in the coordinates or clicking on the map. The height can be any height as long as it is within the range calculated on the wind resource (see Figure 109). This new CLIMA object can be exported to the tree structure as well. If the option selected is *"At turbine position"* then the program calculates the CLIMA object at all turbine positions selected on the tree. Before calculating the program warns about the number of new CLIMA objects which will be calculated (see Figure 110) and once calculated they are created on the tree structure.

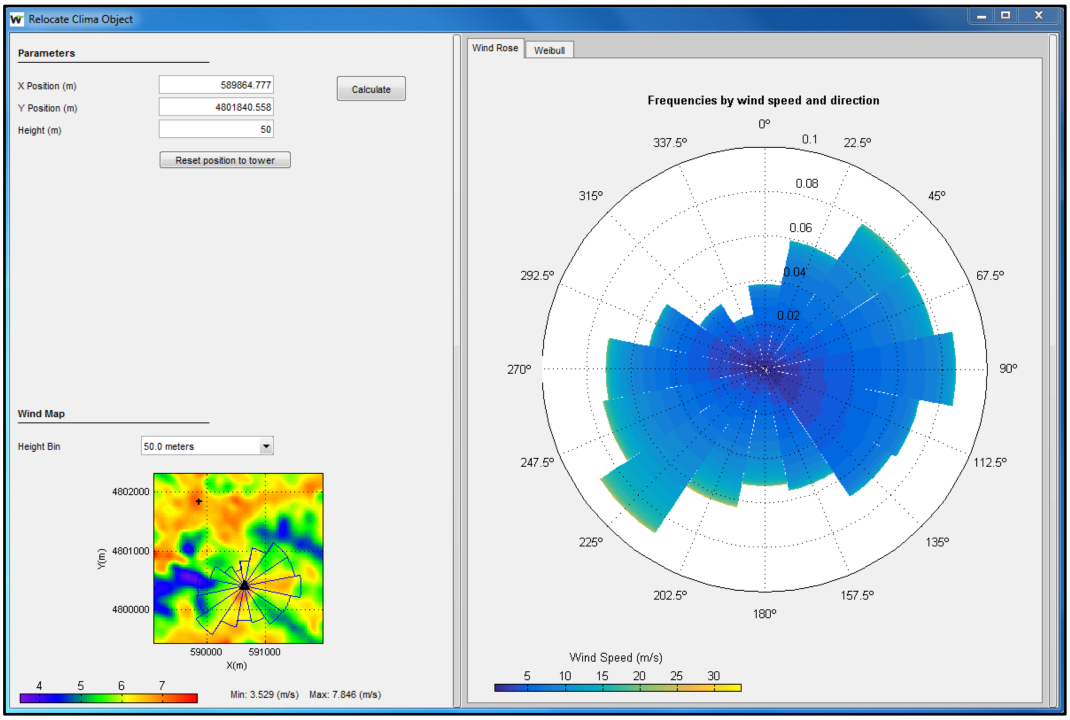


Figure 109: Relocate CLIMA object at any position

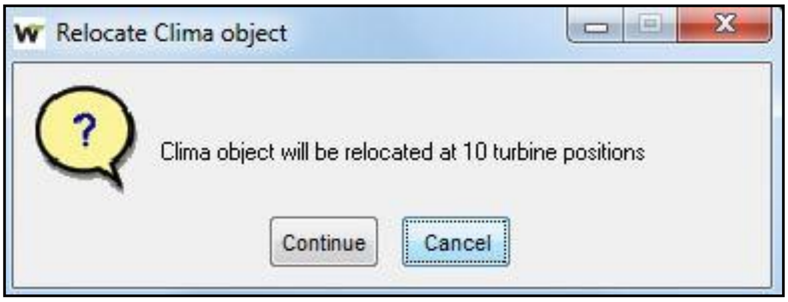


Figure 110: Relocate CLIMA object at turbines positions

12.10 Relocate time series

In the same manner as the CLIMA object, time series of wind speed, wind direction, standard deviation of wind speed, temperature and pressure can be extrapolated to any other position of the site. In this case, apart from the CLIMA object, the user must select the channels from the wind data to which accelerations and differences will be applied. It is mandatory to at least select a wind speed and a wind direction channel which must be at the same height as the CLIMA object (within a small range of 2m and 5m). The WIND DATA object must have the same coordinates as the CLIMA object in order to accept the channels. Once these conditions are fulfilled, the user again can choose to extrapolate the results to a given position of the site or to all wind turbine positions selected by the user. On Figure 111 it can be seen how wind speed is extrapolated at another position and another height. Finally, time series can be exported to the tree from the *Results panel* as a new WIND DATA object.

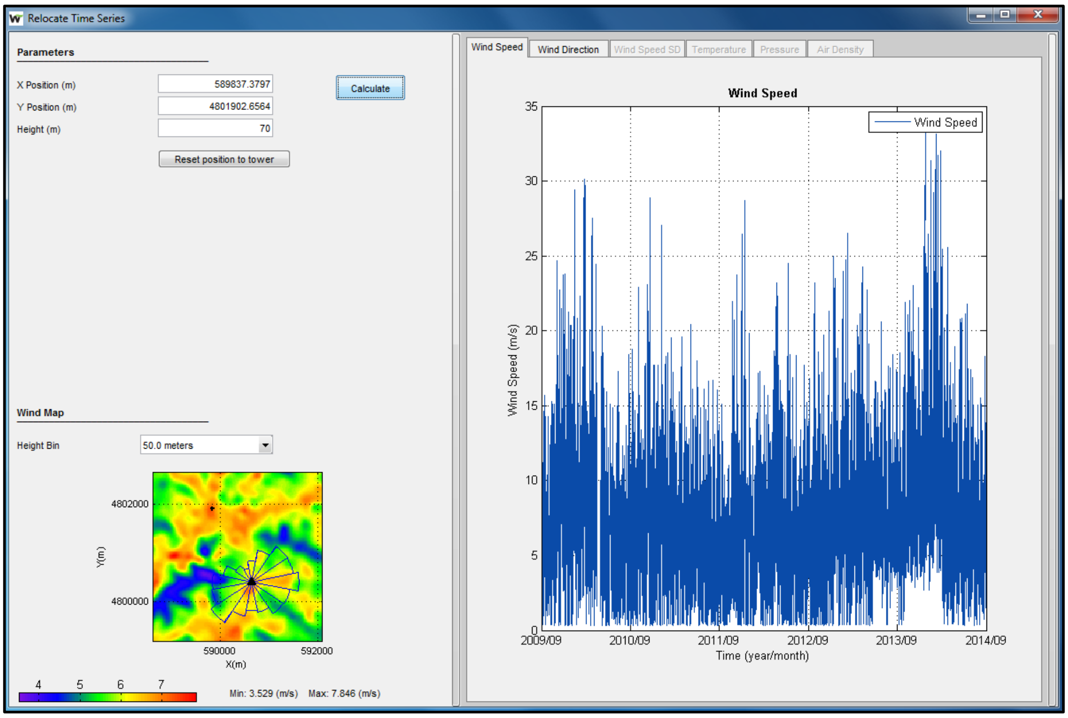


Figure 111: Relocate time series at any position

13 CFD wind resource calculator

Aside the linear model available in the wind resource calculator mentioned in Section 12, **FUROW** also provides a CFD model for more complex terrains. This model uses a linear calculation to set the boundary conditions for the CFD domain. For this reason, the linear model parameters remain important for an accurate CFD calculation.

The CFD calculations are launched using tokens. These tokens must be bought from **SOLUTE** and each token roughly corresponds to a CFD for a 1km^2 area with 16 sectors and a 25m resolution. These tokens can be purchased by contacting commercial responsibles of **SOLUTE** at furow@solute.es or +34 91 658 82 04. These tokens correspond to tokens that can be bought through **FUROW** on a credit basis, requiring payment through invoice as other transactions with **SOLUTE**. As a general rule, tokens must be paid to be loaded into the client´s Furow CFD module.

13.1 Launching a CFD case

Launching a CFD calculation works much like launching a calculation with the linear model. In order to generate all CFD wind resource maps, the user must select one CLIMA object and one TOPOGRAPHIC GRID CONTAINER object (see Figure 91) and then go to *Wind Resource/Calculate Wind Resource/Map*. Then, a new window allows the user to select the parameters to perform the calculation such us the grid resolution, the number of heights and the height step. Wind speed bins and direction sectors used in computations are derived from the CLIMA object. The boundaries of the polygon to calculate the wind resource can be given by introducing the coordinates of the most southwest point and the most northeast point, or by selecting the calculation area with the mouse (first clicking and then dragging) (See Figure 92).

Unlike the linear models in Section 12, for the CFD model only the simplified calculation method is available. This method calculates the solution for only one wind speed bin and is preferred to avoid prohibitive calculation times that would occur for a complete calculation. The description of the model and the theoretical background is described in detail on the ***Theory Manual***. On the other hand, the same turbulence intensity calculation options are available as in Section 12.1.

Other advanced parameters can be modified in the "Advanced parameters" tab as described in Section 12.1. The exception is the *"Independent hills distance"*. This distance is internally set as 1000m to limit the linear model calculation times, which become overwhelming due to a much finer mesh in the z-direction.

Once parameters have been set and the area to perform the calculation is selected, the CFD parameters can be set (see Figure 113). In order to ensure simplicity, an automatic turbulence parameter selection is available. This option selects the k-ω turbulence model automatically and leaves the turbulence closure parameters at their default values. These values are the default values for the models, extensively available in literature (see the ***Theory Manual*** for more information).

Calculation starts by clicking on “Ok” in the “CFD” tab. This opens a window containing CFD token data that prompts the user to confirm before launching the CFD case (see Figure 112).

Figure 112 : Token information and prompt to confirm launching CFD

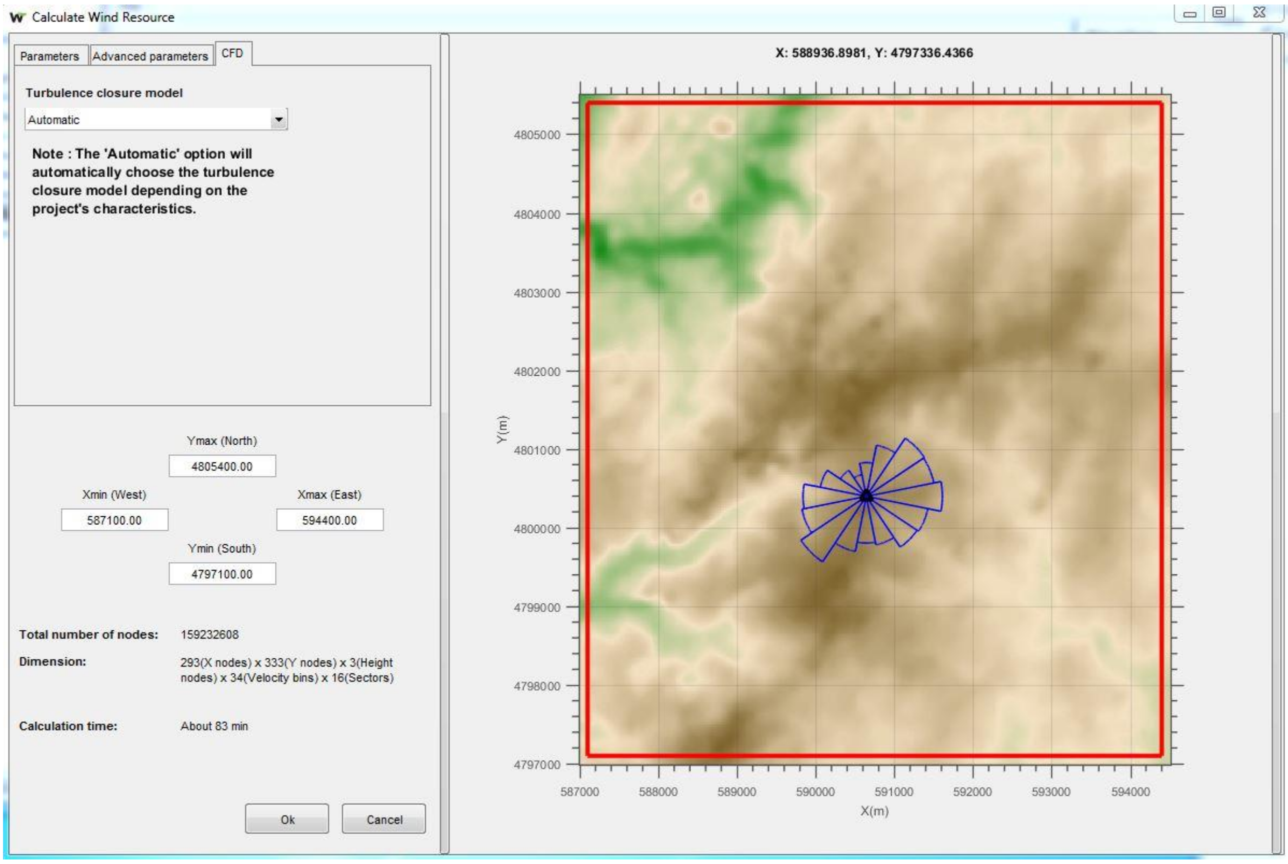


Figure 113 : CFD tab for wind resource calculation

Once all linear calculations have been made, the information is sent to **SOLUTE**’s server, and the CFD calculations are placed in a queue. This queue allows four simulations to be launched simultaneously.

13.2 Managing CFD cases

If the user wishes to consult the status of current and past CFD simulations or to download/delete cases, "Manage CFD" can be selected from the File menu. This opens the window seen in Figure 114.

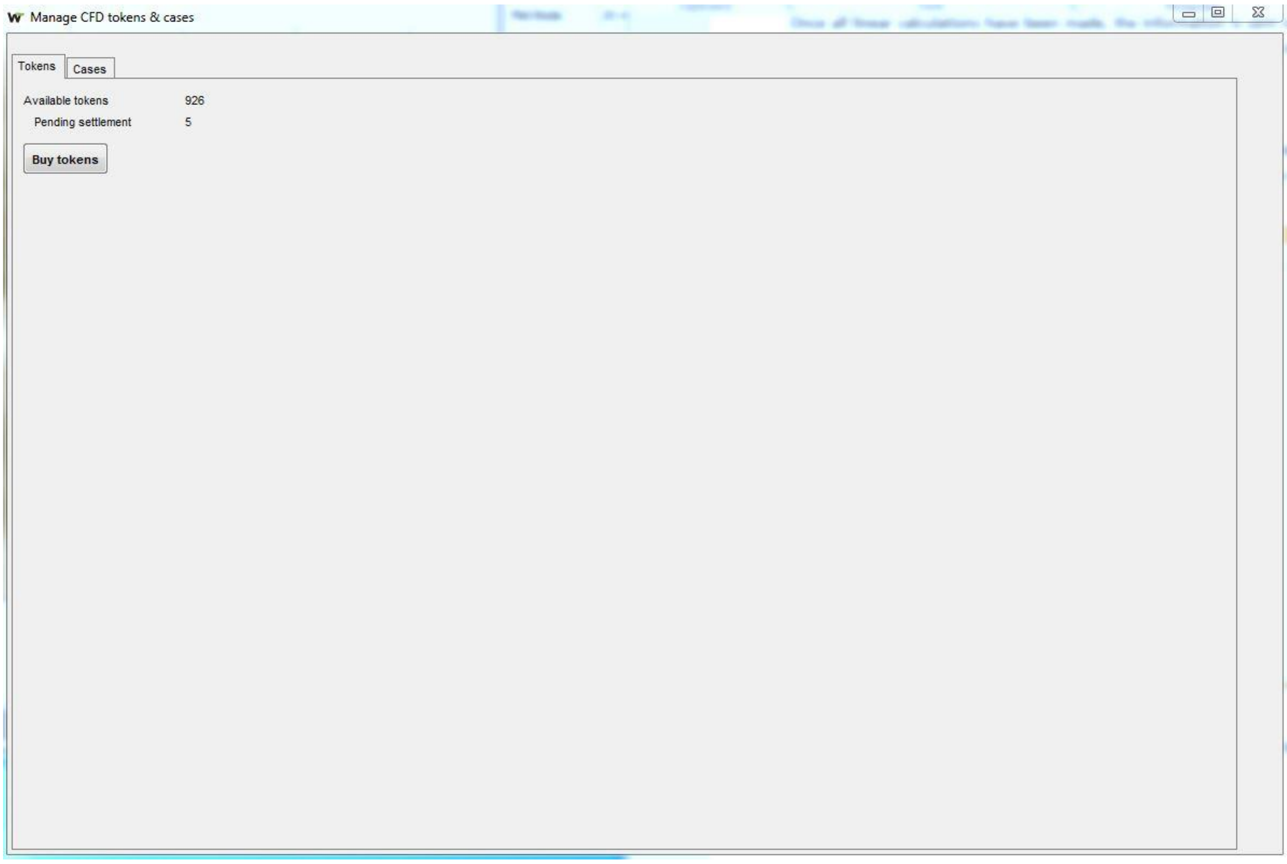


Figure 114 : Manage CFD tokens tab

In this window, new tokens can be bought by pressing "Buy tokens". The cases can be managed in the "Cases" tab (see Figure 115).

