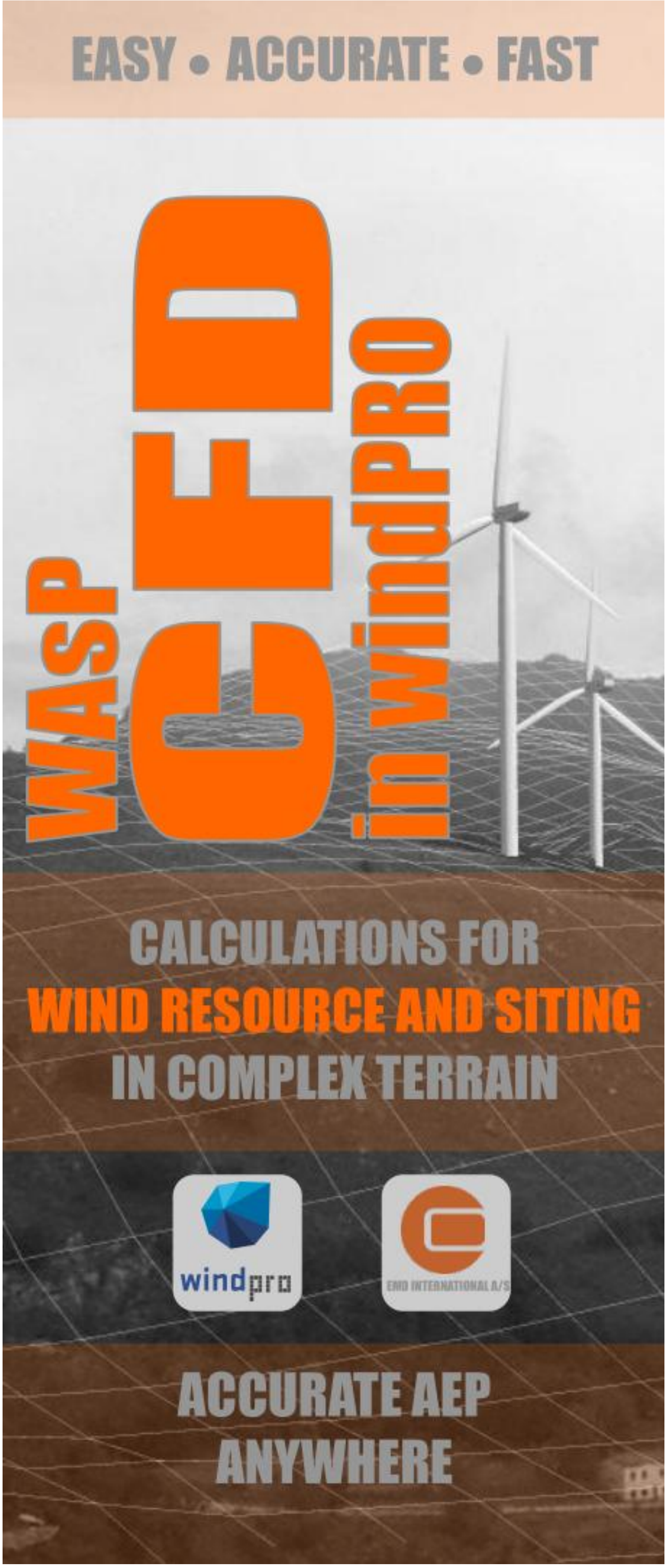
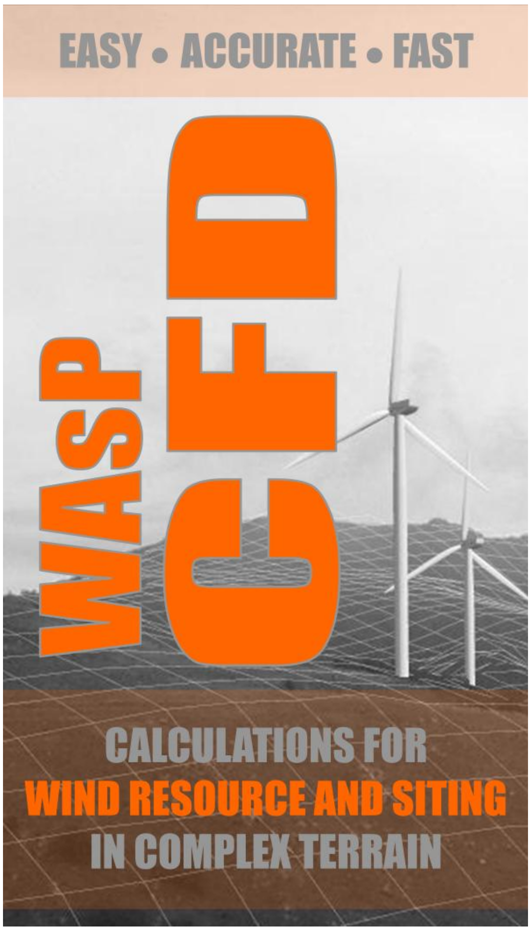
WAsP CFD in WindPRO 2.9

