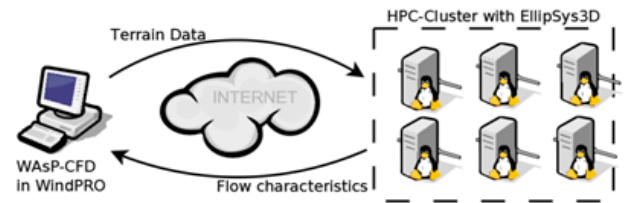
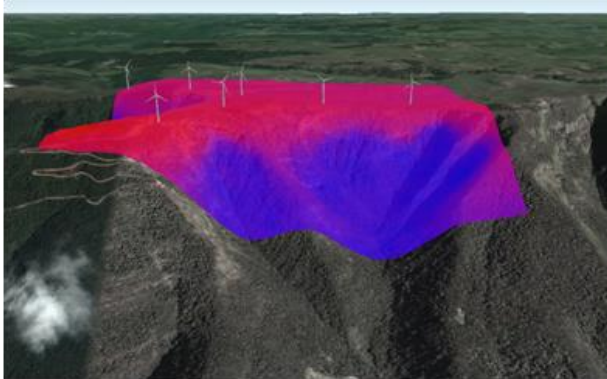


QUICK GUIDE - WASP-CFD IN WINDPRO

Purpose:

The purpose of the WASP CFD model in windPRO is to enable the windPRO user to calculate wind resources in semi-complex or complex terrain.



The model is capable of calculating both wind resource maps and individual wind turbine positions, but the actual CFD-analysis is always done in tiles with the central domain sized 2 km x 2 km.

In order to operate the WASP-CFD model in windPRO you will need:

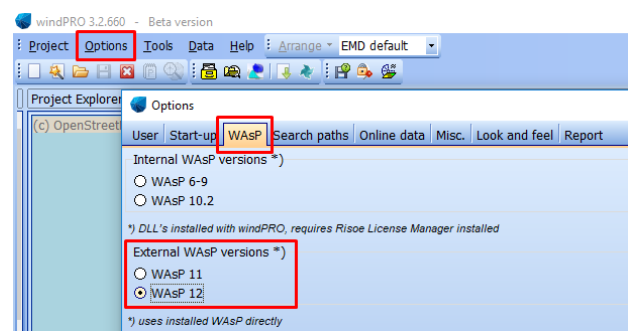
- WASP 11 (or higher)
- windPRO 2.9 (or higher)
- Calculation credits on the Cerebrum cluster

Calculation credits can be purchased from EMD.

Outline of Guide:

1. Preparing data input for WASP-CFD
2. Submit and download calculation
3. Using results
 - a. For resource map generation
 - b. For MCP
 - c. For PARK and optimization

If you have WASP versions older than version 11 installed on your computer, then please remember to select the latest version before starting your CFD jobs (this is found in the 'options' menu, see the image below).



1. REQUIREMENTS FOR WASP-CFD

WASP CFD in windPRO works much the same way as a traditional WASP analysis and it needs the same data for the calculation, i.e. at least some wind data, a digital elevation model and a roughness model. Due to the very demanding nature of the CFD calculations, the actual CFD analysis is made on the Cerebrum high-performance computer cluster operated at EMD.

2. TERRAIN DATA FOR THE CFD-ANALYSIS

The WASP-CFD analysis is very similar to the WASP analysis and it requires the same data - but with an extended 20km distance requirement for the orography. In this guide we assume that you have already prepared data for a standard WASP run, so our assumption is, that you have already processed your wind data, made a roughness-classification as well as

Quick Guide - WASP CFD in windPRO

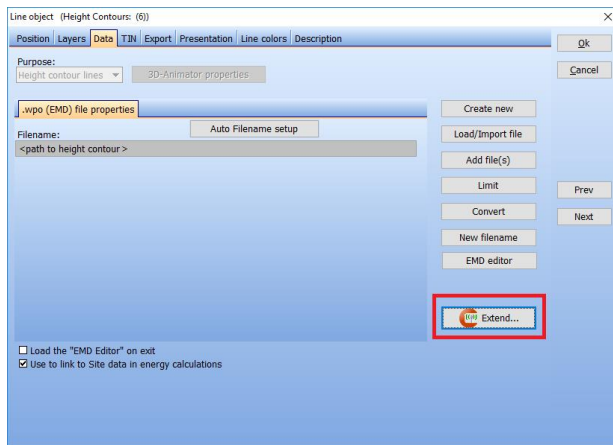
added the height contours within a 10km distance from the site.