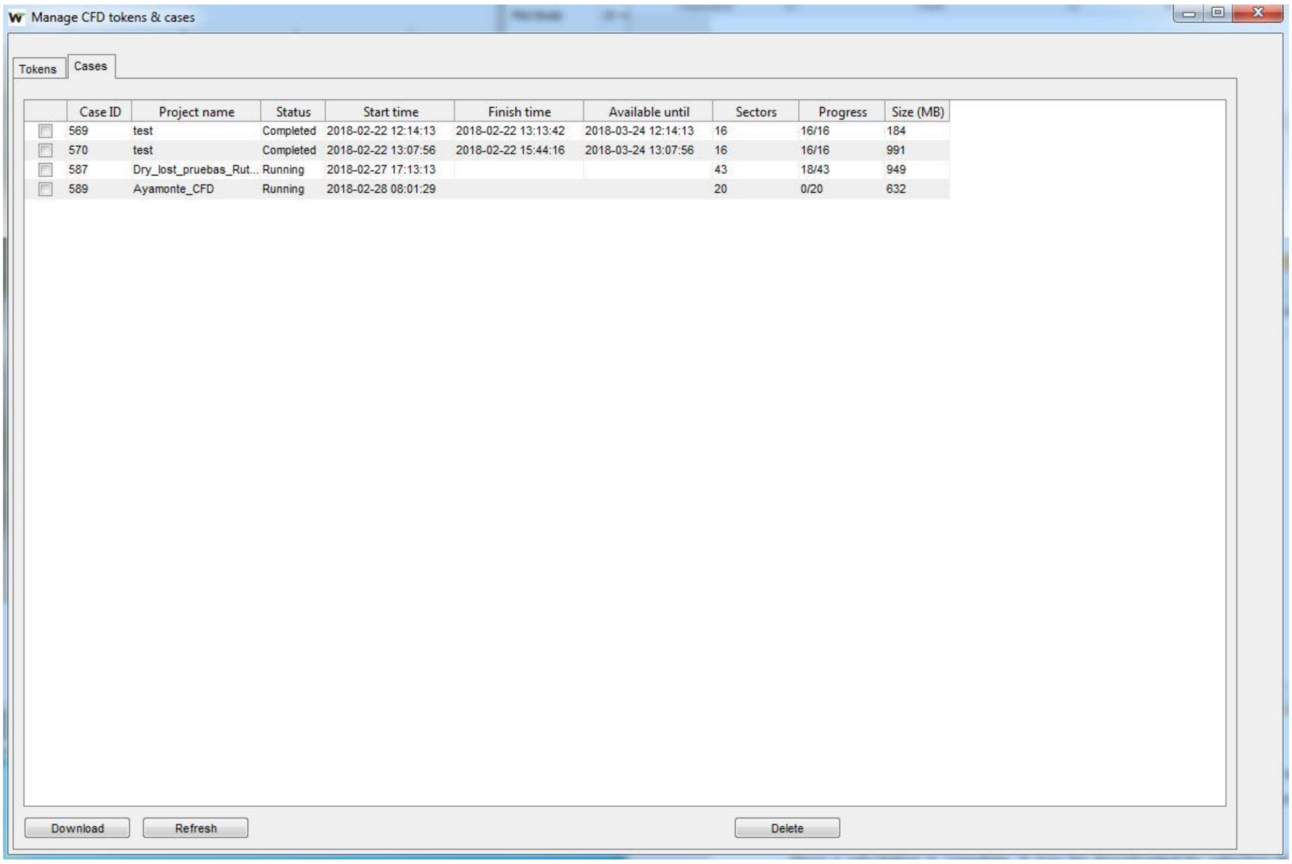


Figure 115 : Manage CFD cases tab

In this tab, the different characteristics of the CFD cases are listed. If not deleted by the user, the cases remain available for 1 month on the server. Afterwards, they are deleted and may no longer be accessed.

Once a calculation is complete, it may be downloaded by selecting the desired case and clicking “Download”. This downloads the results and place them in the tree structure (see Figure 95) alongside other **FUROW** results. The results are presented in the same format as those from Section 12.

14 Vector layers: Polygons and lines

In order to determine the boundary limits of a wind farm or to characterize any other important feature to include or exclude when positioning wind turbines, and consequently when estimating the energy yield, **FUROW** allows the inclusion of polygons and lines.

The user can insert polygons and lines by clicking on the option *"Create Vector Layer"* on the SITE object. Then a new window is opened and any feature can be created. It is possible to decide if the layer will be a line or a polygon and if it will be valid or not for placing the wind turbines and the lines can have a buffer to exclude certain area around the line. Valid objects are drawn in green color whereas excluded areas are drawn in red (See Figure 116). Once the shape is created, the user must click on *"Add Vector Layer".*

The creation of a vector layer can be done using any layer which contains geographic information such as a MAP or a WIND RESOURCE object, and even a Google image could be used for creating vector layers.

On this new version it is possible to select contour lines such as elevation or roughness to make valid or invalid areas. There is an option to *"Select"* the contours or even another one to *"Follow"* the lines and create a new vector layer as shown on Figure 116.

To delete the most recent point when creating a line, then the user must press **Delete** key. If the whole feature needs to be deleted, then the **Backspace** key must be pressed.

Also, it is now possible to modify the existing vector layers by right-clicking on the VECTOR LAYER CONTAINER object under *"Modify Vector Layer".* It is then possible to remove any vector layer on the list by clicking on *"Delete checked",* change their characteristics by selecting each of them and clicking on *"Modify checked"* and add new vector layers within the same VECTOR LAYER CONTAINER.

Finally, it is important to make a right use of the hierarchy of the vector layers. The arrows above the vector layer list allows determining the priority of the vector layers, and even the way lines are represented on the dialogue give an idea on the priority. Thus, on Figure 116, a first polygon was created making valid what is inside and excluded what is outside. When creating a new excluded line, then it is also excluding part of the initial valid polygon with the buffer indicated on the table. However, if the second vector layer is moved up with the arrows, the logic would be somewhat different: since there is an excluded line, the rest of the map will be valid, and when the polygon is overlapped on top, then part of the line is made valid. Additionally, when the order is such as it is shown on Figure 116, the second vector layer (red) is represented on top of the first one (green). When changing the order, the green polygon will be represented on top of the red one as shown on Figure 117.

As a conclusion, depending on the order of the vector layers, the resultant available land for placing wind turbines will be different.

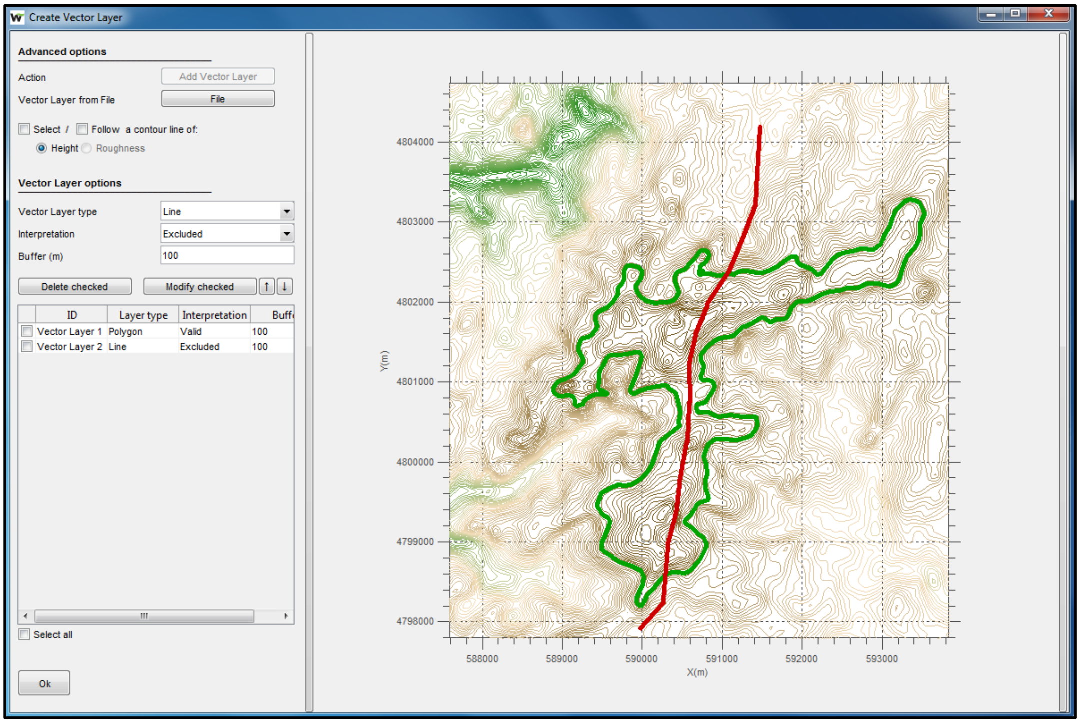


Figure 116: Example of a vector layer creation

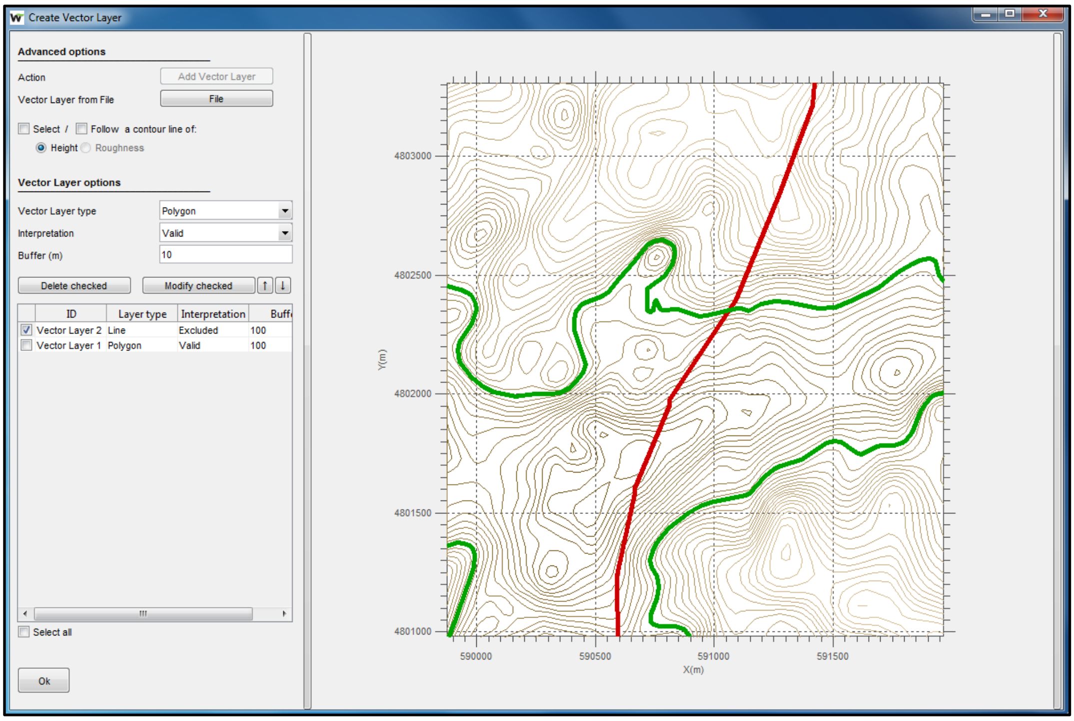


Figure 117: Example of a change on vector layer hierarchy

Within this dialogue the user can import polygons and lines created in Google Earth as **.kml** files, but one by one. Once opened, the user must indicate which will be its properties and then click on *"Add Vector Layer"*. Objects with extension .kml and multiple objects inside can also be opened from File menu or SITE object, depending on where to place them at the tree structure. It must be remarked that "correct" positioning of these objects on the map will be possible if maps themselves are created on UTM WGS84 projection and datum. Once created on the tree the user can modify their characteristics. Figure 118 shows an example of vector layers created on Google Earth, and then imported on **FUROW**.

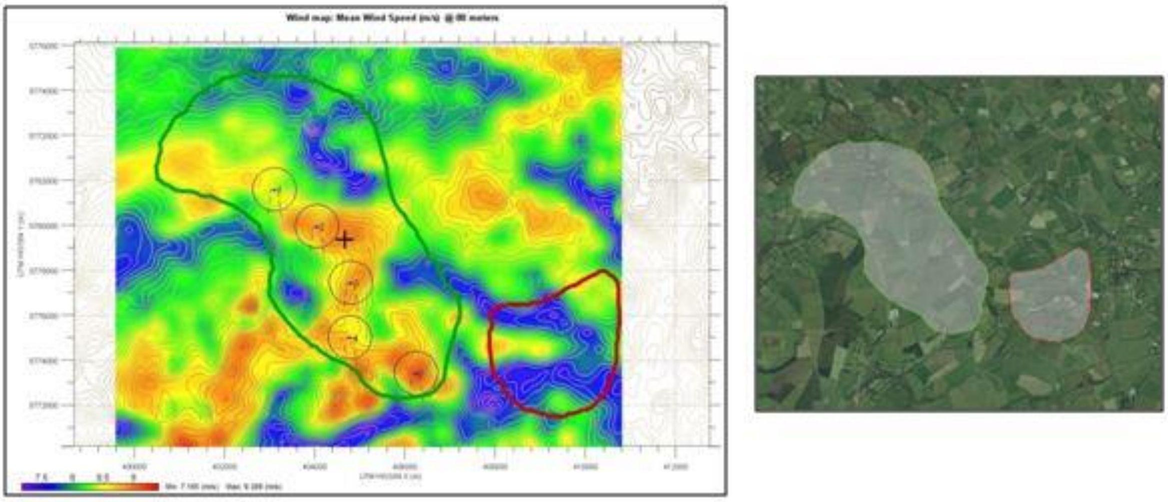


Figure 118: Example of polygons and lines from Google Earth

The coordinates of a polygon or a line can be opened from an ASCII file provided the coordinates **X** and **Y** of the points forming the vector layer are given. Coordinates must be written in the appropriate order to obtain the desired object. The extension which can be read by **FUROW** is **.vly**, so the user should always change the extension to the original **.txt** or **.dat** file.

On this new version it is possible to load **.shp** files. When this type of file is loaded then every individual object in the **.shp** file is loaded at once and is assigned with the current properties of the vector layer (type, interpretation and buffer). Once all the objects are created as individual vector layers their properties can be changed according to the user criteria.

Additionally, once created the vector layers it is possible to export the coordinates of those vector layers by going to *Site/Export visible selected layers to .vly*. Generated files are ASCII files but with **.vly** extension.

15 Wind farm objects

This type of object contains information of each wind farm added into the tree structure of the project. WIND FARM objects can be created by selecting the option *"Create new wind farm"* on the SITE object and then left-clicking on the positions the user wants to place the wind turbines while being selected the mouse action *"Add"* (see Figure 119). Before adding new wind turbines, the user can change the wind turbine model and hub height, thus having different wind turbines within the same wind farm. It is important to clarify that turbines of different kind and with different hub heights can form a wind farm object, and energy yield can be calculated as long as hub heights are within the range of heights calculated on the wind resource. Another option is to import a **.wfc** file (which is an ASCII file) with the **X** and **Y** coordinates of wind turbines, as well as its ID name, all of them separated by tabs. Once the whole wind farm is created, by clicking on OK, a new wind farm object is created on the tree structure.

It is also possible to open a **.kml** file from the SITE object with different place marks, indicating each one of them the potential position of a wind turbine. It must be remarked that "correct" positioning of these objects on the map will be possible if maps themselves are created on UTM WGS84 projection and datum.

On this version, an option of auto-placing turbines has been implemented, so the user can place as many wind turbines as desired by clicking just one button.

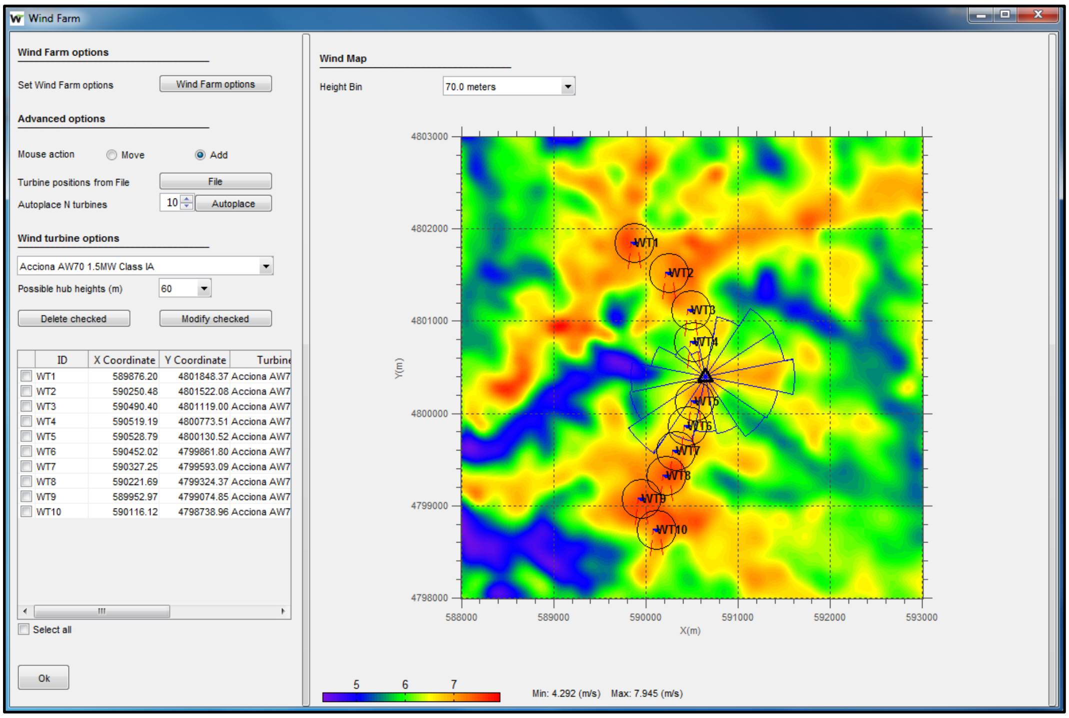


Figure 119: Example of the creation of a wind farm

Once the wind farm is created, it can be modified by right-clicking on the object and selecting *"Modify Wind farm"*. Inside the module, the user can add new turbines or even move the existing wind turbines using the mouse action *"Move"*. Under the list of turbine positions, it is possible to select one or several wind turbines and while changing their characteristics click on *"Modify checked"*, and automatically the existing properties are changed to the new ones. Also, wind turbine positions can be removed by using *"Delete checked"*.