DATA SHEET



WAsP CFD in WAsP 11 & WindPRO 2.9

Order Sheet



Resource assessment & siting in complex terrain

Introduction

The WAsP CFD model is available from within WAsP 11 and WindPRO 2.9. It is an advanced non-linear flow model dedicated to wind energy applications and it delivers fast, accurate and trustworthy CFD results for wind resource assessment and siting in any terrain. Calculations are performed on a super-computer at EMD International, so you will not need to worry about excessive calculation times or additional investments in expensive equipment. With the latest additions to the model in early 2014, the model also includes turbulences and inflow angles in addition to the wind resource assessment.

WAsP 11 and WindPRO 2.9

______ WAsP 11 (WAsP CFD) licence: €3,600
______ WAsP 11 upgrade from v. 10 / earlier: €550 / €1,100
______ WindPRO 2.9
(Free interface to CFD in MODEL, but WAsP 11 is required)

WAsP CFD calculation credits – ad hoc usage

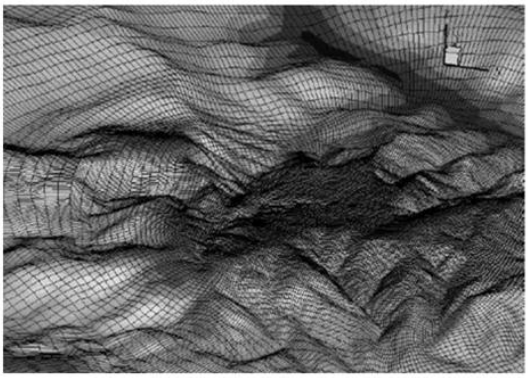
One calculation credit will give you accurate results in one tile sized 2 km x 2 km.

______ WAsP CFD Calculation credit: €200

WAsP CFD calculation credits – discounts

Discounts are available for recurring users of WAsP CFD. We offer three different discount plans dependent on your calculation needs

______ Regular User: 15 credits for €2,400
______ Frequent User: 50 credits for €7,000
______ Intensive: 150 credits for €18,000



Discount Type	Typical Projects *)	Number of Credits	Prices	Unit Price
Regular	3	15	€2,400	€160
Frequent	10	50	€7,000	€140
Intensive	30	150	€18,000	€120

*) Number of wind energy projects in complex terrain that a company normally calculates during the financial period of consideration (typically a year). It is a typical number, estimated by assuming that 5 calculation credits are required on average for a wind energy project in complex terrain.

Note: All prices are excluding VAT

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emd@emd.dk

Time limited offer

New WAsP 11 users will receive 2 free WAsP CFD calculation credits per WAsP 11 license. These will be valid in a period of one month after you register your WAsP CFD account.

