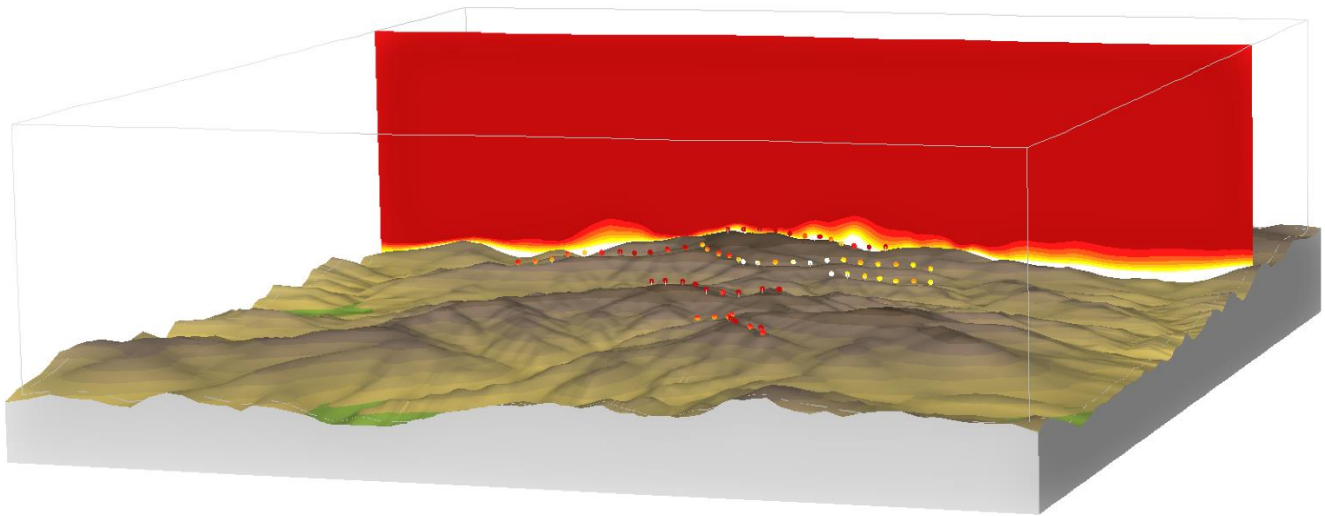


Wind Farm Design

CHAMPIONSHIP



Maximize energy production

Find the windiest position for each wind turbine

08.27.2021 – version 1.7

REVISION HISTORY

| Version | date | Summary |
|---------|------------|---|
| 1.0 | 15/08/2018 | Original issue |
| 1.1 | 30/08/2018 | Replacement of figure 3 |
| 1.2 | 12/10/2018 | Introduce a new rule on project specific input with associated corrections and extensions of the text |
| 1.3 | 25/09/2019 | The maximum number of cells to be used in the championship is set to 50 000, which is aligned with the maximum number of cells of the WindSim Evaluation version 10. This allows everyone to take part in the championship without having access to a commercial WindSim version. |
| 1.4 | 20/08/2020 | Introduce a new rule for suitability, language corrections and extensions. |
| 1.5 | 02/12/2020 | Language and layout corrections. Official version to be used in the 2021 Championship. |
| 1.6 | 31/05/2021 | Change links to windsim.com, the old links were outdated in connection with a launch of a new windsim.com web site. |
| 1.7 | 08/27/2021 | The dummy climatology in section 3.2 has been changed. Official version to be used in the 2022 Championship. |

CONTENT

| | | |
|----------|--|-----------|
| 1 | WIND FARM DESIGN CHAMPIONSHIP | 4 |
| 2 | SOFTWARE GUIDANCE | 4 |
| 2.1 | <i>3D numerical model.....</i> | <i>5</i> |
| 2.2 | <i>Simulations</i> | <i>5</i> |
| 2.3 | <i>Climatology and turbines.....</i> | <i>5</i> |
| 2.4 | <i>Wind Resources</i> | <i>5</i> |
| 2.5 | <i>Energy.....</i> | <i>5</i> |
| 2.6 | <i>Layouts</i> | <i>6</i> |
| 2.7 | <i>And the winner is...</i> | <i>6</i> |
| 3 | RULES AND INPUT..... | 6 |
| 3.1 | <i>Rule 1 – Project specific input.....</i> | <i>6</i> |
| 3.2 | <i>Rule 2 – Climatology and position</i> | <i>8</i> |
| 3.3 | <i>Rule 3 – Wind turbine</i> | <i>10</i> |
| 3.4 | <i>Rule 4 – Wind farm</i> | <i>11</i> |
| 3.5 | <i>Rule 5 – Suitability.....</i> | <i>11</i> |