WIND FARM objects have different properties which serve as inputs for energy yield calculations, such as the energy losses and the wind sector management (WSM) strategies. Also, the turbine separation distance can be edited and will allow placing the turbines keeping a minimum distance among them. For these purposes the user can go to *"Wind Farm options"* and there it is possible to modify them. Turbine coordinates and the turbine type cannot be modified here. In that case, the user should go to "*Modify Wind Farm"* option. There, it is possible to modify the wind turbine type, the hub height (if several are available) and the coordinates. When a wind farm object is modified, especially by removing some wind turbines or moving their positions, it is recommended to revise energy losses values as well as sector management strategies (curtailment strategies from deleted turbines are immediately removed).

If a WIND FARM object is selected, all coordinates of the wind farm can be exported to an ASCII file from *Site/Export visible selected layers to* **.wfc**.

15.1 Wind turbines

Wind turbine objects are created once the wind farm is created. The properties of each wind turbine include the coordinate **X** and **Y** at the grid as well as multiple properties characteristic of the machine itself. As stated before, every wind turbine model should be created before at the Turbine Database. An example of wind turbine object is shown below (see Figure 120).

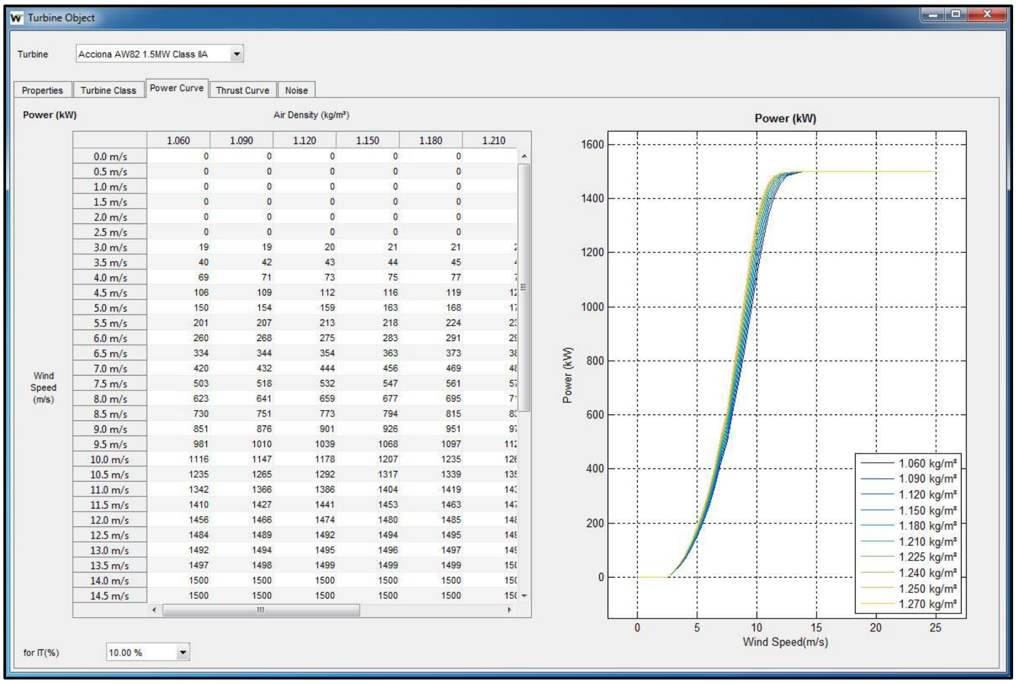


Figure 120: Example of wind turbine power curve

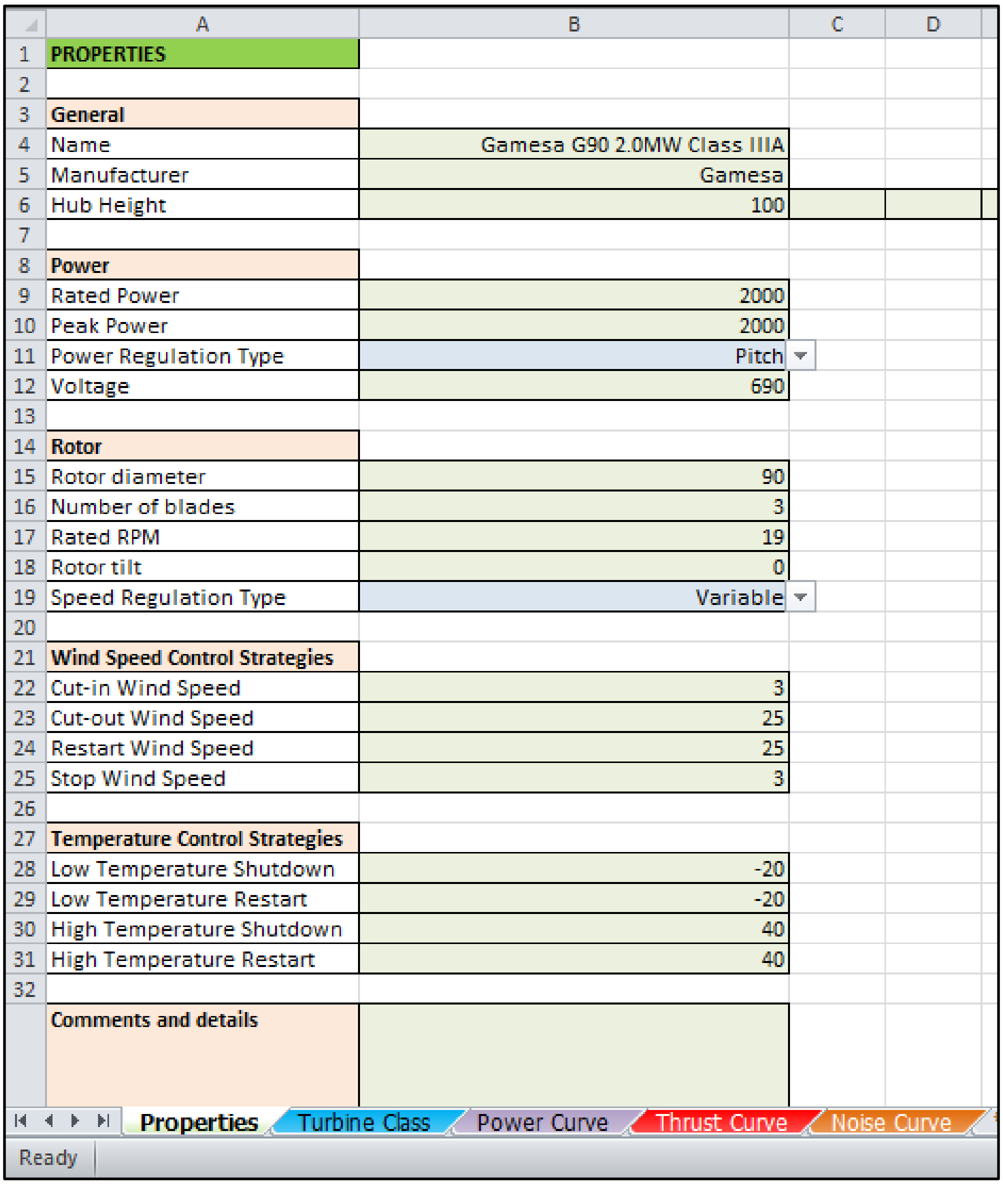
Properties of the wind turbine can be inserted through an **.xls** template, containing the following information:

- General properties
    - ✓ Turbine model: typically, is the commercial name of the wind turbine
    - ✓ Manufacturer name
    - ✓ Hub height: there can be different hub heights for a given wind turbine model
- Power properties
    - ✓ Rated power: power at rated wind speed and characteristic of the machine
    - ✓ Peak power: maximum power
    - ✓ Power regulation type: Pitch or Stall
    - ✓ Generator voltage: voltage at generator terminals
- Rotor properties
    - ✓ Rotor diameter
    - ✓ Number of blades
    - ✓ Rated RPM: rotor rotational speed at rated conditions
    - ✓ Rotor tilt: inclination of the rotor with respect to horizontal plane
    - ✓ Speed regulation type: Variable or Fixed
- Wind speed control strategies
    - ✓ Cut-in wind speed: speed at which the turbine starts to rotate and generate power
    - ✓ Cut-out wind speed: speed at which will turbine will stop operating
    - ✓ Restart wind speed: speed at which the turbine starts operating again when cut-out has previously reached
    - ✓ Stop wind speed: speed at which turbine will stop for low wind speeds
- Temperature control strategies
    - ✓ Low temperature shutdown: temperature at which turbine stops operation due to cold conditions
    - ✓ Low temperature restart: temperature at which turbine starts operation after cold conditions
    - ✓ High temperature shutdown: temperature at which turbine stops operation due to hot conditions
    - ✓ High temperature restart: temperature at which turbine starts operation after hot conditions
- Comments and details of the wind turbine
- Class and Subclass of the wind turbine
- Certification parameters
    - ✓ Certification standard: Unknown or IEC Editions
    - ✓ V_{ave}: design average wind speed
    - ✓ V_{ref}: design extreme 10-min wind speed

- ✓ Design TI: design turbulence intensity defined as the characteristic or representative at 15m/s
- Power curve for different air densities and different values of turbulence intensity.
- Thrust curve for different air densities.
- Sound power levels for different octave bands and wind speeds

15.2 Wind turbine template

In order to create a new WIND TURBINE object and include it within the database, it must first be created using a template file. This template is an **.xls** file where the user can easily modify and add all the characteristics described on the previous section. On Figure 121 a screenshot from a wind turbine model is shown.



	A	B	C	D
1	PROPERTIES			
2				
3	General			
4	Name	Gamesa G90 2.0MW Class IIIA		
5	Manufacturer	Gamesa		
6	Hub Height	100		
7				
8	Power			
9	Rated Power	2000		
10	Peak Power	2000		
11	Power Regulation Type	Pitch		
12	Voltage	690		
13				
14	Rotor			
15	Rotor diameter	90		
16	Number of blades	3		
17	Rated RPM	19		
18	Rotor tilt	0		
19	Speed Regulation Type	Variable		
20				
21	Wind Speed Control Strategies			
22	Cut-in Wind Speed	3		
23	Cut-out Wind Speed	25		
24	Restart Wind Speed	25		
25	Stop Wind Speed	3		
26				
27	Temperature Control Strategies			
28	Low Temperature Shutdown	-20		
29	Low Temperature Restart	-20		
30	High Temperature Shutdown	40		
31	High Temperature Restart	40		
32				
	Comments and details			

Figure 121: Wind turbine template

16 Wake effects

Even before making any calculation of the energy yield, there is a specific module within the Micro-siting menu called *"Wake effects"* that allows recreating the whole wind field for a particular sector including the wake induced wind speed deficits (See Figure 122). For this purpose, a topographical grid container and a wind farm object need to be checked; however simulations are performed as if all turbines were in flat terrain.

In order to calculate, the user just needs to enter the following parameters: incident wind speed, wind direction, turbulence intensity and wake model. As a result, the user can see the wind speed map, and can also export this map to the tree structure (under the wind farm object) by clicking on *"Export raster"* button.

It is important to remark that it is possible to visualize the wakes at different heights so the user can determine up to which height the wake effect is extended. For this version, the possibility of using the near wake model and the use of several iterations is included.

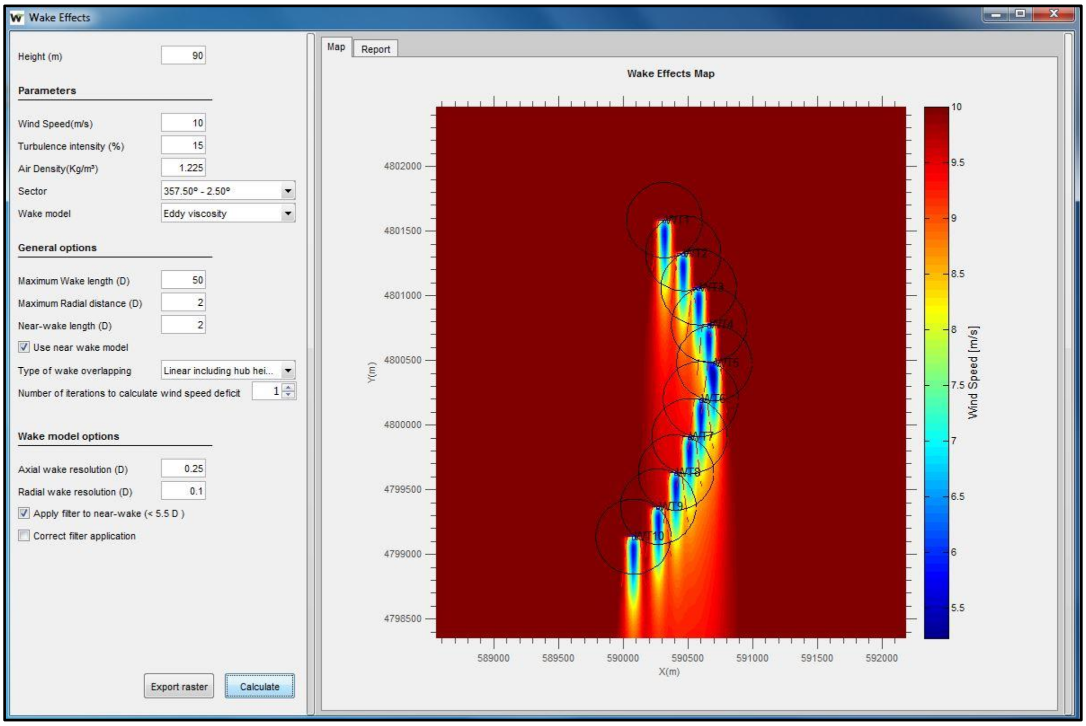


Figure 122: Example of Wake Effects module

In this new version, another tab called "Report" is available. On this tab, **FUROW** shows the exact wind speed and power of each individual wind turbine. An example of a report is shown on Figure 123. When the FUROWAKE model is run it is possible to request several heights besides the hub height.

	1	2	3	4	5
1					
2	Wind Speed [...	10.00			
3	Turbulence i...	15.0			
4	Air Density(K...	1.225			
5	Wind Directio...	0.00			
6	Wake model	Eddy Viscosity			
7					
8	Turbine ID	X [m]	Y [m]	Waked wind ...	Power [kW]
9	WT1	590319.5	4801584.7	10.000000	1836.000000
10	WT2	590463.5	4801328.8	10.000000	1836.000000
11	WT3	590583.4	4801064.9	9.996424	1834.827117
12	WT4	590663.4	4800777.0	9.790951	1767.431838
13	WT5	590703.4	4800481.1	8.092121	1123.059466
14	WT6	590599.4	4800201.2	8.783182	1416.069370
15	WT7	590511.5	4799913.3	9.341586	1620.040307
16	WT8	590407.5	4799633.3	9.532486	1682.655327
17	WT9	590271.5	4799369.4	9.683241	1732.103050
18	WT10	590079.6	4799137.5	10.000000	1836.000000

Figure 123: Example of Wake Effects report

17 Energy yield calculations

Once the whole project has been assembled, that is, there is a CLIMA object with met mast statistics, there is a WIND RESOURCE object with all properties set up and a new WIND FARM object has been created, it is time to run the Energy Yield calculations. This action can be performed under the Micro-siting menu and *"Energy Yield"* option.

In first place, the wake model must be selected. For each wake model there are some options which can be modified:

- **None (No wake losses)**
- **Jensen:** it is possible to modify the way the wake decay constant, "k".
- **Frandsen:** it is possible to use a simplified version of the proposed method
- **Larsen**
- **Isihara**
- **Simplified Eddy Viscosity:** the axial wake resolution can be changed in the resolution of the equations. Also, a filter for the near wake and a correction to this filter can be applied.
- **Eddy Viscosity:** the axial and radial wake resolutions can be changed in the resolution of the equations. Also, a filter for the near wake and a correction to this filter can be applied.
- **Bastankahk & Porté-Agel:** it is possible to modify the wake growth rate constant, "k".

There are some general options for energy calculations which are the following:

- **Number of sectors:** typically, between 72 and 360.
- **Number of hours per year:** typically, 8760 or 8766.
- **Use DRIX correction:** if the user wants to correct wind speeds with the DRIX value at every point (DRIX has a directional dependence).
- **Maximum wake length:** maximum distance up to which wakes are taken into account
- **Maximum radial distance:** maximum distance perpendicular to the wind direction and from the wake centerline up to which the wake is considered to have influence.
- **Near-wake length:** minimum distance at which wake models are usually initialized being commonly 2 diameters.
- **Near-wake model:** if this option is checked the near wake model described on the ***Theory Manual*** is applied.
- **Overlapping:** in the case more conservative results are desired for distances up to a number of diameters for the overlapping factor. That is, it is possible to consider that for a given distance (i.e. 3 diameters), as long as there is some partial wake overlapping, a complete overlapping can be assumed (in this case overlapping equals to 1, which represents 100%).
- **Type of overlapping:** refer to ***Theory manual*** to see the differences.
- **Number of iterations:** this parameter is used to control the number of times the program iterates to calculate deficits with incident wind speeds.

- **Use constant power curve with TI:** in the case a power curve has more than one power curve depending on turbulence intensity, the user can select to use just one power curve.
- **Calculate effective wind speed:** this parameter is calculated when the check is applied.