Your Contact Information

Your Name ______________________________
Company ______________________________
Address ______________________________
City ______________________________
Country ______________________________
Email ______________________________
Phone ______________________________
VAT-number ______________________________
Other information ______________________________
____
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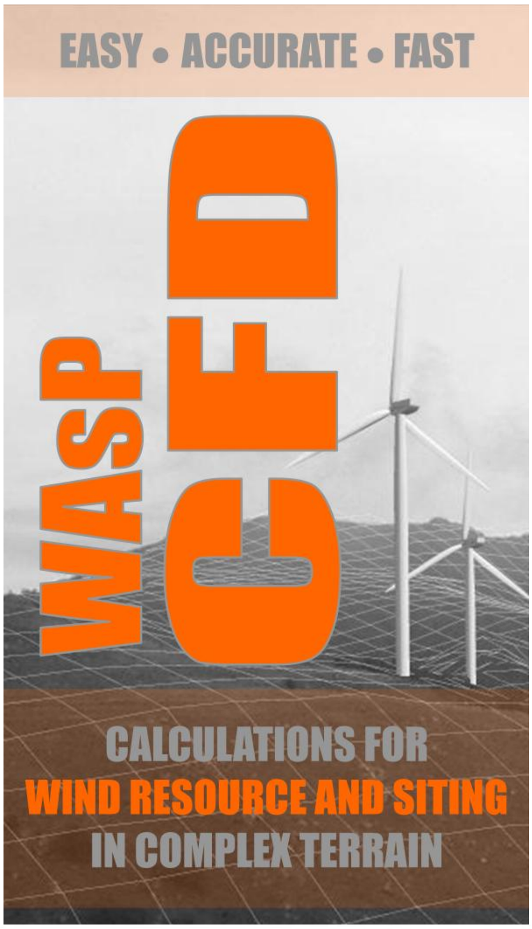
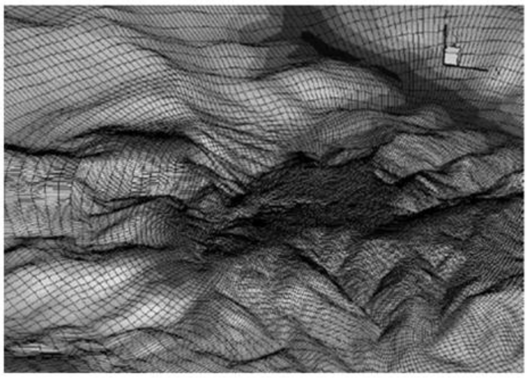
More Information

EMD International A/S, Morten Lybech Thøgersen, mlt@emd.dk

Acknowledgement

The WAsP-CFD project and model development is a joint effort by EMD International, Vattenfall and DTU. The project is co-funded by the Danish “Businness Innovation Fund”





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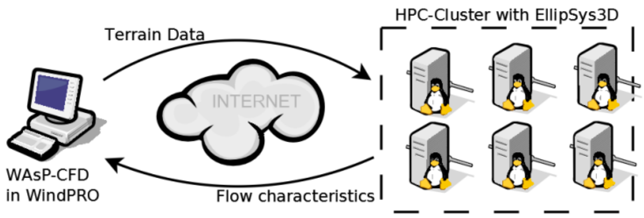
WAsP CFD in WindPRO

Energy Calculations with CFD

New for 2014:
Discounts for recurring users
Site suitability parameters



Introduction

Working with wind models for wind farms in mountainous terrain is a real challenge for the wind resource analysts and any numerical models they use. With WAsP CFD in WindPRO, the road to accurate and reliable estimates has become much shorter.

Traditionally, the requirement of highly specialized and trained CFD-professionals has been an absolute must in order to successfully use computational fluid dynamics (CFD) for wind turbine siting purposes and accurate wind farm energy yield estimations. To achieve an acceptable accuracy from the numerical models when running the flow-model, either access to large dedicated computational resources is needed – or alternatively an excessive calculating time has to be endured.

The WAsP CFD model within WindPRO provides a novel approach to the wind resource assessment and siting of wind farms in all types of terrain.

User-friendly

The WAsP CFD module in WindPRO is designed with 'ease-of-use' in mind. As a WindPRO user, you can leverage your existing WindPRO and WAsP competences and skills in order to do accurate energy yield estimates - also in complex terrain.

Accessibility

The WAsP CFD module in WindPRO provides direct access to a high-performance computer (HPC) cluster directly from your PC-desktop – but without any initial hardware investment or continuous maintenance costs. While acceptable accuracy in numerical modelling requires large computational resources beyond the capabilities of a high-performance PC, the WAsP CFD module in WindPRO provides fully automated access to the HPC cluster operated and hosted at the WindPRO headquarters in Aalborg, Denmark.

Efficiency

Performing an analysis with the WAsP CFD model in WindPRO is very efficient as you are essentially using the same input-data for your analysis as you would do with a WAsP or ATLAS calculation. WAsP CFD is the natural evolution to the wind data-centric approach in WAsP. You will find that you will use quite well-known approaches in WAsP CFD – such as the generation of wind statistics (STATGEN) and application of long-term correction methods (MCP). As the WAsP CFD approach is fully automated – you need only to consider that the results are delivered to your desktop within hours after the calculation has been up-loaded to the HPC-cluster.