1 Wind Farm Design CHAMPIONSHIP

You are hereby invited to take part in the annual wind farm design championship. The target is to design the world's best performing wind farm, that is the wind farm with the highest energy production. This is not a championship in finding the windiest spot in the world. This is a championship in designing wind farms, finding the best layout for your particular site. In order to take part, you will need to learn how to operate the wind farm design software WindSim, next you must make yourself familiar with the rules set in order to make this a fair competition. Let's look at the software first.

2 Software guidance

We will use WindSim or WindSim Evaluation (EV) and its companion WindSim Express for the design. Notice that a hardware key with a valid license is required to run WindSim, whereas WindSim EV is a freely available software where no hardware key is required. Hence, WindSim EV is the free version of the software WindSim. The two versions are identical, except for one crucial difference, in WindSim EV there is a set maximum of the number of cells that can be used to establish the 3D numerical model. The maximum number of cells allowed to be used in WindSim Evaluation is 50 000, which is less cells than what is typically used in commercial projects, where 3D numerical models established in WindSim typically could use many million cells. The accuracy of the simulation results depends on the number of cells used in the 3D numerical model, improved accuracy is obtained with increased number of cells. Still, with the limitation set in WindSim EV we get reasonable results which can be used in this championship. Further, one of the rules is to only use 50 000 cells for the 3D numerical, thereby all participants whether using WindSim or WindSim EV face the same restriction, with the same set maximum number of cells limit of 50 000 cells.

WindSim and WindSim Express can be downloaded from: <https://windsim.com/downloads/latest-version/>

WindSim EV can be downloaded from: <https://windsim.com/downloads/evaluation/>

In the following we will use WindSim as a reference to both WindSim and WindSim EV, as it would be optional to use one or the other software.

WindSim is a so-called "Wind Farm Design Software" which will guide you through the following design steps:

- 1) Establish a 3D numerical model of the wind farm area, based on elevation and land cover (roughness) data
- 2) Simulate the local wind fields
- 3) Establish information about the local wind climate, we call it a climatology
- 4) Establish the wind resource map
- 5) Positioning the turbines at optimal spots, maximize the energy based on the wind resource map and wake losses

Here is a short guidance on which software and modules to use to perform the above step. If you are a new WindSim user we recommend you to visit the link "Learning WindSim": <https://windsim.com/learning-windsim/>

2.1 3D numerical model

It is recommended to use WindSim Express to establish the 3D numerical model. WindSim Express is designed as a wizard which will extract terrain elevation and land cover data from online global datasets, you will be able to establish 3D numerical models all over the world within seconds.

Land cover is the physical material at the surface of the earth. Land covers include grass, trees, bare ground, water, cities etc. Depending on the land cover the wind will be slowed down more or less. In wind energy it is convenient to replace the land cover type with a roughness height which is a measure of the friction towards the ground. The higher the roughness height is, the higher is the friction and the lower is the wind speed. The replacement of land cover types with roughness heights is done automatically in WindSim Express.

Towards the final setup of the 3D numerical model it is recommended to swap from WindSim Express to WindSim, as it allows for larger flexibility in the setup. But, also because we will use it for all the remaining steps. In WindSim Express right after the 3D model has been displayed you should click the lower left button "Switch to WindSim". In the WindSim module "*Terrain*" you make your final decision on model extensions and resolution. Now you have established a 3D numerical model, you are ready to perform the wind simulations.

Note that since the 3D numerical model was established in WindSim Express, an automatic gridding is used. It is recommended to turn of the automatic gridding when establishing the 3D numerical model in WindSim, which is achieved by setting the property "Automatic gridding" equal to "False"

2.2 Simulations

Simulations of the local wind fields are done in WindSim in the module "*Wind Fields*". The default setting can be used in this module.