Now, the terrain data needs to be prepared for the CFD analysis, as the CFD model requires the orography to a distance not less than 20 km from the site. The WASP-CFD model uses height contours (not gridded data). These contours can be stored or created from either in a line-object or in an elevation grid object.

Please note, that WASP CFD is able to handle not more than 2 million points. windPRO will check if your terrain data meet this requirement.

Orography in a Line Object

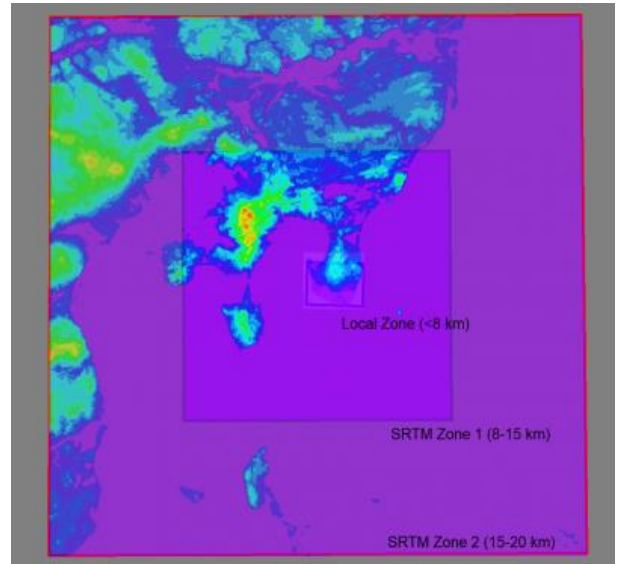
Assuming that you have your 'normal' WASP orography data in a line object covering a distance approximately 10km from your site, then just press the 'Extend' button in the line object ('Properties', 'Data' tab), to add the extra contours to your existing local data. In the far field, 10 m or 20 m contour separation is sufficient.



Contours in a Grid Elevation Object

If your original elevation data originates from gridded sources, then it may be advantageous to continue to store the data in a grid elevation object. If your data covers a distance less than 20km from the site, then you must add more data from other sources such as SRTM.

Since the current version of WASP-CFD always uses contour lines, then your grid elevation object data will be converted into lines when the CFD calculation is run. You should setup your grid elevation object, so that you use a contour separation of 10 m or 20 m in the outer zones as this gives a sufficient degree of detail, but in the local zone, the contour separation should be 5 m.



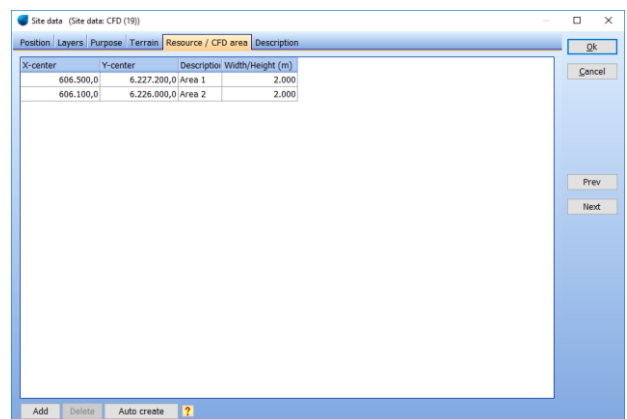
Roughness Lines

Roughness lines should cover an area not less than 20-30 km from the site. Again, if more data are needed, add data from an appropriate source.

3. PREPARE FOR THE CFD CALCULATION

Step 1: Prepare terrain data and CFD-areas

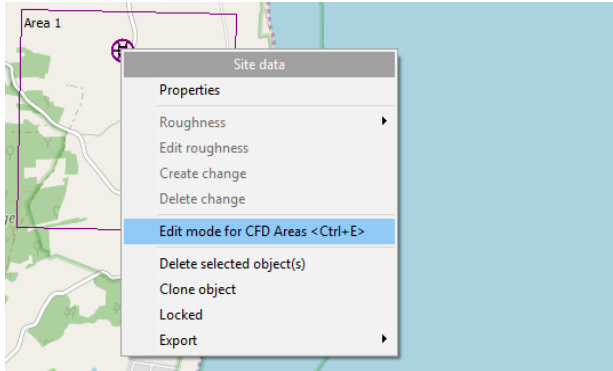
- Insert a site-data object with purpose: “CFD calculation” and name it
- Go to the **Terrain tab** and provide links to your roughness and orography data.
- Go to the **Resource / CFD area**
- Click the **Add** button to add a number of 2km x 2km CFD calculation areas (don't worry about the actual coordinates of the squares yet)
- Alternatively - if you have a WTG area object - you can also use the **Auto-create** button.
- Press **OK**.