There are also some options regarding the calculation of the turbulence intensity, both for the physical turbulence intensity and the effective turbulence intensity:

- **Added turbulence:** the user can choose between 3 different models to calculate the physical added turbulence.
- **Wöhler slope:** this is the slope of the S-N fatigue curves and ranges between 4 and 14 (typical value of 10 is usually used). This parameter is used to compute effective turbulence.
- **Use Ct approximation option:** it can be applied to calculate the effective turbulence instead of only using the wind speed.
- **Use real distance between wind turbines:** in **FUROW** the distance between turbines to calculate the effective turbulence is chosen perpendicularly and parallel to wind direction. If the true distance needs to be used, this option should be checked.
- **Set overlapping value: FUROW** calculates the overlapping factor and uses it in the formulas to calculate effective turbulence. However, in the Standards it is considered that as long as part of the wake overlaps with the downwind turbine is counted as full affection in terms of added turbulence. Thus, the user can set this parameter equals to 1 for full affection or to any other value if it is considered to yield better results.
- **Use unavailability losses in calculations:** this option can be applied if the user wants to exclude from operational range the time the wind turbine has been unavailable when calculating the effective turbulence intensity.

Figure 124 shows all the Energy Yield options explained above.

<u>Note:</u> energy yield calculations can use a lot of RAM memory, so depending on the characteristics of the computer on which FUROW is being run, some calculations may not be performed. An estimation for the needed RAM memory (in GB) on calculations is the following:

$$\boldsymbol{RAM\ memory = \frac{180 \cdot N_t^{1.9} \cdot N_v \cdot N_d}{1024^3} + K}$$

where N_t is the number of wind turbines, N_v the number of wind speed bins, N_d the number of sectors for the energy yield and K gives an idea of the size of the project.

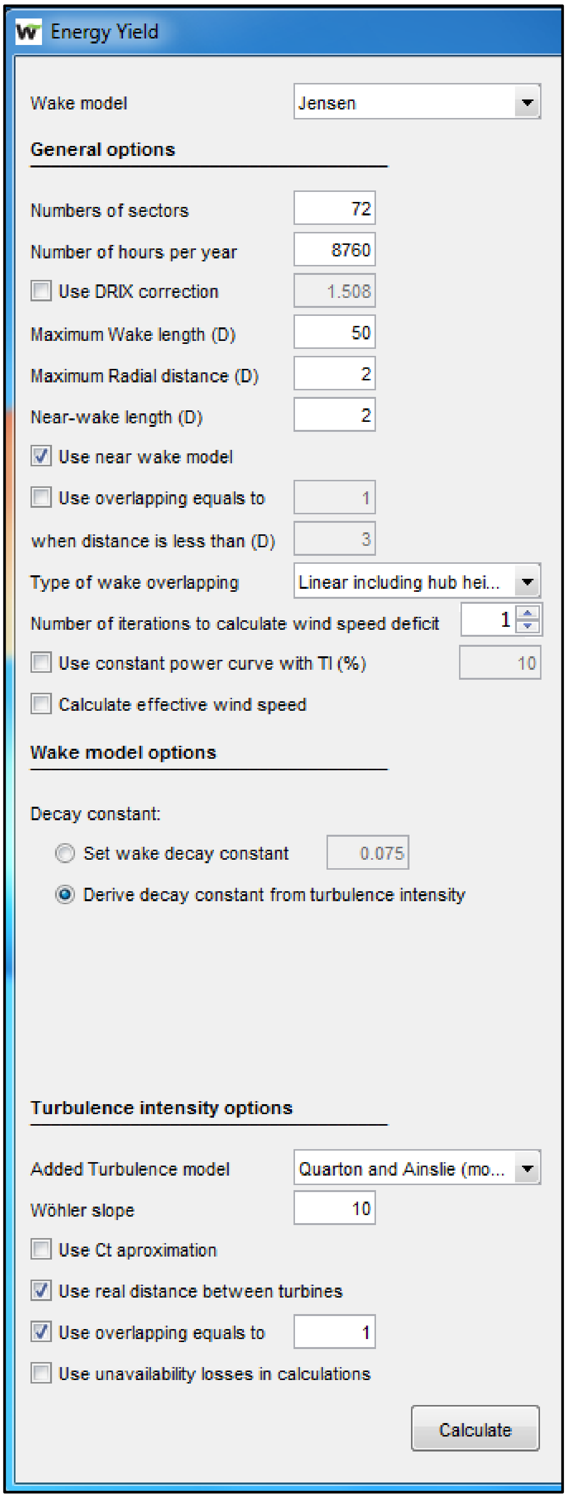


Figure 124: Energy Yield options

17.1 Energy report

After performing the Energy yield calculations, **FUROW** allows the user to generate an energy report with all energy outputs of the wind project as well as some energy roses (see Figure 125). These are the typical outputs:

1) Main parameters of every wind turbine of the wind farm
2) Results related to atmospheric parameters at each turbine position: temperature, pressure, relative humidity and air density
3) Results related to wind speed: mean free wind speed and mean wake affected wind speed
4) Results related to turbulence intensity: ambient turbulence intensity and total turbulence intensity
5) Results related to energy calculations: ideal energy, gross energy, wake losses, other losses combined, net energy, capacity factors and full load hours.

A screenshot of the report of a calculation is shown on Figure 126.

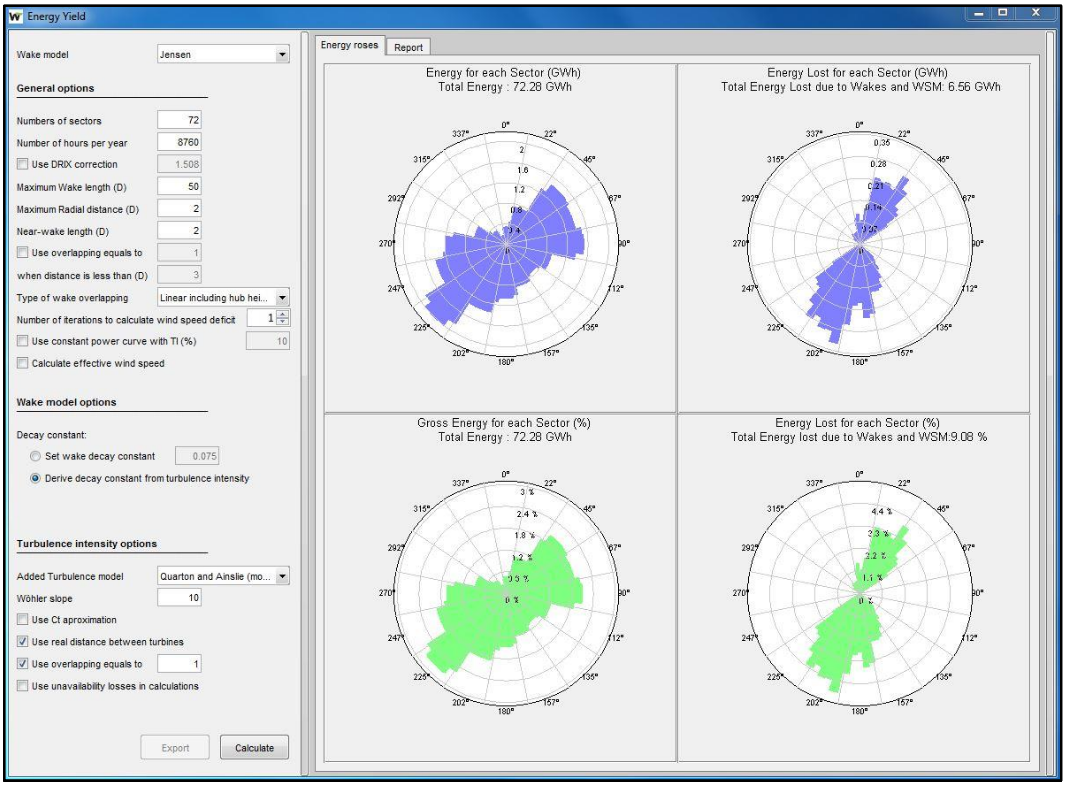


Figure 125: Example of Energy Yield Roses

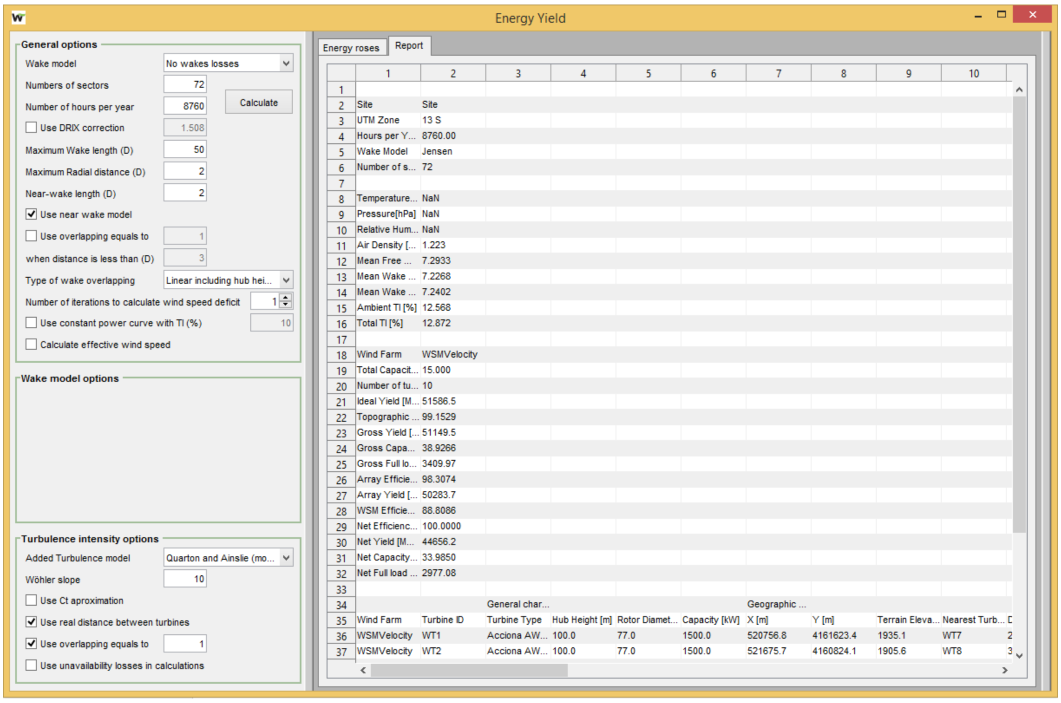


Figure 126: Example of the Energy Yield Report

17.2 Energy losses

As stated on previous sections, one of the properties of a wind farm is the *Energy Losses* (See Figure 127). These losses are taken into account when launching an Energy Yield calculation in order to provide the user with the final net values of energy production.

Potential sources of energy losses are the following:

1) Unavailability losses: from wind turbines, collection system, substation, utility grid and others.
2) Electrical losses: from wind turbine transformer, collection system, substation, transmission line, power consumption in idling mode and others.
3) Turbine performance losses: power curve adjustment, inflow angle, wind shear, high wind control hysteresis, yaw misalignment and others.
4) Environmental losses: blade degradation, blade icing, low temperature shutdown, high temperature shutdown and others.

In the energy report, all losses are combined to yield a Net Efficiency value.

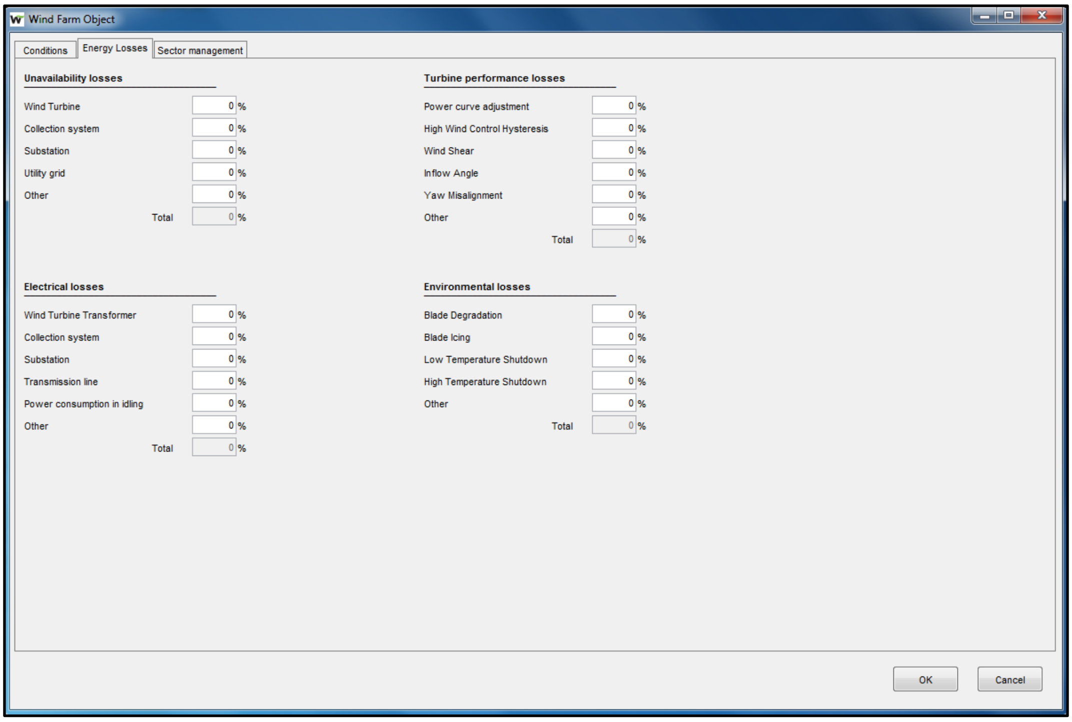


Figure 127: Energy losses tab

17.3 Sector management

Within the WIND FARM object options, there is a tab where it is possible to manually implement a wind sector management strategy to stop wind turbines for certain wind speed and direction ranges. Several strategies can be added for every wind turbine (one by one), but it is also possible to visualize all strategies within the same table (see Figure 128). If any of the strategies wants to be deleted, it is also possible to perform this option either one by one (removing from last to first for each turbine) or all strategies at the same time. In order to ease the process, the options of copying and pasting all the shown strategies has been enabled.

For preliminary calculations, also a constant value of losses can be added. This constant value is applied to all wind turbines as another efficiency.

It must be remarked that on this version, the user can enter hysteresis values for wind direction and wind speed to take into account the time the wind turbine is stopped on these hysteresis intervals (by default in **FUROW** it is assumed as 50% of the time).

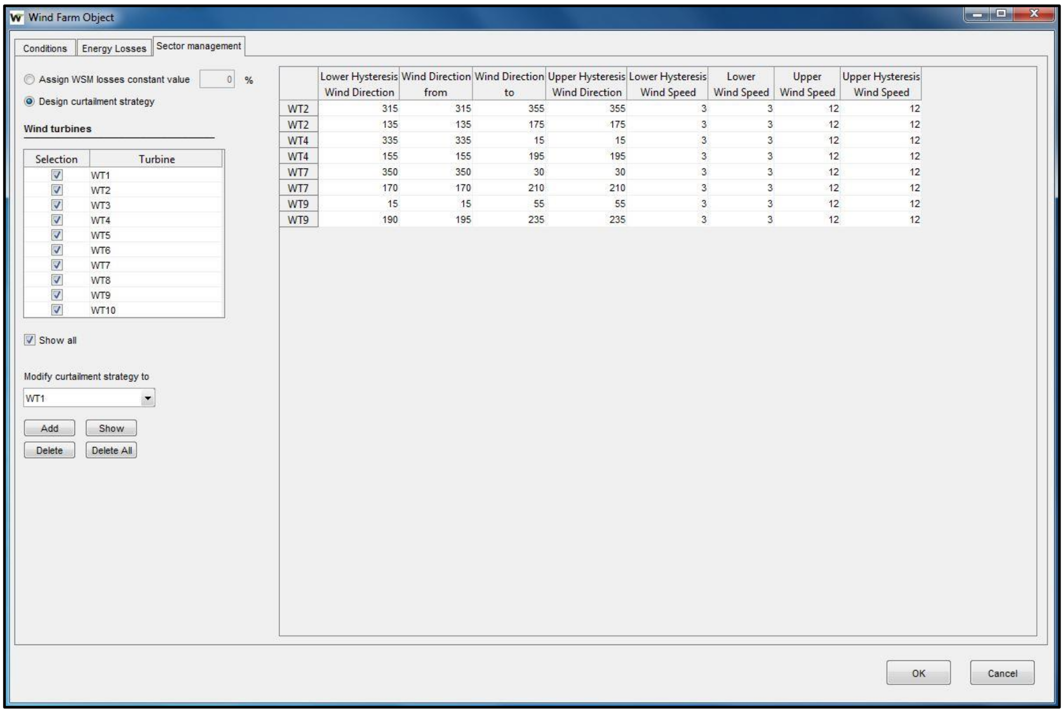


Figure 128: Wind Sector management tab

Additionally, a “*Show*” button has been added which allows visualizing the wind sector management strategies rose. The color code is the following: green indicates that turbine is ON, light brown indicates the HYSTERESIS intervals and red indicates that the turbine is OFF (see Figure 129).