Note however, that the value of "Number of iterations" depends on the value of "Maximum number of cells" set in the preceding module "*Terrain*". The value of "Number of iterations" must be sufficiently large for convergence to be reached. The default value of 100 is usually sufficient for small models with 50 000 cells. For larger models the value of "Number of iterations" usually must be raised to several hundreds.

2.3 Climatology and turbines

The climatology and turbines are special in this championship as all participant are supposed to use the same local wind climate and the same type of turbines, see the below rules. Adding a climatology and turbines to the wind farm is done in WindSim in the module "*Objects*".

2.4 Wind Resources

The wind resource map is established in WindSim in the module "*Wind Resources*". Establish a wind resource map at the same height as the hub height of the wind turbine. It is the wind resource map which is your primary source for the optimization of the energy which follows next.

2.5 Energy

To optimize the energy production is an iterative process, where you test out many layouts. A layout defines a given positions for all the wind turbine in the wind farm. First you have to position each turbine at a windy spot. Next, the wind turbines should not be too close to each other. A wind turbine extracts a

large amount of energy, leaving an area with lower wind speed on its leeward side. Try to avoid placing wind turbines in these regions and thereby reduce the so-called wake losses.

In WindSim you position wind turbines in the module “*Objects*”. The wind resource map and the effect of the wakes are visually explored in the module “*Wind Resources*”, while the calculation of the energy production and wake losses is done in the module “*Energy*”.

The software Park Optimizer is part of WindSim’s software suite, which automatically optimizes the layout with respect to maximizing the energy production. We will not use this software – here you should use your own skills in designing the best performing layout.

2.6 Layouts

In WindSim there is a possibility to easily compare results from various layouts. Take a copy of an existing layout, the changes you make will be saved as a new layout. Swap between the layouts to determine which is the best performing for your site.

2.7 And the winner is...

To take part in the championship send your best performing layout to us. A layout is exported from WindSim under “Export” – “Export HTML report...” (it is under “Tools” in WindSim 9.0 and older versions), which will establish the following folder:

```
C:\Users\your_user\Documents\WindSim Projects\your_project\your_layout\report_export
```

Notice that only one layout is exported, which is the currently opened layout in WindSim when the export is done. Check that you have exported your best performing layout before you zip the whole folder and send it to us at: info@windsim.com, the subject of the email should be: “Wind Farm Design Championship”.

The participant presenting the wind farm with the highest energy production (AEP, Annual Energy Production) is the winner. The list with all top designers, including their projects, will be published at <https://windsim.com/library/annual-championship/>

3 Rules and input

This is a championship in designing the best performing wind farm. You pick a location somewhere, hopefully with some favourable terrain features, which will accelerate the wind. The challenge is to understand how the wind varies and to position each turbine in a windy spot. Still you need a certain distance between the turbines to prevent too large wake losses.

3.1 Rule 1 – Project specific input

In order to make this a fair competition we have to use common settings for some of the input parameters, which would affect the energy production.

The model resolution will affect the energy production. A high-resolution model will have higher extreme values compared with a low-resolution model, see figure 1.