Quick Guide - WASP CFD in windPRO

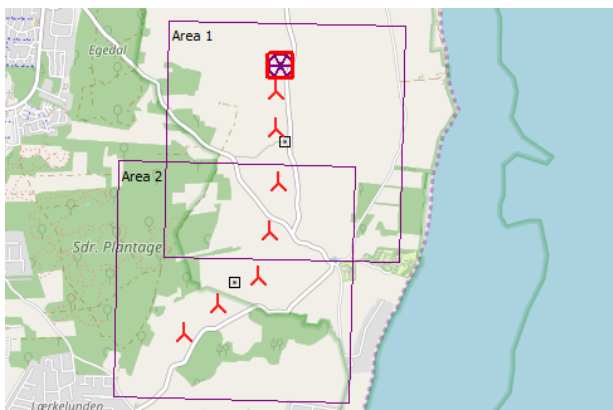
Step 2 - Add, edit and adjust CFD-areas

- In the map Window: Right click the site data object symbol
- Select **Edit Mode** for CFD areas
- Move the individual CFD-squares by dragging in the center of the square
- If you need more areas to cover the whole site: Whilst still in edit mode, right click the site-data object and choose to 'Add CFD area'.



Step 3 - Inspect CFD-areas - see image below

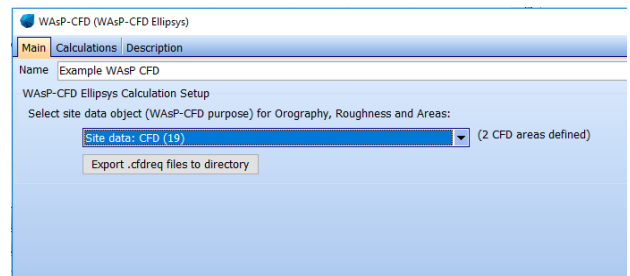
- Inspect the position of your CFD area(s) to ensure that all WTG-positions are covered (or all areas that you want to cover with a wind resource map).



4. SUBMITTING THE JOB TO THE CLUSTER

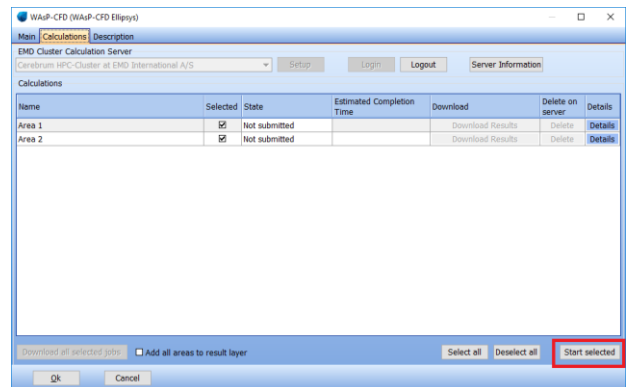
Step 1 - see the image below

- Create a new WASP-CFD calculation from the windPRO main calculation window
- Name the calculation and select the site data object containing your CFD-areas



Step 2 - see the image below

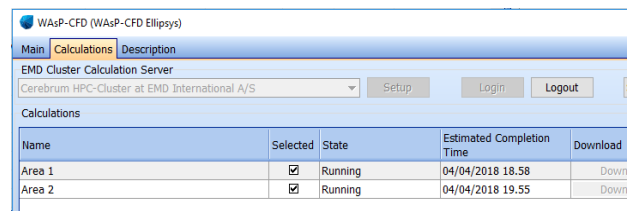
- Go-to the tab-sheet named 'Calculations'
- Use your credentials (contained in your windPRO license file) to login to the Cerebrum Server (just press the Login button)
- Choose which areas to include in the CFD-analysis (by checking the boxes in the selected column)
- Press the **Start selected** button
- Wait until the calculation has finalized (you may continue your normal windPRO work or exit windPRO or even shutdown the computer). The CFD analysis will take several hours or even days to complete.