Accuracy

The entire modelling approach has been optimized to deliver consistent, reproducible and accurate results. Errors from modelling, numerical schemes and user inter-action are minimized due to the automated procedures involved. On the rear side of this document you will find some of the validation cases conducted for the WAsP-CFD model.

Focussed

Results from the WAsP CFD module in WindPRO are directly integrated into many other WindPRO calculation modules and models. CFD based results can easily be used directly in wake loss calculations, wind resource maps, optimization of layouts, loss and uncertainty evaluations and many other calculations. The wind resource analyst can also use the advanced cross-prediction tools and wind profile evaluations to gain an even better understanding of the on-site wind conditions.

Proven

The WAsP CFD model is essentially a new approach to the challenge of delivering reliable results in complex terrain. All major model components used within the WAsP CFD solution in WindPRO have been developed as dedicated wind turbine assessment and wind engineering tools during many years – and all have proven their worth by years of service. The WAsP flow model and WindPRO have been the leading standards during the last 20 years. The EllipSys3D CFD-solver from DTU Wind Energy (Risø) has set the standards in various industry applications since the mid 1990's.

Available now

The first release of the method was in April 2013. This version enabled the user to submit wind resource calculations. The 2014 release of the model includes site suitability assessment modelling, i.e. result data such as inflow angles, wind shear and turbulence levels.

Environmentally-friendly

All electric power consumed on the high-performance computer-cluster at EMD International A/S are delivered from our own wind turbine, a 3 MW wind turbine commissioned in summer 2013.

Acknowledgement

WAsP CFD in WindPRO is co-funded by the Danish 'Market Developent Fund' – see www.markedsmodningsfonden.dk. WAsP CFD is developed in cooperation between Risø DTU, EMD International A/S and Vattenfall A/S, and WAsP CFD is available in WindPRO and WAsP.

WAsP CFD in WindPRO

Energy Calculations with CFD

Validation

WAsP-CFD is already thoroughly validated as part of an on-going validation process. The validation process has been approached from different directions with three groups of validation cases:

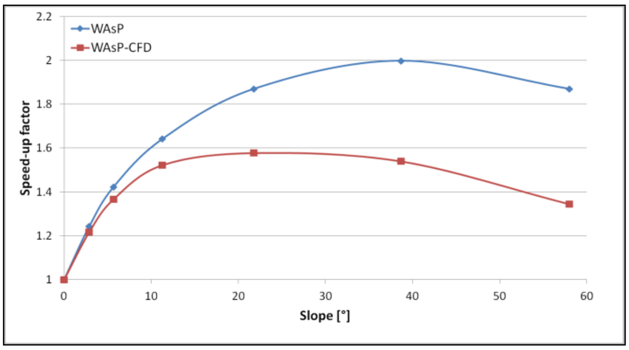
1. Classical cases
   - *Focus:* fundamental/theoretical behaviour
   - Speed-up versus terrain slope
   - Idealized roughness changes
   - Askervein hill experiment
   - The classical 'RIX-site', Portugal
2. Reference cases
   - *Focus:* quantitative validation of model accuracy
   - *6 sites* selected
   - Multiple masts of acceptable high quality
   - Geographically spread
   - Studied in-depth
3. Ad hoc cases
   - *Focus:* qualitative validation with high volume
   - Any site available to the validation team
   - Flat or complex
   - Compared to WAsP and local mast data

Classical Test Cases

Speed-up versus terrain slope

It is a well-known fact that linearized models like WAsP tend to overestimate speed-up of wind flow in steep terrain. But at which terrain slope does the linearizing approximation break down? The below graph shows this analysis comparing the predicted speed-up of WAsP and WAsP-CFD.

Results show that, already at average slopes of 10° (or 17%), linearized models overestimate speed-up by nearly 10%.

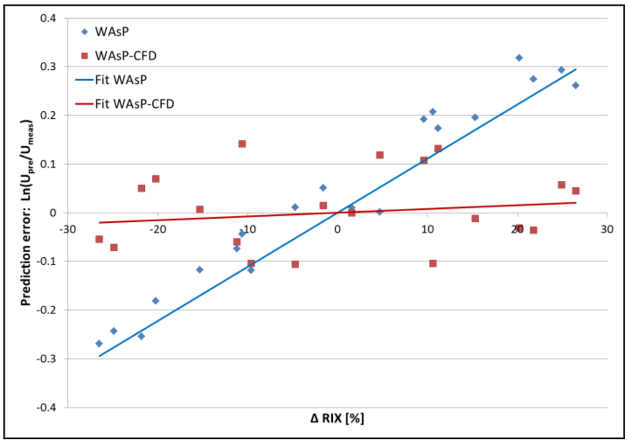


Speed-up versus slope for WAsP and WAsP-CFD.