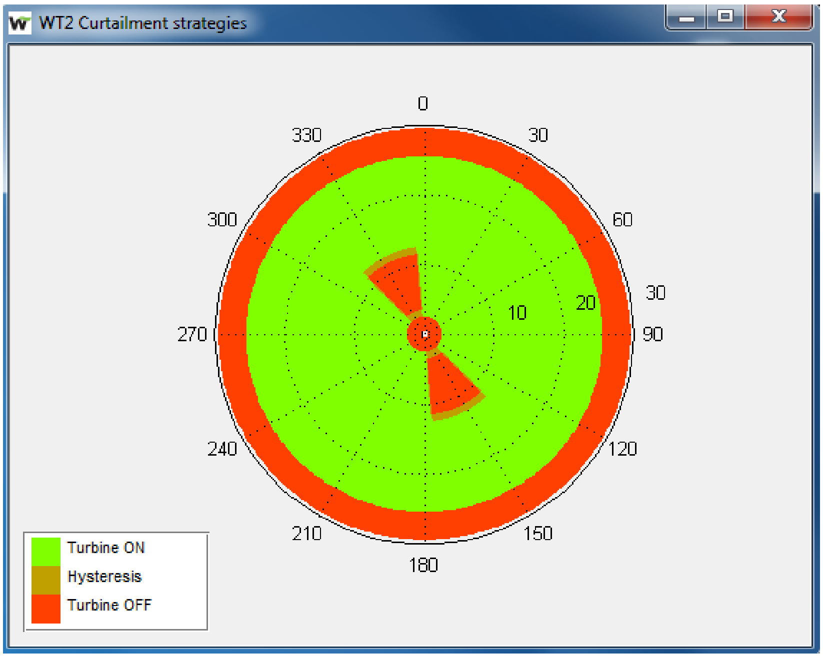


Figure 129: Wind Sector management strategies rose

Any strategy can also be modified graphically by the user by right clicking with the mouse on top of the table of strategies provided one of the cells corresponding to any strategy is marked. A rose like the one showed on Figure 130 is shown and by dragging the two black dotes wind direction and speed intervals can be modified.

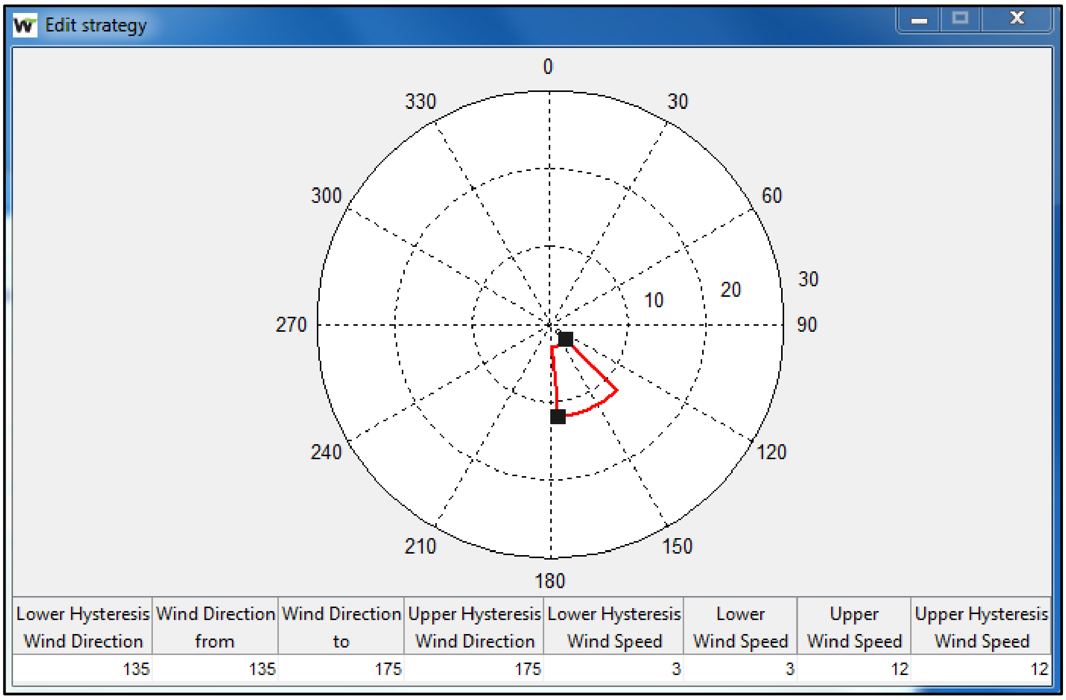


Figure 130: Module to edit curtailment strategy

18 Optimizer

The optimizer launches multiple Energy Yield calculations and uses these to find the optimal position of the given wind turbines maximizing the annual energy production of the wind farm. The user must thus select a CLIMA object with met mast statistics, a WIND RESOURCE object, and a WIND FARM object. The WIND FARM object is used to define the initial seed for the random search that is used to optimize the wind turbine positions.

Upon selecting the *"Optimizer"* option from the Micro-siting menu, the optimizer window in opens.

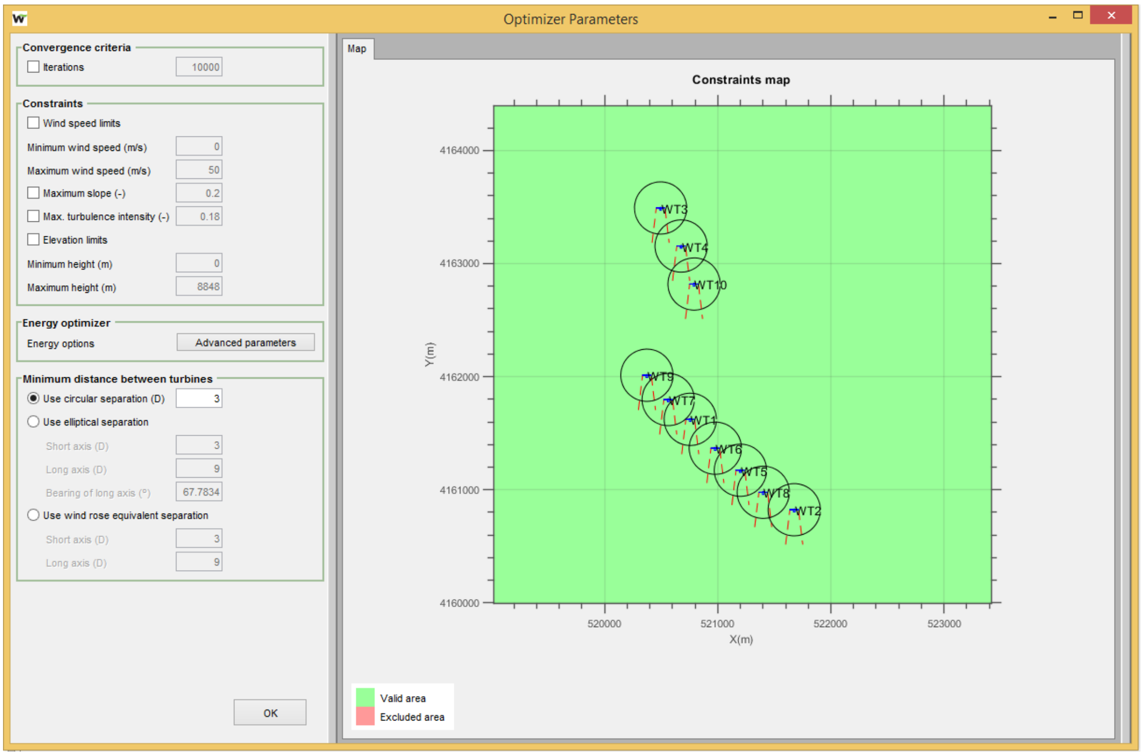


Figure 131: Optimizer options window

In this window, the following convergence criteria options can be modified:

- **Iterations:** this can be left unchecked for the optimizer to continue iterating until convergence, or it can be checked and the number of iterations can be defined.

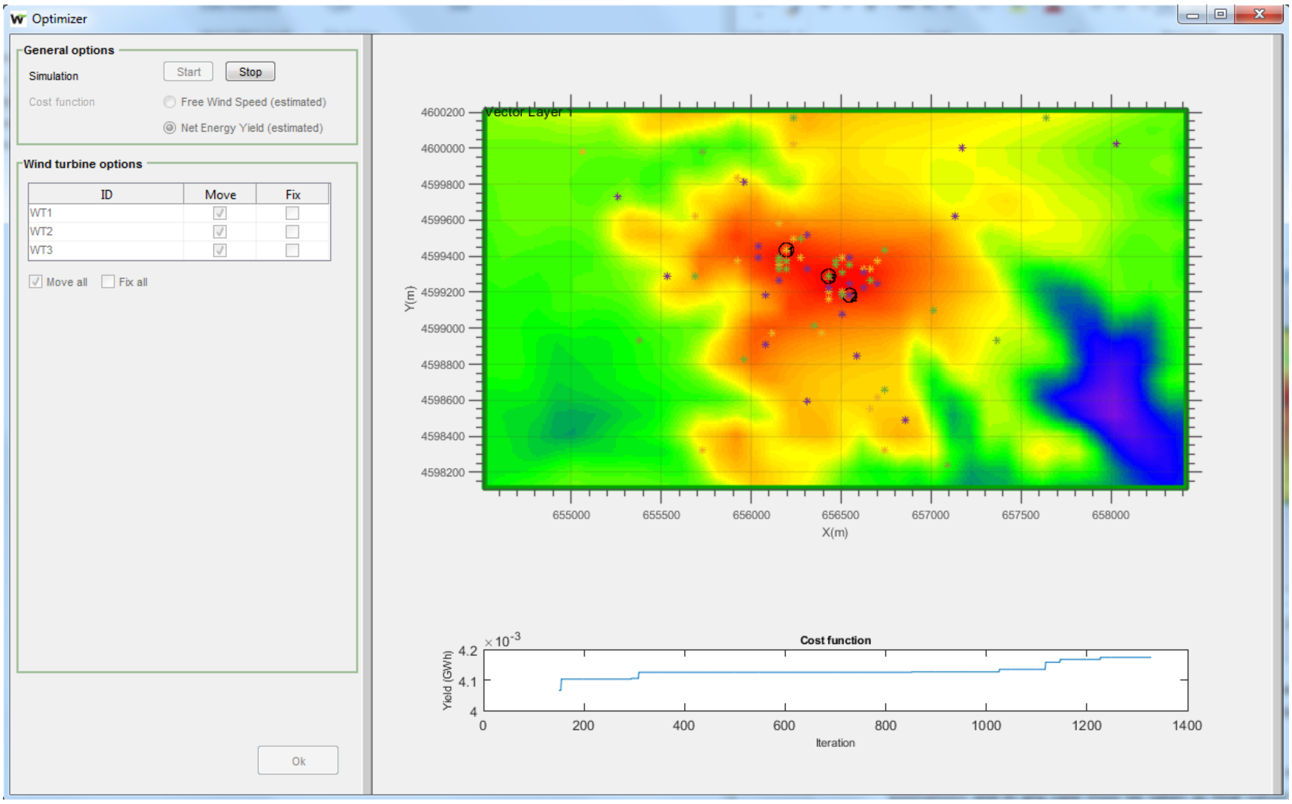
Various constraints can also be modified, ensuring that no wind turbine is placed in an area where the local characteristics are outside of the acceptable range of parameters:

- **Wind speed limits**
- **Maximum slope**
- **Maximum turbulence intensity**
- **Elevation limits**

Upon clicking the "*Advanced parameters*" button, the Energy Yield options can be modified. A description of these options may be found in Section 17.

The lower panel contains options related with turbine separation constraints, namely: circular, elliptical and wind rose equivalent separation, ordered by increasing complexity.

Once the options have been set, the next window opens a new dialog once the necessary information has been computed. Among these calculations performed in this preprocessing, wakes and geometric relations are included.



The user is freely to choose between free wind speed or net energy yield optimization. Both are estimations and, in any case, must not be taken as final values, but illustrative ones. The final values must be computed by the specific module provided by FUROW: energy yield. Also, one or several turbines can be fixed and omitted from the search for new positions, but it will affect optimization results.

It is possible to place a turbine in an unavailable position If the user wants to place a turbine in an unavailable position if it is considered as a fixed turbine by the user.

During the simulation the cost function (depending the selected case free wind speed or energy production) is represented in the bottom part of the window as a function of the iterations.

19 Uncertainty analysis

After performing the Energy Yield calculation, at this module, wind uncertainties (applied directly to wind speed and direction) and wind farm uncertainties (applied directly to energy assessment) are inserted by the user, and finally, combined values of uncertainty of wind speed and energy production for each concept are shown. It is important to remark that future wind speed variability for any number of years can be defined by the user or can be calculated.

Results of historical uncertainty, future uncertainties and plant uncertainties are combined on the Results tab to obtain the total uncertainty for 1 year and N years. Conversion to energy uncertainties are calculated through the *"Sensitivity Factor"* directly calculated or defined by the user.

As a result of all calculations, the energy figures for different exceedance values are shown (P50, P75, P90, etc.) for different cumulative time periods so that the user can choose the appropriate for the project requirements (See Figure 132).

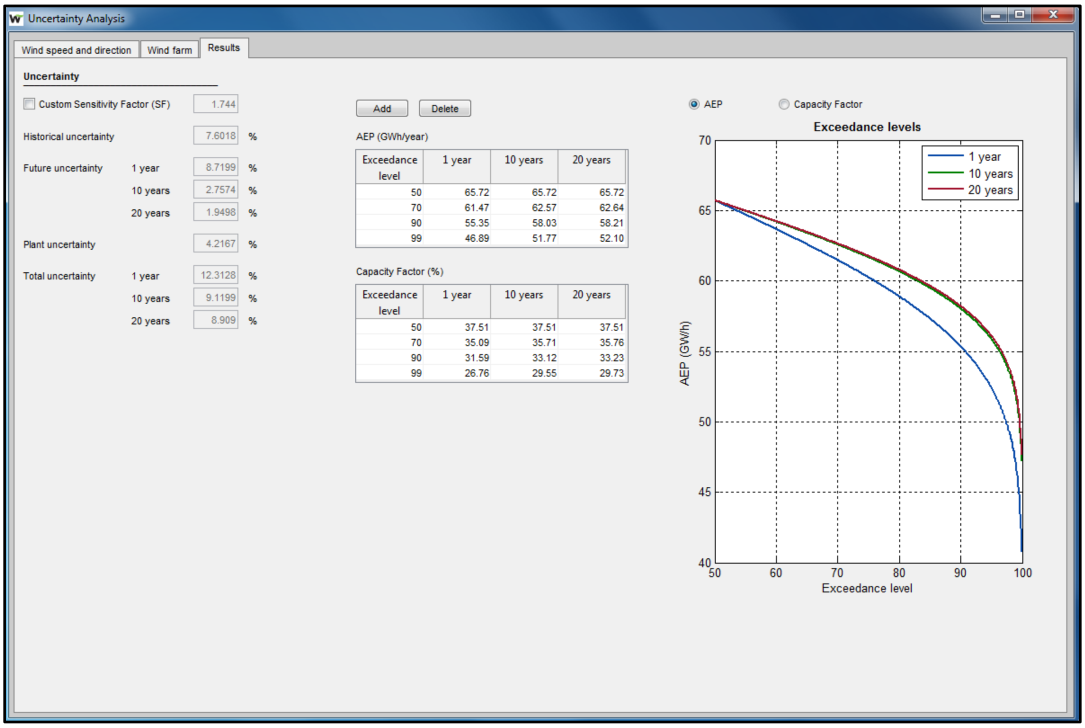


Figure 132: Uncertainty analysis window

20 Site compliance

Within the Micro-siting menu, it is possible to evaluate the IEC parameters to check the class and subclass for each position of the wind farm provided a CLIMA object, a WIND FARM object and a WIND RESOURCE object are selected. If the extreme wind speed wants to be analyzed it is necessary that the ExtremeWind map is selected under the WIND RESOURCE object.

For the moment, the following parameters are checked at every position:

1) Wind speed distribution (plus Weibull parameters)
2) Mean wind speed (V_{ave})
3) Extreme wind speed (V_{ref}, V_{e50})
4) Turbulence intensity (ambient, characteristic/representative, effective)
5) Inflow angle
6) Alpha
7) RIX
8) Mean air density
9) Terrain complexity

For each parameter, there is a *Graph tab* and a *Table tab* where the variables or options checked on the left panel are represented. Moreover, the Report tab shows a summary of all design parameters for every wind turbine.

Depending of each parameter, there are *"Advanced options"* which can be chosen such as the IEC Edition and the conditions of the incident wind speed (free conditions, without WSM strategies and with WSM strategies). In this version it is also possible to assign the wind turbine conditions in order to show frequencies and effective turbulence intensity depending if the wind turbine is in idling (wind turbine is stopped) or operative conditions. All calculations are always compared with the values recommended on the standards.

For the average wind speed calculation, it is possible to show the effective wind speed for all wind turbine positions provided this value has been calculated on the Energy Yield module.

On Figure 133 the graph of the effective turbulence intensity and IEC 3rd Edition Amendment for 3 wind turbine positions is shown.