5. INSPECT THE PROGRESS

To inspect the progress for a single calculation

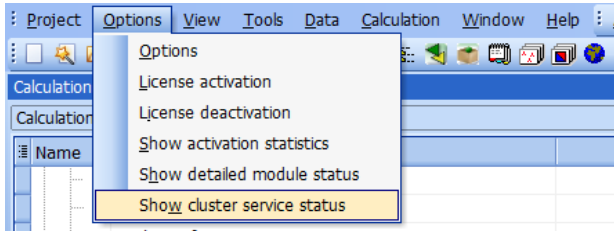
- Open the CFD calculation
- Go-to the 'Calculation' tab
- Login to the cluster
- In the table you will be able to see the estimated completion time.



Quick Guide - WASP CFD in windPRO

To inspect the progress for all your calculations

- Go into the windPRO - Options menu
- Click **Show cluster service status**
- Login to the cluster
- You are now able to see the status on all your calculations (actually for the whole company/organization)



6. DOWNLOAD THE RESULTS

When the calculation has finished, an e-mail will be sent to the e-mail address used during the activation process for windPRO. The e-mail will simply say "Job completed OK".

You then need to download the results.

- Start windPRO and load the project
- Open the CFD calculation go-to the **Calculations** tab
- Login to the cluster
- In the table you will be able to see that the **Download Results** button is now available.
- Click and save the results.

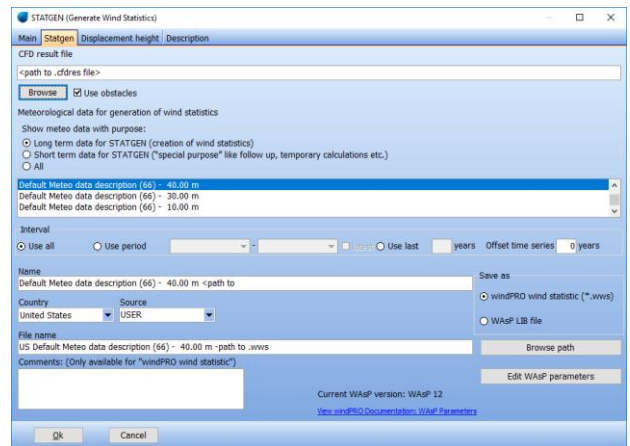
You can also download the results of any calculation from the **Options** menu on the windPRO Main Menu. You will have to ensure that you save the results (which have the same filename) in the correct project folder as a multiple download will put them into a single folder.

7. STATGEN: CREATE A WIND-ATLAS

1. Open a STATGEN calculation and name it
2. Set the source data to "Use WASP CFD result file(s)"
3. Go-to the Statgen tab-sheet
4. Select the *.CFDRES file where within the mast is located (if in doubt, go-to the map-window to locate the right cfd-area)
5. Select the meteorological data to use - this must be located within the 2km x 2km CFD calculation area

6. Name the wind statistic / wind atlas file
7. Press **Ok** to make the wind statistic / wind atlas

If you have more mast, more heights or more CFD-result files, then repeat the process above to create wind atlases corresponding to each mast position.

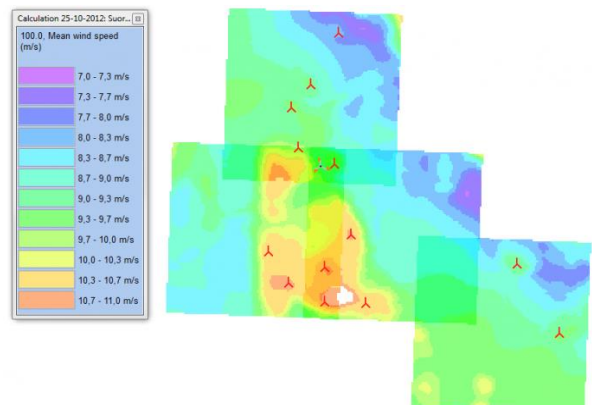


8. RESOURCE: CREATE A RESOURCE MAP

Before you can create a wind resource map, then a wind-atlas must be created. See more in the appropriate section above. When using CFD results, then the resolution always is 20 m (corresponding to the native resolution of the CFD result files).