The classical 'RIX-site' in Portugal

Mortensen et al. (2006) and Bowen and Mortensen (2004) introduced the RIX analysis and correction for WAsP. RIX is an abbreviation of "Ruggedness IndeX", and is calculated as the fractional area of the terrain in a circular vicinity around a mast, e.g. 3-4 km, which exceeds a steepness threshold of 30-40%. In the RIX method, cross prediction errors between masts are plotted against differences in RIX values, ΔRIX.

Result of this classical key study is reproduced using WAsP and WAsP-CFD and showed in the next graph. Note the very low prediction errors of WAsP-CFD at ΔRIX exceeds ±10%.

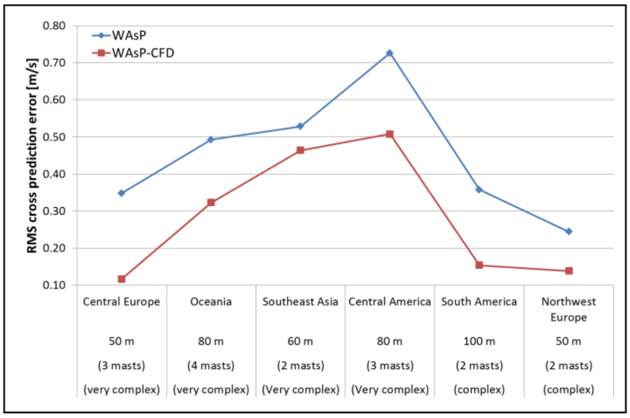


ΔRIX-analysis for the classical RIX site in Portugal.

Reference Test Sites

In the initial phases of the WAsP-CFD project a gross list of reference projects was compiled. Eventually the list was abbreviated to six sites with a very large geographical variety, fulfilling the requirements to on-site measurements. Measurements were thoroughly screened and detailed terrain and roughness models were established for each site prior to performing the mast cross prediction analyses presented below for the top-level anemometers.

Results show a clear reduction in cross prediction error using WAsP-CFD for all reference sites demonstrating the improved accuracy of WAsP-CFD.



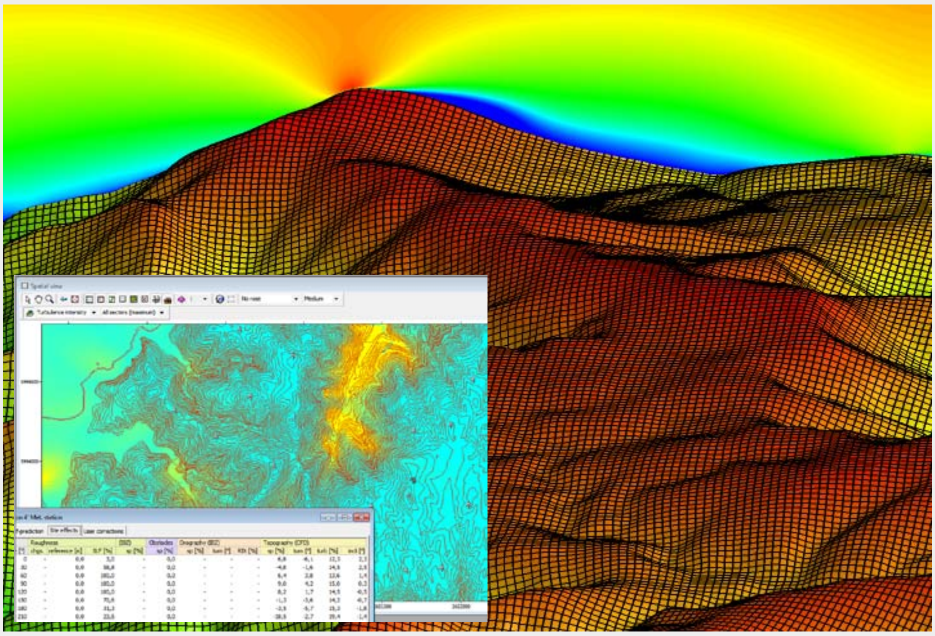
RMS cross prediction errors for reference sites.