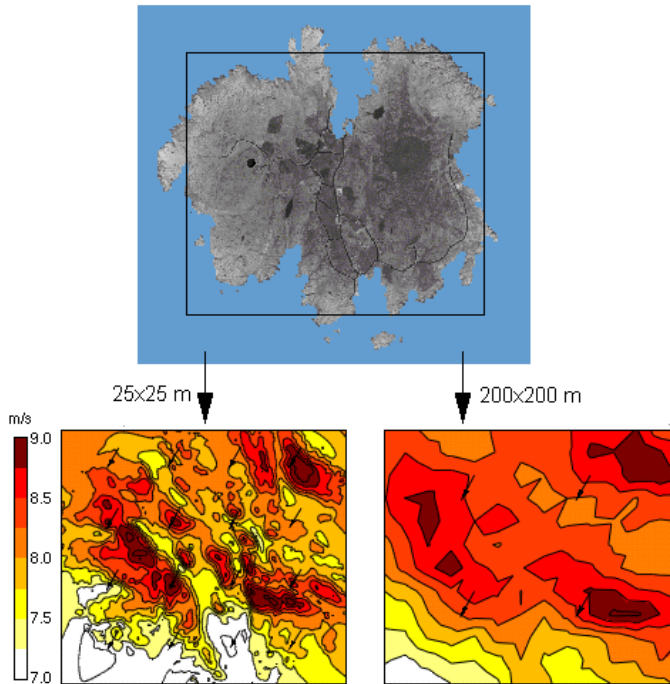


Figure 1. Wind speeds obtained from two identical models except for differences in the resolution. The high-resolution model (left) displays higher maximum wind speed and lower minimum wind speed than the low-resolution model (right)

Hence, in the module “Terrain” the property “Maximum number of cells” should be set to: 50 000. Likewise the number of cells in Z direction should be set to 10, which is also the maximum limit in WindSim Evaluation.

It should be noted, that a numerical 3D model with 50 000 cells in total and only 10 cells in Z direction, is a relatively small model. Then simulations can be performed on low-end computers within a few minutes, which of course is a great advantage. However, the results obtained with such a low-resolution model is most likely not grid independent. In commercial projects a high-resolution model should be used ensuring grid independency. What is grid independency? A numerical model is said to be grid independent whenever an increase of the resolution doesn’t change the numerical results. Grid independency is an ideal measure, that professional wind and site engineers strive to meet. Whereas in this championship we will not be able to meet the ideal requirement of grid independency.

Another ideal measure would be to have results independent of the defined conditions along the borders of the model, the so-called boundary conditions. We will not be able to comply with this ideal requirement of boundary condition independency either. In order to reduce the effects of the boundary conditions, a minimum required horizontal extension of the 3D numerical model is set to 10x10 km. The locations of the turbines should be in the central part of the model.

Likewise, the chosen wake model will affect the energy production. Hence in the module “Energy” the property “Wake model” should be set to Wake Model 1.

Finally, the Annual Energy Production in the module “Energy” is reported in two different ways based on the representation of the climatology. The climatology is either so-called Weibull fitted or not. We choose

to use the non-fitted distribution called “Frequency table” when reporting the energy production, that is the value in Table 1 in column “AEP with wake losses”.

3.2 Rule 2 – Climatology and position

All participants should use the same climatology, which should be downloaded at: https://windsim.com/library/championship/dummy_climatology_2022.zip

The dummy climatology has a wide spread of wind directions, see figure 2. The dummy climatology is changed every year, in this way a new terrain location needs to be found every year.

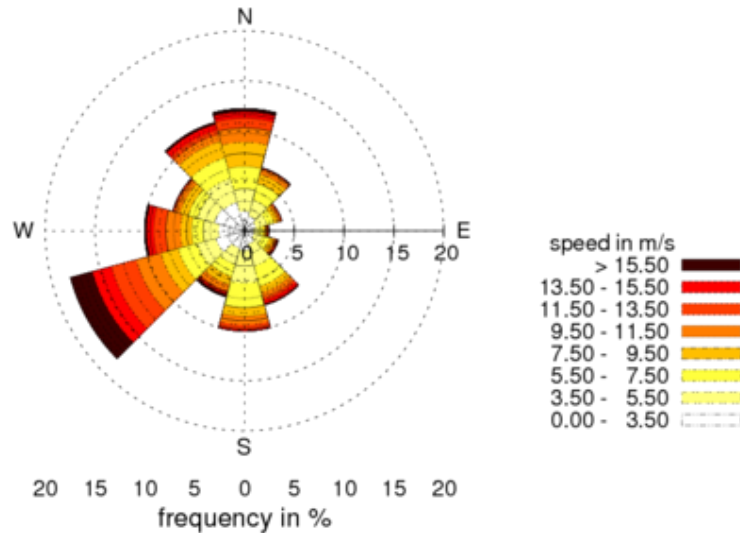


Figure 2. Wind rose for the dummy climatology 2022 (to be used in the 2022 Championship)

Whenever a dummy climatology is introduced in a 3D numerical model at a location where it strictly doesn't belong, that is at a location where it was not measured, then the wind resources map derived from the numerical model using this climatology will be incorrect. If the dummy climatology is introduced at a high wind speed hilltop a certain wind resource map is obtained, whereas if the same climatology is introduced down in a low wind speed valley the wind resource map would be significantly different, the latter would actually display much higher wind resources. For this reason, the participants are not allowed to position the climatology in an arbitrary position.