The procedure for creating a wind resource map is:

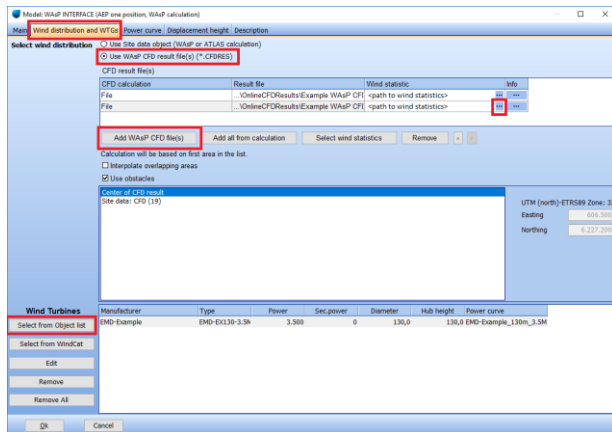
1. Create a RESOURCE calculation and name it
2. Add your CFD result files by clicking the button **Add WASP CFD file(s)**
3. Select your wind statistic / wind atlas (it **MUST** be created with WASP-CFD).
4. Add the calculation heights (and possibly your hub-height(s))
5. Press **Ok** to calculate the wind resource map
6. When the calculation is done it is typically stored as *.rsf files in your project directory




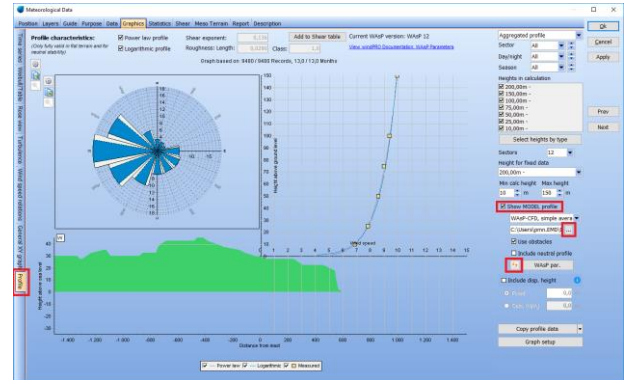
Quick Guide - WASP CFD in windPRO

9. WASP-INTERFACE: SINGLE POSITIONS

1. Open a WASP-Interface calculation
2. On the 'Main' tab, check to *Calculate Wind Profile*
3. On the *Wind distribution and WTGs* tab - choose to use *.CFDRES result files
4. Add some CFD-result files (click button *Add CFD result file(s)*)
5. Choose a wind statistic (click the ... button). This should be generated using WASP-CFD only
6. Choose your position for the calculation from the list (see the coordinates to the right)
7. Choose which wind turbine types to calculate (e.g. click *Select from Object List*)
8. Set your air density and power curve model settings using the appropriate tabs
9. Press *Ok* to calculate
10. After calculation has been done: Inspect results (and wind profile) from the windPRO reports.



5. In the drop-down list for selecting the site data object: Select *Use CFD result*
6. Click the '...' button below the list and select the CFD-Result area which contains your mast
7. Click the update button to draw the WASP-CFD wind profile 
8. Note: If you want to copy the actual wind profile values into the another software tool (e.g. MS-Excel), then click the button *Copy Profile Data*

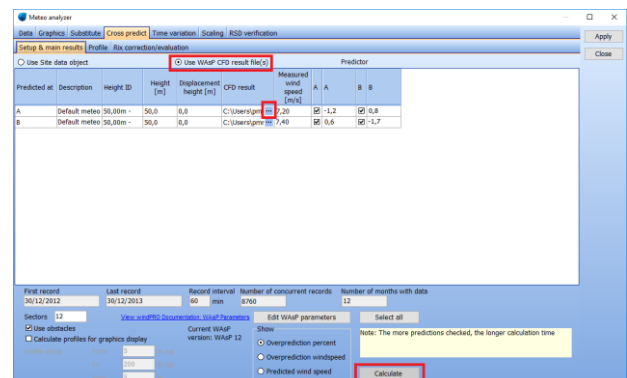
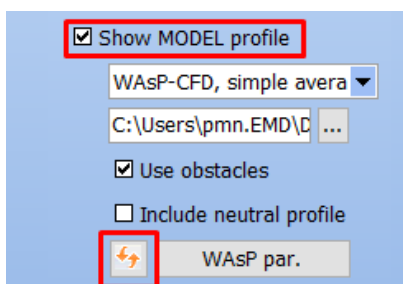