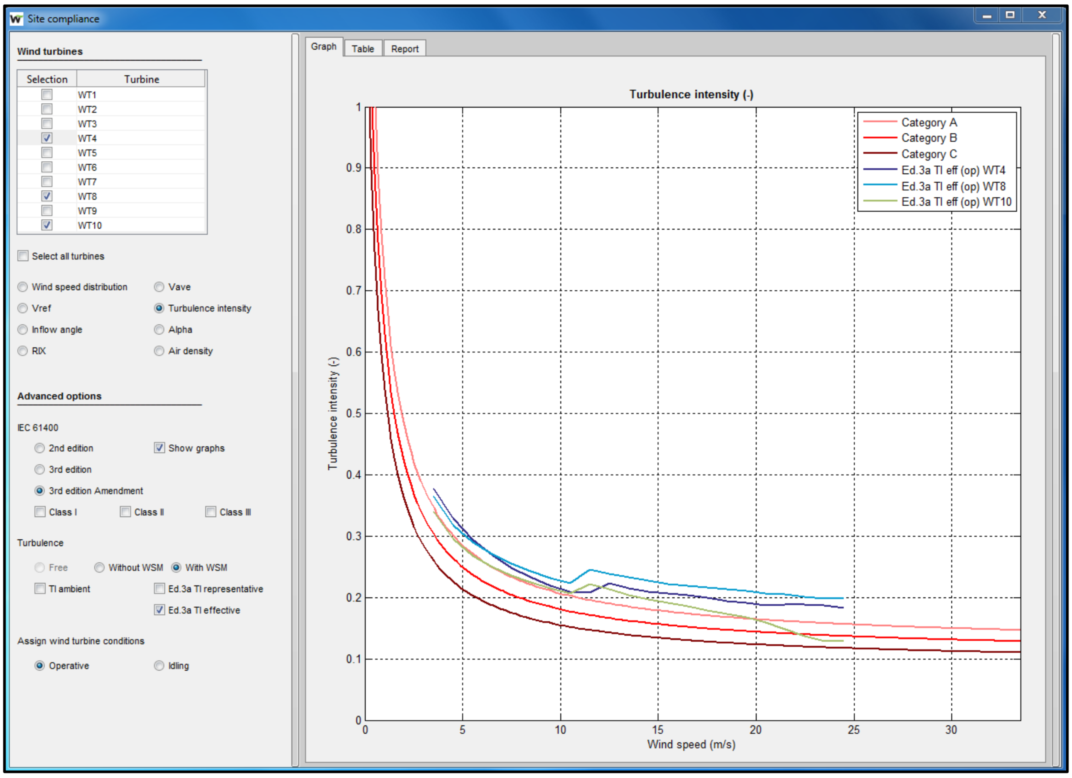


Figure 133: Site Compliance menu

21 Wind farm power curve

A wind farm power curve indicates the power level of a given wind farm for every wind speed and direction measured at any point of the site and considering the mean air density at each wind turbine. By default, the wind farm power curve is calculated at the met mast position, but it is possible to select any other grid point of the wind grid to obtain this curve (See Figure 134). When calculating the power curve, it is possible to check or uncheck the option *"Use electrical losses"* which includes for every bin and direction the reduction of power due to electrical losses in accordance to the losses set for the wind farm.

The default resolution for wind speed and for wind direction is derived from the bin size in the CLIMA objects and the number of sectors used in the Energy Yield calculations (usually 72 sectors or 5º). However, the user can use any other resolution to obtain a finer output.

Once the wind farm power curve is calculated, the results can be exported to a table format under the Report tab.

Finally, from this module it is possible to obtain a time series of the energy production including wakes and also with electrical losses. For this purpose, it is necessary to select the wind speed, wind direction and air density channels at the CLIMA object position and height. Then, the power production channel is generated at the Results panel (which is hidden on the right of the dialogue by default). If the point where to calculate the power curve is not the same as the wind data location, then the power production channel will not be generated. The power production channel can be exported to the tree structure.

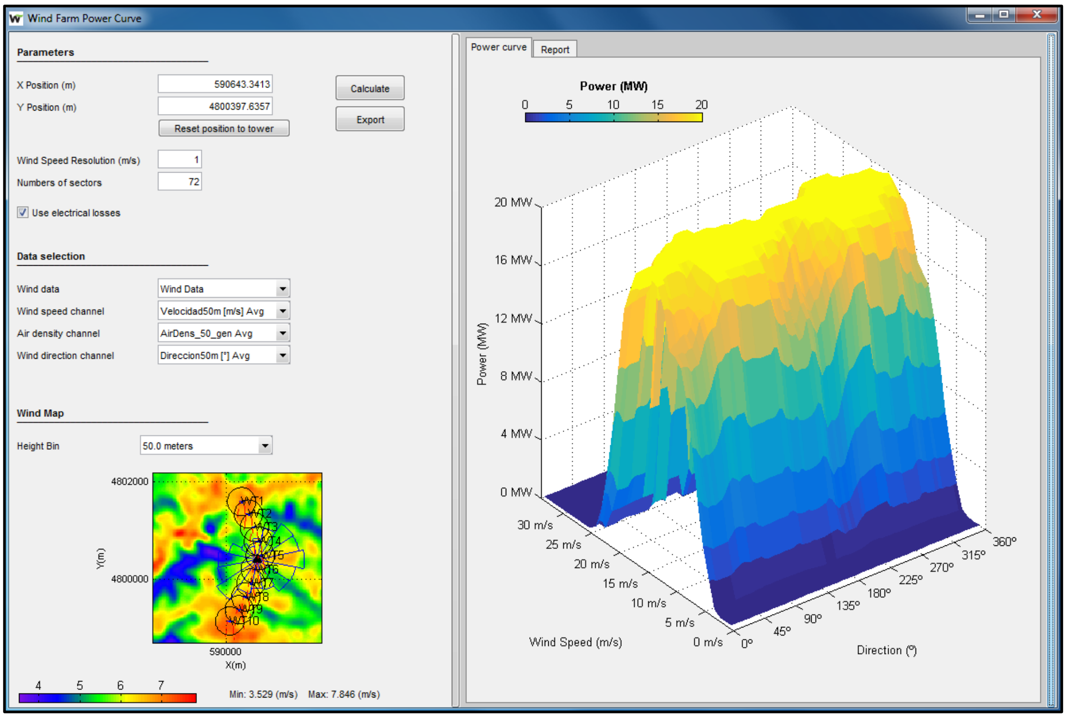


Figure 134: Wind farm power curve window

22 Site distortion

This module allows the calculation of wind speed deficits and added turbulence at any point of the site when the point is affected by wakes at any wind direction. The user can select any of the wake models described on previous sections.

This module is very useful when there are measurements of a mast which are being affected by some of the wakes generated by wind turbines in front for some wind directions. Numerical results are shown on the first two tabs (See Figure 135) and graphical results on the third and fourth tab (See Figure 136). In this case, no channel of wind speed standard deviation is available, but the same results are shown in terms of turbulence when available.

For this module, the position of the "hypothetical target met mast" where the wind data had been measured must be set; the wake model and the turbulence model with their options must be selected; the number of sectors for calculating the deficits and the added turbulence must be indicated; and the wind data channels available must be selected.

Finally, on the Results panel (which is hidden on the right of the dialogue by default), the corrected time series of wind speed and standard deviation are calculated and can be exported as new channels, already "cleaned" from wake effects and thus representing the free conditions.

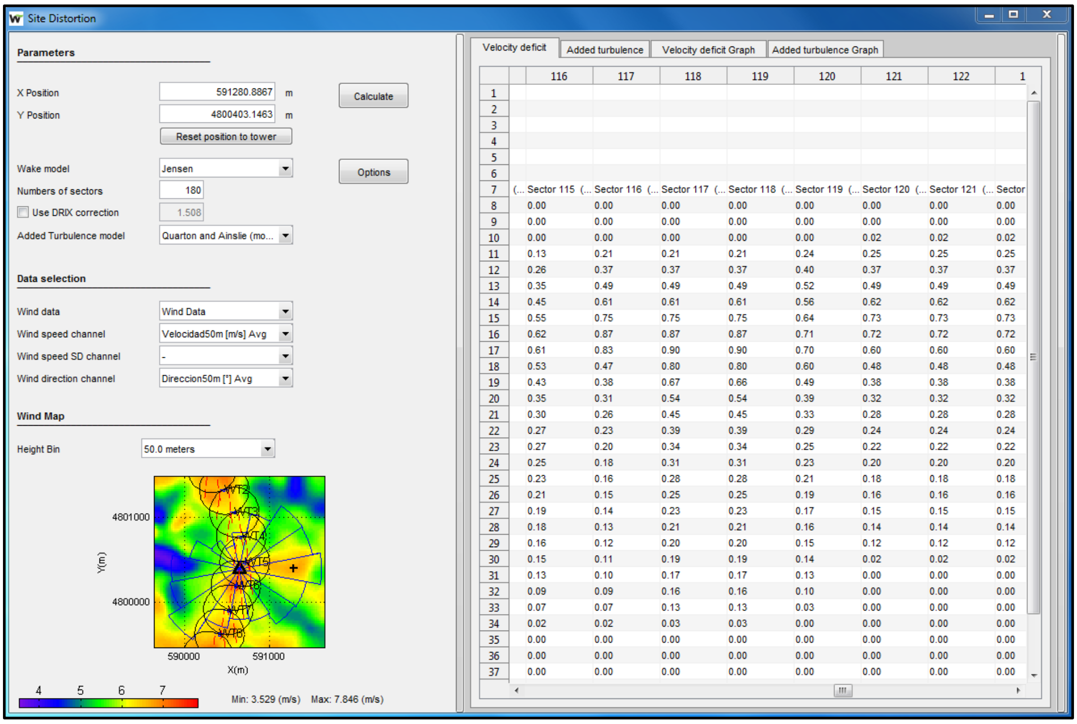


Figure 135: Site distortion window with numerical results

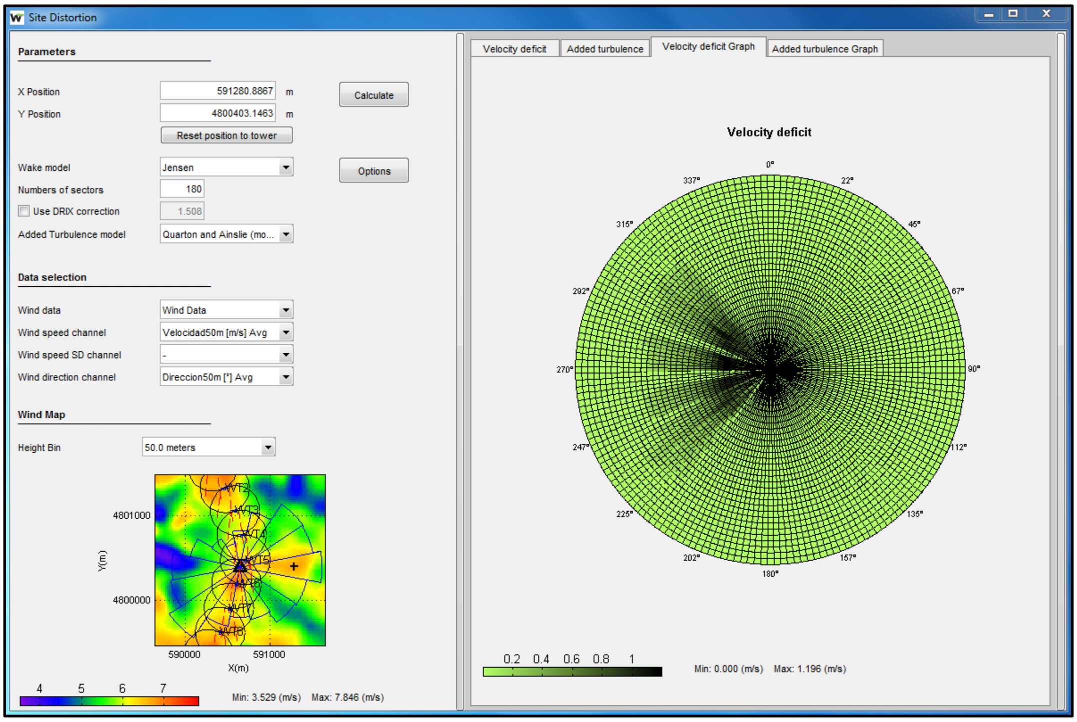


Figure 136: Site distortion window with graphical results

23 Noise analysis

This module allows the calculation of noise levels around the whole wind farm area due to the turbine operation. In order to learn about the formulation applied, please refer to the ***Theory Manual***. There are several parameters, options and models which can be modified to carry out the noise calculations.

The noise can be calculated at dwelling positions which are interpreted as points at a certain reference height and with noise limits determined by the local regulations (see Figure 137).

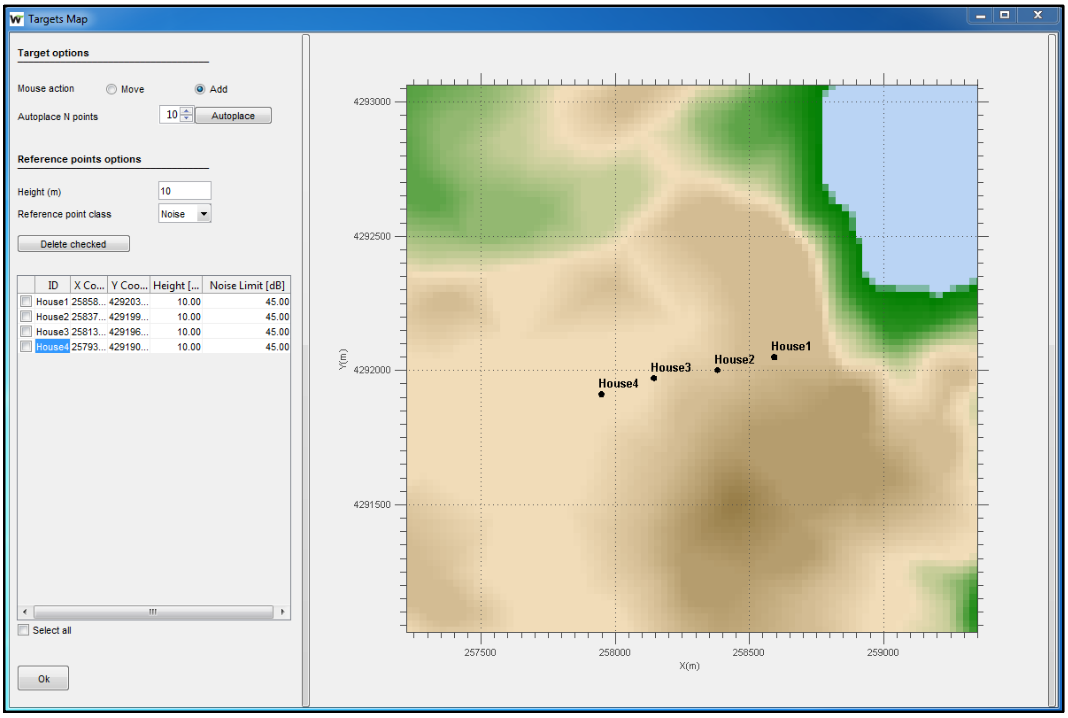


Figure 137: Targets map

For calculations of the noise map the user must select the Representation height (which will usually be the typical height of the dwellings) and the maximum distance to be mapped (by default 3000m). Additionally, the Atmospheric parameters should be selected as they will be used to calculate the absorption coefficients. However, wind speed will determine the turbine sound power level.

As for the model options, a default sound power level of the wind turbine can be selected. When octave bands are not known, the recommended calculation model should be the one with *Fixed frequency 500Hz*. Another parameter is the Ground porosity which is different for the source (wind turbine), receptor (dwellings) and middle region. Porosities close to 0 imply hard ground, whereas those values close to 1 indicate very porous ground. The ground attenuation model is the general one described on the ISO 9613-2, but the so-called alternative is also available.

Finally, in order to modify the attenuation of sound, the absorption coefficients can be defined. Those coefficients could be user defined or derived from the atmospheric conditions. Other miscellaneous coefficients related to foliage, industrial site and housing can be included on the calculations.

Once all parameters have been defined, the user can run the Noise model by clicking on Calculate button. As a result of this calculation a raster map at a given height is obtained and a report with the noise at the different target points is provided. The noise map can be exported as a raster layer under the WIND FARM object in the tree structure.

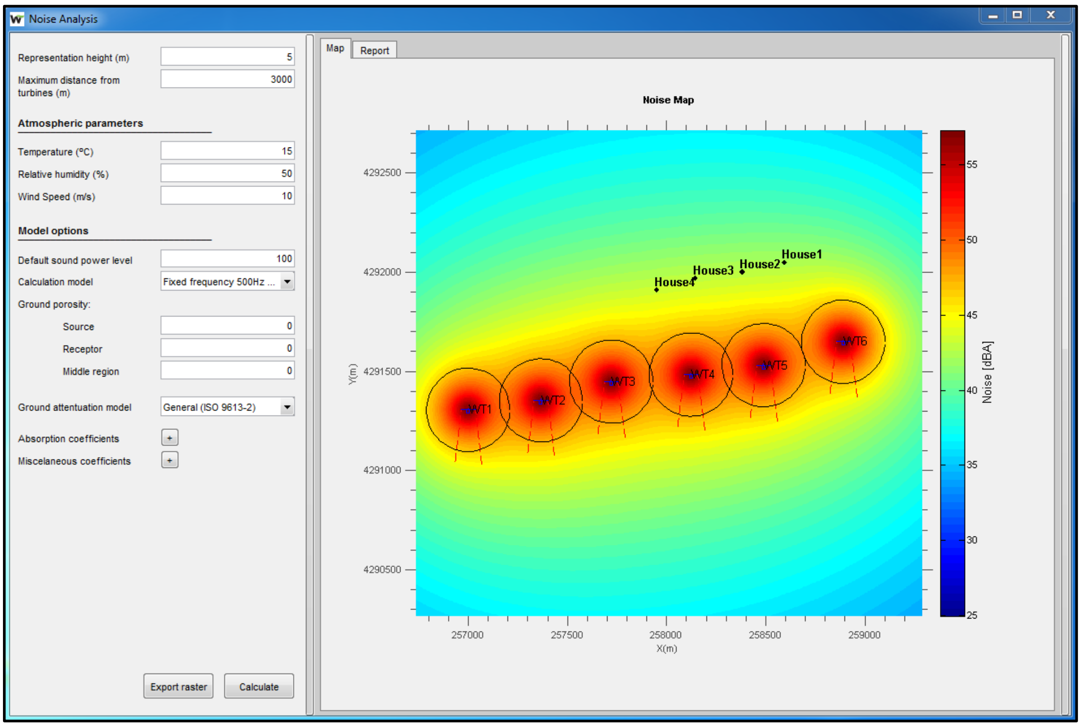


Figure 138: Noise module

24 Shadow flicker analysis

This module allows the calculation of a shadow flicker map around the whole wind farm area and/or on a target point map previously selected. In order to calculate the shadow flicker due to the turbine operation a grid container, a clima object and a wind farm must be selected, additionally a shadow target point map can be selected. When shadow target points are created is possible to set up the azimuth and tilt of each target point in order to provide more information about the orientation of them.