The position of the dummy climatology will be fixed towards the top border of your model. By default, the top border is sufficiently far away from the ground not to be influenced from terrain effects. Thereby positioning the dummy climatology at this location will introduce the same wind climate in all models.

The height of the top border is model specific, it is found in the report in the module “Terrain”, see figure 3.

Terrain

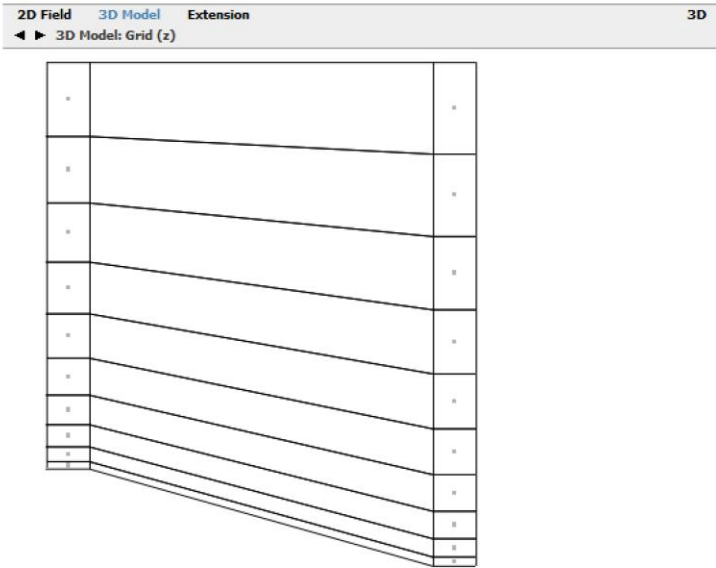


Fig 1. Digital terrain model - Grid (z).

The grid extends **967.2** (m) above the point in the terrain with the highest elevation. The grid is refined towards the ground. The left and right columns display a schematic view of the distribution at the position with maximum and minimum elevation respectively. The nodes, where results from the simulations are available, are situated in the cell centers indicated by dots.

Figure 3. The height of the top border is 976.2 meters in this example model

The height of the dummy climatology must be set to the height of the top border. Open the file “dummy_climatology_2022.wws” in a text editor and replace the default value 9999.0 meters with the height of the top border, see figure 4.

| | |
|--|--|
| version : 43 | version : 43 |
| site name : Data 2000 to 2020 | site name : Data 2000 to 2020 |
| measurement period : 01.01.2000 00:00 - 31.12.2021 00:00 | measurement period : 01.01.2000 00:00 - 31.12.2021 00:00 |
| site position : 2000.0 2000.0 | site position : 2000.0 2000.0 |
| coordinate system : 1 | coordinate system : 1 |
| measurement height : 9999.0 | measurement height : 976.2 |
| number of sectors : 12 | number of sectors : 12 |
| number of bins : 25 | number of bins : 25 |
| total records : 175200 | total records : 175200 |

Figure 4. The original header of the file dummy_climatology.wws (left) and corrected header (right)

By default the dummy climatology will be positioned 2000 meters north and 2000 meters east of the lower left corner of any model. This position should remain unchanged. Figure 5 displays a typical 3D numerical model and the position of the dummy climatology.