Ad-hoc Test Sites

The ad-hoc group of projects includes all project types - and not limited to complex terrain - ranging from mountainous terrain in deep forest in Sweden to rolling hills or coastal sites near equatorial Brazil and projects on a flat coastal plain in Pakistan. There are no constraints in terms on number of masts, multiple measuring levels or data quality. Hence, the main outcome for each project is mainly qualitative - does the model converge? Are the results meaningful? How do results compare with WAsP and local mast data?

More than 1000 analyses have already been calculated successfully using WAsP CFD.

WAsP 11 – including CFD



WAsP CFD is designed for complex terrain. The picture gives an impression of the high resolution grids used by the CFD model to allow accurate wind resource assessments. Additionally, high turbulence regions can be identified when using WAsP CFD.

What's new in WAsP 11?

The well-proven linear IBZ flow model is still there but in addition, WAsP 11 includes a new validated approach to Computational Fluid Dynamics (CFD) for wind resource assessment in complex terrain. We call it WAsP CFD and it combines WAsP with the CFD solver EllipSys. The most profound changes and additions to WAsP 11 are listed under the following headings:

- WAsP CFD, also with turbulence and flow-inclination estimates.
- New Terrain Analysis hierarchy member, to which vector maps are always associated.
- New Generalized Wind Climate (*.gwc) file format replaces the Wind Atlas (*.lib) file format.
- Vertical wind profile model and parameter settings are now part of the Generalized Wind Climate file.
- Unlimited number of points in WAsP Terrain Map files.
- Features like map-handling and resource-grid calculations have. been improved over WAsP 10
- A new dongle-free, internet-based licensing system is introduced.

System requirements

Windows XP or later is recommended. Windows 2000 may be used with various updates and patches from Microsoft, but not earlier Windows versions.

Why WAsP CFD?

Linear wind flow models such as WAsP have their limitations in respect to complex terrain due to the exclusion of non-linear effects. CFD includes these effects and predicts turbulence and is therefore better suited for very complex terrain. The design philosophy of WAsP CFD has been a joint model approach; you set up a normal WAsP project and can subsequently opt for a CFD solution if the site complexity justifies the added computational effort. WAsP CFD is easy to use and quickly provides accurate and reliable results at low cost. It will add value to wind energy projects in complex terrain by helping you maximize production and minimize uncertainty.

How does it work?

Historically, CFD has two main drawbacks; CFD requires highly trained users and large computational resources in order to minimize model- and numerical errors. WAsP CFD has its own unique solutions to these problems:

1. The CFD calculations are fully automatic. Setting up the WAsP project simultaneously creates the WAsP CFD project – no CFD training is needed.
2. The computational resources required for high-quality CFD calculations are available via the internet on the Cerebrum high-performance computer cluster. By performing the calculations online, unprecedented numerical resolution can be offered and full wind rose results will be returned within a few hours.
3. No computer investments needed.

New WAsP CFD Calculation Manager

This new tool is the gateway for the WAsP 11 user to connect to the Cerebrum high-performance computer cluster and make WAsP CFD calculations via the internet. Each CFD calculation costs a calculation credit that can be purchased individually or by subscription.

More information

The software described in this document is continually being developed. There may be differences between the description given here and the actual software when a new version is released. If you are particularly interested in some feature of the software, please contact the WAsP team for advice.

Contact & Information:

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WAsP CFD details

The WAsP CFD calculations are performed fully automatically on the ‘Cerebrum’ computer cluster. In order to perform CFD calculations the user sends a ‘CFD request’ to the cluster using the ‘WAsP CFD Calculation Manager’. The request file contains the WAsP map file and the coordinates of the CFD calculation. No information about wind turbines or wind data is sent to Cerebrum.

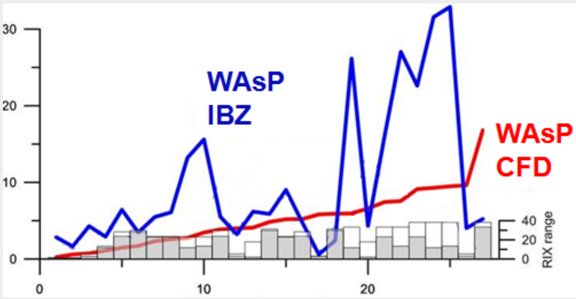
What’s going on on the cluster?
Once the cluster has received the request file the CFD calculations start.