11. METEO ANALYZER, CROSS PREDICTIONS

1. Open the Meteo-Analyzer
2. Select your masts holding concurrent time series (meteo objects)
3. Go-to the *Cross Predict* tab-sheet
4. Choose to use WASP CFD result files
5. For each of the meteorological masts chosen: Choose the right CFD-area
6. Press the *Calculate* button

10. METEO OBJECT, WIND PROFILES

1. Go into the Meteo object (must be placed within a WASP-CFD calculation area and it must contain time series data)
2. Go into the Graphics tab-sheet (to the top)
3. Go into the Profile tab-sheet (to the left)
4. Check *Show MODEL Profile*



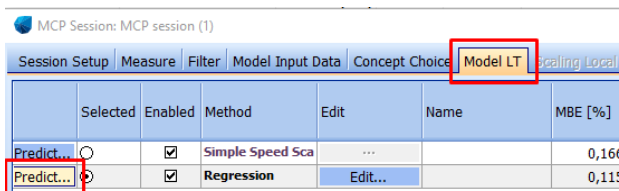
Quick Guide - WASP CFD in windPRO

12. MCP: LONG TERM CORRECTION

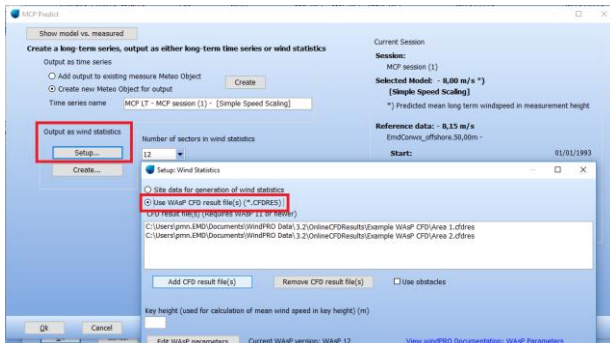
This guide assumes that you have already processed your local data as well as loaded a decent candidate for a long-term reference wind data series. Two approaches exist:

Primary Approach (directly from MCP)

1. Start a MCP-calculation
2. Load your long-term reference data as well as local data
3. Go to “Model LT” tab
4. Click the **Predict** button for the model you wish to use.



5. In the “MCP Predict” window, click the **Setup** button in the “output as wind statistics” section.
6. Choose to use WASP CFD result files
7. Select your *.CFDRES file that contains your mast
8. Click **OK** to close the window



9. Click **Create...** to create a wind statistics

Alternative Approach (Via STATGEN calculation)

1. Do your MCP calculations
2. Click **Predict**
3. Choose “Create new Meteo Object for output”
4. Perform a STATGEN calculation using the newly created long-term corrected time series using the approach described in section 7 above.

13. OPTIMIZATION OF A WTG LAYOUT

Simply calculate some wind resource maps (see section 8) and use these as input to your windPRO optimizations.

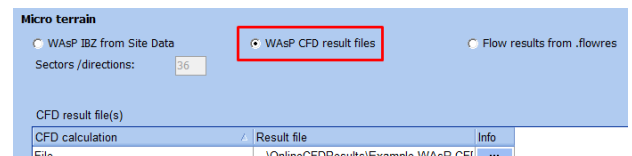
14. PARK: WAKE LOSS CALCULATIONS - WIND STATISTICS BASED

Either use a wind resource map directly (see section 8) or invoke WASP-CFD directly.

1. Open a PARK calculation
2. Select “Standard PARK with WasP CFD”
3. On the WTGs tab-sheet, select which turbines / layers to calculate
4. On the CFD result files tab select your .cfdres files
5. On the Wind statistics tab select select the Wind Statistic / Wind Atlas that you created earlier (with STATGEN and using CFD results)
6. Setup air density, wake decay constants etc. as in your normal PARK calculations
7. Press **OK** to do the calculation using the WASP-CFD flow results and the PARK wake-model

15. PARK: WAKE LOSS CALCULATIONS - TIME VARYING BASED

1. Open a new PARK calculation
2. Select “Time varying based on measured data” or “Time varying based on MESO data”
3. On the WTGs tab-sheet, select which turbines / layers to calculate
4. On the Scaling tab, select which scaler configuration to use.
5. Click **Setup** to ensure the micro terrain in the selected Scaler is set to “WasP CFD result files” and that the .cfdres files are added.



6. Click **OK**
7. Select which Meteo objects the Scaler should scale from.
8. Setup air density, wake decay constants etc. as in your normal PARK calculations
9. Press **OK** to do the calculation using the WASP-CFD flow results and the PARK wake-model.