Objects

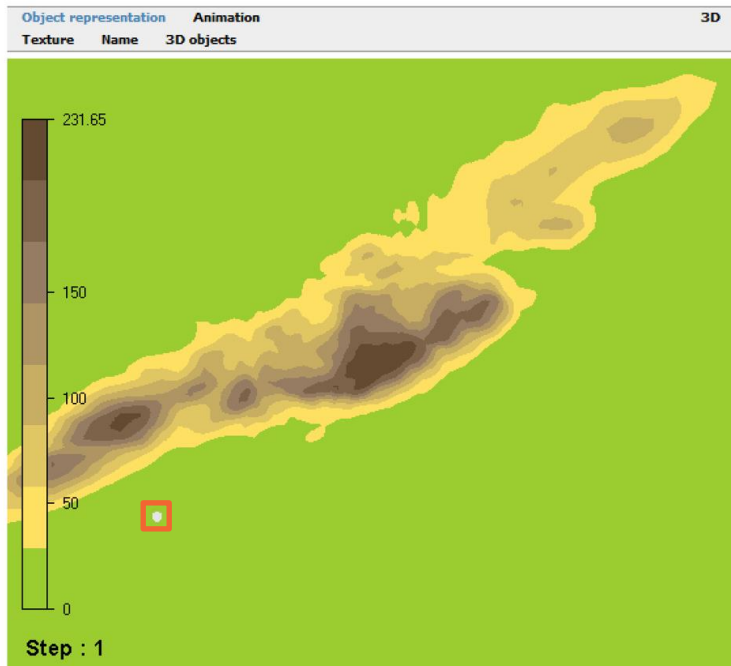


Fig 1. Digital terrain model with objects ● Climatology station

Figure 5. Position of the dummy climatology 2000 meters north and east of the lower left corner in this example model

3.3 Rule 3 – Wind turbine

All participants should use the same wind turbine, which is a 3MW turbine to be downloaded at: https://windsim.com/library/championship/dummy_turbine.zip

The turbine height should be set to 100 meters and the rotor diameter should be set to 90 meters, see figure 6.

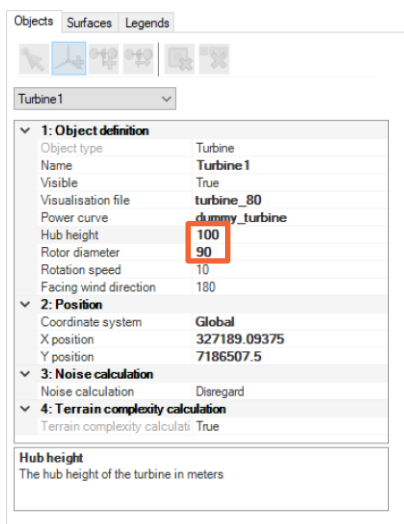


Figure 6. Wind turbine hub height and rotor diameter should be 100 meters and 90 meters respectively.

3.4 Rule 4 – Wind farm

The wind farm should consist of 10 wind turbines. The wind farm area is limited, all turbines must fit into a square of 1500x1500 meters, which should be in the central part of the 3D numerical model with a size of minimum 10x10 km.

In the report of the module “Objects” there is a table giving the position of all turbines, verify that the turbines are not too far apart, that is inside a 1500x1500 meters area.

3.5 Rule 5 – Suitability

The last rule should secure that the wind farm could be build. If you position your wind farm at the top of Mount Everest, it would not be feasible to build it. There would be some practical constraints in the civil work, like road construction and erection of the turbines which we need to respect – it has to be a suitable site.

As a measure of “suitability” we use the turbulence level at each turbine position at 100 meters height, which is the hub height. In the module “Results” you can extract 2D plots for any flow variable, for any wind direction and at any height. Extract the turbulent kinetic energy from all 12 wind directions at 100 meters height, see figure 7.

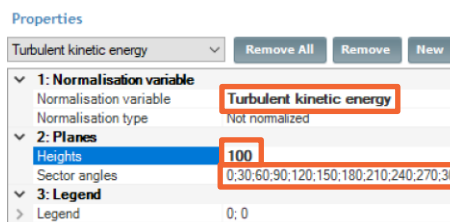


Figure 7. Generation of plots of the turbulent kinetic energy at 100 meters height for all 12 wind directions

The level of the turbulent kinetic energy should be below the set limit of 0.4 [m²/s²] at each turbine position at hub height for all 12 wind directions. If, according to the generated plots of the turbulent kinetic energy is close to the limit for a given case or for multiple cases, a case being defined as a given wind direction and a given turbine, then a special check has to be performed determining the exact values at the four surrounding nodes of the turbine, which all should be below the set limit.