Step one of the CFD process is the generation of a computational grid. The EllipSys-model employs a high-resolution, zooming, polar grid, similar to the one of the IBZ-model. The zooming grid is illustrated in the figures to the right. The top figure shows the whole 32 km diameter polar grid of Aveiro-Viseu in Portugal centered on Station 8 (*European Wind Atlas II, 1995*). Closer views of the grid are found in the other figures.

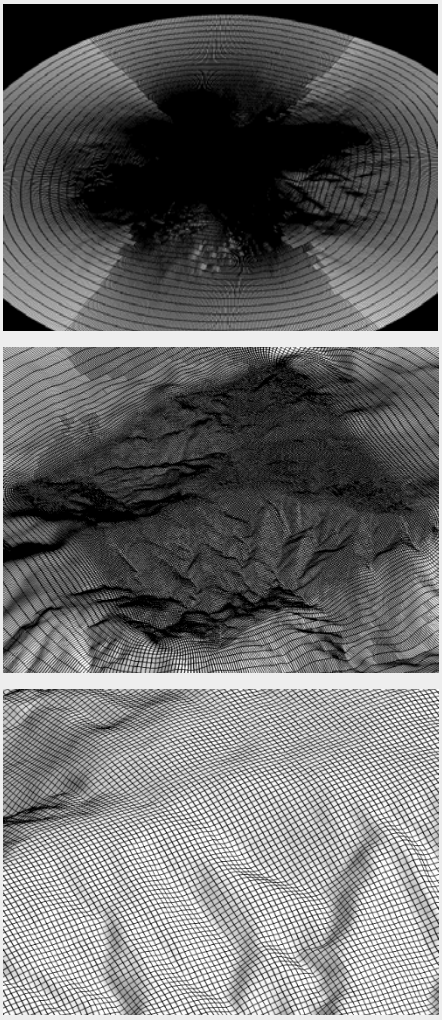
The grid resolution in a certain direction, following the local terrain, is 20 m in the 4 km by 4 km central part. As you move further away the grid gradually coarsens. The vertical resolution of the grid is 5 cm (= 0.05 m) near the ground and also coarsens with height. The final grid consists of 7 million grid points.

The computational grid is generated on basis of your WAsP map file. The best practice guidelines still hold for WAsP CFD; so old WAsP maps should be fine.

Once the CFD grid has been generated the second step is the CFD simulations. For this part, the directional resolution of the simulations is important; in complex terrain large changes in wind speed often occur for small changes in wind direction. Because of this 36 directions are always simulated with WAsP CFD.



WAsP CFD has been thoroughly validated against on-site data provided by wind power developers. This plot shows the relative prediction error (y-axis) from 26 mast pairs (x-axis) located in very complex terrain (for further details see Troen et al. EWEA 2014).



The top figure shows a 32 by 32 sq. km section of Aveiro-Viseu. In the middle a closer view of the of the same grid is shown, covering an area of 6 by 6 sq. km, while the bottom figure covers an area of about 2 by 2 sq. km

Turbulence is modeled using the *k-ε* RANS model by Launder and Spalding (*Comp. Methods., 1974*). Additionally, the third order QUICK scheme is used to discretize convective terms and solution is continued until all variable residuals have converged to below $5 \cdot 10^{-5}$.

Finally, the calculated speedup factors, wind turnings, turbulence and flow-inclinations are extracted and returned to the user. The CFD model calculates the wind speed at every grid point in the entire domain, but only the results from the central 2 km by 2 km area is returned to you. This is the area with the highest accuracy and the area that can be used reliably for wind resource assessments.

Has WAsP CFD been validated?
WAsP CFD uses the solver EllipSys developed since the mid 1990 by DTU (Risø). EllipSys is today used for a series of wind energy applications and is presently developed by a 20-man research team. About 50.000 CFD simulations of similar type to the ones described above was conducted in 2013. These simulations are used to check the quality and robustness of individual CFD components and to validate the whole model chain needed for estimating wind resources. The figure on the top shows the results of such a validation (please see Troen et al. EWEA 2014).