For calculations of the shadow flicker the user must select the representation height, the maximum distance to be mapped from the each turbine position or from the center of the wind farm, the minimum sun angle elevation over the horizon (from which shadows are considered to exist), calculation time step and the UTC time offset of the placement (is very important that this Offset matches with the temporal series used in the calculations).

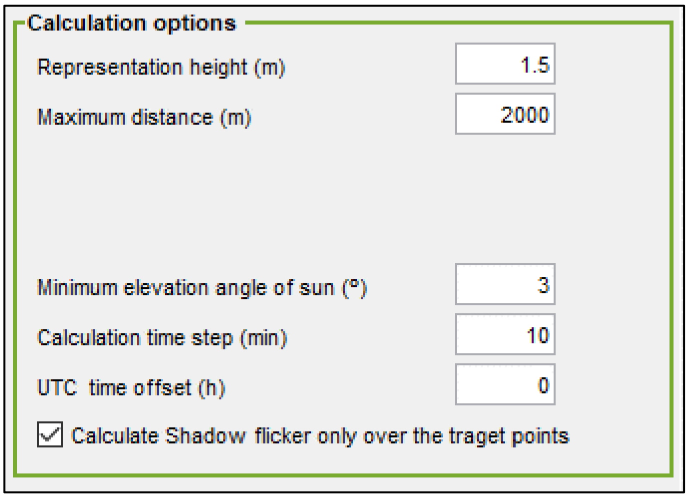


Figure 139: Shadow Flicker calculation options

There are two calculations models:

- **Worst Case:** in this case the turbine is always oriented towards the receptor, working and there are never clouds that cover the sun. This model will provide the maximum Shadow Flicker hours that could be in each point.
- **Real case:** in this case there are multiple options, wind speed and direction series during a period of one year or statistical distributions for each month of the year, could be used. In the first case, it will be obtained a shadow flicker map that match with the one year data selected and corrected with the monthly clouds frequency provided by the user.
  In the second case, the *worst case* is corrected with the clima object or a distribution user's provided wind direction distribution, a monthly working frequency provided by the user and the sunshine percentage for each month (clear sky enough to cast shadows).

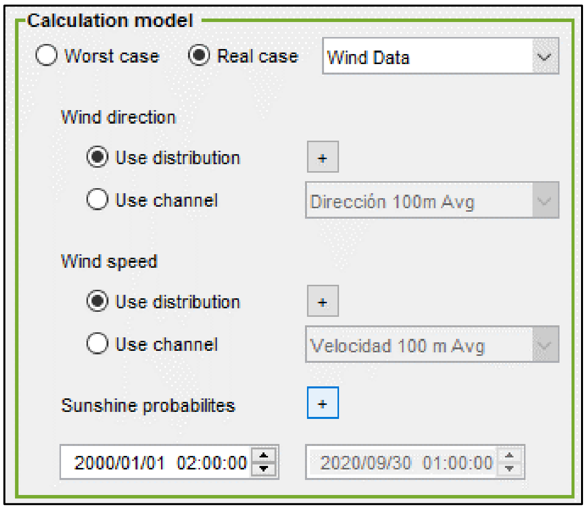


Figure 140: Shadow flicker calculation model

Finally, if a shadow target point map has been included, the option that allows to calculate the shadow flicker over these points can be selected (in order to improve the calculate speed) and chose the target point that it will be visualized in the representation panel.

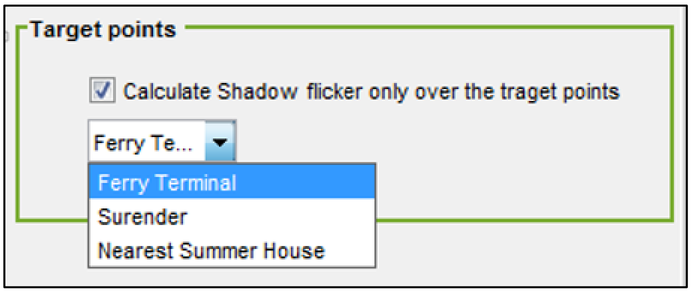


Figure 141: Shadow flicker target points options

This module uses a solar algorithm that calculate the sun position in function of the latitude and longitude of the clima object and the date and hour in each moment along one year. This algorithm returns a vector that point at the sun from any point of map or target point. By trigonometric checks is possible to detect if this vector intercept with the turbine action sphere and so, it can be determinate if exist the possibility that shadow flicker happen (Worst case).

Moreover, this data could be corrected by the orientation frequency of the turbine that intercept the sun beam, by the working status and the possibility that there are clouds (Real case). If time series are available it can check if in this moment exist de shadow flicker possibility, checking if the turbine is oriented in this direction and if is working (Real case).

During this process additional information about the target points will be saved in order to obtain a report more detailed in each point.

The module gives back some results:

- **Shadow Flicker map:** a mapfor the selected calculate area that represents the number of hours that shadow flicker is produced. This map is not calculated if the *Calculate Shadow flicker only over the target* check box is selected. It is possible to export the shadow flicker map as a raster map.

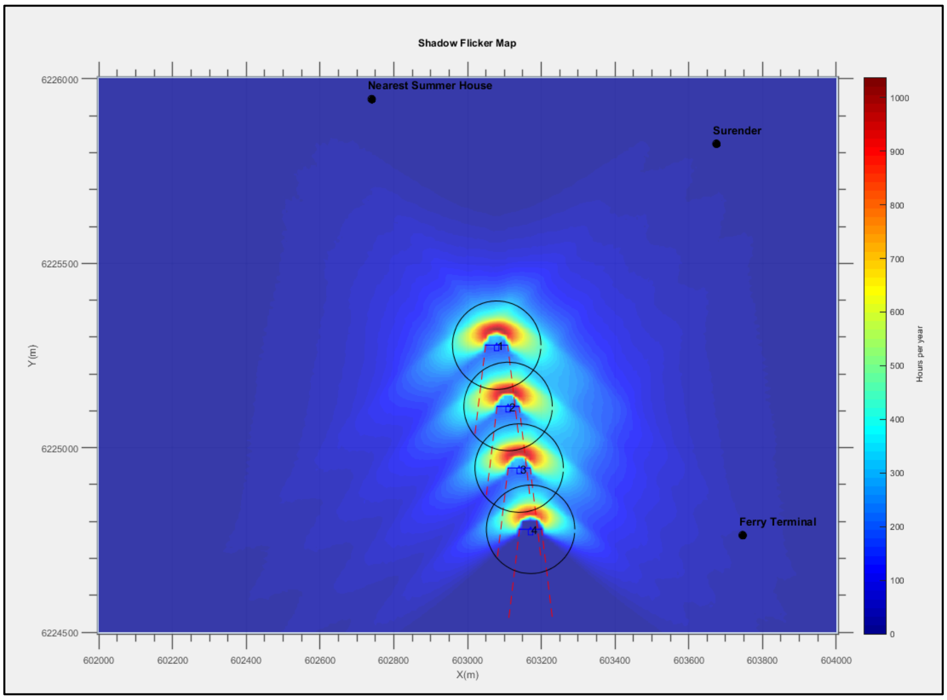


Figure 142: Shadow flicker map

- **Summary report:** It is provided a summary of the shadow flicker means at each target point included in the study.

Point ID	X [m]	Y [m]	Shadow Flicker Limit [h]	Height [m]	Shadow Flicker hours [h]	Maximun daily flicker [min]	Day maximun flicker
Ferry Terminal	603736.0	6224753.0	30.00	0.00	30.20	24.0	Apr-04
Surender	603665.0	6225814.0	30.00	10.10	7.97	14.0	Jan-28
Nearest Summer House	602730.0	6225935.0	30.00	10.00	0.00	0.0	-

Figure 143: Shadow flicker summary report

- **Advanced Report:** It is provided information day by day about solar geometry (hour of sunrise and sunset each day regarding with the UTC given). Furthermore, if a shadow target point map is included, it will be provide information about the shadow flicker duration and the first and last moment of shadow flicker of each day and the turbine that produce them for each target point.

	January	February	March	April			May		
Day									
1	07:59	07:21	06:17	04:55		17:08 (4)	03:41		17:56 (3)
	14:44	15:39	16:41	17:46	16	17:24 (4)	18:47	19	18:15 (3)
2	07:59	07:19	06:14	04:52		17:07 (4)	03:39		17:56 (3)
	14:45	15:42	16:44	17:48	20	17:27 (4)	18:49	18	18:14 (3)
3	07:58	07:17	06:12	04:50		17:07 (4)	03:37		17:58 (3)
	14:46	15:44	16:46	17:50	22	17:29 (4)	18:51	15	18:13 (3)
4	07:58	07:15	06:09	04:47		17:07 (4)	03:34		17:59 (3)
	14:47	15:46	16:48	17:52	24	17:31 (4)	18:53	12	18:11 (3)
5	07:57	07:13	06:06	04:45		17:06 (4)	03:32		18:02 (3)
	14:49	15:48	16:50	17:54	24	17:30 (4)	18:55	6	18:08 (3)
6	07:57	07:11	06:04	04:42		17:06 (4)	03:30		
	14:50	15:51	16:52	17:56	24	17:30 (4)	18:57		
7	07:56	07:09	06:01	04:39		17:07 (4)	03:28		
	14:52	15:53	16:54	17:58	22	17:29 (4)	18:59		
8	07:55	07:07	05:59	04:37		17:06 (4)	03:26		
	14:53	15:55	16:56	18:00	21	17:27 (4)	19:01		
9	07:55	07:05	05:56	04:34		17:08 (4)	03:24		
	14:55	15:57	16:58	18:02	18	17:26 (4)	19:03		
10	07:54	07:03	05:53	04:32		17:09 (4)	03:22		
	14:56	15:59	17:01	18:04	16	17:25 (4)	19:05		

Potential sun hours	229	260	359	419	498	518
Total, worst case (min)	0	0	33	386	310	273

Figure 144: Shadow flicker advance report

- **Shadow calendar:** A graphic calendar of sunrise and sunset along with the shadow flicker moments and the turbine that produce them in each moment is calculated for each target point.

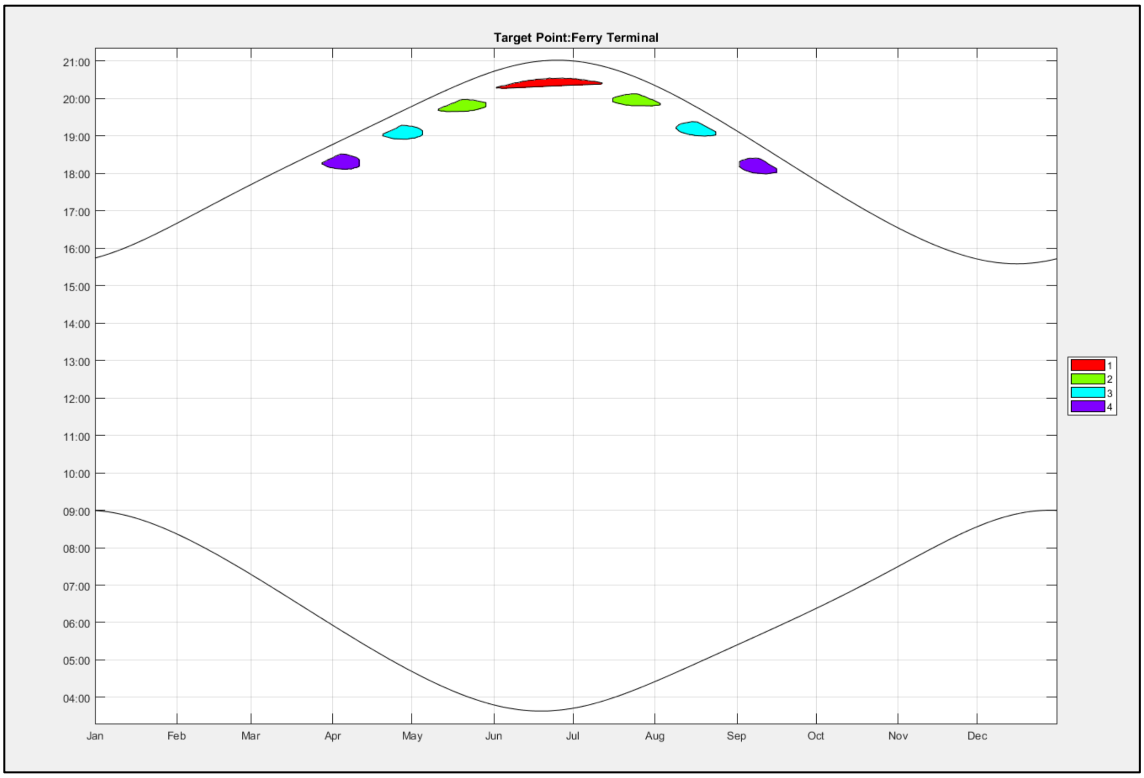


Figure 145: Shadow flicker calendar

25 Financial analysis

On this new module of **FUROW** the user will be capable of making a full financial assessment of the wind farm which is being developed in order to determine its future economic viability as well as the profitability of the project and shareholders.

In order to be able to run the *Financial Analysis* module under the *Micrositing* menu a WIND FARM object must be selected. It is a condition that the Energy Yield has been run in advance in order to be able to calculate the future revenues of the wind farm.

Once the module is opened, then 5 tabs show up. The first four must be filled with inputs whereas the last one shows the results. A description of each one of them is presented:

1) Project assumptions

On this tab, the main project figures and production figures are included. Some of them are internally defined such as the number of turbines, wind farm capacity and energy yield. The other parameters should be defined by the user (see Figure 146).

- Project lifetime: usually will be between 20 and 30 years, but some financial figures will be calculated until one year later as project must be dismantled or sold which has an influence on the economic model.
- Currency: for the moment the user can select three different currencies such as dollar, euro or sterling pound.
- Energy rate: it is the amount paid for every MWh produced by the wind farm and it is assumed to be constant year after year, only modified by the escalation rate defined on the *Economic Assumptions* tab.
- Sale of wind farm: it represents the amount of cash to be received for the sale of the wind farm at the end of the project lifetime.
- Net energy yield P50: this is the result of the energy production calculation, typically the P50.
- Uncertainty: this figure can be taken from the "*Uncertainty Analysis*" module.
- Percentile: this refers to the probability of exceedance considered.
- Net energy yield PXX: it is the energy production figure based on previous uncertainty and probability of exceedance figures.

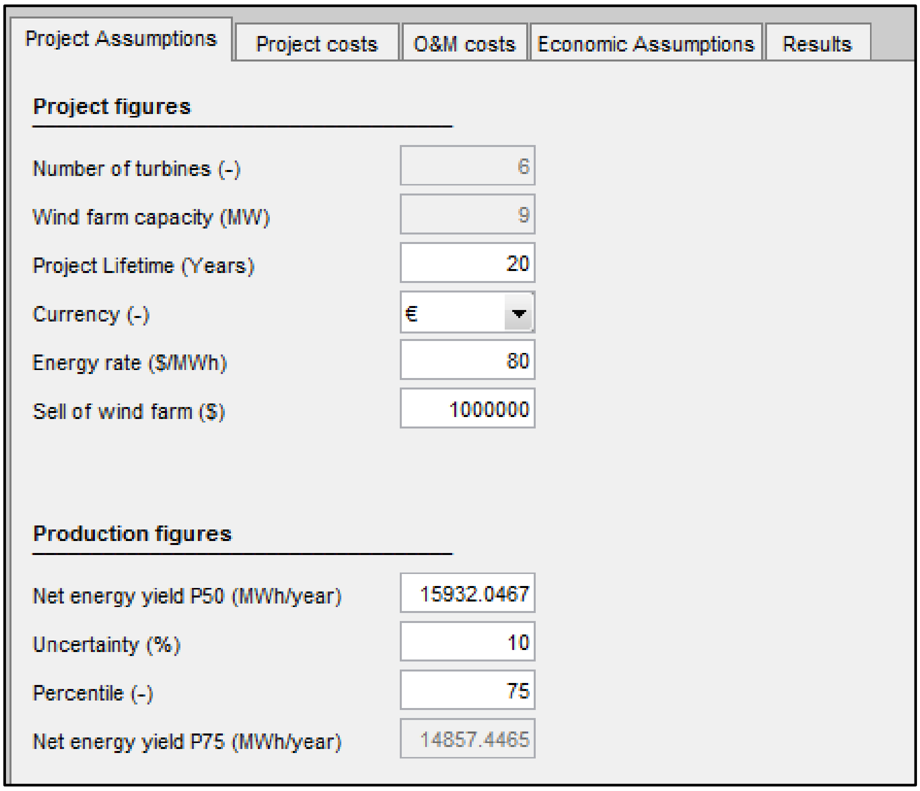


Figure 146: Project assumptions tab

2) Project costs

This is the part where the user includes all the costs involved in the project. They must be entered as totals for each concept. Project costs have been classified under the following concepts and further description can be seen on Figure 147:

- Wind turbines
- Transportation
- Wind turbines installation
- Wind farm mast
- Civil works
- Electrical works
- Development and engineering
- Other costs
- Working capital requirements

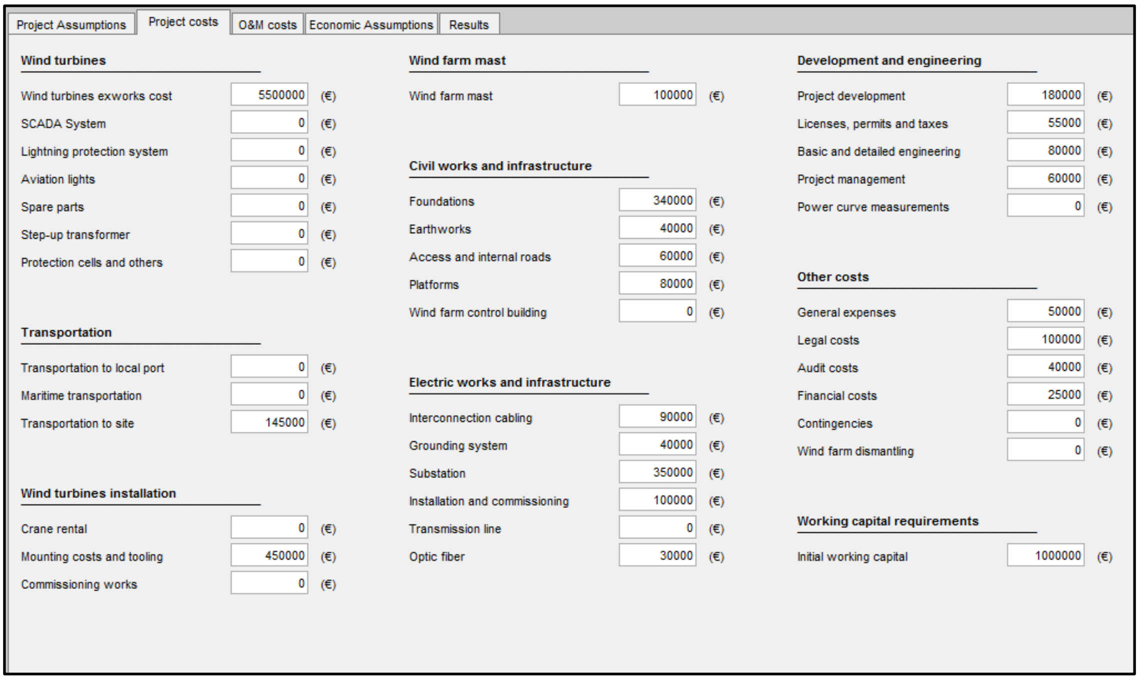


Figure 147: Project costs tab

3) O&M costs

These costs are related to the operation and maintenance of the wind farm as well as any other costs needed to incur during the project lifetime. Also warranty extension of that provided by the manufacturers is included, as well as any sort of insurance. On Figure 148 an extended list of these costs is included.