The check of limiting case(s) is performed by opening the case(s) in the 3D viewer, see figure 8, and determine the exact values of the surrounding nodes, see figure 9. The selection of a cell in the 3D viewer is made by clicking the left mouse button while holding the “Shift” button down. Properties of the cell are displayed by clicking the right mouse button while holding the “Shift” button down, chose “Show polygon info ...” to display the node values.

Results

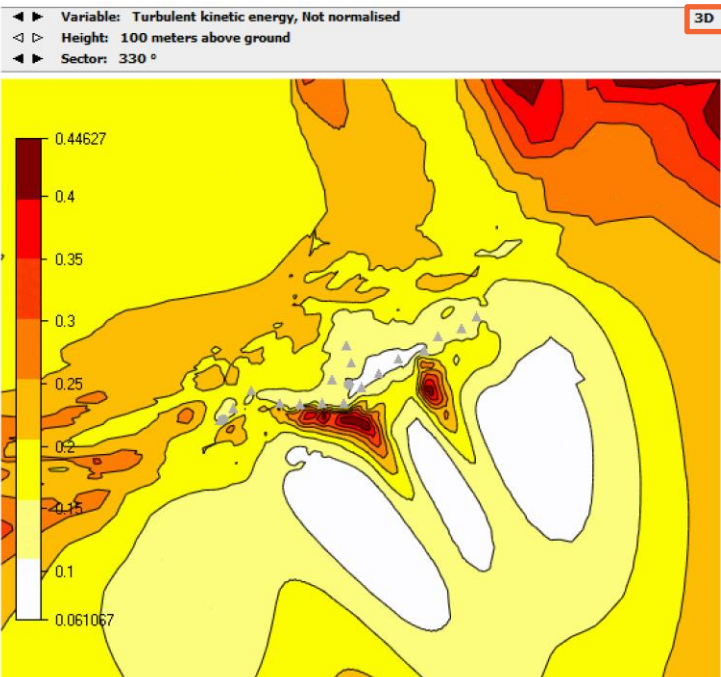


Figure 8. Activation of the 3D viewer is obtained by pressing the “3D” button in the upper right of reports of the module “Results” for a given dataset

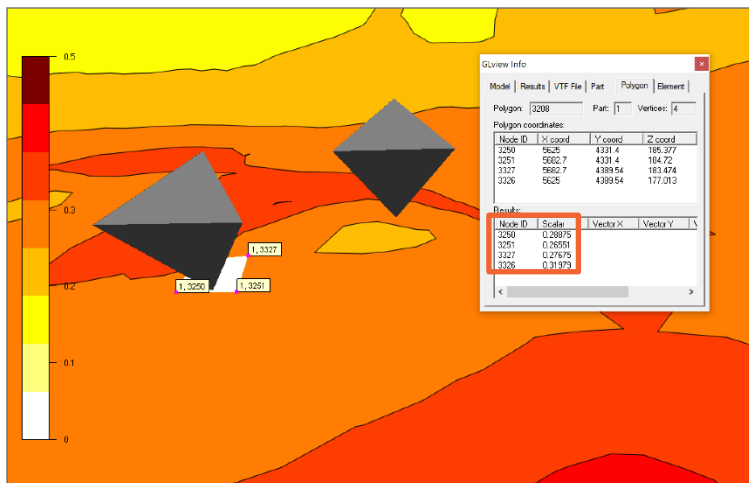


Figure 9. Inspection of exact node values for a given dataset

For all limiting cases we will ask you to send the following information in one single file called: limiting_cases.txt. Here is a sample file showing the required information.

Limiting case ID: 1
 Wind direction: 120
 Turbine Name: wecs 1
 Node IDs: 3250, 3251, 3327, 3326
 Scalar: 0.38875, 0.36551, 0.37675, 0.39979

Limiting case ID: 2
Wind direction: 120
Turbine Name: wecs 5
Node IDs 3850, 3851, 4327, 4326
Scalar 0.37875, 0.35551, 0.36675, 0.38979
.....
.....
.....

Notice that a professional WindSim user will use many more cells in the z-direction than the limit of 10 cells set for this championship. A professional WindSim user will tailor the vertical grid to get output at heights of interest without the need of interpolation. The export functionality "Export vertical profile" will secure easy access to exact values for all flow variables.