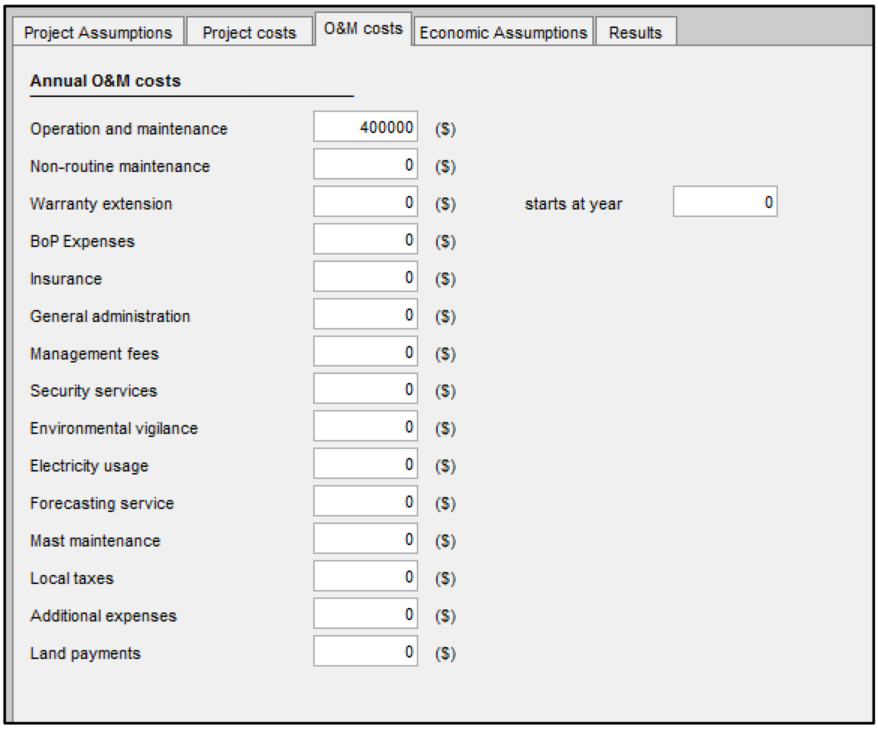


Figure 148: O&M costs tab

4) Economic Assumptions

On this tab (see Figure 149) the user must define the main economic and financial parameters to run the economic model in order to calculate the profitability of the project.

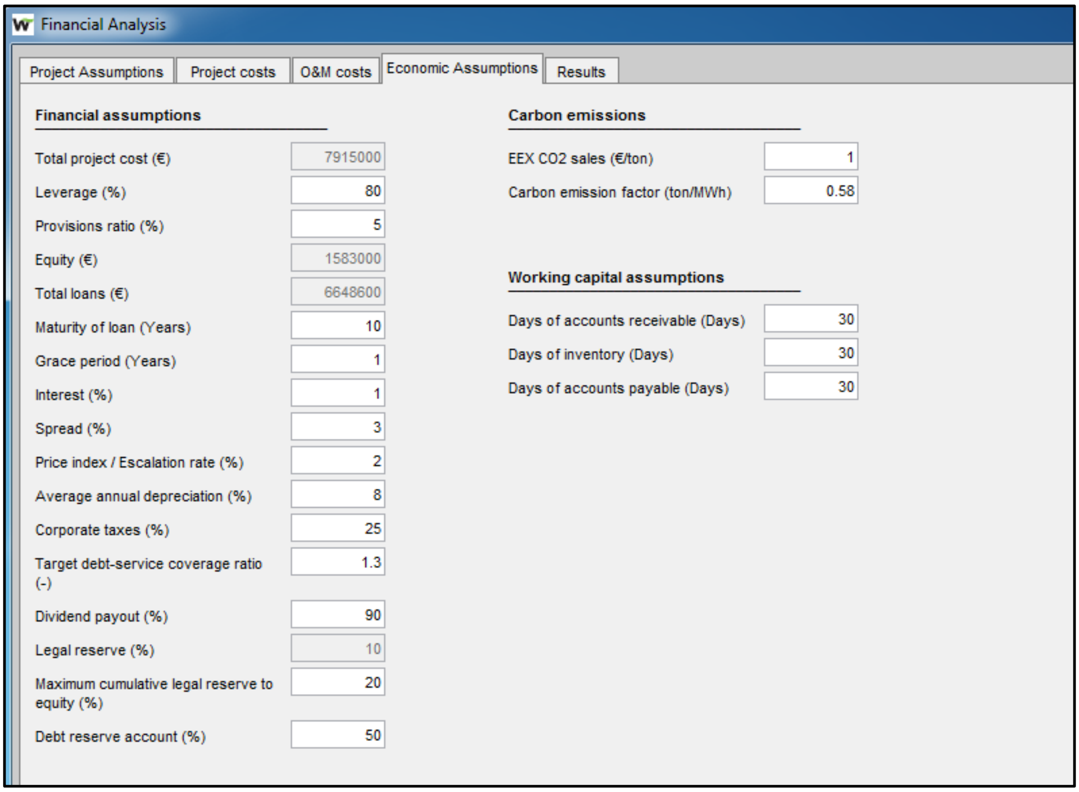


Figure 149: Economic Assumptions

The parameters are the following:

- <u>Leverage:</u> indicates percentage of borrowed funds for the development and construction of the wind farm. Usually it ranges between 60% and 80% for wind projects.
- <u>Provisions ratio:</u> this percentage increases the amount of total loans to be borrowed for the project to account for potential deviations.
- <u>Maturity of loan:</u> indicates the number of years to returns the loan
- <u>Grace period:</u> it represents the number of years during which the return of the debt will be postponed, that is, if there is a 1 it means that debt will start to be paid during the second year.
- <u>Interest:</u> it is the cost of borrowing money EURIBOR or LIBOR based
- <u>Spread:</u> it is the risk premium paid in addition to the interest
- <u>Price index / escalation rate:</u> corresponds to the inflation of the country and should be taken into account to correct the O&M costs and the price of energy.
- <u>Average annual depreciation:</u> is the annual rate at which the wind farm loses value in term of tax and accounting purposes.

- Corporate taxes: it represents the tax to be paid in the Income Statement after quantifying the earnings excluding depreciation and interest expenses. In general, if earnings are positive taxes will be paid, and the other way around.
- Target debt-service coverage ratio (DSCR): this ratio is calculated as the EBITDA divided by the total debt and represent a measure of the cash available to pay current debt obligations. In this module is just a number that will not be used, but it will be a parameter to be compared with the DSCR calculated year after year.
- Dividend payout: this is the percentage of the net income to be paid in dividends
- Legal reserve: it is the mandated minimum monetary amount that the company needs to maintain as security. Here is referred as a percentage of the net income (usually greater than 10%).
- Maximum cumulative legal reserve to equity: this percentage (which is usually a 20%) is a measure of the maximum cash retained as cumulative reserve in relation to the common equity. Thus, when this percentage is achieved, there is no need in increasing the legal reserve.
- Debt reserve account: it works as an additional security measure for lenders. It is generally a deposit which is equal to a percentage of the total debt which must kept as a deposit in the balance. A typical number for this parameter is 50%.
- EEX CO2: it is the cost per ton of CO2 paid in case carbon credits apply.
- Carbon emission factor: this is a factor which considers the number of tons saved per MWh produced.
- Days of accounts receivable: the average number of days the company takes to collect payments derived from energy sales.
- Days of inventory: measures the average number of days the company holds its inventory before selling it.
- Days of accounts payable: the average number of days the company takes to pay its bills.

5) Results

Once all necessary information has been included on the previous four tabs, then the user can go to the *Results* tab (see Figure 150) to inspect the profitability parameters such as the NPV, IRR or Payback time at a given discount rate (typically 8%). In order to perform the calculations, the user must click on the *"Calculate"* button.

This module enables the user to save economic projects as a **.fin** file in such a way that, whenever a new analysis wants to be done, all figures can be loaded back into the project through the "*Load*" button.

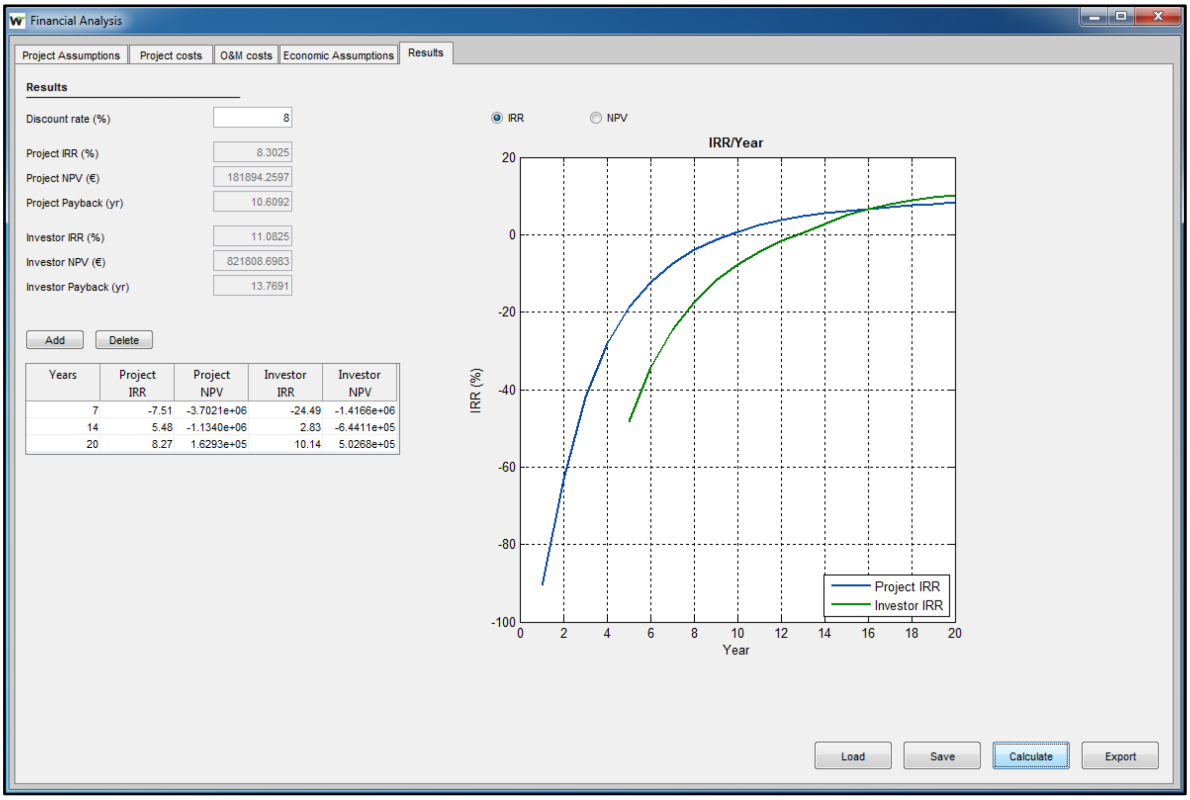
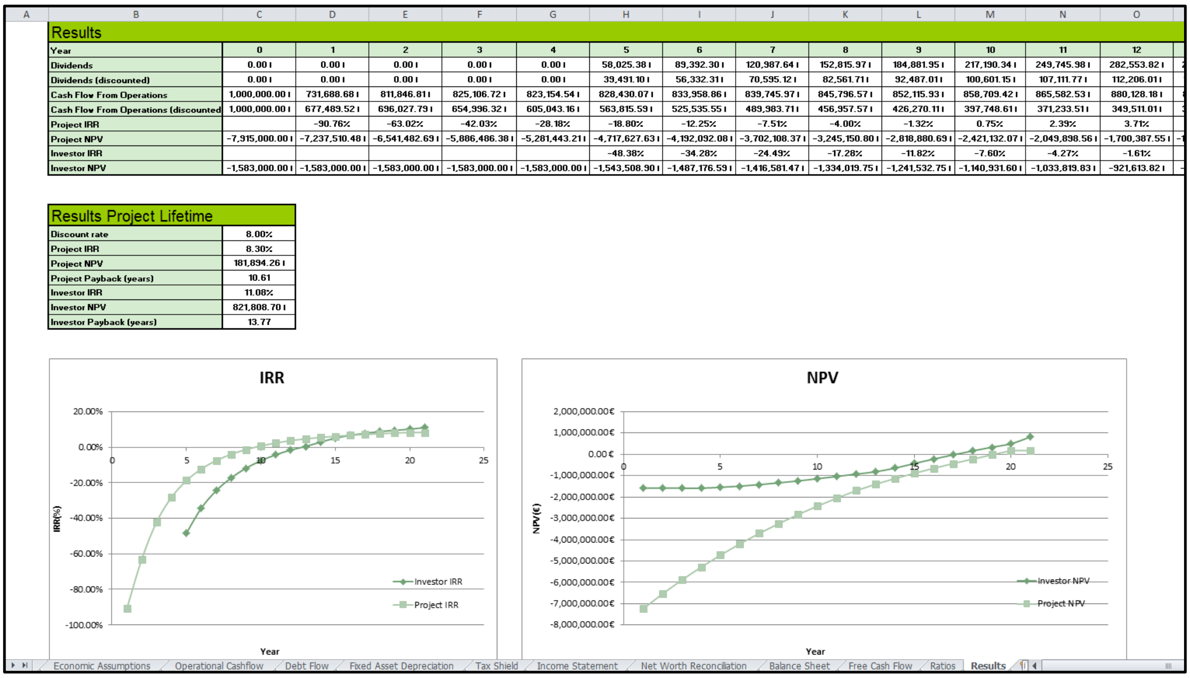


Figure 150: Results tab

Finally, a full detailed financial report can be generated on **.xlsx** format by clicking on the "Export" button. Different sheets with the input data, debt flow, operational cashflow, balance sheet, income statement and others are presented on this report.



Results													
Year	0	1	2	3	4	5	6	7	8	9	10	11	12
Dividends	0.00	0.00	0.00	0.00	0.00	58,025.38	89,392.30	120,987.64	152,815.97	184,881.95	217,190.34	249,745.98	282,553.82
Dividends (discounted)	0.00	0.00	0.00	0.00	0.00	39,491.10	56,332.31	70,595.12	82,561.71	92,487.01	100,601.15	107,111.77	112,206.01
Cash Flow From Operations	1,000,000.00	731,688.68	811,846.81	825,106.72	823,154.54	828,430.07	833,958.86	839,745.97	845,796.57	852,115.93	858,709.42	865,582.53	880,128.18
Cash Flow From Operations (discounted	1,000,000.00	677,489.52	696,027.79	654,996.32	605,043.16	563,815.59	525,535.55	489,983.71	456,957.57	426,270.11	397,748.61	371,233.51	349,511.01
Project IRR		-90.76%	-63.02%	-42.03%	-28.18%	-18.80%	-12.25%	-7.51%	-4.00%	-1.32%	0.75%	2.39%	3.71%
Project NPV	-7,915,000.00	-7,237,510.48	-6,541,482.69	-5,886,486.38	-5,281,443.21	-4,717,627.63	-4,192,092.08	-3,702,108.37	-3,245,150.80	-2,818,880.69	-2,421,132.07	-2,049,898.56	-1,700,387.55
Investor IRR						-48.38%	-34.28%	-24.49%	-17.28%	-11.82%	-7.60%	-4.27%	-1.61%
Investor NPV	-1,583,000.00	-1,583,000.00	-1,583,000.00	-1,583,000.00	-1,583,000.00	-1,543,508.90	-1,487,176.59	-1,416,581.47	-1,334,019.75	-1,241,532.75	-1,140,931.60	-1,033,819.83	-921,613.82

Results Project Lifetime	
Discount rate	8.00%
Project IRR	8.30%
Project NPV	181,894.26
Project Payback (years)	10.61
Investor IRR	11.08%
Investor NPV	821,808.70
Investor Payback (years)	13.77

Figure 151: Excel report